**Alaska Transportation & Infrastructure**

*Identifying Permafrost Subsidence Using NASA Earth Observations to Pinpoint Road & Infrastructure Vulnerability in Fairbanks, Alaska*

**Project Team**

***Project Team:***

Patrick Saylor (Project Lead)

Marissa Dudek

Joshua Green

Katie Lange

***Advisors & Mentors:***

Bruce Chapman (NASA Jet Propulsion Laboratory, California Institute of Technology)

Benjamin Holt (NASA Jet Propulsion Laboratory, California Institute of Technology)

***Team POC:*** Patrick Saylor, saylor.pat@gmail.com

***Software Release POC:*** Patrick Saylor, saylor.pat@gmail.com

***Partner POC:*** Christopher Hiemstra, christopher.a.hiemstra@erdc.dren.mil

**Project Overview**

***Project Synopsis:***

Permafrost thaw and subsequent surface deformation are of increasing concern to the state of Alaska. Permafrost underlies ~85% of the state and can be up to 650 meters thick. Recent warming has exacerbated permafrost thaw in the Arctic region, causing land surface subsidence and thermokarst formation. These surface deformation processes can pose a serious threat to the structural integrity of Alaska's transportation and infrastructure. In order to enhance project partners’ decision-making capabilities surrounding this issue, this project identified permafrost thaw within areas of interest and built a data processing module for future monitoring.

***Abstract:***

A rapidly warming Arctic has compromised the structural integrity of critical infrastructure through accelerated permafrost thaw and thermokarst development underlying these areas. Infrastructure, including roads, bridges, and airports across the state of Alaska are particularly at risk, as permafrost underlies ~85% of the state. However, monitoring the impacts of permafrost thaw on infrastructure is largely limited to *in situ* observations and frequently identified after the damage is evident. In order to assist transportation and infrastructure decision-makers in Alaska, this project identified and quantified areas of surface subsidence near critical infrastructure. Seasonal interferograms were created using Sentinel-1 C-band Synthetic Aperture Radar (SAR) and L-band Uninhabited Aerial Vehicle SAR (UAVSAR) data to identify areas experiencing surface deformation. Additionally, Light Detection and Ranging (LiDAR) datasets were used to validate select interferograms created between 2017 and 2019. Validation of subsidence detection across platforms was performed over a 7x8 sq. kilometer field site for 2017. The strongest relationship in spatial deformation is observed between Sentinel-1 and UAVSAR with a residual root mean square error of 20 mm. These results suggest that both UAVSAR and Sentinel-1 platforms are capable of detecting surface subsidence. The higher resolution of UAVSAR is better able to resolve localized subsidence features of less than 80 meters, but is limited by temporal resolution. In conjunction, UAVSAR and Sentinel-1 can provide complementary spatial and temporal resolutions for subsidence analysis in the absence of *in situ* data.

***Key Terms:***

Alaska, permafrost, subsidence, thermokarst, infrastructure, Sentinel-1, UAVSAR, LiDAR

***National Application Area Addressed:*** Transportation & Infrastructure

***Study Location:*** Fairbanks, AK

***Study Period:*** 2017 to 2019 (May to September)

***Community Concerns:***

* Permafrost thaw poses environmental impacts on both local and global scales, from slope instabilities and the destabilization of critical infrastructure to the massive release of greenhouse gases from thawing organic-rich soils.
* Widely accepted climate scenarios project that by 2100, the near surface permafrost present under 38% of boreal and arctic Alaska will be reduced by 16% to 24%.
* Surface deformation poses significant economic and environmental threats to Alaskan communities' infrastructure, including structural damage to buildings, roads, bridges, and oil and gas pipelines.
* Current ground-based survey methods are resource intensive and limit the ability of decision-makers to assess large spatial areas for surface deformation.

***Project Objectives:***

* Identify areas of permafrost thaw and thermokarst formation posing risks to critical infrastructure
* Assess the performance of Sentinel-1, UAVSAR, and LiDAR in the quantification of surface subsidence
* Evaluate the feasibility and accuracy of using Sentinel-1 and UAVSAR to detect seasonal and annual surface subsidence
* Create a processing module to compare permafrost subsidence and thermokarst detection across remote sensing platforms

**Partner Overview**

***Partner Organizations:***

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| --- | --- | --- | --- |
| **Organization** | **POC (Name, Position/Title)** | **Partner Type** | **Boundary Org?** |
| **US Army Corps of Engineers, Cold Regions Research and Engineering Laboratory** | Tom Douglas, Senior Scientist; Christopher Hiemstra, Research Scientist | End User | Yes |
| **Alaska Department of Transportation & Public Facilities**  | Garrett Speeter, Regional Engineering Geologist | End User | Yes |
| **Alaska Department of Natural Resources** | Ronald Daanen, Field Hydrologist | End User | Yes |
| **Alaska Satellite Facility** | Franz Meyer, Chief Scientist | Collaborator | No |

