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Quest-2003 Polarimetric Signature Trial:

Experiment Design, SAR Calibration, Data Acquisition and Initial Results

Chen Liu, Lloyd Gallop and Dave Schlingmeier

Defence R&D Canada – Ottawa
TECHNICAL MEMORANDUM
DRDC Ottawa TM 2004-207
November 2004

Canada

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Abstract

The Quest-2003 Polarimetric Signature Trial was successfully conducted off the coast of Halifax, Nova Scotia, using the Environment Canada CV-580 C-band SAR in conjunction with the CFAV *Quest* trial Q-277.

This report addresses the polarimetric synthetic aperture radar (PolSAR) experiments that were conducted on 6 and 7 October, 2003.

A radar calibration site was established at CFB Shearwater. It was composed of four corner reflectors (CRs), four active radar calibrators (ARCs) and two Global Positioning System (GPS) base stations. CFB Shearwater offers relatively flat, uniform terrain with low radar reflectivity so that a high target-to-clutter ratio (TCR) was achieved.

During the PolSAR experiments, 11 CFAV *Quest* images were successfully collected with various incidence angles, aspect angles, and environmental conditions. Initial results indicate that the ship image is clearly distinguished from the ocean clutter in the PolSAR images. But, several image problems have been noted including image defocus, azimuth ambiguities, and target saturation. Overall, the ship images appear to be smeared in the azimuth direction, an issue that will be the focus of subsequent analysis.

Résumé

L'essai de signature polarimétrique Quest-2003 a été mené avec succès au large d'Halifax (Nouvelle-Écosse), à l'aide du SAR en bande C du CV-580 d'Environnement Canada, conjointement avec l'essai Q-277 du NAFC *Quest*.

Le présent rapport traite des expériences effectuées avec le radar à synthèse d'ouverture polarimétrique (PolSAR) les 6 et 7 octobre 2003.

Un site d'étalonnage radar a été établi à la BFC Shearwater. Ce site était constitué de quatre réflecteurs à coin (CR), quatre étalonneurs radar actifs (ARC) et deux stations de base GPS (système de positionnement mondial). La BFC Shearwater offre un terrain relativement plat et uniforme à faible réflectivité radar, ce qui a permis d'obtenir un rapport signal de cible/clutter (rapport S/C) élevé.

Dans les expériences effectuées avec le PolSAR, on a recueilli avec succès 11 images du NAFC *Quest* pour différents angles d'incidence, différents angles d'aspect et diverses conditions environnementales. Les premiers résultats indiquent que le navire se distingue nettement du clutter d'océan dans les images PolSAR. On a cependant observé plusieurs problèmes, notamment la défocalisation de l'image, l'ambiguïté en azimut et la saturation de la cible. Dans l'ensemble, les images du navire semblent présenter un effet de bavure en azimut, et on se penchera sur ce problème dans une analyse ultérieure.

Executive summary

The Quest-2003 Polarimetric Signature Trial was successfully conducted off the coast of Halifax, Nova Scotia, using the Environment Canada CV-580 C-band SAR in conjunction with the CFAV *Quest* trial Q-277.

This report addresses the polarimetric synthetic aperture radar (PolSAR) experiments that were conducted on 6 and 7 October 2003 for a known vessel at sea. The entire trial consisted of three separate sets of experiments: maritime moving-target indication (MMTI), wake and ocean observation, and polarimetric signature collection of a known vessel at sea.

The PolSAR experiments were designed to acquire imagery of CFAV *Quest* at sea to determine the effect of vessel velocity and motion on radar polarimetric signatures. The experiments were planned to optimise the collection of the CFAV *Quest* imagery with various *incidence angles* and *aspect angles,* and for various *environmental conditions*. These signatures are critical for supporting the development of ship detection and classification algorithms, for evaluation of ship detection performance analysis, and for ship velocity estimation. These signatures will be compared with simulation data that are being generated at DRDC Ottawa. Two flights, each consisting of 6 ship lines and 2 calibration site lines, were planned.

Although the trial was initially planned to occur entirely on a non-interference basis, portions of the original Cruise Plan for Q-277 were modified due to Hurricane *Juan*, which passed through the region one week prior to this trial. As a result, an opportunity arose for the DRDC Ottawa SAR experiment team to discuss specific requirements with the CFAV *Quest* crew prior to the trial, such as maintaining a constant ship course and speed during each data acquisition pass. In addition, ship motion data including heading, speed, three dimensional acceleration, and position for each radar pass were also requested.

The PolSAR data set was acquired using the airborne C-band fully polarimetric SAR sensor developed by the Canada Centre for Remote Sensing (CCRS) [1]. Prior to the trial, the inverse Surface Acoustic Wave (SAW^{-1}) portion of the radar system, which is normally used to carry out range compression, was modified to include a by-pass selection option that is intended to reduce point-target saturation problems that often arise in the raw data from this radar [2]. Both SAW^{-1} On and Off (by-pass) configurations of the radar receiver were used for this trial because the by-pass configuration had not previously been used.

A radar calibration site was established at CFB Shearwater. It was composed of four corner reflectors (CRs), four active radar calibrators (ARCs) and two Global Positioning System (GPS) base stations. CFB Shearwater offers relatively flat, uniform terrain with low radar reflectivity so that a high target-to-clutter ratio (TCR) was achieved.

During the PolSAR experiments, 11 CFAV *Quest* images were successfully collected with various incidence angles, aspect angles, and environmental conditions. Initial results indicate that the ship image is clearly distinguished from the ocean clutter in the PolSAR images. But several image problems have been noted including image defocus, azimuth ambiguities, and

target saturation. Furthermore, there may be evidence of signal data saturation, even for the SAW^{-1} Off configuration. Overall, most of the ship images appear to be smeared in the azimuth direction, an issue that will be the focus of subsequent analysis.

This report describes the trial plan, the calibration site setup, the data actually acquired and the initial data analysis results. The report also addresses the observed data problems and makes recommendations toward solving these problems.

Liu, C., Gallop, L. Schlingmeier, D. 2004. Quest-2003 Polarimetric Signature Trial. DRDC Ottawa TM 2004-207. Defence R&D Canada – Ottawa.

Sommaire

L'essai de signature polarimétrique Quest-2003 a été mené avec succès au large d'Halifax (Nouvelle-Écosse), à l'aide du SAR en bande C du CV-580 d'Environnement Canada, conjointement avec l'essai Q-277 du NAFC *Quest*.

Le présent rapport traite des expériences portant sur un navire connu en mer, effectuées avec le radar à synthèse d'ouverture polarimétrique (PolSAR) les 6 et 7 octobre 2003. L'essai complet consistait en trois séries d'expériences distinctes : indication de cible maritime mobile (MMTI), observation du sillage et de l'océan, et collecte de signature polarimétrique d'un navire connu en mer.

Les expériences PolSAR visaient à faire l'acquisition d'images du NAFC *Quest* en mer dans le but de déterminer l'effet de la vitesse et des mouvements du navire sur les signatures radar polarimétriques. Elles ont été planifiées de manière à optimiser la collecte d'images du NAFC *Quest* à différents *angles d'incidence* et *angles d'aspect,* dans diverses *conditions environnementales*. Les signatures en question constituent des éléments critiques pour le soutien de l'élaboration d'algorithmes de détection et de classification des navires, pour l'évaluation de l'analyse des performances de détection des navires, et pour l'estimation de la vitesse des navires. On les comparera avec les données de simulation qui sont produites à RDDC Ottawa. Deux vols, comprenant chacun 6 lignes de navire et 2 lignes de site d'étalonnage, ont été prévus.

Dans les prévisions initiales, l'essai devait s'effectuer entièrement sur une base sans interférence, mais des sections du plan de déplacement d'origine pour l'essai Q-277 ont été modifiées en raison du passage de l'ouragan *Juan* dans la région la semaine précédente. Cette situation a donné à l'équipe de RDDC Ottawa responsable de l'expérience menée avec le SAR l'occasion de discuter avec l'équipage du NAFC *Quest*, avant l'essai, d'exigences particulières telles que le maintien d'une vitesse et d'un cap constants du navire durant chaque passage d'acquisition de données. On avait aussi besoin de données relatives aux mouvements du navire, notamment au cap, à la vitesse, à l'accélération tridimensionnelle et à la position, pour chacun des passages du radar.

L'acquisition de l'ensemble de données PolSAR a été effectuée à l'aide du capteur SAR entièrement polarimétrique aéroporté exploitant la bande C, mis au point par le Centre canadien de télédétection (CCT) [1]. Avant l'essai, la partie onde acoustique de surface inverse (SAW^{-1}) du système radar, qui est normalement utilisée pour effectuer la compression en distance, a été modifiée de façon à comprendre une option de sélection de contournement visant à atténuer les problèmes de saturation de cible ponctuelle qu'on éprouve souvent avec les données brutes fournies par ce radar [2]. La configuration avec SAW^{-1} et la configuration sans SAW^{-1} (contournement) du récepteur radar ont toutes deux été utilisées pour cet essai, étant donné que la configuration de contournement n'avait pas été utilisée auparavant.

Un site d'étalonnage radar a été établi à la BFC Shearwater. Il était constitué de quatre réflecteurs à coin (CR), quatre étalonneurs radar actifs (ARC) et deux stations de base GPS (système de positionnement mondial). La BFC Shearwater offre un terrain relativement plat et

uniforme à faible réflectivité radar, ce qui a permis d'obtenir un rapport signal de cible/clutter (rapport S/C) élevé.

Dans les expériences effectuées avec le PolSAR, on a recueilli avec succès 11 images du NAFC *Quest* pour différents angles d'incidence, différents angles d'aspect et diverses conditions environnementales. Les premiers résultats indiquent que le navire se distingue nettement du clutter d'océan dans les images PolSAR. On a cependant observé plusieurs problèmes, notamment la défocalisation de l'image, l'ambiguïté en azimut et la saturation de la cible. De plus, d'après certaines indications, il pourrait y avoir saturation des données de signal, même avec la configuration de contournement de SAW^{-1}. Dans l'ensemble, la plupart des images du navire semblent présenter un effet de bavure en azimut, et on se penchera sur ce problème dans une analyse ultérieure.

Le présent rapport décrit le plan d'essai, la configuration du site d'étalonnage, les données réelles acquises et les premiers résultats de l'analyse des données. Il expose aussi les problèmes observés relativement aux données et il contient des recommandations en vue de leur résolution.

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1. Introduction

The Quest-2003 Polarimetric Signature Trial was successfully conducted off the coast of Halifax, Nova Scotia, using the Environment Canada CV-580 C-band SAR in conjunction with CFAV *Quest* trial Q-277.

This report addresses the polarimetric synthetic aperture radar (PolSAR) experiments that were conducted on 6 and 7 October, 2003 for a known vessel at sea. The entire trial consisted of three separate sets of experiments: maritime moving-target indication (MMTI), wake and ocean observation, and polarimetric signature collection of a known vessel at sea.

