symposium
Northern Alaska 2023

LEARNING FROM THE PERMAFROST & INFRASTRUCTURE SYMPOSIUM

Merging Science, Engineering and Community-based Knowledge

JULY 28–AUGUST 5, 2023

CONFERENCE REPORT

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Online Proceedings Portal

Conference materials, including presentation slides, recordings, agendas and participant bios, are archived online at the Arctic Data Center portal: **Proceedings of the Permafrost & Infrastructure Symposium**
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Look for these icons throughout the report to find where to watch, listen, or read more about the topic from symposium participants:

Video Recording / Audio Recording / Written Material

Cover Photos

FRONT COVER (FROM LEFT): Permafrost & Infrastructure Symposium participants view the mobile, adjustable foundation of a "sled home" during a field trip to visit infrastructure and permafrost research sites in Utqiaġvik (Photo: Steven Rowell/ MCAD, 2023). A breakout group discussion of community-scale actions to mitigate permafrost thaw during the Utqiaġvik conference (Photo: Jana Peirce). Participants on the Dalton Highway excursion examine exposed permafrost at Mile 362.5 (Photo: Jana Peirce). BACK COVER (FROM LEFT): Utqiaġvik Conference participants (Photo: Lloyd Pikok). Dalton Highway participants (Photo: Billy Connor).

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In Memoriam: Ronald "Ronnie" Daanen (1972-2023). Permafrost & Infrastructure Symposium participants stop to share memories of Ronnie at frozen debris lobe site FDL-A on the Dalton Highway, where he led research for over a decade. A brilliant permafrost hydrologist, Ronnie was to have joined the symposium from Deadhorse to Fairbanks to share his knowledge and passion for the geology and ecology of Northern Alaska.

UIC SCIENCE / NSF / UNIVERSITY OF ALASKA FAIRBANKS / NNA Ice-Rich Permafrost Systems IRPS / UAF INE AIDC / PERMAFROST COASTAL SYSTEMS NETWORK

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FIGURE PANELS & SIDEBARS

There is no substitute to being in a place like Point Lay. It's an efficient way to do away with a whole bunch of assumptions. There is never a better way to get more people on the same page faster, so we can move onto the next phase faster.

— Griffin Hagle-Forster, TNHA

PHOTO: JANA PEIRCE

PHOTO: JANA PEIRCE

Discussions are invaluable when you have people with different expertise looking at the same thing. It requires them to explain things in terms that everyone can understand.

— Billy Connor, Co-chair

INTRODUCTION

The 2023 Permafrost & Infrastructure Symposium brought over 30 Arctic scientists, engineers, planners, and policymakers to Northern Alaska to see the impacts of permafrost thaw on roads and community infrastructure firsthand and to learn from those who live and work in the Arctic. For the symposium's first half (July 28–August 1), participants gathered at the Barrow Arctic Research Center in Utqiaġvik for presentations, field trips and discussions focused on critical climate-related issues prioritized by local governments on the North Slope. They were joined in Utqiaġvik by key personnel from the North Slope Borough (NSB), regional housing authority, local utility cooperative, and the Alaska Native villages of Point Lay and Wainwright.

International participants contributed research perspectives from Greenland, Svalbard, and Arctic Canada. The concept for the event was based on a convergence research model used by Transport Canada to pair scientific and engineering research practices with local knowledge and priorities to develop better strategies for improving Arctic infrastructure.

Visitors to the region chose between field trips to Point Lay, Wainwright, or around Utqiaġvik to view the impacts of permafrost thaw and coastal erosion and their interactions with critical infrastructure, including water-wastewater systems, power plants, landfills, ice cellars, and building foundations.

The first half of the symposium concluded with a three-hour workshop with the NSB Assembly and mayor that was broadcast on local radio.

Twenty participants flew to Deadhorse, Alaska, for the start of the second half of the symposium (August 1–5), which focused on transportation infrastructure and permafrost landscapes in Prudhoe Bay and south along the 416-mile Dalton Highway towards Fairbanks. For the three-day excursion by motor coach, they were joined by tundra restoration ecologist Lorene Lynn of Red Mountain Consulting and geotechnical engineers and construction managers from the Alaska Department of Transportation & Public Facilities (DOT&PF) Northern Region.

A closing half-day session at the University of Alaska Fairbanks (UAF) Usibelli Engineering Learning and Innovation Building explored climate adaptation planning strategies with talks by the Commissioner of Alaska DOT&PF and the U.S. Department of Transportation's Office of the Secretary. The symposium concluded with a field trip to the CRREL Permafrost Research Tunnel near Fox, Alaska.

GOALS OF THE SYMPOSIUM

- Create a forum for North Slope leaders and residents to engage with top scientists and engineers on high-priority issues
- Allow visiting scientists and engineers to see issues related to permafrost thaw and erosion firsthand and to learn from local experts
- Increase dialog between scientists and engineers
- Reduce research fatigue by consolidating the community outreach and engagement activities of multiple science teams working in the same region
- Develop better adaptive strategies for improving Arctic infrastructure through better understanding of the interactions between permafrost and the built environment

PHOTO: STEVEN ROWELL/MCAD, 2023

KEY RECOMMENDATIONS: A ROADMAP TO RESILIENCE

FOR PLANNERS AND POLICYMAKERS

- Adapt now! Secure funds to remediate or replace homes and other vulnerable infrastructure on sensitive terrain before conditions worsen or infrastructure fails. Consider how to mitigate greenhouse gas emissions when planning new capital projects and adaptation measures. (See p. 45)
- Conduct community-wide drainage assessments and implement active snow management and drainage programs to reduce hydrology impacts on permafrost. (See p. 27)
- Hold a hands-on permafrost mapping workshop in the region to support community-scale mapping. (See p. 53)
- Fund collection of baseline data, monitoring, and trend analysis see what is happening over time. Integrate thaw and erosion projections into land use plans. (See p. 48)
- Understand the risks from existing and legacy industrial and contaminant sites on permafrost and develop plans to mitigate them. (See p. 40)
- Fund tundra restoration research and training to meet the need for more restoration ecologists to rehabilitate and stabilize former industrial sites using the most successful and cost-effective techniques. (See p. 43)
- Incubate the next generation of climate journalists by bringing experienced reporters to northern communities and training aspiring local journalists to cover climate stories in their own communities. (See p. 15)

FOR SCIENTISTS, ENGINEERS AND DESIGNERS

- Shift the focus from designing infrastructure that tries to keep the ground frozen to designing more resilient structures that can react to the unpredictability of permafrost through mobility, adjustability, and other means. (See p. 29)
- Map permafrost conditions at community scales using a standard methodology and legend for all communities in a region, including potential relocation sites. (See p. 53)
- Increase piling depth and fill thaw depressions with fine-grained soil to stabilize structures and protect underlying permafrost. If building over ice wedges is unavoidable, remove the upper portion and replace with fine-grained, thaw-stable soils. Set piles in winter. (See p. 31)
- Conduct research with community needs in mind by focusing on communication, developing local capacity, engaging youth, addressing research fatigue, and making research more actionable. (See p. 57)
- Make data easier to access by local planners, grant writers, and decision makers. (See pp. 45 & 59)
- Listen to locals. They know what is wrong in their communities but may lack the data or capacity for implementing adaptive strategies and grant writing. (See pp. 9-13)
- Convene meetings like the symposium in other regions: focused on convergence, codeveloped with host communities, and centered on local priorities. (See pp. 63-65)

PHOTO: LLOYD PIKOK

From left, Griffin Hagle-Forster, executive director of TNHA, Yves Brower, assistant superintendent of the BUECI utility cooperative in Utqiaġvik, and Scott Evans, director of the North Slope Borough Port Authority, opened the symposium's Utqiaġvik conference with a discussion of local and regional issues and priorities related to permafrost thaw, coastal erosion, and infrastructure. They were followed by a panel of North Slope village leaders from Wainwright and Point Lay, who talked about their communities' experiences with rapid Arctic warming.

STARTING WITH LISTENING

PROCEEDINGS

Talks by Brower, Evans & Hagle-Forster

Village Infrastructure Panel

Reflections by Kilioni & Tracey

The symposium opened with a listening session in Utqiaġvik to understand local concerns, learn about current projects and priorities, and hear what questions local experts have for visiting scientists and engineers.

Stable Infrastructure to Support Growth

- Opening remarks from the NSB Mayor's Office highlighted the need for solutions to support the region's growth. Current infrastructure challenges are surpassing what the borough can address at a time when more housing and more connections to water and sewer services are needed.

Preventing Coastal Erosion and Storm Damage

- Increasingly frequent and severe fall storms have resulted in significant coastal erosion in Utqiaġvik, causing millions of dollars in damages and risking homes and critical infrastructure.
- The North Slope Borough has tried to slow erosion using HESCO containers, concrete revetment, and burying tanks and tar barrels with limited success.
- The Barrow Coastal Erosion Project will protect about 5 miles of coastline with rock revetment, a protective berm, and by raising the elevation of Stevenson Street. The U.S. Army Corps of Engineers project is scheduled for completion by 2031.
- The runway at Utqiaġvik's airport had to be realigned due to erosion that was preventing larger planes from landing.

New Roads for Better Connectivity

- Road construction can save tens of thousands of dollars on the cost of barging freight. The NSB is partnering with the State of Alaska on ASTAR, a project to connect communities and improve the quality of life on the North Slope by lowering the cost of goods and increasing opportunities.
- The availability of gravel is a major challenge in the region. A 2-mile test section is being built to assess the durability of alternative materials in different weather conditions.

Future-proofed Housing

- With limited resources and high logistics costs (roughly 20–35% of project budgets), Taġiuġmiullu Nunamiullu Housing Authority (TNHA) faces challenging constraints in meeting its mandate to build homes comparable to those in the community with design and construction features reasonable and necessary for the environment and with accessibility features for a wide range of abilities.
- A new TNHA construction specification that considers the carbon footprint of materials also helps justify the higher cost of building in the Arctic.

Eddie Kagak, Tribal Council, Village of Wainwright

Jimmie Kagak, Acting Mayor and Fire Chief, City of Wainwright

PHOTOS: JANA PEIRCE

Wainwright is built on ice-rich permafrost between the Chukchi Sea and Wainwright Inlet. Driven largely by storm surges during the ice-free season, coastal erosion is encroaching on roads and other infrastructure and impacting access to the beach and the subsistence hunting and fishing practices that are vital to the community's culture, economy, and the health of its people.

PHOTO: EDDIE KAGAK

- Based on feedback received from communities, TNHA has been moving away from some more novel construction materials and techniques to building more conventional-looking homes.
- An exception is a "sled home" that can be relocated if needed and has a foundation that can be adjusted differentially. New duplexes in Point Lay can be separated and moved independently (see pp. 28 & 33). The goal is homes built to be future-proofed, ensuring efficiency, comfort, and reliability.

Utqiaġvik Water and Sewer Systems

- Barrow Utilities and Electric Cooperative, Inc. (BUECI) operates an underground utilidor, a direct-bury system, and a tank-operated system to provide water-sewer services across Utqiaġvik.
- At $17,000 per square foot, the utilidor is by far the most expensive but least problematic of the three systems. It is maintained at ~50° F to keep pipes from freezing and permafrost from thawing. Some water infiltrates through service connections in summer, but it is dry in winter. (See p. 34)
- More issues with permafrost thaw occur in the direct-bury system: the pipes, service barrels, and houses themselves are moving, leading to broken pipes, water leaks, and sewer backups. Houses built on blocks rather than pilings have moved the most and need near constant leveling.
- Built on a pre-engineered pad, Block A has been the most stable area of town. Putting gravel down on top of insulation seems to make the best pads.

Protecting the Shoreline in Wainwright

- Protecting the shoreline especially around town is the highest priority issue in Wainwright. More severe storms are causing unprecedented erosion. The beach has receded 30 feet, and the village has lost about 75 feet of bluff in town.
- Attempts to slow erosion with sandbags and other materials have not worked. Engineers tried using old fuel tanks welded together to protect the shoreline in the past, but they broke apart during a big storm. Now all rusted out, the old tanks are still visible on the south side of the village.
- It took ten years, but the community was eventually able to get rock to reinforce the shoreline, and it is holding up well. It has protected that section of beach from significant erosion, while the unprotected shoreline to the south has been wiped out by recent storms (see p. 18). They would like to see another rock wall on the south side of town.
- With more severe storms, they have witnessed the lagoon being filled up for the first time in local memory. A tidal surge of six feet caused massive erosion and changed a place called Thomas Point at the mouth of the river. That one storm changed the entire beach area and drained a saltwater lake.
- The tundra along the coast is also collapsing due to permafrost thaw. Ice wedges are now exposed in the bluff face along the beach. Locals observe, "when the ice melts, the tundra falls."

There are eight communities on the North Slope, and each and every one of our communities is unique. Some of us are very windy communities. Some of us that are inland are warming up more. Even though we're unique, we're all doing the same kind of construction, and I think we need that uniqueness considered in our modeling. Respect our uniqueness.

— Bill Tracey, Sr.

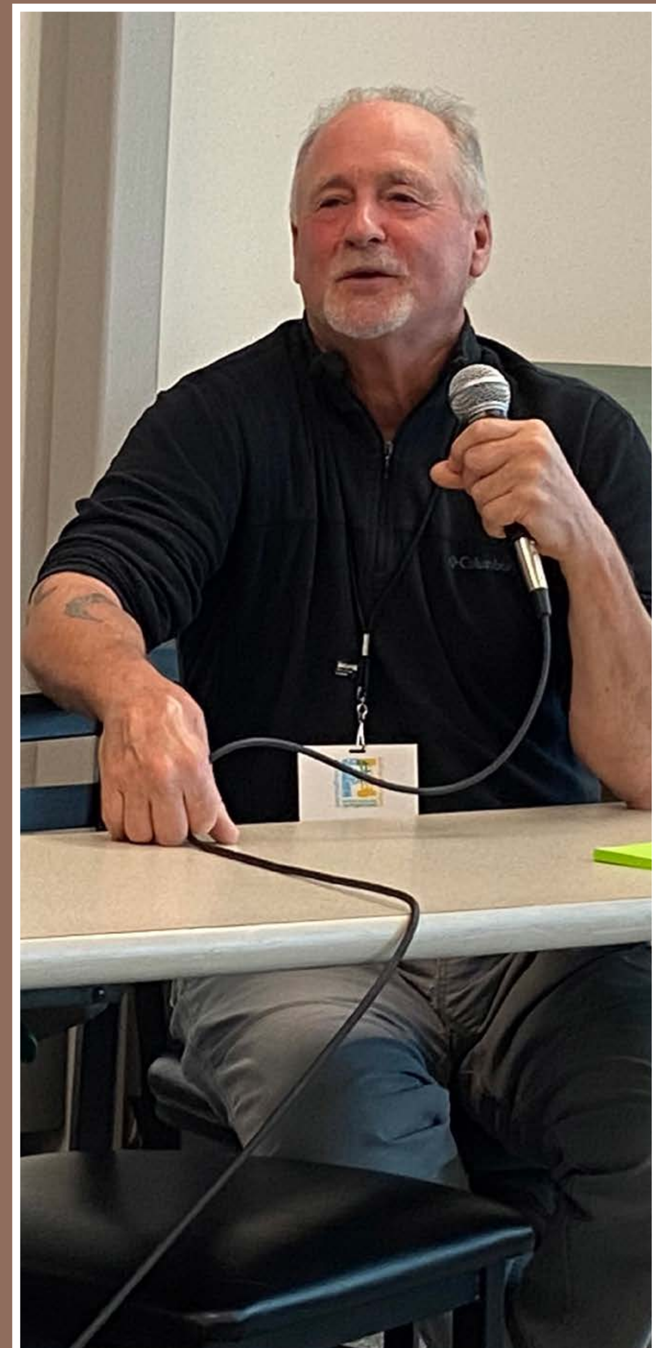


PHOTO: JANA PEIRCE

Bill Tracey, Sr., NSB Assembly, Point Lay resident

- "We live in our villages. We know what is wrong, and we know how to fix it. We would like people to listen to what we have to say. There are entities that can help us bring you to our villages to see what's there, what works, what doesn't, what we need, and how we can get it. Come work with us."
- Village leaders would especially like help with grant writing to fund the construction of a rock revetment in front of the town.

Addressing Permafrost Thaw in Point Lay

- In Point Lay, the ground is very ice rich, causing massive subsidence and ponding. "Our homes create snowdrifts, and the drifts add to the ponding, which contributes to the subsidence and gets down into our pilings."
- They have had to fence around some ponds to keep children safe. They also need a way to move water out of town during spring break up.
- The ground has subsided so much that pilings that were buried 10–12 feet deep are almost completely exposed. Houses are shifting, doors do not work, and windows and walls are cracked.
- Many homes are so damaged they are not worth rebuilding or remodeling. Some have already been relocated once.
- Deeper gravel pads and longer pilings help. However, the community is running out of gravel.
- The direct-bury water and sewer system is being abandoned. They are installing holding tanks for homes and going back to honeybuckets.
- A million-gallon water holding tank failed several years ago when the bottom gave way due to subsidence. That third holding tank was vital, since the village's fresh drinking water lake had already been lost to permafrost thaw when it drained overnight into an adjacent river.
- While looking for a more permanent freshwater source, the community is getting its water from the river. Too saline to drink, the water needs to be filtered by an expensive reverse osmosis system. The river is also where they used to dredge for gravel, but the two uses are not compatible.
- As in Wainwright, significant sloughing is occurring along the coastal bluff in Point Lay. It was 40 feet above sea level and is now closer to 30.
- The community would like engineers to come in to assess its infrastructure, so they know what is sound and can plan from there.
- "We welcome help from grant writers. In smaller villages like Point Lay, we do not have the capacity to look for grants and administer them. Capacity in our village settings is a big deal."

Aging Infrastructure Across the Slope

- Most public infrastructure on the North Slope was constructed in the 1970s–80s when the borough had a large capital improvement program. Now, that infrastructure is all aging at the same time, while the budget is a fraction of what it was. Most goes for major repairs or to replace key structures, like the village school lost to fire.

