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Exercise Narwhal: Visibility of deployed Radar Targets and Change Detection with RADARSAT-1 fine beam mode SAR imagery

Karim E. Mattar, Paris W. Vachon, Ryan English
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Abstract

In August 2004 the Canadian Forces undertook Exercise Narwhal near Pangnirtung on Baffin Island. DRDC Ottawa participated in a supporting role, providing corner reflectors to simulate several crashed satellite debris fields and RADARSAT-1 synthetic aperture radar data collects in interferometric pairs and triplets. The interferometric data provided images for demonstration of coherent and non-coherent change detection. This report assesses the detection of the deployed satellite debris fields as well as scene changes on land and in the littoral zone around the time of the exercise.

Résumé

Au mois d'août 2004, les Forces canadiennes ont entrepris l'exercice Narwhal à proximité de Pangnirtung, sur l'île de Baffin. RDDC Ottawa y a participé dans un rôle de soutien, fournissant des réflecteurs dièdres pour simuler plusieurs zones de débris d'un satellite écrasé et des séries de données de radar à ouverture synthétique (SAR) RADARSAT-1 regroupées en paires et en triplets de mesures interférométriques. Les données interférométriques ont permis de tracer des images pour démontrer la détection de modifications cohérentes et non cohérentes. Le présent rapport évalue la détection des zones déployées de débris de satellite, ainsi que les modifications intervenues sur les lieux d'action au sol et dans la zone littorale à peu près au moment de la tenue de l'exercice.

Executive summary

The Canadian Forces undertook Exercise Narwhal near Pangnirtung on Baffin Island between 18 and 24 August 2004. The Exercise scenario considered a potentially belligerent and non-cooperating nation sending a warship and ground troops to locate and retrieve the remains of a crashed satellite. The Canadian Forces were tasked to secure the area, locate and retrieve the satellite remains, monitor the belligerent warship, and locate the belligerent nation's camp on the island, using various sensors.

DRDC Ottawa participated in the exercise in a supporting role. DRDC Ottawa provided three sets of expendable corner reflectors to simulate the satellite debris fields, organized RADARSAT-1 synthetic aperture radar (SAR) data acquisition, and processed the data for debris field detection as well as coherent and non-coherent change detection. In total, nine RADARSAT-1 images were acquired of the Pangnirtung site before, during, and after the exercise. The acquisitions were timed to produce three interferometric pairs and one interferometric triplet, from which providing several coherence and two-colour magnitude change images of the Pangnirtung region were generated.

Two simulated debris fields were fully deployed by the CF during the exercise. The simulated debris field was readily detected in the available RADARSAT-1 fine beam mode magnitude image. The two-colour magnitude change images facilitated identification of even subtle changes in the image magnitude that occurred during the time between the two acquisitions. Consequently, it enhanced the visibility of the debris field, and appears to be a useful product for detecting changes on land and in the littoral zone. For example, the two-colour magnitude change images highlighted changes in the coastline due to differences in the tidal height between the two acquisitions. This in turn allows identification of the location of rocky or muddy shoals near the coastline that could impact the activities of a landing party.

The inclement weather reported during the exercise caused decorrelation between the interferometric pairs, resulting in a general loss of coherence. This affect was particularly noticeable in the valleys, such as where the simulated debris fields were deployed. Mountainous areas, normally barren and rocky, maintained their coherence very well over the 24-day time interval that separates the interferometric image pairs.

Mattar, K.E., Vachon, P.W., English, R., Schlingmeier, D., "Exercise Narwhal: Visibility of deployed Radar Targets and Change Detection with RADARSAT-1 fine beam mode SAR imagery", DRDC Ottawa TM 2005-202, Defence R&D Canada – Ottawa.

Sommaire

Les Forces canadiennes (FC) ont mené l'exercice Narwhal à proximité de Pangnirtung, sur l'île de Baffin, du 18 au 24 août 2004. Le scénario de l'exercice reposait sur l'envoi, par un pays possiblement belligérant et non coopérant, d'un navire de guerre et de troupes au sol pour localiser et récupérer les débris d'un satellite écrasé. Les FC ont été chargées de prendre et de tenir la zone, de localiser et de récupérer les débris du satellite, de surveiller le navire de guerre du pays belligérant et de localiser le camp installé sur l'île par le pays belligérant, le tout au moyen de divers capteurs.

RDDC Ottawa a participé à l'exercice dans un rôle de soutien. RDDC Ottawa a fourni trois jeux de réflecteurs dièdres non réutilisables pour simuler les zones de débris du satellite, organisé l'acquisition de données de radar à ouverture synthétique (SAR) RADARSAT-1 et assuré le traitement des données pour la détection des zones de débris et des modifications cohérentes et non cohérentes. En tout, neuf images RADARSAT-1 ont été acquises sur le site à proximité de Pangnirtung avant, pendant et après l'exercice. Les séries d'acquisition ont été tenues de manière à produire trois paires et un triplet de mesures interférométriques, à partir desquelles ont été produites plusieurs images de variation de la magnitude en deux couleurs et de la cohérence de la région de Pangnirtung.

Deux zones simulées de débris ont été entièrement déployées par les FC l'exercice. Une zone simulée de débris a été facilement détectée dans l'image de la magnitude en mode de faisceau fin disponible de RADARSAT-1. Les images de variation de la magnitude en deux couleurs ont facilité l'identification de modifications même subtiles de la magnitude qui se sont produites entre les deux séries d'acquisition, ce qui a eu pour effet d'améliorer la visibilité de la zone de débris. Ces images semblent donc être un produit utile pour la détection de modifications au sol et dans la zone littorale. Par exemple, les images de variation de la magnitude en deux couleurs ont mis en évidence des modifications intervenues le long de la côte en raison des différences d'amplitude de la marée entre les deux séries d'acquisitions, ce qui, en retour, permet l'identification de l'emplacement, à proximité de la côte, de hauts-fonds rocheux ou vaseux susceptibles d'avoir une incidence sur les activités d'une équipe de débarquement.

Le mauvais temps qui a prévalu durant l'exercice a causé une décorrélation entre les paires de mesures interférométriques, ce qui a occasionné une perte générale de cohérence. Cet effet a été particulièrement remarquable dans les vallées, comme celles où se trouvaient les zones simulées de débris. Les zones montagneuses, normalement dénudées et rocheuses, ont très bien maintenu leur cohérence au cours de l'intervalle de 24 jours qui a séparé les paires d'images interférométriques.

Mattar, K.E., Vachon, P.W., English, R., Schlingmeier, D., "Exercise Narwhal: Visibility of deployed Radar Targets and Change Detection with RADARSAT-1 fine beam mode SAR imagery", DRDC Ottawa TM 2005-202, R & D pour la défense Canada – Ottawa.

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Acknowledgements

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Introduction

In August 2004, the Canadian Forces (CF) undertook a major exercise near Pangnirtung, Nunavut on Baffin Island. This event, exercise Narwhal, considered a scenario in which a foreign satellite crashed in the Pangnirtung area; a foreign, non-cooperative nation had sent a ship with troops to retrieve the debris field. The task of the Canadian Forces was to secure the area, locate and recover the debris field, locate the belligerent nation's camp on the island, and monitor the belligerent warship. This would be accomplished using available sensors.

The Canadian Forces requested the participation of Defence Research and Development Canada – Ottawa (DRDC Ottawa) in a supporting role. DRDC Ottawa designed and prepared a set of variable sized expendable radar corner reflectors (CRs) that were to be deployed to simulate up to three debris fields. These were tested in a pre-trial deployment exercise held in Ottawa May 2004 [4]. DRDC Ottawa also organized RADARSAT-1 data acquisition and processing to test detection of any debris fields using RADARSAT-1 fine beam mode SAR data. The RADARSAT-1 data acquisitions were timed to form several interferometric data sets, enabling the testing and demonstration of both coherent and non-coherent change detection in a realistic scenario.

Motivation & Objective

The CFs objectives for Exercise Narwhal include:

1. To exercise the CF role in supporting the Nunavut territorial government's response to a crisis and consequence management of the event within the Canadian Forces Northern Area (CFNA) region of responsibility;

2. To exercise Headquarters CFNA in the planning and conduct of joint operations required to fulfil selected assigned defence tasks in the northern area;

3. To exercise Canadian sovereignty by projecting a CF presence within the North; and

4. To ascertain the capability of detection of a debris field from a notional satellite launch failure using spaceborne radar (SBR).

DRDC Ottawa participated in Exercise Narwhal in a supporting role. DRDC Ottawa provided expendable trihedral CRs of various sizes that were deployed by the CF to simulate the satellite debris field within an area of approximately 3200 km^2. The debris field provided targets for detection with the RADARSAT-1 imagery, and provided the participating infantry personnel with targets to locate.

DRDC Ottawa also provided expertise in radar data exploitation; particularly coherent and non-coherent change detection and wide area surveillance. The demonstration of these capabilities contributes to CF objective number 4.

The use of Commercial Satellite Imagery (CSI) was a key component of the Exercise. The purpose of CSI in this exercise was to locate and track ships in nearby waters to enhance the recognized maritime picture and to provide unclassified CSI with high-resolution optical imagery within a short timeframe to the CF. RADARSAT-1 fine beam mode imagery was the principal satellite data employed for land surveillance, while ScanSAR imagery was used for maritime surveillance.

Summary of Pre-trial deployment tests

In preparation for Exercise Narwhal, DRDC Ottawa conducted a mini trial in the Ottawa area in May 2004 [4]. Expendable trihedral CRs of the same size and configuration as proposed for deployment during Exercise Narwhal were deployed at Connaught Range in the National Capital Region (NCR). Additional trihedral CRs were deployed throughout the overlapping regions of the swaths for ground control purposes. The latitude and longitude of the CRs were measured using a differential Global Positioning System (GPS) unit. Coincident with the deployment, three RADARSAT-1 fine beam mode images of the area were acquired. The objectives of these pre-trial deployment tests were as follows:

1. To validate the methodology used to determine the azimuth and elevation angles such that the trihedral CRs are visible in ascending and descending passes of RADARSAT-1 fine beam mode imagery;

2. To assess the visibility of trihedral CRs of various sizes in RADARSAT-1 fine beam mode imagery; and

3. To produce a multi-temporal SAR dataset with Ground Control Points (GCPs) for future studies.

Of the five trihedral CRs deployed at Connaught Range (of 30 cm, 45 cm, 60 cm, 75 cm, and 100 cm back spine dimensions) all were visible in all SAR acquisitions except for the smallest one (30 cm). The larger trihedral CRs (100 cm) that were deployed throughout the NCR were all visible in all SAR acquisitions. This indicated that aligning the trihedral CR boresight with the midswath point of the beam mode of interest was an acceptable method for establishing the elevation angle of the CR, at least for purposes of target detection for position control. Each target identified in the imagery was verified using the Canada Centre for Remote Sensing (CCRS) VUSAR software, which also provided estimates of the latitude and longitude and the radar cross section (RCS). The SAR-derived values were compared to the GPS-measured latitude and longitude and to theoretical RCS values. The RCS comparisons were within 3 dB of each other while the latitude and longitude errors were relatively consistent within each acquisition. Since the VUSAR software does not account for elevation changes, longitude errors were larger for GCPs at higher altitudes.

