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# Expendable Trihedral Corner Reflectors for Target Enhancement and Position Control in RADARSAT-1 Fine Beam Mode SAR Imagery:

*Results from an Exercise Narwhal Pre-Trial Deployment*

Jason Norris, Paris W. Vachon, David Schlingmeier,
Ryan English and Lloyd Gallop

**Defence R&D Canada – Ottawa**
TECHNICAL MEMORANDUM
DRDC Ottawa TM 2004-197
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Canada

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# Abstract

In August 2004 Defence Research and Development Canada (DRDC) Ottawa will participate in Exercise Narwhal, which will be held on Baffin Island. The objectives of Exercise Narwhal are to exercise the Canadian Forces' (CF) role in supporting the Nunavut territorial government's response to a crisis within the Canadian Forces Northern Area (CFNA), to exercise Headquarters CFNA, and to exercise Canadian sovereignty by projecting a CF presence within the North. One activity within Exercise Narwhal is simulation of the recovery of a crashed rocket and satellite payload. For this activity, expendable trihedral Corner Reflectors (CRs) will be distributed over an area of approximately 3200 $km^2$ to increase the radar reflectivity of the crash site. In preparation, DRDC Ottawa conducted a mini trial in May 2004. The objective of the mini trial was to validate the methodology of determining the pointing angles of the trihedral CRs, to assess the visibility of trihedral CRs of different sizes in RADARSAT-1 fine beam mode imagery, and to obtain a coincident Synthetic Aperture Radar (SAR) dataset with Ground Control Points (GCPs). Trihedral CRs of various sizes were deployed at Connaught Range and other trihedral CRs were deployed throughout the National Capital Region (NCR); three fine beam mode RADARSAT-1 passes were acquired. All deployed CRs were visible with the exception of the smallest, which had a 30 cm back spine dimension, thus validating the deployment methodology. The visibility of trihedral CRs depends upon the normalized RCS of the background against which they are deployed. The smallest CR visible had a back spine dimension of 45 cm. A problem with the RADARSAT-1 orbit resulted in only two of the three images containing all of the GCPs; however, two coincident SAR images with GCPs were produced and are available for SAR geometry studies. Prior to this exercise SAR imagery with ground control was not readily available.

# Résumé

En août 2004, Recherche et développement pour la défense Canada (RDDC) - Ottawa prendra part à l’exercice Narwhal, qui aura lieu sur l’île Baffin. L’exercice Narwhal a pour objectifs de mettre à l’essai la capacité des Forces canadiennes (FC) à soutenir les interventions du gouvernement territorial du Nunavut en cas de crise dans le Secteur Nord des Forces canadiennes (SNFC), de mettre à l’essai la capacité du Quartier général – SNFC et de faire respecter la souveraineté canadienne en projetant la présence des FC dans le Nord. Une activité de l’exercice Narwhal consiste à simuler la récupération d’une charge utile de fusée et de satellite écrasés. Pour cette activité, des réflecteurs en trièdre non réutilisables seront déployés au-dessus d’une région d’environ 3200 $km^2$ afin d’accroître la réflectivité radar du site d’écrasement. En prévision de l’exercice, RDDC Ottawa a effectué un mini-essai au cours de mai 2004. Le mini-essai visait à valider la méthode de détermination des angles de pointage des réflecteurs en trièdre, à évaluer la visibilité de réflecteurs en trièdre de différentes tailles dans l’imagerie du mode à faisceau de précision de RADARSAT-1 et à produire un ensemble de données coïncidentes de radar à ouverture synthétique (ROS) couvrant les points de contrôle terrestres (GCP). Des réflecteurs en trièdre de différentes tailles ont été déployés au Polygone de Connaught et d’autres réflecteurs en trièdre l’ont été dans l’ensemble de la région de la capitale nationale (RCN); trois passages de RADARSAT-1 ont été effectués dans un mode à faisceau de précision. Tous les réflecteurs déployés étaient visibles, sauf le plus petit, dont la dorsale était de 30 cm, ce qui valide la méthode de déploiement. La visibilité des réflecteurs en trièdre dépend de la SER normalisée de l’arrière-plan sur lequel s’effectue le déploiement. Le plus petit réflecteur visible présente une dorsale de 45 cm. En raison d’un problème lié à l’orbite de RADARSAT-1, seulement deux des trois images contenaient tous les GCP; deux images coïncidentes de ROS couvrant les GCP ont toutefois été produites et sont disponibles pour des études de géométrie ROS. Avant cet exercice, il n’était pas facile d’obtenir une imagerie ROS avec contrôle terrestre.

# Executive summary

In August 2004 Defence Research and Development Canada (DRDC) Ottawa will participate in Exercise Narwhal, which will be held on Baffin Island. The objectives of Exercise Narwhal are to:

- Exercise the Canadian Forces' (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's (CFNA) area of responsibility;
- Exercise Headquarters CFNA in the planning and conduct of joint operations required to fulfil selected assigned defence tasks;
- Exercise Canadian sovereignty by projecting a CF presence within the North.

One activity is the simulation of the recovery of a crashed rocket and satellite payload The Exercise Narwhal scenario considers a warship, including ground troops, being sent by a belligerent nation to locate and retrieve the remains of the crashed satellite. The CF will be tasked to locate and retrieve the satellite remains, monitor the belligerent warship, and locate the belligerent nation's camp on the island, using various sensors. RADARSAT-1 fine beam mode imagery will be the principal satellite data employed for land surveillance. For Exercise Narwhal, DRDC Ottawa has provided expendable trihedral Corner Reflectors (CRs) that will be deployed over an area of approximately 3200 km$^2$ to increase the radar reflectivity of the satellite crash sites.

In preparation for Exercise Narwhal, DRDC Ottawa conducted a mini trial in May 2004, during which three RADARSAT-1 fine beam mode images of the National Capital Region (NCR) were acquired. Prior to the acquisitions, expendable trihedral CRs of differing back spine dimensions[1] were deployed at Connaught Range in the deployment configuration recommended for Exercise Narwhal. Additional trihedral CRs were deployed throughout the overlapping regions of the swaths for ground control purposes to ensure the Synthetic Aperture Radar (SAR) images could be used for image geometry analyses as well. The latitude and longitude of the CRs were measured using a differential Global Positioning System (GPS) unit. The objectives of this deployment 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;

[1] Refer to Figure D.1 in Annex D for a clarification of this term.

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

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

Of the five trihedral CRs deployed at Connaught Range (30, 45, 60, 75, and 100 cm) all were visible in all SAR acquisitions except the smallest one (30 cm). The larger trihedral CRs (100 cm) that were deployed throughout the NCR were also visible in all SAR acquisitions. This indicates that aligning the trihedral CR boresight with the mid-swath point of the beam mode of interest is an acceptable method for establishing the elevation angle of the CR, at least for purposes of target detection for position control.

The targets identified in the imagery were verified using the Canada Centre for Remote Sensing (CCRS) VUSAR software: the latitude and longitude coordinates of each trihedral CR, acquired using a differential GPS unit, as well as the theoretical Radar Cross Section (RCS), were compared to the latitude, longitude, and RCS values computed using VUSAR. 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, the longitude errors were larger for GCPs at higher altitudes.

A change in the RADARSAT-1 orbit, which occurred during a routine manoeuvre, caused a 20 km Westerly shift (approximately) in swaths acquired during the month of May. Consequently, the second acquisition did not contain all of the trihedral CRs deployed. The beam mode selected for the third was altered from Fine 2 Near to Fine 3 to accommodate this shift, and as a result two coincident SAR images covering all GCPs were acquired.

Norris, J., Vachon, P.W., Schlingmeier, D., English, R., Gallop, L. 2004. Expendable Trihedral Corner Reflectors for Target Enhancement and Position Control in RADARSAT-1 Fine Beam Mode SAR Imagery: Results from an Exercise Narwhal Pre-Trial Deployment. DRDC Ottawa TM 2004-197. Defence R&D Canada – Ottawa.

# Sommaire


En août 2004, Recherche et développement pour la défense Canada (RDDC) - Ottawa prendra part à l'exercice Narwhal, qui aura lieu sur l'île Baffin. L'exercice Narwhal a pour objectifs :

- de mettre à l'essai la capacité des Forces canadiennes (FC) à soutenir les interventions du gouvernement territorial du Nunavut en cas de crise ainsi que la gestion ultérieure de l'événement dans la zone de responsabilité du Secteur Nord des Forces canadiennes (SNFC);
- de mettre à l'essai la capacité du Quartier général – SNFC en matière de planification et de conduite des opérations conjointes nécessaires à l'exécution de certaines tâches de défense assignées;
- de faire respecter la souveraineté canadienne en projetant la présence des FC dans le Nord.

Une activité consiste à simuler la récupération d'une charge utile de fusée et de satellite écrasés. Selon le scénario de l'exercice Narwhal, un navire de guerre, à bord duquel se trouvent des troupes au sol, est envoyé par un pays belligérant pour localiser et récupérer les restes du satellite écrasé. Les FC auront pour tâche de localiser et de récupérer les restes du satellite, de surveiller le navire de guerre belligérant et de localiser le camp du pays belligérant sur l'île, à l'aide de divers détecteurs. L'imagerie obtenue dans le mode à faisceau de précision de RADARSAT-1 fournira les principales données de satellite servant à la surveillance terrestre. Pour l'exercice Narwhal, RDDC Ottawa a fourni des réflecteurs en trièdre non réutilisables qui seront déployés au-dessus d'une région d'environ 3200 km$^2$ afin d'accroître la réflectivité radar du site d'écrasement du satellite.

En prévision de l'exercice Narwhal, RDDC Ottawa a effectué, au cours de mai 2004, un mini-essai durant lequel trois images de la région de la capitale nationale (RCN) ont été acquises dans un mode à faisceau de précision de RADARSAT-1. Avant les acquisitions, des réflecteurs en trièdre non réutilisables, caractérisés par des dorsales de dimensions différentes[2], ont été déployés au Polygone de Connaught, dans la configuration recommandée pour l'exercice Narwhal. D'autres réflecteurs en trièdre ont été déployés dans l'ensemble des régions chevauchantes des couloirs balayés à des fins de contrôle terrestre, de façon que les images du radar à ouverture synthétique (ROS) puissent également servir à l'analyse géométrique des images. La latitude et la longitude des réflecteurs en trièdre ont été mesurées au moyen d'un système de positionnement global (GPS) différentiel. Ce déploiement visait les objectifs suivants :


[2] Des détails à ce sujet se trouvent sur la figure D.1 de l'annexe D.

1. Valider la méthode utilisée pour déterminer les angles d'azimut et de site permettant que les réflecteurs en trièdre soient visibles durant les passages ascendants et descendants de l'imagerie dans un mode à faisceau de précision de RADARSAT-1.

2. Évaluer la visibilité de réflecteurs en trièdre de différentes tailles dans l'imagerie de mode à faisceau de précision de RADARSAT-1.

3. Produire un ensemble de données multi-temporelles de ROS couvrant des points de contrôle terrestres (GCP).

Des cinq réflecteurs en trièdre déployés au Polygone de Connaught (30, 45, 60, 75 et 100 cm), tous étaient visibles dans les images du ROS, sauf le plus petit (30 cm). Les plus grands réflecteurs en trièdre (100 cm) déployés dans l'ensemble de la RCN étaient également visibles dans toutes les acquisitions du ROS. Cela signifie que l'alignement de l'axe de visée des réflecteurs en trièdre par rapport au milieu du couloir de balayage dans le mode d'intérêt constitue une méthode acceptable pour établir l'angle de site du réflecteur, au moins pour la détection de cibles à des fins de contrôle de position.

Les cibles identifiées dans l'imagerie ont été vérifiées à l'aide du logiciel VUSAR du Centre canadien de télédétection (CCT). Les coordonnées de latitude et de longitude de chaque réflecteur en trièdre, acquises au moyen d'un GPS différentiel, ainsi que la section équivalente radar (SER) théorique ont été comparées aux valeurs de latitude, de longitude et de SER calculées à l'aide de VUSAR. Les comparaisons des SER ont indiqué des écarts d'au plus 3 dB tandis que les erreurs de latitude et de longitude demeuraient relativement constantes pour chaque acquisition. Comme le logiciel VUSAR ne tient pas compte des changements d'altitude, les erreurs de longitude étaient supérieures aux GCP des plus hautes altitudes.