The main objective of the PolSAR experiments was to acquire imagery of CFAV *Quest* at sea to determine the effect of vessel velocity and motion on polarimetric signatures. These signatures are critical for supporting the development of ship detection and classification algorithms, for evaluation of ship detection performance analysis, and for ship velocity estimation. These signatures will be compared with simulated signatures that are being generated at DRDC Ottawa.

The experiments were planned to optimise the collection of the CFAV *Quest* imagery with various *incidence angles* and *aspect angles*, and for various *environmental conditions*. Considering all parameters of interest, two flights, each consisting of 6 flight lines over the ship and 2 flight lines over the calibration site, were planned.

Although the trial was initially planned to occur entirely on a non-interference basis, portions of the original Cruise Plan for Q-277 were modified due to Hurricane *Juan*, which passed through the region one week prior to this trial. As a result, an opportunity arose for the DRDC Ottawa SAR experiment team to discuss specific requirements with the CFAV *Quest* crew. CFAV *Quest* participated as a cooperative target maintaining a fixed course and a constant speed during each data acquisition pass. Unfortunately, the speed of CFAV *Quest* could not be specified a priori since the original experiment plan did not include CFAV *Quest* as a cooperative target in the Q-277 trial plan. Truthing information, such as the ship's log data including heading, speed, position and motion for each radar pass were obtained.

The PolSAR data was acquired using the airborne C-band fully polarimetric SAR sensor developed by the Canada Centre for Remote Sensing (CCRS) and flown on the Environment Canada (EC) Convair-580 (CV-580) airborne platform [1]. Prior to the trial, the inverse Surface Acoustic Wave (SAW^{-1}) portion of the radar system, which is normally used for range compression, was modified to include a by-pass option to reduce point-target saturation problems that often arise in the raw data from this radar [2]. Both SAW^{-1} On and Off (i.e. by-pass) configurations of the radar receiver were used for this trial to reduce risk because the by-pass configuration had not previously been tested during a trial.

Polarimetric calibration using reference calibrator devices with known scattering properties, such as corner reflectors (CRs) and active radar calibrators (ARCs), is essential for this radar. A radar calibration site was established at CFB Shearwater. It was composed of four corner reflectors (CRs), four active radar calibrators (ARCs) and two Global Positioning System (GPS) base stations. CFB Shearwater offers relatively flat, uniform terrain with low radar reflectivity so that a high target-to-clutter ratio (TCR) was achieved.

During the PolSAR experiments, 11 CFAV *Quest* images were successfully collected with various incidence angles, aspect angles, and environmental conditions. Initial results indicate that the ship image is clearly distinguished from the ocean clutter in the PolSAR images. But, several image problems have been noted including image defocus and azimuth ambiguities. Overall, most of the ship images appear to be smeared in the azimuth direction. A detailed investigation of this issue will be carried out as part of the data analysis activities.

This report describes the trial plan, the calibration site setup, the data actually acquired and the initial data analysis results. The report also addresses the observed data problems and makes recommendations toward solving these problems.

2. Experiment

2.1 Experiment Design

The Quest-2003 Polarimetric Signature Trial was combined with CFAV *Quest* trial Q-277. The purpose of the Polarimetric SAR experiment was to acquire data of the CFAV *Quest* at sea to determine the effects of vessel velocity and motion on polarimetric signatures. These signatures will be compared with simulated polarimetric signatures that are being generated at DRDC Ottawa. These signatures are critical for supporting the development of ship detection and classification algorithms, evaluation of ship detection performance, and ship velocity estimation.

There are many parameters to be considered when designing a trial, in which the number of SAR scenes that can be collected is limited. For example, the flight lines were selected to optimise the collection of CFAV *Quest* imagery with various *incidence angles* and *aspect angles* for various *environmental conditions*. The CV-580 SAR, originally developed by CCRS, can be operated either in right or left looking mode [1]. The aspect angle is defined by the aircraft heading relative to the target heading. Both the aircraft and the target heading are defined with respect to *True North* in this memorandum.

Another parameter to be considered was the SAW^{-1} configuration within the receiver. The present CV-580 SAR system has serious limitations for point-like targets. The system performs 6-bit digitization of the received signal after range compression, which is done in hardware (HW) [2]. To reduce the limitations of the CV-580 SAR for point-like targets during the trial, a switch was installed in the system to by-pass the HW range compressor in the high resolution mode of the SAR. The new configuration (i.e., SAW^{-1} Off) was used in some flight lines. The original SAW^{-1} configuration (i.e., SAW^{-1} On) was also used for some flight lines.

Polarimetric calibration using known calibration devices, including corner reflectors (CRs) and active radar calibrators (ARCs), is essential for this radar. Ideally, these known calibrators should be in the same scene as the targets of interest. However, in this mission, the target was about 240 nm from the calibration site, so it was impossible to obtain an image of the calibration site in the same scene as the targets of interest.

The CV-580 can fly approximately 5 mission hours from take off to landing. Under poor conditions, or with a distant alternate airport, the mission time may be reduced [3]. For mission planning purposes, the aircraft ground speed was chosen to be 240 knots at an altitude of 20,000 feet. The target for the mission, CFAV *Quest*, was assumed to be 240 nm from the airport. Therefore, the transit time from airport to the target was nominally 1 hour, and the transit time from the target back to the airport was also 1 hour. Since the airport was far from the target and useful alternate airports, the data acquisition plan was based upon a total mission time of 4 hours (i.e., two hours transit time and two hours data acquisition time).

For a point or small area target set, the data acquisition line length is usually 10 to 20 nm to ensure that the targets of interest are imaged. A 20 nm flight line was assumed for ship data acquisition and a 10 nm line was assumed for the calibration site. In addition to the data acquisition line length, the aircraft lead-in distance of 20 nm and lead-out distance of 20 nm must also be included. Therefore, the total flight line distance required for each acquisition is 60 nm, corresponding to about 20 minutes of flight time. Also, the aircraft needs about 5 minutes to turn after each line is completed. Therefore, the total flight time required for each data acquisition line is approximately 25 minutes.

For the PolSAR experiments, two flights were planned. Considering all of these constrains, we planned that each flight would consist of 6 flight lines over the ship and 2 flight lines over the calibration site.

We requested that the CFAV *Quest* be moving along a fixed course, preferably using a different speed for each of the aircraft passes (including stationary for one pass). During the radar passes, the CFAV *Quest* position, heading, and speed were recorded along with 3-axis accelerometer data. During the radar passes we requested that as much additional truthing as possible be recorded.

The planned flights and radar configuration parameters are summarized in Table 1 and an example of the planned flight lines is illustrated in Figure 1. In Table 1, the CFAV *Quest* heading is assumed to be 0° as a reference and the CV-580 heading is given relative to the CFAV *Quest* heading. For example, a CV-580 heading of 180° indicates that the CV-580 is parallel to CFAV *Quest,* but heading in the opposite direction.

Table 1. Planned flight and radar configuration parameters.

Line	θ_{inc} (°)	CV-580 heading relative to CFAV *Quest* heading (°)	SAR antenna look direction	SAW^{-1}	Objective
October 6					
CFAV *Quest*		**0** (reference)			
1	45	180	R	Off	CFAV *Quest*
2	45	225	R	Off	CFAV *Quest*
3	45	45	R	Off	CFAV *Quest*
4	35	225	L	Off	CFAV *Quest*
5	55	45	R	Off	CFAV *Quest*
6	45	270	L	Off	CFAV *Quest*
7 (Cal 1)	45	318	R	Off	Cal site
8 (Cal 2)	35	138	L	On	Cal site
October 7					
CFAV *Quest*		**0** (reference)			
1	35	180	R	On	CFAV *Quest*
2	35	225	R	On	CFAV *Quest*
3	45	45	R	On	CFAV *Quest*
4	35	225	L	Off	CFAV *Quest*
5	45	45	R	Off	CFAV *Quest*
6	35	270	L	On	CFAV *Quest*
7 (Cal 1)	45	318	R	Off	Cal site
8 (Cal 2)	35	138	L	On	Cal site

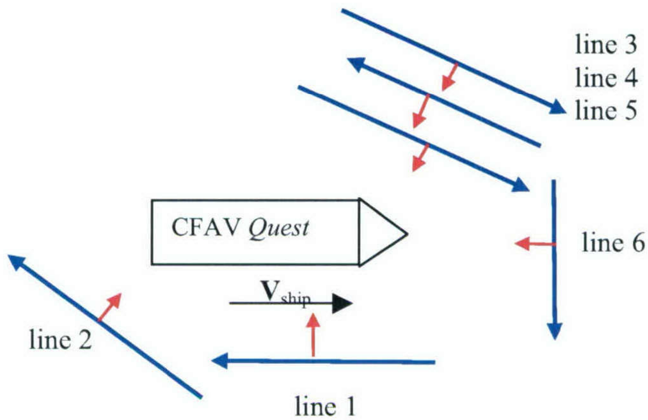


Figure 1. Example of proposed flight lines for the experiments.

2.2 Timing and Communications

Timing and communications are critical for a successful trial. During the experiments, the aircrew needed to contact the CFAV *Quest* in order to determine the vessel's current position, speed and course, so that the imagery acquisition could be carried out to meet the planned incidence angle and aspect angle criteria for each flight line. At the calibration site, the ground team must know when the aircraft is approaching the calibration site so that the required equipment can be switched on. The ground team must also know when the aircraft has finished a calibration line so that ARCs and CRs may be re-positioned in preparation for the next line. In order to allow for these successful exchanges, a communications plan was established prior to the experiment. This involved selection of communication frequencies for the calibration site and the CFAV *Quest*. The communication frequencies used in this trial were:

Calibration site: Air/Ground frequency 149.590 MHz, Ground/Ground frequency 148.075MHz; and

CFAV *Quest*: Air/Sea frequency 279.400 MHz, alternate 302.250 MHz.

The pilot of the EC CV-580 carried out communications either with the CFAV *Quest* captain or the calibration site team.

Universal Time Coordinated (UTC) was used for this trial. Daylight Savings is implemented in North America from the first Sunday in April to the last Sunday in October. In 2003, this fell on October 26th. Therefere, Daylight Savings Time was in force during the trials. During Daylight Saving Time, UTC was three hours ahead of the Halifax local time, i.e., when it was 1500 hrs UTC it was 1200 hrs Halifax local time.

3. Calibration

3.1 Calibration Site

Polarimetric calibration using calibrators with known scattering properties is essential for the CV-580 SAR radar. The trihedral corner reflectors (CRs) which have well-defined Radar Cross Section (RCS) are used to perform the radiometric calibration of the imagery for each scene. However, the CRs can only provide the amplitude calibration for an image. Therefore, active radar calibrators (ARCs) are used to calibrate the phase response between each channel for this radar.

The radar calibration site was established at CFB Shearwater, Nova Scotia. The equipment deployed at the calibration site included four CRs, four ARCs and two Global Positioning System (GPS) base stations. The GPS data is used to calculate an accurate CV-580 position through differential processing.

