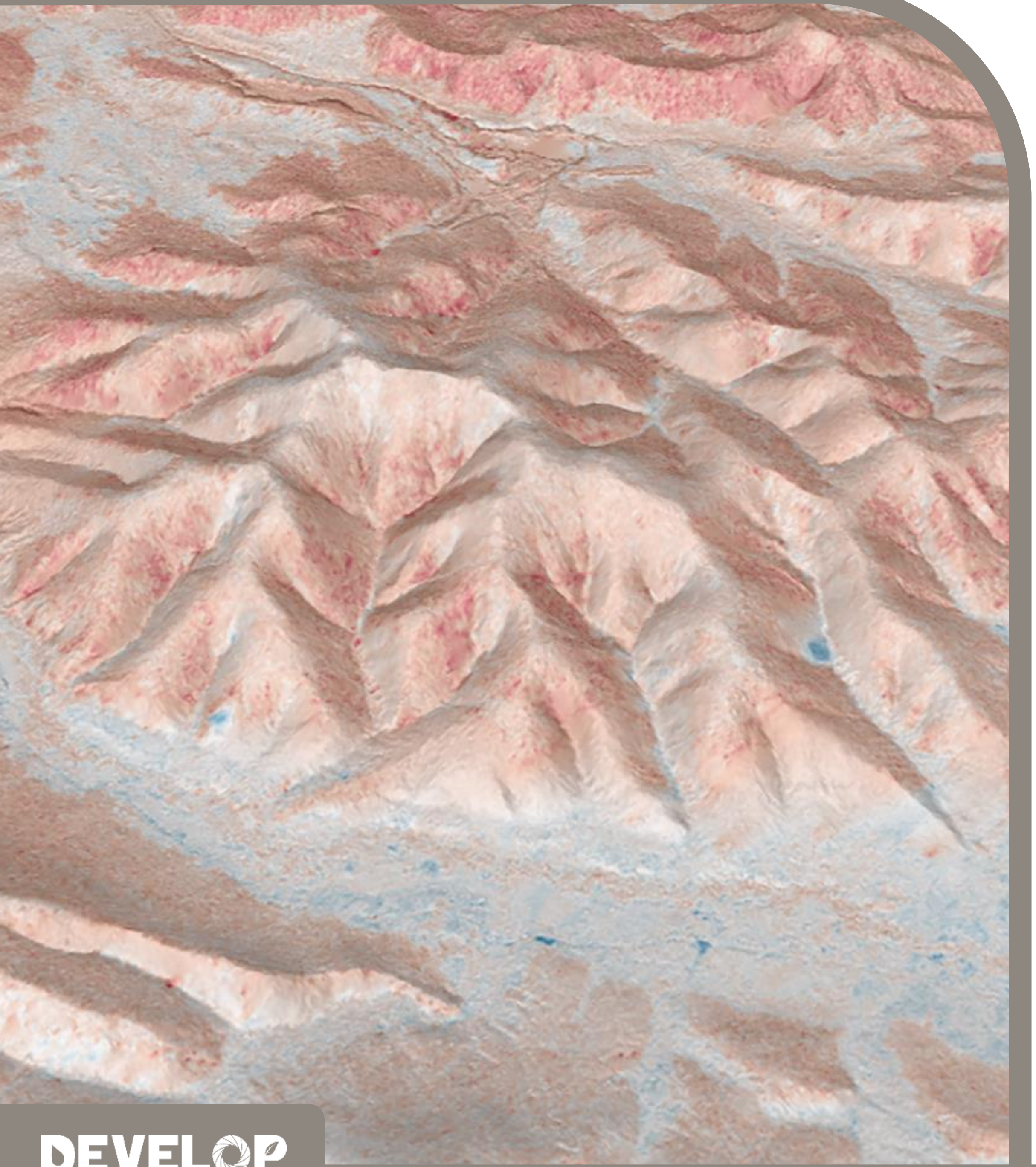


National Aeronautics and Space Administration

ALASKA

Transportation & Infrastructure

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

Patrick Saylor, Marissa Dudek, Katie Lange, Joshua Green

DEVELOP

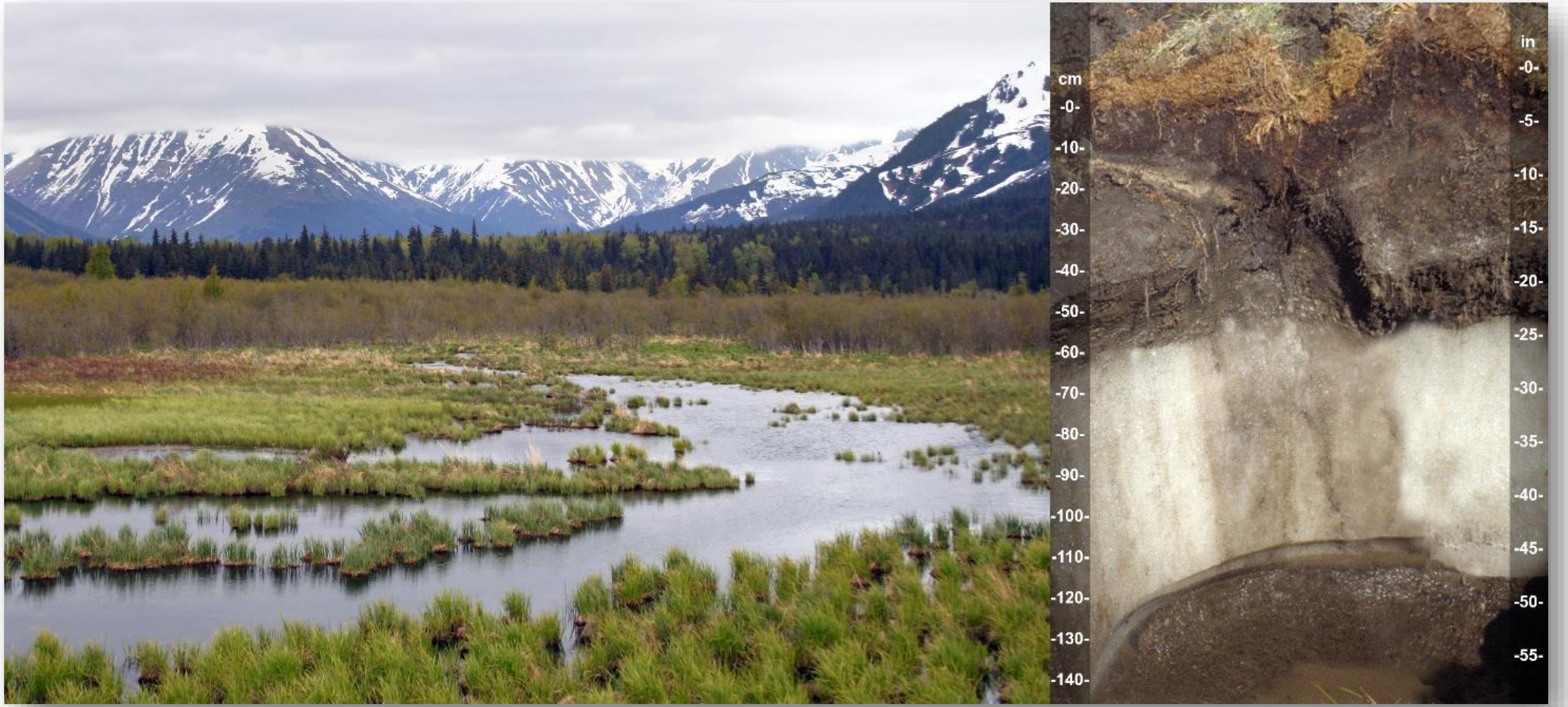
Overview

- **Background & Overview**
  - Community Concerns
  - Current Monitoring Techniques
  - Project Partners
  - Project Objectives
  - Study Area
  - Satellites & Sensors
- **Methods**
  - Data Processing
  - Cross-Platform Analysis
- **Results**
  - Conclusions
  - Limitations & Errors
  - Future Work
- **Acknowledgements**

