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PD/PI Name:	Donald A Walker, Principal Investigator Gary P Kofinas, Co-Principal Investigator Anna Liljedahl, Co-Principal Investigator Dmitry J Nicolsky, Co-Principal Investigator Yuri L Shur, Co-Principal Investigator
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Accomplishments

*** What are the major goals of the project?**

Overview: ice-rich permafrost (IRP). IRP is at the center of a web of interacting ecosystem components that we call the IRP system (IRPS). Our key questions are: How are climate change and infrastructure affecting IRPSs? What roles do ecosystems play in the development and degradation of IRP? and How can people and their infrastructure adapt to changing IRPSs? We are particularly interested in how differences in vegetation, water, and time influence the accumulation and degradation of ground ice in IRP landscapes, and how the loss of ground ice can radically change these landscapes, their components, and the infrastructure built on them. Our ultimate goal is to understand IRPS at local, regional and circumpolar scales.

Goals related to intellectual merit: Our initial focus is at Prudhoe Bay and Point Lay, Alaska, where permafrost temperatures are changing rapidly with large impacts to ecosystems and infrastructure. Both areas provide excellent examples of IRP-related issues relevant to many other areas of Alaska and the Arctic. We are developing three main IRP observatories: (1) Roadside IRP Observatory (RIRPO, including the Colleen Site, Airport Site, and Jorgenson Site In the Prudhoe Bay oilfield; (2) Natural IRP Observatory (NIRPO) that is relatively remote from infrastructure and also in the Prudhoe Bay oilfield; and (3) Village IRP Observatory (VIRPO) at Point Lay. The Prudhoe Bay region has the best historical record of geoecological change within the Arctic with key legacy datasets and historical collaboration between industry and science. We will revisit permanent plots and remap Prudhoe Bay vegetation and landscapes first studied in the 1970s. We will characterize and compare the permafrost, hydrology, vegetation, and greenhouse gas (GHG) fluxes of IRPS in three main situations: (1) disturbance gradients

adjacent to heavily traveled roads in the Prudhoe Bay oilfield; (2) undisturbed tundra first mapped in the 1970s in a relatively undisturbed landscape consisting of drained lake basins and residual surfaces unaffected by thaw lake processes; and 3) extremely-ice-rich yedoma soils underlying the village of Point Lay. We will use a multidimensional remote-sensing time-series to measure and monitor changes to microtopography, water, snow cover, vegetation, thermokarst, and thermo-erosional features. We will use the field observations, detailed geoecological maps, and remote-sensing products to provide input for improved permafrost and hydrology models to predict permafrost degradation over the next century under different GHG emission scenarios.

Goals with broader impacts: The project offers a transformative view that places IRP at the center of change to social-ecological systems in many areas of the new Arctic. Much of the response to permafrost-related damage has been incremental actions driven by the necessity to repair and stabilize existing roads and structures. There is an immediate need to develop more strategic approaches to mitigation and adaptation informed by science and engineering in collaboration with local observations, knowledge, and preferences. Point Lay has received less research and agency attention than other climate-impacted communities, yet its thaw-related issues are among the most critical. Researchers from the UAF Institute of Northern Engineering, Geophysical Institute, Institute of Arctic Biology, and International Arctic Research Center will combine their expertise to address IRPS-related questions in collaboration with project partners. We will work with the Cold Climate Housing Research Center, Regional Housing Authority, Point Lay community, and North Slope Borough planners to collaboratively produce adaptive housing strategies and actionable knowledge regarding other infrastructure that is relevant to many arctic villages. We will leverage previous and current NSF research, oil-industry resources, and ongoing work by the Alaska Department of Transportation to advance knowledge on IRP-related impacts to roads and industrial infrastructure and contribute to best practice guidelines for road and airport construction. STEAM education and training components will reach K-12, undergraduate, graduate, and post-doctoral students. A permafrost and infrastructure symposium will bring together US-Canadian science and engineering expertise. We will communicate the results to other circumpolar communities through the IASC Rapid Arctic Transitions due to Infrastructure and Climate (RATIC) action group.

*** What was accomplished under these goals and objectives (you must provide information for at least one of the 4 categories below)?**

Major Activities:

Landscape Evolution component (led by Skip Walker)

Four expeditions to the Prudhoe Bay IRPS research sites:

21 August–September 6, 2021: Late-summer thaw, cryostratigraphy and remote sensing surveys and installation of temperature sensors at Natural and Roadside Ice-rich Observatories

- Measured thaw depth, water depth, vegetation height, and categorized vegetation type at 1-m intervals along the 4 NIRPO transects spanning different-aged thaw-lake landscapes and at 6 additional transects at established research sites (Airport, Colleen, Jorgenson) adjacent to industrial roads and infrastructure (Walker, Peirce, Mahoney, Spath).
- Acquired 2,463 high-resolution aerial images using a DJIP4RTK quadcopter and produced a base-map orthomosaic (5-cm spatial resolution) and digital surface model (220 million points) covering 230 acres, including the NIRPO, Jorgenson, and Colleen research sites (Jones).
- Drilled 66 permafrost boreholes to examine the status of permafrost, cryostratigraphy, and protective layers above ice-wedges. NIRPO and Jorgenson sites: 6 boreholes in polygon centers, 35 troughs and rims, 12 thermokarst ponds; 13 boreholes at the Airport site (Kanevskiy).
- Drilled and instrumented eight permafrost-temperature boreholes (1-inch diameter, 1.5–2.5 m deep) with four sensors at 0, 0.5, 1.0 m and the bottom of the borehole (Nikolsky).

April 26–May 10, 2022: Ground and aerial snow surveys and winter trace-gas fluxes at the Colleen and NIRPO sites

- Characterized winter snow depths, density and snow-water equivlent at the 35 NIRPO terrestrial plots, 40 aquatic pond plots, and 24 Colleen permanent vegetation plots (Breen, Kade, Peirce, Hobgood).

