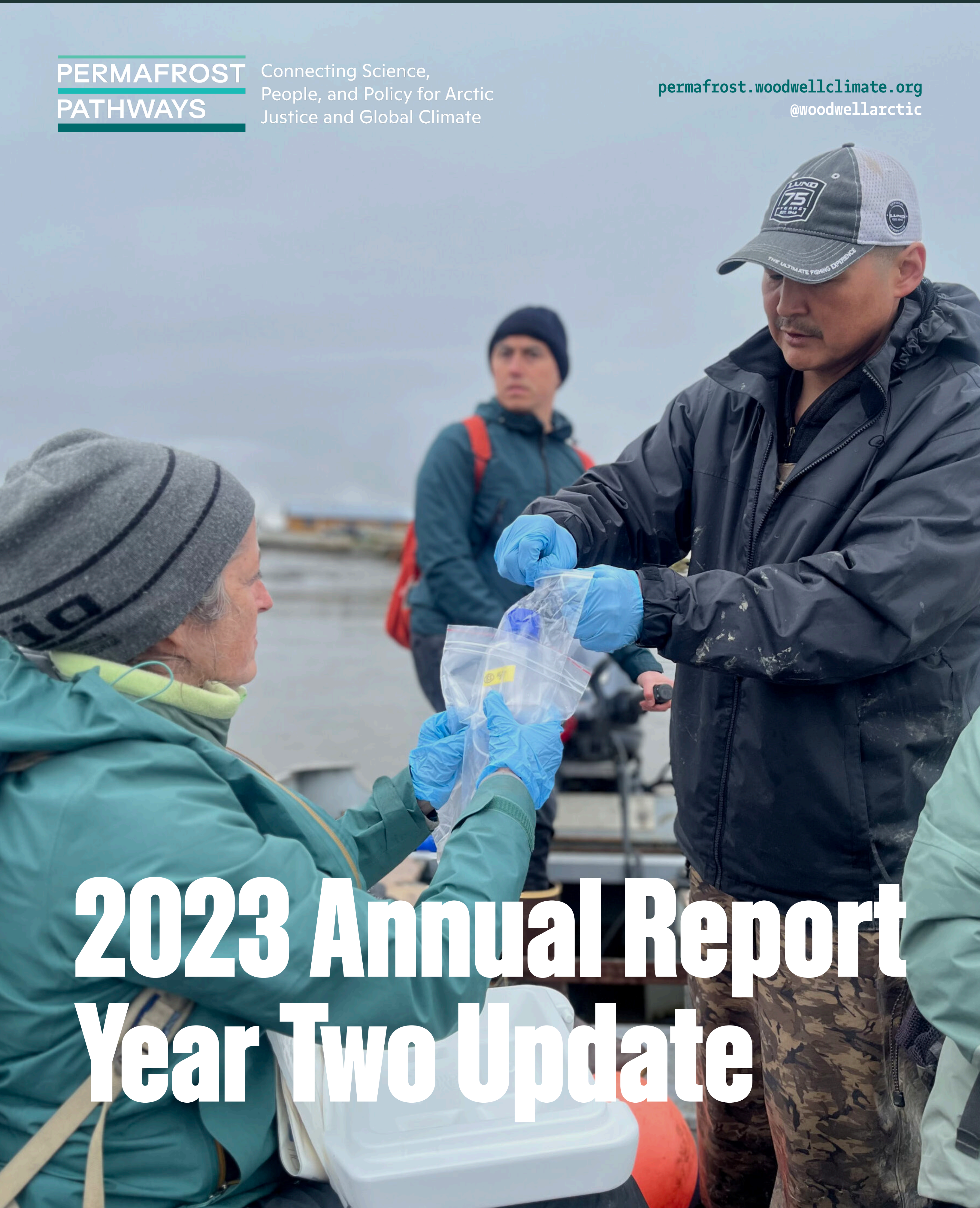
Woodwell Climate Research Center • Arctic Initiative at Harvard Kennedy School • Alaska Institute for Justice

PERMAFROST PATHWAYS

Connecting Science, People, and Policy for Arctic Justice and Global Climate

permafrost.woodwellclimate.org
@woodwellarctic



2023 Annual Report
Year Two Update

Contents

COVER: Dr. Sue Natali and Permafrost Pathways tribal liaison from Kipnuk, Chris Dock, collecting water samples. Snow at dusk in Kuigilnguq, Alaska. Photos by Greg Fiske / Woodwell Climate Research Center

Overview

In its second year, Permafrost Pathways sharpened its scientific understanding, supported community-led information-gathering and capacity-building, and extended its policy reach by strengthening its monitoring and modeling efforts, advancing equitable responses in strategic policy fora, and developing new collaborations in Alaska, Canada, and across the Arctic.

The team made critical scientific discoveries about the permafrost region's shift from carbon sink to source and finalized model analyses that show unaccounted-for permafrost emissions could claim nearly a quarter of the remaining global carbon budget. Both of these findings underscore the importance of a core project goal to urge decision-makers to cut fossil fuel emissions more rapidly to mitigate catastrophic climate impacts in the Arctic-boreal zone and globally.

The project team supported community-led relocation and planning efforts and capacity-building with 10 Alaska Native partner communities in Alaska, sharing environmental monitoring practices and tools during community visits to inform community-led assessment and decision-making.

The team successfully elevated awareness of permafrost thaw and its impacts on Arctic communities and global climate in U.S., international, and pan-Arctic arenas, garnering mention in key U.S. Arctic strategy plans and invitations to agenda-setting climate policy events in the United States and internationally..

The project refined and coordinated messaging with important new collaborators and increased their recognition as a trusted source for permafrost sciences, garnering mentions in influential media outlets including The New York Times and CNN. The team developed a high-engagement quarterly newsletter and continued to build out its communications channels to better amplify Indigenous voices, partners, and relevant stories about the impacts of permafrost thaw in the North and equitable solutions to address them.

Progress toward our goals

Woodwell Climate's Marco Montemayor supporting tower site fieldwork at Scotty Creek Research Station.
Photo by Dominik Heilig

Project highlights and key findings

Team findings suggest **global permafrost region is now a net source of carbon dioxide (CO_2) and methane (CH_4)** to the atmosphere, and that carbon emissions from permafrost thaw and northern wildfire will reduce global carbon budgets to remain below 1.5° or 2°C by up to 20%.

Permafrost Pathways was recognized as a key federal collaborator in the **Implementation Plan for the U.S. National Strategy for the Arctic Region**.

Permafrost Pathways is providing input to federal climate adaptation strategies through an appointment by the **U.S. Department of the Interior to the federal Advisory Council on Climate Adaptation Science**.

Permafrost Pathways was recognized for its social influence and impact by being named a **winner of the Anthem Awards in three different categories**—Special Projects (Silver), Collaboration (Bronze), and Community Outreach (Silver).

Task 1 - Monitor permafrost thaw and carbon emissions

Permafrost Pathways is monitoring carbon dioxide (CO_2) and methane (CH_4) fluxes (i.e., uptake and emissions from Arctic lands) so that we can track when and where the Arctic has shifted into a net source of carbon to the atmosphere. We do this by both installing new carbon flux monitoring towers (i.e., eddy covariance towers) and supporting existing towers that comprise a comprehensive carbon flux monitoring network representative of the entire permafrost region (Figure 1). During the past year, we made several research trips to maintain and repair towers in Alaska and Canada, and to connect with communities and local and Tribal governments to work together to identify sites for 2024 installations. In 2023, we installed a new tower in the Northwest Territories, Canada, to replace a long-term flux tower that burned down in October 2022. The project also supported the continued operation of five existing eddy covariance towers (one in Canada, two in Alaska, and two in Russia) by providing funding, instrumentation, and/or technical support to ensure these towers continue to collect data and to expand their measurement capacity to include both CO_2 and methane CH_4 measurements throughout the year.