Trial Plan

DRDC Ottawa provided a sufficient number of expendable trihedral CRs of various sizes to simulate three debris fields. Each debris field consisted of five pairs of CRs with back spine dimensions of 30 cm, 45 cm, 60 cm, 75 cm, and 100 cm. The trial plan called for deployment of the CRs in pairs, facing the nominal ascending and descending orbits of RADARSAT-1. The five pairs were to be deployed along a line, each separated by 100 m, forming a line 400 m in length. Each line consisted of a pair of the 100 cm CRs, followed by pairs of the 60 cm CRs, the 30 cm CRs, the 45 cm CRs, and ending with the 75 cm CRs. Detailed instructions for deploying the corner reflectors were developed and are available in Annex D of [4]. A CR deployment training session was carried out at CFB Gagetown in August 2004 in preparation for the deployments on Nunavut.

The trihedral CRs were constructed using 0.010" aluminium bonded to 0.5" plywood (see Annex C of [4] for a complete description of the CR construction). A 0.5" hole at the inside apex of the corner permits water drainage. The CRs were considered to be expendable since they were relatively inexpensive to construct.

Debris Field Deployment

The main portion of Exercise Narwhal took place on Nunavut's Baffin Island on the Cumberland Peninsula near the Hamlet of Pangnirtung, as well as the nearby offshore areas, from 18 to 24 August 2004. Inclement weather caused a delay and shortage of air assets. Therefore, only two of the three planned debris field sites were ever deployed. The asterisks (*) in Figure 1 mark the two debris field sites. The simulated debris field of five pairs of CRs was deployed at Site 1 on the evening of 21 August 2004, and was completed the following morning. A similar debris field was deployed at Site 2 the morning of 22 August 2004. The corner reflectors were removed at the end of the exercise on August 25.

Photographs of the deployed CRs were taken only at Site 2. Figure 2 through Figure 6 show the five pairs of CRs, with back spine dimensions of 100 cm, 60 cm, 30 cm, 45 cm, and 75 cm, respectively. The direction the CR faced is noted where it is known. Standing water, perhaps from the recent precipitation, is visible in four of the photographs.

The positions of all the CRs were measured using a Magellan Meridian GPS unit. The positions of the ten corner reflectors at Site 1 are shown in Table 1. The position of the ten corner reflectors at Site 2 are shown in Table 2. Note that since the actual azimuth and elevation angles were not recorded at Site 2, the desired azimuth and elevation angles are tabulated instead. At Site 1, the actual and desired azimuth and elevations angles agree to within ±0.5°, the precision of the instrumentation.

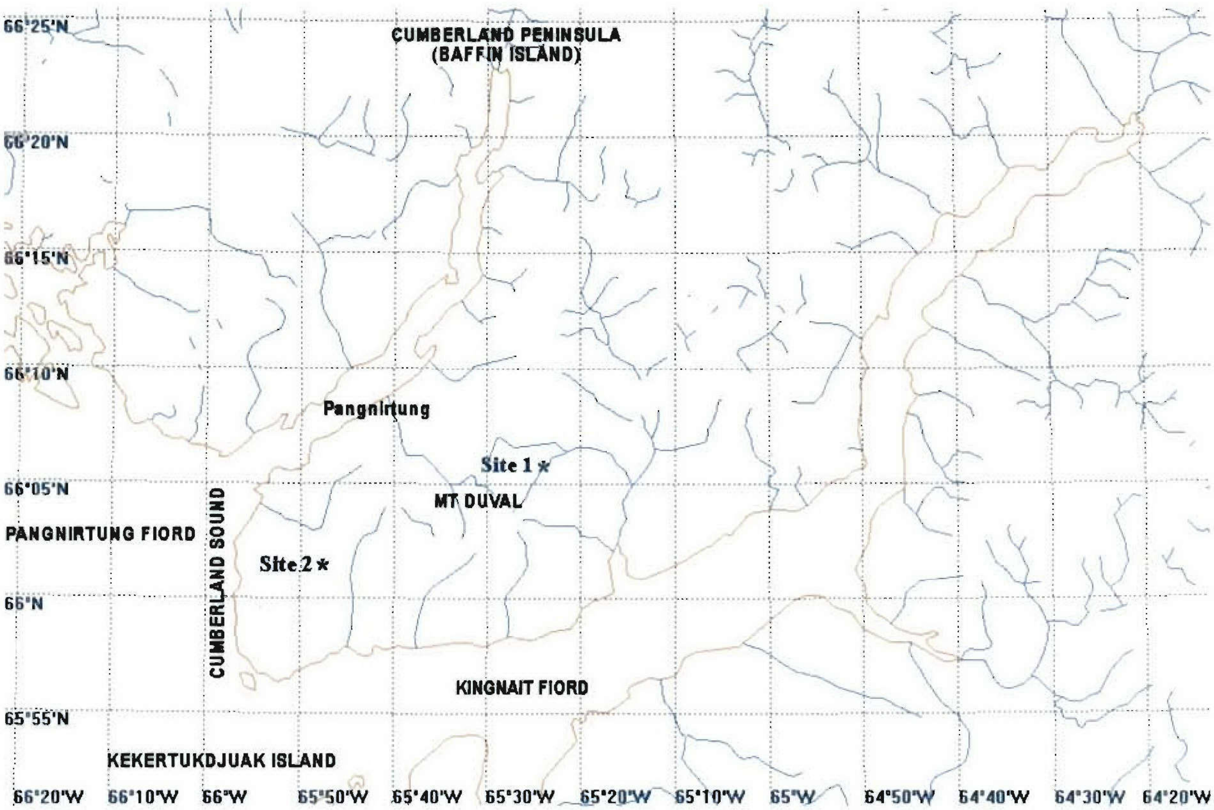

Figure 1: Map of the Pangnirtung area on the Cumberland Peninsula. The two stars (*) indicate the sites of the deployed debris fields.

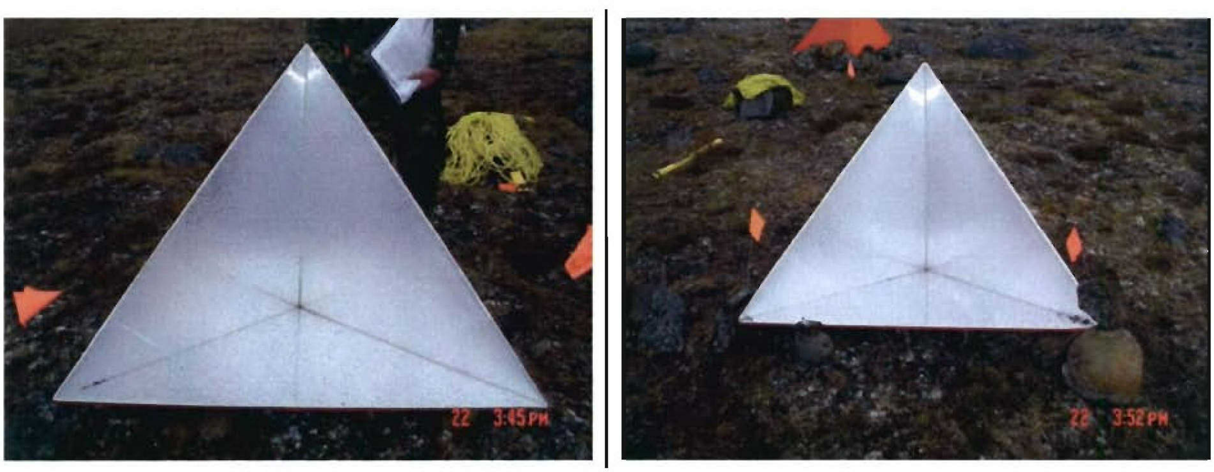

Figure 2: Photographs of deployed 100 cm CRs at Site 2 taken on 22 August 2004 near Pangnirtung. The CR on the left is facing West; the one on the right is facing East.

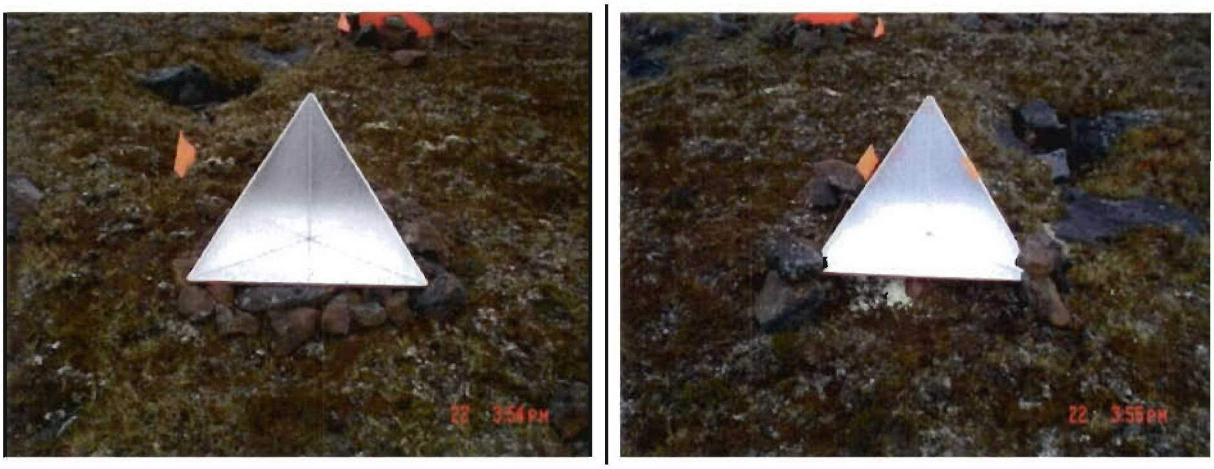

Figure 3: Photographs of deployed 60 cm CRs at Site 2 taken on 22 August 2004 near Pangnirtung. The CR on the left is facing West; the one on the right is facing East.