SAR imagery is acquired in slant range and azimuth coordinates. As such, the orientation and elevation of the CRs and ARCs were matched to the parameters of the flight line to obtain maximum radar returns. When deployed in an open field, a high target to clutter ratio (TCR) may be achieved over a ±20° deviation from the boresight of the corner reflector. However, the deviation from the boresight of the ARC's horn antenna can be only a few degrees since these devices have a much more directional response [4].

In order to obtain a high TCR, the calibration site requires a relatively flat, uniform terrain with low reflectivity. It also requires no obscuration from forest canopy within the data acquisition path of the airborne sensors. With consideration for these requirements and the geographical constraints imposed by the site, the eight radar calibrators were deployed on a coarse gravel surface, 7 m east of the West-Delta taxiway. The CRs were individually mounted on tripods using additional hardware, which allowed azimuth and elevation adjustments so that the direction of the corner boresight would align with the line-of-sight of the radar. In general, there was adequate time between the flight lines to allow the direction of the boresight to be changed to accommodate the corresponding radar incidence angle. The ARCs were similarly deployed on the ground, with changes to the horn orientation as dictated by the flight line parameters. By pointing the boresight of the calibrators at the expected location of the radar, the maximum radar signatures of CRs and ARCs would be present in the SAR imagery.

The calibration array was formed by alternately deploying CRs and ARCs with a 60 meter separation between each device. The overall line was 420 meters in length, along bearing of 318° T (True North) as indicated in Figure 3. There is a small treed area to the west across the taxiway,. The distance from the position of the CR named DREA across the taxiway to the tree line is 120 meters; a shadow angle of 8° at the CR was measured from the ground to the top of the tree line. This shadow angle was much lower than the designed depression angles of 45° and 65°. Therefore, the radar calibrators were not obscured by the trees. GPS positions of each calibration device deployment location were measured and recorded. Looking northeast, the West-Delta asphalt surface is 61 m wide, followed by 10 m of coarse gravel, then 20 meters of low cut grass, then light brush towards runway 16/34 (160°/340° Magnetic North).

The calibration site map and the equipment locations are indicated in Figure 2 and 3 respectively. The azimuth angles for all calibrators were set at 337.4° MN (Magnetic North), corresponding to 318° T. The conversion factor between true north and MN is obtained by subtracting the local magnetic declination of −19.4° for the Shearwater calibration site (i.e. 318° T − (−19.4°) = 337.4° MN). Magnetic North was used as a direction reference because a magnetic compass was used to set the azimuth angle of the calibration devices. The elevation angles of the calibration devices were measured using a digital level.

The detailed CR and ARC setups are discussed in Sections 5.2 and 5.3, respectively, and the detailed deployment set up, and ground photos of the calibration site, are presented in the Annex.

A Trimble GPS unit was used to perform the calibration site survey. The Trimble differential GPS (dGPS) track data was logged for the CFB Shearwater calibration site to identify the asphalt perimeter of the North and West-Delta taxiways, as shown in Table 2 and Figure 3. In addition, the track and position data collected was used to generate a scale map of the calibration site. The data was overlaid on a local map to place the calibration site and its components in context with the local topography.

In order to calculate an accurate aircraft position post mission for SAR image processing, two Ashtech Z12 GPS base stations were deployed. One was deployed over the survey benchmark (BM) 66D31 on the east side of runway 16/34 (see Figure 11 and Annex B), about 60 meters beyond the tarmac surface in low grass. The antenna height and position were measured with respect to the benchmark. The data from this base station was used as an absolute reference for the post trial differential correction software application. The generated corrections were used with data from the GPS receiver on board the CV-580 to derive accurate dGPS information required for processing of the SAR imagery. The calculated differential corrections are then applied to the GPS data set recorded aboard the CV-580, to better define the aircraft position and velocity. Given that the aircraft velocity is about 120 m/s, a 2 Hz data rate provides a position correction every 60 meters. The GPS base station setup is illustrated in Figure 12.

A second GPS base station was deployed at the north end of the West-Delta (see the tent in Figure 3), this station provides redundancy for the trial's critical data sets. The data logged could be used as a relative reference or the primary base station could be used to process and calculate an accurate position for the secondary base station.

Table 2. Geo-locations of calibrators.

Waypoint #	Position	Latitude	Longitude	Altitude (m)	EHE* (m)
West Delta	Tent	N 44 38 39.94743	W 063 30 37.60583	43.636	0.7
West Delta	Antenna	N 44 38 39.84495	W 063 30 37.90618	43.464	0.6
West Delta	CR DREA	N 44 38 39.45018	W 063 30 38.00003	43.863	0.6
West Delta	ARC PowerHog (1-2542)	N 44 38 37.97013	W 063 30 36.18846	43.611	0.7
West Delta	CR DREV	N 44 38 36.56396	W 063 30 34.35581	43.082	0.7
West Delta	ARC Germini (s/n 001)	N 44 38 35.12133	W 063 30 32.55101	42.808	0.7
West Delta	CR DREP	N 44 38 33.67597	W 063 30 30.75839	42.531	0.7
West Delta	ARC Serafina (1-2756)	N 44 38 32.20574	W 063 30 28.92664	42.100	0.7
West Delta	DREO	N 44 38 30.80309	W 063 30 27.08555	42.371	0.7
West Delta	ARC Noah	N 44 38 29.27335	W 063 30 25.22186	42.811	0.6
North Delta	GPS Antenna BM 66D31	N 44 38 51.05701	W 063 30 09.24675	41.625	0.6
North Delta	GPS Tent BM 66D31	N 44 38 51.19004	W 063 30 09.16106	41.500	0.8

EHE is estimate horizontal error.

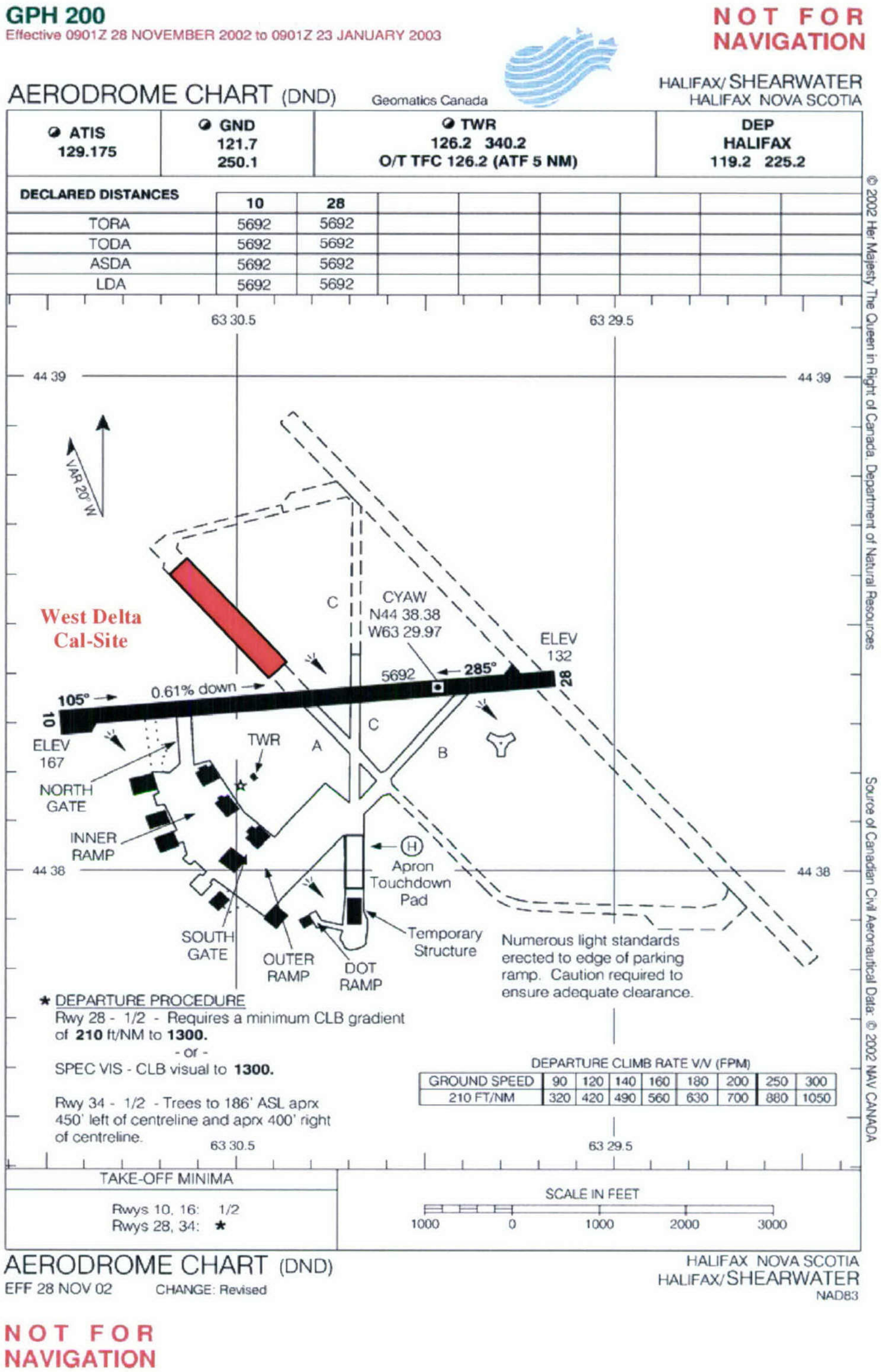


Figure 2. Shearwater calibration site area map.

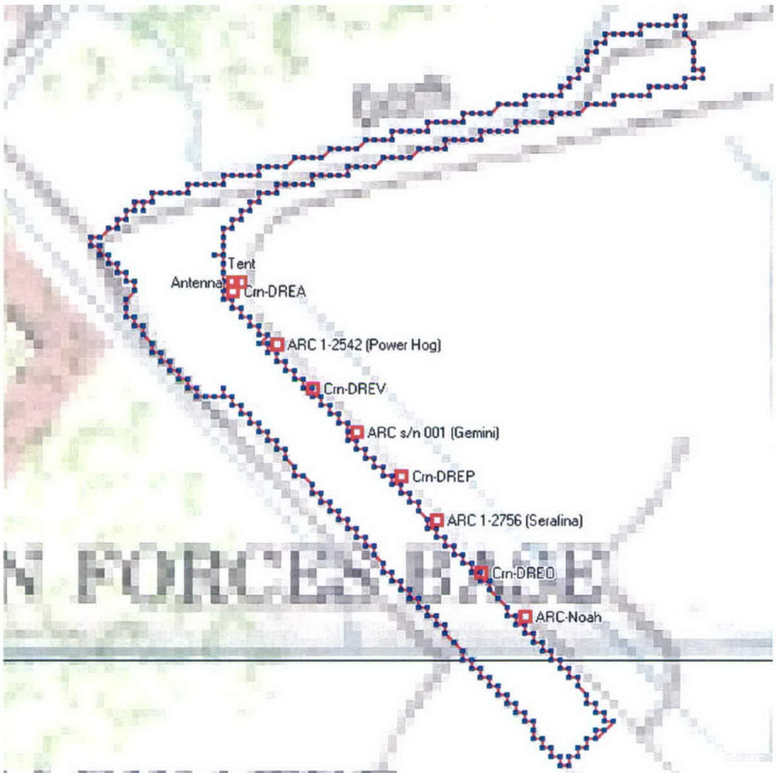


Figure 3. Calibration site survey map.