Developing a fuller picture of permafrost region fluxes: We are synthesizing this new and existing CO_2 and CH_4 flux data into a comprehensive database to assess the carbon balance of the entire northern permafrost region. During Year 2, we finalized our initial pan-Arctic CO_2 and CH_4 flux assessments (Virkkala et al., in review; Ying et al., in prep) and the results are consequential. When accounting for wildfire emissions, the permafrost region, which has been a carbon sink for thousands of years (from plants removing CO_2 from the atmosphere and locking it away in permafrost), is now a source of CO_2 to the atmosphere (Figure 2). Carbon emissions from permafrost ecosystems are expected to be an important amplifier of global climate warming, and CH_4 emissions further amplifies this warming effect.

Better disturbance detection and real-time tools: We are also monitoring the increasing frequency of climate-driven disturbances, which may double the effect of permafrost thaw on global climate in the coming century. We have completed analyses of wildfires across Alaska and Canada (Potter et al., in review) and plan to extend this work to Eurasia. We are developing a near real-time burned area algorithm that will provide timely information to land managers, scientists, and the public during extreme wildfire seasons such as this past one in Canada, and are also developing a tool to track and map Arctic wildfires at high spatial resolution using satellite imagery and artificial intelligence (i.e., deep learning) techniques (see Appendix 2).

Another important disturbance in the northern region is abrupt ground collapse caused by the thawing of ice-rich permafrost (see Appendix 2), which can accelerate permafrost carbon release. To better monitor this disturbance, we are working toward the first-ever maps of pan-Arctic thaw slumps using very high-resolution commercial satellite imagery and deep learning. In Year 2, with supplemental support from Google.org and the

Heising-Simons Foundation, we published our methods (Yang et al., 2023), synthesized a database of all known thaw slump occurrences (Yang et al., in review), assessed the influence of satellite imagery sources on model performance (Rodenhizer et al., in review), and secured a data licensing agreement with Planet Labs for access to high resolution satellite data across the Arctic to continue and expand this work.

Task 2 — Develop more accurate Arctic carbon models

The Permafrost Pathways modeling team made substantial progress toward our goal of developing the most accurate ecosystem model for carbon fluxes across the permafrost region. During Year 2, we finalized development of a semi-automated approach for integrating ground observations into our model, including carbon flux data, which greatly increases model efficiency and accuracy (Briones et al., in review). We are deploying this framework at 42 carefully selected Arctic research sites that vary in permafrost, vegetation, and hydrology.

Data-assimilation for better predictions: We are building a system that will allow us to integrate pan-Arctic remote sensing data into the model. While the integration of site data allows us to tune the model to point locations, this next step will constrain model behavior across the entire Arctic. In particular, we began integrating the Data Assimilation Research Testbed (DART) into our ecosystem model, which will allow us to build on state-of-the-art data assimilation tools.

As we move towards deploying our model across the entire Arctic, our team has been developing the necessary input datasets such as climate and land cover maps. To accommodate the high computation requirements of circumpolar simulations, we developed a computing framework within Google Cloud Computing, including a dashboard for monitoring processing and billing, which provides a scalable, efficient, and carbon-neutral computing infrastructure. We are currently optimizing model efficiency and leveraging resources through our new partnership with the Permafrost Discovery Gateway and Google.org.

Adding methane and wildfire to the equation: A primary goal of our modeling work is to improve Arctic models by incorporating key processes that impact carbon cycling in permafrost environments. During Year 2, we began implementing new modules to accurately simulate CH_4

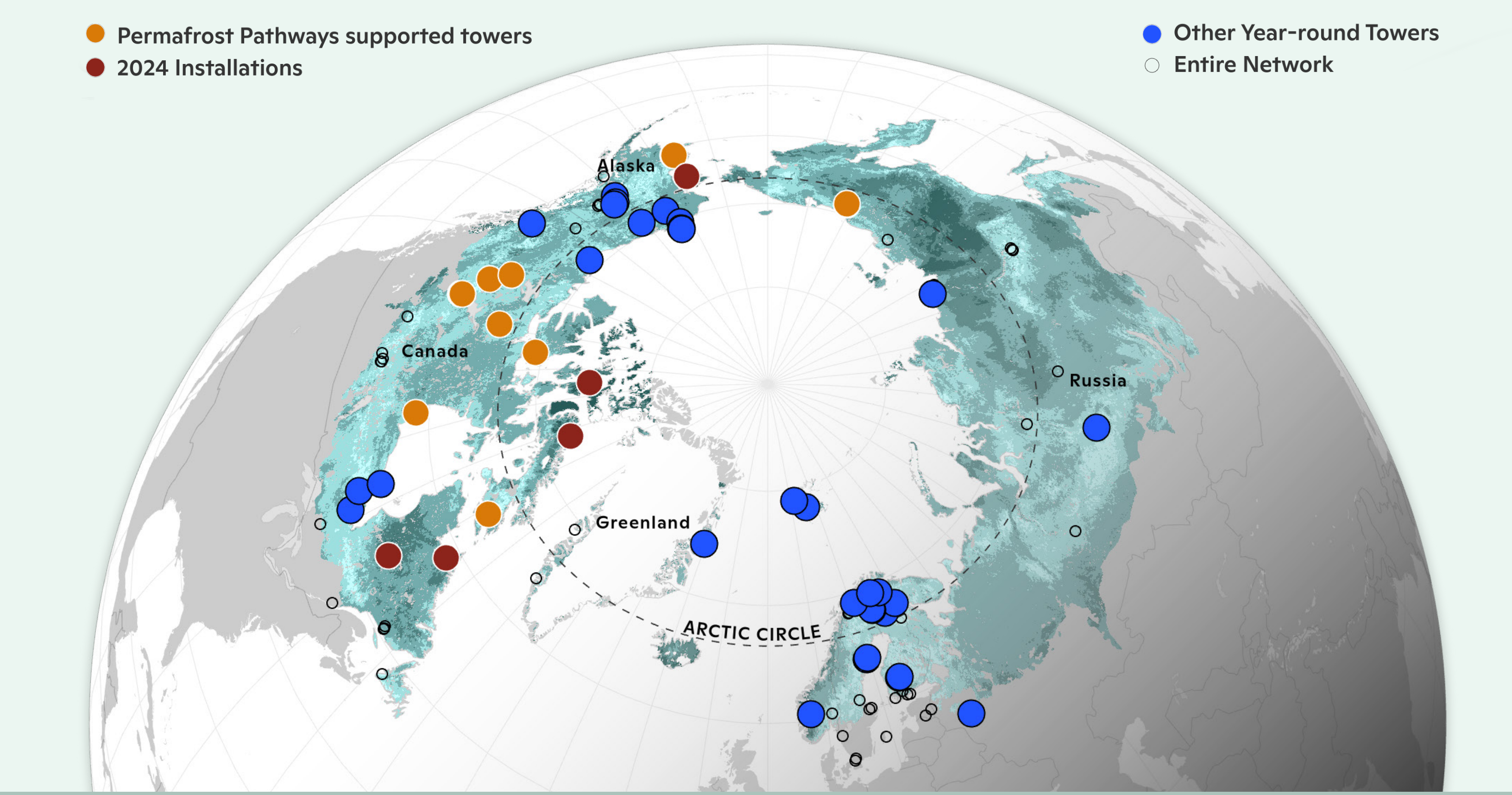


Figure 1: Arctic carbon monitoring sites
Permafrost Pathways is expanding the coverage of year-round sites that measure both CO2 and CH4 to fill critical gaps and reduce uncertainty in Arctic carbon estimates. Map by Greg Fiske / Woodwell Climate Research Center

emissions and wildfire, including its occurrence, effects on ecosystems and permafrost, and carbon emissions to the atmosphere. These are critical for accurately estimating climate feedbacks that have been largely neglected in carbon and climate models to date.

