InSAR monitoring of a retrogressive thaw flow at Thunder River, lower Mackenzie

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ABSTRACT
In this study we analysed 55 RADARSAT 1 InSAR images acquired from August 2006-July 2010 to monitor deformation of permafrost slopes along the Mackenzie Valley Pipeline Corridor. Results from two corner reflectors installed near a landslide show a 10 and 20 cm motion from 2006-2010. Our InSAR measurement also shows that the lower steeper slope is moving faster than upper slope. This differential motion may be due to a combination of thaw depth, slope angle and ground moisture.

RÉSUMÉ
Cette étude porte sur l'analyse de 55 scènes RADARSAT-1 acquises d'août 2006 à juillet 2010 dans le but d'effectuer le suivi d'une déformation sur des pentes en terrain pergélisolé, le long du couloir de pipeline de la vallée du Mackenzie. L'analyse interférométrique de deux trièdres métalliques installés près d'un glissement de terrain montre des déplacements de 10 et 20 cm durant cette période. Par cette analyse, on estime également un taux de déplacement plus rapide sur la portion basse et plus abrupte que sur la partie supérieure de la pente. Cette variation de déplacement peut être causée par une combinaison de la profondeur du dégel, l'angle de la pente et l'humidité du sol.

1 INTRODUCTION

Radar interferometry (InSAR) techniques using images from several radar satellites are increasingly being used in slope stability assessment as documented by Singhroy (2008), Singhroy and Molch (2004). Froese et al. (2008) and others. Our research has shown that interferometric SAR techniques can be used to monitor permafrost slopes in sub-arctic regions of Canada.

Recently, landslide mapping triggered by permafrost degradation within the Mackenzie Valley has received extensive investigation by Alysworth et al. (2000), Couture and Riopel (2008a, b) and Dyke and Brooks (2000) and others. There is current need for detailed baseline terrain and surficial geological mapping, including landslide inventory and activity before the construction of the proposed Mackenzie Valley pipeline. The 1300 km pipeline is aimed at delivering natural gas to markets in southern Canada and United States.

There are approximately 2,000 landslides along the proposed pipeline route (Alysworth et al. 2000). The Mackenzie Valley is experiencing one of the highest rises in mean annual temperature for any region in Canada, thereby triggering melting in the permafrost and subsequent landslide activity. In areas where the thin forest cover is burned by wildfires, landslide activity and permafrost melt can be accelerated (Dyke 2000). Therefore the monitoring of active slopes using InSAR techniques will be useful once the pipeline is constructed.

2 Study Area

Our investigation focuses on the Thunder River pilot site (TTPS) that is situated on both sides of an East-West striking valley adjacent to the Thunder River Valley at the confluent of the Mackenzie River about 140 km southeast of Inuvik, Northwest Territories (Figure 1). This site is in the vicinity of a proposed natural gas pipeline route from the Mackenzie Delta to Alberta. It was part of a study area (Mackenzie Valley Study Area-MVSA) subjected to landslide inventorying and susceptibility mapping (Couture&Riopel,2008a).

