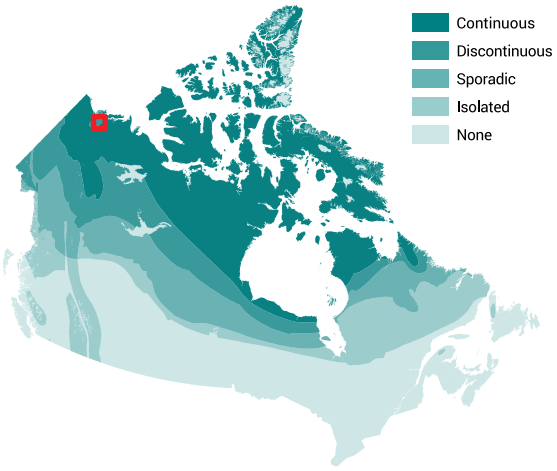
InSAR techniques for the permafrost environment



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Study locations: Inuvik, Northwest Territories

Keywords: Active-layer, monitoring, satellite, remote sensing, freeze-thaw cycle, snow cover.

This research evaluated the capabilities of InSAR (a satellite radar method for spotting small ground movements) processing techniques for monitoring permafrost active-layer dynamics in a tundra environment, using data from three different sensors validated against ground-truth measurements. While InSAR is a well-established technique, its application in northern regions remains challenging due to the scarcity of stable reference points (such as exposed bedrock and infrastructure) and the presence of persistent snow cover. This study identified both the strengths of InSAR in these conditions and the areas where further improvements are needed.

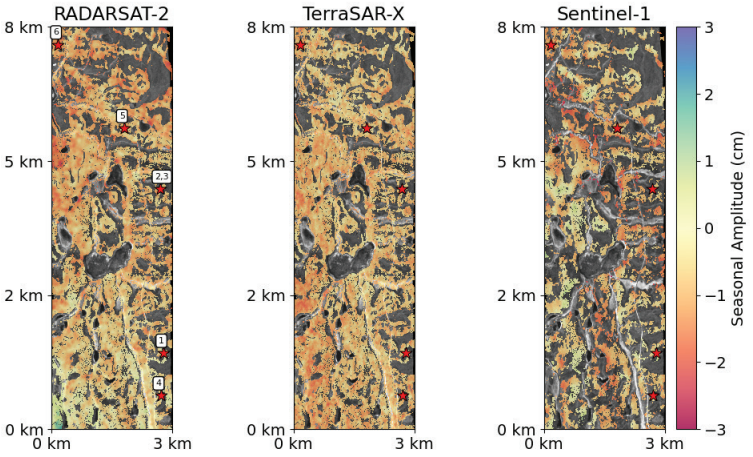

Figure 1. Seasonal amplitude maps (cm/year) as measured by three InSAR satellite sensors (Left) RADARSAT-2, C-Band, (Middle) TerraSAR-X, X-band, (Right) Sentinel-1, C-band.

Research summary

Rising temperatures can cause thickening of the active-layer (the top layer of the ground over permafrost that thaws in summer and freezes in winter), triggering ground subsidence and thermokarst, which can destabilize infrastructure and ecosystems. We investigated the challenge of comprehensive, year-round monitoring of the active-layer using Interferometric Synthetic Aperture Radar (InSAR), a remote sensing technique for detecting small surface changes. Seasonal and long-term trends in the Mackenzie Delta uplands were analyzed with C-band and X-band InSAR data, combined with corner reflector pairs either anchored in permafrost or surface-mounted. Field measurements of displacement (inclinometers) and snow depth (ultrasonic rangers) provided ground-truth validation and insight into the impact of snow cover.

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The study found that InSAR can measure surface changes from active-layer displacement, but current available spaceborne SAR sensors tend to underestimate larger subsidence rates (compared with in-situ data) due to decorrelation from snow-cover leading to long gaps in the data. InSAR showed potential for estimating Snow Water Equivalent (SWE); however, resolution and accuracy were insufficient to correct images to restore winter displacement trends. While incorporating winter data after correcting for snow-induced phase effects could advance continuous permafrost monitoring, reliability remains limited and is compounded by rapid, complex motion during thaw and freeze-back.

Taking action

Modeling of active-layer dynamics under thawing permafrost can be improved by integrating multi-sensor InSAR with ground observations. Necessary advancements include more robust phase unwrapping and modelling to handle freeze-thaw and snow effects, and new SAR sensors (e.g., NiSAR L-band, short-repeat constellations) to reduce phase ambiguities and capture large displacements. Combining detailed displacement and snow data in regional assessments will support more resilient infrastructure design and land-use planning in vulnerable permafrost regions.

Connections to other projects

2 This project is part of Theme 2 — *Monitoring of permafrost change and linked to other projects in the theme*.

Partners, team members and support

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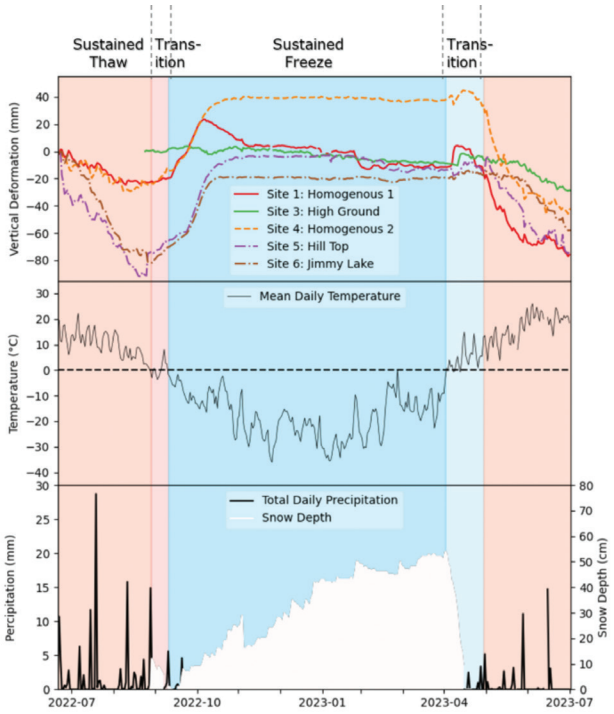

Figure 2. Field data demonstrating how rapid surface displacement in the 2022-2023 season coincides with the freezeback and thaw periods.

References

Plourde, A. (2024) '*Analysis of a topographic-based InSAR SWE estimation technique for low-land permafrost terrain north of Inuvik, Northwest Territories*', in Beddoe, R. and Karunaratne, K. (eds.) 12th International Conference on Permafrost Proceedings. 12th International Conference on Permafrost, 16-20 June 2024, Whitehorse, Yukon, Canada. Available at: https://doi.org/10.52381/ICOP2024.65.1

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