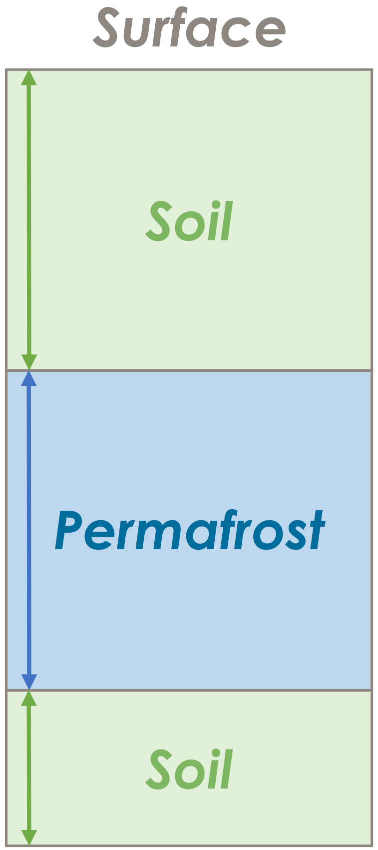
Credit: Pixabay

Background and Overview

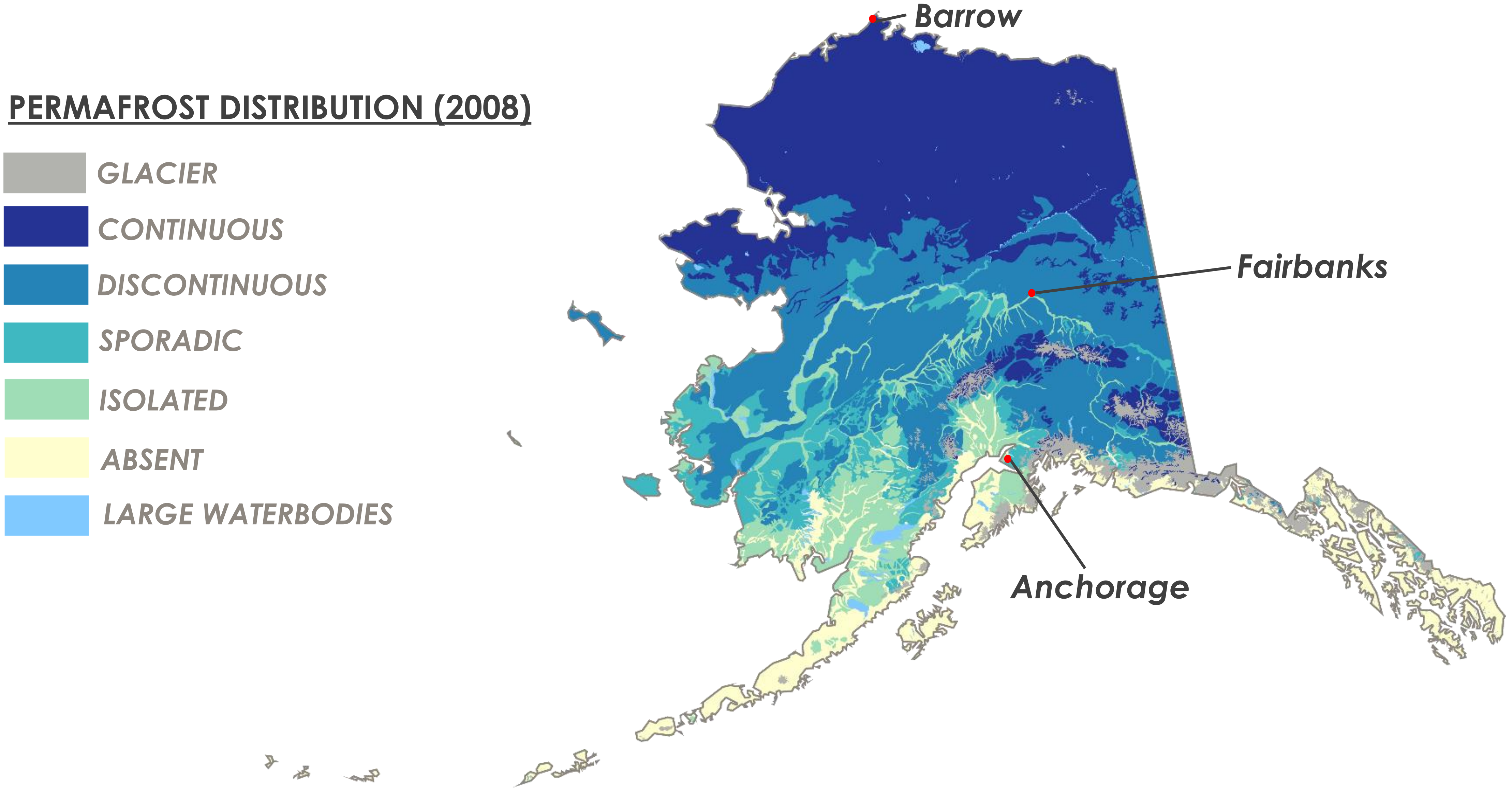
PERMAFROST: Ground that remains frozen for 2+ years;
can be an inch to several miles deep beneath the Earth's surface.



Credit: *John Kelley, USDA Natural Resources Conservation Service*



Background: Permafrost in Alaska

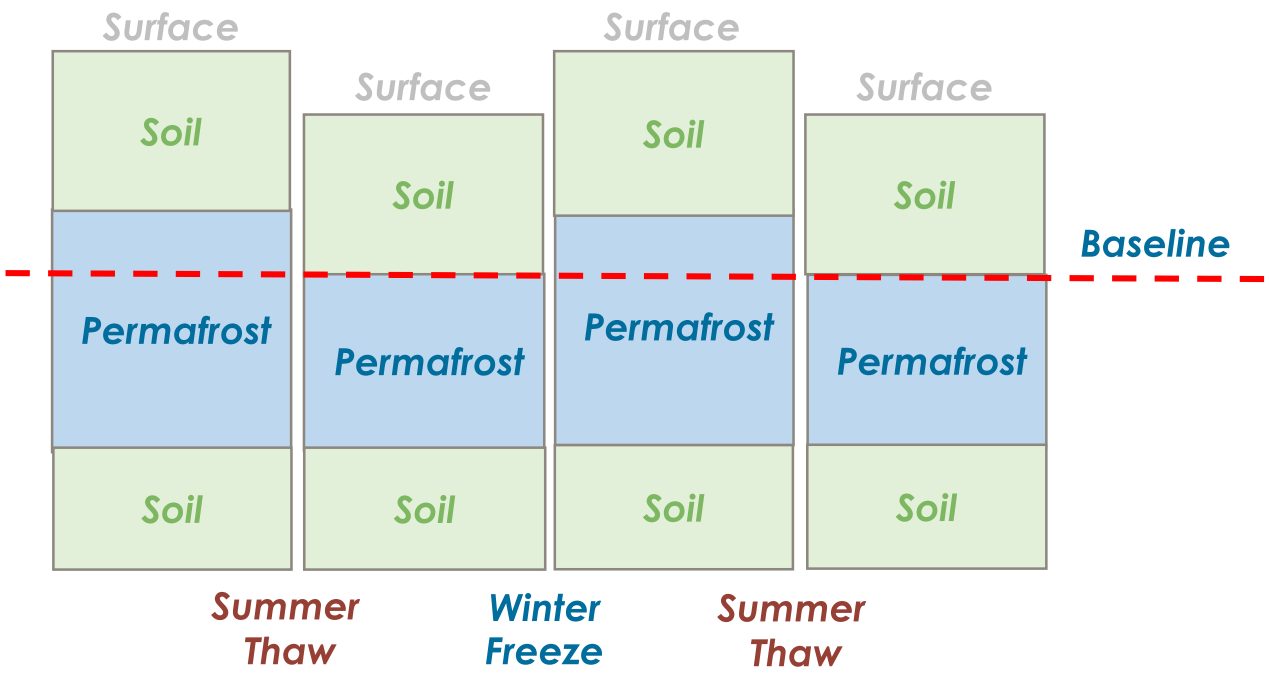


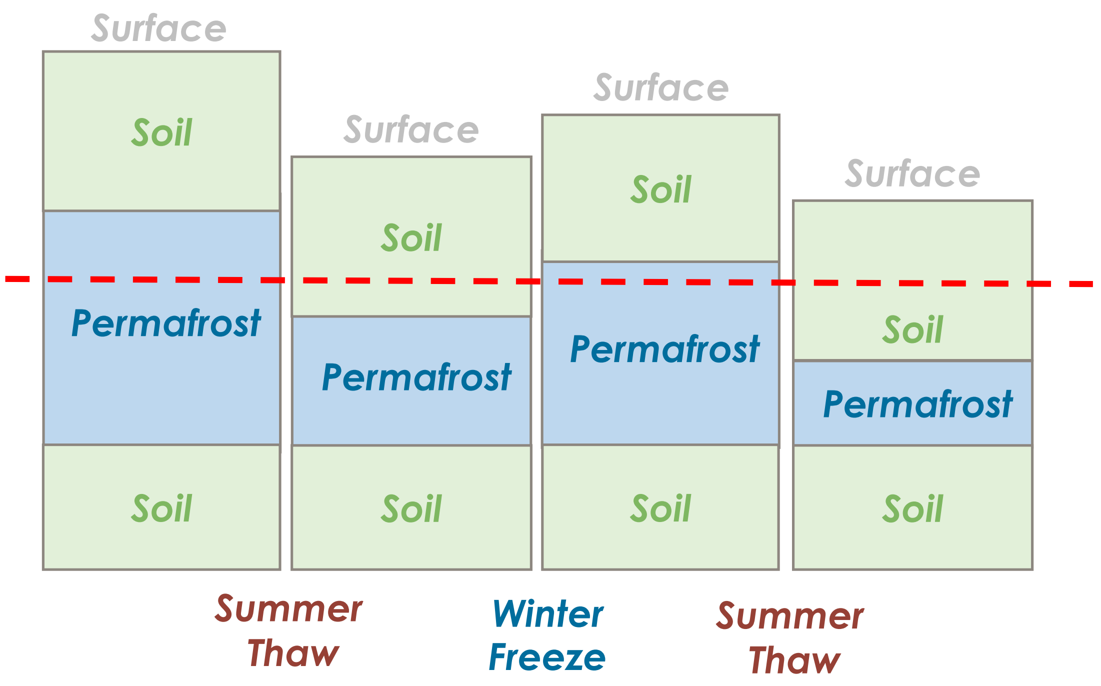
Credit: UAF Institute of Northern Engineering; ADNR, DGGS; NASA DEVELOP

Background: Permafrost Deformation

SEASONAL THAW: thaws a similar amount in summer and freezes in winter, causing **surface rebound**

LONG-TERM THAW: thaws more in summer and freezes less in winter, causing **surface subsidence**





Community Concerns

- **Economic impacts**
  - Structural damage of private and public property
  - Structural damage to infrastructure including roads, bridges, and oil & gas pipelines
- **Environmental impacts**
  - Slope instabilities; release of greenhouses from organic-rich soils
  - Destabilization of critical infrastructure posing an environmental hazard (oil and gas pipeline spills, etc.)