Un changement d'orbite RADARSAT-1, qui s'est produit durant une manœuvre courante, a occasionné un déplacement de 20 km (environ) vers l'ouest dans les couloirs balayés au cours du mois de mai. Par conséquent, la deuxième acquisition n'a pas permis d'inclure tous les réflecteurs en trièdre déployés. Pour la troisième acquisition, on est passé du mode de faisceau à précision 2 rapprochée au mode à précision 3 afin de tenir compte du déplacement, de sorte que deux images coïncidentes de ROS couvrant tous les GCP ont été acquises.

Norris, J., Vachon, P.W., Schlingmeier, D., English, R., Gallop, L. 2004. Expendable Trihedral Corner Reflectors for Target Enhancement and Position Control in RADARSAT-1 Fine Beam Mode SAR Imagery: Results from an Exercise Narwhal Pre-Trial Deployment. DRDC Ottawa TM 2004-197. R & D pour la défense Canada – Ottawa.

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# 1. Introduction

In August 2004 Defence Research and Development Canada (DRDC) Ottawa will participate in Exercise Narwhal, which will be held on Baffin Island. The objectives of Exercise Narwhal are to exercise the Canadian Forces' (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's (CFNA) area of responsibility, to exercise Headquarters CFNA in the planning and conduct of joint operations required to fulfil selected assigned defence tasks, and to exercise Canadian sovereignty by projecting a CF presence within the North. One activity is simulation of the recovery of a crashed rocket and satellite payload. For Exercise Narwhal, DRDC Ottawa has provided expendable trihedral Corner Reflectors (CRs) that will be deployed over an area of approximately 3200 $km^2$ to increase the radar reflectivity of the satellite crash sites.

The Exercise Narwhal scenario considers a warship, including ground troops, being sent by a belligerent nation to locate and retrieve the remains of the crashed satellite. The CF will be tasked to locate and retrieve the satellite remains, monitor the belligerent warship, and locate the belligerent nation's camp on the island, using various sensors. Commercial Satellite Imagery (CSI) is being used as a key component of these capabilities. The purpose of CSI in this exercise is 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 time to the CF. RADARSAT-1 fine beam mode imagery will be the principal satellite data employed for land surveillance, while ScanSAR imagery will be used for maritime surveillance.

In preparation for Exercise Narwhal, DRDC Ottawa conducted a mini trial in May 2004, during which three RADARSAT-1 fine beam mode images of the National Capital Region (NCR) were acquired. Prior to the acquisitions, expendable trihedral CRs of differing back spine dimensions[3] were deployed at Connaught Range in the deployment configuration recommended for Exercise Narwhal. Additional trihedral CRs were deployed throughout the overlapping regions of the swaths for ground control purposes to ensure the Synthetic Aperture Radar (SAR) images could be used for image geometry analyses as well. The latitude and longitude of the CRs were measured using a differential Global Positioning System (GPS) unit. The objectives of this deployment 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;

[3] Refer to Figure D.1 in Annex D for a clarification of this term.

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

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

This Technical Memorandum summarizes the methodology used to determine the trihedral CR azimuth and elevation angles, the procedures that were followed for trihedral CR deployment, the results that were obtained from the RADARSAT-1 imagery analysis, and the recommended trihedral CR configuration and deployment instructions for Exercise Narwhal. Included in the annexes of this document are the trihedral CR deployment instructions for the min-trial and for Exercise Narwhal. With the exception of minor formatting changes, these documents are unaltered from the final approved versions. They have been included to ensure that all pre-Exercise Narwhal activities have been documented.

# 2. Visibility of Trihedral Corner Reflectors in SAR Imagery

A trihedral CR is a precision-built passive radar calibration device that is composed of three right-triangular metal panels configured to form a perfect scattering corner [1]. When the boresight of the trihedral CR is pointed optimally, a reasonably compact trihedral CR provides a rather large and well-known Radar Cross Section (RCS) that can be used as a radiometric calibration reference. The RCS of a trihedral CR is maximum when it is pointed directly along the boresight of the SAR antenna. The methodology to determine the orientation is discussed in Annex A. The beamwidth of a trihedral CR is rather broad (having a 3 dB beamwidth of 40° in both elevation and azimuth), so trihedral CRs are fairly tolerant to installation errors. However, the peak RCS is reduced if the trihedral CR is not optimally deployed.

For Exercise Narwhal, it is proposed to deploy expendable trihedral CRs of plywood and metal sheet construction as positional references within the SAR image and to enhance the radar reflectivity of the satellite crash sites. A description of the trihedral CR construction process is included in Annex C. To ensure the visibility and detection of the trihedral CRs in the RADARSAT-1 fine beam mode imagery, the CRs must be an appropriate size. For an optimally pointed trihedral CR, the RCS is [1]:

$$\sigma = 4.19\frac{a^4}{\lambda^2}, \qquad (1)$$

where $\sigma$ is the RCS in metres-squared, $\lambda$ is the radar wavelength in meters (0.056 m for C-band), and $a$ is the back spine dimension of the trihedral CR in meters. The detectability of the trihedral CR will vary depending upon the normalized RCS, $\sigma_o$, of the background clutter against which the CR is deployed. This is expressed as a signal-to-clutter ratio (SCR), $S$, which is given by [2]:

$$S = \frac{\left(\dfrac{\sigma}{\rho_a \rho_r}\right)}{\sigma_o}, \qquad (2)$$

where $\rho_a$ is the azimuth and $\rho_r$ is the ground range resolution of the radar (both of which are nominally 8 m for RADARSAT-1 fine beam mode data)[4].

[4] Note that [2] defines the SCR in terms of the slant range resolution instead of the ground range resolution i.e. $\rho_r = \rho_s/\sin\theta_i$, where $\rho_s$ is the slant range resolution and $\theta_i$ is the incidence angle.

Substituting and re-arranging, we can express the required trihedral CR size as a function of the SCR and $\sigma_o$:

$$a = \left( \frac{1}{4.19} S \sigma_o \lambda^2 \rho_a \rho_r \right)^{1/4}, \qquad (3)$$

which is plotted in Figure 1 as a function of the clutter level for various signal-to-clutter ratios. Note that RADARSAT-1 fine beam mode data are processed to 1-look, corresponding to a radiometric resolution of 3 dB. In general, it is desirable to have at least a 15 dB signal-to-clutter ratio in order to guarantee detectability. For a clutter level of −10 dB, a trihedral CR with back spine length larger than 0.6 m is required. It is possible to detect smaller trihedral CRs provided that the background clutter level is low or if a lower signal-to-clutter ratio can be tolerated.

The ability to identify smaller targets is improved by using additional contextual information such as the location of the smaller targets relative to known targets. Furthermore, the trihedral CRs may be sub-optimally deployed, thus reducing their RCS. As such, it was decided that an array of trihedral CRs would be deployed for Exercise Narwhal. The array will consist of 5 expendable trihedral CRs of 5 different sizes with smaller trihedral CRs bracketed by larger ones, thus providing an opportunity to detect and identify the smaller trihedral CRs in the SAR imagery. Based upon the availability of existing equipment, the chosen array will be composed of 5 trihedral CRs, each spaced by roughly 100 m along a straight line, and arranged in the following size order: 100 cm, 60 cm, 30 cm, 45 cm, 75 cm. This array concept was deployed and tested during the Exercise Narwhal pre-trial activities.

It should be noted that the software used to perform the point target analysis of the trihedral CRs (VUSAR), computes the peak-to-clutter ratio (PCR) instead of the SCR. The PCR, defined as the ratio of the peak value of the target response and the mean clutter level, is a good measure of target detectability. The PCR is closely related to the SCR, which amounts to the ratio of the integral over the target response and the mean clutter level. For certain target response shapes the PCR and the SCR are identical. A more in-depth comparison of the PCR and SCR can be found in [2].

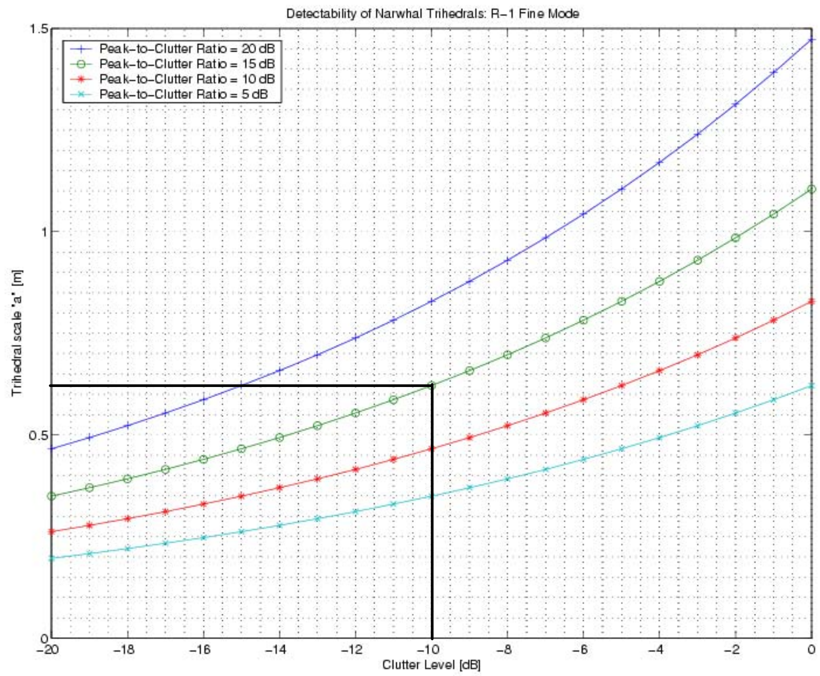



***Figure 1: Trihedral CR back spine length as a function of clutter level for signal-to-clutter ratios of 5, 10, 15, and 20 dB.***

# 3. Pre-Trial Set-Up

## 3.1 Imagery Acquisition

For the pre-trial deployment three RADARSAT-1 fine beam mode acquisitions were scheduled. These acquisitions were initially set for 30 April, and 7 and 8 May 2004. However, due to a change in the RADARSAT-1 orbit, the acquisition on 30 April was lost and was rescheduled for 15 May. A summary of the acquisitions is shown in Table 1.

***Table 1: RADARSAT-1 imagery acquisition summary.***

| DATE | SCENE ID | TIME (UTC) | BEAM MODE | DIRECTION |
|---|---|---|---|---|
| 7 May 2004 | P0369632 | 22:59 | Fine 2 Near | Ascending |
| 8 May 2004 | P0368694 | 11:09 | Fine 2 Near | Descending |
| 15 May 2004 | P0368677 | 11:09 | Fine 3 | Descending |

Prior to the first acquisition, trihedral CRs were deployed at specific locations throughout the NCR to serve as GCPs. The locations were selected based on the swath coverage predicted by the Swath Planning Application (SPA) and the deployment area was limited to the overlapping region of the swaths. The specific deployment regions were as follows:

- Communications Research Centre (CRC) Campus
- Connaught Range
- Connaught Range Area 5
- CRC Area 6
- Cantley
- Munster
- Canada Centre for Remote Sensing (CCRS) Calibration Site
- RADARSAT-1 Calibration Transponder Site

The overlapping portion of the swath coverage and the GCP locations are shown in Figure 2. For the 7 and 15 May acquisitions the swath covered all of the GCPs, while for the 8 May acquisition three locations were missed (Cantley, the CCRS Calibration Site, and the RADARSAT Calibration Transponder Site). This was not considered a problem since coverage of Connaught Range in all 3 images was the requirement to meet objectives 1 and 2, and coverage of all GCPs in two images was the requirement to meet objective 3.