- Conducted a helicopter-supported LIDAR snow topography survey (Daanen)
- Measured late-winter CO2 fluxes at the the Colleen and NIRPO permanent plots (Kade).

July 13–22, 2022: Mid-summer trace-gas fluxes and introduction of new students to the flora and landscape of the NNA-IRPS study sites

- Measured late-winter CO2 fluxes at the the Colleen and NIRPO permanent plots (Kade).
- New graduate student and intern collect vascular plants and mosses, and become familiar with the NIRPO and Colleen sites (Hobgood, Kućerova).

August 19-September 1, 2022: Late-summer measurements, new plots and boreholes, and ERT surveys

- Established and surveyed 15 new vegetation plots to extend the site moisture gradient to dry and lake habitats (6 dry tundra, 1 snowbed, 1 zoogenic site on pingo top, 1 bird mound, 6 aquatic lake sites) (Walker, Breen, Hobgood, Kućerova).
- Attached 50-cm orange pin-flags to the top of 40 aquatic-plot snow poles so they can be located in winter (Hobgood).
- Established soil-termperature monitoring (Maxim iButtons®) at 0, 15, and 40-cm depths at 30 selected plots along the site moisture gradient (Walker et al.).
- Measured thaw depth, water depth, and vegetation height at al IRPS permanent plots (Walker et al).
- Measured thaw and water depths at 1-m intervals along Transect T8 (Romanovsky)
- Installed water-level sensors in seven ponds at NIRPO and Jorgenson sites to investigate the effects of water depth on pond bottom temperatures (Nicolsky, Wright).
- Drilled new boreholes in 18 ponds at NIRPO and Jorgenso sites (Kanevskiy, Veremeeva)
- Conducted electrical risistivity tomogrpahy (ERT) surveys along NIRPO Transect 8 and 9, Colleen transects 1 and 2, and the NIRPO pingo (Rybakov, Veremeeva).

Adaptation to Change component (led by Jana Peirce)

Point Lay Steering Committee and regional Advisory Group

- The steering committee met 4 times between September 2021 and August 2022 to assist the project team in planning the year's activities, including community outreach, local hire, research activities, locations to install sensors, and logistics for upcoming research trips.
- The annual Advisory Group meeting planned for June was postponed to Fall due to a scheduling conflict with a visit to Point Lay by a delegation of U.S. HUD and congressional staff.

April 10-16, 2022: Point Lay Housing Survey

- Project Coordinator Jana Peirce traveled with Cold Climate Housing Research Center Project Manager Vanessa Stevens and five CCHRC staff to conduct a housing survey in April 2022.
- Hired three community members to assist with the survey. Publicized the survey through a meeting with the Tribal Council, posted flyers, social media, VHF radio and word of mouth.
- Surveyed 54 housing units (48 occupied, 6 vacant), comprising 74% of all residential buildings, to determine housing characteristics (size, accessbility, ownership, overcrowding), building condition, functionality of systems, foundation type, permafrost-related issues, resident concerns, and priorities for repairs. Photos of homes and foundations were taken with permission.

- Coordinated with the village store to provide gift cards to all survey participants to keep money in the community. A raffle for Amazon gift cards provided an additional incentive.
- Held in-person meeting with community leaders to review project plans, solicit input on interview topics and next steps, including focus and speakers for the next Advisory Group meeting.

June 23-July 1, 2022: Permafrost, remote sensing and social science field work at Point Lay, Alaska

- Traveled to Point Lay to conduct permafrost studies, engineering assessments, community interviews and outreach in June 2022. Peirce, Connor, Jones, Kanevskiy, and Shur were accompanied by two researchers funded by other projects (Croft, Curry).
- Studied permafrost properties and ground-ice conditions in three main terrain units (elevated areas, slopes, and drained-lake basins).
- Drilled 10 boreholes up to 3 m deep to describe and sample frozen soils and ground ice, and 19 boreholes up to 5.5 m deep to estimate depth to wedge ice and vertical extent of ice wedges.
- Mapped a 110 ha area using a survey-grade drone with a high-resolution digital camera to produce an orthomosaic and digital surface model of the village and its surrounding area to help quantify the effect of thermokarst on village infrastructure.
- Interviewed 7 community residents about their observations of changes in the landscape, the impacts of permafrost thaw on community life and safety, local concerns, and information needs.
- Conducted visual assessment of foundatons for signs of failure due to permafrost degradation and estimated the percent of pilings founded in wedge ice.
- Hosted a community barbecue that featured oral and poster presentations discussing permafrost degredation and preliminary observations from our research.
- Met in Utqiagvik with with North Slope Borough and tribal government officials and planners before and after the research trip to share research plans, resources and preliminary results.

Permafrost and Infrastructure Symposium

- Submitted a conference proposal to expand the planned June 2023 symposium to include more projects, participants and topics, which NSF has recommended for funding (Peirce).

Co-development networking and professional development:

- Project team members attended a variety of NNA seminars, workshops, focus group discussions and presentations during the year on community engagement, data sharing, and approaches for effective collaboration between communities and researchers, especially during COVID, including the NNA Community Office Annual Meeting in November 2022, community meetings at ASSW, and the RATIC Arctic Infrastructure Science Talk Series.
- Peirce and Kofinas renewed their IRB certification in Human Research in May 2022.

Data management component:

- Peirce completed the NCEAS Reproducible Research Techniques for Synthesis short course, February 14-18, 2022.
- Created ArcGIS Online map with locations of all research site, transect, plot, borehole and sensor locations in the Prudoe Bay IRPO.
- Submitted dataset with 2020 field data to ADC archive.

- Summarized data from 2020–2021 field seasons in a data report to be published in Fall 2022 and prepped all data tables for archiving.
- Started on 2022 season data report that will be published in Spring 2023.
- Drafted metadata for housing survey.