Credit: United States Geological Survey

Credit: National Park Service

Current Monitoring Techniques

- **Ground-based geologic investigations**
  - Expensive and time consuming
  - Remote permafrost thaw areas are logistically challenging to survey
  - Permafrost thaw areas are often identified after damage is evident
- **Limited satellite data incorporation**
  - Project partners use some remote sensing techniques on a project-by-project basis

Credit: Thomas A. Douglas, U.S. Army Cold Regions Research and Engineering Laboratory

Project Partners

- **US Army Corps of Engineers, Cold Regions Research & Engineering Laboratory** (CRREL)
- **Alaska Department of Transportation & Public Facilities** (ADOT & PF)
- **Alaska Department of Natural Resources** (ADNR)
- **Alaska Satellite Facility** (ASF)

Credit: Pixabay

Credit: James Pack

Project Objectives

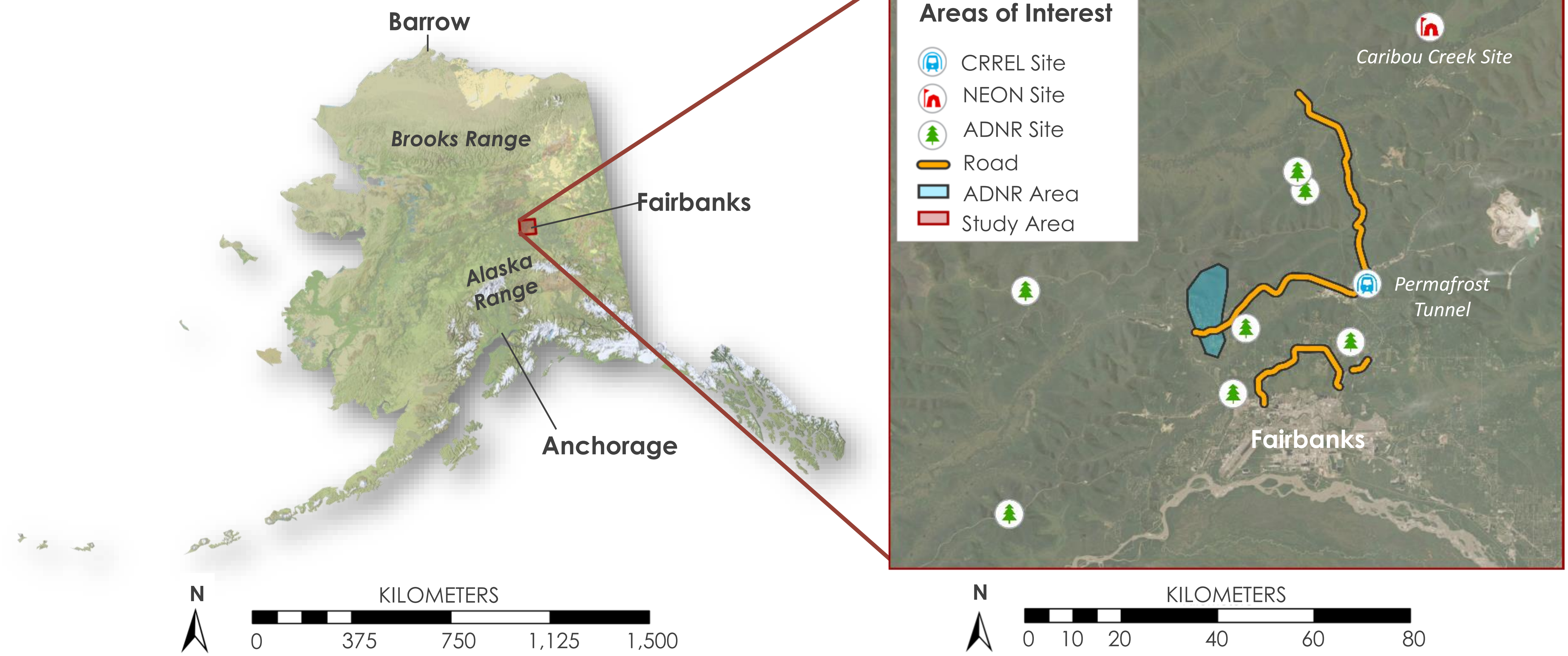
- **DETECT** permafrost subsidence and thermokarst formation
- **IDENTIFY** road & infrastructure vulnerability

- **CREATE** an InSAR processing module *(PerMA)*
- **EVALUATE** the feasibility & accuracy of using InSAR to detect permafrost thaw

Credit from top to bottom: Thomas A. Douglas, U.S. Army Cold Regions Research and Engineering Laboratory; K.P. Marcin

Study Area: Fairbanks, AK

Study Period: 2017 – 2020



Credit (left): Esri, USGS

Credit (right): Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA,

Study Area: Objectives

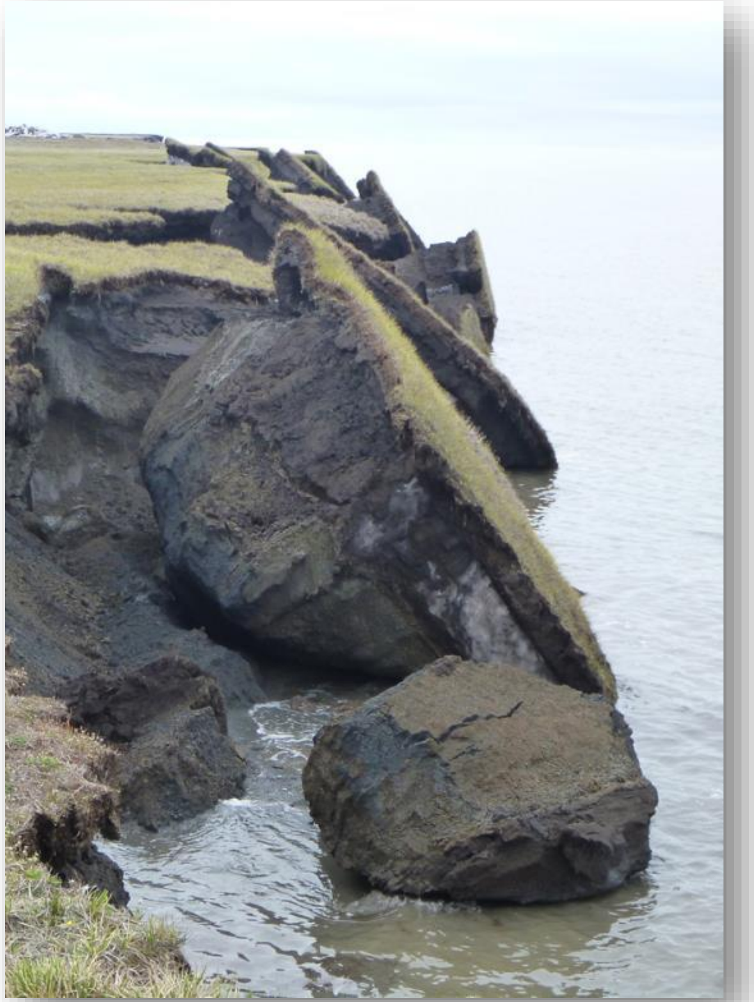
TRANSPORTATION

Credit: T. Douglas (CRREL)

INFRASTRUCTURE

Credit from top to bottom: Jeffery Fox (USGS); Thomas A. Douglas, U.S. Army Cold Regions Research and Engineering

RESEARCH



Credit: United States Geological Survey

Satellites & Sensors

Sentinel-1 C-SAR

Level-1 Single Look Complex Interferograms

Credit: Rama, 2012

NASA Gulfstream III UAVSAR

L-Band Ground-Based Unwrapped Interferograms

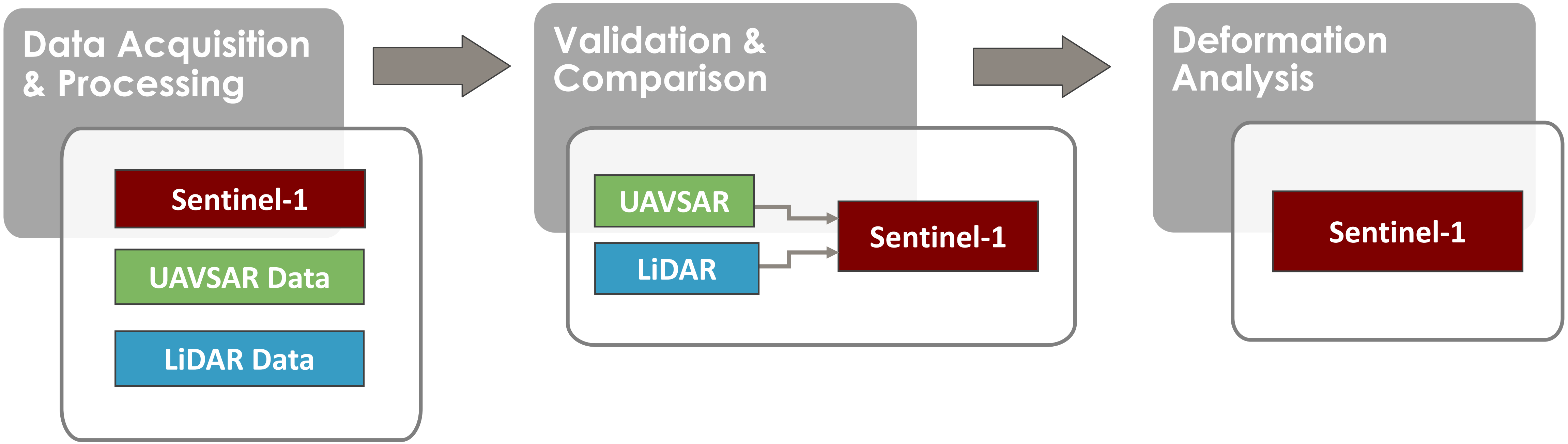
Credit: NASA Jet Propulsion Laboratory

Airborne LiDAR

Digital Elevation Model (DSM/DTM)

Credit: John Davies, 2004

Methods: Overview



Methods: Sentinel-1 C-SAR Processing

HyP3 → OpenSARLab → GIAnT

HyP3 — Create Interferograms

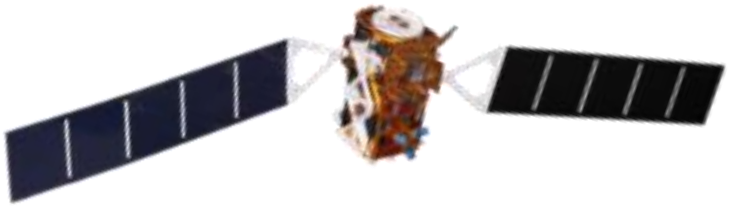
- 4 Co-register of C-SAR SLC Stack
- 4 Computation of Interferograms
- 4 Topographic-related phase removal
- 4 Conduct Adaptive Phase Filtering & Multi-look
- 4 Undergo Phase Unwrapping
- 4 Terrain Geo-coding

OpenSARLab — Pre-Processing

- 4 Subset Areas of Interest
- 4 Cull Data According to Timeframe and Orbital Characteristics
- 4 Correct for Atmospheric Noise Present in the Data

GIAnT — Time Series Analysis

- 4 Create Ancillary Files and Functions
- 4 Reformat Interferograms
- 4 Run GIAnT



HyP3: *Hybrid Pluggable Processing Pipeline*
GIAnT: *Generic InSAR Analysis Toolbox*

