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COHERENT STACKS OF RADARSAT-2 SPOTLIGHT MODE INTERFEROMETRY DATA FOR MONITORING ARCTIC DEW LINE CLEAN-UP

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ABSTRACT

The DEW Line Clean-Up proof-of-concept project was conducted to determine if space-based Synthetic Aperture Radar (SAR) data from the Canadian satellite RADARSAT-2 can be used for landfill monitoring at the DEW Line sites. Interferometric stacks (time series consisting of interleaved 24-day cycles) of RADARSAT-2 Spotlight mode images are being acquired over four of the former DEW Line sites. Results show that amplitude change detection, coherent change detection and surface deformation products are useful for detecting change in and around landfills. Although these techniques cannot fully eliminate site visits and visual inspection, this study has shown that space-borne SAR can detect structural changes not yet evident to the field inspection teams and provide other useful information such as flooding. The RADARSAT Constellation Mission (RCM) with its four-day coherent repeat (scheduled for launch in 2018) will prove a great asset for monitoring the former DEW Line sites.

Index Terms— Synthetic aperture radar (SAR), DEW Line sites, Arctic site monitoring, change detection, interferometry, RADARSAT

1. INTRODUCTION

The Distant Early Warning (DEW) Line consists of a string of continental defence radars stretching from Alaska across the Canadian Arctic into Greenland (see Fig. 1). Completed in the 1950s, they are the product of the Cold War. Much of the equipment used to build and maintain the sites was abandoned or discarded on the landscape without regard to environment hazards they pose. By the 1990s the last of the DEW line sites were decommissioned or transformed into Long Range Radar Sites (LRRSs) for the North Warning System (NWS). The Canadian Department of National Defence (DND) has cleaned up and remediated the environmental hazards left behind [1]. This clean-up and continued site monitoring is managed by the DEW Line Clean-Up (DLCU) Project Office.

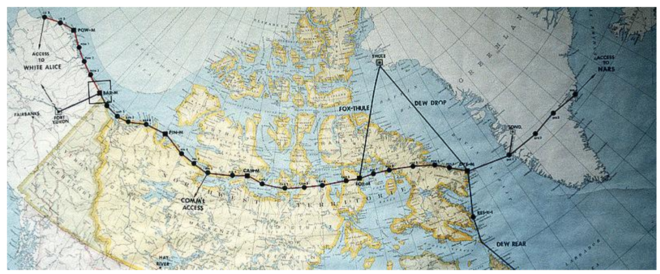

Fig. 1. DEW Line stretches across Canadian Arctic from Alaska to Greenland and (from Wikipedia).

In the spring of 2012, the DEW Line Clean-Up (DLCU) proof-of-concept project was initiated to determine if space-based Synthetic Aperture Radar (SAR) data could be used for landfill monitoring at these DEW Line sites. Of specific interest was the ability to detect landfill changes such as structural flaws (e.g., cracks in the surface or sides), differential settlement, depressions, water ponding and other events such as slumping, cracking, frost-related activities, animal burrows, human alterations and evidence of permafrost melt around the landfills. The DLCU proof-of-concept project was led by the Canadian Armed Forces (CAF) Mapping and Charting Establishment (MCE; Ottawa) with DRDC Ottawa collecting, processing and analysing the SAR data.

2. SELECTION OF DEW LINE STUDY SITES

Four DEW Line sites were selected for the further study. The four sites were representative of the geographic, topographic, and ecological diversity of the sites throughout the Canadian Arctic. They were also representative of the different types of facilities, and different remediation tactics and stages being employed. The sites included BAR-2 at Shingle Point in Yukon coast, Northwest Territories (NT); CAM-M at Cambridge Bay in Victoria Island, Nunavut (NU); DYE-M at Cape Dyer in Baffin Island, NU; and FOX-5 at Broughton Island, NU.