3.2 Corner Reflectors

Precision built trihedral corner reflectors have a well-defined RCS. Therefore, they are used to perform a radiometric calibration of each image. The maximum RCS of a trihedral corner reflector is given by [5]:

$$\sigma_{\max} = \frac{4 \cdot \pi \cdot b^4}{3 \cdot \lambda^2} \qquad (1)$$

where b is the length of the short (or box) side (see Figure 4 or 5) and λ is the wavelength of the incident wave.

In order to obtain the maximum RCS of a trihedral CR, the boresight of the CR should be aligned with the line-of-sight of the incident radar beam. In practice, an elevation angle was measured from a surface of the CR, which was measured as $90° - \theta_{inc} - \theta_{bore}$, where θ_{inc} is the incidence angle of the radar wave and θ_{bore} is the boresight angle of a trihedral CR, which is 35.2° (i.e. $\tan^{-1}(1/\sqrt{2})$, as shown in Figure 4. The trihedral CRs used in the trial were referred to as DREA, DREV, DREP and DREO. These CRs have similar dimensions and approximately the same RCS of 26 dB. The setup is illustrated in Figure 4 and 5.

Figure 4. Side view of CR showing the boresight direction.

Figure 5. Front view of CR setup.

3.3 Active Radar Calibrators

In polarimetric mode, the CV-580 SAR system alternately transmits H and V polarized electromagnetic waves from an antenna which is mounted on the aircraft and receives both the H and V polarized scattered waves simultaneously. Horn antennas are used in all ARCs. The receiver (R_X) horn of the ARC was to receive both horizontal (H) and vertical (V) polarized waves. The transmitter (T_X) horn of the ARC was configured to simultaneously re-transmit both H and V polarized waves with a delay [6]. With this configuration, the ARCs are used to estimate the relative gain and channel phase calibration of the imagery.

The peak RCS of an active radar calibrator is given by [4]:

$$\sigma_{pk} = \lambda^2 G^T G^R G_e / 4 \cdot \pi \tag{2}$$

where G^T, G^R are the transmit and receive antenna gains, G_e is the net gain of the ARC electronics. The desired RCS of the ARC is achieved by selecting amplifiers with the required gain. The antenna selection is determined by cross-polarization isolation, beamwidth, and gain requirements.

The antenna configuration of the DRDC Ottawa ARC that is referred to as Noah is illustrated in Figure 6 and 7. The setups for CCRS ARCs PowerHog (CCRS 1-2542), Serafina (CCRS 1-2756) and Gemini (CCRS 2-2811) are illustrated in Figure 8 through 10, respectively. The ARC Gemini failed to operate due to an RF cable problem during the trial.

Figure 6. ARC Noah antenna configuration.

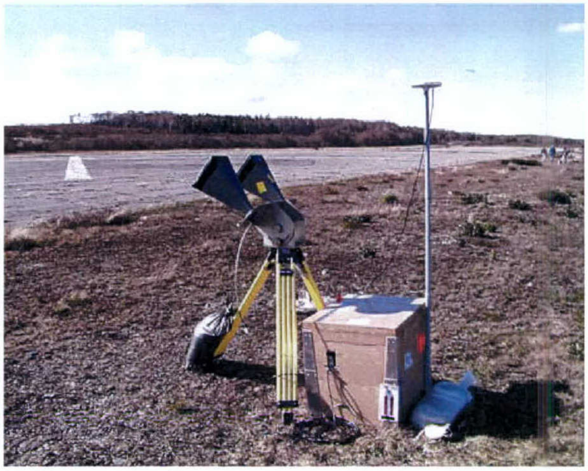


Figure 7. ARC Noah setup.

Figure 8. ARC PowerHog setup.

Figure 9. ARC Serafina setup.

Figure 10. ARC Gemini setup.

CFB Shearwater Survey Benchmark
Site Identification
Unique Number: 661516
Name: PM 66 D 31
Vertical Datum: CGVD28
Elevation: 41.160 m
Datum WGS 84 (calculated from NAD 27)
Latitude: N 44° 38’ 50.85590”
Longitude: W 063° 30’ 09.18413”
UTM: Zone = 20
Northing 4943911.71 m
Easting 0460149.14 m

Figure 11. Survey benchmark, PM 66 D 31.

Figure 12. GPS base station setup.

4. Polarimetric SAR Image Acquisition

The PolSAR stripmap data was acquired using the airborne C-band SAR sensor flown on the EC CV-580 aircraft. The Nadir mode [1] of the PolSAR sensor was used in the trial. Single look complex (SLC) imagery was generated using the PolGASP software run at DRDC Ottawa [7]. The resulting imagery has 4096 pixels across the swath, which is approximately 19 km wide. In the nadir mode, the incidence angle varies from $\theta = 28°$ to $\theta = 74°$, with a centre incidence angle of 57°. The imaging geometry used during the Quest-2003 trial is illustrated in Figure 13 [1, 7].

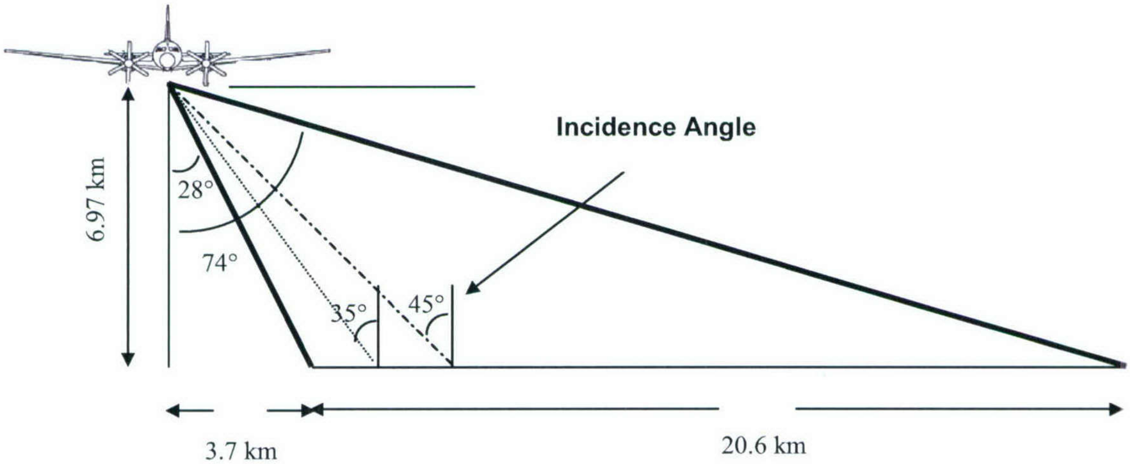


Figure 13. Geometry for the EC CV-580 PolSAR acquisition.

In the azimuth direction, the image coverage depends on the aircraft ground speed and the data acquisition time. In this trial, the azimuth distance during each acquisition was selected to be 20 nm (i.e., about 37 km).

The C-band (5.30 GHz, λ=5.66 cm) PolSAR sensor is a fully polarimetric system. There are four combinations of incident and scattered electric fields, HH, HV, VH, and VV, which are often described mathematically by a 2×2 scattering matrix, *S*, with components S_{HH}, S_{HV}, S_{VH} and S_{VV}. An *S* matrix is measured for each sample element (i.e., pixel) in an image. The components of *S* can be written as [9]:

$$S = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \qquad (3)$$

The C-band imagery products are calibrated using the ComplexCAL software developed by CCRS [8] and run at DRDC Ottawa together with an analysis of returns from the CRs and ARCs deployed at the SAR Calibration Site.

The incidence angle is illustrated in Figure 13. For an aircraft at a constant altitude above a flat earth, targets that are farther from the aircraft have a larger incidence angle than targets that are closer to the aircraft. To obtain a different incidence angle, the aircraft was flown at various lateral offset distance from the image centre. An aspect angle is defined by the difference between the angle of the aircraft heading and the CFAV *Quest* course. During the experiments, the radar receiver was operated with SAW^{-1} On configuration for some flight lines and SAW^{-1} Off configuration for the other flight lines.

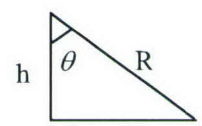
5. Initial Results

5.1 General

A total of 17 flight lines were successfully acquired, including 11 CFAV *Quest* images and 6 calibration site images (no image of CFAV *Quest* was collected in l4p5, October 6). Nine of these images were collected with the SAW^{-1} Off and 8 were collected with the SAW^{-1} On configuration. The actual key data acquisition parameters and the environmental conditions are indicated in Table 3 and the CFAV *Quest* motion is indicated in Table 3 and 4. The processed images are presented in an Annex.

The incidence angles θ_{inc} are calculated from the aircraft altitude and the slant range as:

$$\theta_{inc} = \cos^{-1}\left(\frac{h}{R}\right) \qquad (4)$$



where h is the aircraft altitude and R is the slant range.

The available azimuth integration time of each image can be derived as:

$$T_{\text{int}} = \varepsilon \cdot R / V \qquad (5)$$

where ε is the antenna azimuth beam width in radians, R is the slant range, and V is the aircraft ground speed. The azimuth integration time is used to calculate the aspect angle and to extract the ship motion and environmental conditions for each image.

The total number of pulses in each sample are defined by the product of the azimuth integration time and the pulse repetition frequency PRF of the transmitter as:

$$N_{pulse} = T_{\text{int}} \cdot PRF \qquad (6)$$

The aspect angle ϕ_{asp} is defined to be the angle of the aircraft heading relative to the CFAV *Quest* course (ϕ_{asp} = Aircraft Heading – Quest Course over Ground|. Both the aircraft heading and the CFAV *Quest* course are the average values during the azimuth integration time for each image, respectively. The aircraft heading was obtained from the dGPS data. The CFAV *Quest* course and speed were obtained from CFAV *Quest* log data identified as *DREO NADAS 6 Oct 03* and *DREO NADAS 7 Oct 03*. The CFAV *Quest* course and speed were extracted from the course over ground (COG) data and the speed over ground (SOG) in which wind effects are included. The CFAV *Quest* motion (pitch, roll) were extracted from CFAV *Quest* data files *6 Oct 03 Ship Motion* and *7 Oct 03 Ship Motion* [11]. The sampling rate for each data recording system is different. The aircraft GPS (latitude, longitude, height, heading, velocity) sampling rate is 2 Hz, the CFAV *Quest* NADAS (latitude, longitude, heading, velocity) sampling rate is 1 Hz, and the CFAV *Quest* Motion (pitch angle, roll angle) sampling rate is 4 Hz. Wind direction, velocity, and wave height measurement are sampled once per hour. The environmental condition data were obtained from the Lahave Bank weather station which is located at 42.5N, 64.02W, which is 125 km from the trial location.