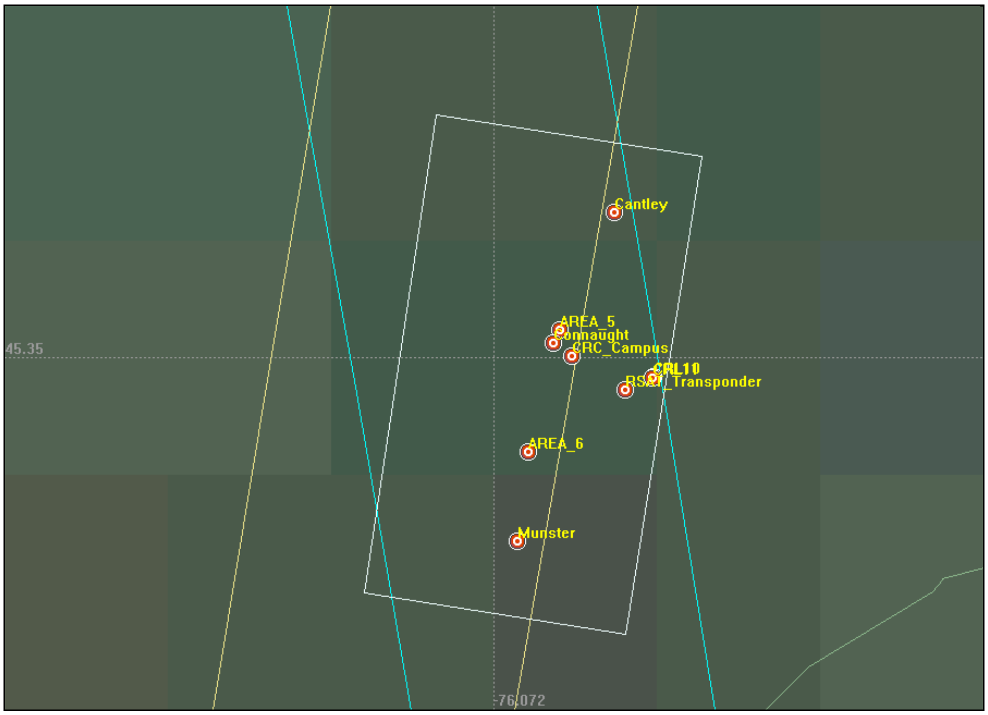



***Figure 2: Swath coverage of GCP locations for 7, 8, and 15 May 2004.***

## 3.2 Trihedral Corner Reflector Deployment

With the exception of the CCRS Calibration Site and the RADARSAT-1 Calibration Transponder Site, a total of eleven trihedral CRs were deployed at the locations shown in Figure 1: six at Connaught Range (expendable trihedral CRs with back spine dimensions of 30, 45, 60, 75, and 100 cm) including DREA (a reorientable tripod mounted trihedral CR), and one expendable trihedral CR at each of the remaining locations (with back spine dimension 100 cm). Because the CCRS Calibration Site is equipped with trihedral CRs mounted on pedestals, there was no need to deploy any additional trihedral CRs at this location. The RADARSAT-1 Calibration Transponder is easily visible in SAR imagery and therefore no trihedral CRs were deployed at this site either.

The azimuth and elevation angles for the trihedral CRs were computed such that the boresight aligns with the nominal incidence angle at mid-swath of the beam mode of interest. Table 2 summarizes these values for the three acquisition dates. The derivation of the pointing angles is included in Annex A.

***Table 2: Nominal corner reflector pointing angles.***

| DATE | CORNER ELEVATION | TRACK ANGLE | CORNER AZIMUTH | LOOK DIRECTION |
|---|---|---|---|---|
| 7 May 2004 | 14.4° ± 2° | 350.4° | 262.9° ± 5° | East |
| 8 May 2004 | 14.4° ± 2° | 189.6° | 97.1° ± 5° | West |
| 15 May 2004 | 14.4° ± 2° | 189.6° | 97.1° ± 5° | West |
| Note: In the original acquisition plan all three images were to be acquired using the Fine 2 Near beam mode. However, the acquisition on 15 May was acquired using the Fine 3 beam mode. The boresight elevation was not altered to reflect a change in mid-swath incidence from 40.3° to 42.5°. However, given an elevation error budget of ±2° the trihedral CRs should still be visible in the imagery. | | | | |

Figure 3 shows the SAR image acquired on 7 May 2004, a close-up of the Connaught Range site, and the ground-truthing photos of the trihedral CRs deployed at this site. The azimuth and elevation for each trihedral CR was set using a compass and a digital level, respectively. Trihedral CRs were held in place using sandbags. The deployment instructions for the trihedral CRs are included in Annex B. The latitude and longitude of each trihedral CR was measured using a differential GPS unit after set-up and again before teardown.

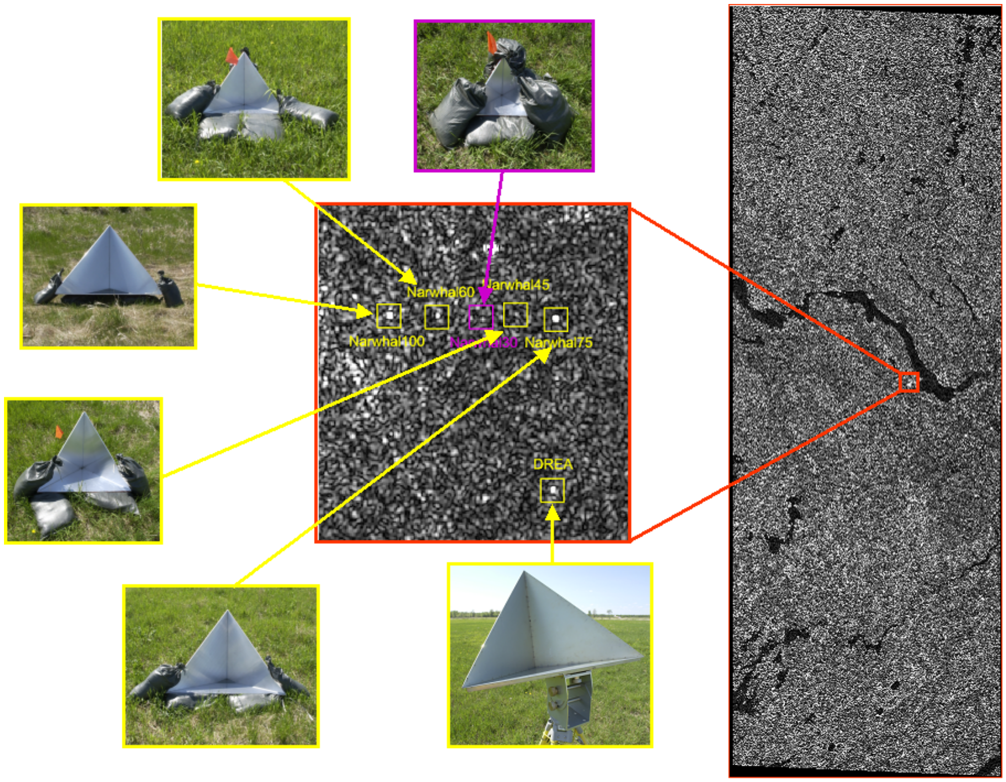



***Figure 3: Trihedral CR Deployment at Connaught Range. Trihedral CRs with visible backscatter are outlined in yellow (45, 60, 75, and 100 cm + DREA) and trihedral CRs with no visible backscatter are outlined in purple (30 cm).***

# 4. Analysis Summary

The RADARSAT-1 imagery was delivered to DRDC Ottawa as raw signal data and was processed to SAR georeferenced extrafine format using the EarthView Advanced Precision Processor (EV-APP), a desktop SAR processor capable of producing high quality image products to custom specifications. The point target analysis of the trihedral CRs was performed using the CCRS VUSAR software. VUSAR is a display system designed to quickly and easily display SAR image products acquired by RADARSAT-1, ENVISAT ASAR, and ERS-1/2. This software is equipped with algorithms for distributed and point target analysis and radiometric correction, and can display the RCS, incidence angle, and latitude and longitude for a given pixel and line location. By interpolating the image data, the target location is reported to an accuracy of $^1/_8$ of a pixel.

With the exception of the 30 cm trihedral CR deployed at Connaught Range, all GCPs covered by each swath were visible in the RADARSAT-1 imagery. The 7 May VUSAR analyses of the 45, 60, 75, and 100 cm trihedral CRs deployed at Connaught Range is shown in Figures 4 through 7, respectively.

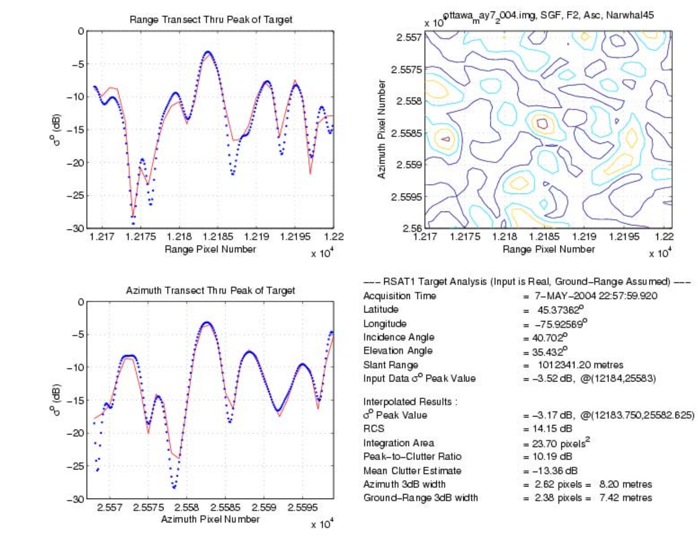



***Figure 4: VUSAR point target analysis of 45 cm trihedral CR for 7 May 2004.***

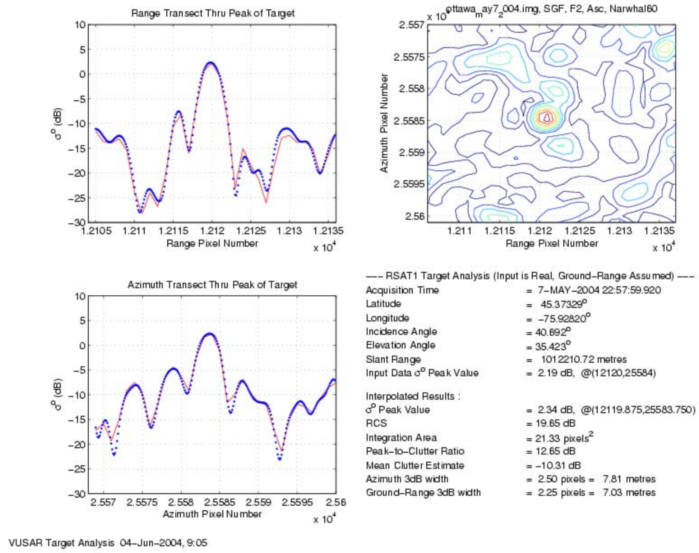



***Figure 5: VUSAR point target analysis of 60 cm trihedral CR for 7 May 2004.***

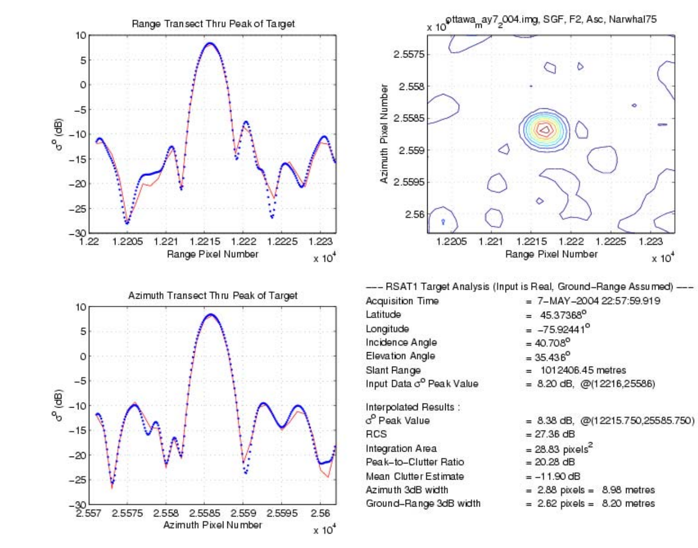



***Figure 6: VUSAR point target analysis of 75 cm trihedral CR for 7 May 2004.***

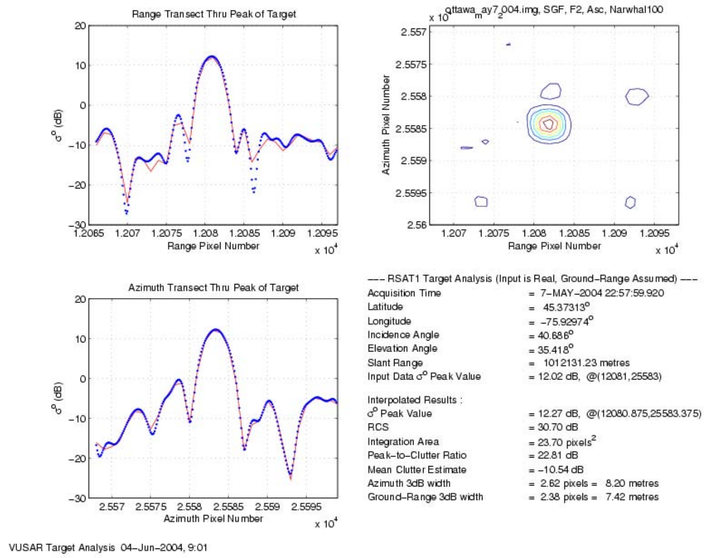



***Figure 7: VUSAR point target analysis of 100 cm trihedral CR for 7 May 2004.***

Tables 3, 4, and 5 summarize the analysis results for the trihedral CRs visible in the SAR imagery for 7, 8 and 15 May, respectively. To ensure the correct targets were analyzed, the difference between the measured (differential GPS) and predicted (VUSAR) latitude and longitude coordinates were computed (Equations 4-7).

$$\Delta_{Lat}(\circ) = Lat_{GPS} - Lat_{VUSAR} \tag{4}$$

$$\Delta_{Lat}(m) = \Delta_{Lat}(rads) \times R_E \tag{5}$$

$$\Delta_{Long}(\circ) = Long_{GPS} - Long_{VUSAR} \tag{6}$$

$$\Delta_{Long}(m) = R_E \times \cos(\min[Lat_{GPS}, Lat_{VUSAR}]) \times \Delta_{Long}(rads), \tag{7}$$

In Equations 4 through 7, $\Delta_{Lat}$ and $\Delta_{Long}$ are the latitude and longitude differences (in degrees and meters), $Lat_{GPS}$ and $Long_{GPS}$ are the coordinates recorded by the differential GPS unit, $Lat_{VUSAR}$ and $Long_{VUSAR}$ are the coordinates predicted by the VUSAR software, and $R_E$ is approximate radius of the Earth ($R_E$ = 6370 km). Note that in the conversion of the coordinate differences from degrees (°) to meters (*m*), all values in degrees must first be converted to radians (*rads*).