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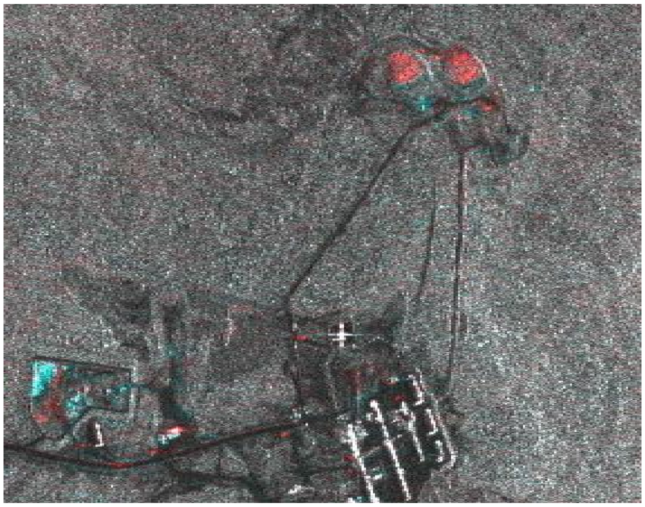

Fig. 2. Combining the radar backscatter from 4 July 2012 in red and 21 August 2012 in cyan highlights the change due to demolition of two large antennae at DYE-M. RADARSAT-2 Data and Products ©MacDonald, Dettwiler and Associates Ltd. (2012) - All Rights Reserved. RADARSAT is an official mark of the Canadian Space Agency.

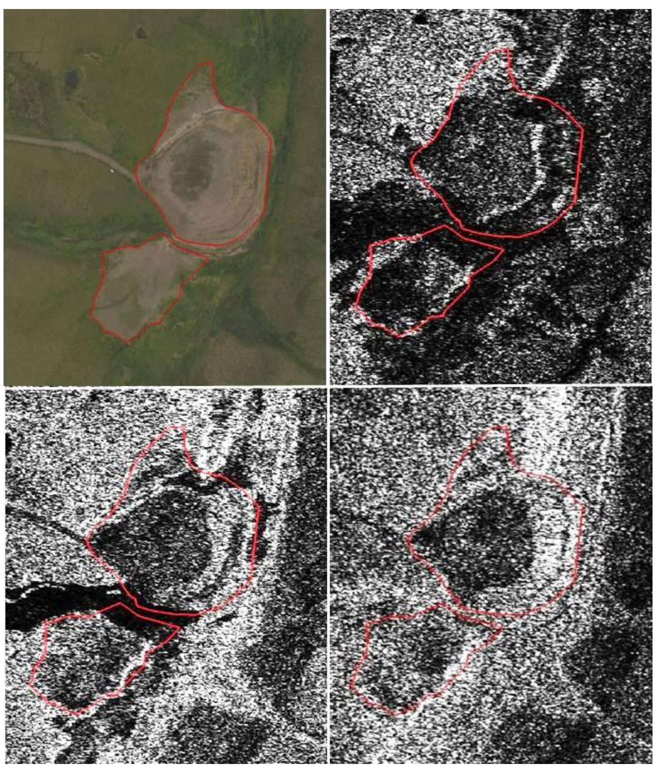

Fig. 3. Water ponding is visible at two landfills (outlined in red) at BAR-2 from the spring melt. CW from upper left are the Applanix airborne imagery from 3 Aug 2012, and radar backscatter from 24 May, 4 Aug and 17 June 2012 (all descending passes). RADARSAT-2 Data and Products ©MacDonald, Dettwiler and Associates Ltd. (2012) - All Rights Reserved. RADARSAT is an official mark of the Canadian Space Agency.

3. DATA COLLECTION

Starting in May 2011 coherent ascending and descending stacks of RADARSAT-2 Spotlight mode (high-resolution) data were acquired over each site. In all cases the spotlight mode data is right looking, horizontal-horizontal (HH) polarized, a single-look complex (SLC) product, and has a nominal slant range pixel and azimuth pixel spacing of 1.3 m and 0.4 m respectively. In December 2014 collection of three coherent stacks of TerraSAR-X SpotLight data began over two of the sites. These offer both higher spatial (range) and temporal resolutions compared with RADARSAT-2.

