Alaska Transporation & Infrastructure

Identifying Permafrost Subsidence Using NASA Earth Observations to Pinpoint Road & Infrastructure Vulnerability

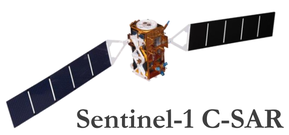
Abstract

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. UAVSAR and Sentinel-1 seasonal deformation returns produced consistent spatial deformation patterns with residual root mean squared errors of 13 and 21 millimeters, respectively. 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.

Objectives

- **Detect** permafrost deformation and thermokarst formation
- **Identify** road and infrastructure vulnerability
- **Create** a Python module to automate Sentinel-1, UAVSAR, and LiDAR processing & analysis
- **Evaluate** the feasibility & accuracy of Earth observations to detect permafrost thaw

Earth Observations



Sentinel-1 C-SAR

NASA Gulfstream III
UAVSAR

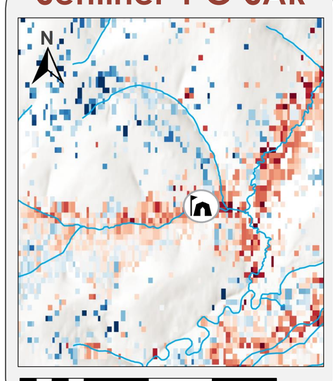
Airborne/UAV
LiDAR

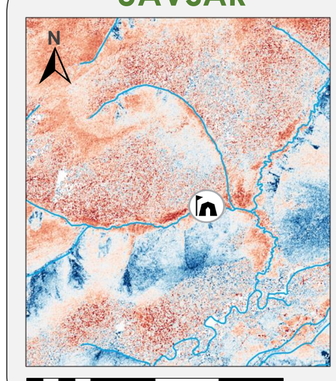
Results

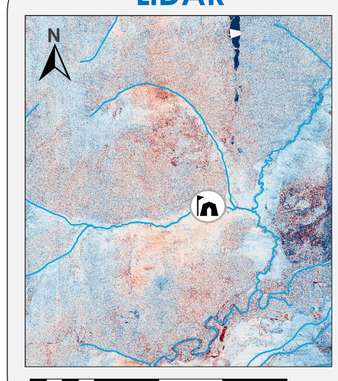
Relative Deformation 2017 vs. 2018

150 / -150 Deformation (mm)