The theoretical values of the RCSs were consistently within 3 dB of the measured values, with the exception of the RADARSAT-1 Calibration Transponder. The measured value of the RADARSAT-1 Calibration Transponder RCS was considerably lower than the theoretical value because the signature used to compute the measured RCS was truncated as a result of the response saturating the image (16-bit) dynamic range. The Gatineau Satellite Station antennas, although present in two of the three SAR images, were not used as GCPs as they too saturate the image. Before any of these points can be used for ground control the data must be reprocessed to eliminate the saturation problem. The reprocessing can be done using either a different output look-up table or outputting to a floating-point product.

The differences between the measured and predicted latitude and longitude coordinates were consistent across the GCPs for each acquisition date, with the exception of the Munster, Cantley, Area 6, and RADARSAT-1 Calibration Transponder sites. For these locations higher longitudinal differences were observed. In general, these positional differences are attributed to the inaccuracies in the orbital data provided by the Canadian Space Agency for the EV-APP, as well as the Earth ellipsoid used by the EV-APP. For the Cantley, Munster, and Area 6 deployment sites, the positional differences are increased as a result of their higher elevation. Since the EV-APP does not use a digital elevation model to model the variation in the terrain above the ellipsoid, GCPs with altitudes that vary significantly from the ellipsoid will tend to have larger latitude and longitude prediction differences. For the RADARSAT-1 Calibration Transponder, some of the differences in the latitude and longitude may be attributed to the altitude. However, the primary source of these differences is the 1.87 μs delay that is built in to the transponder, which causes a slant range shift of the transponder location in the imagery. While it is possible to convert this location to the correct place in the imagery by accounting for the shift during processing, this has not been done. Therefore, this point cannot be used as a GCP until the shift is accounted for.

*Table 3: 7 May 2004 trihedral CR analysis summary (N/V = Not Visible. N/A = Not Applicable).*

**RADARSAT-1 Acquisition for 7 May 2004**
**Fine 2 Near Beam Mode**
**Ascending Pass**
**Desired Elevation = 14.4**
**Desired Azimuth = 7**
**Desired Horzontal Elevation = 0**
**UTC Time = 22:59**

| | | Differential GPS Results | | | | Target Analysis Results | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Back Spine Length (a) (m) | GPS Latitude (°) | GPS Longitude (°) | GPS Altitude (m) | Theoretical RCS (dBm^2) | Measured RCS (dBm^2) | Peak-to-Clutter Ratio (dB) | Mean Clutter Estimate (dB) | Sub-Pixel Location | Sub-Line Location | Latitude (°) | Longitude (°) | Delta Latitude (°) | Delta Latitude (m) | Delta Longitude (°) | Delta Longitude (m) |
| Area 5 | 1 | 45.3944 | -75.9130 | 69.4780 | 31.18 | 29.95 | 23.97 | -12.86 | 12601.875 | 24902.500 | 45.3945 | -75.9139 | -0.00010 | -10.90 | 0.00086 | 66.91 |
| Area 6 | 1 | 45.1925 | -75.9862 | 130.8810 | 31.18 | 30.87 | 23.38 | -11.36 | 9542.500 | 31653.125 | 45.1925 | -75.9880 | 0.00005 | 5.78 | 0.00183 | 143.07 |
| CRC Campus | 1 | 45.3513 | -75.8839 | 67.4442 | 31.18 | 30.65 | 22.76 | -10.82 | 13062.625 | 26533.625 | 45.3513 | -75.8847 | -0.00008 | -8.34 | 0.00079 | 62.11 |
| Cantley | 1 | 45.5839 | -75.7804 | 161.2260 | 31.18 | 28.84 | 20.13 | -9.84 | 16977.250 | 18822.625 | 45.5839 | -75.7826 | 0.00008 | 8.67 | 0.00226 | 175.46 |
| Munster | 1 | 45.0439 | -76.0137 | 139.4090 | 31.18 | 29.94 | 22.62 | -11.02 | 7947.625 | 36727.875 | 45.0439 | -76.0156 | 0.00007 | 7.89 | 0.00189 | 148.23 |
| Limebank CRL10 | 1.135 | 45.3168 | -75.6880 | 93.1770 | 33.38 | 31.01 | 25.16 | -12.36 | 17688.000 | 28555.625 | 45.3168 | -75.6892 | 0.00000 | -0.56 | 0.00128 | 99.91 |
| Limebank CRL11 | 1.132 | 45.3156 | -75.6892 | 92.6690 | 33.34 | 32.23 | 21.57 | -7.93 | 17649.625 | 28593.375 | 45.3156 | -75.6905 | -0.00003 | -3.78 | 0.00125 | 97.96 |
| RSAT Transponder | N/A | 45.2947 | -75.7573 | 95.5530 | 55.68 | > 45.6 | >36.33 | -12.42 | 15976.625 | 29044.500 | 45.2953 | -75.7533 | -0.00061 | -68.37 | -0.00395 | -308.93 |
| Narwhal30 | 0.3 | 45.3735 | -75.9261 | 65.9020 | 10.27 | N/V | N/V | N/V | N/V | N/V | N/V | N/V | N/V | N/V | N/V | N/V |
| Narwhal45 | 0.45 | 45.3735 | -75.9249 | 66.2560 | 17.31 | 14.15 | 10.19 | -13.36 | 12183.750 | 25582.625 | 45.3736 | -75.9257 | -0.00010 | -10.90 | 0.00080 | 62.48 |
| Narwhal60 | 0.6 | 45.3732 | -75.9274 | 66.0670 | 22.31 | 19.65 | 12.65 | -10.31 | 12119.875 | 25583.750 | 45.3733 | -75.9282 | -0.00009 | -9.56 | 0.00079 | 62.01 |
| Narwhal75 | 0.75 | 45.3736 | -75.9236 | 65.8630 | 26.18 | 27.36 | 20.28 | -11.90 | 12215.750 | 25585.750 | 45.3737 | -75.9244 | -0.00008 | -9.01 | 0.00079 | 61.46 |
| Narwhal100 | 1 | 45.3730 | -75.9289 | 66.1560 | 31.18 | 30.70 | 22.81 | -10.54 | 12080.875 | 25583.375 | 45.3731 | -75.9297 | -0.00010 | -11.45 | 0.00081 | 62.95 |
| Drea Tripod Mounted | 0.75 | 45.3697 | -75.9227 | 65.7670 | 26.18 | 24.75 | 19.88 | -13.85 | 12213.500 | 25725.375 | 45.3698 | -75.9235 | -0.00010 | -11.45 | 0.00081 | 63.42 |

*Table 4: 8 May trihedral CR analysis summary (N/V = Not Visible, N/I = Not Imaged, N/A = Not Applicable).*

**RADARSAT-1 Acquisition for 8 May 2004**
**Fine 2 Near Beam Mode**
**Descending Pass**
**Desired Elevation = 14.4**
**Desired Azimuth = 201**
**Desired Horzontal Elevation = 0**
**UTC Time = 11:09**

| | | Differential GPS Results | | | | Target Analysis Results | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Back Spine Length (a) (m) | GPS Latitude (°) | GPS Longitude (°) | GPS Altitude (m) | Theoretical RCS (dBm^2) | Measured RCS (dBm^2) | Peak-to-Clutter Ratio (dB) | Mean Clutter Estimate (dB) | Sub-Pixel Location | Sub-Line Location | Latitude (°) | Longitude (°) | Delta Latitude (°) | Delta Latitude (m) | Delta Longitude (°) | Delta Longitude (m) |
| Area 5 | 1 | 45.3944 | -75.9130 | 69.4780 | 31.18 | 30.87 | 24.76 | -12.44 | 17064.125 | 22759.750 | 45.3941 | -75.9123 | 0.00034 | 38.02 | -0.00072 | -56.45 |
| Area 6 | 1 | 45.1925 | -75.9862 | 130.8810 | 31.18 | 30.84 | 25.98 | -13.83 | 16534.125 | 30127.250 | 45.1920 | -75.9844 | 0.00047 | 52.48 | -0.00171 | -134.29 |
| CRC Campus | 1 | 45.3513 | -75.8839 | 67.4442 | 31.18 | 30.04 | 25.31 | -13.90 | 18051.500 | 24141.250 | 45.3509 | -75.8832 | 0.00033 | 37.24 | -0.00068 | -52.74 |
| Cantley | 1 | 45.5839 | -75.7804 | 161.2260 | 31.18 | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I |
| Munster | 1 | 45.0439 | -76.0137 | 139.4090 | 31.18 | 30.08 | 21.84 | -10.38 | 16774.875 | 35436.125 | 45.0434 | -76.0119 | 0.00050 | 55.70 | -0.00181 | -142.42 |
| Limebank CRL10 | 1.135 | 45.3168 | -75.6880 | 93.1770 | 33.38 | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I |
| Limebank CRL11 | 1.132 | 45.3156 | -75.6892 | 92.6690 | 33.34 | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I |
| RSAT Transponder | N/A | 45.2947 | -75.7573 | 95.5530 | 55.68 | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I |
| Narwhal30 | 0.3 | 45.3735 | -75.9261 | 65.9020 | 10.27 | N/V | N/V | N/V | N/V | N/V | N/V | N/V | N/V | N/V | N/V | N/V |
| Narwhal45 | 0.45 | 45.3735 | -75.9249 | 66.2560 | 17.31 | 17.36 | 12.09 | -13.71 | 16899.500 | 23540.750 | 45.3732 | -75.9242 | 0.00034 | 38.02 | -0.00065 | -50.77 |
| Narwhal60 | 0.6 | 45.3732 | -75.9274 | 66.0670 | 22.31 | 23.72 | 16.90 | -11.88 | 16839.500 | 23562.625 | 45.3729 | -75.9267 | 0.00034 | 38.25 | -0.00070 | -54.36 |
| Narwhal75 | 0.75 | 45.3736 | -75.9236 | 65.8630 | 26.18 | 26.86 | 22.79 | -14.57 | 16930.375 | 23532.500 | 45.3733 | -75.9230 | 0.00035 | 38.80 | -0.00065 | -51.00 |
| Narwhal100 | 1 | 45.3730 | -75.9289 | 66.1560 | 31.18 | 31.34 | 25.33 | -12.82 | 16802.750 | 23575.250 | 45.3727 | -75.9283 | 0.00033 | 36.36 | -0.00068 | -53.42 |
| Drea Tripod Mounted | 0.75 | 45.3697 | -75.9227 | 65.7670 | 26.18 | 24.89 | 20.88 | -14.95 | 16977.125 | 23664.500 | 45.3694 | -75.9220 | 0.00032 | 35.24 | -0.00070 | -54.52 |

*Table 5: 15 May trihedral CR analysis summary (N/V = Not Visible, N/A = Not Applicable).*