Specific Objectives:

Establishment of new permafrost observatories in the Prudhoe Bay Oilfield and the village of Point Lay

Significant Results:

The new Prudhoe Bay permafrost observatory consists of two main areas: The new Natural Ice-Rich Permafrost Observatory (NIRPO) was established in 2020–2022 to examine long-term permafrost, vegetation and andscape evolution related to natural processes, including climate change. The NIRPO site consists of four different aged thaw-lake surfaces and a small pingo where a variety of observations and monitoring were conducted in 2020-2022. Observations are also being at the nearby Jorgenson transect that was established in 2011–2015. The Roadside Permafrost Observatory (RIRPO) was established in 2014–2019 under previous NSF ArcSEES funding to examine decadal-scale permafrost and landscape changes related mainly to roads and other forms of infrastructure. A description of the NIRPO and data collected to date are contained in two forthcoming data reports (Walker and Peirce, 2022, 2023).

A village permafrost observatory and improved understanding of climate- and permafrost-related impacts at oint Lay

The impact of climate change and permafrost degradation in the Village of Point Lay are being studied through a variety of approaches that were initiated in 2022 (Jones et al. 2022). We completed a housing survey of 54 homes (74% of all residential units). The Village Ice-Rich Permafrost Observatory (VIRPO) at Point Lay, includes a variety new observations and monitoring were established in collaboration between the village, the Cold Climate Housing Research Center (CCHRC) and researchers from the NNA-IRPS project and other NNA projects. A new orthomosaic and digital surface model of the village and its surrounding area is helping to quantify the effect of thermokarst on village infrastructure and inform local planning decisions. Using a survey-grade drone with a high-resolution digital camera, we mapped 110 ha area, producing the highest resolution imagery currently available for the community. The orthomosaic provides visible indicators of thawing permafrost near infrastructure that can be compared to historic aerial photographs (Figure 3), whereas the digital surface model provides very accurate topographic information that we can use to measure permafrost thaw subsidence. Additionally, we processed the digital surface model data using algorithms that remove all infrastructure and interpolate a digital terrain model so that we can identify homes and buildings affected by ice-wedge thermokarst. Initial estimates indicate that thermokarst troughs and ponds underly at least 25% of the building footprint of more than half the homes in the Village.

Advances in our understanding of the cumulative impact gravel roads

Environmental impact assessments for new Arctic infrastructure do not adequately consider the likely long-term cumulative effects of climate change and infrastructure to landforms and vegetation in areas with ice-rich permafrost, due in part to lack of long-term environmental studies that monitor changes after the infrastructure is built. Our case study of the road impacts at the Colleen site (Walker et al. 2022) examines long-term (1949–2020) climate- and road-related changes in a network of ice-wedge polygons,. We studied four trajectories of change along a heavily traveled road and a relatively remote site. During 20 years prior to the oilfield development, the climate and

landscapes changed very little. During 50 years after development, climate-related changes included increased numbers of thermokarst ponds, changes to ice-wedge-polygon morphology, snow distribution, thaw depths, dominant vegetation types, and shrub abundance. Road dust strongly affected plant-community structure and composition, particularly small forbs, mosses, and lichens. Flooding increased permafrost degradation, polygon center-trough elevation contrasts, and vegetation productivity. It was not possible to isolate infrastructure impacts from climate impacts, but the combined datasets provide unique insights into the rate and extent of ecological disturbances associated with infrastructure- affected landscapes under decades of climate warming. We conclude with recommendations for future cumulative impact assessments in areas with ice-rich permafrost.

Advances in our understanding of ice-wedges and thermokarst pond formation

Processes of ice-wedge degradation and stabilization were studied at three sites adjacent to road infrastructure in the Prudhoe Bay Oilfield, Alaska, USA to examine climatic, environmental, and subsurface conditions and evaluate the vulnerability of ice wedges to thermokarst in undisturbed and road-affected areas (Kanevskiy et al. 2022). Vulnerability of ice wedges strongly depends on the structure and thickness of soil layers above ice wedges, including the active, transient, and intermediate layers. In comparison with the undisturbed area, sites adjacent to the roads had smaller average thicknesses of the protective intermediate layer (4 cm vs. 9 cm), and this layer was absent above almost 60% of ice wedges (vs. ~45% in undisturbed areas). Despite the strong influence of infrastructure, ice-wedge degradation is a reversible process. Deepening of troughs during ice-wedge degradation leads to a substantial increase in mean annual ground temperatures but not in thaw depths. Thus, stabilization of ice wedges in the areas of cold continuous permafrost can occur despite accumulation of snow and water in the troughs. Although thermokarst is usually more severe in flooded areas, higher plant productivity, more litter, and mineral material (including road dust) accumulating in the troughs contribute to formation of the intermediate layer, which protects ice wedges from further melting.

Advances in our understanding the extent of road-dust impacts to timing of snow melt, vegetation productivity, and early season water cover

Increased industrial development in the Arctic has led to a rapid expansion of infrastructure in the region. Localized impacts of infrastructure on snow distribution, road dust, and snowmelt timing and duration feeds back into the coupled Arctic system causing a series of cascading effects that are poorly understood. Bergsted et al. (2022) quantified spatial and temporal patterns of snow-off dates in the Prudhoe Bay Oilfield, Alaska, using Sentinel-2 data. We derive the Normalized Difference Snow Index (NDSI) to quantify snow persistence in 2019-2020. The Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) were used to show linkages of vegetation and surface hydrology, in relationship to patterns of snowmelt. Newly available infrastructure data was used to analyze snowmelt patterns in relation infrastructure. Results show a relationship between snowmelt and distance to infrastructure varying by use and traffic load, and orientation relative to the prevailing wind direction (up to 1 month difference in snow-free dates). Post-snowmelt surface water area showed a strong negative correlation (up to -0.927) with distance to infrastructure. Results from field observations indicate an impact of infrastructure on winter near-surface ground temperature and snow depth. This study highlights the impact of infrastructure on a large area beyond the direct human footprint and the interconnectedness between snow-off timing, vegetation, surface hydrology, and near-surface ground temperatures.