Incorporating permafrost into Earth System Models: As we work to develop the most advanced process-based model for pan-Arctic ecosystems and carbon cycling to date, we recognize the urgent need to help the broader modeling community advance permafrost carbon processes in international climate models. During Year 2, we hosted a workshop focused on improvements needed to better represent permafrost in Earth System Models (ESMs; used in international climate assessments), including comparisons of model accuracy at experimental permafrost thaw sites, and we prepared a comment in *Nature Climate Change* on the need for ESMs to better represent permafrost processes (Schädel et al., 2024).

Emulator model yields important, policy-relevant results: Understanding that fully incorporating permafrost processes into complex models will take many years to complete—and recognizing the urgency of integrating this knowledge into climate policy action—we have been using an Earth System Model of reduced complexity (i.e., OSCAR) to assess permafrost carbon feedbacks on global climate. Using this simpler modeling approach, we have integrated gradual and abrupt thaw, as well as wildfire and fire-permafrost interactions, to assess their cumulative impact on global climate and remaining carbon budgets to limit global warming to 1.5 or 2°C. Results indicate that permafrost thaw and high-latitude wildfires will reduce allowable remaining carbon budgets by roughly 20%. This information is critical because these emissions are currently not fully accounted for in international climate policy.

Task 3 — Co-create an Indigenous-led adaptation process

We now have Tribal agreements in place with 10 Alaska Native communities (Figure 3) , all of whom have hired a full-time staff member to lead community adaptation planning, coordinate with the project team to develop a relocation toolkit, and identify policy priorities to address the impacts of permafrost thaw and other climate-caused hazards in their communities. We have been meeting with Tribal partners regularly to build relationships and coordinate work to co-produce climate adaptation strategies.

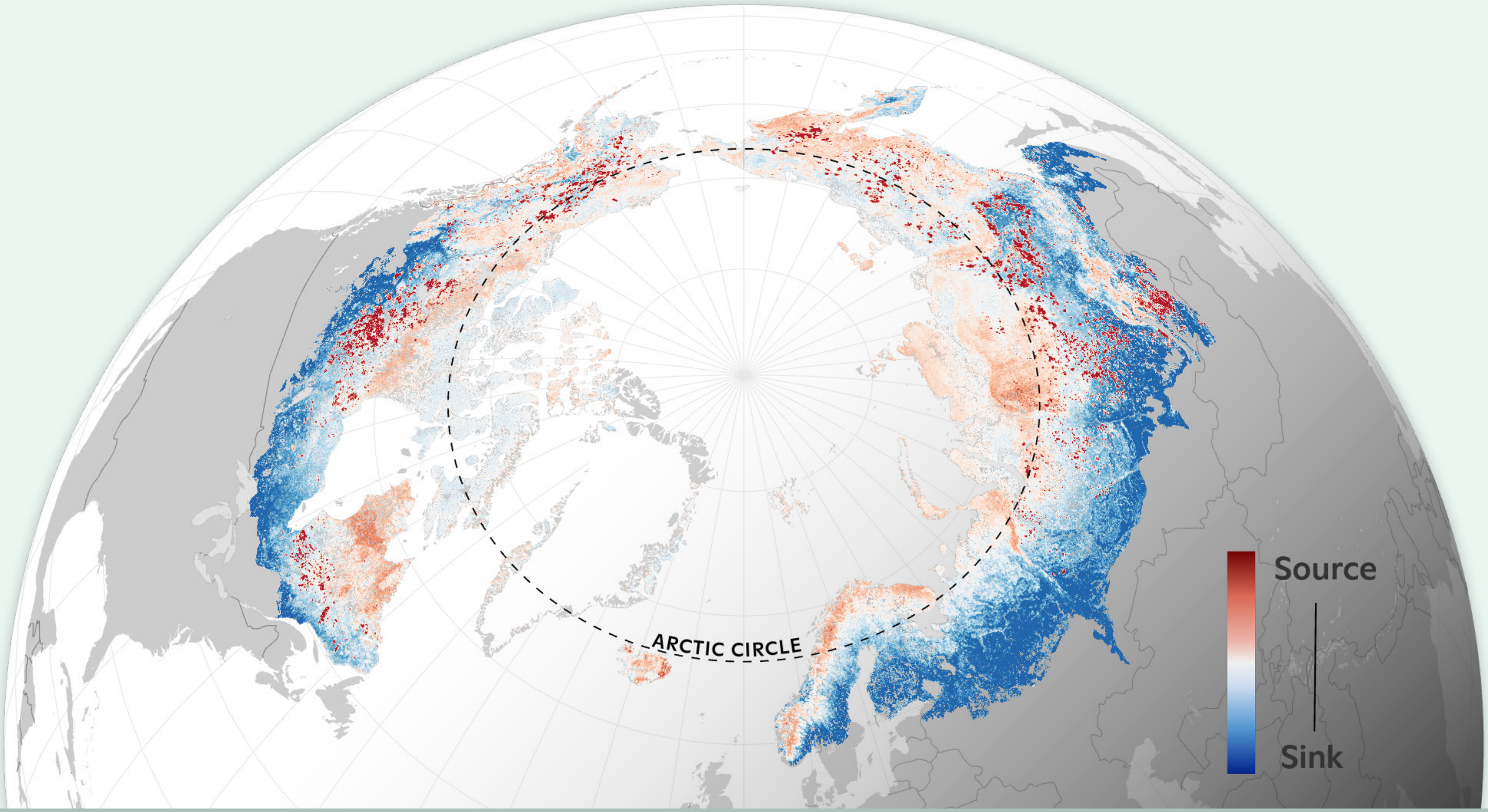


Figure 2: CO_2 sources and sinks
CO_2 sources and sinks, including emissions from fires, based on our flux upscaling.
Map by Greg Fiske / Woodwell Climate Research Center

Our scientific and technical contributions to this adaptation work focus on tracking and documenting current and past rates of environmental change, information which is needed both to make decisions and to facilitate funding from government agencies. We are also assessing environmental conditions at potential relocation sites and modeling future rates of change to guide our partners' adaptation planning.

Tracking past and current changes: In Year 2, we conducted site visits with six partner communities (Kuigilnguq, Nunapicuaq, Golovin/Chinik, Chevak, Kipnuk, and Akiak) to plan and implement environmental monitoring. We set up erosion and thaw monitoring sites as well as weather stations, and community partners collected water samples to track water quality, which is degrading due to permafrost thaw. We also co-produced a flood map with Kuigilnguq after learning that their current flood map vastly underrepresented the magnitude of tidal flooding that impacts their community multiple times each year (see appendix 3). To support our partner communities' efforts to document climate and weather impacts that have affected them, we also co-developed a storm and permafrost thaw impact survey, which we have supported with both a training video and one-on-one technical assistance for Tribal liaisons.

Relocation site assessments: Both Kuigilnguq and Nunapicuaq have selected potential relocation sites, which we visited in Year 2 to conduct preliminary environmental assessments (e.g., ground ice content, permafrost temperature and structure, and water quality testing). Permafrost sampling conducted in Nunapicuaq's potential relocation site showed low ground ice and coarse compacted substrates close to the surface, which are generally good conditions to support infrastructure and consistent with the community's' knowledge of conditions at this location. This information is being used by the community and government agencies to determine if these sites are feasible relocation options based on current and future conditions. In Year 3, we will revisit both communities to conduct further assessments.