Table 3. Actual data acquisition parameters and environmental conditions.

Asar No.	Line/ pass	θ_{inc} (°)	ϕ_{asp} (°)	Aircraft		CFAV *Quest*		Wind		Wave height (m)	SAW[-1]	SAR antenna look direction	Comments
				Heading (° T)	V (m/s)	COG (° T)	VOG (kts)	Course (° T)	V (m/s)				
October 6													
278	l1p2	52.3	2.7	254.7	116.9	252.0	5.3	168	3.3	2.0	Off	L	
279	l2p3	48.0	46.3	299.3	126.7	253.0	5.6	168	3.3	2.0	Off	L	GPS, MAID file problems are solved
280	l3p4	68.5	136.1	119.9	134.8	256.0	5.1	168	3.3	2.0	Off	L	Azimuth ambiguity
281	l4p5										Off	R	No ship
282	l5p6	57.5	135.5	122.5	135.5	258.0	5.6	167	1.6	1.9	Off	L	
283	l6p7	42.8	89.0	345.0	105.5	256.0	5.9	167	1.6	1.9	Off	R	Azimuth ambiguity
284	l33p8											R	Transit line, couldn't process
285	l7p9	22.3									Off	R	Cal line, no ARC
286	l8p10										On	L	Cal line, missed cal site
287	l8p11										On	R	Cal line, missed cal site
October 7													
288	l1p1	41.8	4.0	180.0	131.5	184.0	2.9	156	6.0	1.6	On	R	
289	l2p2	40.4	224.2	225.2	123.1	1.0	3.6	147	6.8	1.6	On	R	
290	l3p3	36.0	39.2	45.2	140.0	6.0	3.4	138	7.5	1.6	On	R	
291	l4p4	28.0	210.7	225.2	118.7	14.5	3.5	138	7.5	1.6	Off	L	
292	l5p5	57.1	128.2	44.8	141.4	173.0	4.4	138	7.5	1.6	Off	R	2 other vessels
293	l6p6	45.4	93.0	270.0	120.4	177.0	4.3	137	7.6	1.7	On	L	
294	l7p7	46.4									Off	R	Cal line
295	l7p8	48.3									On	L	Cal line
296	l8p9										On	R	Cal line, out of focus

Table 4. CFAV *Quest* motion.

File No	Line/ pass	Pitch Angle (°)	Pitch Rate (°/s)	Roll Angle (°)	Roll Rate (°/s)	Yaw Rate (°/s)	Long Acc (G's)	Lat Acc (G's)	Vert Acc (G's)
October 6									
278	l1p2	-0.0509	0.1525	-1.7466	0.0335	-0.5673	-0.0001	-0.0310	0.0002
279	l2p3	-0.3665	-0.3665	-1.5562	-0.5176	-0.7313	0.0003	-0.0143	-0.0029
280	l3p4	-0.1596	-0.2195	-1.9720	-0.0849	-0.5395	-0.0008	-0.0346	-0.0004
282	l5p6	-0.4629	-0.2446	-1.5337	-0.1264	-0.4717	0.0030	-0.0277	0.0086
283	l6p7	-1.0306	-0.5608	-2.6409	-1.1112	-0.3027	0.0048	-0.0345	0.0176
October 7									
288	l1p1								
289	l2p2								
290	l3p3	-0.1093	0.2517	-2.5849	0.5529	-0.1450	0.0001	-0.0557	-0.0188
291	l4p4	-0.5158	0.0160	-0.2532	0.3892	-0.2832	0.0043	-0.0043	-0.0108
292	l5p5	0.4379	-0.2668	0.1526	0.0380	-0.5541	-0.0028	0.0046	0.0010
293	l6p6	0.3042	-0.2631	-0.5446	-0.3906	-0.4458	-0.0013	-0.0063	-0.0066

Note that the first CFAV *Quest* motion measurement on October 7 was made from l3p3 acquisition.

5.2 Calibration Site

An example of a multi-polarized SAR image of the calibration site is shown in Figure 14, in which the magnitude of the HH channel is displayed in Red, the magnitude of VV in Blue, and the mean of the magnitudes of HV and VH in Green. Four CRs and four ARCs are evident in the image. This data was obtained from l7p7 on October 7, 2003, with an incidence angle of 45° and SAW^{-1} Off configuration. In Figure 14, the ARC Noah is seen close to azimuth pixel 220, followed by the CR DREO, ARC Serafina, CR DREP, ARC Gemini, CR DREV, ARC PowerHog, and the CR DREA. A bright spot close to azimuth pixel 1650 is a radar image of a truck which was parked at the end of the taxiway during the acquisition. Figure 14 also shows the recirculations from the ARCs. In order to validate the quality of the image, the target to clutter ratio, the image focus, and the saturation are verified using a CR.

A mean TCR of greater than 15 dB is obtained. An HH channel transect of deployed calibration devices in azimuth is shown in Figure 15, while a CR transect in range is shown in Figure 16.

The image focus can be verified by measuring the 3dB "width" of a CR response, in azimuth and range, respectively. An image is well focused when the –3dB "width" is 0.8 m in azimuth and 6 m in range with the SAW^{-1} On configuration. With the SAW^{-1} Off, the –3dB "width" should be the same as the SAW^{-1} On in azimuth, and slightly worse in range. This degradation in range is due to the fact that the sampling rate is not changed, but the maximum signal bandwidth is greater with the SAW^{-1} Off. With reference to the HH channel, Figure 17 shows a CR response with the SAW^{-1} Off configuration, the -3dB "width" of ~ 2.4 m in azimuth can be seen in a), and the –3 dB "width" of ~ 9.2 m in range can be seen in b). The azimuth –3dB "width" is much wider than it should be. This degradation may be due to data processing. However, the range –3 dB "width" of 9.2 m is poor compared to the SAW^{-1} On case. This degradation due to under sampling is expected.

Channel saturation was verified by using a histogram of the signal data. The results of the real and imaginary parts of the HH and VV channels are shown in Figure 19 through 22, respectively. The signal data are uniformly quantized from –64 to +64, therefore, there is no saturation observed in this image. However, the return from the ARC Noah was saturated. The gain of this ARC should be reduced before future deployment.

Six calibration lines were acquired. However, three lines from October 6 (l7p9, l8p10 and l8p11) are not usable for various reasons. The four CRs were seen in l7p9, however, none of the four ARCs were observed. The calibration site set up notes indicate that the CRs and ARCs were set for an incidence angle of 45°. However, analysis of the calibration site image indicates that the incidence angle was only 22° during the acquisition, which was 23° from the designed incidence angle of 45°. The calibration site was completely missed in l8p10 and l8p11. This problem is due to the error of the flight path and must be avoided at future trials since the calibration site is critical for data utilization. The three usable calibration lines are l7p7, l7p8 and l8p9 from October 7. Each of the calibration lines underwent quality control analysis prior to radiometric calibration of ship images.

The lines from 7 October were used for calibration of the data from both 6 & 7 October. Ideally, the calibration site should be within the same image as the targets of interest. This was not possible in our case, since the vessel was 240 nm from the calibration site, as described in Section 2.1. The impact of using calibration data from a different day can be minimized if atmospheric conditions are similar. To evaluate the importance of this impact, we suggest a detailed investigation using the MarCo Pola trial data (March 2004) in which the setup of the calibration site is similar to the Quest 2003 trial. We suggest comparing results when using calibration data from other days to the nominal case where calibration data for the correct day is applied. The results of this investigation will be very useful for future trial planning. If the impact is significant, the future trial plan should include a contingency line for the calibration site to ensure at least one calibration line per flight, and if the calibration site or the calibrators is missed during the flight, it would require an additional calibration line to be flown, even if this means that the aircraft must land, re-fuel and make another flight.

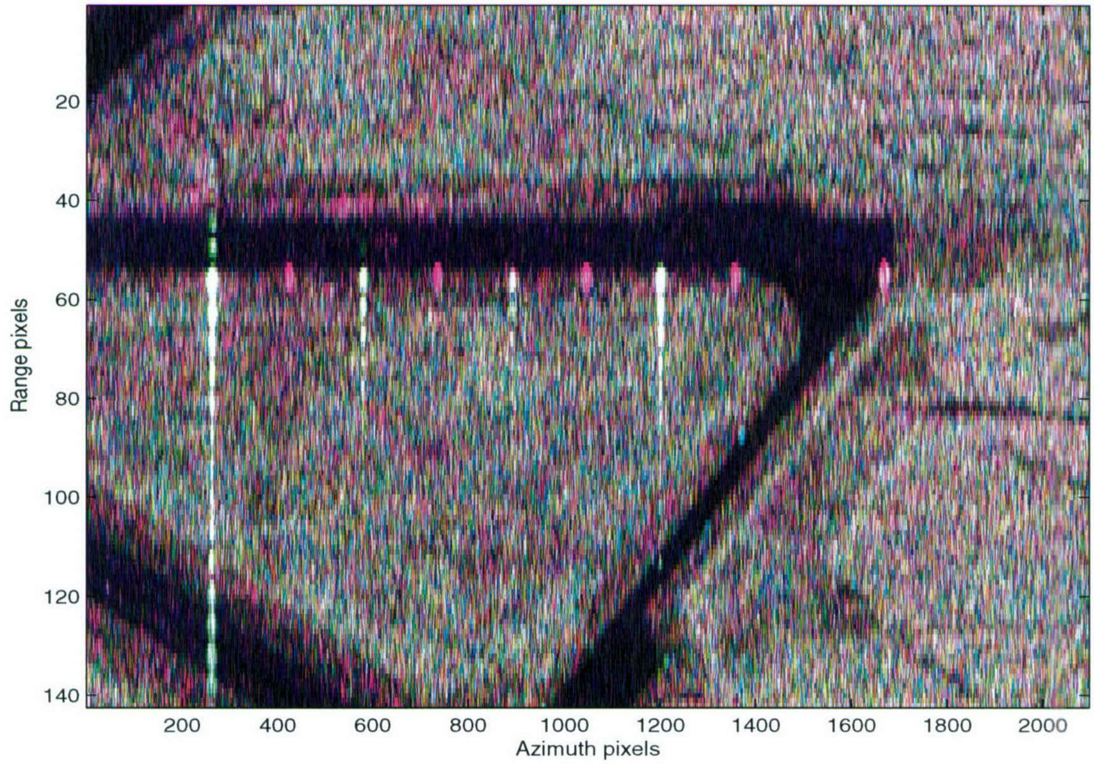


Figure 14. CV-580 polarimetric SAR image of the calibration site.