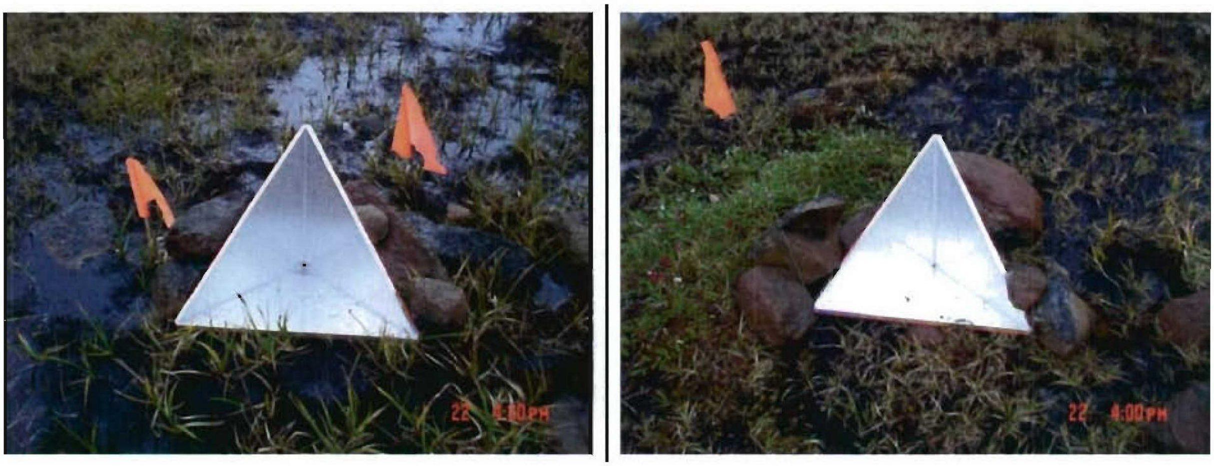

Figure 4: Photographs of deployed 30 cm CRs at Site 2 taken on 22 August 2004 near Pangnirtung.

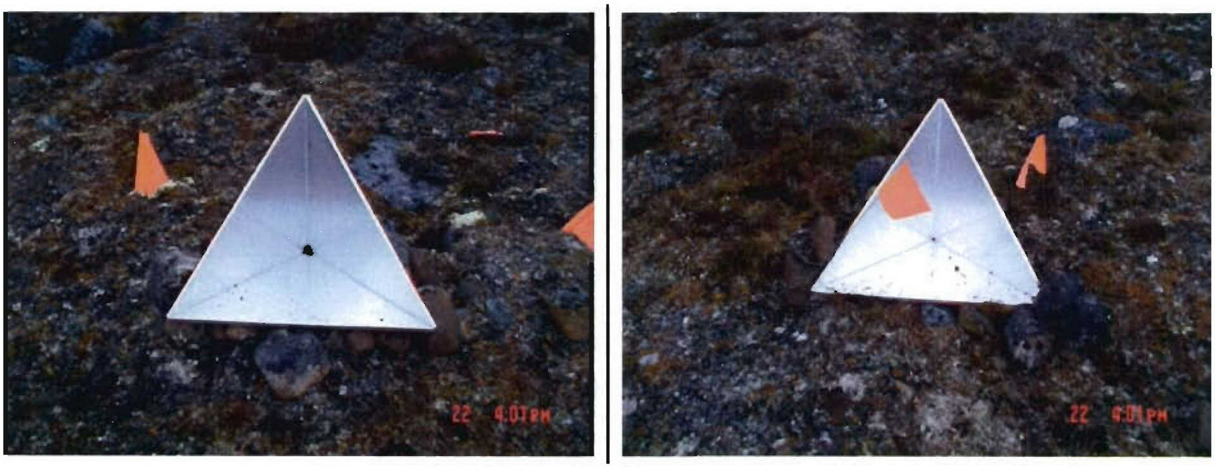

Figure 5: Photographs of deployed 45 cm CRs at Site 2 taken on 22 August 2004 near Pangnirtung.

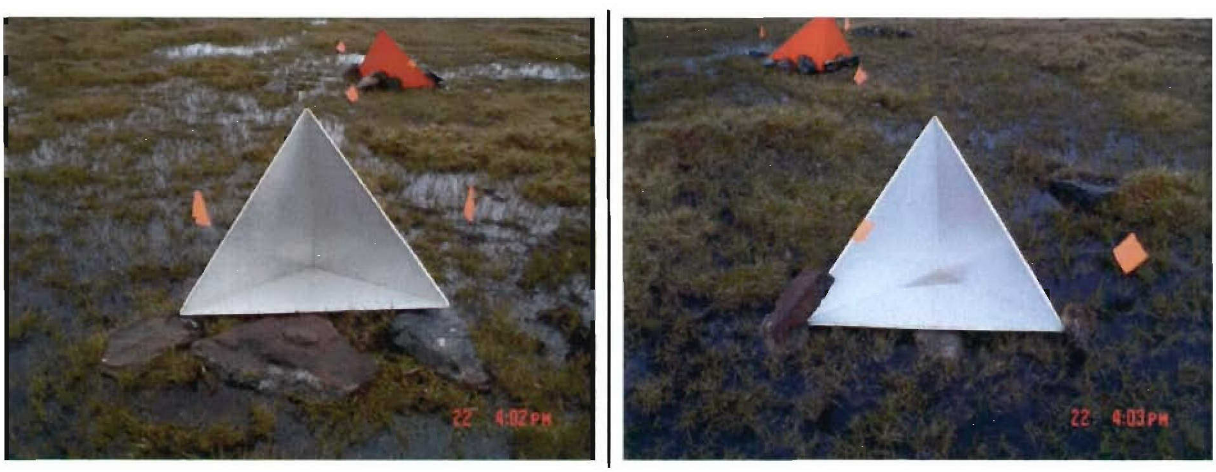

Figure 6: Photographs of deployed 75 cm CRs at Site 2 taken on 22 August 2004 near Pangnirtung. The CR on the left is facing West; the one on the right is facing East.

Table 1: Data taken from the CR deployment data sheet for Site 1. All GPS measurements were recorded on a Magellan Meridian GPS in MGRS. The data were collected on 21 & 22 August 2004.

CR#	SITE	POSITION	FACING	SIZE (CM)	ACTUAL AZIMUTH ANGLE (DEG)	ACTUAL ELEVATION ANGLE (DEG)	MEASURED LAT. (MGRS)	MEASURED LONG. (MGRS)	MEASURED ALT (M)
1	1	1	East	100	190	12	N 9108	W 3443	458
2	1	1	West	100	350	12	N 9107	W 3443	458
3	1	2	East	60	190	12	N 91171	W 34393	452
4	1	2	West	60	350	12	N 91167	W 34394	453
5	1	3	East	30	190	12	N 91264	W 34365	473
6	1	3	West	30	350	12	N 91259	W 34364	473
7	1	4	East	45	190	12.2	N 91357	W 34332	457
8	1	4	West	45	350	12	N 91353	W 34334	457
9	1	5	East	75	190	12	N 91455	W 34297	446
10	1	5	West	75	350	12	N 91451	W 34298	446

Table 2: Data taken from the CR deployment data sheet for Site 2. All GPS measurements were recorded on a Magellan Meridian GPS in MGRS. The data were collected on 22 August 2004.

CR#	SITE	POSITION	FACING	SIZE (CM)	DESIRED AZIMUTH ANGLE (DEG)	DESIRED ELEVATION ANGLE (DEG)	MEASURED LAT. (MGRS)	MEASURED LONG. (MGRS)	MEASURED ALT (M)
1	2	1	East	100	190	12	N 73387	W 26368	417
2	2	1	West	100	350	12	N 73383	W 26367	417
3	2	2	East	60	190	12	N 73399	W 26325	418
4	2	2	West	60	350	12	N 73398	W 26326	418
5	2	3	East	30	190	12	N 73417	W 26282	417
6	2	3	West	30	350	12	N 73412	W 26280	417
7	2	4	East	45	190	12.2	N 73428	W 26241	416
8	2	4	West	45	350	12	N 73425	W 26239	416
9	2	5	East	75	190	12	N 73442	W 26199	412
10	2	5	West	75	350	12	N 73438	W 26192	412

RADARSAT-1 Data Acquisition and Processing

A series of RADARSAT-1 SAR fine beam mode image acquisitions were tasked to coincide with Exercise Narwhal. In all, 11 acquisitions were requested, but only nine were actually acquired. The scheduled acquisitions are listed in Table 3. Two requests (30 July and 6 August) were not imaged due to conflicts with higher priority image acquisitions. The nine data sets form four interferometric sets: three pairs and one triplet. A 24-day minimum time separation between interferometric pairs is dictated by the repeat orbit cycle of RADARSAT-1, and is one of the important limitations to RADARSAT-1 interferometry.

From each interferometric data set, coherence, phase, and two magnitude images (one from each of the passes that form the pair) are obtained. By virtue of the interferometric processing these two magnitude images are registered to sub-pixel accuracy, even in the absence of high coherence. Subsequently, a two-colour magnitude change image is obtained. Furthermore, since the two data sets were imaged from nearly the same perspective in space, parallax is minimal.

Table 3: Scheduled RADARSAT-1 SAR acquisitions over Pangnirtung. The cells shown in grey indicate acquisitions that were not acquired due to conflicts with higher priority imagery.

INTERFEROMETRIC SET	ACQUISITION DATE (2004)	MODE	ORBIT	SCENE CENTRE ACQUISITION TIME (GMT)	LST (PANGNIRTUNG)
I	27 July	F3F	Ascending	21:59:48	15:59:48
	20 Aug				
II	30 July	F3F	Descending	10:40:33	4:40:33
	23 Aug				
	16 Sep				
III	6 Aug	F5N	Descending	10:36:17	4:36:17
	30 Aug				
	23 Sep				
IV	6 Aug	F5F	Ascending	22:08:12	16:08:12
	30 Aug				
	23 Sep				

Some important parameters for the fine-beam mode of RADARSAT-1 are listed in Table 4. A key advantage of RADARSAT-1 is its large swath width of approximately 50 km at its highest resolution. Its ground range and azimuth resolution are between 8 and 9 meters, while the slant range and azimuth spacing are approximately 5 meters. Since coherence is a statistical calculation carried out within a window of pixels, its resolution is normally 3 to 5 times worse than that of the magnitude or raw phase images [2, 3], depending on the size of the coherence window used. Conversely, the two-colour magnitude change image retains the resolution of the original magnitude images. The magnitude change image, therefore, always has better resolution than the coherence image.