Assessing future rates of change: We are using satellite data to measure past rates of coastal and riverine erosion and to assess future erosion risk, analyses which

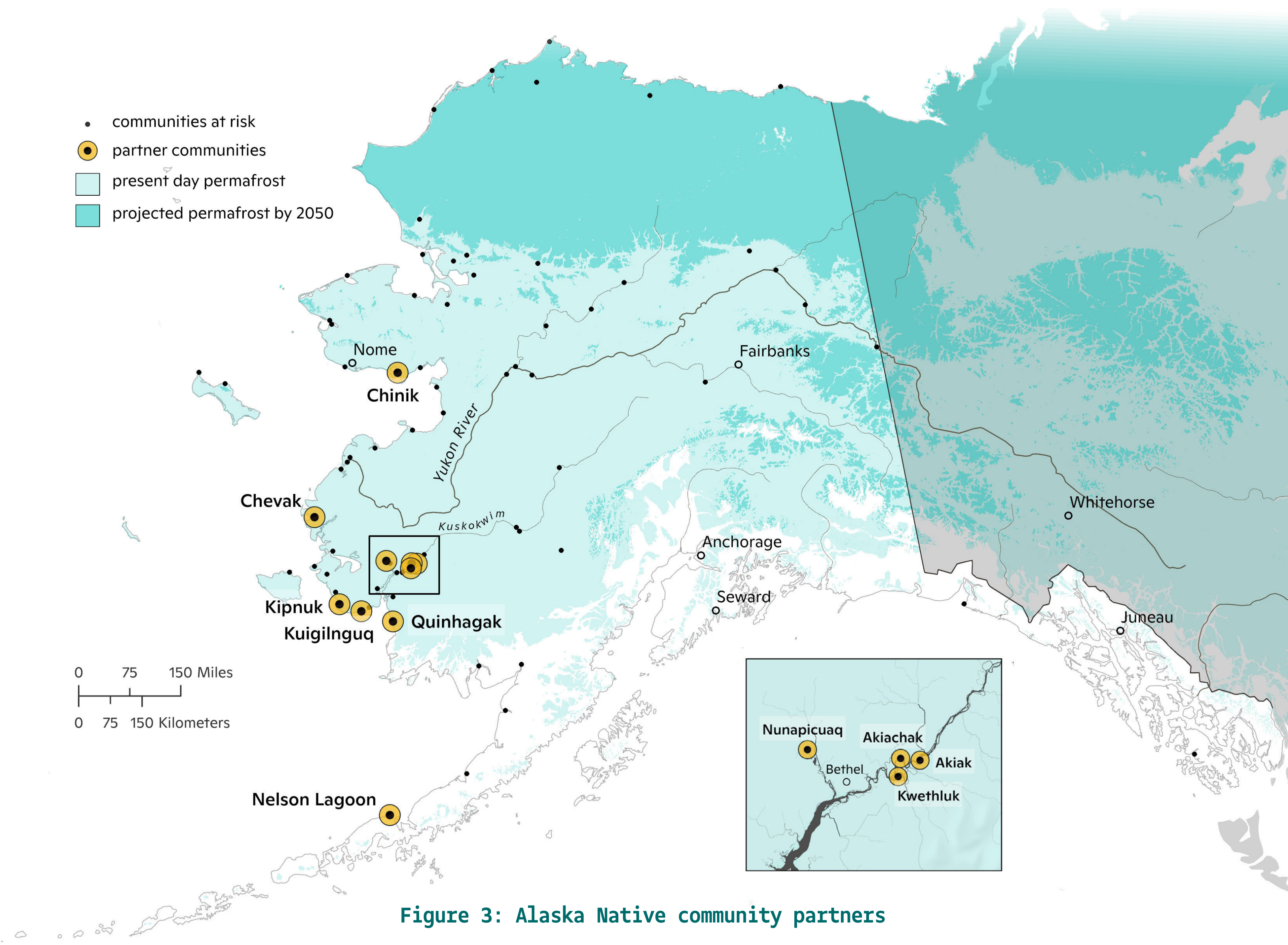


Figure 3: Alaska Native community partners

communities and federal agencies can use to identify lands for future relocation of homes and community infrastructure. We are also using a permafrost thaw model to determine future rates of ground thaw and ground slumping, and we are working to develop a flood map that integrates the impact of ground thaw on flood risk. To date, climate risk assessments have not incorporated multiple climate hazards, despite the non-linear and amplifying impact of the combined effects of flooding, erosion, and permafrost thaw.

As we continue this work, the lack of relocation and adaptation guidance from the federal government is becoming increasingly clear. A primary goal of our project is to co-create and implement those guidelines with our community partners and relevant agencies. To further this goal, Permafrost Pathways' partner, Alaska Institute for Justice, hosted a workshop in September 2023 that brought together 65 representatives from our ten partner communities and more than 50 representatives from federal and Alaska state government agencies to further address policy opportunities and programs to support adaptation responses for Alaska Native communities.

Task 4 — Influence national and international climate policy related to permafrost thaw

During the second year of the project, our policy actions spanned across three overarching areas:

- **Recognition:** Integrating permafrost thaw processes and impacts into climate policy frameworks at the international, pan-Arctic, national, and sub-national level;
- **Coordination:** Improving coordination among policymakers to better understand, quantify, and consider permafrost thaw in decision-making processes; and
- **Response:** Advancing adaptation and resilience policy frameworks that more adequately respond to local, pan-Arctic, and global risks from permafrost thaw.

Raising visibility of permafrost thaw mitigation and adaptation in Pan-Arctic and International fora: We continued to expand the global reach of the project, contributing to the recognition and consideration of permafrost thaw in pan-Arctic and global settings. In the wake of Norway's assumption of Arctic Council Chairmanship, for example, project partners at the Arctic Initiative hosted a small, invitation-only workshop that brought together Arctic governance experts and practitioners to discuss concrete, pragmatic actions that can strengthen working-level cooperation through the Arctic Council and/or the broader network of institutions that support the management and advancement of Arctic issues.

We supported greater integration of permafrost thaw into global climate negotiations and responses. In coordination with its close collaborator International Cryosphere Climate Initiative (ICCI), Permafrost Pathways backed the "Ambition on Melting Ice," a coalition of countries that are committed to elevating visibility of cryosphere issues in UNFCCC proceedings at COP27. In concert with ICCI researchers, the Permafrost Pathways team presented findings about the permafrost climate feedback at a high-urgency AMI coalition meeting with the Swedish Ministry of Climate and Enterprise in Stockholm in March 2023, and ahead of the Global Stock Take UNFCCC Intersessional (SB58) in Bonn, Germany.

Permafrost Pathways also provided input to the World Meteorological Organisation's Global Greenhouse Gas Watch resulting in the rapidly changing Arctic being highlighted in the draft implementation plan as a target area that requires more monitoring, resources, and representation in global carbon monitoring and modeling.

We continued to advance these key science and policy messages at the 28th Conference of the Parties of the UNFCCC (COP28) in Dubai in December 2023. While onsite at COP, Permafrost Pathways organized "Permafrost Day" at the ICCI Cryosphere Pavilion and organized programming featuring Youth activists, Arctic Indigenous leaders, Permafrost scientists, and government officials from the U.S. and Iceland. Senators Ed Markey (D-MA) and Lisa Murkowski (R-AK) engaged in meaningful conversations at the Woodwell pavilion, noting the intensity of permafrost thaw captured in maps designed by Woodwell Climate's Christina Shintani and Greg Fiske.

Strengthening permafrost science—U.S. government collaborations: Permafrost Pathways continued to catalyze improved interagency coordination on climate risk and landscape degradation in Alaska through convenings and *ad hoc* meetings with U.S. government agency representatives.

In May 2023, Permafrost Pathways' partner, the Arctic Initiative at the Harvard Kennedy School's Belfer Center, and the U.S. Department of Homeland Security (DHS) hosted a high-level workshop focused on security challenges posed by the impacts of rapid climate change in Alaska, including permafrost thaw. The workshop featured discussions on concrete steps for DHS and its components to improve upon existing policies and responses.

Our team met regularly with representatives from agencies who are central to climate adaptation in the U.S., including the Denali Commission, FEMA, Dept. of Agriculture, Army Corps of Engineers, Housing and Urban Development, and Dept. of Interior (DOI), on the status of community-driven relocation and enhanced government response to permafrost thaw.