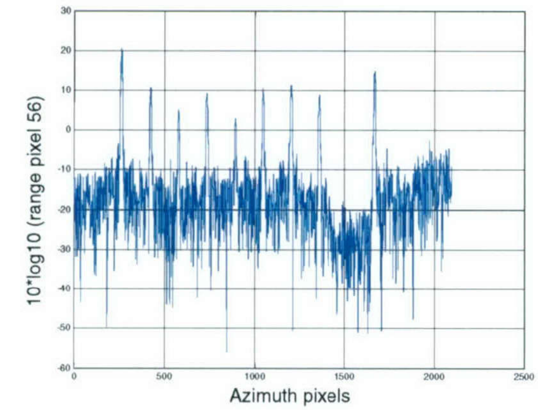


Figure 15. Image transect of deployed calibration devices in azimuth.

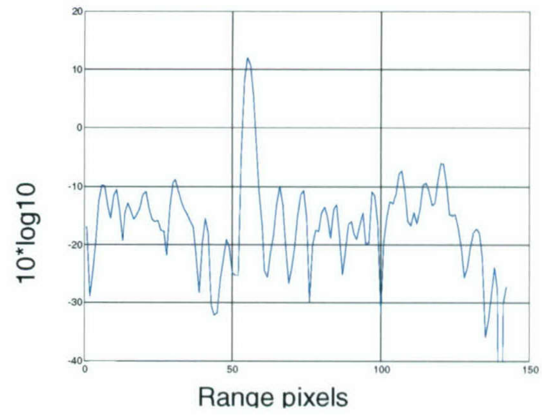


Figure 16. Image transect of a CR in range.

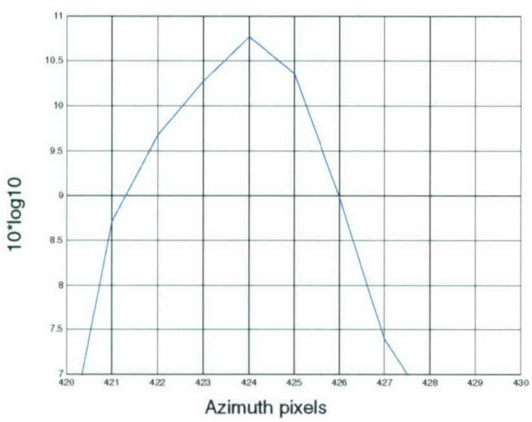


Figure 17. Transect of a CR in azimuth.

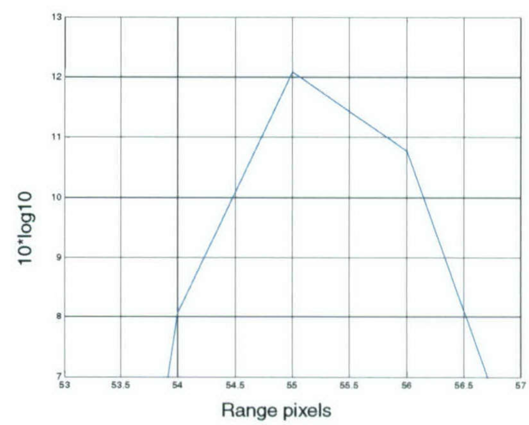


Figure 18. Transect of a CR in range.

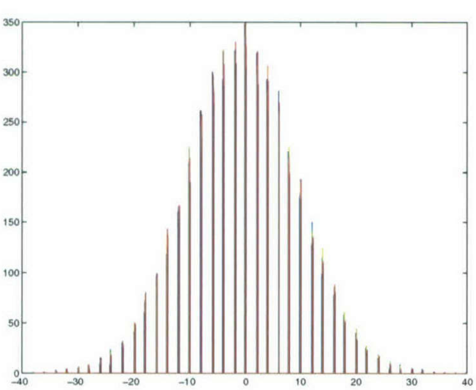


Figure 19. Histogram of the HH signal (real part).

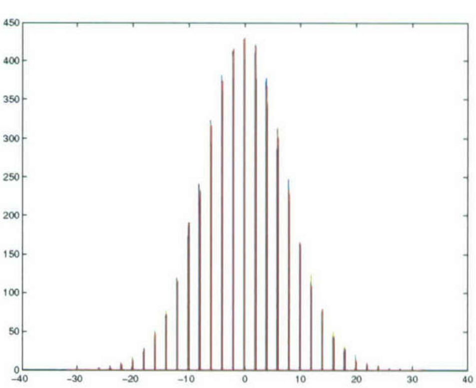


Figure 20. Histogram of VV signal (real part).

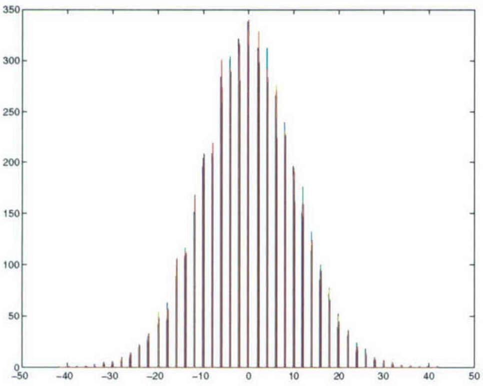


Figure 21. Histogram of the HH signal (imaginary part).

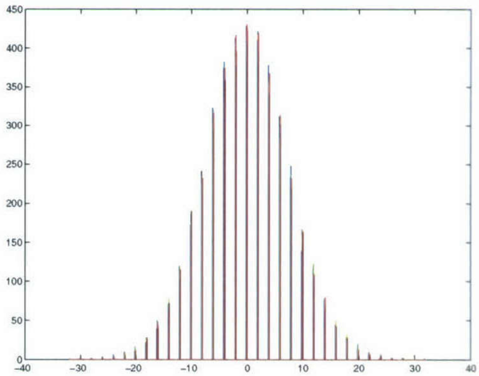


Figure 22. Histogram of the VV signal (imaginary part).

5.3 CFAV *Quest* Images

A photo of the CFAV *Quest* at sea is shown in Figure 23 and an example of a multi-polarized CV-580 SAR image of the CFAV *Quest* is shown in Figure 24. Herein, the magnitude of the HH channel is displayed in Red, the magnitude of VV in Blue, and the mean of the magnitudes of HV and VH is shown in Green. This data was obtained from 11p1 on October 7 2003, the key data acquisition parameters are summarized in Table 3. The dimensions of the CFAV *Quest* are 76 m × 12.6 m × 4.8 m (length × beam × draft).

The ship image is clearly distinguished from the ocean clutter. A detailed analysis of the trial data is ongoing. However, some of the ship images obtained during the trial appear to be smeared in azimuth. The reason for a smeared image is complex. It can be caused by ship motion and environmental conditions. Azimuth ambiguities are also observed in some images. A detailed investigation of these issues will be addressed in future analysis and research.

Figure 23. CFAV *Quest* at sea.

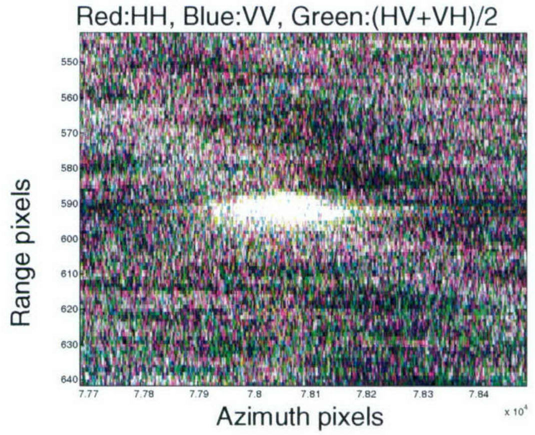


Figure 24. CV-580 polarimetric image of CFAV *Quest*.

5.4 CV-580 SAR Signal

The ARC Noah as deployed on the CFB Shearwater Cal-Site was able to capture a sample of the Convair 580 SAR signal. Figure 25 illustrates the receiver signal captured on October 7. While the pulse of the radar is only 7 μs in duration, the ARC circuitry stretches the pulse width to ~150 μs so that the ARC's analog-to-digital converter sample rate of 10,000 samples per second (100 μs) is able to measure the pulse. The SAR is set up with a PRF of ~660 Hz for both H and V planes and these are interlaced in a manner that generates a pulse at a 330 Hz rate. The H gain is 26 dB while the V gain is 24.8 dB at peak signal. However, there were a few issues observed during the trial: a complete radar pattern was not captured due to sample duration issues (see Figure 25), electromagnetic compatibility problems, the gain setting was too high and can not be adjusted in the field during the trial, etc. Modifications of the ARC are being considered for future trials.

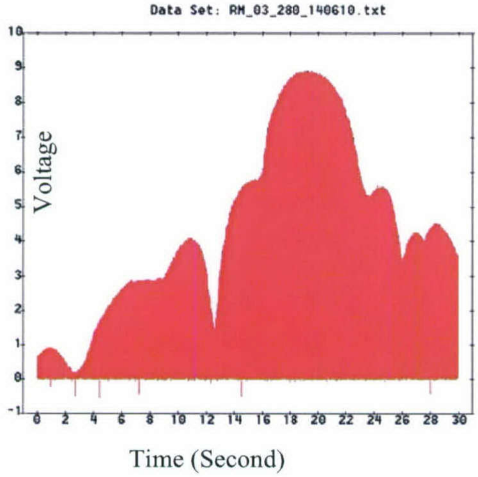


Figure 25. CV-580 azimuth radar pattern captured by Noah.

6. Conclusions and Recommendations

CFB Shearwater provides a relatively flat, uniform terrain with low reflectivity so that a high target-to-clutter ratio was achieved. In addition, the overall support from the CFB Shearwater staff was excellent, it is therefore recommended as a calibration site for future trials.

The new DRDC Ottawa ARC, called Noah, was tested. It has the potential to be very useful, since it has an automated control and data recording system. Data is logged only for the time period when the incident radar signal occurs. A number of modifications, such as improved operator-interface software, increased electromagnetic interference shielding, and reduced gain, are recommended. These will improve the functionality of the ARC and the utility of the data.

Analysis of the data indicated several problems including azimuth ambiguities, image defocus and target saturation. Overall, most of the ship images appear to be smeared in azimuth. To investigate this problem, the recommendations are provided as follows.

A point target, such as a corner reflector, can be used to verify the image quality. The image quality verification procedures described in Section 5.2 are recommended as a quality control measure.

To improve the image quality, other data processing methodologies, such as coherent sub-aperture or ISAR processing, will be explored in subsequent work.