Table 4: Principal parameters for RADARSAT-1 (courtesy of RSI).

Parameter	*RADARSAT-1 mode*		
	F3F	*F5N*	*F5F*
Frequency	5.3 GHz		
Wavelength	5.66 cm		
Incidence Angle Range (deg)	41.8-44.3	45.0-47.3	45.6-47.8
Resolution Ground Range x Azimuth (m)	8.4 x 8.4	8.1 x 8.4	7.8 x 8.5
Slant Range Pixel Spacing (m)	4.64	4.64	4.64
Ground Range Pixel Spacing at Scene Centre (m)	6.80	6.43	6.38
Azimuth Resolution (m)	8.77	8.75	8.75
Azimuth Line Spacing (m)	4.84	5.07	5.07
Nominal Area (km x km)	50 x 50	50 x 50	50 x 50
Antenna Polarization	HH		

Table 5: Interferometric parameters for the processed data sets.

INTERFEROMETRIC SET	ACQUISITION DATES (2004)	PERPENDICULAR BASELINE AT SCENE CENTRE (M)	RANGE TO SCENE CENTRE (KM)	INCIDENCE ANGLE AT SCENE CENTRE (DEGREES)	TERRAIN HEIGHT AMBIGUITY AT SCENE CENTRE (M)
I	27 July 20 Aug	90	1,029.50	43.1	219
II	23 Aug 16 Sep	213	1,034.16	43.1	93
IVa	6 Aug 30 Aug	446	1,084.45	46.7	50

To maximize the utility of the imagery, an attempt was made to coordinate image acquisition with the expected exercise and deployment of the simulated debris field. Due to the loss of acquisitions, and the deployment of the debris field between 21 and 22 August, the acquisition on the 23 August is the only pass that includes the simulated debris field. While the 23 August and 16 September InSAR pair and the 6 August and 30 August InSAR pair are the only two interferometric pairs that surround the time period of interest. Therefore, these interferometric pairs became the principal focus of the processing efforts.

Processing of the RADARSAT-1 data followed the procedures discussed in [2, 3]. The data were processed to focused single look complex (SLC) data using the MacDonald, Dettwiler and Associates (MDA) processor PGS. Subsequent interferometric processing of the data to magnitude, magnitude change, interferometric phase, and interferometric coherence were accomplished using R&D software. Parameters for the three interferometric data sets processed are summarized in Table 5. Of the three pairs, the 6 August and 30 August InSAR pair has the largest perpendicular baseline, and correspondingly, the smallest height ambiguity, providing for an interferometric phase that is particularly sensitive to changes in terrain height.

Debris Field Detection

The RADARSAT-1 acquisition on 23 August 2004 was the only pass that included the simulated debris fields. A full resolution image of Site 1 centred on the debris field is shown in Figure 7. By combining the 23 August image with its interferometric complement acquired on 16 September, a two-colour composite image was formed. This RGB image enhances detection of even subtle differences between the two image magnitudes. Figure 8 presents the 23 August magnitude image in red and the 16 September image in cyan. Scatterers that are identical in both images appear in shades of grey. Scatterers that have undergone change appear in colour; red if the scatterer is **brighter** in the first image or **darker** in the second image; cyan if the scatterer is **darker** in the first image or **brighter** in the second image. The GPS measured positions of the 5 CR pairs were mapped into the radar perspective [3], and are each identified by a '+' sign. The discrepancy between the measured and imaged positions of the CRs is due to the relatively large uncertainly in the position of the RADARSAT-1 satellite itself [3].

In Figure 7, from left-to-right, one can see the CRs with back spine dimensions of 100 cm, 60 cm, 30 cm, 45 cm, and 75 cm. Of the five sizes, only the 100 cm, 60 cm, and 75 cm CRs are clearly visible. The 45 cm CR might be marginally visible in Figure 7, but is slightly easier to identify in the colour composite change image of Figure 8. The 30 cm CR is not identifiable in either image.

A full resolution image of Site 2 is shown in Figure 9. The corresponding colour composite change image is reproduced in Figure 10. Photographs of these CRs appear in Figure 2 through Figure 6. The GPS measured positions of the 5 CR pairs were also mapped to radar perspective and are each identified by a '+' sign. Only the CR with a 100 cm back spine dimension is visible in either image. The statistics of the visible CR at Site 1 and 2 are summarized in Table 6.

Table 6: Statistics of the CRs visible in the 23 August 2004 RADARSAT-1 image.

CR#	SITE	BACK SPINE DIMENSION (CM)	σ^0 PEAK VALUE (dB)	RCS (dB)	INTEGRATION AREA (PIXELS^2)	PEAK-TO-CLUTTER RATIO (dB)	MEAN CLUTTER ESTIMATE (dB)	AZIMUTH 3dB WIDTH (M)	GROUND-RANGE 3dB WIDTH (M)
1	1	100	11.51	30.00	24.86	25.86	-14.13	8.6	7.4
3	1	60	4.25	23.28	28.89	17.16	-12.91	8.6	8.6
7	1	45	-1.91	15.83	27.17	11.53	-13.53	9.4	7.4
9	1	75	7.45	25.53	23.77	18.06	-10.61	7.8	7.8
1	2	100	6.62	24.54	21.14	19.26	-12.64	8.2	6.6

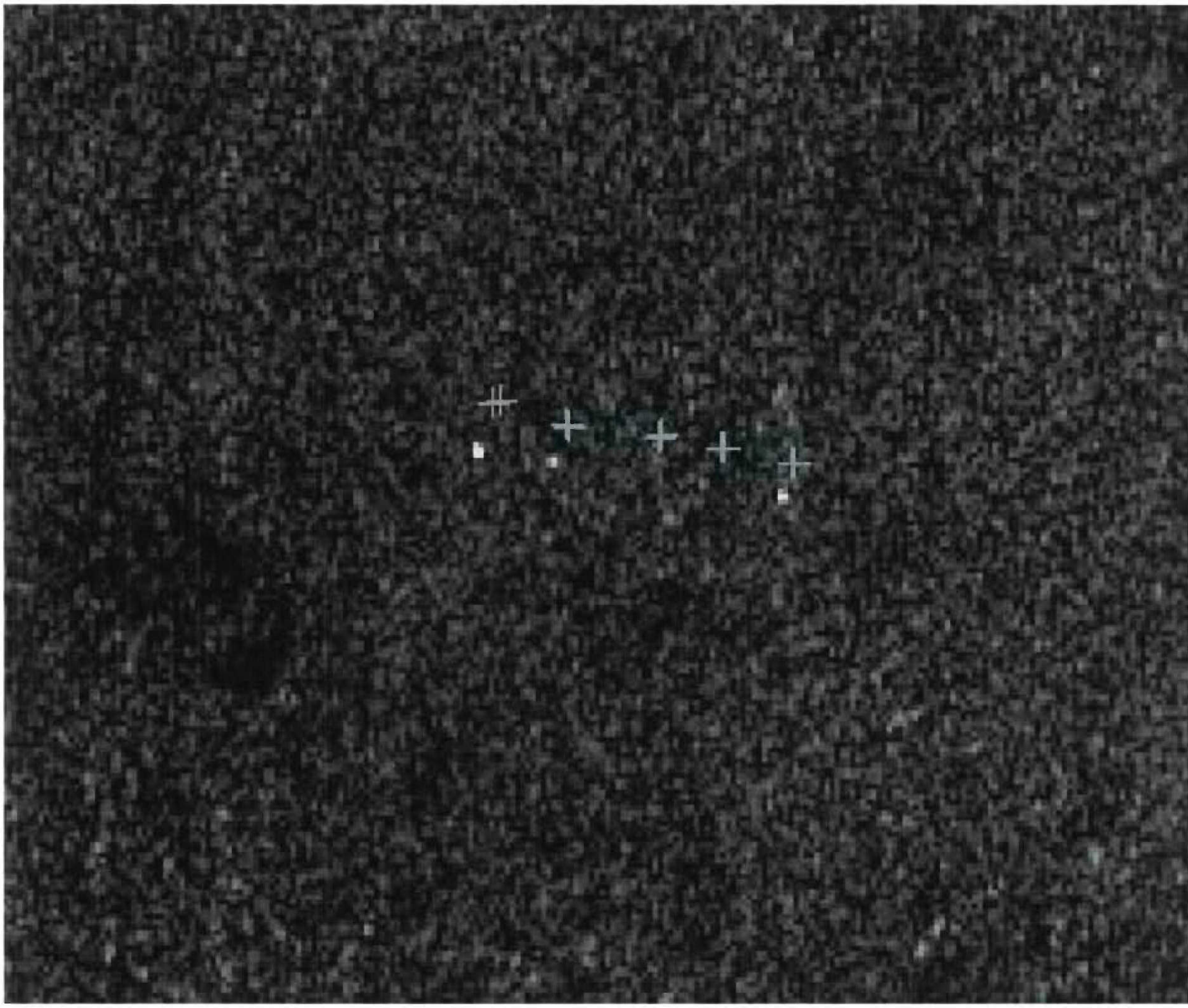

Figure 7: RADARSAT-1 image of the simulated debris field from Site 1 on 23 August 2004. The plus (+) signs identify the GPS measurements taken at the sites of the CRs.