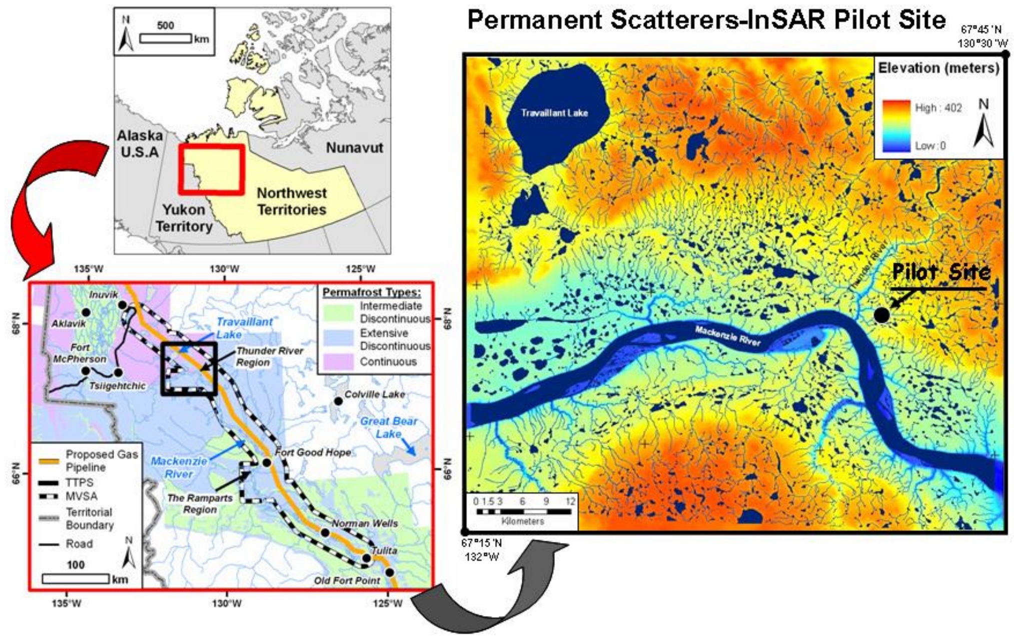

Figure 1. Location map illustrating the study area and the pilot site (black dot) for the application of coherent target InSAR. TTPS: Travaillant Lake-Thunder River Pilot Site, MVSA: Mackenzie Valley Study Area (from Couture et al. 2007).

The selected site offers a wide variety of terrains in terms of permafrost conditions, surficial geology, relief and slope, vegetation, and is known for widespread landsliding. The unconsolidated sediments are dominated by morainal and lacustrine deposits (Aylsworth *et al.* 2000a). Three types of permafrost are encountered, i.e. continuous (90 – 100% occurrence), extensive discontinuous (65 – 90% occurrence), and intermediate discontinuous (35 – 65% occurrence) (Heginbottom & Radburn 1992). The permafrost thickness can be as deep as 200m (Wolfe, 1998) with an active layer depth varying from around 30 cm (plateaus and north facing slopes) to more than 2 m in remoulded terrains and south facing slopes. The vegetation cover is dominated by sparse to open coniferous forest, shrub land (low and tall), and exposed land (Cihlar & Beaubien 1998; Ritchie 1984; Wulder and Cranny 2005). The area experienced a large forest fires in 1986 that burnt the entire pilot site. The relief is dominated by the east-west striking valley bearing an unnamed creek flowing westward. The lowermost parts of valley walls are generally steep with slope angle around 20° and even more locally, whereas upper parts of slopes are moderate with angles usually varying between 5 and 10°.

The pilot site is characterized by cold winters (-27.6°C, daily average) with low precipitation (13.8 mm, total precipitation) and relatively warm summers (14.2°C, daily average) with moderate precipitation (33.2 mm, total precipitation) (Inuvik Weather Station, January and July months, Environment Canada 2004). The prevailing wind direction is commonly south-southwest with mean monthly wind speeds up to 10km/h in spring. Winters are characterized by a very small number of hours of sun illumination, i.e. less than 6 hours from December to February. From May to July, the number of hours during which the sun is above the horizon varies from 15 to 24 hours (Dyke 2000).

Valley slopes, especially those facing south, are subjected to landsliding activity (Figure 2). Numerous types of landslide have been mapped in the study area, including retrogressive thaw flows and slides (Figure 3), active layer detachments and debris flows (Couture & Riopel 2008a, b). Some of them are still active and have shown reactivation in the last few years. Initial slope failures generally occur on steep parts of slopes and subsequently retrogress and extend laterally on plateaus or low angle slopes through series of multiple retrogressive failures.