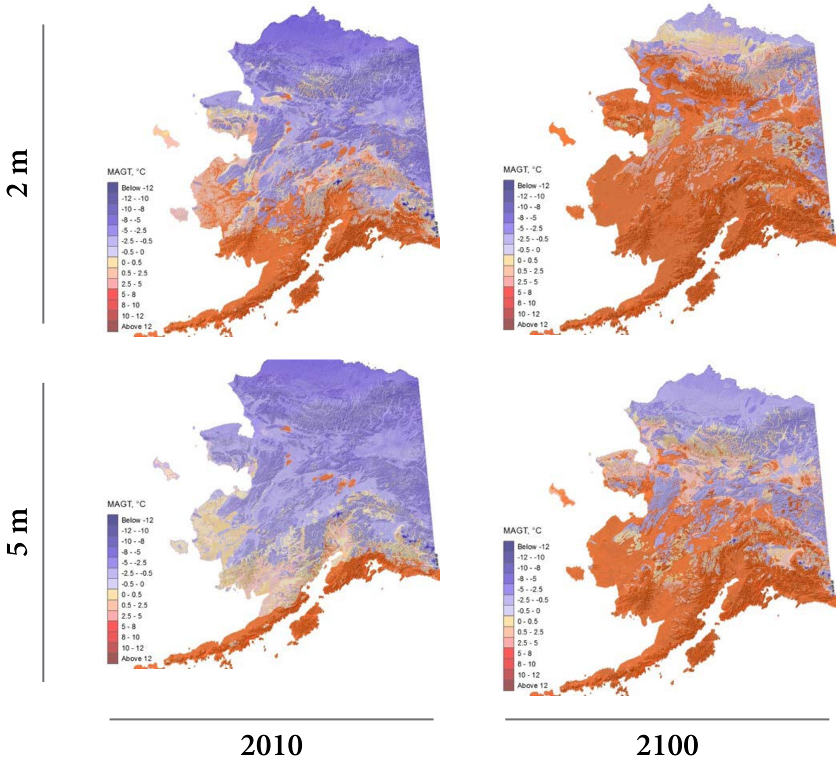


FIGURE: UAF SNAP

PROJECTING GROUND TEMPERATURES

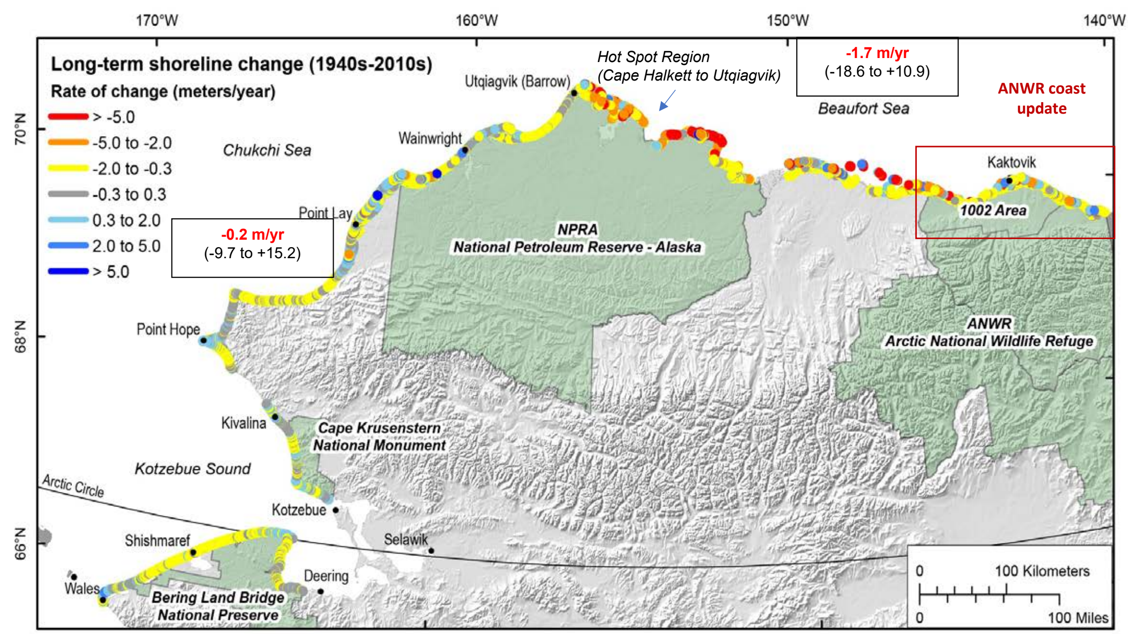
Future ground temperatures at 2- and 5-m depths have been projected to the end of the century using an ensemble of five global climate model (GCM) outputs in a balanced emission scenario (A1B). Permafrost temperature and active layer thickness for specific locations in Alaska can be forecast with a model from UAF's Geophysical Institute Permafrost Lab (permamap.gi.alaska.edu).

— Kevin Bjella presentation

MONITORING SHORELINE CHANGE

Long-term shoreline change rates have been considerably higher along the Beaufort Sea coast compared to the Chukchi Sea coast. They are highest on exposed mainland coasts compared with sheltered coasts. Over the short-term, rates are highly variable at -25 to +20-m per year.

— Li Erikson presentation



Gibbs and Richmond, 2017; Gibbs et al 2019

THE IMPACTS OF ARCTIC WARMING

PROCEEDINGS

Talks by Bjella, Erikson, Kanevskiy, Langer, Miller-Hooks & Romanovsky

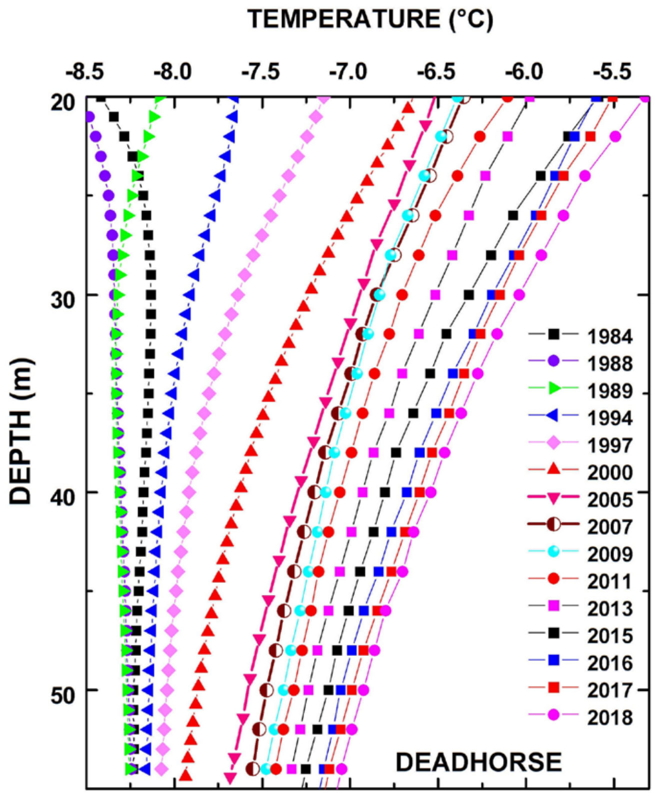
Arctic Science Sessions Podcast

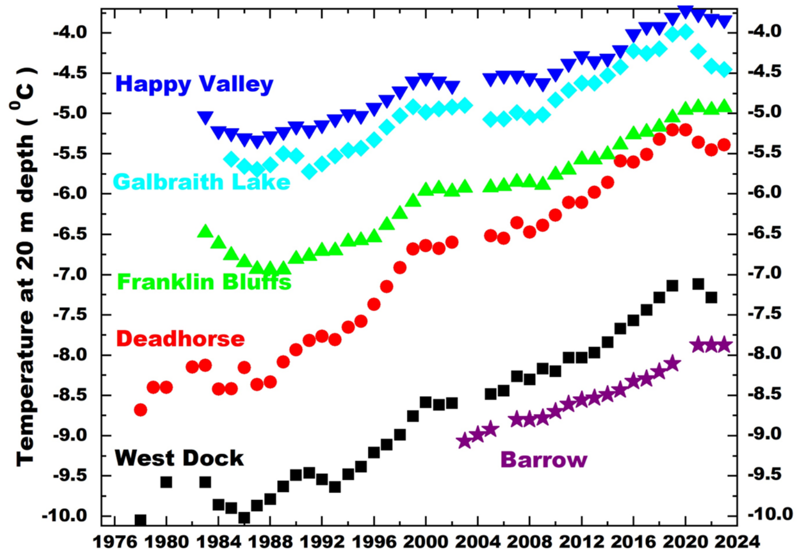
The Challenge

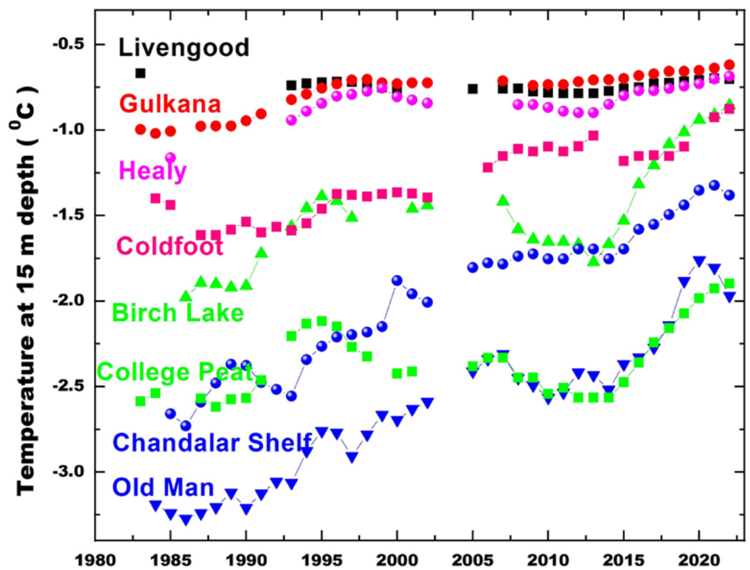
- The Arctic is at the forefront of climate change with air temperatures at high latitudes rising four times faster than global averages. Climate projections show this strong warming trend persisting well beyond 2050.
- Increasing air temperatures equate to increasing permafrost temperatures. Dramatic Arctic warming has triggered permafrost thaw, ground subsidence, and ponding especially in those regions with high ground-ice content.
- Increasing precipitation in the form of rain and snow increases potential for thermal degradation from standing or flowing water. The presence of infrastructure often contributes to ponding leading to accelerated thaw near buildings and roads.
- The decreased sea-ice extent and longer ice-free seasons due to warming air and ocean trends are exposing coastal communities in the Arctic to more frequent and severe fall storms, resulting in increased flooding and coastal erosion.
- Declining sea-ice cover could lead to significant large-vessel traffic in Arctic waters, which will affect sea life, the environment, coastal communities, and local and global economies.

Insights and Opportunities

- Adapt now but plan for the long term. Current thermal conditions allow for technical measures for permafrost stabilization, but long-term mitigation strategies are also needed for a future when technical solutions may no longer be adequate.
- Integrate projections of permafrost thaw, coastal erosion, and sea-level rise into land use plans.
- Train community-based monitors to collect observational data on climate change and its impacts.
- Install ground-temperature monitoring stations in every community in the region. Place two in natural areas away from infrastructure.
- Implement an active snow management and drainage program in each community.
- Conduct permafrost mapping in all communities to aid in selecting building sites and foundation designs. Maps may also be useful in strengthening requests for financial and political support.
- Monitor projections of Arctic maritime traffic to support business strategy and capital investment planning for port construction or expansion.
- Incubate the next generation of climate reporters and train aspiring local journalists to cover climate impacts in their communities.







FIGURES: VLADIMIR ROMANOVSKY

ABOVE: Example of a permafrost temperature profile for Deadhorse, Alaska, from 1984 to 2018. Each line shows the data for a single year, with 1 to 5 years between measurements. At depths of 20 to 60 m, there is no seasonal variation in temperature. In the early years of monitoring (see 1984 and 1988 lines at far left), there was a cooling trend with temperatures getting colder nearer the ground surface. Starting in 1989 (green line), there is a steady warming trend that accelerates throughout the 1990s. Warming is greatest nearer the surface, but the trend is still apparent at 60 m.

RIGHT: Permafrost temperatures at 20 m (top) and 15 m (bottom) along the climate gradient from Utqiaġvik (formerly Barrow) in the north to Gulkana in Southcentral Alaska. As with air temperature, permafrost temperatures tend to get warmer as you travel south. The coldest temperatures (~8 °C at 20 m) are in Utqiaġvik. Almost all sites show a significant increase in permafrost temperature over the past 40 years. North of the Brooks Range (top), permafrost temperatures are driven primarily by climate and decrease relatively steadily with latitude. South of the range, other factors play a larger role, including snow accumulation and vegetation type and thickness, which is why the permafrost at College Peat, a site in Fairbanks, can be colder than in Coldfoot, 180 miles to the north.

40+ YEARS OF PERMAFROST MONITORING

- The Geophysical Institute Permafrost Lab (GIPL) at UAF focuses on understanding changes in the thermal and structural state of circumpolar permafrost, including permafrost conditions on Alaska's North Slope where they have been monitoring temperatures almost continuously for 40 years.
- These data are used to detect changes in permafrost temperature, distribution, and active layer thickness over time (permafrost monitoring), develop methods to model permafrost interactions with changes in climate (permafrost modeling), and predict impacts from permafrost changes on the environment (e.g., ecosystems, hydrology, and the carbon cycle) and society (e.g., infrastructure).
- Earlier permafrost temperatures were collected in the 1950s and 60s by Max Brewer of the Naval Arctic Research Laboratory in Barrow. In 1986, U.S. Geological Survey (USGS) scientist Art Lachenbruch published an analysis of North Slope permafrost temperature data, providing the first geothermal evidence of Arctic warming. The analysis revealed widespread warming of the upper permafrost in the range of 2-4 °C over the past 30–100 years.
- Permafrost has been getting warmer since the 1980s. The formation of taliks, areas that remain unfrozen year-round, is an emerging phenomenon driven by deep summer thaw and insufficient winter refreezing. New taliks have formed in about half of GIPL's 54 monitoring sites located in Alaska's discontinuous permafrost zone. Many were initiated in the warm and snowy winter of 2018.

— Vladimir Romanovsky presentations

DEFINING PERMAFROST

- Permafrost is ground material that remains at or below 0 °C for two or more consecutive years, as defined by the International Permafrost Association.
- Permafrost is defined only by temperature, not ground material composition. It is heterogeneous, and as a result, its response to thaw is dependent on its composition, with ground-ice content being a primary factor.
- Ground ice, any ice below the surface of the ground, ranges from nothing to large ice bodies several meters thick. Because water is in a frozen state, it can accumulate in significant amounts, far exceeding saturation in unfrozen conditions.
- In areas with high ground-ice content, the ice provides structure to the soil and is a potential source of water. When the permafrost thaws, the ground-ice content determines the ground's response to thaw; it will either simply rise in temperature if it is ice-poor, or if ice-rich, the ground surface will collapse, known as subsidence or thermokarst.

— Melissa Ward Jones

PERMAFROST GROWN: THE HETEROGENEITY OF PERMAFROST CONDITIONS
OPEN ACCESS GOVERNMENT, APRIL 2024. DOI: 10.56367/OAG-042-11172

Three ground-ice cores of similar volume but varying ice content before thaw. The previously ice-rich core on the left has lost half its volume to subsidence after 12 hours of thaw. The ice-poor core on the right remains structurally intact after thawing.

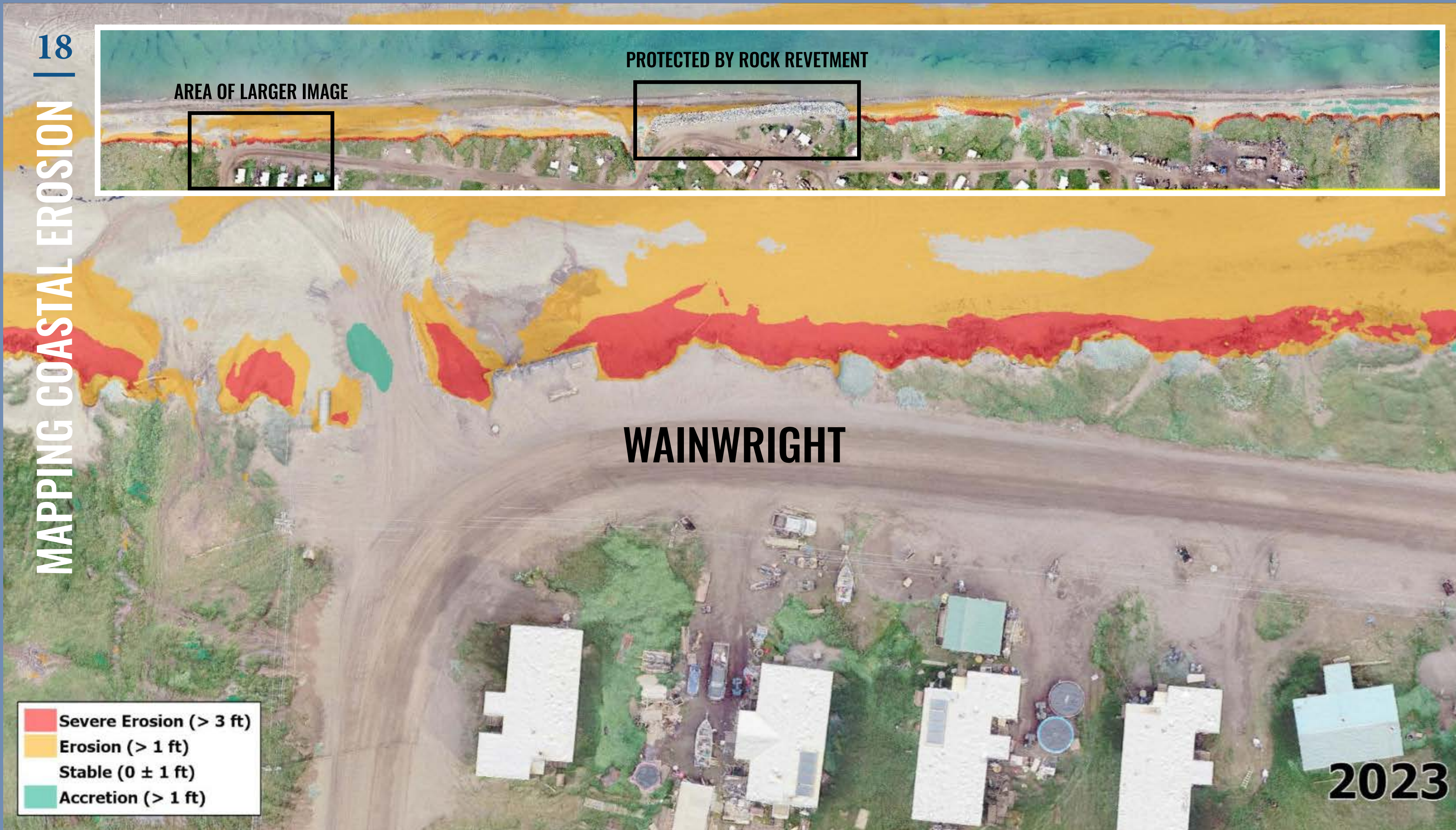


FIGURE: HOREN ET AL. 2023

This screenshot from an online Story Map by the Alaska Division of Geological & Geophysical Surveys shows dramatic changes to the coast at the southern end of Wainwright from the destructive October 2022 storm based on differences in the 2021 and 2023 imagery captured by repeat UAV (uncrewed aerial vehicle or "drone") surveys. High-resolution digital surface models (DSMs) created from such surveys can be used to map erosion and calculate volumetric land loss. Difference maps like the one above can reveal more subtle changes that are not easily identified in aerial imagery, such as beach erosion and accretion. Used along with local knowledge, this information can provide valuable insight for communities seeking to design and implement appropriate mitigative measures to protect their coastlines.

— StoryMap: Monitoring event-driven erosion in Wainwright

COASTAL EROSION: WAINWRIGHT CASE STUDY

PROCEEDINGS

Talks by Erikson, Evans, Poisson & Xiao

Village Infrastructure Panel

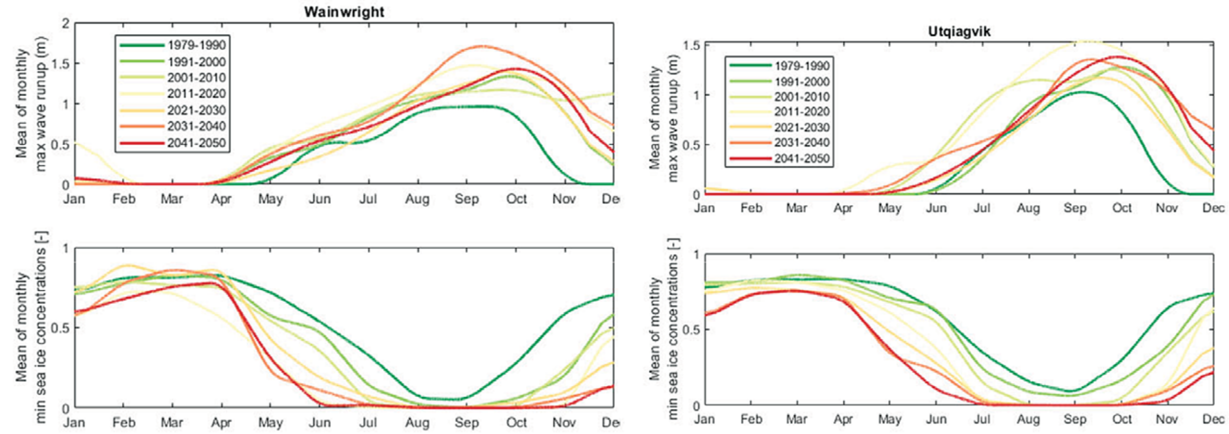
Group 2 Breakout Notes

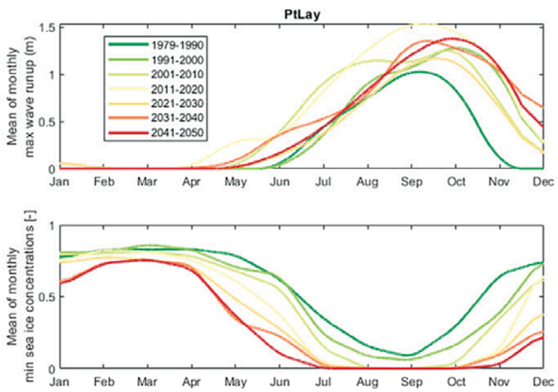
The Challenge

- The top community priority for climate change mitigation in Wainwright is halting the erosion of the beach and coastal bluff. Ground subsidence due to permafrost thaw is also a concern.
- Wainwright's coast is vulnerable to both thawing permafrost and reduced sea ice, which have increased fetch and lengthened the open water season resulting in more wave energy reaching the coast compared to the past.
- Semi-protected and unprotected sections of the bluff face experienced significant erosion after a damaging storm in October 2022.
- As ice-free seasons in the Arctic Ocean have gotten longer, the exposure of coastal communities to storm events with less protection from shorefast sea ice has also increased.
- Thermo-abrasion is the combined effect of advective heat transfer to the permafrost from moving water and the mechanical erosion and removal of particles by the swash of incoming waves. Thermo-denudation is the degradation of permafrost from warming air, causing subsidence or slumping under gravitational forces. Both provoke the fast recession of Arctic coastlines.