Dr. Brendan Rogers' work on managing northern fires to protect permafrost carbon contributed to a historic decision by U.S. federal land management agencies to dedicate [1.6 million acres of the Yukon Flats National Wildlife Refuge] to piloting fire suppression strategies to preserve carbon and vulnerable permafrost — a decision that was the result of iterative consultation with Indigenous communities within the refuge who are impacted by increasing smoke pollution and disruption to subsistence activities.

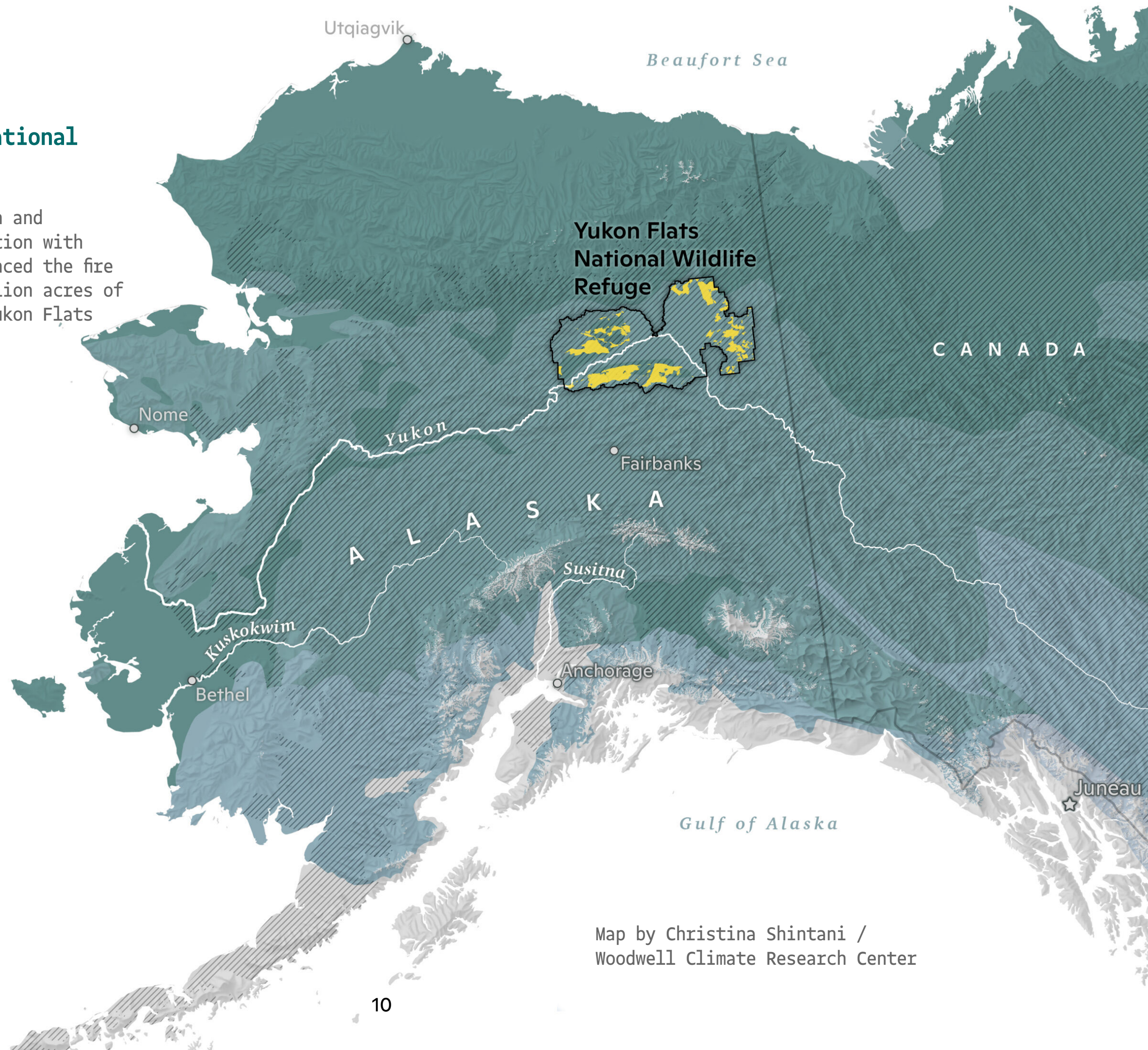
Advancing adaptation and resilience frameworks: In October 2024, the Permafrost Pathways policy team traveled to Washington, D.C. to brief offices of Alaska Rep. Mary Peltola, Alaska Sen. Dan Sullivan, and Massachusetts Sen. Ed Markey on the latest activities of Permafrost Pathways. Project team members subsequently met with representatives from Alaska Sen. Lisa Murkowski's office to emphasize the unique challenges facing Alaska Native communities living on lands underlain by thawing permafrost. These meetings provided an opportunity for the project team to inform Congressional members on the challenges to improved permafrost thaw adaptation and mitigation responses and to recommend priority actions—including those prescribed in the Implementation Plan for the National Strategy for the Arctic Region, which [explicitly named Permafrost Pathways] as a key collaborator.

We also addressed proposed regulatory amendments to and guidance for the National Environmental Policy Act; offered inputs to the Fifth National Climate Assessment; contributed expert advice to the development of a Federal Strategy to Advance an Integrated U.S. Greenhouse Gas Monitoring and Information Systems; and provided written and oral testimony on fisheries management decisions in permafrost lands in Alaska.

As the project continues to strengthen science-policy collaboration in the United States, key leadership appointments within government bodies will further secure permafrost science and adaptation perspectives in policy decision-making at the highest level. Such appointments include Climate Adaptation Specialist Brooke Woods' selection to the Arctic-Yukon-Kuskokwim Regional Work Group within the Alaska Salmon Research Task Force and [Dr. Natali's selection to the DOI Federal Advisory Council for Climate Adaptation Science]. See Appendix 1 to read more about Permafrost Pathways policy priorities and strategy.

Figure 4: Yukon Flats National Wildlife Refuge

In January 2023, the U.S. Fish and Wildlife Service, in consultation with the Alaska Fire Service, enhanced the fire suppression status of 1.6 million acres of permafrost-rich land in the Yukon Flats National Wildlife Refuge.



Permafrost

- Continuous
- Discontinuous
- Sporadic
- Isolated
- Boreal forest
- Permafrost prioritized for fire protection

Expanding our reach

Arctic Indigenous youth policy workshop at the Arendalsuka Political Gathering in Norway.
Photo courtesy of the Arctic Initiative at Harvard Kennedy School.

Collaborations and partnerships

Over the past year, we have expanded the scope of Permafrost Pathways through new research collaborations and partnerships that have developed as a result of our work. Some of these new collaborations included the following activities:

- We signed a memorandum of understanding with the Łíídlı̨ı̨ Kų́ę́ First Nation (LKFN) in early 2023 and supported the rebuilding of the Scotty Creek Research Station, where the tower is located and which is the only Indigenous-led research station in the Arctic.
- We co-hosted a workshop with Ikaarvik, an Inuit youth-led organization bridging the gap between Western science and Indigenous Knowledge.
- We met with the Cree Nation Government about collaborating on research in Eeyou Istchee, a Cree region in Quebec, Canada.
- We initiated a collaboration with the Permafrost Discovery Gateway (housed at Woodwell Climate) to support modeling and remote sensing activities to better identify ice-rich permafrost.
- We strengthened collaboration with the International Centre for Reindeer Husbandry (ICR) around shared priorities of mapping and addressing land degradation from thawing permafrost in the North.

Project Staff Overview

Woodwell Climate: 31 full-time and seven part-time or temporary staff members.

Alaska Institute for Justice: Five full-time staff.