**RADARSAT-1 Acquisition for 15 May 2004**
**Fine 3 Beam Mode**
**Descending Pass**
**Desired Elevation = 14.4**
**Desired Azimuth = 201**
**Desired Horzontal Elevation = 0**
**UTC Time = 11:09**

| | | Differential GPS Results | | | | Target Analysis Results | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Back Spine Length (a) (m) | GPS Latitude (°) | GPS Longitude (°) | GPS Altitude (m) | Theoretical RCS (dBm^2) | Measured RCS (dBm^2) | Peak-to-Clutter Ratio (dB) | Mean Clutter Estimate (dB) | Sub-Pixel Location | Sub-Line Location | Latitude (°) | Longitude (°) | Delta Latitude (°) | Delta Latitude (m) | Delta Longitude (°) | Delta Longitude (m) |
| Area 5 | 1 | 45.3944 | -75.9130 | 69.4780 | 31.18 | 30.90 | 26.15 | -13.61 | 8361.000 | 20847.625 | 45.3940 | -75.9123 | 0.00041 | 45.81 | -0.00069 | -54.10 |
| Area 6 | 1 | 45.1925 | -75.9862 | 130.8810 | 31.18 | 30.83 | 25.88 | -13.90 | 7746.375 | 28213.125 | 45.1920 | -75.9846 | 0.00052 | 58.03 | -0.00155 | -121.76 |
| CRC Campus | 1 | 45.3513 | -75.8839 | 67.4442 | 31.18 | 31.31 | 25.80 | -12.86 | 9332.875 | 22240.375 | 45.3509 | -75.8832 | 0.00039 | 43.92 | -0.00068 | -52.74 |
| Cantley | 1 | 45.5839 | -75.7804 | 161.2260 | 31.18 | 31.11 | 24.50 | -11.81 | 10562.250 | 13675.500 | 45.5834 | -75.7784 | 0.00056 | 62.04 | -0.00200 | -156.01 |
| Munster | 1 | 45.0439 | -76.0137 | 139.4090 | 31.18 | 30.23 | 23.74 | -12.01 | 7927.750 | 33527.625 | 45.0434 | -76.0121 | 0.00056 | 62.37 | -0.00165 | -129.85 |
| Limebank CRL10 | 1.135 | 45.3168 | -75.6880 | 93.1770 | 33.38 | 32.07 | 26.77 | -13.19 | 14392.750 | 22647.125 | 45.3163 | -75.6869 | 0.00046 | 50.59 | -0.00108 | -84.59 |
| Limebank CRL11 | 1.132 | 45.3156 | -75.6892 | 92.6690 | 33.34 | 32.58 | 22.87 | -8.83 | 14368.375 | 22695.375 | 45.3151 | -75.6882 | 0.00045 | 49.59 | -0.00104 | -81.07 |
| RSAT Transponder | N/A | 45.2947 | -75.7573 | 95.5530 | 55.68 | >45.85 | >34.77 | -10.68 | 12674.375 | 23708.500 | 45.2948 | -75.7614 | -0.00012 | -12.79 | 0.00417 | 463.61 |
| Narwhal30 | 0.3 | 45.3735 | -75.9261 | 65.9020 | 10.27 | N/V | N/V | N/V | N/V | N/V | N/V | N/V | N/V | N/V | N/V | N/V |
| Narwhal45 | 0.45 | 45.3735 | -75.9249 | 66.2560 | 17.31 | 12.58 | 11.09 | -14.92 | 8187.750 | 21626.625 | 45.3731 | -75.9242 | 0.00040 | 44.69 | -0.00065 | -50.77 |
| Narwhal60 | 0.6 | 45.3732 | -75.9274 | 66.0670 | 22.31 | 23.44 | 17.60 | -12.87 | 8127.625 | 21647.875 | 45.3728 | -75.9267 | 0.00039 | 43.80 | -0.00067 | -52.02 |
| Narwhal75 | 0.75 | 45.3736 | -75.9236 | 65.8630 | 26.18 | 26.74 | 22.13 | -13.88 | 8218.750 | 21619.125 | 45.3732 | -75.9230 | 0.00040 | 44.36 | -0.00065 | -51.00 |
| Narwhal100 | 1 | 45.3730 | -75.9289 | 66.1560 | 31.18 | 31.25 | 25.48 | -12.78 | 8091.000 | 21660.500 | 45.3726 | -75.9283 | 0.00041 | 45.25 | -0.00065 | -51.08 |
| Drea Tripod Mounted | 0.75 | 45.3697 | -75.9227 | 65.7670 | 26.18 | 26.17 | 21.56 | -13.77 | 8264.000 | 21751.625 | 45.3693 | -75.9221 | 0.00041 | 45.25 | -0.00066 | -51.39 |

# 5. Preparation for Exercise Narwhal

For Exercise Narwhal, 30 trihedral CRs will be distributed among 3 separate sites. Each site will be equipped with pairs of trihedral CRs with the following back spine dimensions: 30 cm, 45 cm, 60 cm, 75 cm, and 100 cm. These trihedral CRs were constructed specifically for this exercise; a description of the construction methodology is included in Annex C. Because of the magnetic variation at high latitudes, the azimuth angles of the trihedral CRs will be based upon GPS tracks instead of a compass bearing. The modified trihedral CR deployment instructions have been included in Annex D. Because the trihedral CR deployment on Baffin Island will not be done by experts, these instructions have been made as explicit as possible. Presently, six RADARSAT-1 fine beam mode acquisitions are planned for Exercise Narwhal. These are summarized in Table 6.

***Table 6: Narwhal Trial planned RADARSAT-1 acquisitions.***

| DATE | TIME (UTC) | BEAM MODE | DIRECTION | INCIDENCE ANGLE RANGE (°) |
|---|---|---|---|---|
| 20 Aug. 2004 | 22:01:42.68 | Fine 3 Far | Ascending | 41.8-44.3 |
| 23 Aug. 2004 | 10:42:23.94 | Fine 3 Far | Descending | 41.8-44.3 |
| 26 Aug. 2004 | 10:54:55.99 | Fine 1 Near | Descending | 36.4-39.6 |
| 27 Aug. 2004 | 21:57:31.85 | Fine 2 | Ascending | 39.2-42.1 |
| 30 Aug. 2004 | 10:38:12.56 | Fine 5 Near | Descending | 45-47.2 |
| 30 Aug. 2004 | 22:10:04.52 | Fine 5 Far | Ascending | 45.6-47.8 |

For the period during which the RADARSAT-1 acquisitions will occur, the elevation angle of the trihedral CRs will not be altered. Therefore, for some of the acquisitions the trihedral CR boresight will not be aligned with the mid-swath point. Since optimal pointing cannot be achieved, given the range of the incidence angles of the fine beam modes being used, the proposed solution is to compute the mean mid-swath incidence angle for both the ascending and descending passes. Trihedral CRs set-up for the ascending passes will be elevated based on the mean ascending pass mid-swath incidence angle, while trihedral CRs set-up for the descending passes will be elevated based on the mean descending pass mid-swath incidence angle. For the ascending and descending passes shown in Table 6, these values are 43.5° and 42.4° respectively. Although these values are only ideal for ascending and descending Fine 3 Far passes, due to the broad beamwidth the trihedral CRs should be visible in the passes acquired with the Fine 1, Fine 2, or Fine 5 beams. For the pre-Narwhal Trial, the trihedral CR boresight elevation was ideally 47.25° for the Fine 3 acquisition on 15 May, and 49.65° for the Fine 2 Near acquisitions on 7 and 8 May. However, the corner elevation was not altered for the 15 May acquisition and the 2.4° difference did not prevent the trihedral CRs from being visible in the 15 May SAR image.

# 6. Concluding Remarks

The objectives of the pre-NARWHAL Trial were threefold:

- To validate the methodology used to determine the trihedral CR pointing angles;
- To assess the visibility of trihedral CRs of various sizes in RADARSAT-1 fine beam mode imagery;
- To produce a multi-temporal SAR dataset with GCPs.

Of the five trihedral CRs deployed at Connaught Range (30, 45, 60, 75, and 100 cm) all were visible in all SAR acquisitions except the smallest one (30 cm). The larger trihedral CRs (100 cm) that were deployed throughout the NCR were also visible in all SAR acquisitions. This indicates that aligning the trihedral CR boresight with the mid-swath point of the beam mode of interest is an acceptable method for establishing the elevation angle of the trihedral CR, at least for purposes of target detection for position control.

The targets identified in the imagery were verified using the CCRS VUSAR software: the latitude and longitude coordinates of each trihedral CR, acquired using the differential GPS unit, as well as the theoretical RCS, were compared to the latitude, longitude, and RCS values computed using VUSAR. 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, the longitude errors were larger for GCPs at higher altitudes.

The change in the RADARSAT-1 orbit, which occurred during a routine manoeuvre, caused a 20 km Westerly shift (approximately) in swaths acquired during the month of May. Consequently, the acquisition acquired on 8 May did not cover all of the trihedral CRs deployed. The beam mode selected for the acquisition on 15 May was altered from Fine 2 Near to Fine 3 to accommodate this shift, and as a result two coincident SAR images covering all GCPs were acquired.

# 7. References

1. Curlander, J.C., and R.N. McDonough, *"Synthetic Aperture Radar: Systems and Signal Processing"*, John Wiley & Sons Canada, November 1991, 672 pages.

2. Ulander, L.M.H., *"Accuracy of Using Points Targets for SAR Calibration"*, IEEE Transactions on Aerospace and Electronic Systems, Vol. 27, No. 1, January 1991, pp. 139-148.

# Annex A – Trihedral Corner Reflector Orientation

Author:  P. W. Vachon

Date:  21 April 2004

In principle, the boresight of the SAR antenna should point directly along the axis-of-symmetry of the trihedral CR.  The boresight of the SAR is nominally oriented perpendicular to the satellite track angle, plus an offset to account for any antenna squint.  In this exercise, we will use an antenna squint angle of 2.5°, which varies as a function of latitude.

Figure A.1 shows a trihedral CR with back spine dimension, *a*, and long side, *b*.  If the trihedral CR is placed upon a flat, level surface then the axis-of-symmetry (also referred to as the trihedral CR boresight) is oriented along a vertical plane that intersects the vertical axis (i.e., the *z*-axis) of the trihedral CR and bisects the long edge of the side panel of the trihedral CR that is resting on the level surface, i.e., along $\psi = \tan^{-1}(1.0) = 45°$; the axis-of-symmetry (boresight) of the trihedral CR is at an elevation angle $\theta = \tan^{-1}(0.7071) = 35.3°$, as measured from the level surface.  Note that the incidence angle is measured from the local vertical, so it is equal to $90°-\theta$.

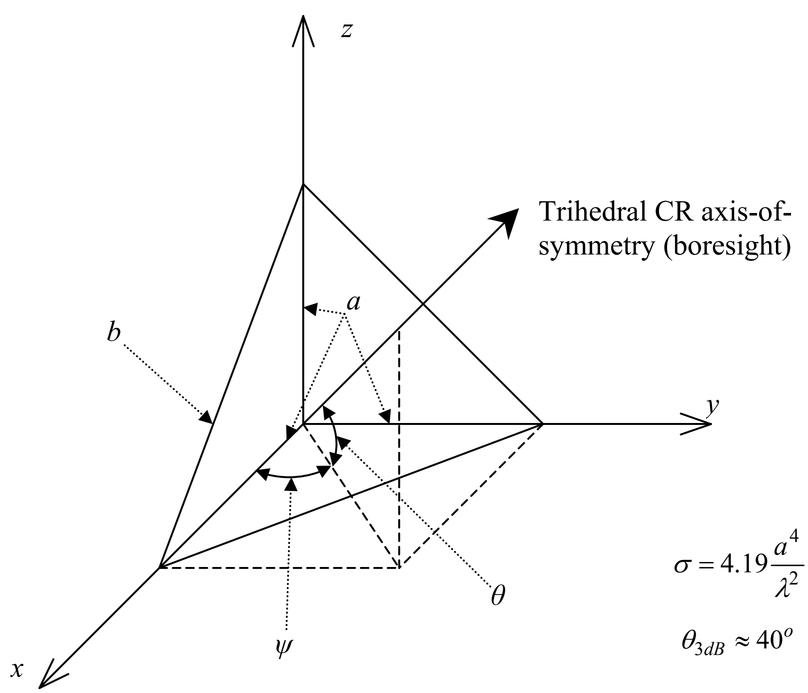



***Figure A.1:  Angular analysis of a trihedral CR.***

Table A.1 lists the upcoming passes and the required trihedral CR orientation angles $\alpha$ and $\beta$, which are illustrated in Figure A.2 and Figure A.3 below. The incidence angle is the nominal value at scene centre for the beam mode of interest. The angle $\alpha$ is the angle of the bottom panel of the trihedral CR from horizontal, as measured in the vertical plane that intersects the axis-of-symmetry and the local vertical axis. The nominal track angle is the satellite track angle measured clockwise from True North and was estimated from the scene corner coordinates, as provided by SPA. The angle $\beta$ is the clockwise orientation of the long edge of the bottom panel with respect to True North, which includes the track angle plus (minus) the 2.5° offset to account for the antenna squint for ascending (descending) passes. Since the 3dB width of the reflection pattern is quite broad, the recommended tolerance on the installation is better than ±2° for each trihedral CR orientation angle.