Insights and Opportunities

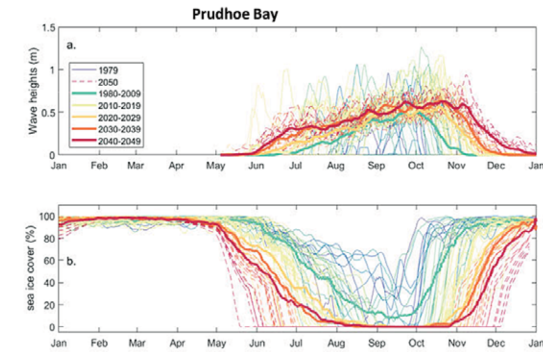
- A 770-foot boulder revetment constructed in 2013 appears to be holding up well but protects less than a quarter of the shoreline.
- Research is needed to better understand longshore and cross-shore sediment transport and associated water currents.
- In open marine conditions, some nature-based solutions may not be suitable, so considering a full range of alternatives is important, including beach nourishment and other near-term solutions such as sandbags and cages (filled with sediment in bags or with rocks) that have been tried with limited success in the past.
- For longer-term mitigation, seek funding to construct a rock revetment to protect the south end of town based on the success of the northern rock wall—the solution also favored by residents.
- Develop comprehensive hazard risk scenarios. Flood maps modeling the flooding that is likely to occur with climate change can identify critical infrastructure and cultural and natural resources that may be exposed to flooding and erosion in the future. Such tools are critical for planning and can help in obtaining funding.





WAVE RUN-UP AND SEA ICE CONCENTRATION

Modeling monthly maximum wave run-up (top graphs) vs. minimum sea ice concentrations (bottom graphs) for 1979 to 2050 in Point Lay, Wainwright, Utqiaġvik, and Prudhoe Bay.



Scientists are modeling scenarios for future storms based on high-resolution digital elevation models (DEMs) of coastlines and projections of sea-level rise due to climate change as part of a USGS Climate Adaptation Science Center initiative. Sample model outputs for coastal communities on the North Slope show an increasing likelihood of hazardous storm surges. The red line in the charts represents predicted conditions in 2041–2050. The dark green line represents historical data from 1979–1990. In all models, wave run-up is highest in the fall when sea ice is at its lowest. Wave run-up is the maximum onshore elevation reached by waves. With less sea ice, there is larger fetch—the distance wind travels over open water to produce waves. With sea ice now forming much later in the fall, there is also a longer season for storms to hit.

— Li Erikson presentation

NEW FLOOD RISK ASSESSMENT & FORECASTING TOOLS

- USGS is developing a suite of flood- and storm-induced erosion hazard maps to assess risks under different wave and surge regimes and sea-level rise (rSLR). Hazard maps for Utqiaġvik are anticipated for fall 2024.
- A real-time system to provide ~6-day forecasts of total water levels (combining tides, storm surge, and wave run-up) is underway in collaboration with NOAA for use in forecasting potential near-term flood hazards. It is operational on the East Coast *(coastal.er.usgs.gov/hurricanes/research/twlviewer)* and anticipated for Alaska by 2026.
- To improve shoreline change projections, algorithms are being developed to automate the extraction of shorelines from satellite data. Anticipate a continuously updated web portal by 2026/27.
- Updating rates of erosion is dependent on acquisition of new coastal mapping data. USGS is reprocessing 1950s and 1970s imagery using Structure from Motion (SfM) techniques to improve their spatial accuracy.
- Getting accurate results for models and forecasts is highly dependent on having accurate bathymetry and topography. Wave run-up is particularly sensitive to the foreshore slope of the exposed beach.
- Bringing the Alaska assessment into conformance with the rest of the nation where modern shoreline positions are elevation based is also dependent on advancements in geodetic and tidal datum information.

— Li Erikson presentation

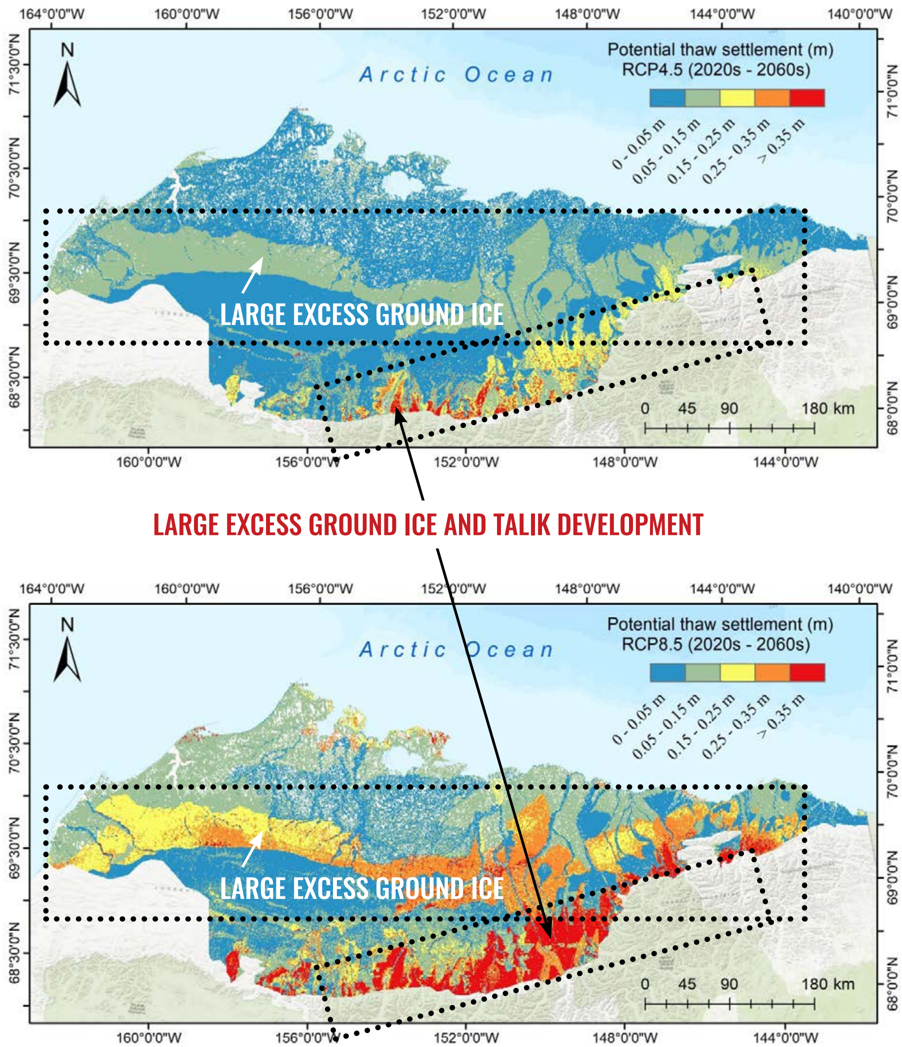
COASTAL HAZARD ASSESSMENT

- The Coastal Hazards Program at the Alaska Division of Geological & Geophysical Surveys (Alaska DGGS) is tasked with helping communities identify their risks from coastal erosion and flooding.
- Data collected are used to create risk assessments, which provide information on how historical erosion rates and flood events may impact current infrastructure.
- Continuous monitoring and baseline data collection are essential. Monitoring does not need to rely on outside experts. Community members can be trained to collect:
  - Photo documentation of ongoing erosion, coastal change, and flood impacts
  - Water level measurements
  - Drone imagery
  - Changes in grain size (beach and nearshore)
  - Fish finder data for seabed-change assessment
  - Thaw depth and permafrost temperatures

— Autumn Poisson presentation / reflection

HESCO® bags and other barriers have not been able to prevent further erosion of coastal bluffs in Utqiaġvik.

PHOTO: SCOTT EVANS

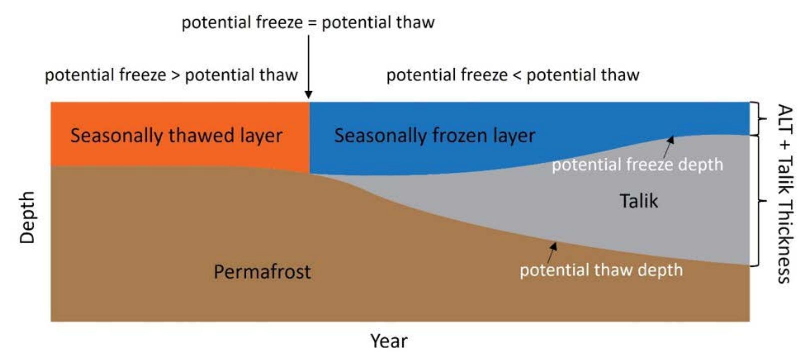


Projections of thaw settlement in 2020–2060 under two different climate scenarios. Representative Concentration Pathway (RCP) 4.5, top, and RCP 8.5, bottom, represent different potential futures based on global success in curbing greenhouse gas (GHG) emissions. RCP 4.5 models an intermediate path in which GHG are stabilized by 2100. RCP 8.5 is a high-emissions scenario, modeling the climate's response if little effort is made to cut GHG. Potential thaw settlement in meters is shown in blue (0–.05 m), green (.05–.15 m), yellow (.15–.25 m) , orange (.25–.35 m), and red (over .35 m).

POTENTIAL THAW SUBSIDENCE

The spatial patterns of potential permafrost thaw subsidence are primarily influenced by the presence and distribution of ground ice, which are closely associated with cryolithology (the structure and genesis of frozen ground) and Quaternary depositional environments.

— Ming Xiao presentation



A talik (grey) is a body of unfrozen ground surrounded by permafrost. Taliks form when the potential seasonal thaw depth exceeds the seasonal freeze depth. They can also form due to the presence of an underlying heat source, such as a body of water or geothermal activity.

FIGURE: UAF GIPL

PERMAFROST THAW: POINT LAY CASE STUDY

PROCEEDINGS

Talks by Connor, Holmes, Kanevskiy, Romanovsky & Xiao

Village Infrastructure Panel

Group 1 Breakout Notes

Reflection by Langer

The Challenge

- Climate change and infrastructure disturbance both impact the thermal regime of frozen soils, leading to permafrost thaw, ground subsidence, and deformations in infrastructure.
- Thaw unstable permafrost is composed of fine-grained sediments and decomposed rock, which have a high bearing capacity when frozen. When thawed, they have low or zero bearing capacity, making stable engineering difficult and costly.
- Communities in ice-rich permafrost regions are most vulnerable to permafrost degradation due to differential ground settlement through thermokarst and other thaw-related processes.
- Ponding water is often associated with thaw, and water and snow can both exacerbate degradation.

Point Lay Case Study

- Point Lay, Alaska, is one of the Arctic settlements most affected by permafrost degradation due to its location on very thaw-sensitive Yedoma deposits (ice-rich syngenetic permafrost).
- Evidence of permafrost degradation outside the village is more subtle, but clear signs of ice-wedge degradation are evident in the surrounding tundra. This suggests that thermokarst could occur there even without the added thermal and hydrologic impacts from infrastructure.
- Thaw settlement has led to widespread structural issues in village homes: exterior stairs not reaching the ground, *kunichuk* (arctic entries) separating from homes, doors and windows not closing, cracked drywall, and failed utility connections.
- Current thermal conditions allow for technical adaptation measures to stabilize infrastructure, but continued warming will exacerbate current challenges. Long-term mitigation strategies may be a more reliable and sustainable investment.

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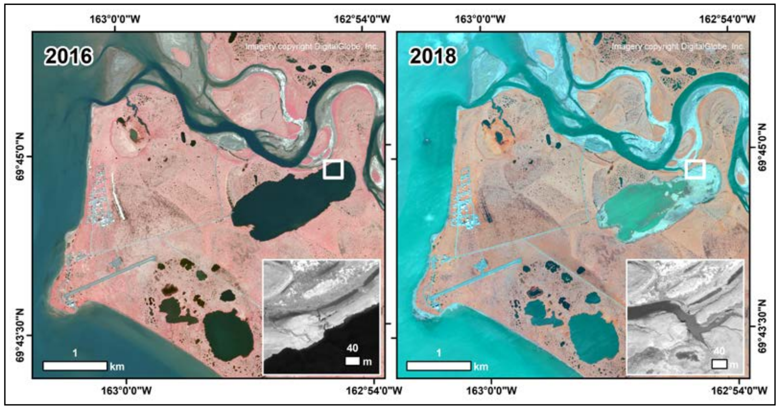
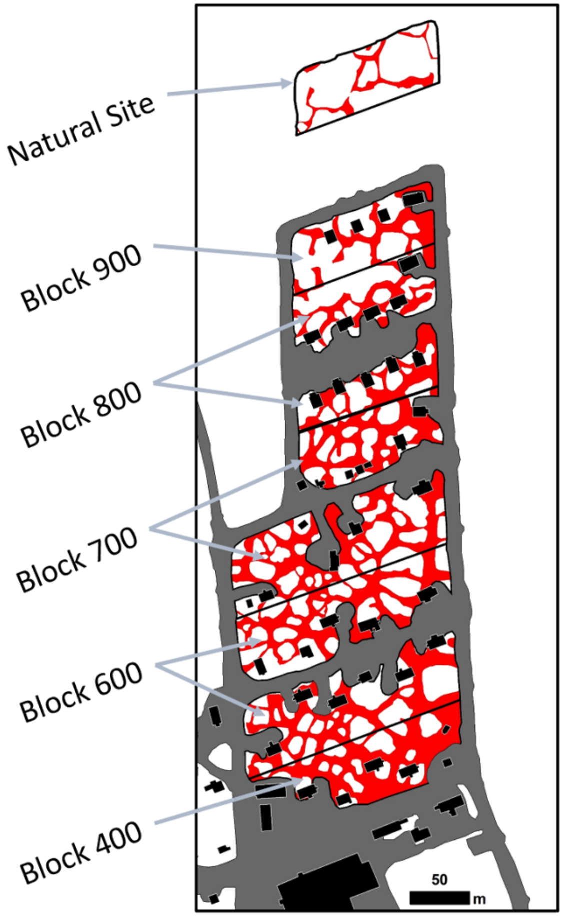


FIGURE: BENJAMIN JONES

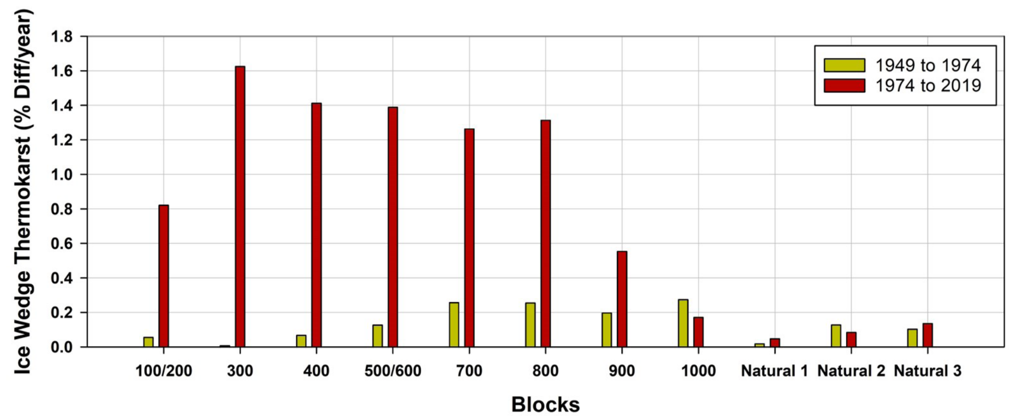
The freshwater lake that supplied the village's drinking water drained overnight into the Kokolik River due to permafrost thaw after a period of intense rainfall in August 2016. The village is still seeking an alternative freshwater supply.



IMPACT OF INFRASTRUCTURE ON THERMOKARST

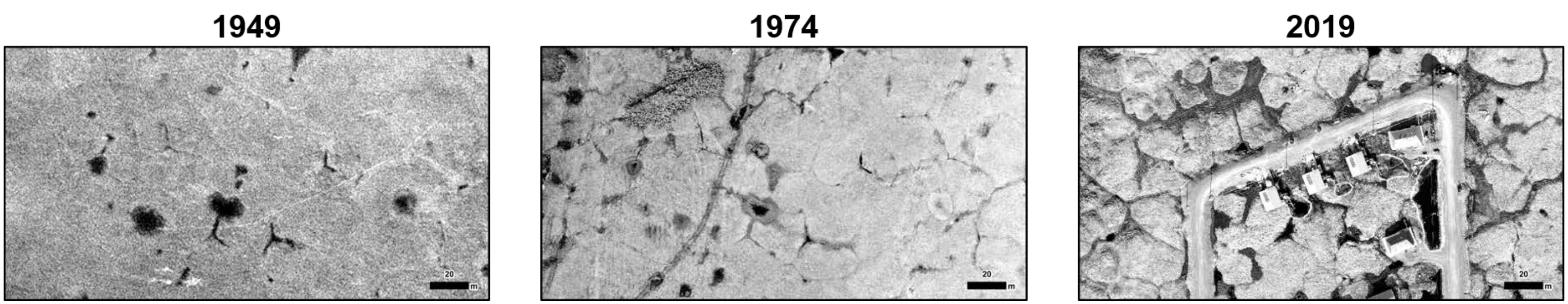
Remote sensing analyses reveal that permafrost thaw in Point Lay has been driven primarily by infrastructure to date. Natural sites with similar terrain but subject only to climate warming show significantly less degradation. The total area impacted by thermokarst (shown in red in image at left) increases as you move south through town to where the oldest residential blocks are located.

— Billy Connor presentation



ABOVE: The percent difference per year in thermokarst area for each residential block in Point Lay over two time periods, 1949–1974 (tan) and 1974–2019 (red), compared with three undeveloped areas.

BELOW: Aerial photos show the progression of thermokarst over time in the area around the 900 block.



FIGURES: BENJAMIN JONES

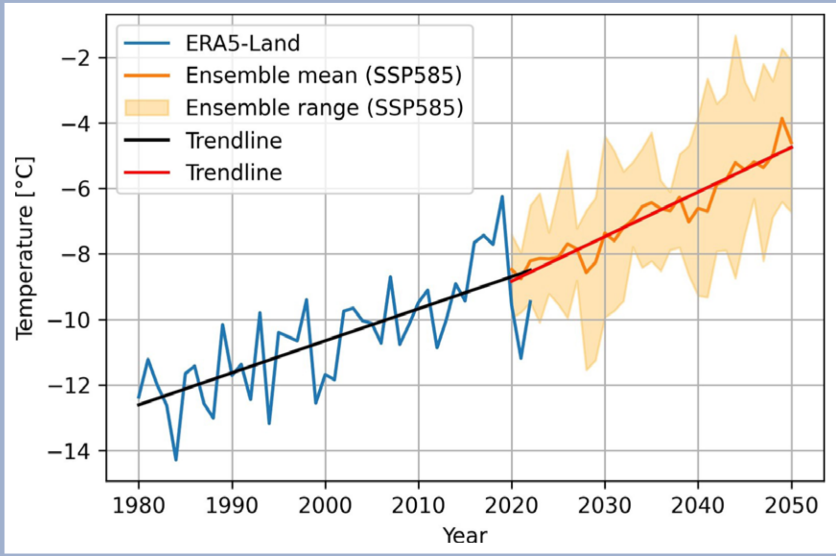
Insights and Opportunities

- Conduct a community-wide infrastructure assessment by structural engineers to inform decisions about moving, repairing, or replacing existing homes that may be in hazardous condition structurally or due to health concerns.
- Backfill one or more thaw-settlement depressions under homes with fine-grained material (or gravel if other material is unavailable), instrument it, and monitor to test its effectiveness for permafrost aggradation (refreezing) and improved surface-water management.
- Identify alternative material sources for gravel and fine-grained fill in proximity to the village or in a location suitable for winter transport.
- Create a community-scale map of permafrost conditions, emphasizing massive ground ice, variation in topographic relief, and hydrology for use in planning. Map permafrost in the village and surrounding area, including any sites being considered for future relocation, if needed.
- Construct a new aboveground water-wastewater system rather than repair the existing system. (See p. 37)
- Implement an active maintenance program for snow management, drainage facilitation, and annual thermokarst monitoring.
- Study the feasibility of alternatives for re-establishing a long-term community drinking water source, including cleaning up and re-damming the previous freshwater lake basin, constructing a road to an alternative lake source, and other options mentioned in the 2017–2035 Point Lay Comprehensive Plan.