Credit: Rama, 2012

Methods: UAVSAR Processing

JPL → Python & GIS → GIS

JPL
Data Acquisition

Processing Mode: InSAR Pair

Type: L-Band

Polarization: HHHH

Ground Range Multi-Looked Products *(.GRD)*

4 Interferogram
4 Unwrapped phase
4 Coherence
4 Amplitude 1 (range)
4 Amplitude 2 (azimuth)
4 DEM
4 Metadata file

Python & GIS
Pre-Processing

4 Build ENVI header (.HDR) file

4 Build Symbolic Image (.IMG) file

4 Convert Ground Range Deformation Products (.GRD) into TIFF Raster Datasets

4 Resample Raster Cell Size to Uniform Scale for Validation

GIS
Data Analysis

4 Create Line of Sight Deformation Map Products through Raster Calculation

4 Deformation Analysis

Credit: NASA Jet Propulsion Laboratory

Methods: LiDAR Processing

USGS & NEON

Data Acquisition

Obtain Bare Earth Terrain DTM Products from Various Organizations, including:

- United States Geological Survey
- National Ecological Observatory Network
- Cold Regions Research & Engineering Laboratory
- NASA Arctic Boreal and Vulnerability Experiment

Credit: John Davies, 2004

GIS

Pre-Processing

- Georeference & Reproject Datasets
- Mosaic Raster Datasets
- Resample Raster Cell Size to Uniform Scale for Validation

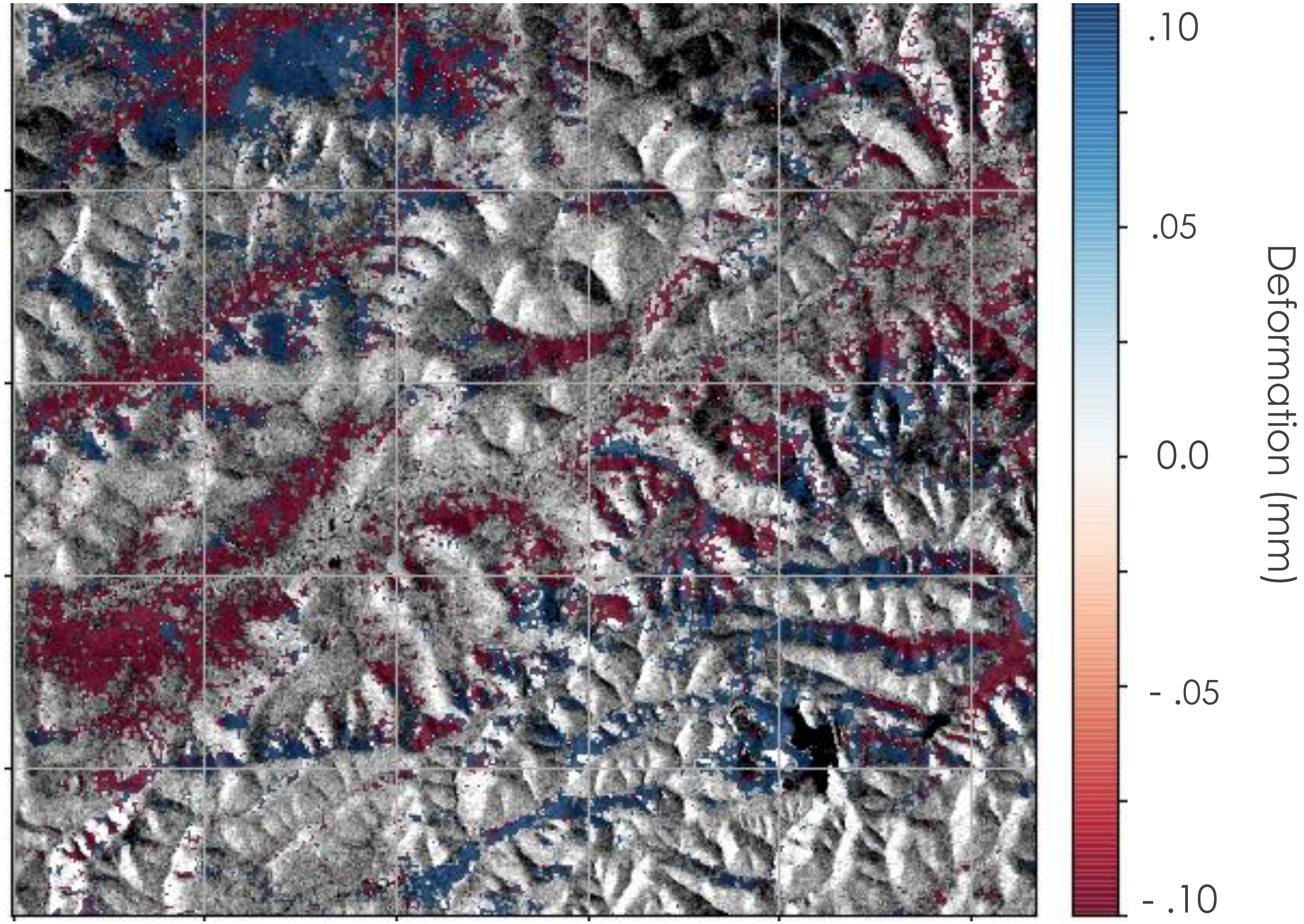
Data Analysis

- Create Deformation Maps
- Conduct Time Series Analysis
- Complete UAVSAR & C-SAR Validation

Methods: Deformation Analysis

Sentinel-1

2017 May-Sept Deformation Near Caribou Creek



- Seasonal/Annual Deformation
- Identify Areas of Consistent Change
- Magnitude of Change
- Spatial & Temporal Patterns
- Basis for Risk Assessment

Methods: Cross-Platform Analysis

COMPARISON

UAVSAR

LiDAR

- Pairwise root mean square error
- Pairwise difference in difference
- Spatial correlation and covariance

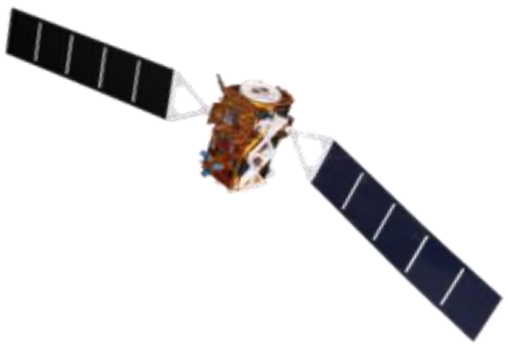
VALIDATION

UAVSAR

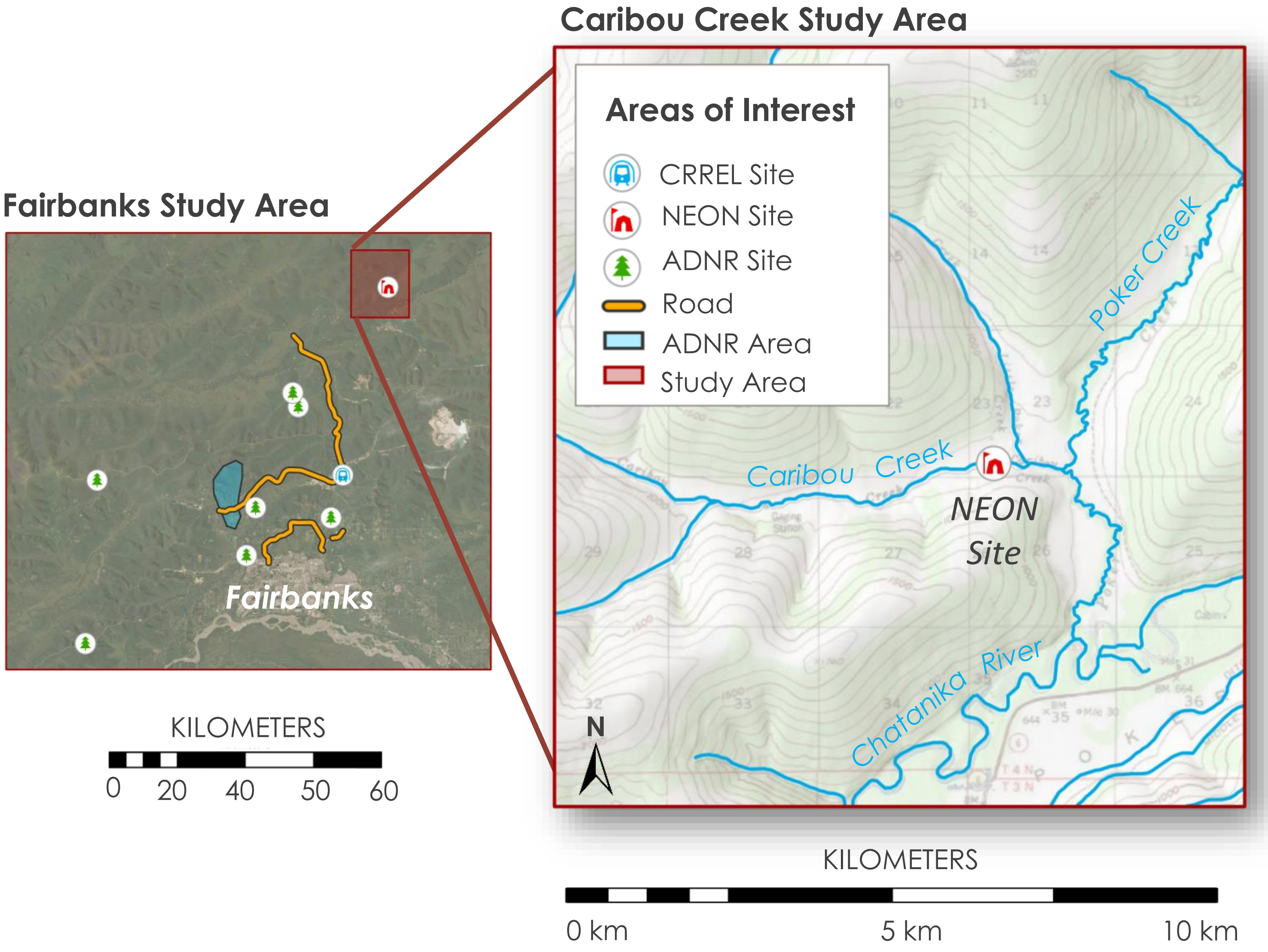
Sentinel-1

LiDAR

- Root mean square error
- Spatial Correlation
- Quantify the accuracy of satellite data to detect surface subsidence as compared to airborne sensors