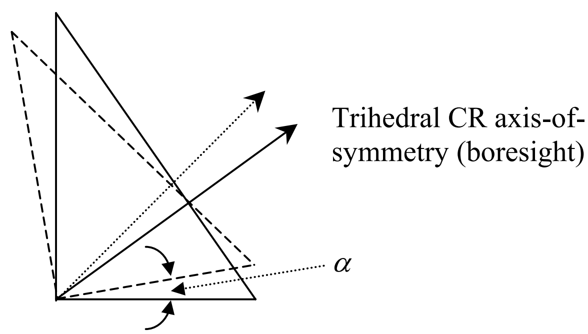



***Figure A.2: Side view of a trihedral CR.***

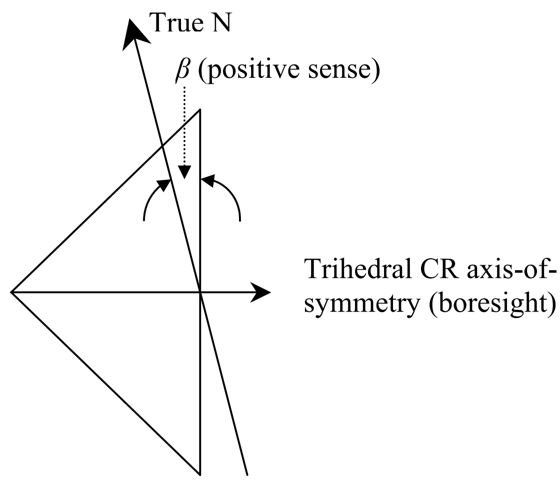



***Figure A.3: Top view of trihedral CR.***

*Table A.1: Trihedral CR orientation angles.*

| DATE | TIME (UTC) | MODE | DIRECTION | INCIDENCE ANGLE (AT MID-SWATH) | $\alpha$ | TRACK ANGLE (MEASURED CLOCKWISE WRT TRUE N) | $\beta$ (MEASURED CLOCKWISE WRT TRUE N) |
|---|---|---|---|---|---|---|---|
| 07 May 2004 | 22:59 | F2N | Ascending | 40.3° | 14.4° | 350.4° | –7.1° (trihedral CR boresight at 262.9°, i.e., pointing west) |
| 08 May 2004 | 11:09 | F2N | Descending | 40.3° | 14.4° | 189.6° | +7.1° (trihedral CR boresight at 97.1°, i.e., pointing east) |
| 15 May 2004 | 11:09 | F3 | Descending | 42.5° | 14.4° | 189.6° | +7.1° (trihedral CR boresight at 97.1°, i.e., pointing east) |

# Annex B – Expendable Trihedral Corner Reflector Deployment Instructions for Pre-Narwhal Trial

Author:  D. Schlingmeier

Date/Version:  6 May 2004, v1.5

Equipment list:

- Radar corner
- 5 sand bags
- Compass (ensure calibration is current, with zero declination set as default procedure)
- Digital level (ensure internal 9V battery is functional, pack spare)
- Cloth (to remove sand/grit)
- Shovel – optional
- Power drill & screwdriver (optional)

1. The power drill for #8 Robertson screws (screwdriver as backup) is required to open the wooden boxes containing the radar corner.  The shovel may be needed to fill sand bags or get additional material to hold corner in place.
2. Check the compass to ensure no declination is set, see Figure B.1.

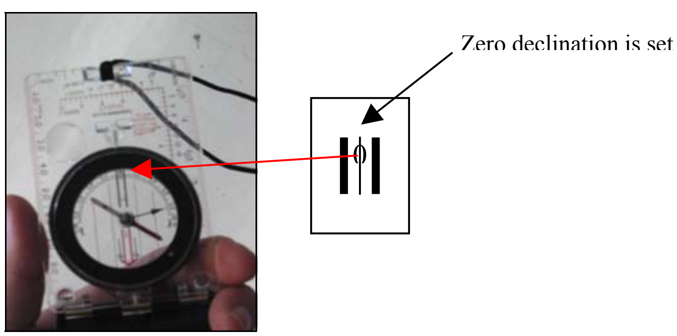



*Figure B.1:  Verifying declination is set to zero.*

3. Next, turn the compass over to set the heading using the dial numbered from zero to 360 degrees. All hash marks correspond to two degrees, for the Silva Ranger Ultra Compasses within the Radar Data Exploitation (RDE) trials kit. Rotate the dial to the azimuth setting listed on the data sheet. Now is a good time to have someone else verify this number is correct.

4. Based on the experiment layout instructions, choose the location on the ground where the corner will be deployed. A flag may have been positioned using GPS, as the reference location. At this point, a sanity check is required – the face (boresight) of the corner should be pointed in the general direction of the imaging radar (satellite vehicle or aircraft). Place the back spine of the corner at the flag and the corner boresight in the direction of the imaging radar.

5. Stand a sandbag up against the spine of the corner, shown in Figure B.2.

***Figure B.2: Placement of sandbag at spine of expendable, near flag.***

6. The next steps are iterative, as sandbags are difficult to work with.

7. Levelling corner face. Place one sandbag under left edge of corner face, as per Figure B.3. Repeat for the right edge. Push down hard on the front edge of the corner …

both left and right sides at the same time (pushing on one side and then the other will just make it harder to end up level). Use a digital level to check that the corner face is horizontal (zero degrees). Adjust sand bags to achieve approximate level. There will be a need to re-adjust all of this later, since this level-horizon and elevation of the corner are both adjusted using the same sandbags.

***Figure B.3: Placement of sandbags under left and right front edge of corner to achieve side-to-side.***

8. Corner azimuth adjustment. The end goal is to have the corner's bore-sight, pointing at the sensor (the front edge of the corner is parallel to the sensor track).

   a) There is much potential for confusion here. The set-up information for the corner may include compass settings different from the bore-sight by 90 degrees. This is because you are using the compass to align the front edge of the corner and not the boresight.

   b) Open the compass so that the mirror and base lie flat when the compass is laid down. Point the mirror to your LEFT when standing in front of the corner. Place the compass along the front edge of the corner, as shown in Figure B.4. Use magnetic north (MN) data to orient the corner's azimuth to within ±1° (no local declination correction to the compass). Rotate the corner appropriately (want the red arrow to line up with the red, magnetic North pointing needle – see Figure B.4).

Warning: The convention is to use a compass calibrated to zero declination along with the MN data provided by the experiment designer. If using a compass corrected to account for the local magnetic declination, or a GPS track, true north (TN) data must be used instead.

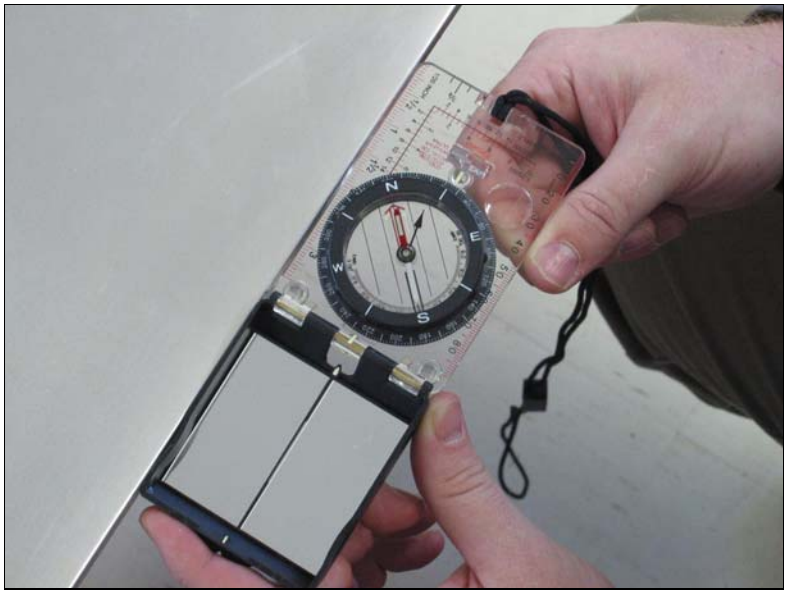


*Figure B.4: Azimuth alignment, with mirror at left.*

Verify that the bore sight is pointing toward the direction of the sensor. Example at Ottawa, TN=MN-declination. In western Canada, TN=MN+declination.

*Table B.1: Compass angles for setting up trihedral CRs.*

| DIRECTION TO AIRCRAFT | SENSOR TRACK (MN) | CORNER BORE-SIGHT (MN) | COMPASS SETTING (MN) | LOCAL DECLINATION | COMPASS GPS SETTING (TN) | ACTUAL @ SETUP | ACTUAL @ TEARDOWN |
|---|---|---|---|---|---|---|---|
| SE | 233.1 | 143.1 | 233.1 | 13.1 | 220 | | |

9. Corner elevation adjustment. Next, the elevation (or depression) must be set.

   a) Place the digital level into the corner, flat on the bottom face, so that the level is along the bore-sight, as per Figure B.5. The convention is that positive angles refer to tilting the bottom of the corner up and negative angles, tilting the bottom of the corner down.

***Figure B.5: Elevation adjustment, level perpendicular to face of corner, parallel to boresight.***

b) Move the sandbags front to back as required to obtain the required elevation.

c) Use data to elevate the corner to within ±0.5° (see table).

***Table B.2: Recording the trihedral CR elevation angle.***

| CORNER ELEVATION (°) | ACTUAL @ SETUP (°) | ACTUAL @ TEARDOWN (°) |
|---|---|---|
| -10.2 | | |

The negative sign indicates the corner bottom of the corner is tilted down.

10. Repeat from step 7 to ensure face is horizontal, azimuth is correct and elevation is correct.

*Figure B.6: Placement of digital level to verify corner is level side-to-side.*

11. To this point, three sand bags have been used. With your partner, and as in Figure B.7, place a sandbag on the front edge of the corner face (one each side, employing the last two of the five sand bags).

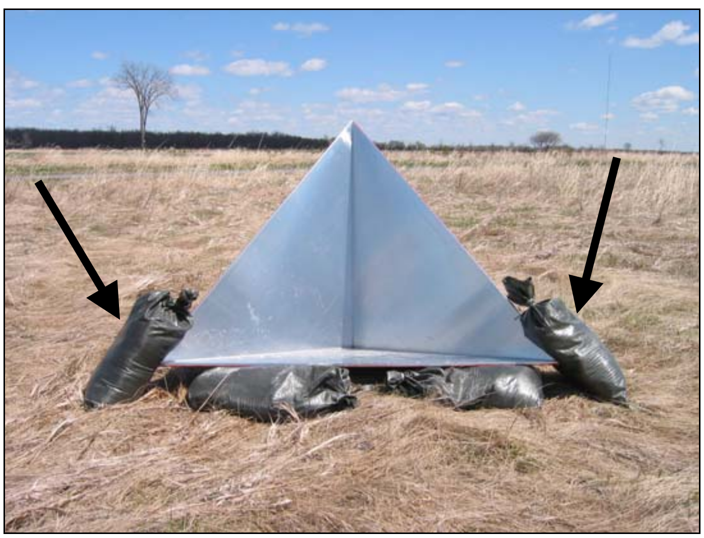


*Figure B.7: Placement of last two sandbags.*

12. Check all measurements to ensure no change and record information on data sheet.

13. Notes for using a compass may be found at [1].

14. Record the GPS position of corner. The convention has been to place the GPS over the apex (where all sides meet). If possible, set the GPS to integrate (average for 60 seconds minimum) on a point, to ensure the reading is of high quality. Alternatively, pace a triangle around the corner, while recording a track, and pause at the apex to obtain a nested point within the track. The position error will be dependent on the type of receiver equipment used, ensure that the position determined for the corner meets the experimental requirements.

| **GPS location of corner** |
| --- |
| |

15. Photograph the corner deployment from both front and back, using a wide enough field of view to capture the background environment surrounding the location.