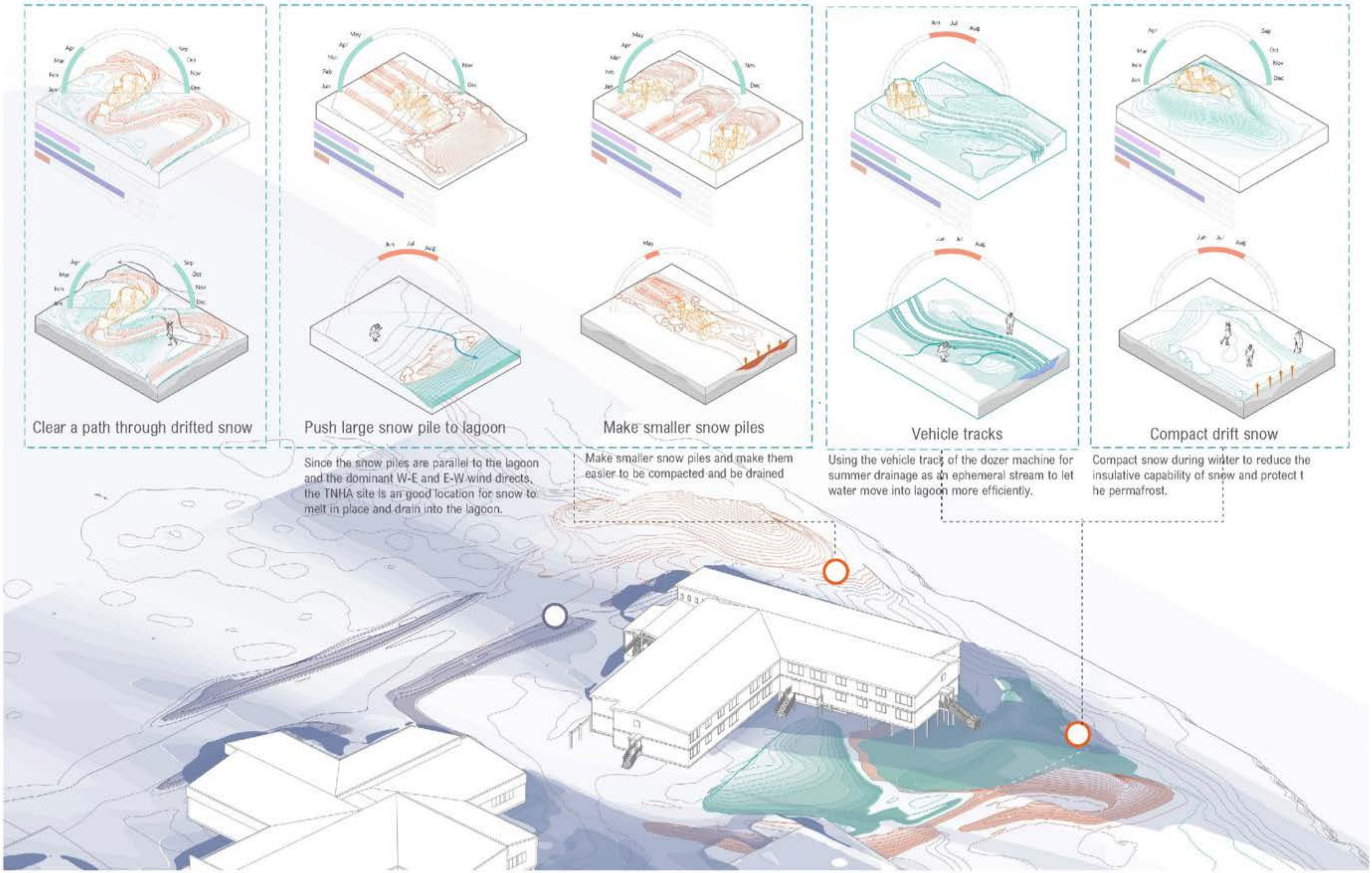
CLIMATE TRENDS & IMPACTS

- Mean annual air temperature at 2 m above ground level in Point Lay increased from below -12 °C to about -9 °C between 1980 and 2022. This average warming trend of 0.098 K per decade threatens a shift in the thermal state of local permafrost, increasing its vulnerability to thermokarst in sensitive locations. Climate models indicate this warming trend will persist well beyond 2050, with mean annual air temperature projected to exceed -5 °C by 2050 under some scenarios such as the one shown below.
- While these data do not provide a full analysis, they indicate a likely trajectory of future warming that can inform decision makers considering long-term mitigations.

— Moritz Langer reflection



Trends in near-surface air temperature at Point Lay. Historical data are based on the re-analysis product ERA5-Land. Future climate projections until 20250 are based on a small model ensemble consisting of MPI-ESM1-2-HR, HadGEM3-GC31-MM, GFDL-CM4, and CNRM-CM6-1, based on the SSP585 scenario.



SNOW & MELTWATER MANAGEMENT

This plan was created for the TNHA building, a 29-plex housing unit in Utqiaġvik, to manage snow removal and meltwater drainage using locally available equipment. Red shaded areas are machine piled snow and green is naturally drifted snow. Strategies include creating drainage channels and "ephemeral streams" to remove snow from the landscape, compacting drifting snow to reduce its insulating capacity especially early in the winter, making smaller and more dispersed snow piles to make them easier to compact and drain, and pushing larger piles to the lagoon.

— Matthew Jull / Leena Cho presentation

THE IMPORTANCE OF HYDROLOGY

PROCEEDINGS

Talks by Bjella, Connor & Jull/Cho

Group 3 Breakout Notes

The Challenge

- The presence and movement of water are key drivers of permafrost degradation: When frozen ground thaws, ground ice melts and the surface subsides in karst-like depressions (thermokarst). These thermokarst pits fill with water, forming ponds and altering drainage patterns. These thaw ponds lead to deeper thaw due to water's thermal conductivity, setting up a positive feedback.
- The increasing precipitation in the form of rain and snow that is associated with climate change contributes to permafrost degradation, especially if there is inadequate drainage or poor snow management.
- Early season snow can trap summer heat in the ground, slowing the refreezing process. Snow at any time insulates the soil from cold winter air.
- Snow accumulates around foundations and along snow fences and embankments leading to deeper thaw and differential settlement.
- The presence of infrastructure also creates obstacles to drainage, exacerbating permafrost thaw and the structural issues it causes. Road embankments can especially impede the movement of water, causing thermo-erosion gullying.
- Spring snowmelt contributes to surface water ponding in thermokarst landscapes and around infrastructure, contributing to the positive feedbacks. Snow fences alter hydrology by extending the duration of snowmelt and increasing water levels throughout the open-water season.
- Differential settlement places stresses on water and sewer pipes and service connections. Underground leaks can be hard to detect, resulting in the discharge of substantial amounts of water, leading to additional thaw, and possibly sinkholes and underground caverns.

Insights and Opportunities

- Conduct community-wide drainage assessments.
- To minimize the impacts on permafrost, design site-specific snow management plans depending on where snow naturally drifts and where snow melt flows or accumulates.
- Where large snow drifts form, add more culverts and angle them away from the dominant wind to speed spring meltwater drainage.
- For new developments, plan how to mitigate impacts from snow—including wind drift, snowmelt drainage patterns, and snow management—and how to remove water from the landscape.

New duplexes in Point Lay being constructed by TNHA are designed so they can be separated at the party wall and a steel sled placed underneath in the event of relocation. The adjustable post and pad foundation is built on a thick gravel pad. When properly installed, it will remain in contact with the ground even as the ground deforms due to thaw.

CREDIT: JANA PEIRCE

IN THE FACE OF UNPREDICTABILITY

...we choose ADJUSTABILITY

...we plan for EXPANSION

...we need MOBILITY

— Aaron Cooke presentation

DESIGNING FOR THE ARCTIC

PROCEEDINGS

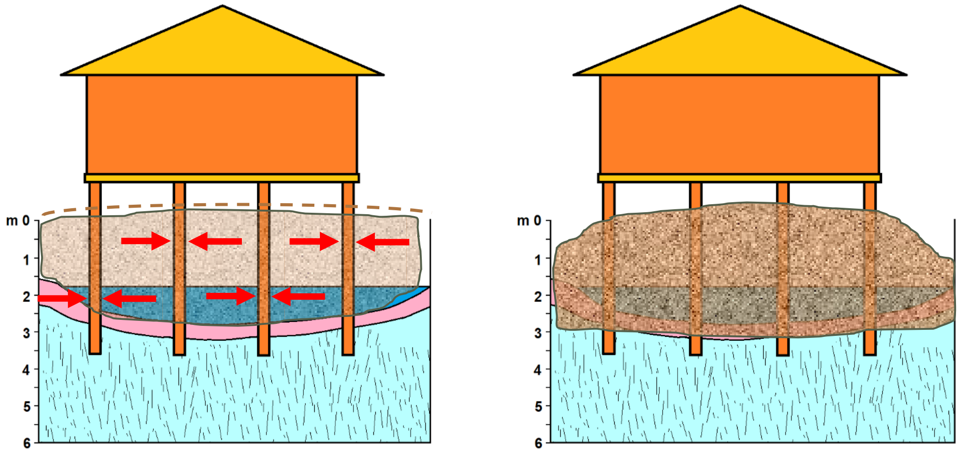
Talks by Cooke, Hagle-Forster, Jull/Cho & Shur

The Challenge

- There is no regulatory framework for building in the Arctic. Building codes do not mention permafrost, and the design guidelines that do exist are limited and often old. At the same time, the Arctic environment requires us to question design conventions imported from the South.
- Arctic construction practices are not consistently collected or shared, so knowledge is typically local and vulnerable. The same mistakes often recur.
- Causes of failure include insufficient geotechnical information, mistakes in design, construction deficiencies, and poor maintenance.
- The speed of erosion and subsidence is often faster than land use planning and permitting, necessitating building homes before they are platted.

Insights and Opportunities

- The best solutions have generally been ones that use active or passive methods to keep the ground frozen, but as the climate continues to warm this becomes more challenging.
- We should shift the focus to designing more resilient structures that can react to the unpredictability of permafrost. Structures should be designed to move both laterally and vertically.
- Adjustability is needed not only in foundations, but anywhere a building meets the ground, such as porches and stairways. All connections should be hinged and adjustable to the foundation. The occupant should be able to adjust the system without access to heavy equipment. Designing homes to be towed ensures they can be moved if needed.
- Foundations with larger decks that can be built on later can reduce future overcrowding at lower cost.
- Prefabricated units can save costs but do not create jobs for local operators and carpenters.
- Geophysical measurements, resistivity transects, and traditional knowledge are needed to understand subsurface conditions.
- Climate-resilient housing solutions focus on permafrost-safe foundation concepts but may use the same electrical and water infrastructure solutions from 40 years ago. These systems should also be updated and integrated into new designs.
- Good innovation in housing is based on consent and must involve people who will live in the homes who are interested in the research. The goal is to create homes that prioritize the use and cultural needs of the inhabitants, while solving technical and engineering challenges.

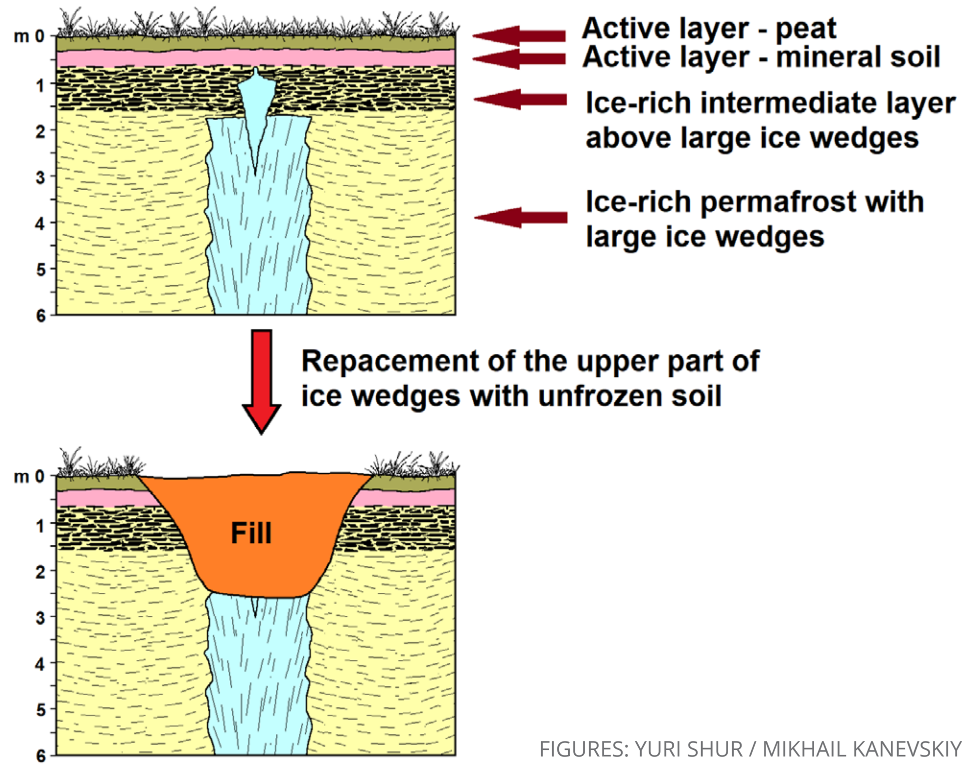


EXISTING BUILDINGS

Filling troughs and depressions with fine-grained soil will help protect the underlying permafrost and establish better drainage throughout the village. Compacted fill material provides immediate lateral support for pile foundations.

NEW CONSTRUCTION

If building above an ice wedge cannot be avoided, removing the upper portion and replacing it with fine-grained, thaw-stable material will protect the ice wedge from degradation and reduce thermal erosion and ponding beneath the building.



FIGURES: YURI SHUR / MIKHAIL KANEVSKIY

PERMAFROST FOUNDATIONS

PROCEEDINGS

Talks by Allard, Brower, Cooke, Connor, Hagle-Forster, Ingeman-Nielsen, Shur & Thornley

Reflections by Bjella & Thornley

The Challenge

- In North Slope communities on the coast, most permafrost is ice rich. It contains ice wedges and segregated ice (lenses and layers of ice) making it thaw-susceptible and thus prone to settlement.
- Frost-heave effects occur when the near-surface soil freezes seasonally and expands vertically. If piles are not embedded deeply enough to resist this force, they will move upwards.
- Shallow foundations designed to be resistant to thaw settlement have had limited success and are not applicable to North Slope conditions. Deep foundations work well but are not generally affordable for residential structures.
- Design specifications for pile length have increased and will need to increase further to ensure stable foundations based on climate modeling.
- Innovative foundations engineered for mobility or adjustability require additional planning, materials, and labor. Overall expenditure may be 30–40% higher than conventional foundations.
- Thermosyphons are used to help keep the ground frozen under foundations and linear infrastructure, such as pipelines and utilities, but are more common on public infrastructure due to expense.
- The cost of concrete is up to 10 times higher per cubic yard in rural Alaska than in Anchorage, due largely to the high cost of shipping the aggregate.
- Some North Slope soils have high salt content, which decreases the freezing point and reduces its bearing capacity. These saline soils are more susceptible to climate change. Utqiaġvik has some pockets of unfrozen soil with brine (cryopegs).
- Pile capacity to transfer load is directly affected by the ground temperature, ice content, and salinity. Engineers face challenges in predicting future conditions, which will impact these factors, leading to higher project costs.

Insights and Opportunities

- Pile foundations are a low-impact and economical option for constructing in the Arctic with the most common type being the adfreeze pile, which provides a bond between the pile and soil.
- Piles should be set in the winter. Pile number, size and length should be designed by an engineer based on a thorough geotechnical investigation.
- The salt content of the soil must be considered in the design of foundations in permafrost. Testing for salinity should become routine.

CONTINUED ON PAGE 33

A Triodetic® foundation supports the Alaska Army National Guard Armory in Utqiaġvik. This multipoint foundation provides a rigid platform for building on permafrost or other unstable soils or in flood-prone regions. Engineered from galvanized steel or aluminum, it can be installed on a concrete slab or bearing pad and can be adjusted to keep the building level in the event of frost heaves or differential thaw settlement.

PHOTO: LORENE LYNN

- When the thickness of ice-rich soil is shallow, replacement of the soil prior to construction is feasible. If a foundation must be set over an ice wedge, remove the upper portion of the wedge ice and replace it with fine-grained, thaw-stable soils.
- In post and pad foundations, a thick gravel pad is placed beneath the structure. The post/pad connection should allow the pad to remain in contact with the soil as the soil subsides.
- Foundations that are designed to be mobile, such as the adjustable, sled-based home by TNHA, allow structures to be moved away from the threat of coastal erosion and thawing permafrost.
- Triodetic® multipoint foundations provide a rigid platform on an adjustable base that can be installed under new or existing buildings.
- Building on rocky outcrops is strategic wherever bedrock is common, such as in Greenland and the Canadian High Arctic. It helps preserve tundra landscapes, reduces the use of scarce sand and gravel resources, and limits community sprawl.
- When building on very ice-rich, sediment-filled basins above bedrock in Greenland, permafrost is excavated until bedrock is reached (up to 15 m), cast piles are constructed, and the excavation is backfilled. Good site knowledge is needed during design to prevent cost overruns.

LEFT: Design specifications for pile length are projected to increase as permafrost temperatures warm.

RIGHT: The "sled home" in Utqiaġvik is built on a giant steel sled. Two attachment points on the frame allow it to be towed across the snow in winter if it becomes necessary to move it.