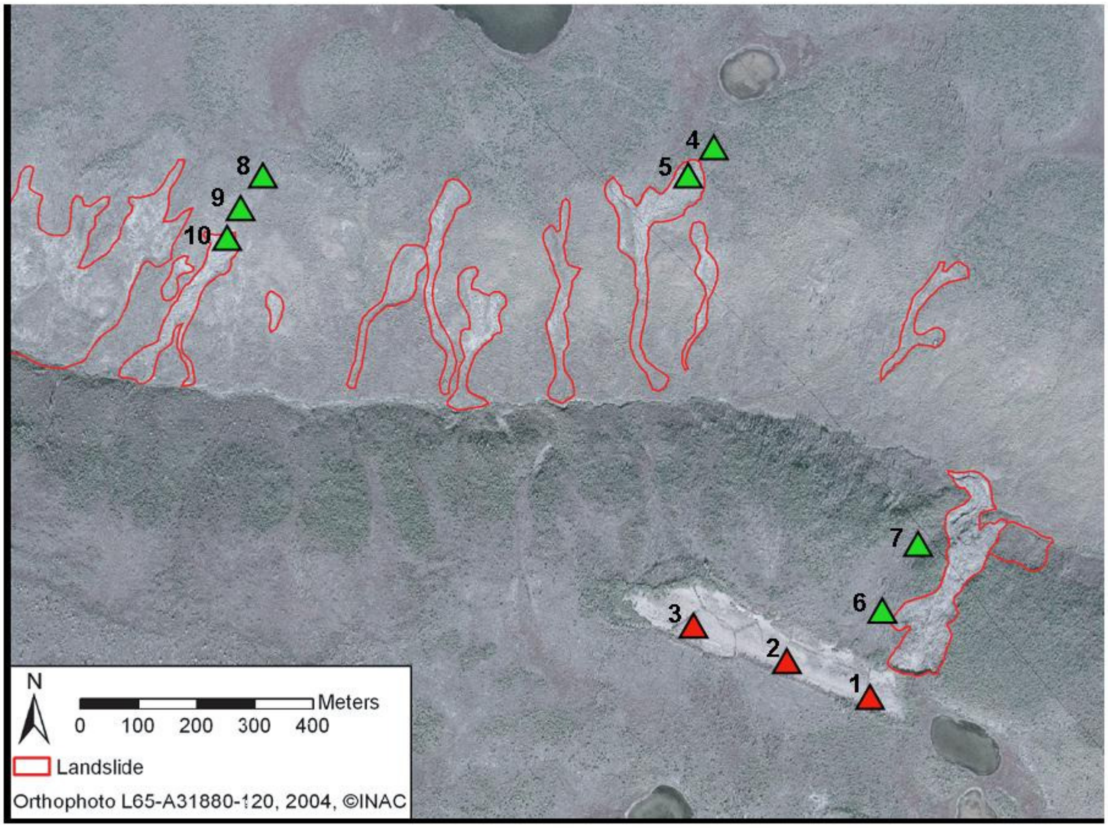

Figure 2. Location of reference or stable (red triangles) and active corner reflectors (green triangles) at the pilot site in the vicinity of Thunder River valley, Northwest Territories (from Couture et al. 2007).

3 Corner Reflectors

Ten corner reflectors were installed at the Thunder River pilot site during the summer of 2006. Corner reflectors are installed at these remote sites because the vegetation cover decorrelates the radar signals which make InSAR measurements difficult. The corner reflectors provide a precise reflector target that can be monitored by radar interferometry.

Three reference corner reflectors (stable targets) have been installed about 100 m apart along an abandoned airstrip on stable ground made of frozen sandy and gravely fluvio-glacial deposits (red triangles in Figure 2).

A total of seven corner reflectors have been installed in the vicinity of three landslide sites within the pilot site (green triangles in Figure 2). Reflectors 6 & 7 seen in Figures 2 and 3) have been installed at an active landslide site which is situated immediately next to an abandoned airstrip. This landslide occurred several years ago on a north-facing slope and was partially reactivated in summer 2006.

The location of the corner reflectors were surveyed with GPS immediately after installation (Couture et al. 2007).

Figure 3: Reactivated retrogressive thaw flow, Thunder River, and location of corner reflectors

4 InSAR Processing

For this study, we are reporting on the three reflectors (CR3, CR6, CR7) located on permafrost slopes adjacent to a landslide. Corner reflector 3 is the stable reference reflector on the corner of the airstrip. Reflectors 6 and 7 are unstable and their line of site displacement is calibrated relative to the reference reflector 3. InSAR measurements of the other reflectors at the Thunder River pilot site will be reported later. RADARSAT InSAR images were acquired from August 2006 to July 2010 over the Thunder River test site. Data are acquired using RADARSAT-1 using mode F4F starting August 2, 2006 and repeating every 24 days. Currently there have been 55 acquisitions. The products were ordered as raw signal data. All processing was done using GAMMA Remote Sensing software. All the raw signal data was processed to Single Look Complex (SLC) products using an average Doppler polynomial and autofocus. The baselines were evaluated to choose August 10, 2009 as the reference product since it occurs during the summer and produces an average perpendicular baseline of 63 m. All the SLCs were re-sampled to the reference product using a 3rd degree polynomial derived from image intensity correlation. A 30 m posting DEM generated from air photos was used to geocode the products and apply topographic correction. Multi-reference baselines of 24, 48, and 72 days were used to generate interferograms. The interferograms were adaptively filtered and then unwrapped using minimum cost flow analysis. The baselines were refined using the interferograms and then recalculated. The corner reflectors coordinates were manual recorded from an average detected image. The interferogram data for the corner reflectors was extracted into a point table. The point table was unwrapped and then the phase time series was calculated. Ambiguity errors were manually removed from the results and a moving window smoothing was applied to produce the results shown in Figure 3

5 Discussion

Previous work by Alasset et al. (2008) has shown a maximum of 15mm displacement from May to July 2007 from simple differential InSAR technique in the Thunder River area. In this paper we provide a more complete picture of slope instability over a 4 year period from July 2006 to July 2010 using our corner reflector InSAR measurements.