Arctic Initiative at Harvard Kennedy School: Six full-time or part-time staff

Alaska Native community partners: All 10 Alaska Native community partners have hired project Tribal liaisons.

Conferences and Workshops

In 2023, Permafrost Pathways attended more than 30 conferences and workshops to advance permafrost science and increase the visibility and awareness of permafrost thaw in both national and international spaces. Major event highlights include:

World Meteorological Organization Greenhouse Gas Symposium - In January, Woodwell Climate Associate Scientist Dr. Jennifer Watts and Research Scientist Dr. Kyle Arndt chaired sessions, presented posters, and helped to draft the statement of need for the subsequently approved Global Greenhouse Gas Watch (G3W) initiative. **READ MORE**

Alaska Forum on the Environment (AFE) - In early February, members of the Permafrost Pathways policy and communications teams presented on co-production efforts at AFE in Anchorage, Alaska and facilitated a participatory mapping exercise to collect information about community observations of land degradation and impacts of climate change. Woodwell Climate's Brooke Woods also presented about the impacts of the devastating salmon decline on Alaska Native subsistence fishing rights.

South by Southwest (SXSW) - In early March, Permafrost Pathways Project Lead Dr. Sue Natali was invited to speak on a panel at SXSW about satellite data in climate science hosted by our partners at Esri. **WATCH THE SESSION**

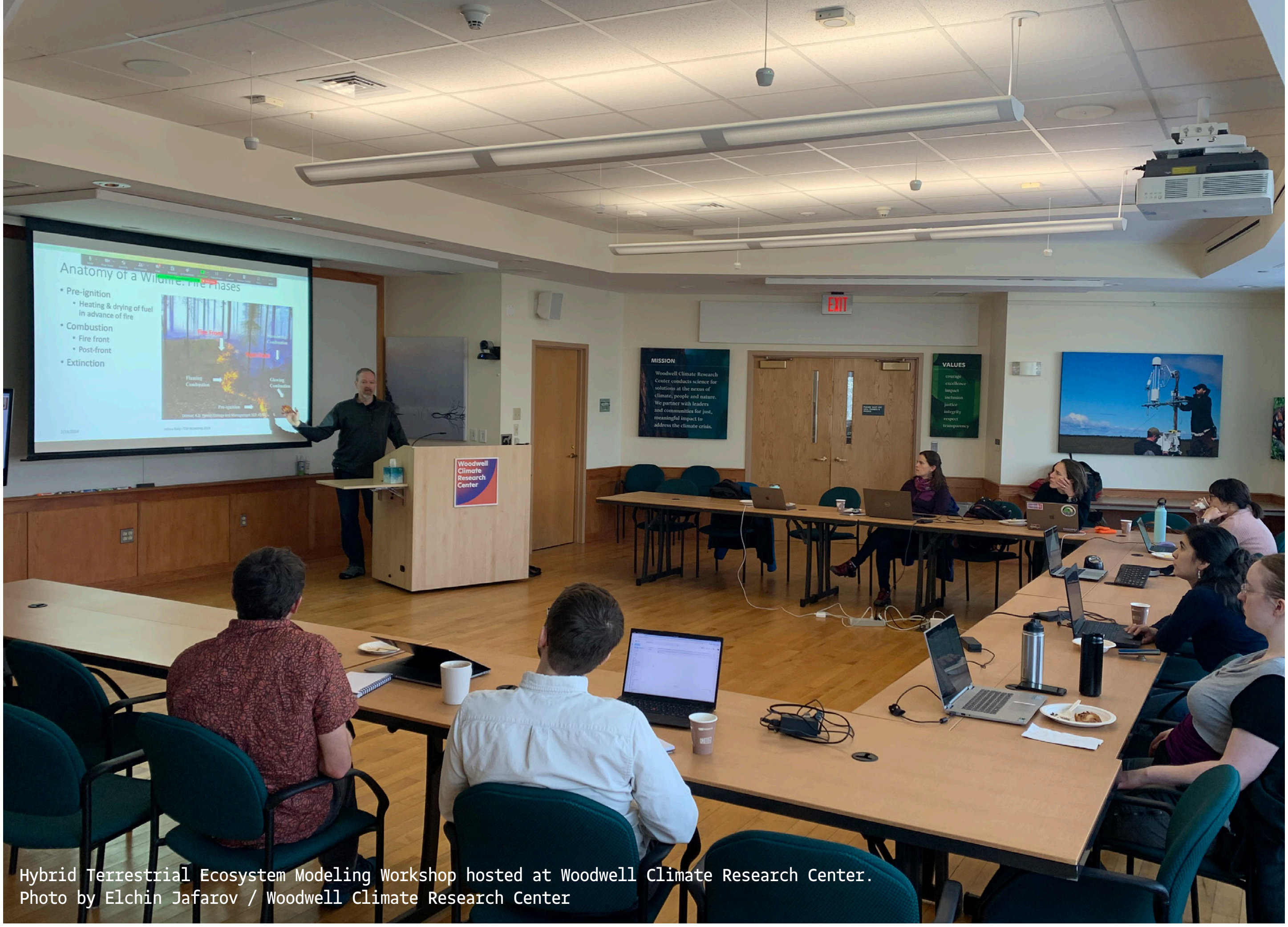
SBSTA UNFCCC - The 58th session of the Subsidiary Bodies (SB58) for Scientific and Technological Advice (SBSTA) and for Implementation (SBI) was held in Bonn, Germany. Meetings of the Subsidiary Bodies provided Permafrost Pathways with a crucial opportunity to elevate the impacts of permafrost thaw on global climate; advocate for more visibility of the cryosphere across negotiation tracks; and engage in discussions about key issues including the Global Stocktake (GST). **READ MORE**

Esri User Conference - In July, Permafrost Pathways attended the annual Esri User Conference to engage with the latest geospatial technology and participate in technical workshops. Woodwell Climate's Senior Geospatial Analyst Greg Fiske won the International Cartographic Association and International Map Industry Association Recognition of Excellence in Cartography, and Cartography Special Interest Group Excellence awards for his Alaska Topography Map. **READ MORE**

Ikaarvik Youth Workshop - Ikaarvik—an Inuit youth-led organization in Mittimatalik, Nunavut—hosted an in-person workshop for our team to provide guidance on ethical community engagement and equitable Arctic research; and discussed community priorities and opportunities for collaboration with Permafrost Pathways. **LEARN MORE**

Arendalsuka Political Gathering - In August, Permafrost Pathways participated in the "Exploring Arctic Sustainability: Enhancing Resilience, Addressing Land Degradation, and Permafrost Thaw Through Indigenous Empowerment" workshop launched by ICR in collaboration with the Arctic Initiative at Harvard Kennedy School. **READ MORE**

"Rights, Resilience, and Community-Led Adaptation" Workshop - In September, AIJ hosted a climate adaptation workshop—alongside partners from Woodwell Climate, the Arctic Initiative, and the Alaska Native Science Commission—that brought together over 65 Alaska Native community members and more than 60



Hybrid Terrestrial Ecosystem Modeling Workshop hosted at Woodwell Climate Research Center.
Photo by Elchin Jafarov / Woodwell Climate Research Center

state and federal agency representatives to facilitate Tribal-led conversations with focused on climate impacts in Alaska. **READ MORE**

Climate Week NYC - Woodwell Climate Senior Research Scientist Dr. Christina Schäedel participated in an Instagram Live interview with climate activist and United Nations Youth Ambassador Sophia Kianni during Climate Week NYC. **WATCH THE INTERVIEW**

International Permafrost Modeling Workshop - In late September, Dr. Christina Schäedel hosted participants from around the world on the Woodwell Climate campus to discuss challenges and pathways for models to include permafrost processes and how experimental data from warming experiments can be used to constrain model output.