NNA-IRPS data reports:

Key outcomes or Other achievements:

- Walker and Peirce (eds). 2022 (in progress). Oservations in ice-rich permafrost systems, Prudhoe Bay, Alaska, 2020-2021.
- Walker and Peirce (eds). 2023 (in progress). 2022 NNA-IRPS data report, Prudhoe Bay, Alaska.

Four publications in T-MOSAiC special issue of Arctic Science:

- Bergstedt, et al. 2022. The spatial and temporal influence of infrastructure and road dust on seasonal snowmelt, vegetation productivity, and early season surface water cover in the Prudhoe Bay Oilfield. *Arctic Science*, https://doi.org/10.1139/AS-2022-0013.
- Kanevskiy, M. et al. 2022. , The shifting mosaic of ice-wedge degradation and stabilization in response to infrastructure and climate change, Prudhoe Bay Oilfield, Alaska, USA. *Arctic Science*, https://doi.org/10.1139/as-2021-0024.
- Povoroznyuk, O., et al.022: Arctic roads and railways: social and environmental consequences of transport infrastructure in the Circumpolar North. *Arctic Science*, https://doi. org/10.1139/AS-2021-0033.
- Walker et al. 2022. Cumulative impacts of a gravel road and climate change in an ice-wedge polygon landscape, Prudhoe Bay, Alaska. *Arctic Science*, https://doi.org/10.1139/as-2021-0014.

Contributions at the 16th Circumpolar Remote Sensing Symposium, 16-22 May 2022:

- Keynote talk: Walker, D. A. 2022. A 50-year retrospective of remote sensing applied to cumulative impact assessments of infrastructure and climate change, Prudhoe Bay Oilfield, Alaska, and the circumpolar Arctic. Proceedings of the *16th International Circumpolar Remote Sensing Symposium*, .https://drive.google.com/file/d/1-HZj-Lqx0UsZuPgqsSKesojCGBxMgbd9/view, p. 16–19;
- Frost, G.V., et al**.** 2022. Forty years through the looking glass: spaceborne circumpolar tundra greenness observation enters its 5th decade. *16th International Circumpolar Remote Sensing Symposium*, Fairbanks, Alaska, 16-20 May 2022. https://drive.google.com/file/d/1-HZj-Lqx0UsZuPgqsSKesojCGBxMgbd9/view, p. 20–21.

Presentation at the American Geophysical Union 2021 Fall Meeting:

- Ward Jones, M., et al. 2021. Preliminary assessment of the micro-topographic impacts of ice-wedge systems using remote sensing and field observations. Oral presentation by Melissa Ward Jones, American Geophysical Union, Fall meeting, New Orleans, Session BO-74.

CCHRC reports and publications:

- Point Lay Housing Survey report draft has been completed and is in review by project partners.
- Two 2-4 page "snapshot" publications designed for the general public have been completed: "Permafrost Overview" and "Foundations for Building on Permafrost"

ARCUS Witness the Arctic feature article: publications and presentations

- Jones et al. October 2022 (in press). NSF and CRREL funded research informing infrastructure issues related to permafrost degradation in Point Lay, Alaska. *Witness the Arctic*, publication of the Arctic Research Consortium of the United States (ARCUS).
- Walker, D.A. 2022. Cumulative impacts of a gravel road and climate change in an ice-wedge polygon landscape, Prudhoe Bay, AK. Online presentation at the Arctic Infrastructure Science Talk Series, January 20, 2022.

*** What opportunities for training and professional development has the project provided?**

Emily Watson-Cook successfully defended her M.S. thesis and will graduate Fall 2022 after receiving some aid from UAF to compensate for several weeks of missed time during Spring Semester while she was undergoing medical assessments in Seattle. Her thesis is titled “Thermokarst-Pond Plant Communities of the Prudhoe Bay Region, Alaska: Plant Community Characteristics and Feedbacks to Ice-Wedge Degradation”. Ice-wedge thermokarst ponds have expanded exponentially across most regions with ice-rich permafrost. Emily’s research is the first study to examine the vegetation in these ponds. Her discovery of extraordinarily large amounts of moss biomass in these ponds has drawn considerable attention because the moss is insulating the wedges from further expansion by promoting development of a protective “intermediate layer” above the ice wedges

Olivia Hobgood is a new M.S. student who is studying the vegetation and environment along the soil moisture gradient at our Natural Ice-Rich Permafrost Observatory (NIRPO) field site at Deadhorse, AK. She worked on biomass sorting and soils analysis last spring and summer and has participated in 3 research trips to the site this year (April-May, July, August). She recently finished collecting her core data set of vegetation samples and is in the process of writing her thesis proposal and doing the necessary lab work.

Post-doctoral training: The project hosted Dr. Helena Bergstedt, a post-doctoral researcher from Germany from January 2020 through September 2021. She was co-hosted by Dr. Ben Jones in the UAF Institute of Northern Engineering. Helena is a hydrologist and remote-sensing specialist who worked on our NNA project studying the effects of permafrost degradation, snow, and road dust. We also hosted Dr. Helga Bültmann from University of Münster, who is helping us with our cryptogam taxonomy.

Anna Kučerová is an M.S. intern from Masaryk University in the Czech Republic who is visiting our lab for 4 months to familiarise herself with the Arctic vegetation, including vascular and non-vascular plants, and learn new methods useful in the specific biotopes of the arctic zone. Anna participated in our field work in July and August and is working on a mini-project examining moss species and growth-forms of the mosses along a site-moisture gradient at our NIRPO research site.