***Decision-Making Practices & Policies:***

End users for this project include the US Army Corps of Engineers’ Cold Regions Research and Engineering Laboratory (CRREL), the Alaska Department of Transportation & Public Facilities (ADOT&PF), and the Alaska Department of Natural Resources (ADNR). CRREL’s Fairbanks, AK office currently focuses its research on Alaska and Greenland. It operates the Permafrost Tunnel Research Facility in Fairbanks and requires more information about permafrost deformation within the area to ensure safety within the tunnel. CRREL typically uses ground-based observations and remote sensing products in their decision-making practices. ADOT&PF’s decision-making entails assessing permafrost deformation near major transportation routes, infrastructure, and public facilities. Depending on the situation, ADOT&PF must decide whether to preserve or purposely thaw permafrost. Staff typically make these decisions based on ground-based geological and geotechnical observations, sometimes using remote sensing products on a project-by-project basis. ADNR is interested in the effects of permafrost on long-term groundwater quality and availability to Alaskans, as well as permafrost melt causing slope movements and drunken trees. It makes decisions based on a combination of ground-based detection and satellite imagery.

**Earth Observations & End Products Overview**

***Earth Observations:***

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| --- | --- | --- |
| **Platform & Sensor** | **Parameters** | **Use** |
| **NASA Gulfstream-III UAVSAR** | Ground-ranged detected phase (GRD) product, horizontal transmit – horizontal receive (HH) polarization, unwrapped interferograms | This dataset was used to create interferograms that identified surface subsidence in the study areas using paired interferograms. |
| **Sentinel-1 C-SAR** | Level-1 Single Look Complex (SLC) product, Interferometric Wide (IW) swath, vertical transmit – vertical receive (VV) polarization, unwrapped interferograms | This dataset was used to create interferograms that identified surface subsidence in the study areas. It was also used to detect surface subsidence in areas without UAVSAR coverage. |

***Ancillary Datasets:***

* National Science Foundation (NSF) National Ecological Observatory Network (NEON) LiDAR datasets – created elevation change products to analyze permafrost deformation near the Caribou Creek NEON site
* CRREL LiDAR dataset – created elevation change products to analyze permafrost deformation near CRREL
* ADOT&PF Division of Geological and Geographic Surveys (DGGS) LiDAR Fairbanks QL1 2017 dataset – created elevation change products to analyze permafrost deformation near the CRREL permafrost tunnel
* ADOT&PF Transportation Geographic Information Section (TGIS) GIS shapefile dataset – created area of interest shapefiles to analyze study area and relate remotely sensed data
* North Slope Science Initiative (NSSI), University of Alaska Fairbanks (UAF) Institute of Northern Engineering (INE), Permafrost Characteristics of Alaska, 2008 GIS shapefile dataset – used to evaluate the extent of local permafrost near critical infrastructure

***Software & Scripting:***

* Esri ArcGIS Pro 2.6 – data processing and map creation
* QGIS 3.10.2 – UAVSAR, LiDAR, Sentinel-1 raster processing
* Python 3.6.5 – scripting of a tool that automates UAVSAR, Sentinel-1, and LiDAR processing and deformation analysis
* Alaska Satellite Facility OpenSARLab – scripting of a tool that automates Sentinel-1 interferogram processing
* Alaska Satellite Facility Hybrid Pluggable Processing Pipeline (HyP3) – cloud-based platform that automates Sentinel-1 interferogram creation

***End Products:***

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| --- | --- | --- | --- |
| **End Products** | **Earth Observations Used**  | **Partner Benefit & Use** | **Software Release Category** |
| **Permafrost Deformation Maps** | Sentinel-1 C-SARNASA Gulfstream III UAVSAR | These maps identify areas experiencing permafrost deformation and severity near major roads and infrastructure. | I |
| **Thermokarst Maps** | Sentinel-1 C-SARNASA Gulfstream III UAVSAR | These maps identify areas experiencing thermokarst formation and severity near major roads and infrastructure. | I |
| **Standard Operating Procedure** | N/A | This document provides partners with the methodology established in this project for future analyses of areas not included in this study. | N/A |
| **Permafrost Measurement and Analysis (PerMA) Python Module** | Sentinel-1 C-SARNASA Gulfstream III UAVSAR | This Python software module automates UAVSAR, Sentinel-1, and LiDAR processing and deformation analysis in user-selected study areas for partners’ future use. | IV |

***Product Benefit to End User:***

The methodology established in this project may be leveraged to improve monitoring and analysis of potential risks to infrastructure. Project products, including hazard assessment maps and image analysis applications, enable end users to identify, prioritize, and accelerate potential mitigation responses to the infrastructure at greatest risk. A systematic assessment of permafrost impact on infrastructure will provide end users with the necessary information and resources to guide decisions for facility modernization and replacement. This will help end users increase the resiliency and lifespan of the Alaska Transportation System and any accompanying infrastructure assets, and achieve policy and planning objectives such as those laid out in the Strategic Highway Safety Plan (2008), Highway Safety Initiative (2013), and 2036 Statewide Long-Range Transportation Plan (2016).

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