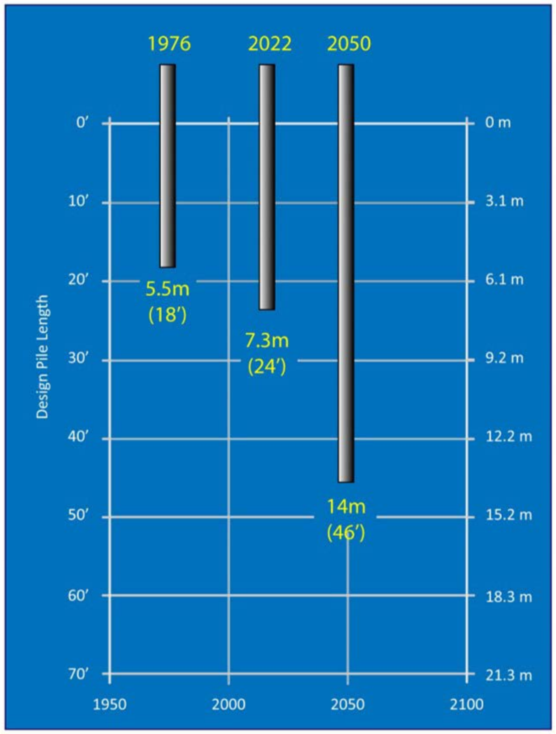
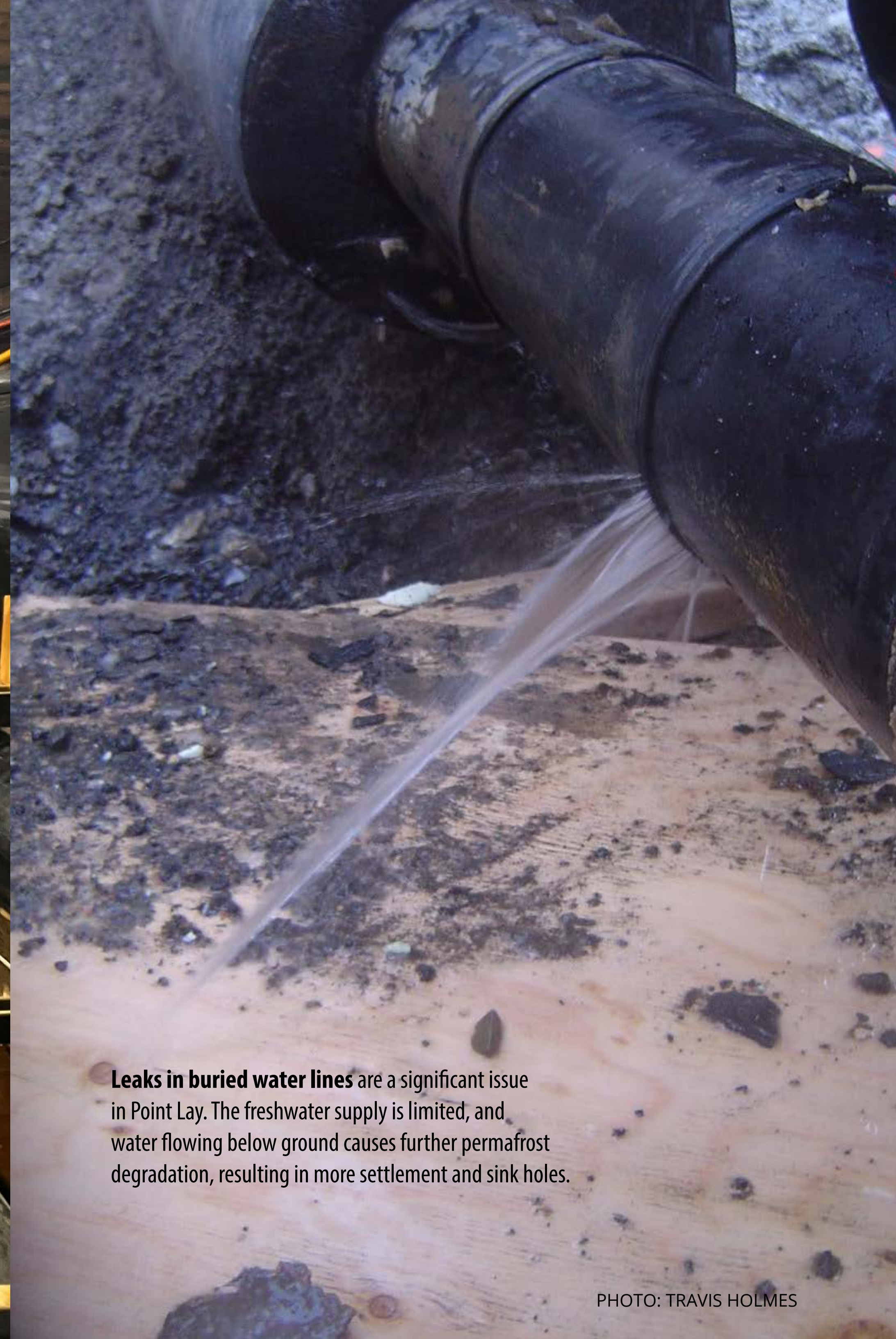


FIGURE: BEEZ HAZEN, NORTHERN ENGINEERING AND SCIENTIFIC

PHOTO: STEVEN ROWELL/MCAD, 2023

A utilidor buried in permafrost runs for 3.2 miles beneath Utqiaġvik at a depth of 6 to 22 feet. It has proved to be the most stable means of providing water and sewer services in Utqiaġvik. The utilidor is maintained year-round at a temperature around 50° F to keep pipes from freezing and the permafrost from thawing.

PHOTO: LI ERIKSON



Leaks in buried water lines are a significant issue in Point Lay. The freshwater supply is limited, and water flowing below ground causes further permafrost degradation, resulting in more settlement and sink holes.

PHOTO: TRAVIS HOLMES

UTILITY INFRASTRUCTURE

PROCEEDINGS

Talks by Brower & Holmes

Village Infrastructure Panel

Group 1 Breakout Notes

The Challenge

- Utility systems on the North Slope are mostly direct-bury systems. Arctic pipe is used, which has a core of high-density plastic (HDPE) and a thick insulation layer with a jacket for protection.
- Substantial construction effort and expense are required to maintain these systems. Thaw settlement issues are worst around large excavations. Using frozen soils to backfill excavation has resulted in the compaction of soils leading to excess settlement after the first thaw season.
- Thaw settlement in the sewer system in Wainwright was quantified using cameras during a large excavation in 2008. The worst deflection was seen on the Summer Road with pipes showing a 5-foot vertical deflection over 50 feet after only 8 years.
- Underground leaks result in a loss of limited water supplies and can create hidden damage if the increased water pressure crushes the pipe's insulation, increasing the risk of pipes freezing.
- The corrosion of underground components is a problem that was not anticipated or planned for. In Utqiaġvik, significant material loss has occurred over 10 years.
- The trenches in which direct-bury pipes are installed have turned out to be more permeable than the permafrost, creating groundwater channels that surface water flows through and leading to thawed conditions in May in trenches that are 10–14 feet deep. The inflow and infiltration into collection systems in wastewater plants taxes the ability to process wastewater from May to July.

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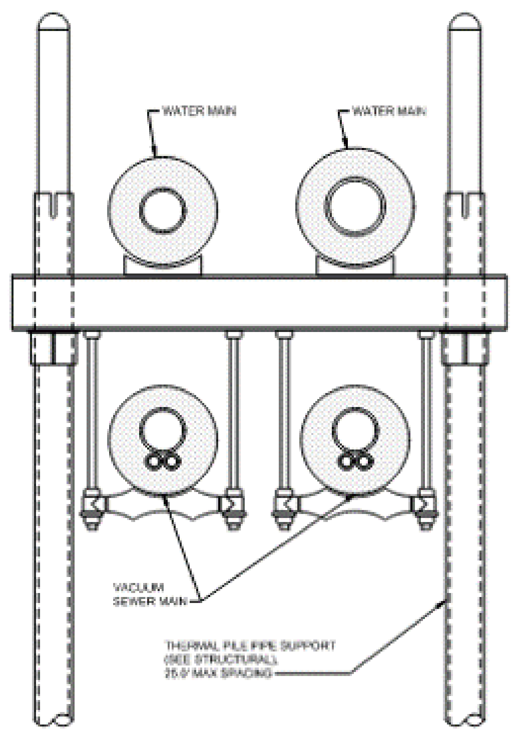
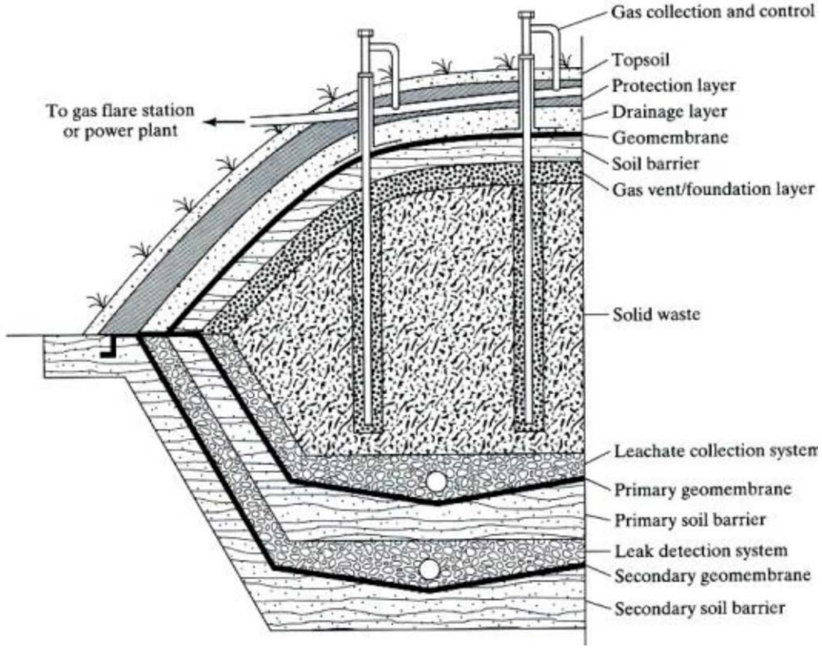


Moving aboveground: Conceptual drawing of the aboveground mainline supports proposed as a replacement for Point Lay's failing direct-bury system.

FIGURE: TRAVIS HOLMES



Landfill Design

- Freezeback landfills are designed, developed, and operated to prevent permafrost degradation and to ensure all the waste will freeze with the permafrost.
- No liner membrane is used. Pad properties otherwise remain similar to conventional landfills. They require a thick gravel pad and thick closure cap designed to shed precipitation and manage erosion, with low permeability to prevent moisture and heat transfer.
- Waste is intended to be encapsulated, not decompose. Closed landfills must protect the underlying permafrost. They need sufficient insulation over the permafrost and waste to meet criteria. Thermal monitoring is required to verify that waste remains frozen.
- Freezeback landfills are exempt from having a containment liner, leachate and methane collection systems, and ground water monitoring. This has reduced construction costs and simplified operations, maintenance, and reporting. Six landfills were approved under these regulations. Only four remain.

Regulatory Changes

- Since 2017 regulators have increased scrutiny on landfill proposals citing conformance to EPA regulation and increasing temperatures in permafrost regions. New freezeback landfills are virtually eliminated under the new guidelines.
- Permit renewals will require updating engineering assumptions perhaps as often as every 5 years to address forecasted temperatures. Confidence is low for 20-year models let alone 50 years or greater.
- Operators will need to maintain both freezeback and conventional landfills on the same site, which has never been done before.

— Travis Holmes presentation

Insights and Opportunities

- As an interim fix for Point Lay's failing direct-bury system, NSB has gone to a shallower-bury system by keeping the utilities as much in the road prism and out of the permafrost as possible. While mostly successful, the main issues have come where a service T ties into the original deeper service. This has become the new weak link.
- Using spray foam for ad hoc repairs on underground pipe has recovered 97% of the manufacturer's stated insulation value. Spray foam also provides a larger footing and a water barrier between the pipe and the permafrost.
- The recommended long-term solution for Point Lay is an above-grade water and sewer system now in design. It features a circulating water main in a single loop with a couple subloops, including one for the industrial area, and a vacuum system for wastewater collection.
- Thermal piles will be used for mainline supports, with taller supports for overhead sections in the industrial area so traffic can pass beneath. Piles must be placed to avoid ice wedges or go below sea level to ensure stability.
- For road crossings in residential areas, the current thought is to heavily insulate and bury the pipe beneath the road and install thermosyphons to stabilize these areas.
- Still to be addressed is what the connection between the service box and the home will look like. It must be very flexible to account for ground movement and settlement.
- As an aboveground system, it will create new and unavoidable barriers to movement in the village for pedestrians and vehicles. A plan for snow removal is still needed.

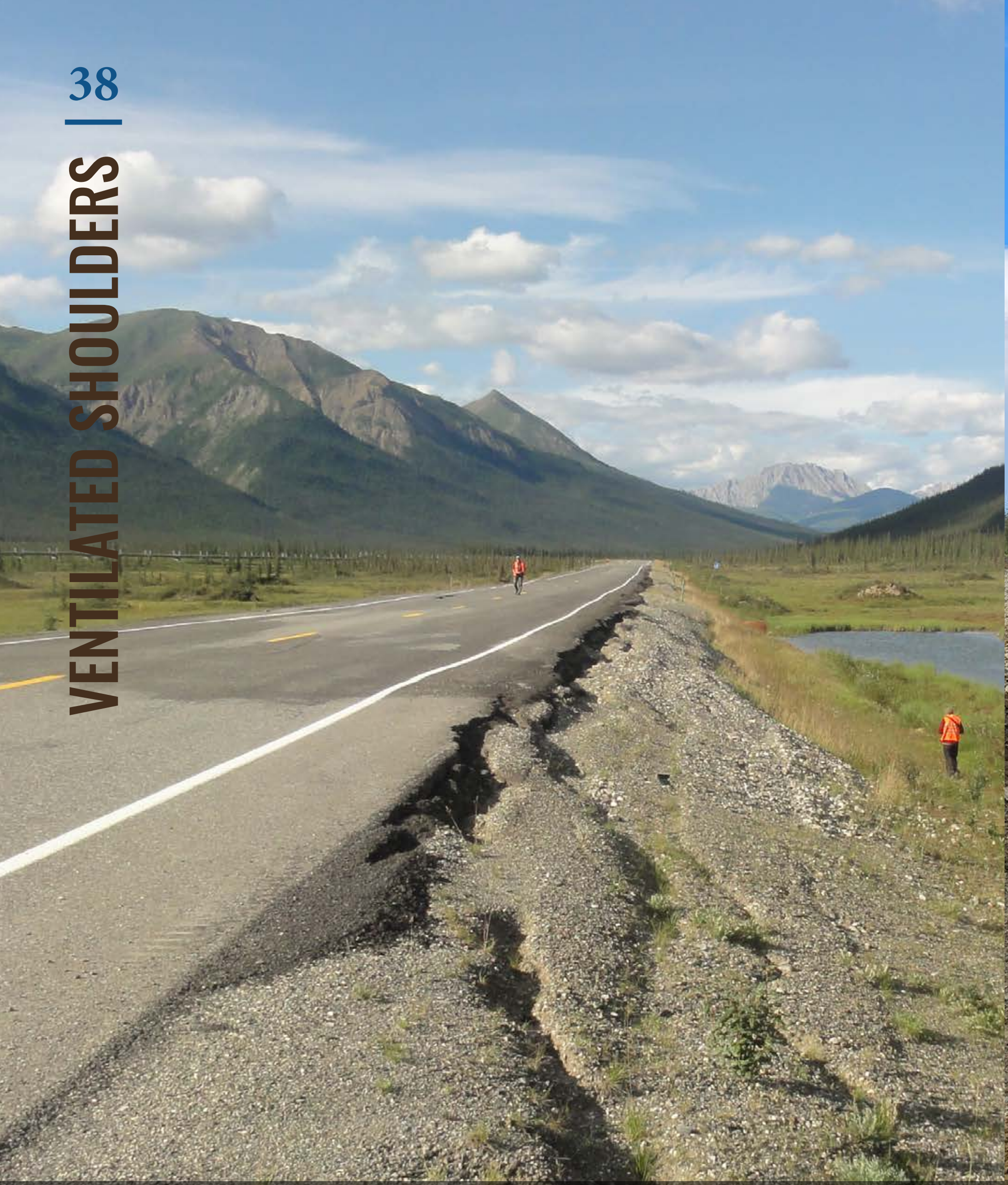
ICE CELLARS (SIĠLUAQS)

- A demonstration project by the Iñupiat Community of the Arctic Slope (ICAS) is adding thermosyphons to *siġluaqs* (hand-dug ice cellars) to learn if they can be used to restore the cellars for use in freezing traditional foods like muktuk and quak, which have not been freezing as solidly.
- By gaining a few degrees of freezeback on the periphery of existing ice cellars, the project hopes to extend their life and perhaps bring back some that have flooded.
- The project is also raising awareness of food security and the need to merge traditional and modern technologies.
- Researchers at the University of Virginia are providing ground sensors to help monitor outcomes.

— Lars Nelson presentation

The first set of thermosyphons installed at a siġluaq in Utqiaġvik as part of the learning project.

PHOTO: LARS NELSON



Shoulder rotation can be seen in the Dalton Highway embankment near Mile 203. The cracks here are due to the insulating properties of the snow berms left behind by plowing. The berms keep the material beneath the shoulders from cooling, which allows the permafrost to thaw and longitudinal cracks to form. In time, these cracks will creep into the paved surface causing unsafe driving conditions. A ventilated shoulder is a configuration of ACE that can work well to preserve permafrost at less cost when the center of the embankment is frozen but the shoulder is thawed.

PHOTO: MICHEL ALLARD

Where appropriate rock is available, air convection embankments (ACE) are proving to be one of the most effective means of maintaining permafrost. In winter, the highly porous embankment material allows relatively warmer air at the base of the embankment to rise until it reaches the cold surface of the roadway. As it cools, it becomes heavier and falls. The process cools the soil, preserving permafrost. The embankment here is being reconstructed as part of a major realignment of the Dalton Highway between Miles 18 and 37.

PHOTO: TRAVIS HOLMES

BUILDING ROADS ON PERMAFROST

PROCEEDINGS

Talks by Evans, Ingeman-Nielsen, Langer & Russell

Information on engineering and construction practices shared by Matt Billings, William Russell, and Alaska DOT&PF project managers during the rolling workshop on the Dalton Highway was not recorded and could not be included in the proceedings.

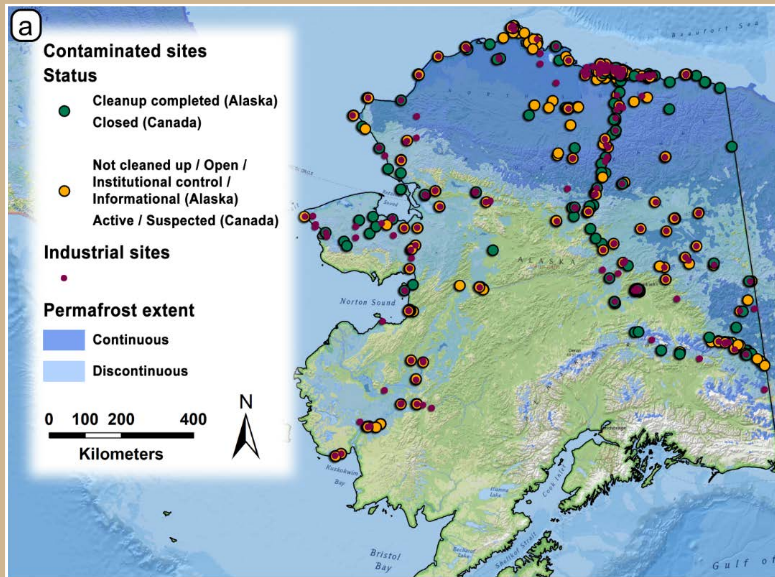
The Challenge

- When constructing roads, engineers have four basic choices for dealing with permafrost: keep it frozen, thaw it, remove it, or accept the consequences of uncontrolled thaw. As the climate warms, the choice to keep it frozen is disappearing as techniques for keeping the permafrost cold no longer work.
- There are generally no codes, standards, and few written guidelines for building and maintaining roadways and airstrips on thaw-unstable permafrost. Instead, adaptive strategies are being tested across the Arctic in real time.
- The challenges faced by Dalton Highway engineers include erosion by seasonal flooding of the Sagavanirktok River, degradation of the roadbed due to unstable permafrost thaw, and the advance of rock glaciers known as frozen debris lobes.
- Designing transportation infrastructure requires the careful balance of safety, functionality, sustainability, and cost, but the most important of these is safety. This can result in the design of infrastructure that crosses ice-rich permafrost terrain knowing maintenance costs will be higher and performance reduced.