Results



1. Deformation Analysis

Sentinel-1	UAVSAR	LiDAR
Sentinel-1	UAVSAR	LiDAR
Sentinel-1	UAVSAR	LiDAR

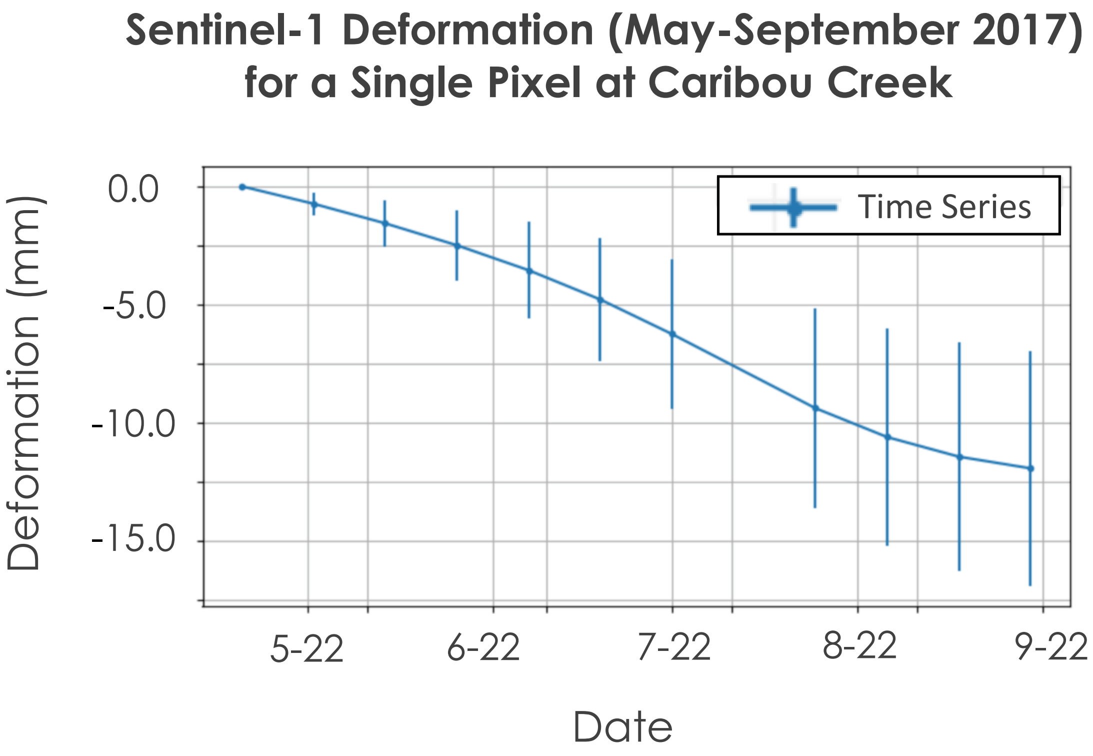
2. Cross-Platform Analysis

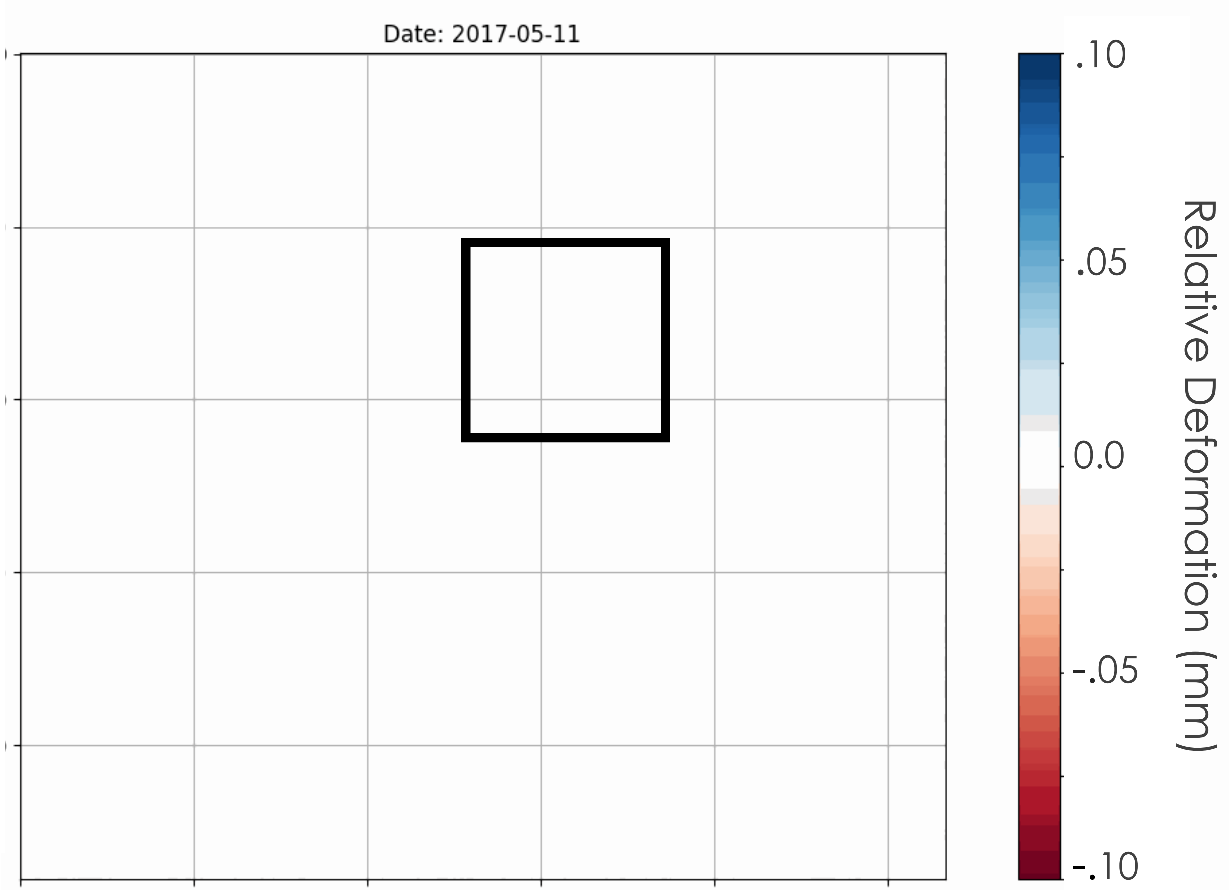
Sentinel-1	UAVSAR	LiDAR
Sentinel-1	UAVSAR	LiDAR
Sentinel-1	UAVSAR	LiDAR

Results: Sentinel-1

Caribou Creek

Sentinel-1 | UAVSAR | LiDAR



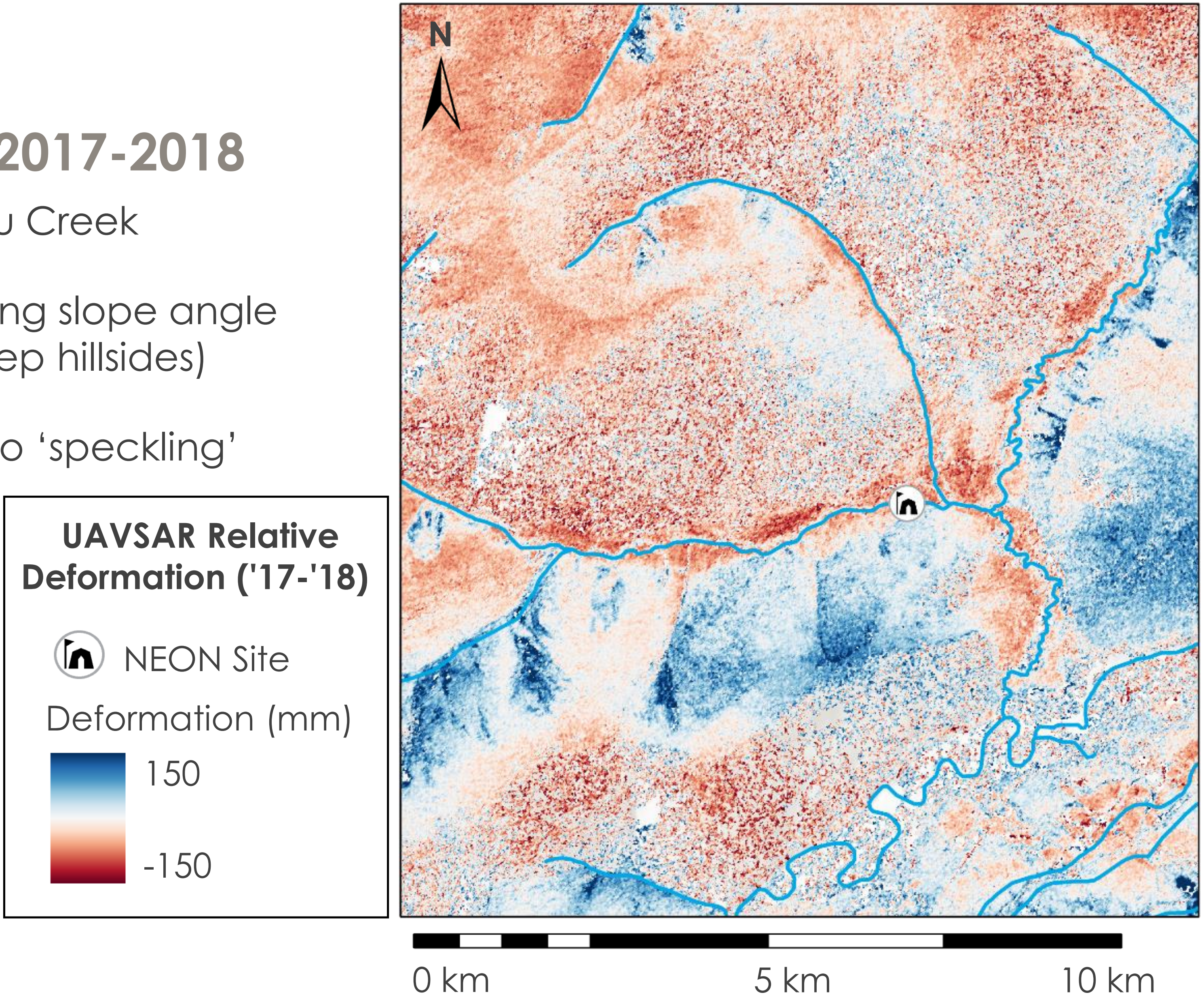


Results: UAVSAR

Caribou Creek

Sentinel-1 | UAVSAR | LiDAR

- **UAVSAR Deformation 2017-2018**
  - Area surrounding Caribou Creek
  - Notable deformation along slope angle gradients (riverbanks, steep hillsides)
  - Terrain complexity adds to 'speckling' effect in pixel variability