Caribou Creek NEON Site

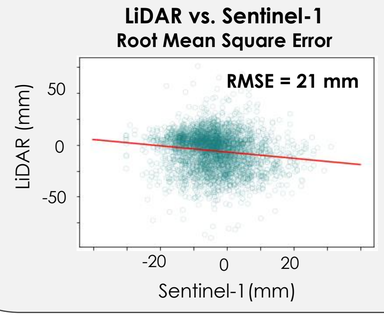


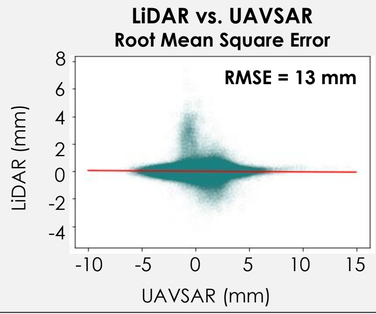




Cross-Platform Validation & Comparison

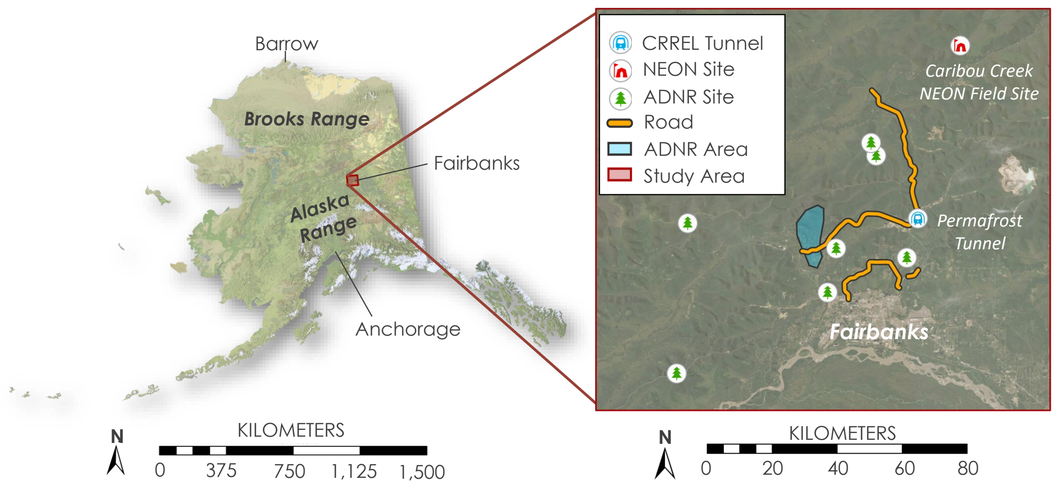
- **UAVSAR** detects deformation at higher spatial resolution than Sentinel-1
- **LiDAR** detects deformation at high spatial but low temporal resolution
- **Validation & Comparison:** UAVSAR demonstrates higher accuracy than Sentinel-1





Study Area

- **Fairbanks, Alaska** Areas of Interest (AOIs): CRREL Permafrost Research Tunnel, Caribou Creek NEON site, four roadways (totaling ~80 miles), O'Connor Creek watershed, and eight environmental locations (e.g. landslides, thermokarst, ice wedges)
- **Caribou Creek** National Ecological Observatory Network (NEON) field site used for validation of deformation detection across satellites and sensors



Methodology

Sentinel-1 C-SAR

HyP3 — Create Interferograms

- Co-registration of Single-Looks
- Compute interferograms
- Topographic phase removal
- Adaptive phase filtering
- Phase unwrapping
- Terrain geo-coding

OpenSARLab — Pre-Process

- Subset to areas of interest
- Data quality assurance
- Cull data selection
- Re-project to UTM

GIAnT — Deformation Analysis

- Build ancillary files & functions
- Run Time-Series Analysis

UAVSAR

JPL — Data Acquisition

- Processing mode: InSAR Pair
- Type: L-Band
- Polarization: HH
- Binary File Type: Ground (.GRD)

Python — Pre-Process

- Build ENVI header (.HDR) file
- Build symbolic image (.IMG) file
- Translate .GRD into raster file

GIS — Deformation Analysis

- Remove no data (NaN) values
- Calc. line of sight deformation
- Deformation analysis
- Resample cell size to Sentinel-1 C-SAR pixel scale

LiDAR

Products — Data Acquisition

- Obtain study area DTM/DEM products from multiple data-bases, including:

1) United States Geological Survey
2) National Ecological Obser-vatory Network
3) Cold Regions Research & Engineering Laboratory
4) NASA Arctic Boreal and Vulnerability Experiment

GIS — Pre-Process

- Georeference DTMs/DEMs
- Mosaic DTM/DEM rasters
- Create deformation maps

Deformation Analysis

- Resample cell size to Sentinel-1 C-SAR pixel scale

Cross-Platform Validation & Comparison

- Pairwise root mean square error calculation (RMSE)
- Pairwise difference in difference calculation
- Raster accuracy quotient comparison

Conclusions

- Sentinel-1 has more spatial and temporal coverage than UAVSAR and LiDAR.
- Sentinel-1 has a higher RMSE than UAVSAR when compared to LiDAR.
- Project partners can use Sentinel-1 C-SAR, UAVSAR, and LiDAR to identify and prioritize areas experiencing the highest intensity of permafrost deformation.

Project Partners

- US Army Corps of Engineers, Cold Regions Research & Engineering Laboratory
- Alaska Department of Transportation & Public Facilities
- Alaska Department of Natural Resources
- Alaska Satellite Facility

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