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Time Series of RADARSAT-1 Fine Mode Images Using Sequential Coherent Target Monitoring Software

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Defence R&D Canada – Ottawa
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Time Series of RADARSAT-1 Fine Mode Images Using Sequential Coherent Target Monitoring Software

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Abstract

Coherent Target Monitoring (CTM) is COTS software that was developed to detect the rate of land subsidence by using Synthetic Aperture Radar (SAR) repeat-pass interferometry applied to persistent scatterers in the scene. DRDC Ottawa has proposed to use the CTM software to produce a time-series of accurately co-registered SAR images and coherence maps that may be used for both non-coherent and coherent change detection. This capability within the CTM software was improved by DRDC Ottawa developing Sequential CTM, whereby the images in the time series are co-registered sequentially in a pair-wise manner. This report documents testing of the Sequential CTM software and includes the time series of RADARSAT-1 Fine mode images that have been processed, as well as processing procedures, some results, and problems that arose. Test sites include Resolute Bay, NU, Kandahar, Afghanistan, CFB Valcartier, and the Miramar, NU mine site.

Résumé

Le logiciel CTM (pour Coherent Target Monitoring : surveillance des cibles cohérentes) est un logiciel commercial standard conçu pour mesurer l’affaissement des terrains à une précision centimétrique, à partir des données d’interférométrie temporelle obtenues avec un radar à synthèse d’ouverture (RSO) en se fondant sur des mesures de diffuseurs stables. RDDC Ottawa a suggéré d’utiliser ce logiciel pour produire des séries temporelles d’images RSO et de cartes de cohérence précisément alignées qui pourraient servir à la détection de changements cohérents et non cohérents. RDDC Ottawa a voulu améliorer cette capacité du logiciel CTM en produisant le logiciel « Sequential CTM » qui permet l’alignement séquentiel, par paires, d’images d’une série temporelle. Le présent rapport fait état des essais du logiciel Sequential CTM, il présente des séries temporelles d’image RADARSAT 1 en mode fin qui ont été traitées, ainsi que les procédures de traitement, certains résultats et les problèmes qui se sont manifestés. Les sites observés sont situés à Resolute Bay (Nunavut), Kandahar (Afghanistan), la BFC Valcartier et dans les aménagements miniers Miramar (Nunavut).

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Executive summary

Time Series of RADARSAT-1 Fine Mode Images Using Sequential Coherent Target Monitoring Software

Wilson, David; DRDC Ottawa CR 2007-228; Defence R&D Canada – Ottawa; October 2007.

Introduction: Coherent Target Monitoring (CTM) is COTS software that was developed to detect the rate of land subsidence at the centimetre scale by using Synthetic Aperture Radar (SAR) repeat-pass interferometry applied to persistent scatterers in the scene. DRDC Ottawa has proposed to use the CTM software to produce a time-series of accurately co-registered SAR images and coherence maps that may be used for both non-coherent and coherent change detection. This capability within the CTM software was improved by DRDC Ottawa developing Sequential CTM, whereby the images in the time series are co-registered sequentially in a pair-wise manner based upon phase coherence.

Although it has a rather long 24-day repeat cycle, repeat-pass SAR interfermetry is well established for the RADARSAT-1 SAR sensor. As a demonstration of using the Sequential CTM software to create time series of accurately co-registered images, DRDC Ottawa has acquired several time series of RADARSAT-1 Fine mode data over favourable terrain, terrain of operational interest, and activities of interest. Test sites include Resolute Bay, NU, Kandahar, Afghanistan, CFB Valcartier, and the Miramar, NU mine site.

Results: This report documents testing of the Sequential CTM software and includes time series of RADARSAT-1 Fine mode images that have been processed, the processing procedures, some results, and problems that arose. Several problems were discovered with the software, which have been logged with the vendor and are still awaiting resolution. In general, the software is able to produce the co-registered time series in a straightforward manner; best practices have been established and documented. A novel output product is the average backscatter image, which is the non-coherent average of the co-registered image products.

The quality and utility of the resulting coherence maps depends strongly upon changes in the scene at the scale of the radar wavelength, 5.6 cm in the case of RADARSAT-1. Moisture (rain, snow, evaporation) and vegetation (wind movement and plant growth) changes between the passes may be limiting, so the Arctic and desert areas considered are particularly well suited to this technology. Based upon the data considered, these types of terrain are often characterized by good or excellent coherence maps.

Significance: Sequential CTM and inherent procedures may be used to produce time series of accurately co-registered SAR images and coherence maps for change analysis. These products could be used to observe how facilities evolve over time, or to detect changes in favourable settings that may not be detectable via non-coherent image comparisons.

Future plans: The Sequential CTM-processed time series of images presented in this document are available for demonstration purposes and for further analysis, such as fusion with images from other sensors and as input to automatic target detection algorithms.