We measure deformation of reflector 6 and 7 relative to the stable reference reflector 3 using RADARSAT InSAR techniques. Our InSAR results show that reflector 6, located on the upper 10°.slope, has moved downward 12 cm from July 2006 to July 2010 (Figure 4). This corresponds to 4 cm a year. Reflector 7 located at the lower and steeper 20°. slope moves about 20 cm from July 2006 to July 2010, which corresponds to 6 cm downward motion a year. This increase in the rates for reflector 7 is most likely due to increase slope steepness. Based on the differential motion of the different slope facets represented by reflector 6 and 7 respectively, there is a need to measure the exact thaw depth at the upper and lower parts of the slope. Future field campaigns may require GPR or probing techniques to estimate thaw depth to properly explain this difference in motion of the slope facets. It is also significant to note that reflector 7 has shown 10 cm displacement toward the satellite from July 2009 to July 2010. The influence of moisture or percentage of water in the uppermost layer of the ground should not be neglected. CR7 is sitting on extremely wet organic matter-dominated soils which make it more sensitive to seasonal frost and thaw than CR6 installed on dryer granular soils. On both reflectors there is a gradual motion varying from 4 to 6 cm a year. This is continuous throughout the year indicating that motion is not seasonal as expected.

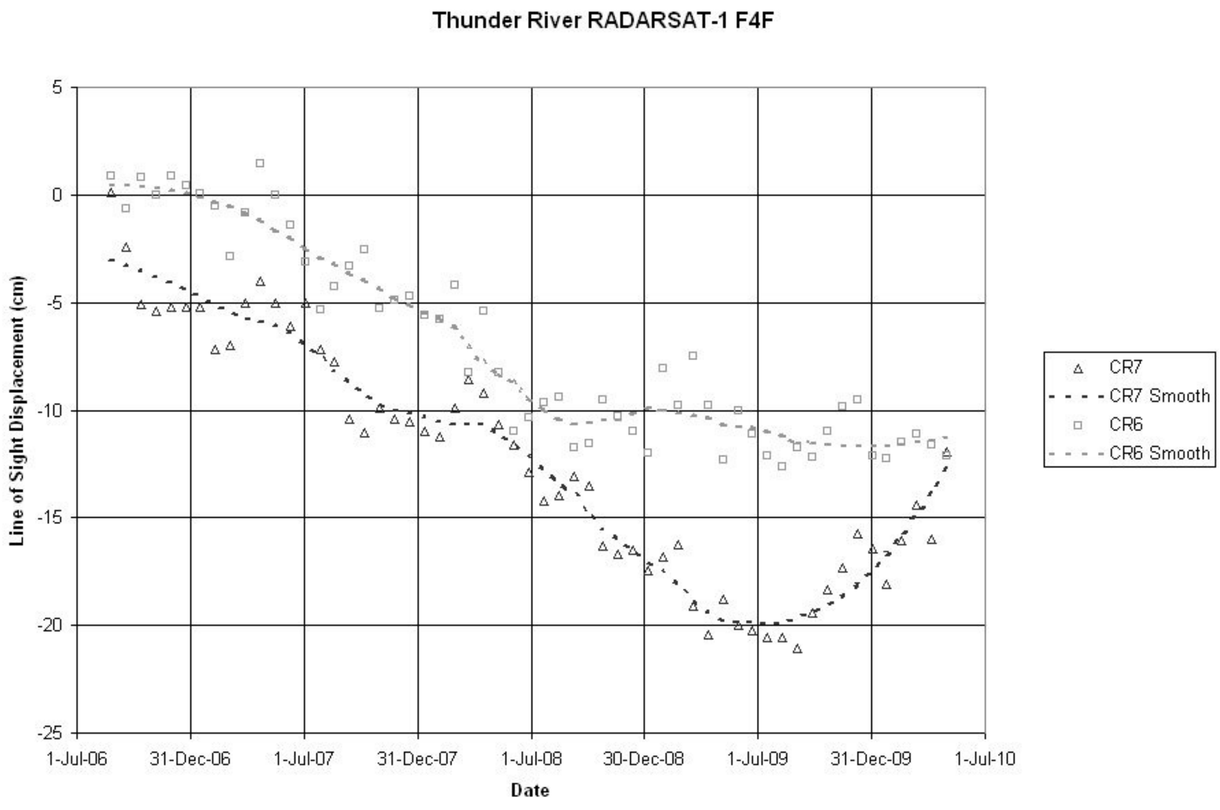

Figure 4: InSAR results of corner reflectors at Thunder River pilot site.

6 Conclusion

Our investigation has shown that InSAR techniques using corner reflectors can provide useful information on slope deformation in permafrost terrain. Results from two corner reflectors installed near a landslide show a 10 and 20 cm downward motion from 2006 to 2010. The movement occurred throughout the year with maximum in the summer months. Our InSAR measurements also show that the lower steeper slope is moving faster than the upper slope. This differential motion may be due to combination of slope angle, thaw depth, and ground moisture.

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