Arctic Circle Assembly (ACA) - In October, Permafrost Pathways joined scientists, policymakers, Indigenous leaders and representatives, Arctic youth, and academics from over 70 countries in Reykjavík, Iceland to discuss the Arctic region's priorities and future in the midst of climate change. **READ MORE**

Canadian Science Policy Conference - in November, Permafrost Pathways joined partners from Arctic Initiative and members of the Natural Sciences and Engineering Research Council and PermafrostNet in Ottawa to identify opportunities for increased collaboration on permafrost knowledge and policy.

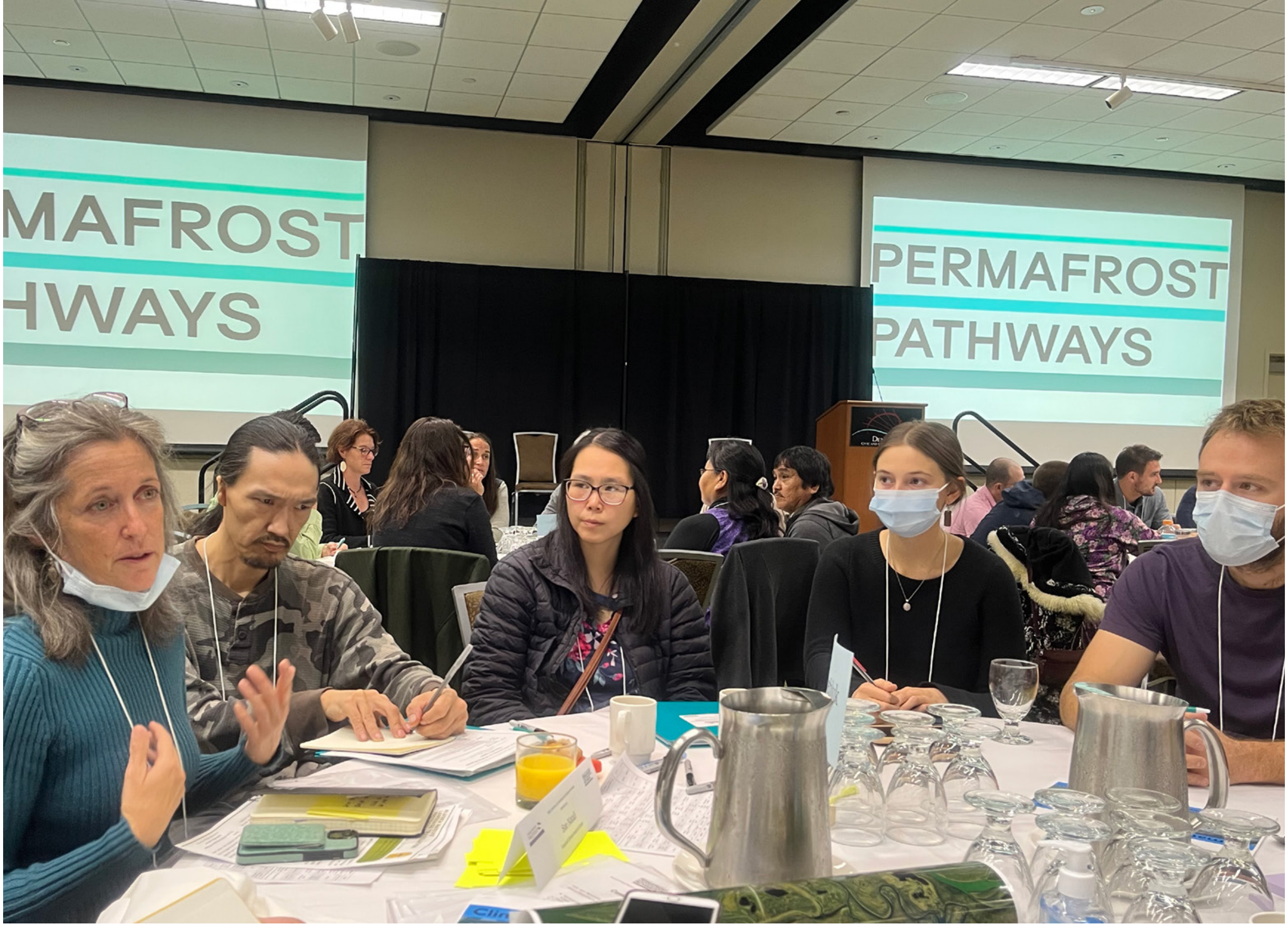
28th Conference of the Parties of the UNFCCC (COP28) - In November, Permafrost Pathways participated in COP28 to amplify Arctic Indigenous voices and raise international awareness of permafrost thaw. For the second year in a row, Permafrost Pathways was a proud co-organizer of Permafrost Day held in the Cryosphere Pavilion and hosted by our colleagues at ICCI. **READ MORE**

American Geophysical Union - Nearly 30 members of the Permafrost Pathways team attended AGU's annual conference in San Francisco to present posters, give talks, and join panels and town halls exploring new scientific approaches to addressing the impacts of a warming Arctic. **READ MORE**

Other conferences and workshops attended by members of the Permafrost Pathways team include the **Arctic Encounter Symposium**, a **Modeling Workshop** at the **University of Alaska Fairbanks**, **NASA ABoVE Science Meeting**, **World Economic Forum**, **Permafrost Carbon Network Annual Workshop**, **AMPAC-Net Methane Workshop**, **Google Earth Geo for Good Summit**, **European Geosciences Union General Assembly**, **Mapping the Arctic Conference**, and **ArcticNet**.

Publications and communications

Greg Fiske and Anders Oskal from the International Centre for Reindeer Husbandry at a meeting hosted at Harvard University.
Photo by Tessa Varvares / Arctic Initiative at Harvard Kennedy School



Meeting with the Native Village of Kwethluk at the Permafrost Pathways adaptation workshop hosted by AIJ.
Photo by Greg Fiske / Woodwell Climate Research Center

Publications

Permafrost Pathways scientists continued to advance the field's understanding of permafrost thaw and Arctic change by publishing more than 20 peer-reviewed studies in 2023, including in high-impact journals such as *Nature Climate Change*, *Nature Communications*, *Global Change Biology*, and *EGU Biogeosciences*. For a complete list, please see appendix 4.

Communications and media coverage

In 2023, Permafrost Pathways continued to establish itself and its team members as trusted voices on the issues of permafrost thaw and monitoring, Arctic warming, community-led adaptation, and the impact of boreal wildfires on permafrost. The project netted more than 600 media mentions over the year, and experts were quoted in high-profile media outlets including the New York Times, Axios, CNN, and important Alaskan outlets including KYUK, which ran a four-part series on permafrost thaw in Nunapicuaq, one of our Alaska Native partner communities.

Communications highlights: Permafrost Pathways developed and delivered an informative quarterly newsletter and grew its subscriber base to nearly 500 subscribers. The newsletter built loyal and engaged readers, boasting open rates (68%) and click-through rates (12%) that significantly surpass industry benchmarks.

We continued to publish frequent project updates, feature stories, and StoryMaps on both our project website and Woodwell Climate channels to keep audiences informed about our progress, elevate Indigenous voices, and contextualize current events relevant to our work.

2023 closed with Permafrost Pathways winning three Anthem Awards—Special Projects (silver), Community Outreach (silver), and Partnership or Collaboration (bronze)—out of thousands of applicants. The project also garnered widespread public support and received an inaugural Community Voice Award. Christina Shintani also won the grand prize in the 2023 Avenza Map Contest for her Permafrost Pathways Arctic Carbon Monitoring Map with contributions from Jessica Howard and Julianne Waite.

Stay connected to Permafrost Pathways—sign up for email updates and follow us on Instagram and Twitter. You can also explore our updates page and previous newsletters (April 2023, September 2023, December 2023) for the latest project news and developments.