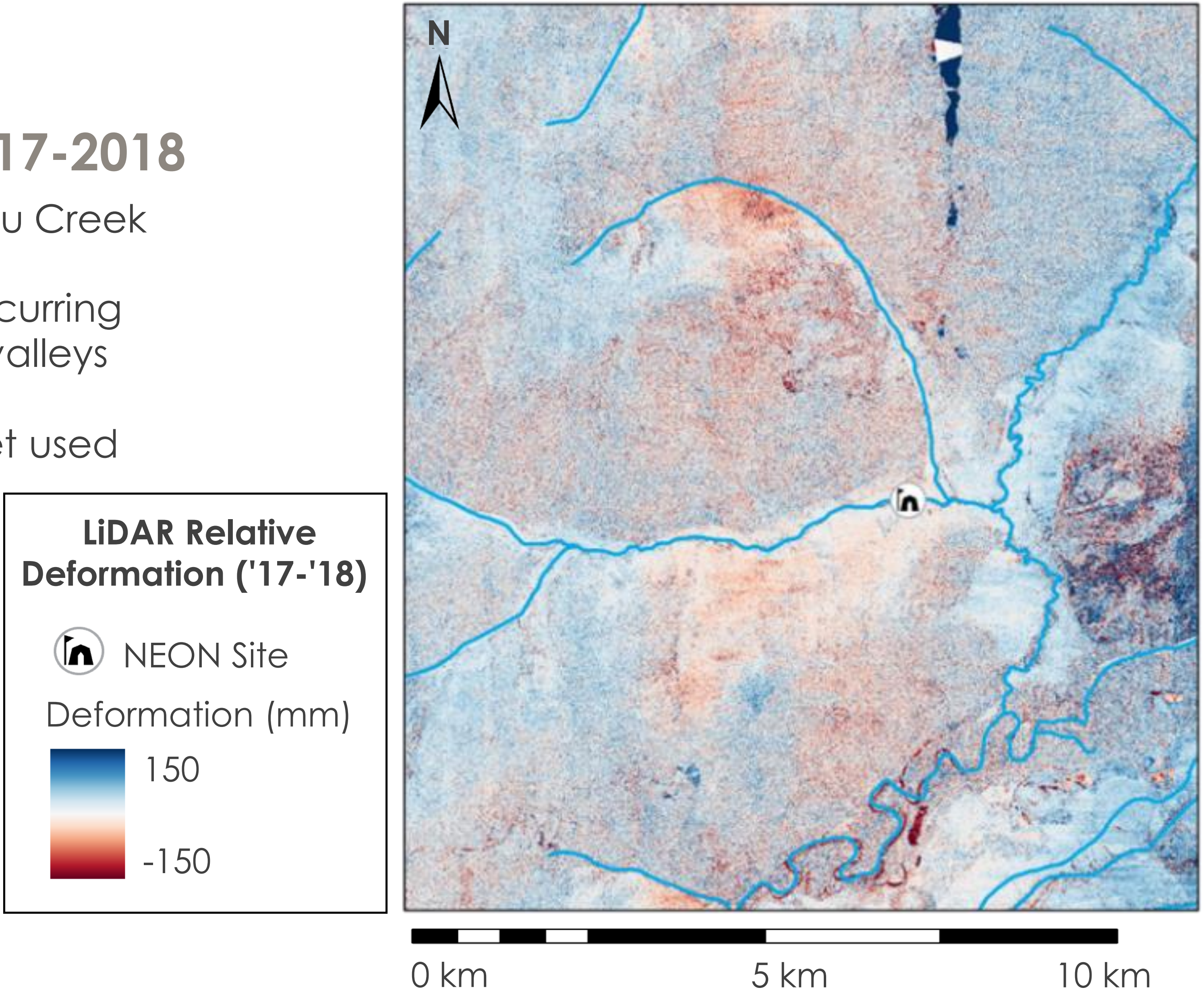


Results: LiDAR

Caribou Creek

Sentinel-1 | UAVSAR | LiDAR

- **LiDAR Deformation 2017-2018**
  - Area Surrounding Caribou Creek
  - Notable deformation occurring along riverbanks and in valleys
  - Highest resolution dataset used for baseline validation