16. Deployed corners should be revisited on a daily basis to verify the corner's deployment with a visual inspection and to ensure that the corners have not been knocked over by wind or local wildlife.

17. When disassembling or moving corners, take note that sand or grit does not contaminate components and take precautions to maintain control of the corner if windy.

18. Local magnetic declination is available from [2].

REFERENCES:

1. http://www.geolab.nrcan.gc.ca/geomag/compass_e.shtml

2. http://www.geolab.nrcan.gc.ca/geomag/mirp_e.shtml.

# Annex C – Expendable Trihedral Corner Reflector Construction

Author: L. Gallop

Date: 28 June 2004

In the last two years, DRDC Ottawa has constructed three sets of expendable trihedral CRs. The first set was a group of four 100 cm trihedral CRs (back spine dimension) used as GCPs for RADARSAT-1 shoreline determination near Canadian Forces Station Alert, Nunavut during the spring and summer of 2002. The second set was a series of twenty-four 75 cm trihedral CRs deployed at Canadian Forces Base Petawawa as GCPs during the 2002 CAMEVAL Trial. The most recent set of trihedral CRs, with back spine dimensions ranging from 30 to 100 cm were built as radar reflector arrays for Exercise Narwhal on Baffin Island in the summer of 2004. All trihedral CRs were constructed by Jerry Achtereekte of CRC.

The construction of these corner sets has followed the same basic techniques over the years. The trihedral structure is formed using 0.5” plywood, with one good face, with 0.010” aluminum bonded to the inside faces of the corner reflector. The three faces of the corner structure are cut to the appropriate dimensions; the edges of the plywood structure to be assembled are rabbited to increase the trihedral structural stability and provide additional surface area for gluing. Prior to assembly of the plywood panels, the aluminum sheet is bonded to the good face of the panels with latex contact cement. The good face of the plywood provides a uniform surface for the aluminum sheet with no surface imperfections. The aluminum sheet is rolled over the front edges of each panel and folded back along the outside face by approximately two cm and fastened with non-magnetic stainless steel staples. This last step is to reduce the plywood’s edge de-lamination by the elements. The non-magnetic staples are used to ensure that a compass is unaffected during the setting of the corners azimuth during field deployment. Care is taken during the panel assembly to maintain the orthogonality of all corner faces. A 0.5” hole is opened at the inside apex of the corner to permit water drainage. When the corner assembly is complete the exterior plywood surfaces are then painted to complete the project.

# Annex D – Exercise Narwhal: Expendable Trihedral Corner Reflector Deployment Instructions

Authors: Instructions prepared and checked by D. Schlingmeier, RAST/RDE, Engineer, L. Gallop, CNEW/Navigation Technologist, P.W. Vachon, RAST/RDE Group Leader, and R.A. English RAST/RDE Defence Scientist.

Date/Version: 17 June 2003, v3.0

Objective: to deploy three arrays of radar trihedral CRs to enhance the RCS of the simulated satellite crash sites, for imaging by RADARSAT-1 SAR.

EQUIPMENT LIST:

Provided by DRDC Ottawa:

30 Radar trihedral CRs (5 different sizes, 10 trihedral CRs per Site, three Sites)

3 Tool kits (one per Site, three Sites), each kit including:

- 1 × digital level (ensure internal 9V battery is functional, pack a spare)
- 1 × spare 9V battery
- 1 × rope for layout of Azimuth Angle
- 25 × flagged stakes (5 to mark Positions every 100 m along the Array Line, and one for each front corner of the 10 trihedral CRs to be installed at each Site)
- 50 × empty sandbags (5 per CR, smaller CRs may require fewer)

These Deployment Instructions

Provided by the Department of National Defence (DND):

The three deployment Sites

Sand/gravel to fill sandbags

GPS units (one per team, minimum)

Shovels (one per team, minimum)

Power drills & screwdrivers (one per team, minimum)

Digital cameras (one per team, minimum)

**Personnel must be familiar with the operation of their GPS unit and digital camera.**

UNPACKING EQUIPMENT

1. A power drill for #8 Robertson screws (screwdriver as backup) is required to open the wooden boxes containing the trihedral CRs. The shovel is needed to fill sandbags and to get additional material to hold the trihedral CRs securely in place, if required.

2. Take precautions when moving un-crated trihedral CRs, especially if windy!

TRIHEDRAL CR DESCRIPTION

3. The various parts of a trihedral CR are shown in Figure D.1.

4. The back of each trihedral CR is plywood (painted red). The front of each trihedral CR is metal sheet.

ARRAY LINE LAYOUT.

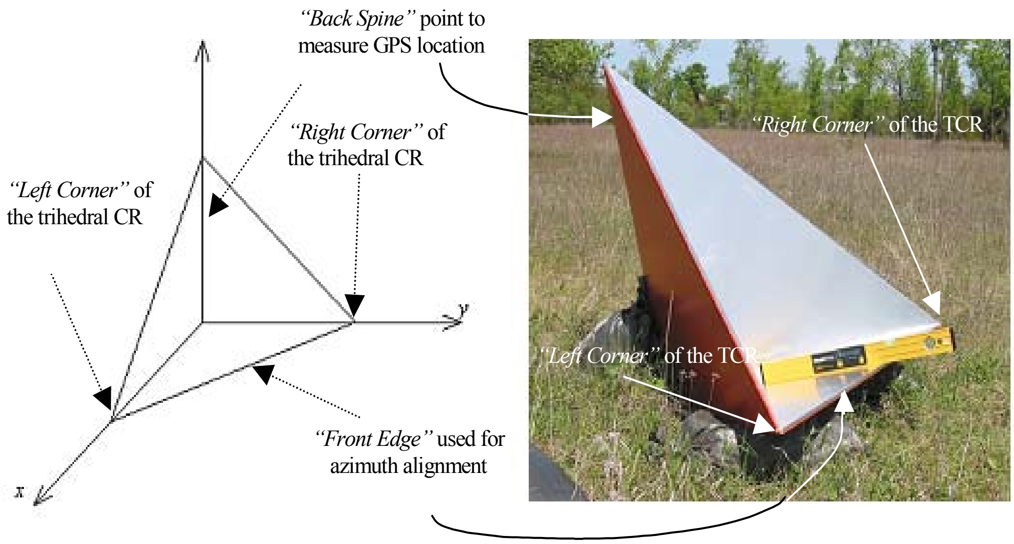



***Figure D.1: Parts of a trihedral CR – the "left corner" and "right corner" are defined for standing <u>in front</u> of the trihedral CR. The back of each trihedral CR is plywood (painted red). The front of each trihedral CR is metal sheet.***

5. Three deployment Sites will be identified in the trial plan. An array of 10 trihedral CRs will be installed at each Site. Each array will be composed of 5 Positions, with 2 trihedral CRs of the same size set-up roughly back-to-back at each Position.

6. Figure D.2 shows a view of a possible Array Line as will be set-up at each Site. The array is set-up over a linear distance of 400 m, with the Position of each pair of trihedral CRs separated by roughly 100 m along the Array Line. Note that the size order of the trihedral CRs along each Array Line is 100, 60, 30, 45, 75 cm (*Back Spine* length) – they DO NOT go from smallest to largest!

7. It is up to the deployment team to select an appropriate area and orientation for the Array Line. The lay of the land will dictate what is practical. Verify the topography:

   7.1. No obstructions within 50 m of the Array Line; and

   7.2. Relatively flat over the length of the Array Line.

8. Establish the initial point for one end of the Array Line and plant a flag. This is Position 1. Create a GPS waypoint. Establish a visual point of reference, towards the horizon, to pace the Array Line. Pace a constant heading towards the reference

point away from the initial waypoint. Every 100 m, create a GPS waypoint and plant a flag to mark each Position. The last flag should be about 400 m from Position 1 and a total of 5 flags should have been planted (Figure D.2) along a straight line.

9. Return to each Position in the Array Line and plant two more flags, one about 2 m to the East of the position flag, the other about 2 m to the West of the Position flag.

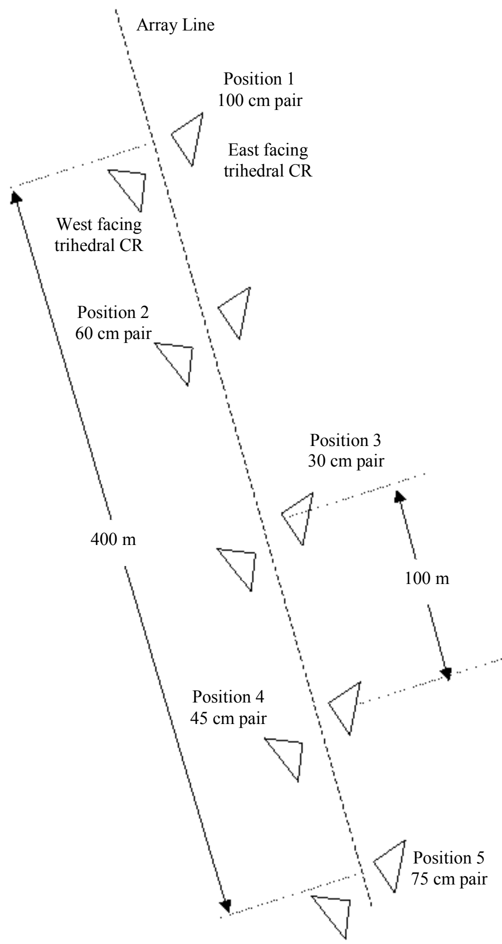
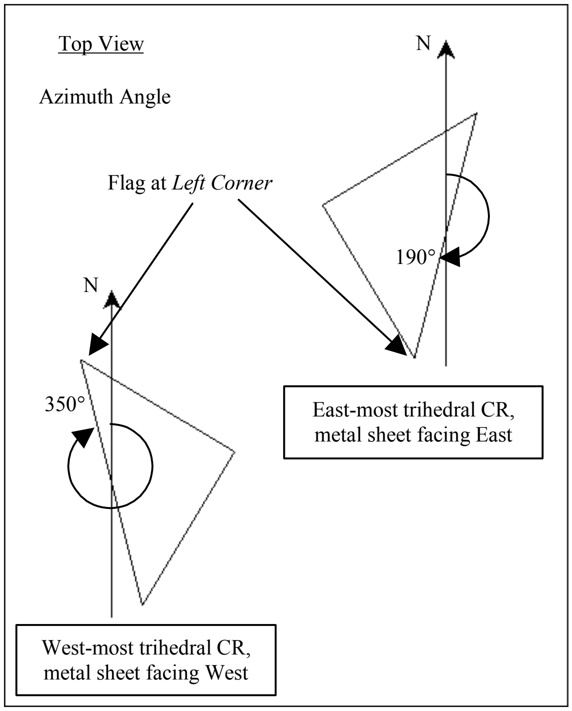



***Figure D.2: A possible Array Line configuration (note that the Array Line orientation is arbitrary and will be dictated by the local terrain). Trihedral CRs of the same size are installed back-to-back in pairs; the size order is 100, 60, 30, 45, and 75 cm (*****Back Spine** ***length) – they DO NOT go from smallest to largest! There is a 100 m separation between trihedral CR-pairs and the total Array Line length is 400 m.***



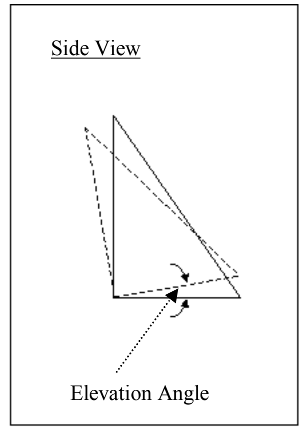




***Figure D.3: Measuring Elevation and Azimuth Angles of trihedral CRs. The Top View (on the left) shows the approximate orientation of a trihedral CR pair at each position in the Array Line.***

TRIHEDRAL CR INSTALLATION

10. The next steps are repeated several times, as sandbags may be difficult to work with. Moving a sandbag to level the trihedral CR side to side, can throw off another measurement. It usually requires about three iterations to ensure that all settings are correct. The set-up order is:

   - Trihedral CR Azimuth Angle adjustment;
   - Level trihedral CR *Front Edge* (side to side); and
   - Trihedral CR Elevation Angle adjustment.

   10.1. Refer to the Information Sheets provided for each Site for the required trihedral CR orientation angles (only the information sheet for Site 1 is included in Annex D).

   10.2. Checklists are provided for each Site to verify installation (only the check list for Site 1 is included in Annex D).