Insights and Opportunities

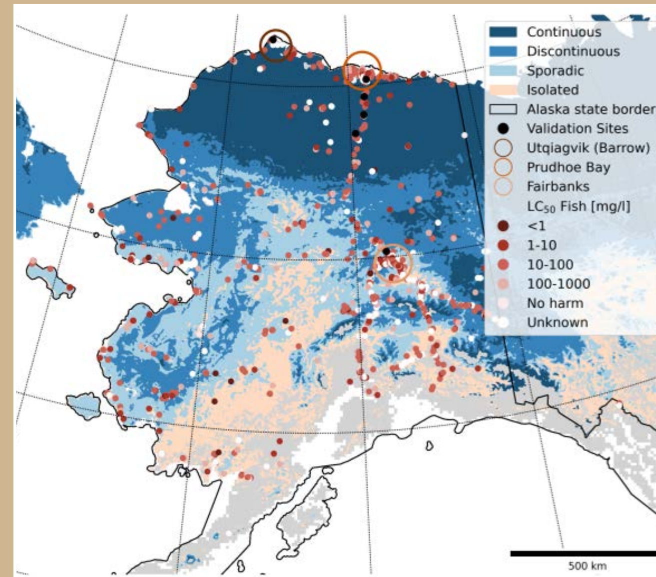
- Avoid permafrost whenever possible. While this may mean higher initial costs or a longer route, the life-cycle cost will usually be lower.
- Preserve vegetation whenever you can. It provides free thermal insulation.
- Avoid roadway cuts if possible, especially in ice-rich permafrost.
- To the greatest extent practicable ensure good drainage. In areas where defined drainage patterns are not evident, this becomes more challenging but is still important.
- Design for thawing permafrost if the Mean Annual Surface Temperature (MAST) is higher than or near 0 °C. If the MAST is well below freezing, consider methods for keeping the ground frozen.
- Examples of systems designed to help keep the roadway frozen include air convection embankments (ACE), ACE ventilated shoulders, air convection culverts, snow sheds and thermosyphons.
- Except for thick embankments, there are no mitigation strategies that are cost effective beyond a short section of roadway. This forces engineers to treat only the worst sections of roadway.

See also: Thaw Susceptibility in Roads, p. 54



MAPPING: ARCGIS VERSION 10.5 (ESRI INC.)

The distribution of industrial sites (red dots) and contaminated sites (green and yellow dots) in permafrost regions of Alaska using data from the Contaminated Sites Program. For pan-Arctic modeling, the spatial density of industrial sites is a good predictor for contaminated sites where national data are unavailable.

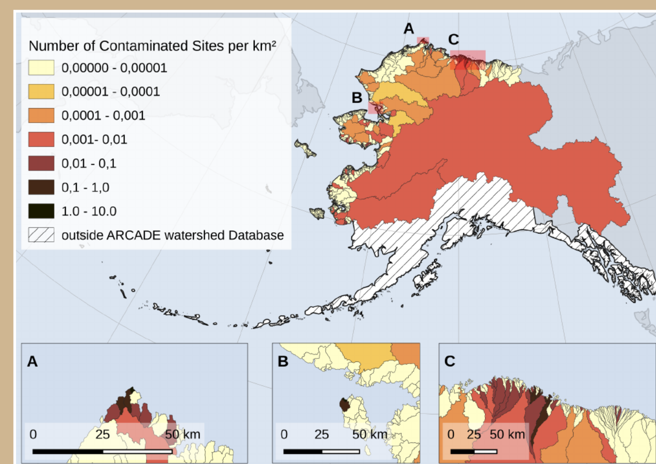


The toxicity of contaminated sites in Alaska permafrost regions. LC50 is the concentration in water that is lethal to 50% of the test fish.

CONTAMINANT RISK IN A WARMING ARCTIC

As a conservative estimate, there are at least 1,100 contaminated sites associated with past and present industrial activities in permafrost regions of Alaska, and well over 10,000 sites across the Arctic. As permafrost becomes less stable with climate warming, the risk of catastrophic failure of critical infrastructure grows as do the ecological risks from hazardous materials released into Arctic watersheds. More data are needed to accurately assess these risks under different climate scenarios.

— Moritz Langer presentation

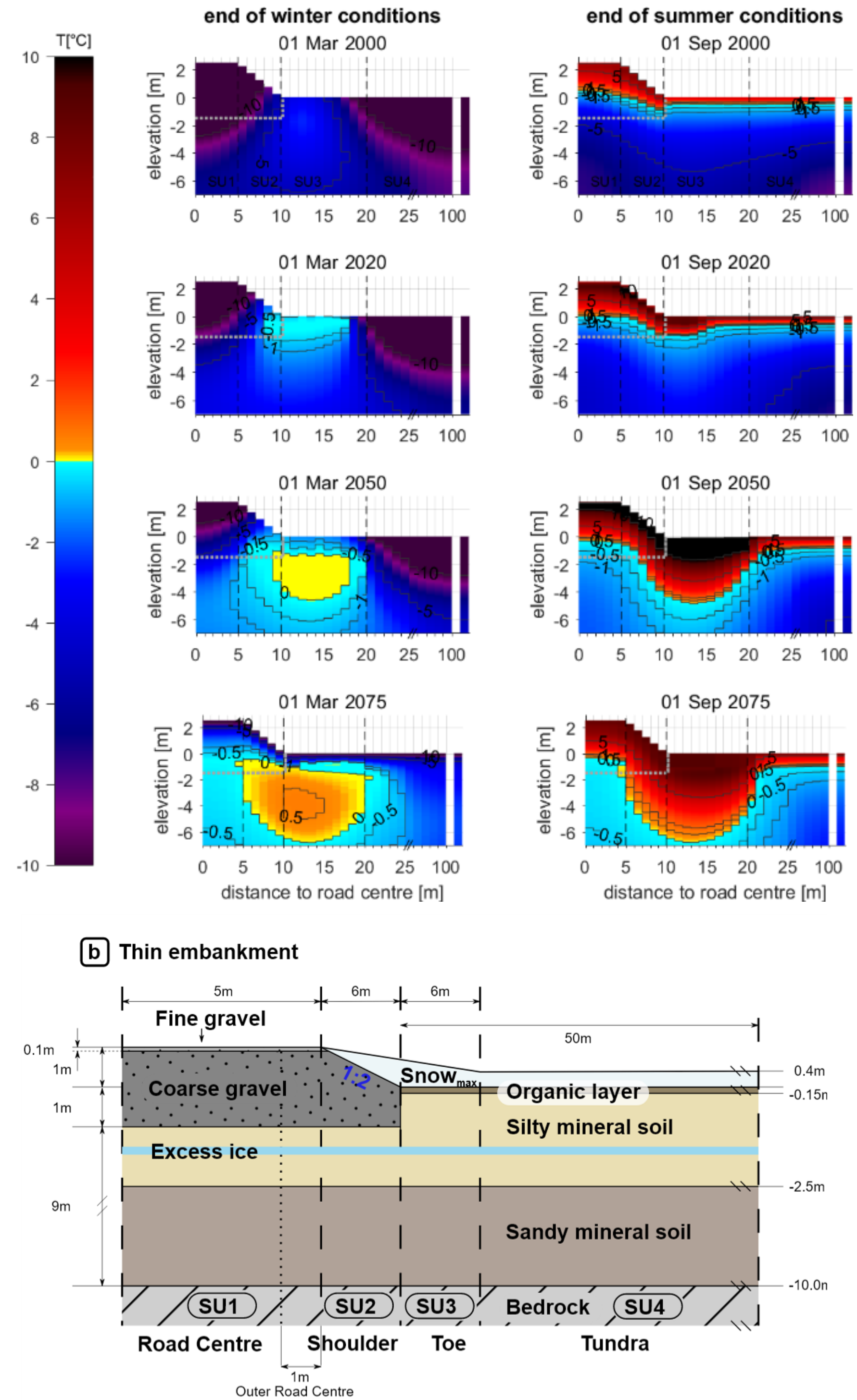


The concentration of contaminated sites within watersheds is an indication of ecological risk. Inset map A shows the watershed along the Beaufort Sea coast with 1.76 contaminated sites per square kilometer, the highest in the dataset. Inset map C shows a range of watersheds in the Prudhoe Bay area.

MODELING INFRASTRUCTURE-PERMAFROST INTERACTIONS

- We model infrastructure-permafrost interaction to test the impact of different warming scenarios, test the sensitivity of different permafrost stratigraphies, identify the most sensitive infrastructure elements, and test the efficiency of technical stabilization methods. In this way, we look at roads and other infrastructure from a climate modeling perspective.
- An example of this approach is a simplified model to test when talik formation would occur beneath a previously stable gravel road on cold permafrost under different climate scenarios, assuming a set of road design parameters (bottom figure). The simulation setup and results are described in the article by Schneider von Deimling et al. in the recommended reading.
- Thaw depths are deepest under the toe of the road. Snow accumulation at the toe and shoulder results in much warmer winter ground temperatures (top figure, left panels). A pronounced talik forms if the model runs long enough under an RCP 8.5 scenario (lower two panels). Because this is now a climate-driven change, it will be hard to engineer the problem away.
- The focus of our climate modeling is not on individual infrastructure but taking a bird's eye view to get the big picture. We can support engineers by testing infrastructure designs for their vulnerability under different climate warming scenarios.

— Moritz Langer presentation



FIGURES: SCHNEIDER VON DEIMLING ET AL. 2021

A living warehouse of tundra sod has been harvested and stored for use in restoration projects. Symposium participants stopped at several locations in the oilfield and along the highway to view the success of different techniques of tundra restoration and rehabilitation with restoration ecologist Lorene Lynn.

TUNDRA SOD

Harvesting and transplanting tundra sod is a Traditional Knowledge technique used to insulate ice cellars and, historically, to build sod homes. It is now being used to help restore tundra landscapes that have been disturbed by commercial activities, including rehabilitating portions of the fiber optic trenches along the Dalton Highway.

— Lorene Lynn presentation

PHOTO: JANA PEIRCE

TUNDRA RESTORATION & REHABILITATION

PROCEEDINGS

Talk by Lynn

Arctic Science Sessions Podcast

Reflection by Lynn

The Challenge

- Restoration refers to returning places to their original condition, while rehabilitation may return them to a different state. Both aim to minimize thermal erosion from standing and flowing water, minimize permafrost thaw, discourage invasive species, and promote indigenous plants where possible as indicators of final stabilization.
- Establishing diverse and productive wetland and upland communities similar to those of the surrounding area improves the appearance of the site and its suitability for some wildlife species.
- Types of oilfield disturbance where rehab is conducted include old exploratory well pads and access roads, partial pad removals, reserve pits, spill sites, tire tracks, and trenches from buried cables.
- Challenges include surficial salt crusts that prevent plants from establishing, gravelly or silty soils that are low in nitrogen and phosphorous, high ground ice, and the short cold seasons to do the work in.

Insights and Opportunities

- More funding, research, and training are needed to meet current and future needs.
- The most successful techniques have been transplanting tundra sod and aquatic grasses.
- Thick tundra sod provides immediate vegetation, thermal regulation, and help with water management. Finding sources of tundra sod is hard, and it is best if you have heavy machinery to move it.
- Transplanting aquatic grasses is labor intensive but works well on sites with very wet conditions. The sites grasses are taken from recover on their own as long as some are left in place.
- Pre-vegetated mats, started in a greenhouse from collected seed and transplanted with roots intact, may increase thermal protection, provide immediate vegetation, and help regulate water.
- Other methods tested: Indigenous seed collection is time and labor intensive and does not produce enough to seed large areas. Willow staking is logistically complex and useful only in places where willows readily grow, like stream banks. Seeding with native grasses has not resulted in increased colonization by other species and may delay recovery to a tundra ecosystem.
- Gravel lift trials have tested how much gravel to remove from an industrial site to plan for subsidence, based on ground-ice content and moisture.
- Elevation monitoring is only useful relative to the adjacent tundra.

A workshop with the NSB Assembly and Mayor Harry K. Brower, Jr. was held in the Assembly chambers on the symposium's final day in Utqiaġvik. A panel of participants shared their knowledge on topics of interest to the region, took questions, and recommended climate adaptation actions to address some of the Borough's priority issues.

PHOTO: JANA PEIRCE

PLANNING, POLICY & GOVERNANCE

PROCEEDINGS

Talks by Allard, Beavers/ Ethun & Robinette

Group 4 Breakout Notes

Reflections by Lynn & Streever

Information for researchers on working with the NSB Planning and Community Services Department shared by Chastity Olemaun at the Saturday evening reception was not recorded and could not be included in the proceedings.

The Challenge

- Best management practices for minimizing permafrost degradation need to be developed. The responsibility for research and implementation of adaptive technologies is unclear.
- Climate change adaptation methods often do not account for associated greenhouse gas emissions.
- Too often data important for community planning must be requested from engineering firms who may deem it proprietary.
- Culture is often overlooked in regulatory policy. For example, FEMA questioned whether a *siġluaq* (ice cellar) was considered infrastructure insurable under the National Flood Insurance Program.

Insights and Opportunities

- Adapt now! Remediate or replace homes and other vulnerable infrastructure on sensitive terrain before conditions worsen or infrastructure fails.
- Third-party review of construction projects is needed to ensure the design is sound, especially when the successful bidder is from outside the region or state. Ideally the review would take place at all stages from design through commissioning and closeout—but at least at some point in the process and by someone with Arctic expertise.
- Consider contracting out research and monitoring activities to track infrastructure performance and identify issues as they become apparent.
- Projections of thaw and erosion should be integrated into land use plans.
- Permafrost mapping can aid in selecting appropriate foundation designs and strengthen requests for political and financial support.
- Permits should require that data important for community planning and mitigation be shared in real time or reasonable time frames.
- Data from past studies and real-time monitoring should be stored in a central location for easier access by planners, grant writers, and others.
- To reduce research redundancy, permit applicants could be asked to review the work of current and past permit holders and explain how their project is different from or builds on previous work.
- When planning new capital projects and climate adaptation measures, consider how to document and minimize emissions from greenhouse gases, including supply chain emissions.
- Convene more meetings like the symposium: co-developed with local policymakers, centered on local priorities, with local participants included.

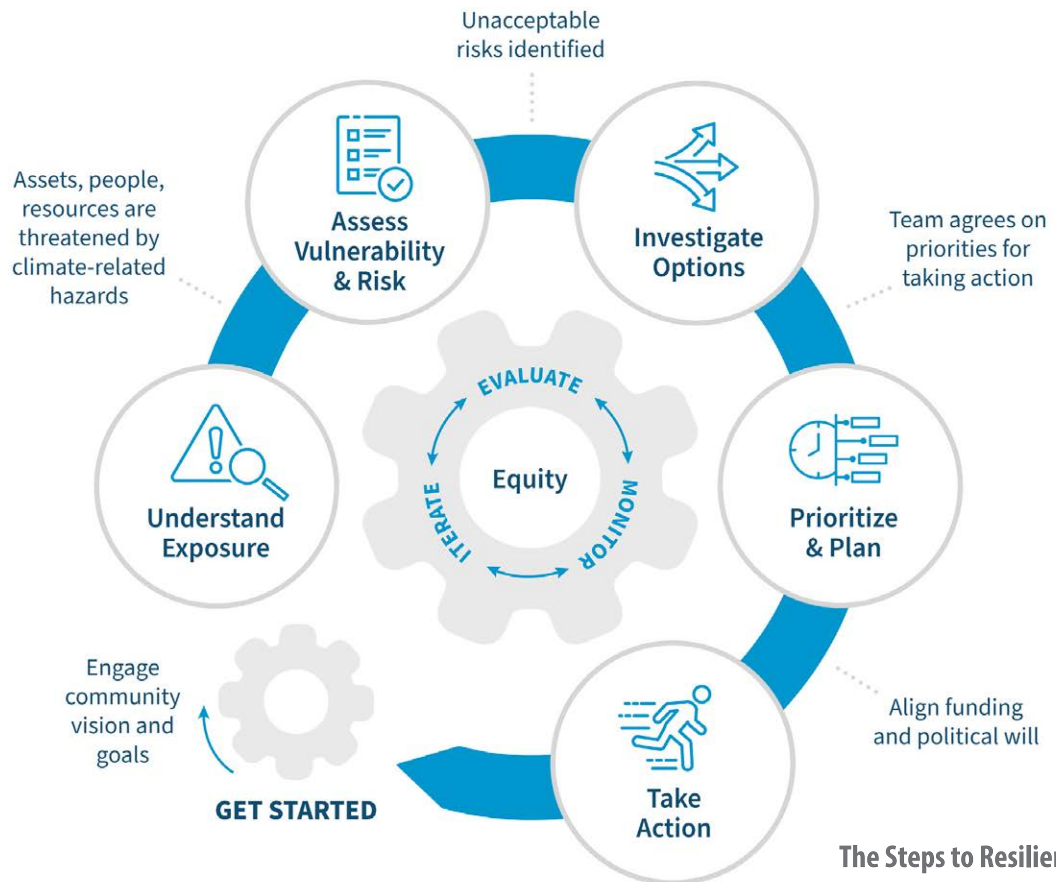


FIGURE: GARDINER ET AL. 2022

The Steps to Resilience from the U.S. Climate Resilience Toolkit

CLIMATE POLICY AT U.S. DOT

Five guiding principles inform the U.S. Department of Transportation's 2021 Climate Action Plan:

- *Use Best-available Science*
- *Prioritize the Most Vulnerable*
- *Preserve Ecosystems*
- *Build Community Relationships*
- *Engage Globally*

DOT includes climate resilience in many of its funding calls and is working to simplify grant application processes, educate its workforce on climate change, and develop technical assistance and decision-making tools.

— Rebecca Beavers / Michelle Ethun presentation

CLIMATE RESILIENCE RESEARCH AND PLANNING TOOLS

TOOL	AGENCY	TYPE	YEAR
Building Resilient Infrastructure	U.S. Department of Transportation	booklet	2022
General information for governments on how to assess vulnerability and implement adaptive strategies to make transportation systems more resilient to climate change			
Checklist for a Strong Climate Change Mitigation, Adaptation and Resilience Grant Application	U.S. Department of Transportation	website	2023
Guidance for applicants to consider in developing strong applications for U.S. DOT funding opportunities with climate criteria			
Implementing the Steps to Resilience: a Practitioner's Guide	NOAA Climate Program Office	workbook	2022
A step-by-step guide for vulnerability and risk assessment, decision making, measuring, evaluating, and reporting on climate adaptation planning and implementation			
Resilience and Disaster Recovery (RDR) Tool Suite	U.S. Department of Transportation	software	2022
A Python-based tool to help transportation agencies analyze returns on investment (ROI) in resilient infrastructure considering a range of uncertain future hazards			

TRANSPORTATION PLANNING FOR RESILIENCE

PROCEEDINGS

Talks by Anderson, Beavers/Ethun & Miller-Hooks

Reflections by Martin & Miller-Hooks

Challenges and Strategies

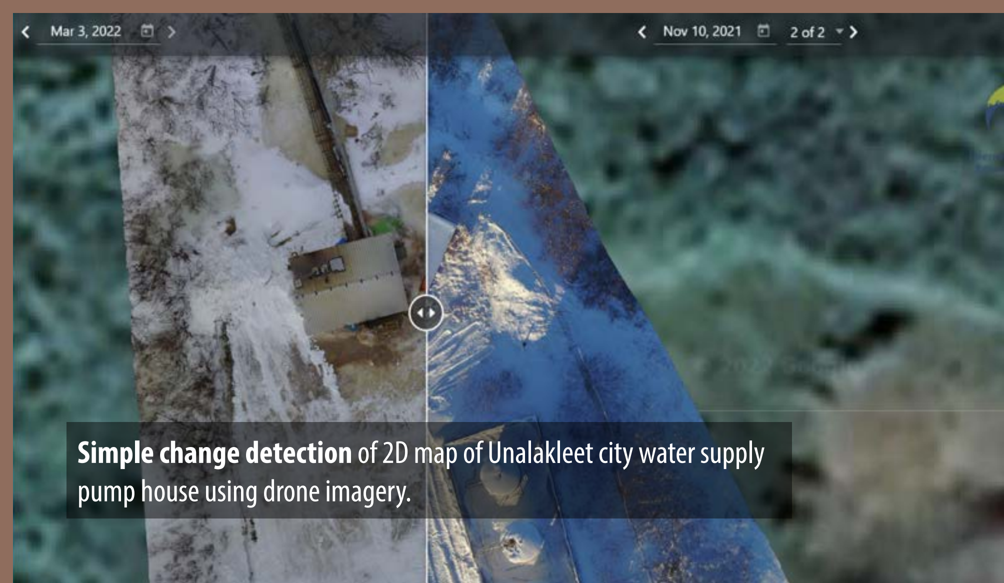
- The mission of Alaska DOT&PF is to Keep Alaska Moving through strategic investments in safety, economic vitality, resiliency, sustainability, and the state of good repair. That includes addressing the challenges posed by permafrost.
- Alaska's transportation network includes 17,000 road miles, a 3,500-mile ferry system, 470-mile railroad, 237 state-owned and operated airports, 16 ports and harbors, and the largest inland waterway system in the U.S. Given this size, planning is critical according to Commissioner Ryan Anderson, because whatever is done requires large investments and maintenance.
- The agency's strategy is to try to be modern, resilient, and agile. Resilience requires having the manpower, equipment, and stockpiles of materials ready to respond when needed.
- Being agile means learning new ways of working and using new tools, including remote sensing and Artificial Intelligence. The agency has established protocols for how it will react to events related to storms, flooding, erosion, permafrost thaw, and seismic damage, using a network of drones and pilots as a means of damage assessment.
- In anticipation of increased shipping traffic as sea ice recedes, DOT&PF has started a new waterways program that is providing new funding for port and harbor improvements in Alaska.
- The Port of Nome has received federal funding for a major expansion to become the first U.S. deep water port in the Arctic.
- With high energy costs, climate impacts, and dependence on multimodal transportation, Alaska is well positioned to compete for federal Infrastructure Investment and Jobs Act and for Inflation Reduction Act funds.
- However, the access to matching funds, technical capacity, and workforce availability remain real issues for many local governments.