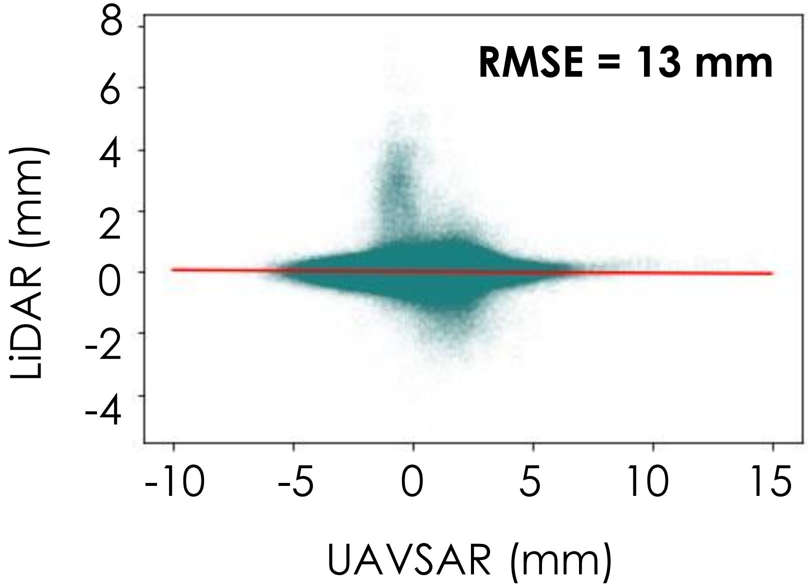


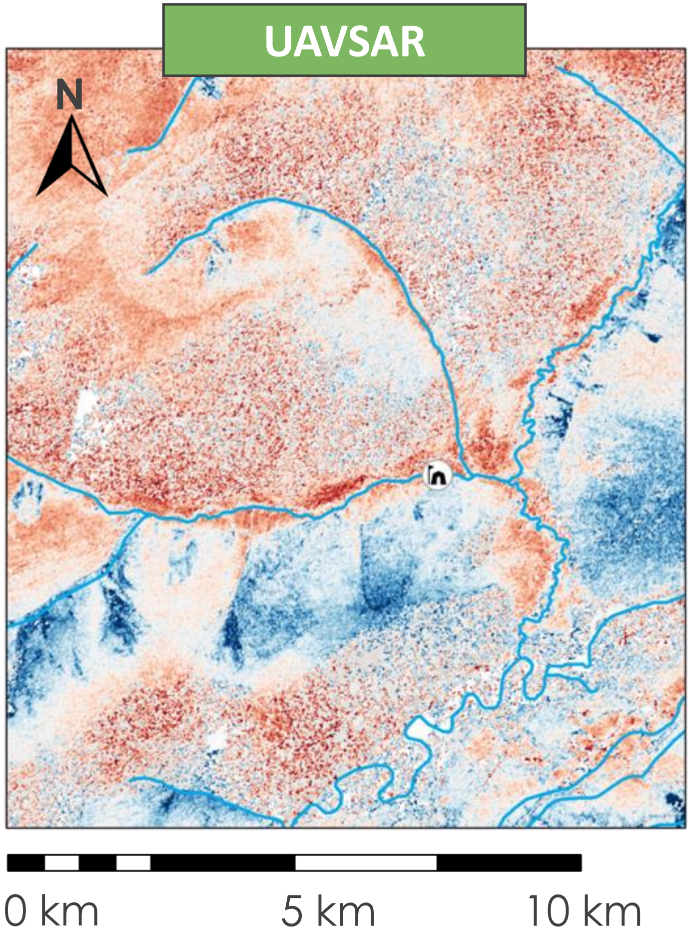
Results: Comparison

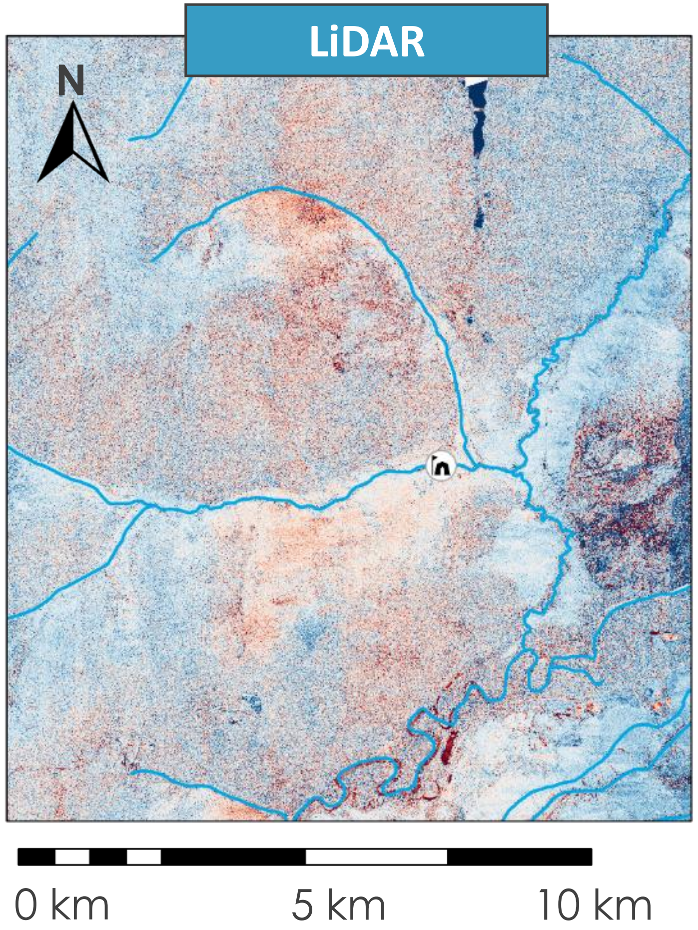
Caribou Creek

Sentinel-1 | UAVSAR | LiDAR

LiDAR vs. UAVSAR
Root Mean Square Error





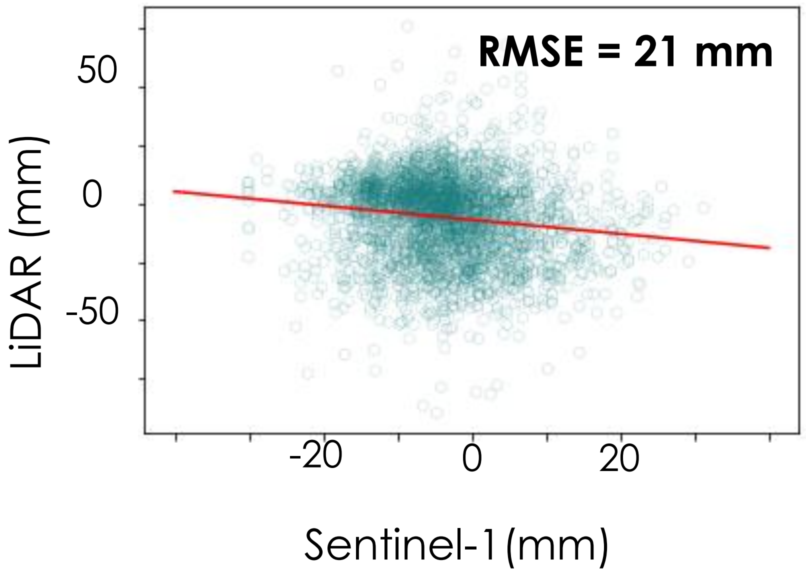


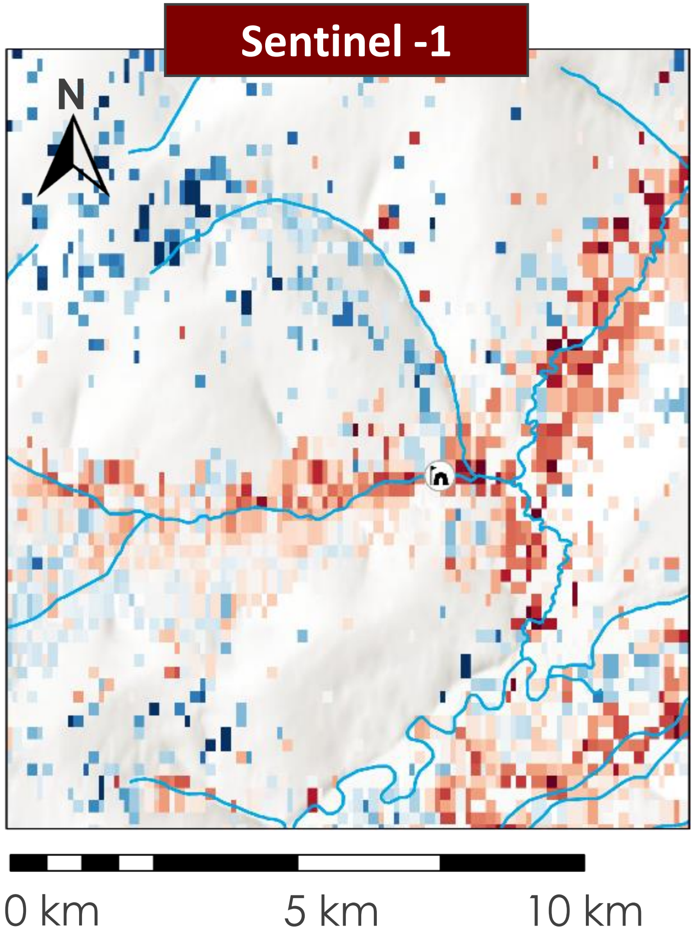
Results: Comparison

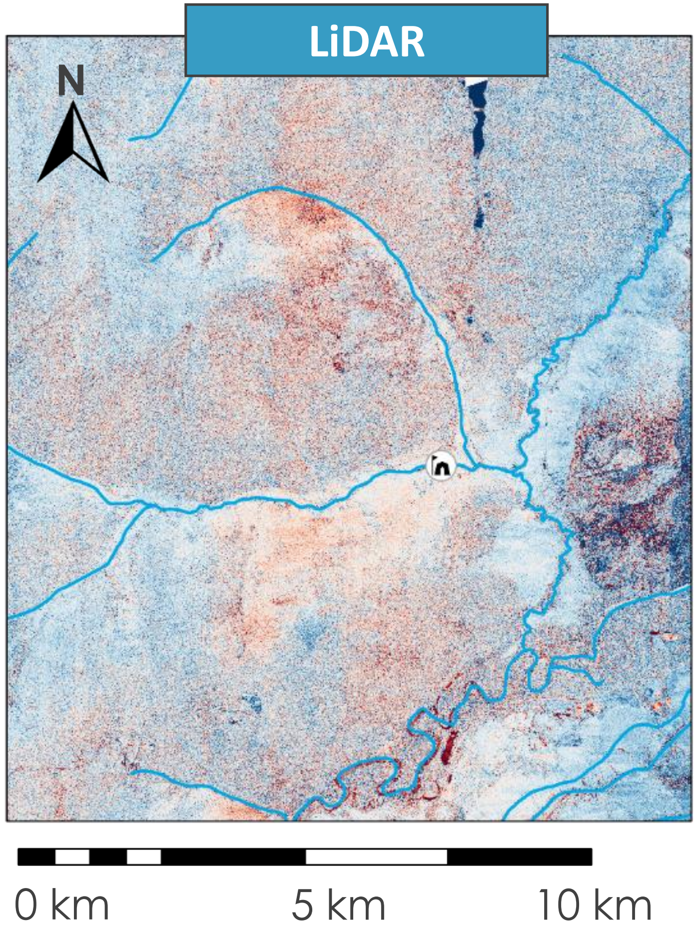
Caribou Creek

Sentinel-1 | UAVSAR | LiDAR

LiDAR vs. Sentinel-1
Root Mean Square Error

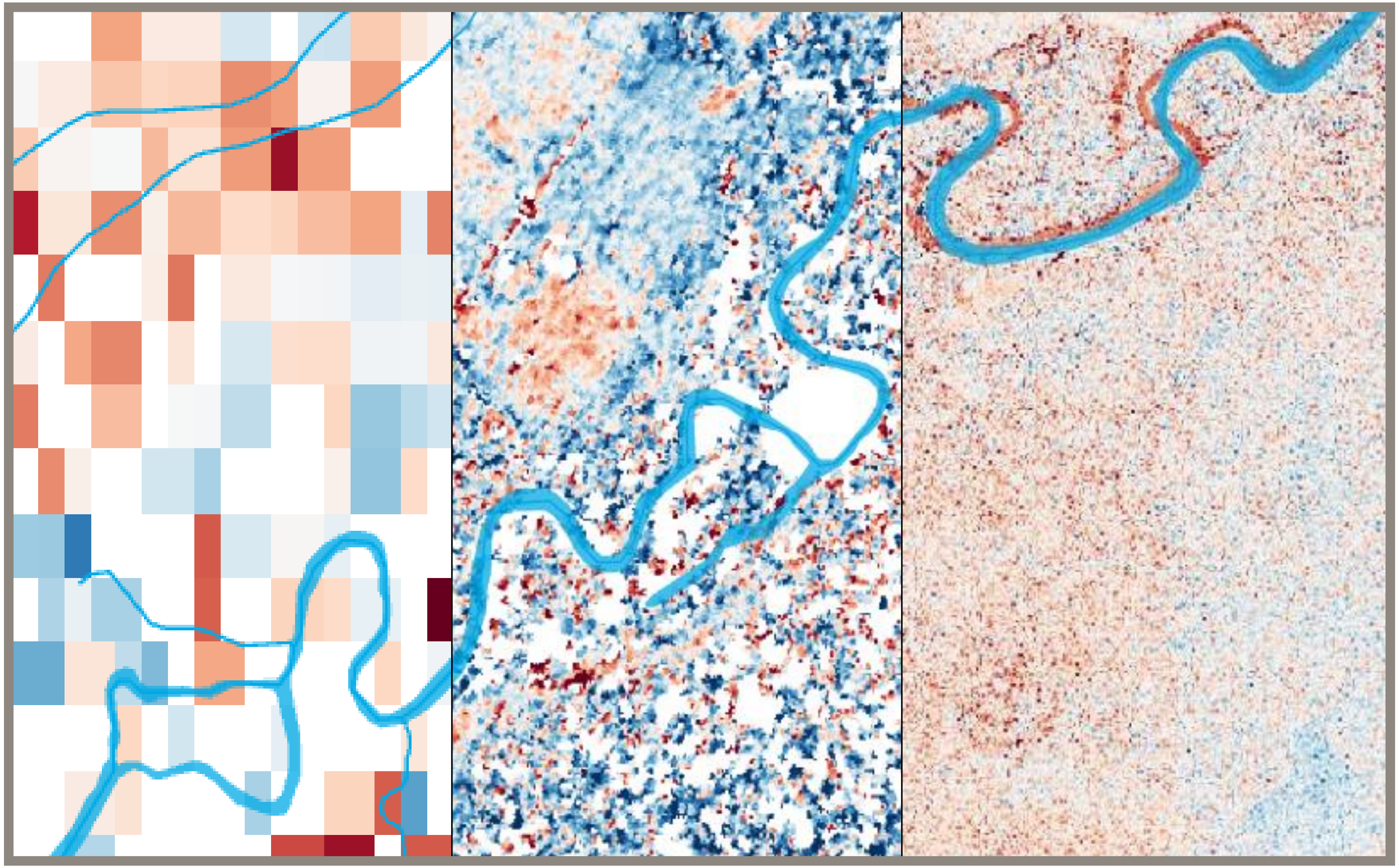






Results: Validation

Sentinel-1 | UAVSAR | LiDAR



Conclusions

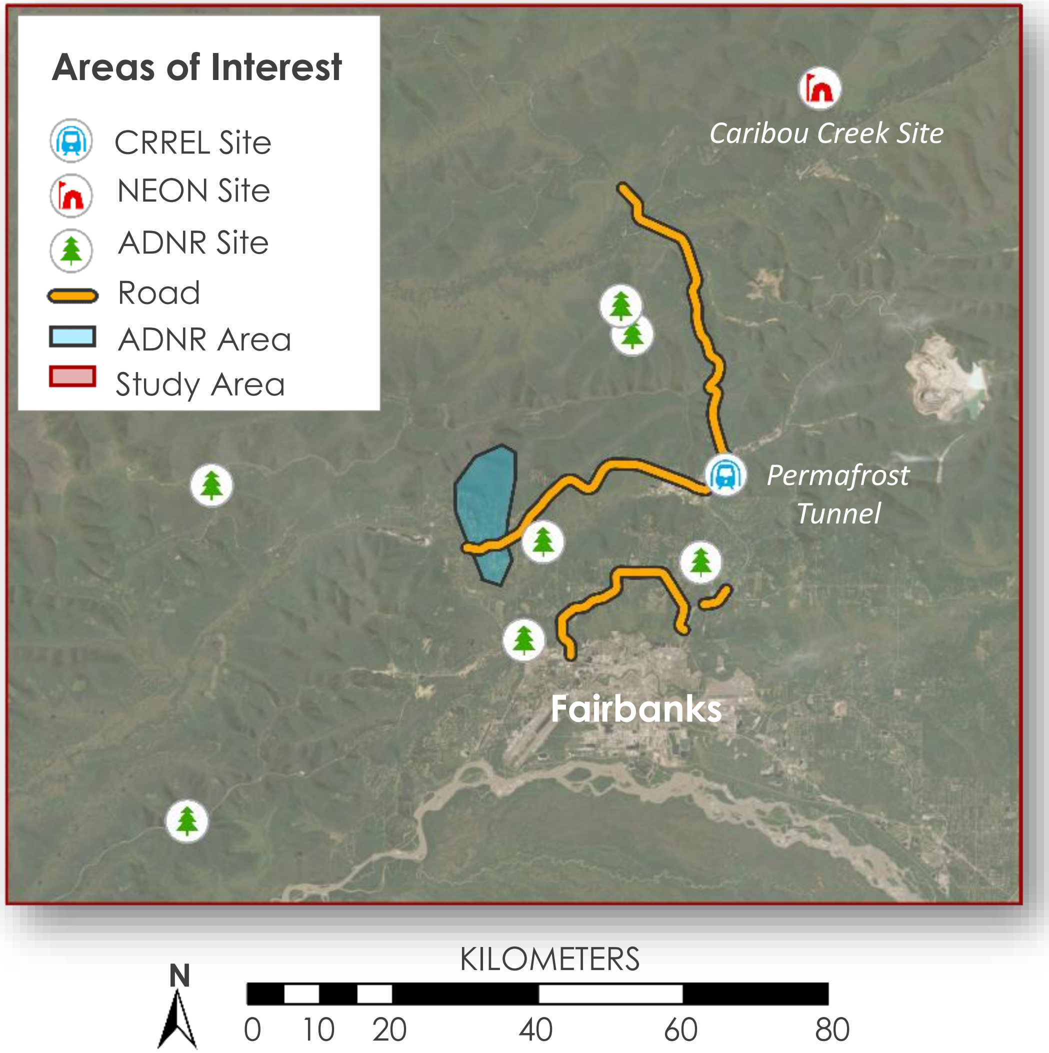
- UAVSAR
  - **RMSE of 13mm** compared to LiDAR
  - **Similar spatial patterns** and magnitude of deformation compared to LIDAR
  - **Higher resolution** imagery enables improved identification of deformation features
  - **Limited coverage** of UAVSAR compared to Sentinel-1 C-SAR

- Sentinel-1 C-SAR
  - **RMSE of 21mm** compared to LiDAR
  - **80m resolution limits** identification of deformation features

Credit: Jacqueline Schmid

Conclusions

- **Earth Observation**
  - Sentinel-1 C-SAR can be used to identify road & infrastructure vulnerability on a large scale
- **Project Partners**
  - Can identify and prioritize areas experiencing the highest intensity of permafrost deformation
  - The PerMA (Permafrost Measurement and Analysis) module can be used to automate processing and deformation detection of Sentinel-1, UAVSAR, and LiDAR



Credit (right): Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA,

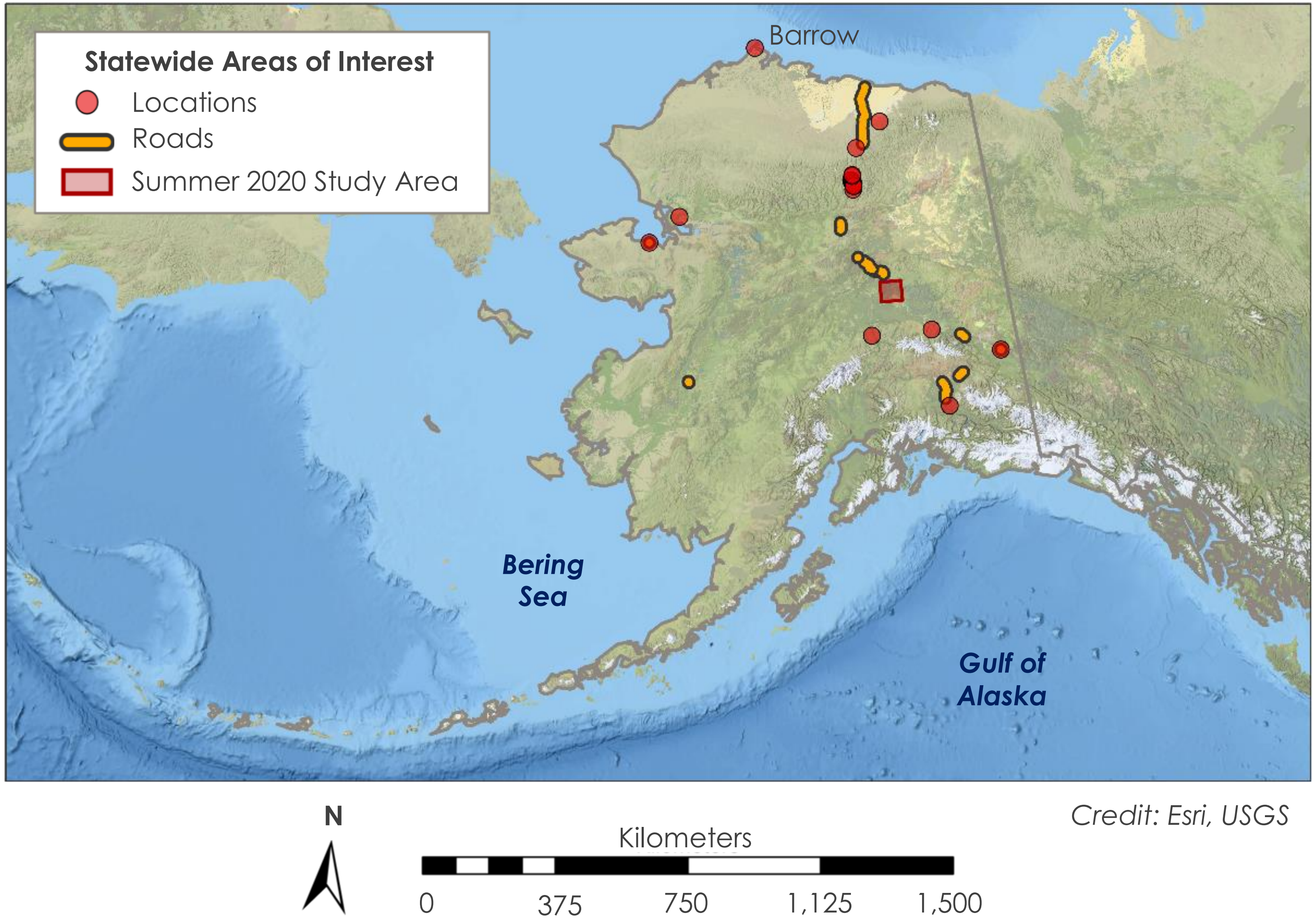
Limitations & Errors

- **LIMITATIONS**