7. References

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Annexes

A. Deployment of Corner Reflectors and ARCs

Table A1. Corner reflector deployment

Declination = -19.3°

Date: **Oct 4/03 - Oct 8/03**

Version Date: *2004/09/09*

Line	Direction to Aircraft	Corner Edge Alignment (Right to Left)	DREA			DREV			DREP			DREO		
		No local declination correction to compass	**Location - Lat / Lon** N 45° 38' 39.450" W 063° 30' 38.000"			**Location - Lat / Lon** N 45° 38' 36.564" W 063° 30' 34.356"			**Location - Lat / Lon** N 45° 38' 33.676" W 063° 30' 30.758"			**Location - Lat / Lon** N 45° 38' 30.803" W 063° 30' 27.086"		
			Az.	Corner Pitch (degrees from horizontal)		Az.	Corner Pitch (degrees from horizontal)		Az.	Corner Pitch (degrees from horizontal)		Az.	Corner Pitch (degrees from horizontal)	
Oct 4	SW	**337.4**	✓	**10.0**	9.9	✓	**10.0**	10.1	✓	**10.0**	9.9	✓	**10.0**	10.0
Oct 5 A	SW	**337.4**	✓	**4.9**	4.9	✓	**4.9**	5.0	✓	**4.9**	4.9	✓	**4.9**	4.9
Oct 5 B	SW	**337.4**	✓	**4.9**	4.9	✓	**4.9**	5.0	✓	**4.9**	4.9	✓	**4.9**	4.9
Oct 6 A	SW	**337.4**	✓	**10.0**	10.0	✓	**10.0**	10.0	✓	**10.0**	10.1	✓	**10.0**	9.9
Oct 6 B	SW	**337.4**	✓	**20.0**	20.0	✓	**20.0**	20.1	✓	**20.0**	20.0	✓	**20.0**	20.0
Oct 6 C	SW	**337.4**	✓	**20.0**	20.0	✓	**20.0**	20.1	✓	**20.0**	20.0	✓	**20.0**	20.0
Oct 7 A	SW	**337.4**	✓	**10.0**	9.9	✓	**10.0**	10.0	✓	**10.0**	10.0	✓	**10.0**	10.0
Oct 7 B	SW	**337.4**	✓	**20.0**	19.9	✓	**20.0**	20.0	✓	**20.0**	20.0	✓	**20.0**	19.9
Oct 7 C	SW	**337.4**	✓	**20.0**	19.9	✓	**20.0**	20.0	✓	**20.0**	20.0	✓	**20.0**	19.9
Oct 8	SW	**337.4**	✓	**10.0**	10.1	✓	**10.0**	10.1	✓	**10.0**	9.9	✓	**10.0**	10.0

Table A2. Active radar calibrator deployment

Declination = -19.3°

Date: **Oct 4/03 - Oct 8/03**

Version Date: 2004/09/09

			Power Hog (CCRS 1-2542)									**Gemini (CCRS 2-2811)**							
		No local declination correction to compass	**Location - Lat / Lon** N 44° 38' 37.970" W 063° 30' 36.188"									**Location - Lat / Lon** N 44° 38' 35.121" W 063° 30' 32.551"							
				ARC Transmit Orientation		ARC Receive Orientation		ARC Pitch (degrees from horizontal)				ARC Transmit Orientation		ARC Receive Orientation		ARC Pitch (degrees from horizontal)		
Line	Direction to Aircraft	ARC Edge Alignment (Right to Left)	Az.						Left	Right	Az.						Left **(Tx)**	Right **(Rx)**
Oct 4	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**44.8**	44.7	44.8	✓	**H**	H	**H**	H	**44.8**	45.2	45.1
Oct 5 A	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**49.8**	49.7	49.8	✓	**V**	H	**V**	H	**49.8**	50.0	49.4
Oct 5 B	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**49.8**	**Aborted**		✓	**H**	H	**H**	H	**49.8**	**Aborted**	
Oct 6 A	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**44.8**	44.6	44.7	✓	**H**	HV	**H**	HV	**44.8**	44.7	44.6
Oct 6 B	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**34.7**	34.5	34.6	✓	**H**	HV	**H**	HV	**34.7**	34.8	34.8
Oct 6 C	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**34.7**	34.5	34.6	✓	**H**	HV	**H**	HV	**34.7**	34.8	34.8
Oct 7 A	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**44.8**	44.8	44.7	✓	**V**	HV	**V**	HV	**44.8**	44.7	44.8
Oct 7 B	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**34.7**	34.8	34.8	✓	**V**	HV	**V**	HV	**34.7**	34.7	34.9
Oct 7 C	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**34.7**	34.8	34.8	✓	**V**	HV	**V**	HV	**34.7**	34.7	34.9
Oct 8	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**44.8**	44.9	44.8	✓	**H**	H	**H**	H	**44.8**	44.8	44.8

			Serafina (CCRS 1-2756)									**Noah (DRDC-Ottawa)**							
		No local declination correction to compass	**Location - Lat / Lon** N 44° 38' 32.206" W 063° 30' 28.927"									**Location - Lat / Lon** N 44° 38' 29.273" W 063° 30' 25.222"							
				ARC Transmit Orientation		ARC Receive Orientation		ARC Pitch (degrees from horizontal)				ARC Transmit Orientation		ARC Receive Orientation		ARC Pitch (degrees from horizontal)		
Line	Direction to Aircraft	ARC Edge Alignment (Right to Left)	Az.						Left **Rx**	Right **Tx**	Az.						Left	Right
Oct 4	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**44.8**	44.7	44.5	✓	**H**	H	**H**	H	**44.8**	44.8	44.8
Oct 5 A	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**49.8**	49.7	49.5	✓	**V**	H	**V**	H	**49.8**	49.8	49.8
Oct 5 B	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**49.8**	**Aborted**		✓	**V**	H	**V**	H	**49.8**	**Aborted**	
Oct 6 A	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**44.8**	44.7	44.8	✓	**HV**	HV	**HV**	HV	**44.8**	44.8	44.8
Oct 6 B	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**34.7**	34.8	34.5	✓	**HV**	HV	**HV**	HV	**34.7**	34.7	34.8
Oct 6 C	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**34.7**	34.8	34.5	✓	**HV**	HV	**HV**	HV	**34.7**	34.7	34.8
Oct 7 A	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**44.8**	44.9	44.8	✓	**HV**	HV	**HV**	HV	**44.8**	44.7	44.7
Oct 7 B	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**34.7**	34.8	34.6	✓	**HV**	HV	**HV**	HV	**34.7**	34.7	34.7
Oct 7 C	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**34.7**	34.8	34.6	✓	**HV**	HV	**HV**	HV	**34.7**	34.7	34.7
Oct 8	SW	**337.4**	✓	**HV**	HV	**HV**	HV	**44.8**	44.8	44.7	✓	**H**	H	**H**	H	**44.8**	44.6	44.8

B. NRCan Survey Monument Reference

SITE IDENTIFICATION

Unique Number : 661516
Name : PM 66 D 31
Established By : Mapping And Charting Establishment
Province : NS
Prov. Identifier : None
NTS Map No : 011D12

STATION COORDINATES

Method : Scaled
Latitude : N44° 38' 49"
Longitude : W63° 30' 11"
Agency : Geodetic Survey Division - NRCan
UTM : Zone = 20 N = 4943861 m E = 460113 m

VERTICAL DATA

Vertical Datum : CGVD28
Elevation : 41.160 m
Order : Adjusted Unclassified
Method : Differential
Adjustment Line : NOVA105
Published Year : 1989

STATION MARKER INFORMATION AND LOCATION

Marker Type : Permanent Agency Marker
Inspected in : 1989
Status : Good
Inspection Comments : No inspection text on file

Accessible by passenger car or light truck and a walk of less than 50 m

MKR TYPE D SETTING CODE 04

LOC AT CFB SHEARWATER AIRPORT APPROX 100 M E FROM INTER OF C/L RUNWAY 16-34 AND CHARLIE TAXIWAY ON THE GRASS SURFACE, 75 M NE FROM EDGE OF RUNWAY, 80 M N FROM THE WOODED AREA AND 105 M SE FROM STA "8915004". MKD BY A DND BRASS TAB, STPD "66D31", SET IN A SQUARE CONC MON 2.5 CM ABOVE GRD LVL.

HISTORICAL COORDINATES NOTE: Coordinates listed below are no longer maintained by GSD and should be verified with your provincial agency before use.

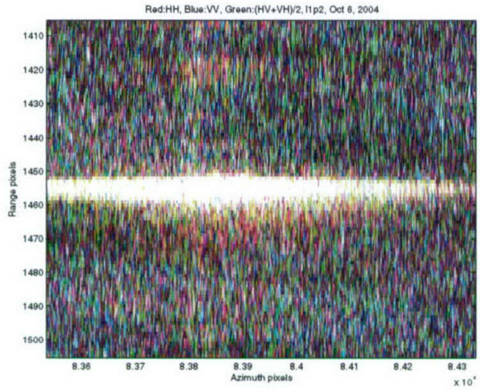
Horizontal Datum : NAD27
Method : Electronic Traversing
Latitude : N44° 38' 50.70000"
Longitude : W63° 30' 11.53000"
UTM : Zone = 20 N = 4943690.353 m E = 460096.268 m

PROJECTS IDENTIFIERS:
D693911

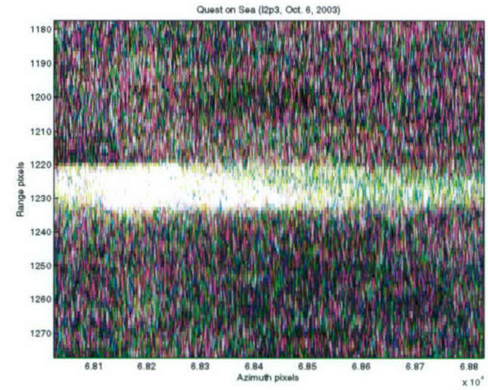
C. Initial Image Results

The initial results of the Quest-2003 trial are presented in this section. All image chips shown in this section are CV-580 polarimetric SAR image of CFAV *Quest* at sea. The image chips in Figure 26 were obtained on 6 October 2003, while the image chirps in Figure 27 were obtained on 7 October 2003. In these Figures, the magnitude of the HH channel is displayed in Red, the magnitude of VV in Blue, and the mean of the magnitudes of HV and VH is shown in Green. The key radar parameters and the environmental conditions for each image are indicated in Table 3 and 4 of Section 5.1.

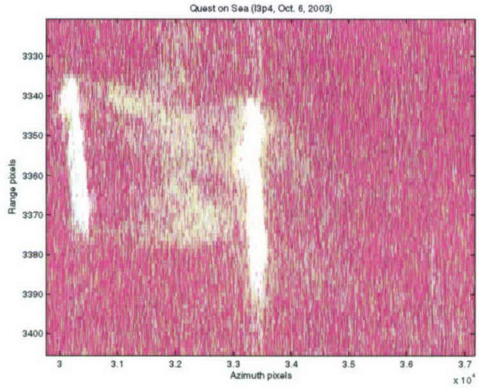
Figure 26. Polarimetric images obtained on 6 October 2003.