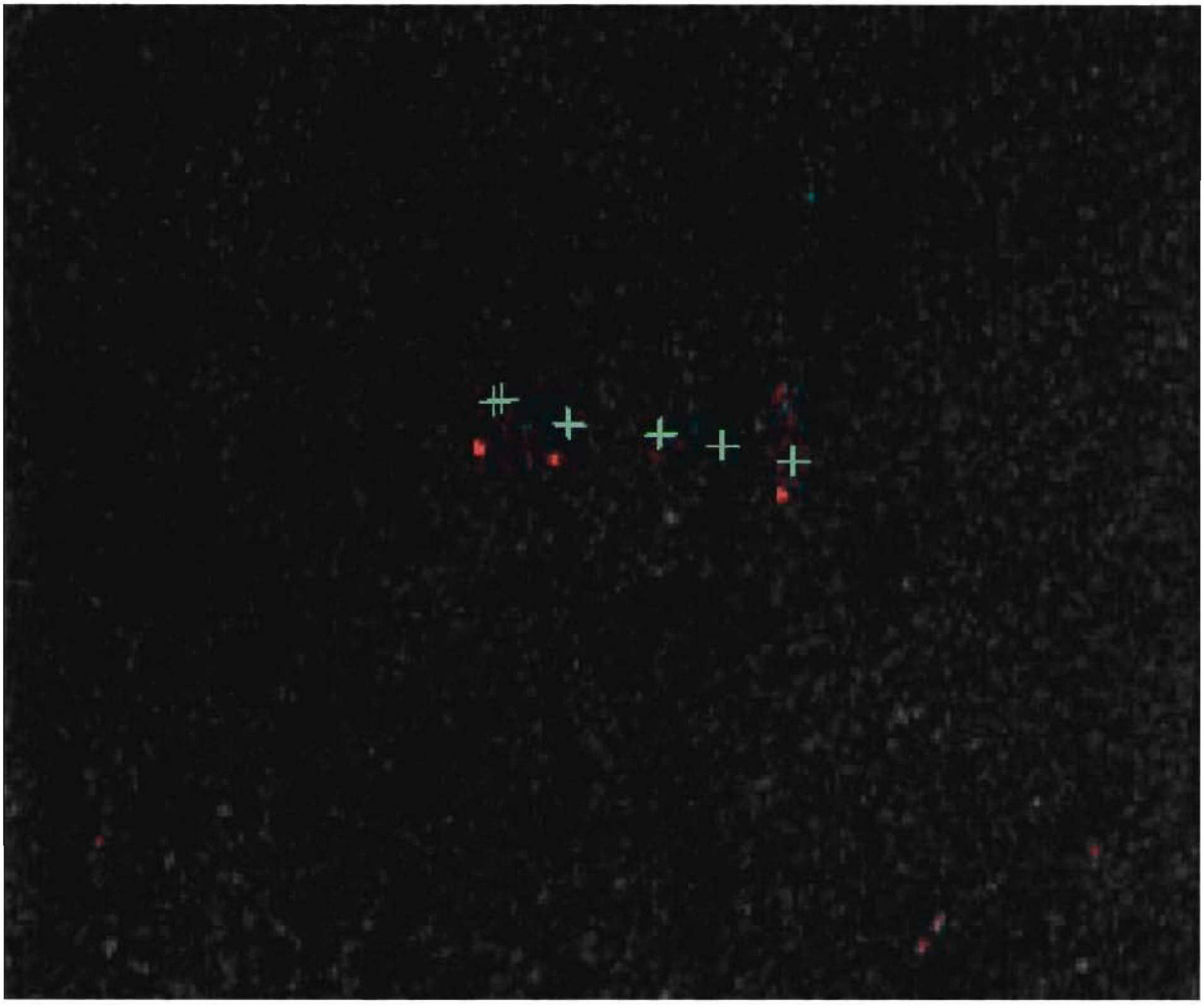

Figure 8: RADARSAT-1 image of the simulated debris field from Site 1. The 23 August image magnitude is presented in red, the 16 September image magnitude is presented in cyan. The green plus (+) signs identify the GPS measurements taken at the sites of the CRs.

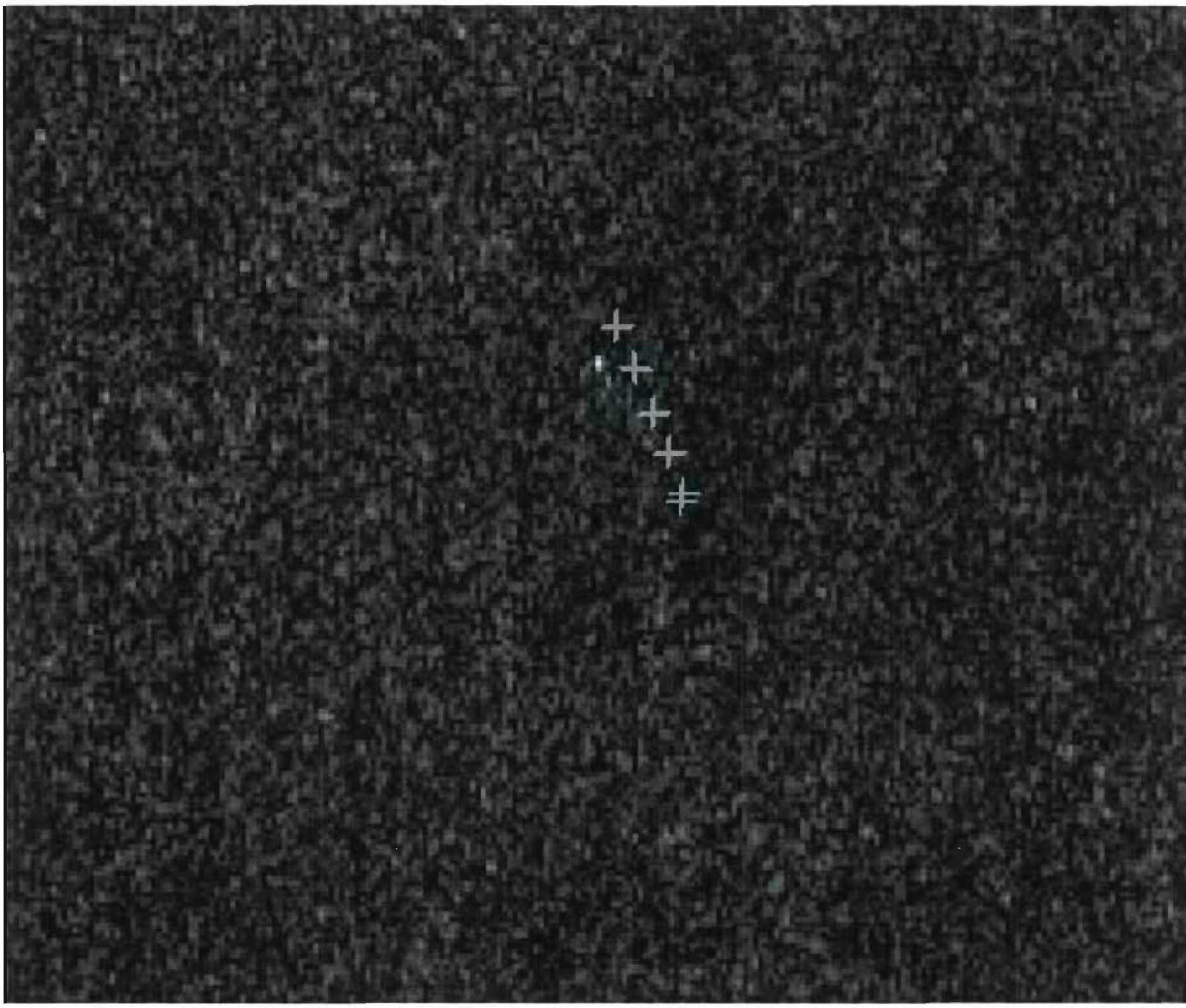

Figure 9: RADARSAT-1 image of the simulated debris field from Site 2 on 23 August. The plus (+) signs identify the GPS measurements taken at the sites of the CRs.

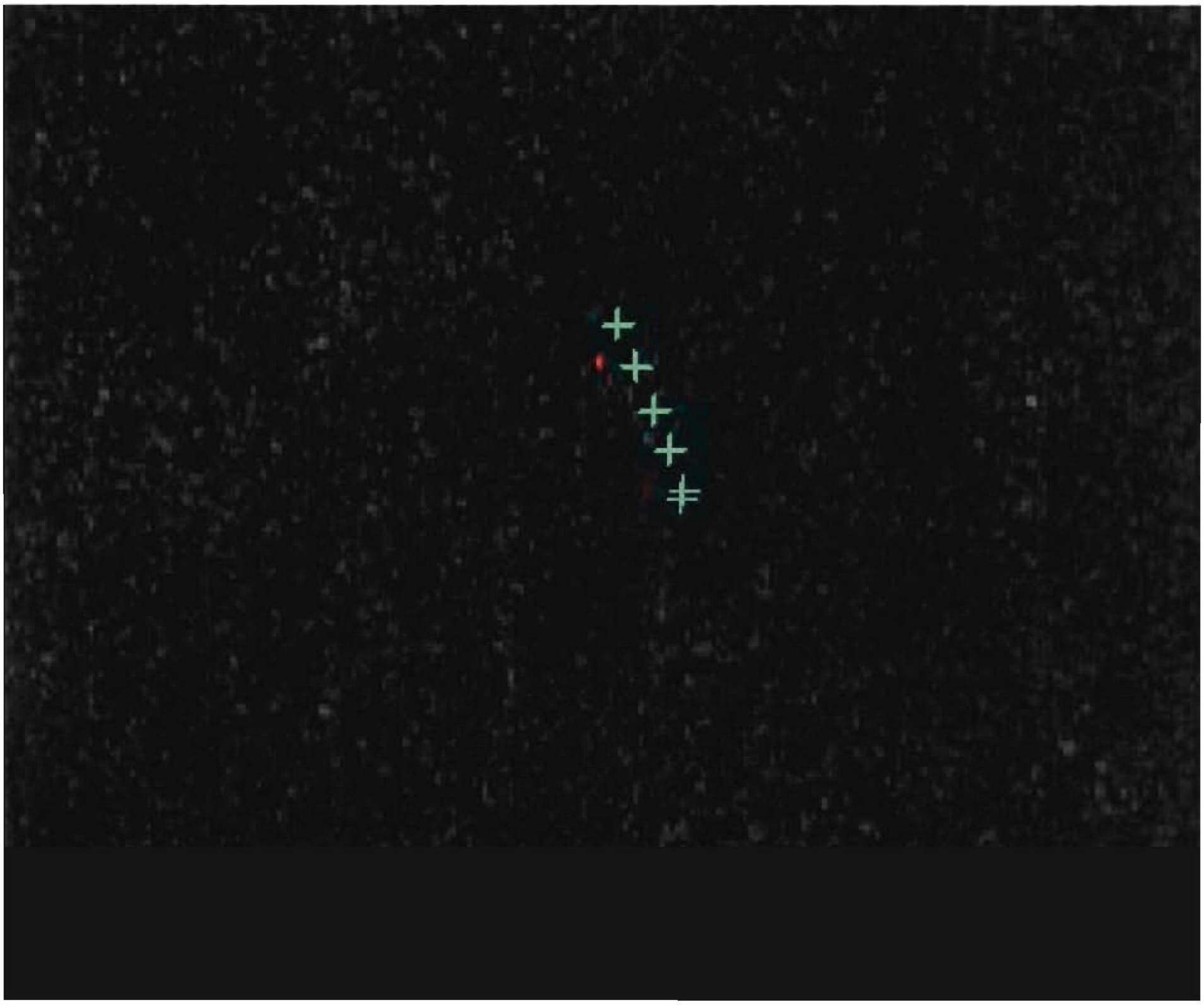

Figure 10: RADARSAT-1 image of the simulated debris field from Site 2. The 23 August image magnitude is presented in red, the 16 September image magnitude is presented in cyan. The green plus (+) signs identify the GPS measurements taken at the sites of the CRs.