COURTESY: ALASKA DOT&PF

Rapid response to spring flooding at Mile 404 Dalton Highway.

TOOLS FOR MONITORING & ADAPTING TO CHANGE

- **Community focused:** Villages have limited resources. Consider what is needed for specific areas to make decisions on adaptation or mitigation. Is the frequency of monitoring adequate? What does the community want?
- **Data sharing:** Are data and research products accessible and intelligible for nonacademic decision makers? Have data sharing principles that include protections for Indigenous data sovereignty been followed? As part of outreach and "sharing back" activities, researchers can offer to meet with local or regional grant writers.
- **Baseline data:** Fund development of baseline data collection, monitoring, and trend analysis to see what is happening over time. Include community members in data collection and monitoring efforts.
- **Temporal frequency:** How often data are collected will vary based on the variable of interest:
  - Geophysical data can be collected once or annually for certain properties, ideally mid-July to mid-September.
  - Micrometeorological data should be continuous.
  - Real-time or near-real-time data should be made available to communities in a manageable form.
  - Topographic data should be collected at least twice a year (ideally late spring and late summer).
- **Adaptive management:** The same techniques used for monitoring change are needed for monitoring the success of mitigation/adaptation efforts. Monitoring allows us to understand why certain changes are happening, to determine whether the efforts are working or not, and to obtain new information needed to improve outcomes.
- **Remote sensing:** Broad remote sensing, including repeated LiDAR scans (ground, drone, or plane-based) can be used to monitor change over time, which is otherwise challenging. For down- and up-scaling, use remote sensing to identify points on the ground for detailed observation and before upscaling that information. Look back in time through air photo and satellite image archives to determine rates of change and changes in those rates overtime.
- **High-resolution products** are 1-m or finer resolution for remote sensing (e.g., topography, hydrology, snow depth) combined with ground observations and geophysics.
- **Permafrost mapping:** Ground-ice content is not homogeneous. Map permafrost characteristics at the scale of communities, including ground-ice content and extent, permafrost temperatures, and saline permafrost distribution, to create high-resolution permafrost maps that can be used for predictive modeling and planning. (See p. 53)



Simple change detection of 2D map of Unalakleet city water supply pump house using drone imagery.

FIGURE: KATIE DANIELS / SKYDIO X2E

- **Geophysical sensing:** Tools for mapping subsurface conditions include borehole coring, electrical resistivity tomography (ERT), capacitively coupled resistivity (CCR), seismic imaging, and fiber-optic sensing (see pp. 50-51).
- **Infrastructure monitoring:** Establish regular infrastructure inspection routines. Use remote sensing for change detection. Develop built-in monitoring capacities with emerging smart technologies—the Internet of things:
- **Smart foundations:** Monitor structural stability, differential settlement, and deformation by instrumenting foundations with smart piles and tiltmeters. Because funding is limited, use remote sensing or other tools to identify the best areas to install sensors.
- **Smart Homes:** Monitor temperature, humidity, home energy use, indoor air quality, and ground moisture.
- **Public infrastructure:** Work with utility managers to instrument public infrastructure and share information with communities and researchers.

PROCEEDINGS

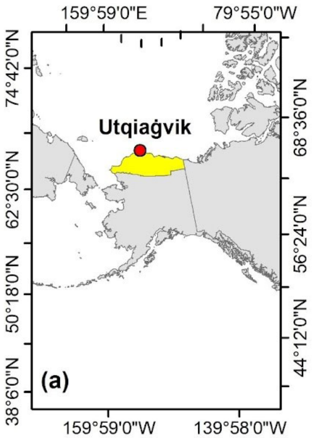
Talks by Bjella, Epstein, Garron, Kanevskiy & Martin

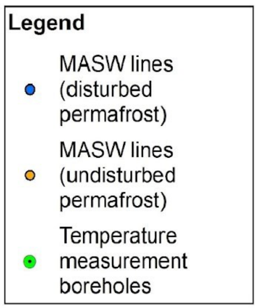
Group 3 Breakout Notes

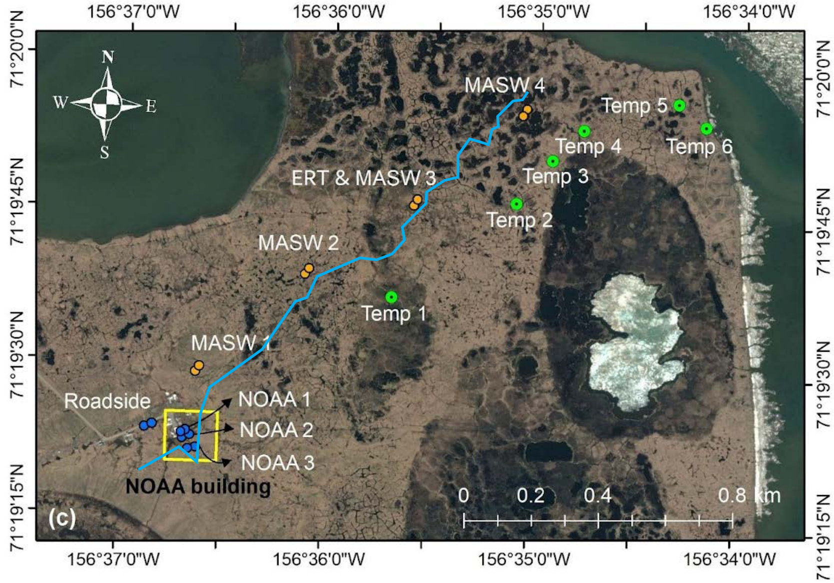
BUILDING CAPACITY FOR CHANGE

- The regular, consistent synthesis of information about permafrost dynamics is crucial for sustaining Alaskan lifestyles, neighbors, and communities through extreme change. The current reliance on ad hoc information and local anecdote is not enough to influence policy. Qualitative and quantitative data collection can do so.
- Scientists must listen to local and Indigenous community members about the changes they have observed to understand community needs and translate their research into everyday value. Community partnerships and training community scientists can help collect and synthesize observational data on climate change impacts.
- Techniques to inform policy, improve climate models, and generate community buy-in include: measuring permafrost locations, temperatures, and unique characteristics; collecting aerial images of land surface and elevation; measuring river flow, silting, and chemistry; instrumenting new building foundations (nonstructural); and establishing regular infrastructure inspection routines.
- Collective monitoring of these geophysical variables can identify tipping points and additional quickening of climate change.
- Communication of Siren Data (red flag data) beyond the local and regional level can garner additional resources for adaptation.
- Building the capacity of Alaskans to synthesize relevant information about climate change into informed decisions is critical.
- Knowledge partnerships among researchers, communities, and agencies can develop Western scientific and financial capacity for long-term monitoring with equitable compensation, while strengthening the local workforce to monitor change and apply solutions.
- Moving past inequitable institutionalized infrastructure is necessary to implement solutions that create thriving communities.

— Jessica Garron reflection







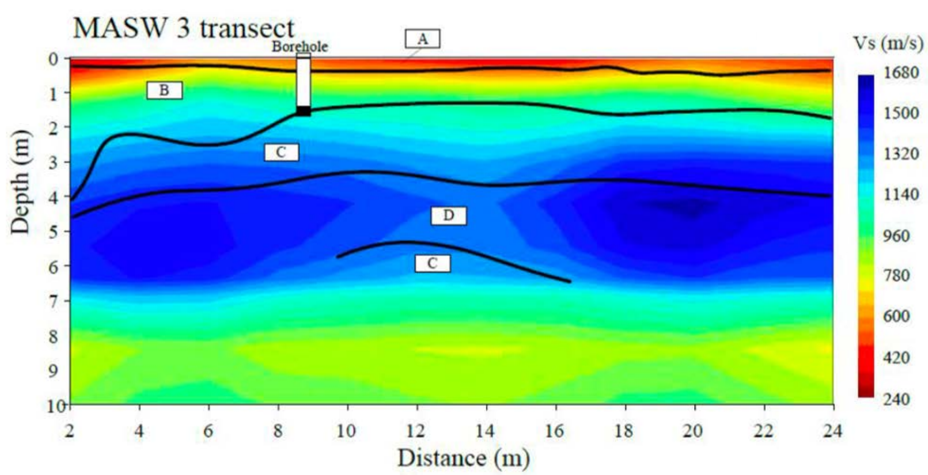
ABOVE: Study region near Elson Lagoon in Utqiaġvik with geophysical monitoring sites identified (legend at left). The blue line showing the location of the fiber-optic cable has been added to the figure.

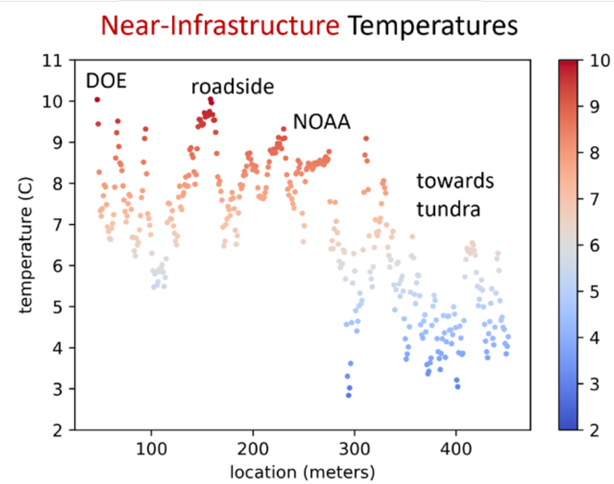
BELOW LEFT: Seismic imaging of a 23-m transect in undisturbed permafrost showing (A) thawed active layer, (B) frozen ground, (C) cryopegs (saline taliks), and (D) ice-rich permafrost. RIGHT: Temperatures recorded over 500 m on a sunny July day. Temperatures near to infrastructure (left side) were warmer than the tundra.

SUBSURFACE MONITORING

Fiber-optic sensing repurposes fiber-optic cables as long arrays of sensors, enabling fine-scale, long-term monitoring of temperature, deformation, and vibration over large distances. It is becoming the subsurface counterpart to match the scale and resolution of remote sensing.

— Eileen Martin presentation





FIGURES: AHMAD TOUREI / EILEEN MARTIN

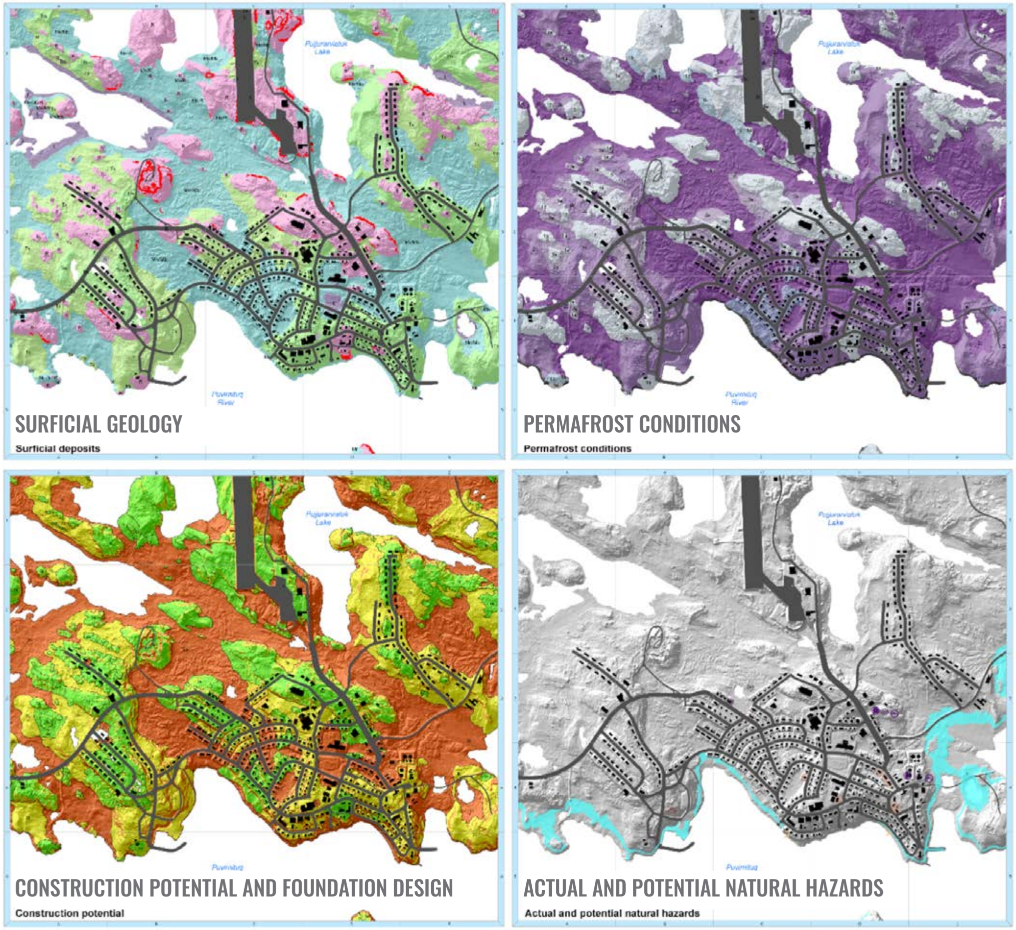
MONITORING SUBSURFACE GROUND CONDITIONS

- Ground conditions that lead to thaw stable or unstable permafrost behavior can vary greatly over short distances, and these differences are frequently not fully characterized when infrastructure is being built.
- Recent advances in using fiber-optic cables to sense small variations in subsurface temperature, deformation, and vibrations in the soil over large distances (over 60 miles for a single system) may provide a feasible path toward more complete and repeat permafrost characterization that allows infrastructure managers and researchers to identify and track risky areas and intervene proactively if possible to avoid a surprise shutdown.
- Tools are still needed to predict areas at highest risk for thaw impacts at several time scales using past and present ground conditions. Also needed are easily interpretable visualizations of ground conditions and changes to enable collaborative decision making. These must be co-designed with infrastructure managers to provide information that is meaningful and actionable.
- We are working on prototypes of fiber-optic sensing of electrical and magnetic fields that should provide better mapping and monitoring of the subsurface water that is connected surface water and thaw stability.
- Fiber-optic cables that are not installed appropriately can lead to surface water pooling and further degradation of the tundra as seen along the Dalton Highway.

— Eileen Martin reflection

Minimally-invasive fiber optic installation: 2 km of cable was carried in by foot and installed by hand. One year later, it was difficult to find the track. Vegetation regrowth occurred within two years.

PHOTO: EILEEN MARTIN

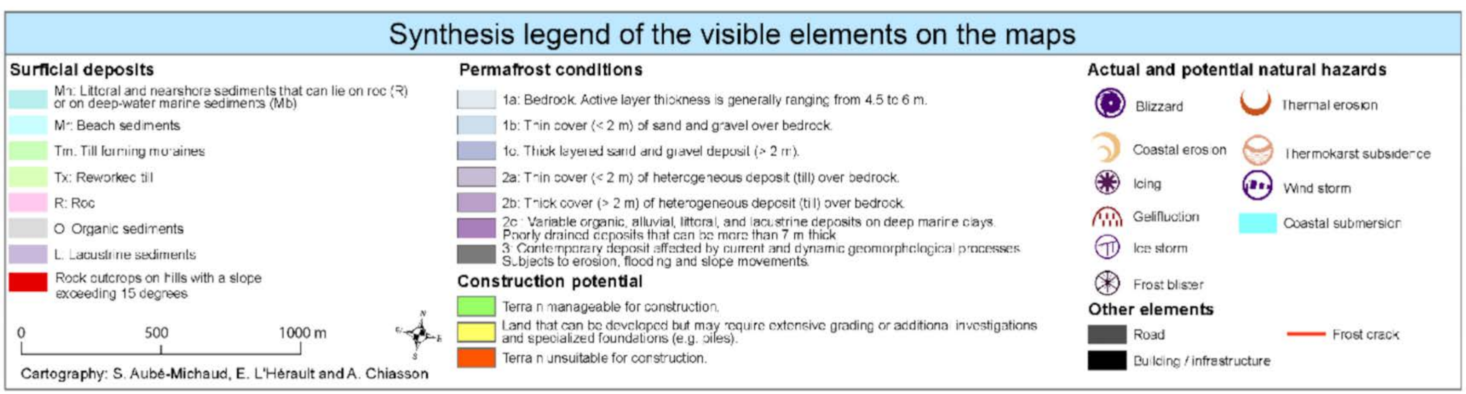


FOUR MAPS FOR EACH COMMUNITY

Maps of permafrost conditions can help select the best areas for new housing and foundation types and aid in decision making for renovation, relocation, or community growth. Mapping all communities in the region with a standardized methodology and common legend is recommended.

— Michel Allard presentation

LEFT: Map excerpts showing just the built area of the Nunavik community of Puvirnituq. BELOW: The synthesis legend for the maps shows features that appear on the excerpts. See Allard et al. 2023 Supplementary Material 1 for full maps and legends.



MAPPING PERMAFROST AT COMMUNITY SCALES

Mapping permafrost conditions at the scale of communities has been a key tool in Arctic Canada for supporting land-use planning and selecting designs for building foundations in the context of adapting to climate change, securing infrastructure, improving construction practices, and building more resilient, higher-quality housing. It has been used in Nunavik, Nunavut, and Yukon, and is currently ongoing in the Northwest Territories.

Creating maps of permafrost conditions would benefit all communities on the North Slope:

- Knowledge of permafrost properties (ground-ice content, temperature, presence of saline permafrost, etc.) can aid in decision making for relocation or new developments.
- Maps of permafrost conditions can help in selecting the best areas for new housing and best foundation types for the area. They are also useful as a planning tool to mitigate future impacts on existing infrastructure.
- Maps can aid in developing community drainage plans to reduce advective heat transfers.
- Sharing permafrost terrain knowledge can help stakeholders determine actions and investments.

Methods for Mapping Permafrost Conditions

- Permafrost characterization precedes mapping permafrost conditions. Steps include assessment of permafrost sensitivity to impacts, terrain classification into mapping units, and representation of punctual and linear terrain phenomena, before the information can be integrated into a map compatible as an information layer with land-use planning maps.
- A high-resolution digital elevation model (DEM) should be used as a mapping base. If using LiDAR to produce DEMs, highly detailed images of the surface microtopography, indicative of active layer and permafrost features, will also be available.
- Map resolution should ideally allow representation of the pattern of all ice wedges in the study area. Since the most widespread permafrost features in the landscape are ice-wedge polygons, resolution should be better than the width of the smaller ice-wedge troughs (i.e., less than 1 m).
- Preliminary mapping should be done by air photo analysis, identifying ice wedges, thermokarst lakes, depressions, ponds, water seepage channels, zones of frost boils, and thermo-erosional gullies, etc.

Assessing size (width) of ice wedges and cryostratigraphy

- Ground penetrating radar (GPR) is the best geophysical tool for estimating ice-wedge presence and approximate size.
- Electrical resistivity tomography (ERT) yields insights into permafrost properties, such as grain size composition, presence of massive ground-ice, salinity, and temperature.
- Overlaying the profiles of the two methods in a GIS or drawing application provides a richer understanding of the subsurface than the sole use of either of them.
- A number of shallow holes (3- to 4-m minimum depth) are needed from different terrain types. Shallow cores and/or augering help measure and estimate surface organic layers, cryogenic structure, and ground-ice type and content in the upper permafrost.