Looking ahead

Visiting partners in the Alaska Native Village of Chinik (Golovin). Photo by Greg Fiske / Woodwell Climate Research Center

Talking with community members at the local co-op in Mittimatalik with Ikaarvik's Damian Enoogoo. Photo by Shelly Elverum / Ikaarvik

Organizational changes/challenges and looking ahead

As we completed Year 2 of Permafrost Pathways, we were approximately 88% spent through December 31, 2023. Our team is approximately 95% staffed ending the year with 38 Woodwell Climate staff on the project with seven new positions. There are a few remaining new hires starting in Year 3.

Highlights regarding our budget to actual variances are:

- **Task 1** in equipment was due to pre-purchasing items to ensure installs in Year 3.
- **Task 3** purchased community weather stations, which were installed in Alaska.
- **Task 3** shows our partner, the Alaska Institute for Justice, is now fully staffed and ramped up earlier than planned at the end of Year 1. They also facilitated a workshop with our Alaska Native partners, Woodwell Climate, and government agencies in Fall 2023.

We continue to revise our funding under Task categories to better reflect actual staffing and anticipated spending going forward. For example, we expect our partner, Harvard Kennedy School's Arctic Initiative under Task 4 will draw additional funds in Years 3 and 4 to expand our policy work. We also increased staff in Tasks 3 and 4. Our Alaska Native partners are also in need of heavy equipment. We are pivoting, when possible, to capitalize on new and unknown project needs or opportunities. We are starting to see gaps in future budget years and are looking at opportunities to cover these shortfalls.

Thank you for your generous support of Permafrost Pathways!

MILESTONES AND KEY METRICS

	Year 1 3/1 - 12/31 2022	Year 2 1/1 - 12/31 2023	Year 3 1/1 - 12/31 2024	Year 4 1/1 - 12/31 2025	Year 5 1/1 - 12/31 2026	Year 6 1/1 - 12/31 2027
Task 1: Monitor permafrost thaw and carbon emissions						
# of new flux sites	1 new flux tower; 9 existing towers expanded	2 new towers (Yrs 1&2); 9 towers supported; 4-6 new towers planned for 2024	6-8 total	10	--	--
% coverage of Arctic lands	25%; Site selection / set-up	Set-up / data collection	Set-up / data collection	All sites complete	75%	75%
Reduction in carbon budget uncertainty	Site selection / set-up	Site set-up / data collection; Conduct uncertainty analyses		>67%	>67%	>67%
Task 2: Develop more accurate Arctic carbon models						
Permafrost processes fully represented in advanced Terrestrial Ecosystem Model	Develop work plan for CH_4 and wildfire development.	Development of wildfire and CH_4 modules; work plan for abrupt thaw.	Initial versions of wildfire and CH_4 modules completed; begin development of abrupt thaw module.	First version and pan-Arctic simulations of model representing fire, abrupt thaw, and CH4 emissions.	Finalized all model elements. Regional & pan-Arctic simulations published and communicated.	100% complete
Existence of a carbon emissions data assimilation model	Software infrastructure built for assimilation.	Beta version of data assimilation model developed and launched.		100% complete	100% complete	100% complete
				Continued refinement to model and integrate site data.		
Task 3: Co-create an Indigenous-led adaptation process						
# of Alaska Native communities using an adaptation monitoring and modeling framework	Coordination of community network; On-the-ground and remote sensing monitoring partnerships launched with 6 communities.	Partnerships launched with 10 communities.	100% complete; Monitoring set up in all 10 communities.	Continued work with communities to tune model to adaptation needs; Continued integration of Indigenous Knowledge into monitoring and models.		
Existence of a relocation toolkit/framework for Arctic communities	Begin remote sensing for detecting past change.	Remote sensing for detecting past change underway in 6 communities.	Beta version of toolkit co-created with Indigenous partners.	100% complete	Continued refinement and updates to relocation toolkit, including dissemination to relevant communities to support implementation.	
Task 4: Influence national and international climate policy related to permafrost thaw						
Integration of permafrost emissions into UNFCCC climate assessments	Policy model (OSCAR) developed to include permafrost emissions from all sources.		OSCAR finalized; engage-ment with UNFCCC initiated.	OSCAR updated based on data assimilation model; Policy scenarios finalized; UNFCCC author teams include permafrost emissions.		Permafrost emissions included in IPCC AR7.
Permafrost emissions accounted for in global climate policies	Contributions made to UNFCCC processes (*e.g.* Global Stocktake) and meetings (*e.g.*, COP and SBI/SBSTA) to raise the profile of permafrost risk in international climate dialogue.					
	Engagements with climate negotiators through coordinated advocacy, data sharing, and policy briefings to account for permafrost thaw in UNFCCC policy commitments.			Incorporation of permafrost carbon processes into IPCC publications and negotiated texts based on the "best available science."		
	As data and insights are developed, ensure our network of leaders are resourced with information to push for global emissions targets informed by permafrost data.					
Permafrost thaw integrated into disaster policies and advancement of climate adaptation governance framework	Meetings held with US agencies and Congressional representatives to build awareness and highlight permafrost risk; Identified opportunities for improved coordination, policy coherence, and resources for disaster response, recovery, and community-led adaptation.		Convenings held to raise the profile and address responses to permafrost risk.	Development of innovative, inclusive, and equitable solutions for communities facing displacement and loss and damage due to permafrost thaw and other climate hazards.		Existence of climate relocation governance framework.
	Work with local communities to develop a list of policy priorities to address impacts of permafrost thaw; Develop targeted policy briefings for permafrost risk adaptation; Work with policymakers and communities to advance international disaster policies and climate relocation governance framework.					

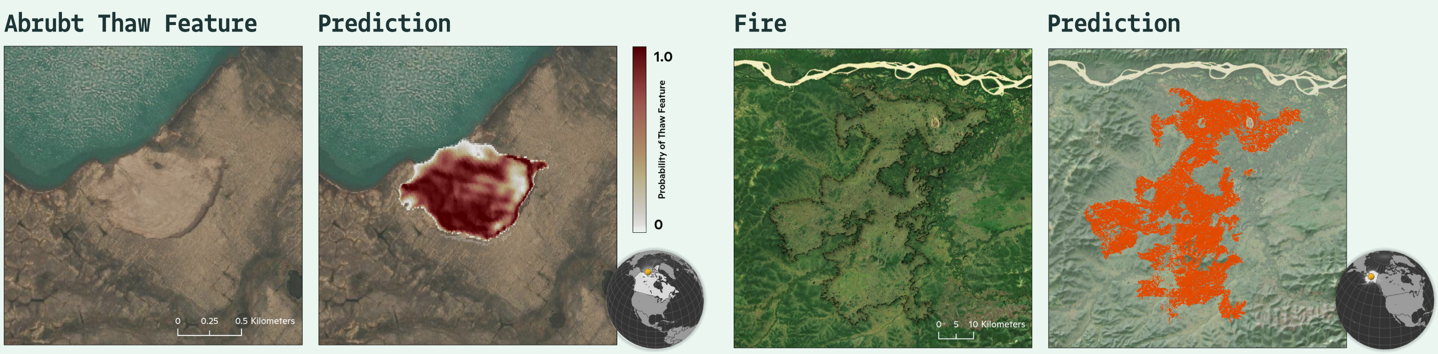
APPENDICES

1. PERMAFROST PATHWAYS POLICY STRATEGY OVERVIEW

Read the Permafrost Pathways policy strategy overview to learn more about the project's policy priorities and tactics.

2. FIRE AND THAW SLUMP MAPPING

Mapping wildfire and retrogressive thaw slumps at high spatial resolution using satellite imagery and deep learning.



3. KUIGILNGUQ TIDAL FLOOD MAP

Tidal flood map of Kuigilnguq co-produced by Greg Fiske and former Permafrost Pathways Tribal Liaison Gary Evon.

4. PUBLICATIONS CO-AUTHORED BY MEMBERS OF THE PERMAFROST PATHWAYS TEAM

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