11. Trihedral CR Azimuth Angle adjustment

11.1. Refer to the Top View of Figure D.3. Start with the East-most flag at each Position along the Array Line. This flag will mark the *Left Corner* of the East facing trihedral CR. (Likewise, the West-most flag at each Position will mark the *Left Corner* of the West facing trihedral CR.)

11.2. The GPS will be used to determine the required Azimuth Angle for the trihedral CR's *Front Edge*. Use the East-most flag at each Position as a reference point and mark it with a GPS waypoint. Have a partner hold one end of the provided rope at the flag, then pull the rope out to its full length (move northward). Using the GPS, find the bearing to the flag waypoint from the end of the extended rope (for example use line 3 in 2-D fast mode of PLGR GPS). Adjust the end of the rope left or right to bring the bearing closer to the required trihedral CR Azimuth Angle of 190°. Repeat as required until the rope lies within ±2° of the required Azimuth Angle. (This procedure will be repeated for the West-most flag with the goal of obtaining an Azimuth Angle of 350°; in this case, move southward from the flag when extending the rope.)

11.3. Place the *Front Edge* of the trihedral CR along the rope with the *Left Corner* at the flag, making sure that the front of the trihedral CR is facing East or West, as required (refer to the Top View of Figure D.3).

11.4. Plant a reference flag in the ground at the *Right Corner* of the trihedral CR. In case of accidental movement of the trihedral CR, the flags will allow the trihedral CR to be quickly re-positioned (this also applies for subsequent days of the trial, if the trihedral CRs are blown over by wind and need to be setup again).

11.5. Stand a sandbag up against the *Back Spine* of the trihedral CR, as shown in Figure D.4.

***Figure D.4: Placement of sandbag at* Back Spine *of trihedral CR.***

12. Level Trihedral CR *Front Edge*.

    12.1. Slide one sandbag under left side of the *Front Edge*, as per Figure D.5. Repeat for the right side. Push down hard on the *Front Edge* of the trihedral CR … both left and right sides at the same time (pushing on one side and then the other will make it harder to end up level).

***Figure D.5: Placement of sandbags under left and right* Front Edge *of trihedral CR to achieve level side to side.***

12.2. Use the digital level to check that the *Front Edge* is horizontal from left to right, as per Figure D.6. Adjust the sand bags until the *Front Edge* is approximately level (i.e., 0°).

***Figure D.6: Placement of the digital level to check that the*** **Front Edge** ***is level side to side.***

13. <u>Trihedral CR Elevation Angle adjustment.</u>

13.1. Place the digital level on the bottom metal surface of the trihedral CR, touching the inside of the *Back Spine* and the middle of the *Front Edge* as per Figure D.7 (refer also to Figure D.3, Side View).

13.2. Nudge the left and right sandbags under the *Front Edge* in or out, as required, to obtain the required Elevation Angle of 12°.

***Figure D.7: Elevation Angle measurement.***

14. Repeat from Paragraph 11 to ensure that the Azimuth Angle is correct, the *Front Edge* is horizontal, and that the Elevation Angle is correct.

15. Place a sandbag on each Corner of the trihedral CR as per Figure D.8, to anchor the trihedral CR in place.

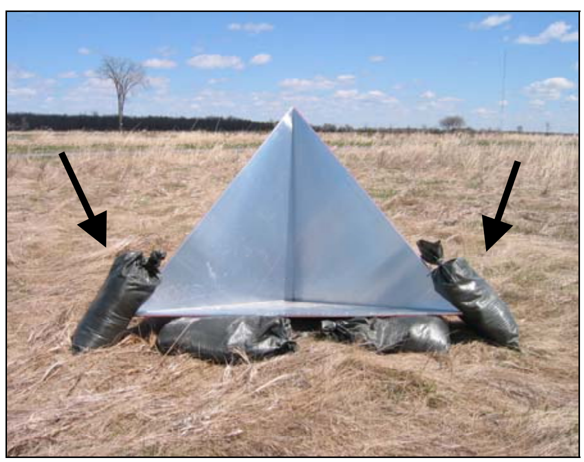


***Figure D.8: Placement of the last two sandbags.***

16. Check all measurements to ensure that there have been no changes and record the angle information on the data sheet provided.

17. Place the GPS at the top of the *Back Spine* of the trihedral CR. If possible, set the GPS to integrate (average for 60 seconds minimum) on a point, to ensure the reading is of high quality. Record the GPS position data.

18. Photograph the trihedral CR deployment from both front and back, using a wide enough field of view to capture the background environment surrounding the trihedral CR location. Include some written indication with the Site, Position, and trihedral CR size in each photograph (e.g. written in large letters on a sheet of paper that is easily visible in the photograph).

19. Repeat for remaining trihedral CRs at each Position in the Array Line at each Site.

20. Questions may be directed to the undersigned. PLEASE FEEL FREE TO CALL AT ANY TIME (day or night) – NOTE I HAVE INCLUDED MY HOME NUMBER.

D. Schlingmeier, M.Sc.
DRDC(Ottawa)/RAST/RDE, Engineer
(613) 998-3552 (office)/(613) 599-8276 (home)
(613) 998-4866 (fax)
mailto:David.Schlingmeier@drdc-rddc.gc.ca
http://www.ottawa.drdc-rddc.gc.ca

Defence Research and Development Canada (DRDC) Ottawa
Radar Applications & Space Technology (RAST) Section
3701 Carling Avenue, Ottawa, Ontario K1A 0Z4

**EXERCISE NARWAL TRIHEDRAL CR INFORMATION SHEETS**

1. Deployed trihedral CRs should be checked prior to each satellite pass to visually verify the trihedral CR's deployment and to ensure that the trihedral CRs have not been knocked over by wind or local wildlife. If the trihedral CR has been moved, re-deploy it as per Paragraph 11.

***Table D.1: RADARSAT-1 Passes during Exercise Narwhal.***

| | DATE | TIME |
|---|---|---|
| 1 | 2004-Aug-20 | 18:02 EDT |
| 2 | 2004-Aug-23 | 06:42 EDT |
| 3 | 2004-Aug-26 | 06:55 EDT |
| 4 | 2004-Aug-27 | 17:57 EDT |
| 5 | 2004-Aug-30 | 06:38 EDT |
| 6 | 2004-Aug-30 | 18:10 EDT |

2. Information Sheets are provided to ensure proper trihedral CR installation:

   a. Deployment Data Sheet: one for each of the three Sites that provide trihedral CR orientation angles and spaces to record actual angles and GPS data (Table D.2 shows a deployment data sheet for Site 1);
   b. Deployment Checklist: one for each of the three sites that will permit basic checks of the Array Line set-up and trihedral CR installation sequence, with cross references to the relevant Paragraph and Figure numbers in the instruction sheets (Table D.3 shows the check list for Site 1).

3. The deployment teams should fill in the shaded areas of the Information Sheets.

Please save the completed Information Sheets; return the Information Sheets and site photographs to D. Schlingmeier.

*Table D.2: Deployment Data Sheet, SITE ONE.*

| NAME OF DEPLOYMENT TEAM MEMBERS: | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DATE AND TIME OF DEPLOYMENT: | | | | | | | | | | | |
| CR# | SITE | POSITION | FACING | SIZE (CM) | AZIMUTH ANGLE | | ELEVATION ANGLE | | | | |
| | | | | | Desired | Actual | Desired | Actual | Latitude | Longitude | Altitude |
| 1 | 1 | 1 | East | 100 | 190° | | 12° | | N | W | |
| 2 | 1 | 1 | West | 100 | 350° | | 12° | | N | W | |
| 3 | 1 | 2 | East | 60 | 190° | | 12° | | N | W | |
| 4 | 1 | 2 | West | 60 | 350° | | 12° | | N | W | |
| 5 | 1 | 3 | East | 30 | 190° | | 12° | | N | W | |
| 6 | 1 | 3 | West | 30 | 350° | | 12° | | N | W | |
| 7 | 1 | 4 | East | 45 | 190° | | 12° | | N | W | |
| 8 | 1 | 4 | West | 45 | 350° | | 12° | | N | W | |
| 9 | 1 | 5 | East | 75 | 190° | | 12° | | N | W | |
| 10 | 1 | 5 | West | 75 | 350° | | 12° | | N | W | |

***Table D.3: Deployment Checklist, SITE ONE***

**NAMES OF DEPLOYMENT TEAM MEMEBERS:**

**DATE AND TIME OF DEPLOYMENT:**

| **ARRAY SITE:** | **1** |
|---|---|
| Relatively flat terrain | |
| Free of obstructions around Array Line | |
| Layout Array Line (400 m) | |
| Mark trihedral CR positions (every 100 m along Array Line) | |

| **FOR EACH TRIHEDRAL CR POSITION IN ARRAY LINE:** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| Pair of trihedral CRs of same size | | | | | |
| Correct trihedral CR size for position | | | | | |

| **FOR EACH TRIHDERAL CR:** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
|---|---|---|---|---|---|---|---|---|---|---|
| Adjust trihedral CR Azimuth Angle – Para 11 | | | | | | | | | | |
| Record Azimuth Angle of *Front Edge* | | | | | | | | | | |
| Level trihedral CR left-to-right– Paragraph 12, Figure D.5 & Figure D.6. | | | | | | | | | | |
| Adjust trihedral CR Elevation Angle – Paragraph 13, Figure D.7. | | | | | | | | | | |
| Record Elevation Angle | | | | | | | | | | |
| Ensure trihedral CR is well-anchored – Figure D.8. | | | | | | | | | | |
| Record GPS information | | | | | | | | | | |
| Take Photographs of trihedral CR | | | | | | | | | | |

| **SANITY CHECK:** | **1** |
|---|---|
| Trihedral CRs oriented back-to-back | |
| East-most trihedral CR faces roughly East | |
| West-most trihedral CR faces roughly West | |
| Trihedral CRs well-anchored and stable | |

# List of symbols/abbreviations/acronyms/initialisms

| | |
|---|---|
| CCRS | Canada Centre for Remote Sensing |
| CF | Canadian Forces |
| CFNA | Canadian Forces Northern Area |
| CR | Corner Reflector |
| CRC | Communications Research Centre |
| CSI | Commercial Satellite Imagery |
| DND | Department of National Defence |
| DRDC | Defence Research and Development Canada |
| EV-APP | EarthView Advanced Precision Processor |
| GCP | Ground Control Point |
| GPS | Global Positioning System |
| MN | Magnetic North |
| NCR | National Capitol Region |
| PCR | Peak-to-Clutter Ration |
| RAST | Radar Applications and Space Technology |
| RCS | Radar Cross Section |
| RDE | Radar Data Exploitation |
| SAR | Synthetic Aperture Radar |
| SCR | Signal-to-Clutter Ratio |
| SPA | Swath Planning Application |
| TN | True North |

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In August 2004 Defence Research and Development Canada (DRDC) Ottawa will participate in Exercise Narwhal, which will be held on Baffin Island. The objectives of Exercise Narwhal are to exercise the Canadian Forces' (CF) role in supporting the Nunavut territorial government's response to a crisis within the Canadian Forces Northern Area (CFNA), to exercise Headquarters CFNA, and to exercise Canadian sovereignty by projecting a CF presence within the North. One activity within Exercise Narwhal is simulation of the recovery of a crashed rocket and satellite payload. For this activity, expendable trihedral Corner Reflectors (CRs) will be distributed over an area of approximately 3200 km2 to increase the radar reflectivity of the crash site. In preparation, DRDC Ottawa conducted a mini trial in May 2004. The objective of the mini trial was to validate the methodology of determining the pointing angles of the trihedral CRs, to assess the visibility of trihedral CRs of different sizes in RADARSAT-1 fine beam mode imagery, and to obtain a coincident Synthetic Aperture Radar (SAR) dataset with Ground Control Points (GCPs). Trihedral CRs of various sizes were deployed at Connaught Range and other trihedral CRs were deployed throughout the National Capital Region (NCR); three fine beam mode RADARSAT-1 passes were acquired. All deployed CRs were visible with the exception of the smallest, which had a 30 cm back spine dimension, thus validating the deployment methodology. The visibility of trihedral CRs depends upon the normalized RCS of the background against which they are deployed. The smallest CR visible had a back spine dimension of 45 cm. A problem with the RADARSAT-1 orbit resulted in only two of the three images containing all of the GCPs; however, two coincident SAR images with GCPs were produced and are available for SAR geometry studies. Prior to this exercise SAR imagery with ground control was not readily available.

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Synthetic Aperture Radar, SAR, Trihedral Corner Reflector, CR, Ground Control Points, GCP, Exercise Narwhal, RADARSAT-1