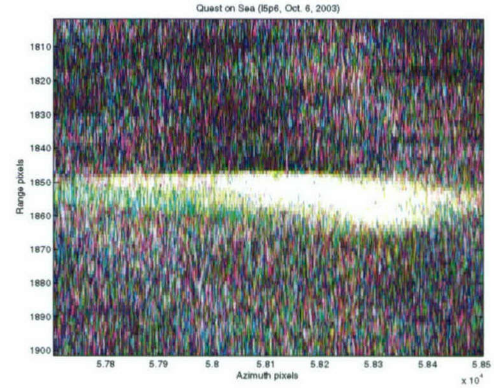
a. l1p2.



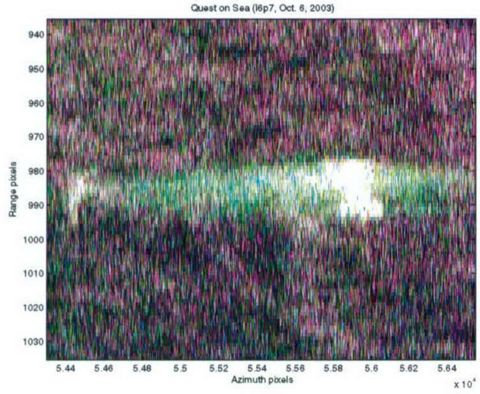
b. l2p3.



c. l3p4.

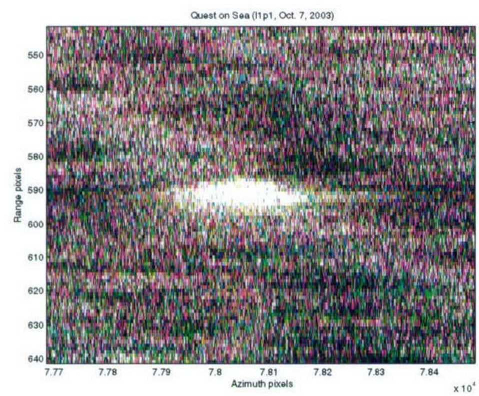


d. l5p6.

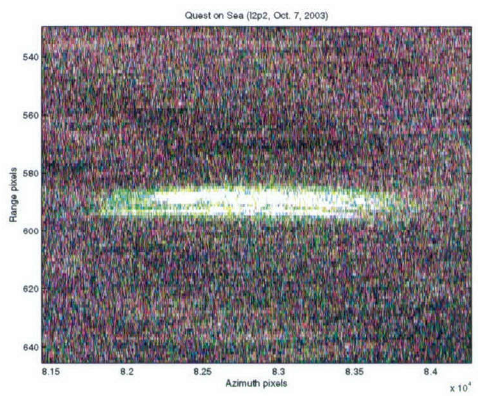


e. l6p7.

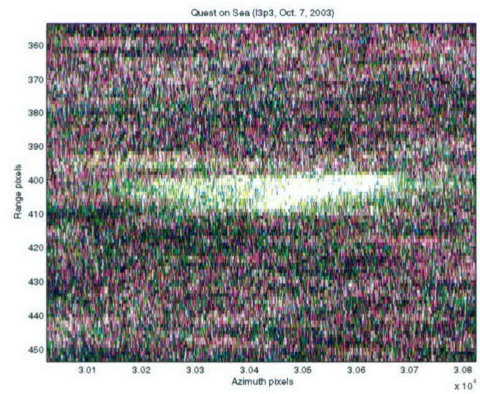
Figure 27. Polarimetric images obtained on 7 October 2003.



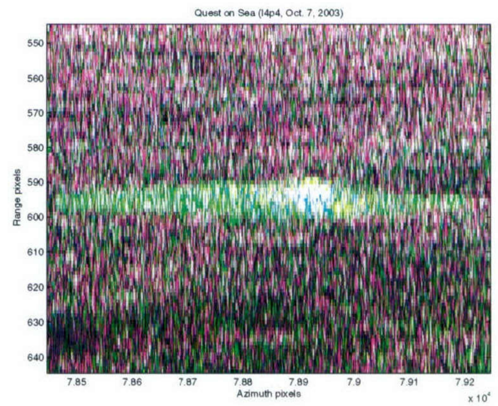
a. l1p1.



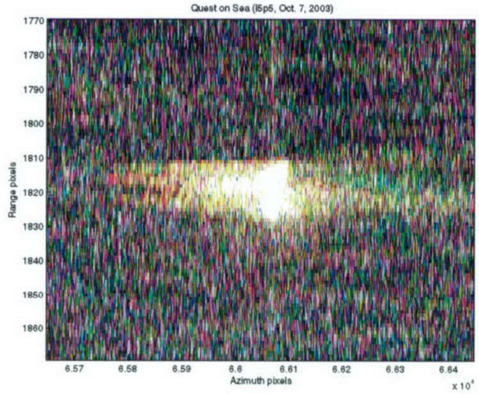
b. l2p2.



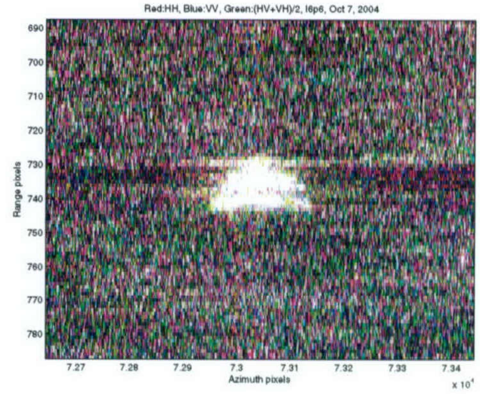
c. l3p3.



d. l4p4.


Quest on Sea (l5p5, Oct. 7, 2003)
Range pixels
1770
1780
1790
1800
1810
1820
1830
1840
1850
1860
6.57
6.58
6.59
6.6
6.61
6.62
6.63
6.64
Azimuth pixels
x 10^4

e. l5p5.


Red:HH, Blue:VV, Green:(HV+VH)/2, l6p6, Oct 7, 2004
Range pixels
690
700
710
720
730
740
750
760
770
780
7.27
7.28
7.29
7.3
7.31
7.32
7.33
7.34
Azimuth pixels
x 10^4

f. l6p6.

D. Calibration Site Ground Truth Photographs

Selected photos of the calibration site are showing in Figure 28 in deployed sequence.

Figure 28. Selected photos of the calibration site at CFB Shearwater.

a. ARC Noah and surroundings.

b. CR DREO and surroundings.

c. ARC Serafina and surroundings.

d. CR DREP and surroundings.

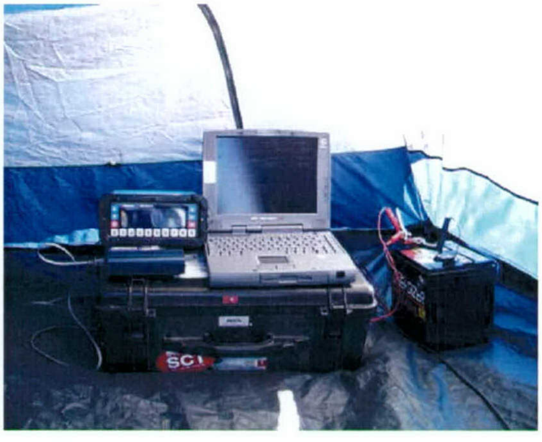
e. ARC Germini and surroundings.

f. CR DREV and surroundings.

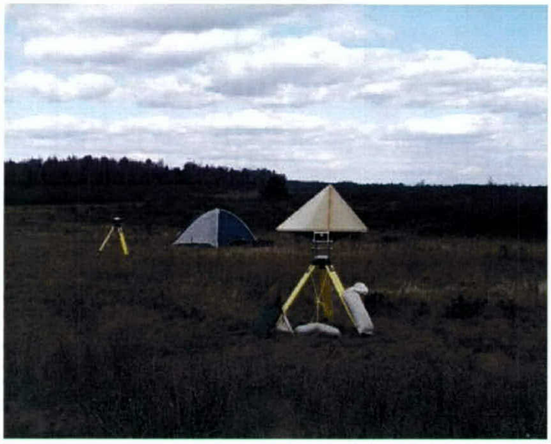
g. ARC PowerHog and surroundings.

h. CR DREA and a GPS station (GPS antenna and receiver in the tent).

i. CR DREA facing a tree canopy area.



j. GPS base station 2 (near CR DREA).



k. GPS base station 2 (antenna (left) and receiver in the tent) and CR DREA (right).

l. GPS base station 1 receiver (set on BM 66D31).

List of symbols/abbreviations/acronyms/initialisms

ARC	Active Radar Calibrator
AZ	Azimuth
BM	benchmark
CCRS	Canada Centre for Remote Sensing
CFAV	Canadian Forces Auxiliary Vessel
CFB	Canadian Forces Base
COG	Course Over Ground
CR	Corner Reflector
CV-580	Convair-580
dB	Decibel
dGPS	Differential Global Positioning System
DND	Department of National Defence
DRDC	Defence Research and Development Canada
D Space D	Director of Space Development
EC	Environment Canada
EHE	Estimate horizontal error
GPS	Global Positioning System
GR	Ground Range
L	Left
L#p#	Line # and pass # of the flight
GMTI	Ground Moving-Target Indication
MN	Magnetic North
nm	nautical mile
NADAS	Non-Acoustic Data Acquisition System

PolSAR	Polarimetric SAR
R	Right
RCS	Radar Cross Section
SAR	Synthetic Aperture Radar
SAW	Surface Acoustic Wave
SAW^{-1}	Inverse Surface Acoustic Wave
SLC	Single Look Complex
SOG	Speed over Ground
SR	Slant Range
T, TN	True North
TCR	Target-to-Clutter Ratio
UTC	Universal Time Coordinated

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(U) The Quest-2003 Polarimetric Signature Trial was successfully conducted off the coast of Halifax, Nova Scotia, using the Environment Canada CV-580 C-band SAR in conjunction with the CFAV Quest trial Q-277.
This report addresses the polarimetric synthetic aperture radar (PolSAR) experiments that were conducted on 6 and 7 October, 2003.

(U) A radar calibration site was established at CFB Shearwater. It was composed of four corner reflectors (CRs), four active radar calibrators (ARCs) and two Global Positioning System (GPS) base stations. CFB Shearwater offers relatively flat, uniform terrain with low radar reflectivity so that a high target-to-clutter ratio (TCR) was achieved. During the PolSAR experiments, 11 CFAV Quest images were successfully collected with various incidence angles, aspect angles, and environmental conditions. Initial results indicate that the ship image is clearly distinguished from the ocean clutter in the PolSAR images. But, several image problems have been noted including image defocus, azimuth ambiguities, and target saturation. Overall, the ship images appear to be smeared in the azimuth direction, an issue that will be the focus of subsequent analysis.

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Polarimetric, Polarimetric Synthetuc Aperture Rasar (SAR), Polarimetric signature

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