Change Detection

The three interferometric pairs listed in Table 5 form the basis for this part of the study. The interferometric pairs permit both coherent and non-coherent change detection methods to be used. Coherent change detection is a statistical measurement of the interferometric phase noise, and is a measurement of the macroscopic changes within a radar footprint. Non-coherent change detection relies on the change in the magnitude of the scatterer. The portions of the two image magnitudes that have not changed between the two dates appear as shades of grey. Localised areas of colour reflect changes in the magnitude of the local scatterer. Large-scale coloration is a strong indication of poor radiometric calibration of one or both images that makes up the pair.

The different methods by which these two change images are calculated has important consequences on their respective resolutions. The resolution of the interferometric coherence is limited by the size of the statistical window over which the coherence is estimated [3]. For this study all coherence calculations were based on a 5 pixel x 5 pixel widow. The resolution of the two-colour magnitude change image is identical to the resolution of each of the magnitude images, and therefore is better suited than the coherence image for detection of point targets. The lower resolution of the RADARSAT-1 coherence image, together with the loss of coherence in the valley areas, combined to make detection of small features such as the simulated debris field virtually impossible.

On Land

Figure 11 and Figure 13 show the magnitude change image of Cumberland Peninsula. In Figure 11, the 27 July magnitude image is red, while the 20 August magnitude image is cyan. The scene covers an area of approximately 42 km x 50 km. In Figure 13, the magnitude of the 6 August image is red, while the magnitude of the 30 August magnitude image is cyan. The area coverage of this image is less than that of Figure 11, being only 31 km x 30 km. The land in Figure 11 has an overall pinkish tinge. This is due to a subtle imbalance in the radiometric scaling between the two scenes. A more serious radiometric calibration problem is evident in Figure 13 from the overall cyan tone of the lower part of the image.

Despite subtle radiometric problems, localized changes are still evident, particularly in Figure 11. Some of the mountain peaks appear blue. This may be due to snow accumulation in the upper elevations prior to the 20 August image acquisition. Some of the nearby lakes are tinted with red, possibly due to the formation of ice on the lakes. Ice on the lake surfaces would lower the radar backscatter [6].

The coherence images for the 23 August and 16 September InSAR pair is shown in Figure 12, and for the 6 August and 30 September InSAR pair is shown in Figure 14. The coherence from the 23 August and 16 September InSAR pair is judged to be fair. The coherence is generally higher over the mountainous areas and lower in the valleys. The loss of coherence in the valleys is explained by reports of inclement weather during the trial. The mountainous areas are rocky, barren, steep and wind swept, thereby less subject to moisture retention than the valleys, hence maintaining scene coherence. The isolated areas that exhibit a complete lack of coherence (i.e. totally black areas) are by and large the same areas that appeared cyan in Figure 11. This is another indication that these areas received a substantive amount of snow accumulation; sufficient to cause a loss of coherence and change in radar backscatter.

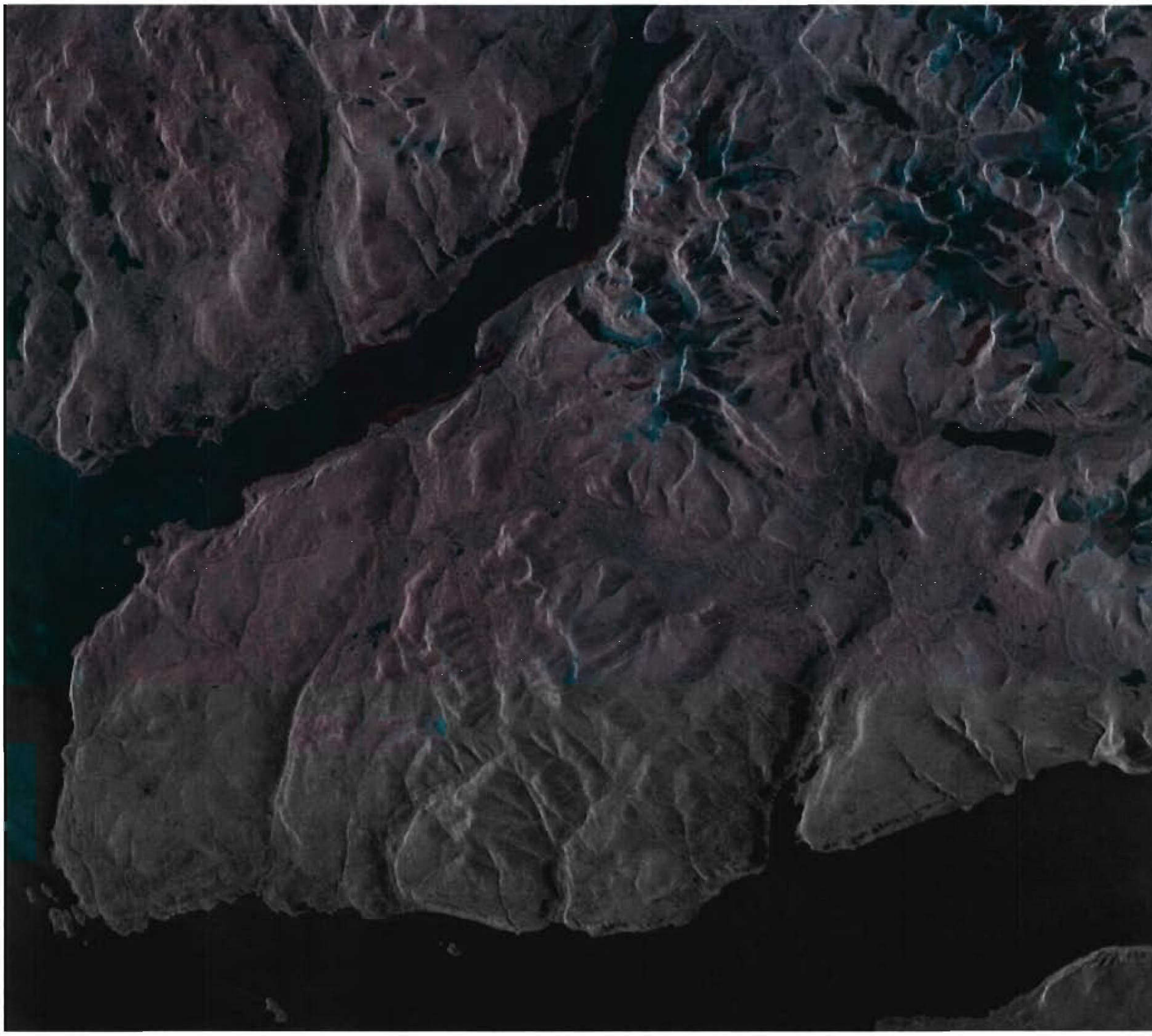

Figure 11: RADARSAT-1 magnitude from 27July (red) and 20 August (cyan) images. The scene covers an area of approximately 42 km x 50 km.

The coherence in Figure 14 for the 6 August and 30 August pair is generally very poor. This pair spans the entire trial, and spans the period of inclement weather [1]. It was obviously more affected by precipitation. Yet the coherence is still high over some of the mountainous areas, many of the same mountainous areas that retained coherence in Figure 12.

Figure 12: RADARSAT-1 interferometric coherence between the 23 August and 16 September InSAR pair. High coherence appears white; complete decorrelation appears black. The scene covers an area of approximately 42 km x 50 km.

Figure 13: RADARSAT-1 magnitude from 6 August (red) and 30 August (cyan) images. The scene covers an area of approximately 31 km x 30 km. The overall cyan tone of the lower portion of the image is due to poor radiometric calibration of one of the images.

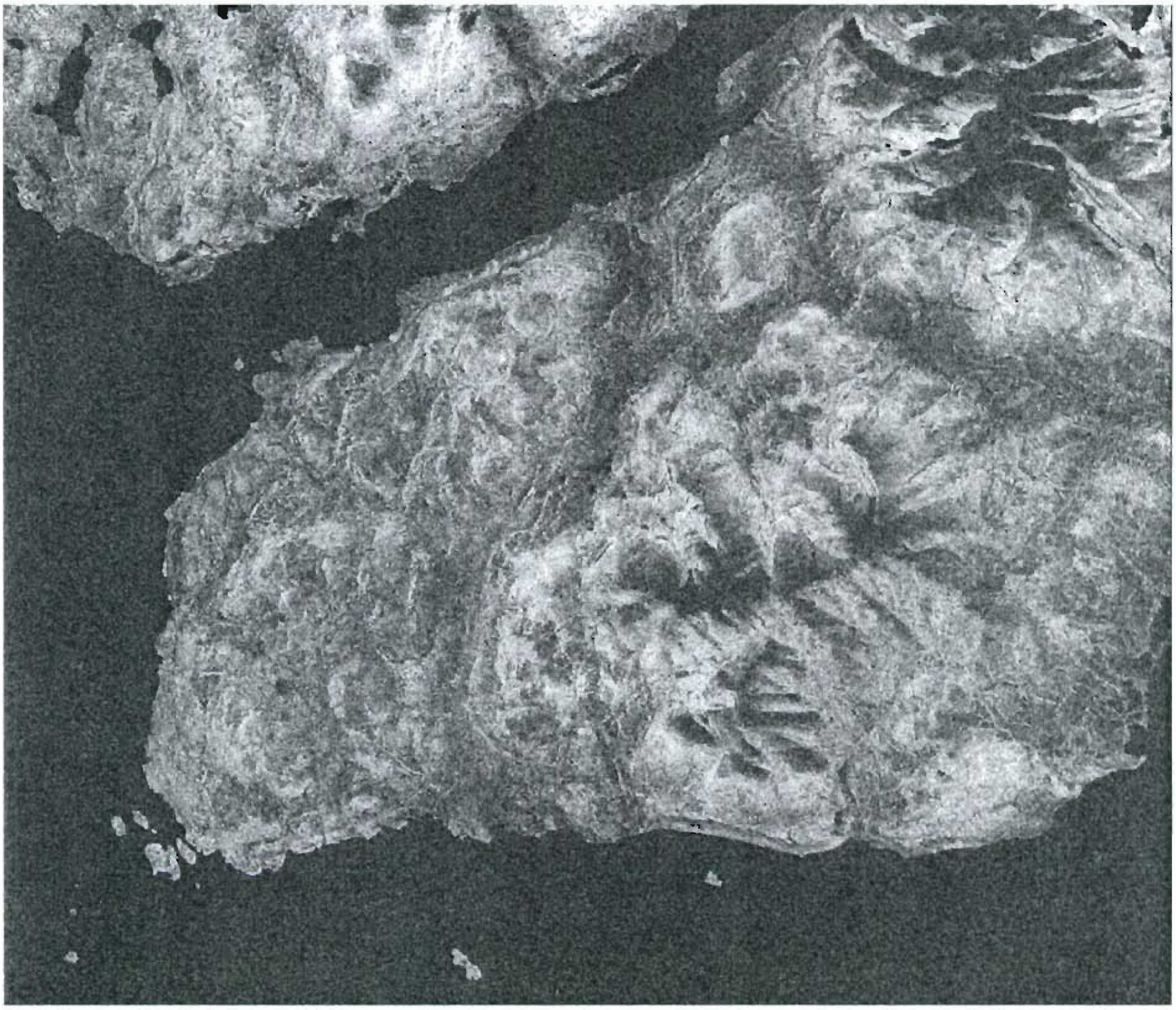

Figure 14: RADARSAT-1 interferometric coherence between the 6 August and 30 August InSAR pair. High coherence appears white; complete decorrelation appears black. The scene covers an area of approximately 31 km x 30 km.