*** Have the results been disseminated to communities of interest? If so, please provide details.**

Adaptation to Change component

- Informal meeting with community leaders (Point Lay, April 12, 2022) to share progress on the housing survey and solicit input on research topics and activities.
- Point Lay Community Open House and BBQ (June 29, 2022) attended by ~100 community members.
- Water and Sewer infrastructure meeting (Utqiagvik, June 24, 2022) with planners, supervisors, and project managers from the NSB departments of Public Works and Capital Improvement Program Management (CIPM), and UMIAQ Design, who are working on the design of a new aboveground water and sewer system for Point Lay.
- Housing infrastructure meeting (June 30, 2022, Utqiagvik) with representatives of the Taġiuġmiullu Nunamiullu Housing Authority (TNHA), Inupiat Community of the Arctic Slope (ICAS), and the NSB Housing Department, to share preliminary results and recommendations.
- Meeting with Mayor's Office and NSB Planning and Community Services director (Utqiagvik, June 30, 2022) to share prelimary results.
- UMIAQ Design charrette (Online, July 20, 2022). We were invited to present preliminary research results and recommendations with community members, engineers and planners from the NSB and UMIAQ Design.

*** What do you plan to do during the next reporting period to accomplish the goals?**

Landscape Evolution component

Fall 2022 – Spring 2023:

- Complete 2022 Data Report (Walker and Peirce)
- Obtain complete (1949-2022) aerial photo record of the NIRPO site to date all ponds (Jones, Hobgood).

- Complete biomass measurements and soils analysis for the 15 new plots (Hobgood).
- Detailed map of surficial geomorphology, landscapes, vegetation (Raynolds)
- Develop thesis proposal and begin data analysis (Hobgood)
- Preliminary vegetation map of NIRPO area based on WV imagery.
- Spring 2023 snow trip (Walker et al.)
- Hierarchy of 3 Vegetation manuscripsts: (1) NIRPO vegetation along site moisture gradient (Hobgood); (2) Analysis of all Prudhoe Bay vegetation data (1970s–2022) (Breen et al.): (3) Vegetation classification of the Alaska North Slope (Sibik et al.)
- Manuscript of changes at the Airport site (IRPS Team)
- Synthesis of existing data toward understanding IRP landscape evolution (IRPS Team)

Summer 2023:

- Assess status of 1970s Prudhoe Bay vegetation plots (Walker)
- World View NDVI analysis at all plots and transects (Jones snd Hobgood)
- Retrieve iButtons at all permanent plots, analysis of vegetation–ground temperature relationships, add additional pingo vegetation plots (Hobgood)
- Begin synthesis effort incorporating all data (IRPS Team)
- Josef Sibik visit
- Helga Bultmann visit

Adapation to Change component

- Permafrost and Infrastructure Symposium, June 2023 - will bring together 45-50 permafrost scientists and engineers together with infrastructure owners, planners, policy makers, and Arctic residents from Northern Alaska for a week of meetings and tours
- Additional research and outreach activities will be planned with the local community through the Steering Committee and regional advisory group.
- Publication of *Guidebook for Building Foundations on Permafrost* and 2 more "snapshot" publications for lay audiences (CCHRC, in progress)
- Video about permafrost degredation in Point Lay (CCHRC)
- Powerpoint for workforce development on building foundations on ice-rich permafrost (CCHRC)

Products

Books

Book Chapters

Inventions

Journals or Juried Conference Papers

View all journal publications currently available in the NSF Public Access Repository for this award.

The results in the NSF Public Access Repository will include a comprehensive listing of all journal publications recorded to date that are associated with this award.

Kanevskiy, Mikhail and Shur, Yuri and (Skip) Walker, D.A. and Jorgenson, Torre and Raynolds, Martha K. and Peirce, Jana L. and Jones, Benjamin M. and Buchhorn, Marcel and Matyshak, Georgiy and Bergstedt, Helena and Breen, Amy L. and Connor, Billy and Daanen, Ronald and Liljedahl, Anna and Romanovsky, Vladimir E. and Watson-Cook, Emily. (2022). The shifting mosaic of ice-wedge degradation and stabilization in response to infrastructure and climate change,

Prudhoe Bay Oilfield, Alaska, USA. *Arctic Science*. 8 (2) 498 to 530. Status = Deposited in NSF-PAR doi:https://doi.org/10.1139/as-2021-0024 ; Federal Government's License = Acknowledged. (Completed by Shur, Yuri on 08/30/2022) Full text Citation details

Shur, Yuri and Fortier, Daniel and Jorgenson, M. Torre and Kanevskiy, Mikhail and Schirrmeister, Lutz and Strauss, Jens and Vasiliev, Alexander and Ward Jones, Melissa. (2022). Yedoma Permafrost Genesis: Over 150 Years of Mystery and Controversy. *Frontiers in Earth Science*. 9 . Status = Deposited in NSF-PAR doi:https://doi.org/10.3389/feart.2021.757891 ; Federal Government's License = Acknowledged. (Completed by Shur, Yuri on 08/30/2022) Full text Citation details

Kanevskiy, Mikhail and Shur, Yuri and Bigelow, Nancy H. and Bjella, Kevin L. and Douglas, Thomas A. and Fortier, Daniel and Jones, Benjamin M. and Jorgenson, M. Torre. (2022). Yedoma Cryostratigraphy of Recently Excavated Sections of the CRREL Permafrost Tunnel Near Fairbanks, Alaska. *Frontiers in Earth Science*. 9 . Status = Deposited in NSF-PAR doi:https://doi.org/10.3389/feart.2021.758800 ; Federal Government's License = Acknowledged. (Completed by Shur, Yuri on 08/30/2022) Full text Citation details