CONTINUED ON PAGE 55

A map showing risks from permafrost degradation to the road network in Ilulissat, Greenland. The thaw susceptibility of each section of the network is characterized as low (green), medium (yellow) or high (red). The maps can also be used to identify problem areas and issues such as water ponding and poor snow removal practices.

A large volume of borehole data from the 1960s and 70s was stored in a paper archive in Nuuk, Greenland, making it difficult to access by local stakeholders. Researchers digitized the logs and used the descriptions of soil texture as a proxy for ground-ice concentrations. Fine-grained, very ice-rich, marine sediments appear as red dots above with more thaw-stable, coarse deposits shown in green.

CREATING MAPS FOR LOCAL DECISION MAKING

The hazard mapping work of researchers in Greenland aims at improving community capacity for knowledge transfer and decision making, especially concerning road maintenance and town planning. This mapping procedure can be easily implemented in other locations in Greenland and could be adapted for use in evaluating construction potential.

— Thomas Ingeman-Nielsen presentation

HAZARD MAPPING IN GREENLAND

- Researchers in Greenland have been working with the municipal government of Ilulissat (pop. 4,500) to create hazard maps for evaluating current road network conditions and susceptibility to permafrost thaw.
- While buildings in Greenland are mostly clustered on bedrock, linear infrastructure (e.g., roads, power lines, and pipelines) must cross very ice-rich sedimentary basins, risking severe deformations from degrading permafrost and resulting in large development costs and risks.
- To map the thaw susceptibility of roads, researchers first compiled existing information into georeferenced datasets and applied a standard risk-based approach, considering the combination of hazards, consequences, and vulnerabilities. Without ground-ice data, they digitized old borehole logs and used their soil texture descriptions to categorize sites as fine-grained (typically very ice-rich marine sediments) or coarse (more thaw stable) sediments.
- Projecting this information onto a hexagonal grid, they filled in gaps in spatial coverage with InSAR data, assuming large surface deformations indicate frost-susceptible sediments as a proxy for ground ice.
- The resulting environmental hazard map included information on water ponding and snow accumulation as additional hazard factors.
- Projecting the hazard map classification onto to the existing road network, they obtained a thaw susceptibility level for every road segment in Ilulissat. The results: 45% of the assessed network is on highly hazardous terrain.

— Thomas Ingeman-Nielsen presentation

- A few deeper cores (~20 m) help ground truth geophysical surveys and assess the presence and depth of coarser materials beneath ice-rich, fine-grained permafrost.

Ground Temperature Monitoring and Modeling

- A thermistor cable should be set to measure ground temperature 20–30-m deep in natural terrain.
- Sensor spacing should be small in the active layer and near the surface to record daily and seasonal temperature variations, then get larger with depth.
- Measured permafrost temperature profiles and soil properties can be useful for calibrating and parameterizing ground temperature models.
- Modeled predictions of changes in active layer thickness and ground temperature profiles under different climate warming scenarios will inform decision making for infrastructure resilience over the long term.

A Common Map Legend for All Communities

- Characterization and mapping methodology should be consistent across all communities in the region.
- Geomorphologic mapping units on the finalized map will be based on a combination of surficial geology units and ground-ice content and structure.
- Some terrain units may not exist in all communities, but this should not prevent making a standardized legend for the whole borough.
- Standardized symbols for point and linear features and colors for terrain/geological units should be maintained.
- A shared understanding of permafrost challenges and solutions will benefit regional decision making.

— Michel Allard reflection

It is not "how to include locals in our work?" It is "How can we work together?" We are all learners. How do we learn this together? How do we build capacity in multigenerational ways and share with each other in meaningful ways?

We need to codevelop the knowledge that comes from research so that it can be translated for community action.

— Breakout Group 4

We are all learners. The Taġiuġmiut Dance group teaches the Mosquito Dance to symposium participants during a community reception on July 29.

PHOTOS: LLOYD PIKOK

Talks by Cooke, Garron, Epstein, Jull/Cho & Robinette

Group 4 Breakout Notes

Reflections by Garber-Slaght, Ingeman-Nielsen, Luhn, Poisson & Sformo

RESEARCH WITH COMMUNITY NEEDS IN MIND

Suggestions from a breakout group discussion on sharing and coproducing data, growing capacity within the community, keeping researchers accountable, bridging gaps, and breaking down silos of information.

Citizen Science and Community Partnerships

- Develop a community cohort of observers. Establish a skill set and help local people to learn how to collect samples, learn protocols, and use available resources.
- Local residents are ideally placed for monitoring change, including making ground observations, such as snow depth and distribution, and using low-cost, open-source sensors or data loggers that can be read by local community members. Those participating will spread the knowledge.
- Developing community partnerships and training citizen scientists to collect and synthesize observational data on climate change impacts can help communities and their partners acquire resources necessary for adaptation.

Involve the Whole Community

- How can we get a larger segment of the population involved for a longer time? Look for ways to develop local capacity in multigenerational ways.
- Connect with the youth to transmit knowledge. Expose them to the research and science that is all around them. Kids will bring home ideas.
- Enlist younger people through a mentorship program with paid mentors from the village. UIC Science could be a great resource for mentoring.
- Work with the school. Ask teachers if they would like a researcher to talk with their class.
- When in the community, meet people where they are. For example, if people are on the beach, bring activities outside.

Provide Equitable Compensation

- Communities deserve equitable compensation for participating in research projects. If pure science and applied science are to be coproduced, local needs for applying research must be integrated into research plans and budgets.
- Community liaison positions should be paid and be involved at every stage of a project, attending project and partner meetings. Internet costs can be high in rural Alaska. Find out their costs for attending a lot of online meetings and offer to cover them if needed.
- Community members should receive a stipend or honorarium for being interviewed, sharing their knowledge, or assisting a project in other ways.

ARCTIC ENGINEERING EDUCATION IN GREENLAND

The Challenge

- Arctic communities face unique challenges in infrastructure establishment, maintenance, and operation due to extreme climate and geographic factors.
- Specialized approaches to foundations, material selection, and construction methods are required due to the presence of permafrost.
- High turnover rates are common due to reliance on external technical labor and outsourcing tasks to companies from milder climates.
- Some universities offer specialized programs in Arctic engineering, but these require students to leave their homes, families, and familiar cultural environments.
- This transition discourages students from seeking education far from home and leads to higher drop-out rates.

Insights and Opportunities

- The North Slope of Alaska faces similar challenges. The experiences from Greenland could inspire stronger educational collaboration between North Slope communities and educational institutions in Alaska.
- The Greenland Government and the Technical University of Denmark established the Engineering Education with a special focus on Arctic Building and Construction, a 4-year Bachelor of Engineering program with specialized courses related to site investigations, geotechnical engineering, foundation design, building design, indoor climate, and general engineering practices and logistics.
- The program has a special structure, with the first three semesters taught in Greenland, followed by a semester in Denmark. Students also have a half-year internship with an engineering company, construction company, or public institution. They can also take a semester abroad or conduct a three-month thesis project on a practical Arctic engineering topic.
- Over 85% of alumni with a Greenland origin have returned to live and work in Greenland. Some of the program's Danish alumni are now also living in Greenland. Several early Greenland graduates have high positions in Greenland private businesses or public administration.

— Thomas Ingeman-Nielsen reflection

COURTESY: THOMAS INGEMAN-NIELSEN

Share Data Early and Often

- Close the gap during and after a project to make sure the community learns about research results.
- Provide a public presentation.
- Write nontechnical research summaries that are understandable if English is a second language.
- Share research results directly with grant writers working in the region in a format that is directly usable by them. Offer to meet with them.
- Make published data easier for communities to find. Add your data to a regional clearinghouse or community data portal if one exists. A clearinghouse should be well funded, with long-term commitment, and gather information from researchers, engineers, and applied scientists.
- NSF could fund the Arctic Data Center to produce an annual report so nonacademic users know what data are available and how to access them.
- Follow the CARE Principles for Indigenous Data Governance *(www.gida-global.org/care)*.

Avoid Redundancy

- When multiple teams are working in the same community, make it easier to find out about each other so they can collaborate rather than duplicate efforts. This also reduces research fatigue.
- Consult repositories of previous research, such as NSF's Arctic Data Center, to learn what has been done before. On the North Slope, this includes the North Slope Science Initiative (NSSI) and Barrow Area Information Database (BAID).
- Permit applications could include the questions: 1) Is your work similar to other research? 2) Does it build on previous research? 3) How does your research benefit the local communities? Permit applications could also require applicants to review other filed permits to avoid redundancy.

Make Research Actionable

- Consult local and regional planning documents, including hazard assessments, land use plans, and comprehensive plans, to see how the proposed research fits in with local and regional priorities.
- Look for more ways the research can benefit the communities involved, rather than seeing them primarily as research subjects. What products or actionable findings might be useful at local scales? Research that is relevant to community needs is less likely to cause fatigue.
- Good grant and permit applications for research impacting communities will ask for a bridge to be drawn from research to actionable outcomes.
- In working with the municipality of Ilulissat in Greenland, researchers have found there is a reasonably good understanding of the issues related to building on permafrost, but they lack the local information needed to understand the risks and evaluate costs and benefits of different solutions.
- Geotechnical information is especially needed. Some information exists, but it is hard to access.
- These challenges impact a community's ability to properly maintain and develop its infrastructure.

PHOTO: JANA PEIRCE

Pat Neakok (center), Deputy Director of Housing for the North Slope Borough, speaks with researchers during a breakout group on community-scale solutions for adapting to permafrost thaw. Matthew Jull (right) is an Associate Professor at the University of Virginia School of Architecture and co-director of the Arctic Design Group. Michel Allard (left) is a professor emeritus of geomorphology and permafrost science at Université Laval in Québec, Canada, who has led permafrost mapping efforts for communities in Nunavut, Canada's northernmost territory.

Address Research Fatigue

- There is a need for increased outreach at the start of and throughout the research process, however research fatigue is a real and growing concern.
- Embed researchers in the community for longer periods, similar to the researcher-in-residence program in Greenland. Longer-term visits provide continuity and increased opportunities to make connections, train, inspire, and work with community members, but housing may be an issue.
- Appeal to economic, environmental and emotional motivations (e.g., love for home and community) to inspire people to get involved.
- Consider how to appeal to the community's goals, not influence them to adopt your goals.

Understand Workforce Challenges

- The implementation of infrastructure services in the Arctic is challenged by short shipping/receiving season, limited skilled workers, and the mandate to be equitable over time and geographies.
- There is a lack of equipment and personnel. Quick turnover in workforce means that it is difficult to retain knowledge in the organization.
- A workforce of mostly transient construction engineers may lack a good understanding of permafrost management principles.
- Do not overlook local people as researchers, engineers, contractors, and skilled operators.
- Grow and retain your own Arctic expertise. The Arctic engineering program in Greenland is a successful model for training Indigenous engineers. About half the graduates are Greenlanders, and 85% of the program's Greenland alumni have returned home to live and work. (See p. 58)

Communicate to be Understood

- Communicate at a level that can be understood by everyone from kids to adults, that will be meaningful to the nonspecialist, and in ways that will draw out people in the community whose interest might be sparked by the research.
- The responsibility for communication goes both ways: Researchers appreciate help learning how to speak to communities and who they can go to for assistance. Communities create a bridge when they help researchers step into their world.
- Local radio plays an important educational role in sharing science stories, but staff are often stretched thin. Alaska Public Media or other entities can help fill the gap by bringing experienced reporters to northern communities and providing training for aspiring local journalists.
- Community visits, especially those that last longer than a day, are undervalued tools for building and maintaining relationships, in addition to regular communication by phone and email.

Combine Coproduction with Convergence

- Convene more meetings like the symposium that are coproduced with partners from the region, involve researchers from across disciplines (convergence), and focus on locally prioritized issues.

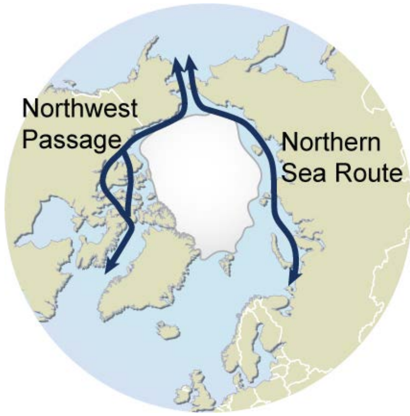


FIGURE: HUGO AHLENIUS

ABOVE: Arctic sea routes expected to open due to diminished sea ice will decrease the number of days to ship goods between the Pacific and Atlantic coasts. RIGHT: U.S. Coast Guard cutter Healy breaks ice in support of scientific research in the Arctic Ocean north of Utqiaġvik, Alaska.

PHOTO: U.S. COAST GUARD/CC BY 2.0 DEED

The Challenge

- Global warming has led to declining sea-ice, making it easier for ice-class vessels to navigate Arctic waters for greater portions of the year.
- As sailing conditions improve over the coming decades, these passageways are expected to open for larger portions of the year and become increasingly viable for unsupported transit and even open-water vessels.
- Due to the shorter distances for many trade partners, growth in cargo traffic can be expected. Improved sailing conditions through Arctic passageways should also lead to increased traffic from leisure and fishing vessels.
- Despite being shorter in distance, these passages are likely to remain risky due to unsuitable bathymetries, extreme low temperatures, high wind, poor visibility, surge, and increased numbers of ice growlers and bergy bits.
- This growth in large-vessel traffic in the Arctic's pristine waterways will affect sea life, the environment, coastal communities, and local and global economies.

Insights and Opportunities

- Predicting maritime vessel traffic in a future with diminished sea ice is not simple, but it can support business strategy and capital investment planning, as well as port construction or expansion planning by municipalities and state or federal governments.
- Understanding the magnitude of vessel traffic change can help forecast environmental impacts, enabling proactive policy development and international agreements.
- Forecasts may also inform security agencies and give time for coastal communities to consider potential impacts.

— Elise Miller-Hooks presentation / reflection

THE VALUE OF THE SYMPOSIUM

Closing comments: Takeaways

6-month evaluation survey

Reflections by Epstein, Kilioni, Tracey, Xiao & others

Reflections on the value of the symposium were shared at the closing session in Fairbanks and six months after the symposium in an evaluation survey. See the following pages for more participant feedback and specific outcomes.

The symposium provided...

- opportunity to connect with other subject matter experts for on-site discussions and brainstorming on climate resilience issues.
- insights into the science and management of infrastructure-permafrost interactions, including methods and solutions practiced in other Arctic countries.
- an opportunity for early career researchers to visit remote sites and learn from local experts before applying for research funding.

The symposium emphasized...

- the need for adaptation strategies based on scientific knowledge and partnerships between community members, permafrost scientists, engineers, and planners.
- the importance of incorporating new scientific and engineering knowledge in planning Arctic projects.
- the importance of translating expert work into actionable items for communities.
- the importance of sharing permafrost science and engineering principles with a wider audience.

The symposium encouraged...

- an inclusive approach to research that acknowledges the unique issues in different regions and the value of traditional knowledge.
- community engagement and potential collaboration on research, starting with grant writing.

More takeaways

- The symposium built community, introduced participants to real issues in the region in detail, shared science of great relevance, and aided in building relationships and trust.
- The respectful debate from differing perspectives changed several participants thoughts on the key processes driving environmental change and the resulting impacts to infrastructure.
- An early career scientist working with communities reported feeling more inspired and less overwhelmed after the symposium, knowing they have many colleagues they can reach out to.
- The participation of key NSB employees fostered dialogue between Borough departments. Broadcasting the NSB Assembly workshop on public radio extended the reach across the region.

THE PERMAFROST & INFRASTRUCTURE SYMPOSIUM provided a rare opportunity for visiting scientists, engineers, planners, and policymakers to witness some of the challenges of living in a rapidly warming Arctic. Many more people wished to attend than could be accommodated. The limited size was by design—necessary due to travel logistics and desirable for facilitating dialog and knowledge sharing across disciplines. However, keeping the participant list small was among the biggest planning challenges. Recordings of the proceedings are available but are not a substitute for attending in person.

Based on the event's success and the overwhelmingly positive feedback from participants and our partners in the region, the organizers recommend planning future symposia along the same model in other regions of Alaska. Communities on the Seward Peninsula or the Yukon-Kuskokwim Delta experience the impacts of climate change differently than those on the North Slope. Local and Indigenous participation in planning any future events is critical to keeping the dialog focused on the needs and priorities of Arctic communities.

Participants shared the following suggestions for planning another symposium on the North Slope or elsewhere:

Local Involvement

- More members of local communities should be involved, more people with Indigenous knowledge, and more representatives from the local and state government.
- Include a field trip for community members to tour research sites and learn about research being done in their communities.
- Include more time for discussions with residents about how to capture their needs and involve them in research.
- A more central location in Utqiaġvik would increase interaction. We were quite isolated in our venue.
- Involve students.

Industry Involvement

- Since the oil industry is a big player on the North Slope, more industry participation and more focus on issues of oilfield abandonment and restoration would be good.

More Breaks, More Time, More Field Trips

- The days were long. Include more or longer breaks and extra free time.
- Go "on location" with more of the experts.
- Include time to report out from separate field days.
- Include more time to stop at relevant sites on the Dalton Highway and more time for discussion at the sites.

Focus on Climate Impacts

- Include targeted discussion on the carbon footprints of infrastructure projects.

Focus on Outcomes

- Provide more direction on the front end of expected outcomes and push to make more outcomes happen.
- Extend the symposium for an additional day to hold a post-symposium workshop with all participants in order to develop an action plan and timeline for implementing the research.
- Plan for more specific outcomes that go beyond the post-symposium reporting. For example, a book with contributions from participants, specific grant opportunities to collaborate on, or addressing issues that the NSB, BUECI or TNHA are experiencing that might benefit from feedback from the participants.

OUTCOMES OF THE SYMPOSIUM

The connections made and information shared at the symposium are having an impact. The outcomes below are based on participant statements made at the conclusion of the event and in a six-month follow up survey.

Actionable Results

- Recommendations to the NSB to help remediate failing foundations in Point Lay are being acted on. Point Lay homeowners have been given access to material to fill in thaw slumps and ponds under and around their homes.
- The NSB Port Authority said the meaningful dialog at the symposium will make it possible to translate the knowledge shared into actionable items at the community level.
- Research on mapping permafrost and coastal impacts is being shared with communities for better planning.
- Conversations have continued with the Alaska DOT&PF on harvesting tundra sod from new gravel pits for use in restoration and on laying fiber optic cable for geophysical monitoring along the Dalton Highway.
- The Cold Regions Research and Engineering Lab will be working in the North Slope village of Kaktovik and perhaps in Point Lay as a result of the connections made.
- The spirit of the symposium helped shape a final Canadian report on sustainable construction in the North.

Expanded Curricula

- Material developed from the Dalton Highway excursion is being used in a new graduate course in Cold Regions Engineering at the University of Pennsylvania.
- Knowledge about Alaska communities has been included in an Arctic engineering course for Greenlander and Danish students as a comparison with Greenland's challenges.

Enhanced Research and Understanding

- At George Mason University in Virginia, dynamic Arctic shipping models are being extended to incorporate whale-related subsistence seasons.
- A participant from the Netherlands was introduced to geotechnical approaches he was not familiar with in Europe, while an Alaska DOT&PF geotechnical engineer said the science shared on the Dalton Highway has caused him to step back and reevaluate some previous beliefs.

New Collaborations and Proposals

- A proposal to NSF is being developed to better monitor and predict permafrost degradation and its impact on civil infrastructure.
- Danish researchers are developing a proposal on capacity building and community engagement, which has benefitted from an improved understanding of North Slope communities, their challenges, and the way they are addressed locally and by national and international research communities.
- The symposium helped Alaska DGGS accelerate its work on the North Slope ASTAR project and expand on other potential opportunities through new partnerships and collaboration.
- An Utqiaġvik resident is looking for grant opportunities to monitor environmental changes at his own property as a way to better understand climate change.

A rolling workshop on the Dalton Highway was made possible by Northern Alaska Tour Company. NATC guide John Peirce washes the windows of the 24-passenger coach that provided transportation for the Prudhoe Bay Oilfield and Dalton Highway tours. Battelle Arctic Research Operations managed logistics for the symposium.

PHOTO: JANA PEIRCE

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THE ORGANIZING COMMITTEE

Our co-chairs and other members of the organizing committee believed in the Permafrost & Infrastructure Symposium from the beginning and generously contributed their time and expertise to make it a success.

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