A more detailed view of Pangnirtung is shown in Figure 15 and Figure 16. Figure 15 shows RADARSAT-1 images over Pangnirtung from the 23 August and 16 September InSAR pair. On top is a 2-colour amplitude image with the 23 August image in red and the September 16 image in cyan. On the bottom is the coherence image estimated from the image pair. The town of Pangnirtung is visible in the upper portion of the images along the south shore of the Pangnirtung Fiord. The sites of the two debris fields are also marked. The coherence of the town and the valley is very poor, no doubt due to the inclement weather and precipitation in the area. The lower resolution and poor coherence of image make the secondary roads or trails impossible to detect. The two-colour amplitude image maintains the 8 to 9 meter resolution of the original amplitude data. Secondary roads are not discernable in this image either.

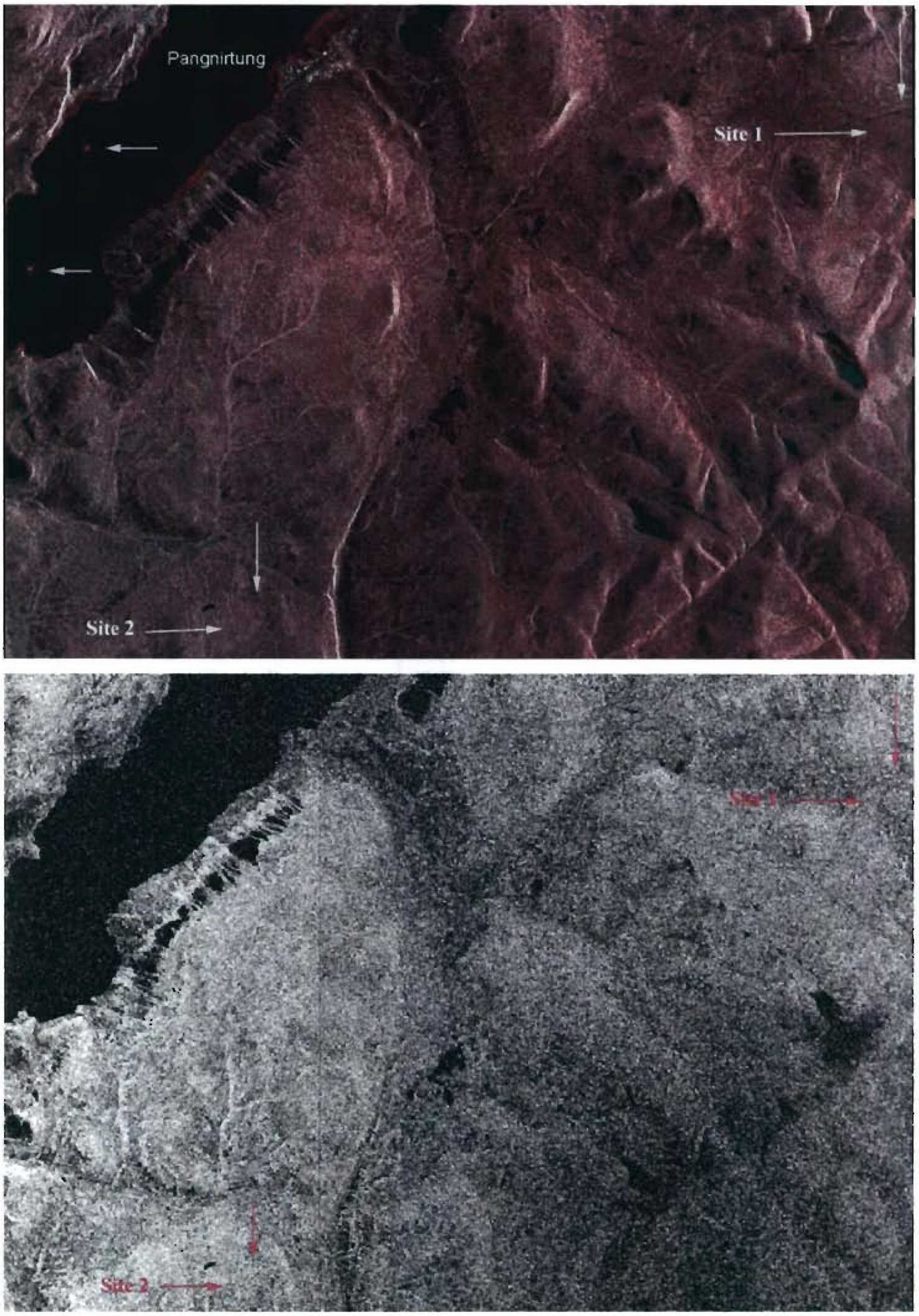

Figure 15: RADARSAT-1 images over Pangnirtung from the 23 August and 16 September InSAR pair. The upper image is a two-colour amplitude image with 23 August in red and September 16 in cyan. The lower image is the coherence image of the InSAR pair. High coherence appears white; complete decorrelation appears black. The scene covers an area of approximately 25 km x 30 km.

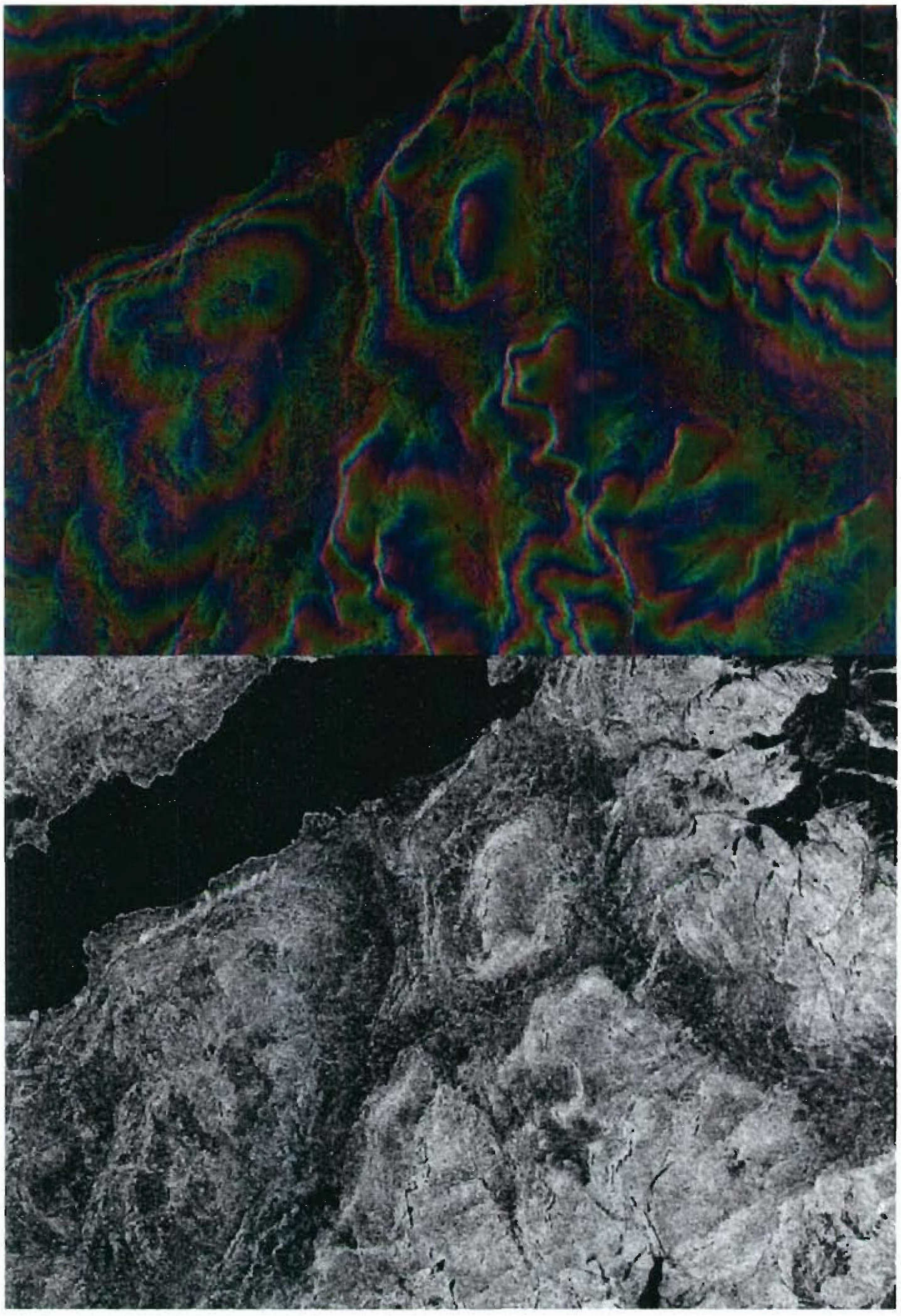

Figure 16: Detailed view of Pangnirtung from the RADARSAT-1 27July and 20 August InSAR pair. The upper image shows the interferogram phase (with the amplitude in the background) wrapped between $-\pi$ and $+\pi$, reflecting primarily the local topography. The lower image shows the interferometric coherence. High coherence appears white; complete decorrelation appears black. The scene covers an area of approximately 5.0 km x 6.5 km.