Raynolds, Martha K. and Jorgenson, Janet C. and Jorgenson, M. Torre and Kanevskiy, Mikhail and Liljedahl, Anna K. and Nolan, Matthew and Sturm, Matthew and Walker, Donald A.. (2020). Landscape impacts of 3D-seismic surveys in the Arctic National Wildlife Refuge, Alaska. *Ecological Applications*. 30 (7) . Status = Deposited in NSF-PAR doi:https://doi.org/10.1002/eap.2143 ; Federal Government's License = Acknowledged. (Completed by Walker, Yuri on 08/06/2021) Full text Citation details

Schneider von Deimling, Thomas and Lee, Hanna and Ingeman-Nielsen, Thomas and Westermann, Sebastian and Romanovsky, Vladimir and Lamoureux, Scott and Walker, Donald A. and Chadburn, Sarah and Trochim, Erin and Cai, Lei and Nitzbon, Jan and Jacobi, Stephan and Langer, Moritz. (2021). Consequences of permafrost degradation for Arctic infrastructure – bridging the model gap between regional and engineering scales. *The Cryosphere*. 15 (5) 2451 to 2471. Status = Deposited in NSF-PAR doi:https://doi.org/10.5194/tc-15-2451-2021 ; Federal Government's License = Acknowledged. (Completed by Walker, null on 08/05/2021) Full text Citation details

Raynolds, Martha K. and Walker, Donald A. and Balser, Andrew and Bay, Christian and Campbell, Mitch and Cherosov, Mikhail M. and Daniëls, Fred J.A. and Eidesen, Pernille Bronken and Ermokhina, Ksenia A. and Frost, Gerald V. and Jedrzejek, Birgit and Jorgenson, M. Torre and Kennedy, Blair E. and Kholod, Sergei S. and Lavrinenko, Igor A. and Lavrinenko, Olga V. and Magnússon, Borgþór and Matveyeva, Nadezhda V. and Metúsalemsson, Sigmar and Nilsen, Lennart and Olthof, Ian and Pospelov, Igor N. and Pospelova, Elena B. and Pouliot, Darren and Razzhivin, Vladimir and Schaepman-Strub, Gabriela and Šibík, Jozef and Telyatnikov, Mikhail Yu. and Troeva, Elena. (2019). A raster version of the Circumpolar Arctic Vegetation Map (CAVM). *Remote Sensing of Environment*. 232 (C) 111297. Status = Deposited in NSF-PAR doi:https://doi.org/10.1016/j.rse.2019.111297 ; Federal Government's License = Acknowledged. (Completed by Walker, null on 08/06/2021) Full text Citation details

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Frost, G. V.. (2020). Tundra greenness. *Bulletin of the American Meteorological Society*. S1–S429. Status = Deposited in NSF-PAR doi:https://doi.org/10.1175/BAMS-D-20-0086. ; Federal Government's License = Acknowledged. (Completed by Walker, null on 08/04/2021) Full text Citation details

• Kanevskiy, M., Shur, Y., Walker, D. A. (Skip), Jorgenson, T., Raynolds, M. K., Peirce, J. L., … Buchhorn, M. 2022: The shifting mosaic of ice-wedge degradation and stabilization in response to infrastructure and climate change, Prudhoe Bay Oilfield, Alaska, USA. Arctic Science, https://doi.org/10.1139/as-2021-0024.. Status =

PUBLISHED.

Walker, D. A., M. K. Raynolds, M. Z. Kanevskiy, Y. Shur, V. E. Romanovsky, B. M. Jones, M. Buchhorn, M. T. Jorgenson, J. Šibík, A. L. Breen, A. Kade, E. Watson-Cook, H. Bergstedt, A. K. Liljedahl, R. Daanen, B. Connor, D. J. Nicolsky, and J. L. Peirce. (2021, in revision). Cumulative impacts of a gravel road and climate change in an ice-wedge polygon landscape, Prudhoe Bay, Alaska. Arctic Science.. Status = PUBLISHED.

Povoroznyuk, O., Vincent, W.F., Schweitzer, P., Laptander, R., Bennett, M., Calmels, F., Sergeev, D. Arp, C., Forbes, B., Roy-Léveillée, P., and Walker, D.A. 2021 submitted. Arctic Roads and Railways: Environmental and Social Consequences of Transport Infrastructure in the Circumpolar North, Arctic Science.. Status = PUBLISHED.

Sehmel, Tracy, 2021. Potential Mitigation Strategies for Buildings and Infrastructure on Thawing Permafrost. UAF One Health Conference. Status = OTHER.

Landers, Zoe. 2021. Effects of Ice Rich Permafrost on Infrastructure presented. National Renewable Energy Laboratory Summer Internship Research Poster Session. Status = OTHER.

Ward Jones, M., Jones, B., Walker, S., Kanevskiy, M., Shur, Y., Peirce, J., Zweiback, S., Breen, Liljedahl, A., Natali, S., Miller, C. 2021 submitted. AGU 2021, Session BO74.. Status = PUBLISHED.

Shur, Y., Fortier, D., Jorgenson, T., Kanevskiy, M., Schirrmeister, L., Strauss, J., Vasiliev, A., Ward Jones, M. (2021, submitted) Yedoma Permafrost Genesis: More than 150 Years of Mystery and Controversy. Submitted to Frontiers in Earth Science.. Status = PUBLISHED.

Kanevskiy, M., Shur, Y., Bigelow, N.H., Bjella, K.L., Douglas, T.A., Jones, B.M., Jorgenson, M.T., Fortier, D. (2021, submitted) Yedoma cryostratigraphy of recently excavated sections of the CRREL Permafrost Tunnel near Fairbanks, Alaska. Submitted to Frontiers in Earth Science.. Status = PUBLISHED.