  - Temporally & spatially sparse LiDAR
  - Temporally & spatially sparse UAVSAR
  - Unprocessed UAVSAR pairs
  - Upscaling raster data to sentinel scale
- **ERRORS**
  - Decorrelation of UAVSAR coverage over water features and forests
  - UAVSAR long range tilt in 2018 & 2019
  - Relative deformation vs. absolute deformation

Credit: Skitterphoto

Future Work

- **EXPAND** study to Areas Of Interest (AOI) beyond the Fairbanks region
- **FURTHER** comparison with additional repeat LiDAR
- **EXPAND** the automated InSAR, UAVSAR, LiDAR processing tool (PerMA)
- **STUDY** the effect of underlying geology and soil on permafrost thaw



Credit: Esri, USGS

ACKNOWLEDGEMENTS

DEVELOP

Advisors

- Dr. Bruce Chapman *(NASA Jet Propulsion Laboratory, California Institute of Technology)*
- Mr. Ben Holt *(NASA Jet Propulsion Laboratory, California Institute of Technology)*
- Mr. Cecil Byles *(NASA DEVELOP JPL Lead/Fellow)*

Project Partners

- Dr. Tom Douglas *(US Army Corps of Engineers, Cold Regions Research and Engineering Laboratory)*
- Dr. Chris Hiemstra *(US Army Corps of Engineers, Cold Regions Research and Engineering Laboratory)*
- Mr. Garrett Speeter *(Alaska Department of Transportation & Public Facilities)*
- Dr. Ronald Daanen *(Alaska Department of Natural Resources)*
- Dr. Franz Meyer *(Alaska Satellite Facility)*

Special Thanks

- Alex Lewandowski *(Alaska Satellite Facility)*
- Soumitra Sakhalkar *(University of Alaska Fairbanks)*

This material contains modified Copernicus Sentinel data (2017-2020), processed by ESA. UAVSAR data courtesy NASA/JPL-Caltech.

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