Figure 16 shows another detailed view of Pangnirtung and the simulated debris field area from the RADARSAT-1 27 July and 20 August InSAR pair. The interferometric phase (top) is primarily proportional to the terrain height and reflects the local topography. At the scene centre, one cycle of phase (e.g. from red to red) is equivalent to a 219-metre change in elevation. The interferometric phase image is a by-product of the coherence calculation. It requires no additional processing, and could potentially provide important contextual information to the magnitude and coherence images. The interferometric phase image covering a 42 km x 50 km area, from the 23 August and 16 September InSAR pair is shown in Figure 17. At scene centre, one cycle of phase is equivalent to a change in elevation of approximately 93 meters.

The Littoral Zone

By taking advantage of tidal effects, the two-colour magnitude change image can be particularly useful at highlighting changes in the littoral zone. Since the tidal cycle is 28 days, compared to the 24-day orbit cycle of RADARSAT, a pair of images will be acquired at different stages of the tidal cycle. As a result, changes to the coastline due to changes in the tide are highlighted and can be mapped. In addition, particular features of the littoral zone, such as possible location of mud flats or shoals, are revealed. In Figure 13, the 6 August image (red) was acquired at relatively low tide compared with the 30 August image (cyan). The terrain exposed by the tides is clearly visible in red. A bright target in blue near the entrance to the Fiord (marked by an arrow) shows the presence of a ship or perhaps an iceberg on 20 August. The tone of the water in Cumberland Sound and around Cumberland Peninsula reflects the stormy weather on that date.

A slightly different interval of the tidal cycle was captured in the 23 August and 16 September InSAR pair, a detail of which is shown in Figure 15. The two bright red targets near the entrance of the Fiord (marked by arrows) reveals the presence of two ships or icebergs.

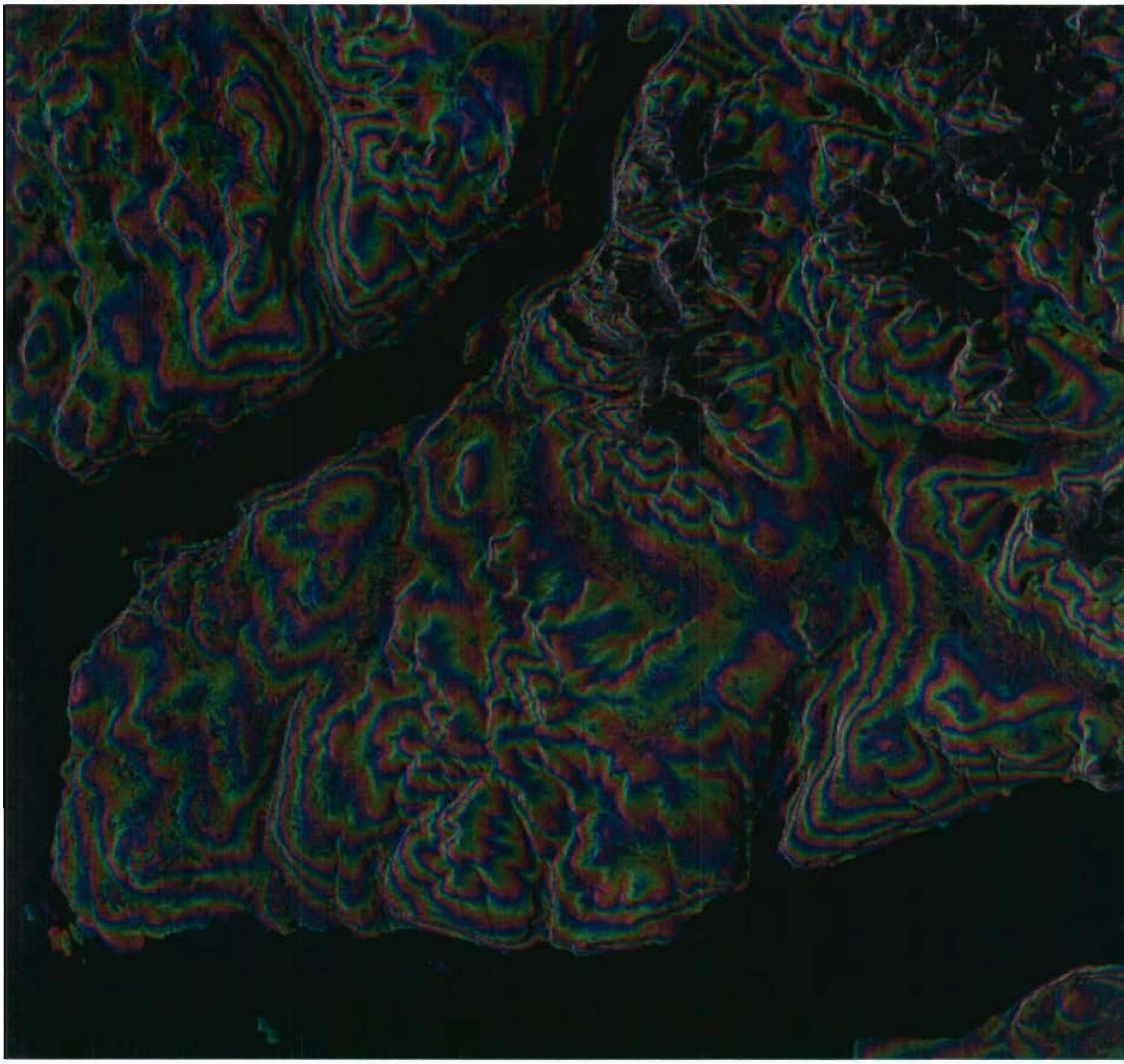

Figure 17: RADARSAT-1 interferometric phase from the 23 August and 16 September InSAR pair. The phase is wrapped between $-\pi$ and $+\pi$, generally following the terrain topography. The scene covers an area of approximately 42 km x 50 km.

Potential Benefits of RADARSAT-2

In addition to the current modes of RADARSAT-1, RADARSAT-2 will offer several new imaging modes that will provide improvements for detection of debris fields and for change detection [5]. RADARSAT-2 will offer a 3-meter resolution ultra fine mode that will help to address the resolution limitations of RADARSAT-1. This will provide radar magnitude and two-colour magnitude change images at a resolution of 3 m x 3 m, while the resolution of the coherence image will be in the 9 m to 15 m range, depending on the size of the processing window. At this higher resolution, the swath width is reduced from 50 km to 20 km, however, strips that are hundreds of kilometres long (in the satellite direction) can be collected.

Further benefits of RADARSAT-2 include: a shorter lead-time to task the satellite or change satellite modes (4-12 hours in emergencies), increased the revisit time, and improved absolute geocoding accuracy due to an onboard GPS. Its polarimetric mode will greatly improve detection and discrimination of certain types of scatterers based on their polarimetric signatures (limited to a 9 m x 9 m resolution and 20 km swath width). RADARSAT-2 will also be capable of interferometry, and polarimetric interferometry, though it will still be limited to a minimum interferometric pair temporal separation of 24 days.

The higher resolution of RADARSAT-2 will improve the probability of detecting debris fields on land and small ships at sea. The combination of higher resolution and improved geocoding accuracy will significantly improve absolute mapping accuracy of the littoral zone, as well as mapping changes to the littoral zone with the tide and over time. The current expectation is for RADARSAT-2 to be launched in mid 2006.

Summary and Conclusions

Exercise Narwhal provided a valuable opportunity for DRDC Ottawa to demonstrate the capabilities for target detection with RADARSAT-1 SAR, as well as change detection in general. The all weather imaging capability of radar proved particularly useful in this case. The heavy fog that affected the exercise, did not impact the quality of the RADARSAT-1 images. Four of the five radar corner reflectors from the first simulated debris field were clearly visible in the radar backscatter image. As expected the smallest corner reflector, with a 30 cm back spine, was not visible. Only the largest corner reflector of the second debris field was visible.

Unfortunate the all weather capability of SAR does not extend to radar interferometry. The coherence is adversely affected by precipitation or changes in the ground moisture that occurs between successive passes. Because of the combination of bad weather and the lower coherence resolution, the debris fields deployed for the exercise were not visible in the coherence images.

One of the by-products of the interferometric processing are two radar backscatter magnitude images registered to sub-pixel accuracy from which a two-colour magnitude change images can easily be obtained. Therefore, even in the absence of good coherence, change detection is still possible. Since both image were acquired from nearly the same perspective in space (a requirement of the interferometric processing) parallax is minimal. The two-colour magnitude change image complements change detection using coherence. It greatly enhances visibility of even subtle changes in the radar magnitude. While the statistical nature of the coherence calculation reduces its resolution, the two-colour magnitude change image maintains the full resolution of the original magnitude images.

In the future, RADARSAT-2 is expected to offer many benefits over RADARSAT-1 that would, in this scenario, enhance the visibility of debris fields and improve change detection. These include enhanced resolution (with a 20 km swath), polarimetry, improved geocoding accuracy and shorter satellite tasking.

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List of Symbols/Abbreviations/Acronyms/Initialisms

CCRS	Canada Centre for Remote Sensing
CF	Canadian Forces
CFNA	Canadian Forces Northern Area
CR	Corner Reflector
CSI	Commercial Satellite Imagery
DND	Department of National Defence
DRDC	Defence Research and Development Canada
DTED	Digital Terrain Elevation Data
EV-APP	EarthView Advanced Precision Processor
GCP	Ground Control Point
GPS	Global Positioning System
InSAR	Inteferometric Synthethic Aperture Radar
LST	Local Standard Time
MDA	MacDonald, Dettwiler and Associates
MGRS	Military Grid Reference System
MN	Magnetic North
NCR	National Capital Region
NGA	National Geospatial - Intelligence Agency
PCR	Peak-to-Clutter Ration
PGS	Product Generation System
RAST	Radar Applications and Space Technologies
RCS	Radar Cross Section
RDE	Radar Data Exploitation
SAR	Synthetic Aperture Radar
SBR	Space-Based Radar
SCR	Signal-to-Clutter Ratio
SLC	Single Look Complex

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In August 2004 the Canadian Forces undertook Exercise Narwhal near Pangnirtung on Baffin Island. DRDC Ottawa participated in a supporting role, providing corner reflectors to simulate several crashed satellite debris fields and RADARSAT-1 synthetic aperture radar data collects in interferometric pairs and triplets. The interferometric data provided images for demonstration of coherent and non-coherent change detection. This report assesses the detection of the deployed satellite debris fields as well as scene changes on land and in the littoral zone around the time of the exercise.

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