4. GROUND TRUTH AND SUPPORT DATA

Ground truth was collected at three of the four test sites (excluding FOX-5) during the summers of 2012 and 2013. This consisted of: collection of high-resolution airborne EO multispectral stereo Applanix imagery for derivation of a Digital Elevation Model (DEM); hand-held imagery; and surveys of the landfills and other structures of interest using Real Time Kinematic (RTK) Global Positioning System (GPS). As well, four trihedral corner reflectors were installed at each of the 3 sites.

5. DATA PROCESSING

The Applanix digital stereo data was processed to Digital Elevation Models (DEM) by MCE. The resulting DEMs had a Ground Sample Distance (GSD) between 12 and 13 cm with absolute horizontal and vertical accuracies under 75 cm and relative vertical accuracies of 25 cm or better. The corresponding imagery also provided a wealth of information on the landfills, site buildings and airstrip, land cover classification, and shoreline location and type.

The RADARSAT-2 data stacks were processed at DRDC using GAMMA Remote Sensing software [3] and in-house software components, and followed standard interferometric processing procedure. The principal outputs include a registered stack of SAR backscatter (magnitude) and coherence imagery.

A key motivation was extraction of surface deformation information for the landfill sites. Two different techniques were used to estimate the surface deformation rate. The first used the GAMMA's Interferometric Point Target Analysis (IPTA) software and followed standard point target processing procedures [5], [6], [7]. The Applanix DEM provided a good reference elevation for the deformation analysis, and the corner reflectors installed in the summer of 2012 as well as the ground truth collected during the summers of 2012 and 2013 provided the fixed reference points.

However the size of these coherent data stacks are relatively short. This is due, in part, to the 24-day exact repeat orbit of RADARSAT-2 limiting the size of the stacks to 16 per year and the loss of a few acquisitions due to scheduling conflicts and satellite anomalies. In this regard the 4-day repeat of RCM will prove very useful for change detection application. The largely poor and patchy coherence over the DEW line sites during the winter months and spring thaw timeframes also reduced the size of the stacks. This combination of large temporal variability and small stack size proved a challenge for the standard point target processing procedure. As a result point target analysis was limited to the individual landfill sites of interest. The second approach was to use the stacking technique developed to extract small deformation signals from small coherent data stacks [4]. By averaging multiple unwrapped interferograms from which the topographic phase component was removed, random noise such as atmospheric signals can be subdued and small, cumulative trends extracted. Both of these approaches assume that the displacement is constant and linear through relevant stacks.

6. CHANGE DETECTION

Both incoherent and coherent techniques were used to detect and assess change in these Arctic DEW Line sites [2]. Site construction/destruction, site regrade or general site activity are most clearly visible by a comparison of the two or three amplitude imagery, such as the as two-colour multi-view image of a landfill at DYE-M shown in Fig 2. The radar backscatter image from 4 July 2012 image displayed in red and 21 August 2012 image displayed in cyan highlights the change due to demolition of two large antennae and subsequent burial of the dismantled components in a landfill.

A time series of images can be used to monitor localized flooding and water ponding, which could potentially lead to soil erosion. A series of collects in the spring of 2012 (see Fig. 3) shows flooding, water ponding, or saturated soil around two landfills at BAR-2. Careful examination of the magnitudes in Fig. 3 and coherence images shown in Fig. 4 shows signs of water ponding also on top of the landfill itself. Similar water ponding was observed in the imagery acquired in the spring of 2013 and 2014. Photographs taken around these landfills in August 2012 show localised soil erosion.

Finally, surface cracks caused by differential settlement of a landfill, and general terrain subsidence can potentially be detected using deformation analysis. Both IPTA analysis and stacking techniques were tested. This analysis had to contend with short stacks of RADARSAT-2 data, very low coherence during the spring thaw and in BAR-2, differential frost heaving. Among the landfills where deformation analysis was possible, none exhibited differential settlement of the surface of the landfill. In three cases (IPTA results shown in Fig. 5), the results suggested a subtle subsidence of the sides of the landfill (on the order of 0.8 cm/year). The flooding and water ponding detected earlier in and around these landfills corroborates this conclusion.