Licenses

Other Conference Presentations / Papers

Walker, DA (2022). *Walker, D. A. 2022. A 50-year retrospective of remote sensing applied to cumulative impact assessments of infrastructure and climate change, Prudhoe Bay Oilfield, Alaska, and the circumpolar Arctic*. 16th International Circumpolar Remote Sensing Symposium. Fairbanks. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Other Products

Other Publications

Patent Applications

Technologies or Techniques

Thesis/Dissertations

Websites or Other Internet Sites

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Walker, Donald	PD/PI	4
Kofinas, Gary	Co PD/PI	0
Liljedahl, Anna	Co PD/PI	1
Nicolsky, Dmitry	Co PD/PI	2
Shur, Yuri	Co PD/PI	1
Breen, Amy	Co-Investigator	2
Connor, Billy	Co-Investigator	1
Jones, Ben	Co-Investigator	2
Kade, Anja	Co-Investigator	2
Kanevskiy, Mikhael	Co-Investigator	2
Peirce, Jana	Co-Investigator	2
Bergstedt, Helena	Postdoctoral (scholar, fellow or other postdoctoral position)	1
Ward-Jones, Melissa	Postdoctoral (scholar, fellow or other postdoctoral position)	1
Druckenmiller, Lisa	Technician	0
Raynolds, Martha	Technician	1
Hobgood, Olivia	Graduate Student (research assistant)	6
Watson-Cook, Emily	Graduate Student (research assistant)	6

Name	Most Senior Project Role	Nearest Person Month Worked
Meade, Zoe	Non-Student Research Assistant	0
Mahoney, Josephine	Undergraduate Student	0
Daanen, Ronald	Consultant	1

Full details of individuals who have worked on the project:

Donald A Walker
Email: dawalker@alaska.edu
Most Senior Project Role: PD/PI
Nearest Person Month Worked: 4

Contribution to the Project: PI, Lead of Vegetation section

Funding Support: This Grant, and UAF

Change in active other support: No

International Collaboration: No
International Travel: No

Gary P Kofinas
Email: gary.kofinas@alaska.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 0

Contribution to the Project: Advising on human dimension component

Funding Support: This award

Change in active other support: No

International Collaboration: No
International Travel: No

Anna Liljedahl
Email: aliljedahl@woodwellclimate.org
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Lead of Hydrology component

Funding Support: This award

Change in active other support: No

International Collaboration: No
International Travel: No

Dmitry J Nicolsky
Email: djnicolsky@alaska.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 2

Contribution to the Project: Collaborator on permafrost modeling and borehole temperature component

Funding Support: this grant and UAF

Change in active other support: No

International Collaboration: No
International Travel: No

Yuri L Shur
Email: yshur@alaska.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Lead on Permafrost cryostratigraphy component

Funding Support: This award, and UAF

Change in active other support: No

International Collaboration: No
International Travel: No

Amy Breen
Email: albreen@alaska.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 2

Contribution to the Project: Leader and collaborator on the vegetation component

Funding Support: This grant, and UAF International Arctic Research Center

International Collaboration: No
International Travel: No

Billy Connor
Email: bgconnor@alaska.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Co-investigator, permafrost engineering infrastructure components in Point Lay and Prudhoe Bay

Funding Support: This grant and UAF Institute of Northern Engineering

International Collaboration: No
International Travel: No

Ben Jones
Email: bmjones3@alaska.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 2

Contribution to the Project: Co investigator, remote sensing component

Funding Support: This award and UAF Institute of Northern Engineering

International Collaboration: No
International Travel: No

Anja Kade
Email: ankade@alaska.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 2

Contribution to the Project: Co-investigator, Vegetation component, trace-gas fluxes

Funding Support: This grant

International Collaboration: No
International Travel: No

Mikhael Kanevskiy
Email: Mikhail Kanevskiy
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 2

Contribution to the Project: Co-investigator, permafrost component, ground ice characterization

Funding Support: This award and UAF Institute of Northern Engineering

International Collaboration: No
International Travel: No

Jana Peirce
Email: jlpeirce@alaska.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 2

Contribution to the Project: Project coordinator, lead on adaptations portions of the award, and codevelopment with village of Point Lay

Funding Support: This award and UAF Institute of Arctic Biology

International Collaboration: No
International Travel: No

Helena Bergstedt
Email: hbergstedt@alaska.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 1

Contribution to the Project: Post-doc on remote sensing component

Funding Support: This award and UAF Institute of Northern Engineering

International Collaboration: No
International Travel: No

Melissa Ward-Jones
Email: mkwardjones@alaska.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 1

Contribution to the Project: Collaboration: Lead author on manuscript for 2021 AGU meeting Session BO74 using ground temperature data from our Colleen and Airport sites "Preliminary assessment of the micro-topographic impacts of ice-wedge systems using remote sensing and field observations"

Funding Support: INE Post-doctoral support through Ben Jones

International Collaboration: No
International Travel: No

Lisa Druckenmiller
Email: ladruckenmiller@alaska.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 0

Contribution to the Project: Data manager, no longer on the project

Funding Support: other than this grant

International Collaboration: No
International Travel: No

Martha Raynolds
Email: mkraynolds@alaska.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 1

Contribution to the Project: GIS and remote sensing support

Funding Support: This award

International Collaboration: No
International Travel: No

Olivia Hobgood
Email: ohobgood@alaska.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

Contribution to the Project: Graduate student vegetation component

Funding Support: This award

International Collaboration: No
International Travel: No

Emily Watson-Cook
Email: ewatsoncook@alaska.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

Contribution to the Project: thesis work and accomplished her field season in summer 2020 and 2021

Funding Support: this grant

International Collaboration: No
International Travel: No

Zoe Meade
Email: zemeade@alaska.edu
Most Senior Project Role: Non-Student Research Assistant
Nearest Person Month Worked: 0

Contribution to the Project: Field assistant in 2021

Funding Support: this grant

International Collaboration: No
International Travel: No

Josephine Mahoney
Email: 18jemahoney@gmail.com
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 0

Contribution to the Project: Field assistant in f2021

Funding Support: This grant and UAF student award

International Collaboration: No
International Travel: No

Ronald Daanen
Email: "Daanen, Ronald P (DNR)"
Most Senior Project Role: Consultant
Nearest Person Month Worked: 1

Contribution to the Project: Consultant, Alaska Department of Geology and Geophysical Surveys (DGGS), consultant on airborne and ground based Lidar

Funding Support: this proposal

International Collaboration: No
International Travel: No

What other organizations have been involved as partners?