7. CONCLUSION

This proof-of-concept study was initiated to determine if space-borne SAR imagery and products can currently be used to effectively, efficiently and reliably monitor all the DEW Line landfill sites, thereby decreasing, re-directing or altogether replacing in situ site monitoring.

As an all-weather, day/night imaging sensor, space-borne SAR provides relatively reliable, repeatable and inexpensive image acquisitions. Data processing of exploitation ready products for amplitude and coherent change detection applications have become fully automated. After the first acquisition of an image stack, amplitude and change detection products could be available for exploitation within hours of image acquisition. Amplitude and change detection can reliable detect major changes to the DEW Line test sites (e.g. construction, regrade) and monitor flooding, water ponding or saturated soil which, over time, could lead to soil erosion and cracking. However, RADARSAT-2 does not have the spatial resolution to detect small features such animal burrows.

Although space-borne SAR also does not currently have the spatial resolution to directly detect thin cracks, it is good at mapping differential surface deformation of one part of a landfill with respect to another that could cause surface cracks. Landfills that exhibited on average good coherence, particularly during the summer months, were those that were generally covered with granular fill or riprap. The landfills that exhibited generally poor coherence were those with heavily vegetated surface. In those cases the deformation technique would greatly benefit if critical landfills were covered with a series of radar corner reflectors or at least a more radar friendly surface.

The 24-day exact repeat of RADARSAT-2 is a limiting factor. In this case interleaving 24-day image stacks with ascending and descending acquisitions can provide increased temporal resolution and monitoring frequency. The four-day coherent repeat of the RADARSAT Constellation Mission, scheduled for launch in 2018 will prove a great asset for monitoring of the DEW Line sites.

In summary, although space-borne SAR imagery and products are not able to completely replace boots-on-the-ground inspection of landfills, it can provide reliable, repeated and continuous site monitoring, pinpoint problem areas and generally reduce and augment site inspection between visits.

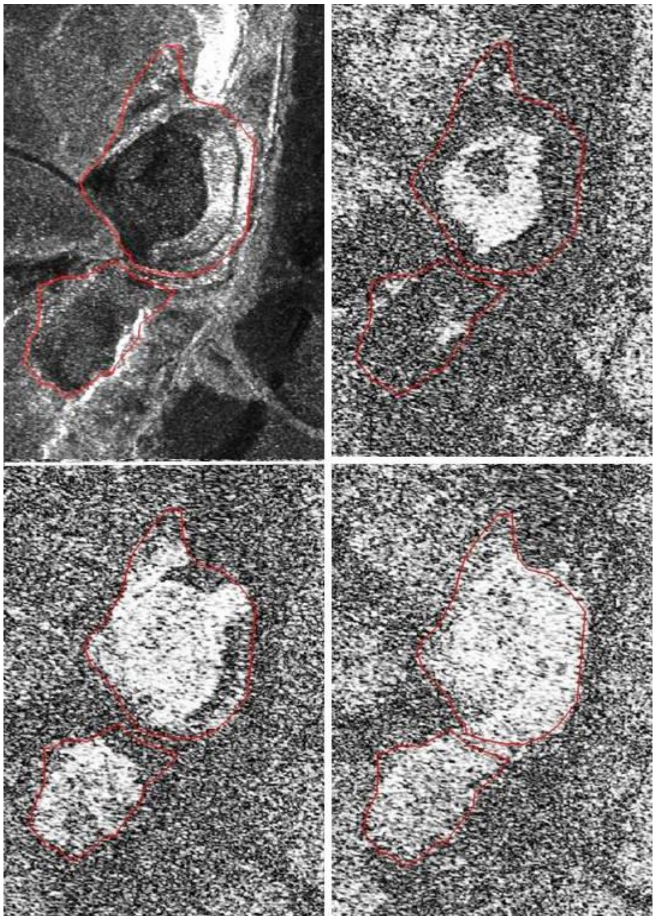

Fig. 4. Water ponding at two of the landfills (outlined in red) at BAR-2 from the Spring melt as observed (clockwise from upper left) in mean backscatter image, the coherence(27 May – 17 June), coherence(4 – 28 August) and the coherence(17 June – 11 July), all acquired in 2012. RADARSAT-2 Data and Products ©MacDonald, Dettwiler and Associates Ltd. (2012) - All Rights Reserved. RADARSAT is an official mark of the Canadian Space Agency.

9. ACKNOWLEDGEMENTS

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10. REFERENCES

[1] Canada News Centre, "The distant early warning line clean-up project," (On-line at: http://news.gc.ca/web/article-eng.do?m=/index&nid=462899; last accessed: May 2015).

[2] Rykhus, R. P. and Lu, Z, "InSAR detects possible thaw settlement in the Alaskan Arctic Coastal Plain," *Canadian Journal of Remote Sensing*, 34(2), pp.100-112, 2008.

.

[3] GAMMA (Gamma Remote Sensing AG), GAMMA Land Application Tools (LAT) package. (On-line at: http://www.gamma-rs.ch/software/lat-land-application-tools.html; last accessed: 2015/01/06).

[4] Short, N., Brisco, B., Couture, N., Pollard, W., Murnaghan, K. and Budkewitsch, P., "A comparison of TerraSAR-X, RADARSAT-2 and ALOS-PALSAR interferometry for monitoring permafrost environments, case study from Herschel Island," *Canada. Remote Sensing of Environment*, Vol. 115, Issue 12, pp. 3491-3506, 2011.

[5] Takeuchi, S. and Yamada, S., "Comparison of InSAR capability for land subsidence detection between C-band and L-band SAR," *Proceedings of IGARSS 2002*, 24–28 June, Toronto, Canada, pp. 2379- 2381, 2002

[6] Constantini, M., Falco, S., Malvarosa, F., Minati, F., Trillo, F., and Vecchioli, F., "Persistent scatterer pairs (PSP) approach in very high resolution SAR interferometry," *Proceedings of the EUSAR 2010*, Aachen, Germany, 2010

[7] Stefan, G. and Bamler, R., "Towards Deformation Monitoring of Single Buildings – Persistent Scatterer Interferometry using TerraSARX Very High Resolution Spotlight Data," *Proceedings of the EUSAR 2010*, Aachen, Germany, 2010.

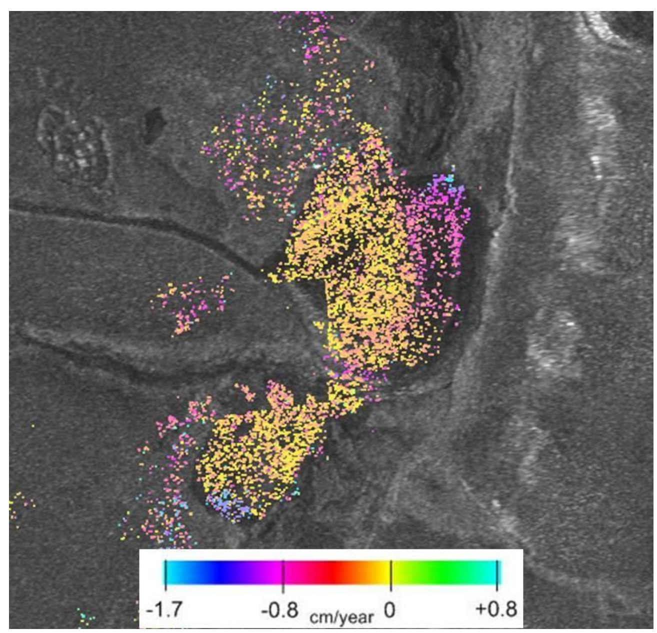

Fig. 5. Deformation map of the same two landfills shown in Figs 3 and 4 suggesting a subtle subsidence or sliding of the sides the landfill. RADARSAT-2 Data and Products ©MacDonald, Dettwiler and Associates Ltd. (2012) - All Rights Reserved. RADARSAT is an official mark of the Canadian Space Agency.