Name	Type of Partner Organization	Location

Name	Type of Partner Organization	Location
Alaska Division of Geological & Geophysical Surveys	State or Local Government	Fairbanks, AK
Cold Climate Housing Research Center	Other Nonprofits	Fairbanks, AK
Kali School	School or School Systems	Point Lay, AK
Native Village of Point Lay IRA	State or Local Government	Point Lay, AK
North Slope Borough Department of Planning and Community Dev	State or Local Government	Utqiagvik, AK
Taġiuġmiullu Nunamiullu Housing Authority	Other Organizations (foreign or domestic)	Utqiagvik, AK
Woodwell Climate Research Center	Other Organizations (foreign or domestic)	Falmouth, MA

Full details of organizations that have been involved as partners:

Alaska Division of Geological & Geophysical Surveys

Organization Type: State or Local Government
Organization Location: Fairbanks, AK

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution: Project researcher Ronald Daanen is a hydrogeololgist with Alaska DGGS. Because of the close coordination and nature of his involvement in the project, his relationship has been changed from a contractor to a subaward with the state agency he works for.

Cold Climate Housing Research Center

Organization Type: Other Nonprofits
Organization Location: Fairbanks, AK

Partner's Contribution to the Project:
Facilities
Personnel Exchanges

More Detail on Partner and Contribution: Partner on the Adaptations to Change component of the research in Point lay

Kali School

Organization Type: School or School Systems
Organization Location: Point Lay, AK

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution: Kali School principal and interested teachers collaborate with researchers to develop and deliver lessons related to the project and host virtual classroom visits by the science team.

Native Village of Point Lay IRA

Organization Type: State or Local Government
Organization Location: Point Lay, AK

Partner's Contribution to the Project:
In-Kind Support
Collaborative Research

More Detail on Partner and Contribution: The Tribal government of Point Lay provides a project liaison and appoints members to a local steering committee to advise the research team on the best ways to work with and in the community. The Tribal president is on the project Advisory Group.

North Slope Borough Department of Planning and Community Dev

Organization Type: State or Local Government
Organization Location: Utqiagvik, AK

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution: The regional planning department advises the research team and helps focus research efforts to ensure the project will have a positive impact. Its director is on the project's Advisory Group and on the Permafrost and Infrastructure Symposium planning committee.

Tagiuġmiullu Nunamiullu Housing Authority

Organization Type: Other Organizations (foreign or domestic)
Organization Location: Utqiagvik, AK

Partner's Contribution to the Project:
Facilities
Collaborative Research

More Detail on Partner and Contribution: TNHA provides lodging for the research team in Point Lay. Its executive director, as a member of the local and regional advisory group for the project and the symposium planning committee, contributes important background information and helps focus research efforts to ensure the project will have a positive impact.

Woodwell Climate Research Center

Organization Type: Other Organizations (foreign or domestic)
Organization Location: Falmouth, MA

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution: Project Co-PI Anna Liljedahl is now research staff at Woodwell Climate. Her funding has been moved from UAF to a subaward with Woodwell Climate.

Were other collaborators or contacts involved? If so, please provide details.

Other research projects we collaborated with include:

- **NSF Navigating the New Arctic** *Track 1: Collaborative Research: Resilience and adaptation to the effects of permafrost degradation induced coastal erosion* (Award 1927718)
- **NSF Arctic System Science** *Collaborative Research: Causes and Consequences of Catastrophic Thermokarst Lake Drainage in an Evolving Arctic System* (Award 1806213)
- **U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory, Fort Wainwright (CRREL)**: *Effort to Engage Local Knowledge to Inform Measures Protecting Alaska Coastal Infrastructure from Erosion and Permafrost Thaw*

International collaboration:

- IASC Rapid Arctic Transitions due to Infrastructure and Climate (RATIC) initiative

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Impacts

What is the impact on the development of the principal discipline(s) of the project?

This research is fundamentally changing the understanding of how ice-wedge polygon systems are responding to both climate change and disturbances caused by infrastructure

What is the impact on other disciplines?
Nothing to report.

What is the impact on the development of human resources?

Several gradauate students, post-docs, and interns are being trained.

What was the impact on teaching and educational experiences?
Nothing to report.

What is the impact on physical resources that form infrastructure?

Nothing to report.

What is the impact on institutional resources that form infrastructure?
Nothing to report.

What is the impact on information resources that form infrastructure?
Nothing to report.

What is the impact on technology transfer?
Nothing to report.

What is the impact on society beyond science and technology?
Nothing to report.

What percentage of the award's budget was spent in a foreign country?

None

Changes/Problems

Changes in approach and reason for change

The symposium planned for Point Lay has been moved to summer 2023 because of the Covid crisis. A proposal to change the venue for the meeting to Barrow, and expand the scope to includle a tour of the Dalton Highway has been recommended for funding.

Actual or Anticipated problems or delays and actions or plans to resolve them

Emily Watson-Cook had go to Seattle for emergency medical assessment for several weeks. She is generally in good health, but will require further assessment this fall. She will complete writing the thesis and a publication this fall while in Seattle. UAF has provided tuition and fees for the Fall 2022 semester, and the grant will supply 1 mo of salary to complete the publication.

Changes that have a significant impact on expenditures
Nothing to report.

Significant changes in use or care of human subjects
Nothing to report.

Significant changes in use or care of vertebrate animals
Nothing to report.

Significant changes in use or care of biohazards
Nothing to report.

Change in primary performance site location

Nothing to report.