Sommaire

Time Series of RADARSAT-1 Fine Mode Images Using Sequential Coherent Target Monitoring Software

Wilson, David; DRDC Ottawa CR 2007-228; R & D pour la défense Canada – Ottawa; Octobre 2007.

Introduction : Le logiciel CTM (pour Coherent Target Monitoring : surveillance des cibles cohérentes) est un logiciel commercial standard conçu pour mesurer l'affaissement des terrains à une précision centimétrique, à partir des données d'interférométrie temporelle obtenues avec un radar à synthèse d'ouverture (RSO) en se fondant sur des mesures de diffuseurs stables. RDDC Ottawa a suggéré d'utiliser ce logiciel pour produire des séries temporelles d'images RSO et de cartes de cohérence précisément alignées qui pourraient servir à la détection de changements cohérents et non cohérents. RDDC Ottawa a voulu améliorer cette capacité du logiciel CTM en produisant le logiciel « Sequential CTM » qui permet l'alignement séquentiel, par paires, d'images d'une série temporelle, en fonction de la cohérence de la phase.

L'interférométrie temporelle est une technique bien établie du satellite RSO RADARSAT 1, en dépit de son très long cycle de répétition de 24 heures. Pour démontrer la production de séries temporelles d'images précisément alignées par le logiciel Sequential CTM, RDDC a acheté plusieurs séries temporelles observées en mode fin par RADARSAT 1 de terrains favorables, de terrains présentant un intérêt opérationnel et de terrains où l'on effectuait des activités d'intérêt. Les sites observés sont situés à Resolute Bay (Nunavut), Kandahar (Afghanistan), la BFC Valcartier et dans les aménagements miniers Miramar (Nunavut).

Résultats : Le présent rapport fait état des essais du logiciel Sequential CTM, il présente des séries temporelles d'images RADARSAT 1 en mode fin qui ont été traitées, les procédures de traitement, certains résultats et les problèmes qui se sont manifestés. Nous avons détecté plusieurs problèmes de logiciels que nous avons signalés au fabricant, mais qui n'ont pas encore été résolus. En général, le logiciel réussit à produire directement des séries temporelles alignées. Les meilleures pratiques ont été déterminées et documentées. Un produit nouveau est l'image de la rétrodiffusion moyenne laquelle est la moyenne non cohérente des produits images alignés.

La qualité et l'utilité des cartes de cohérence résultantes dépendent fortement des changements dans la scène et la longueur d'onde du radar. (La longueur d'onde exploitée par RADARSAT 1 est 5.6 cm.) L'humidité atmosphérique (pluie, neige, évaporation) et la végétation (mouvements dus au vent, croissance végétale) varient d'un passage à l'autre, ce qui constitue une limite de cette technologie. En contrepartie, cette dernière est particulièrement bien adaptée à l'Arctique et aux terrains désertiques. Nos données prises dans ce type de terrains ont produit des cartes de cohérences bonnes ou excellentes.

Importance : À l'aide du logiciel Sequential CTM et des procédures inhérentes, nous pouvons produire des séries temporelles d'images RSO et de cartes de cohérence précisément alignées, destinées à l'analyse des changements. On pourra utiliser ces produits pour observer l'évolution d'installations avec le temps ou, dans des conditions favorables, pour déceler des changements difficilement détectables par des comparaisons d'images non cohérentes.

Perspectives : Les séries temporelles d'images traitées avec le logiciel Sequential CTM, présentées dans ce document, sont disponibles aux fins de démonstration et pour des analyses plus poussées, telles que la fusion avec des images obtenues avec d'autres capteurs ou comme données d'entrées d'algorithmes de détection automatique de cibles.

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Acknowledgements

The use of CTM software to produce a time series of co-registered images and coherence maps for non-coherent and coherent change detection for site monitoring, and the Sequential CTM concept were proposed by J. Secker and P.W. Vachon (DRDC Ottawa). Initial evaluation of the CTM software at DRDC Ottawa was carried out by N. Tayebi (Procomm) in 2006, under contract to DRDC Ottawa. The contributions of J. Secker, P.W. Vachon, and J. Wolfe (DRDC Ottawa), and A. Giles (Vexcel Canada) are greatly appreciated.

1 Introduction

Coherent Target Monitoring (CTM) uses the concept of repeat-pass Synthetic Aperture Radar (SAR) interferometry, but applies it to a series of images rather than just a pair of images. The requirements for SAR interferometry are compatible radars with compatible geometries. Since RADARSAT-1 has an orbit repeat cycle of 24 days, the spacecraft will be in the same location (within the orbital drift tolerance, which is closely controlled by the satellite operator, the Canadian Space Agency (CSA)) whenever it is at the same relative orbit number. Since the SAR has a very stable reference oscillator (i.e., the radar pulses are coherent) and the baseline (i.e., the distance between the two passes) is small, repeat-pass SAR interferometry is possible with RADARSAT-1.

In an Intelligence Surveillance and Reconnaissance (ISR) context, change detection is a key tool to narrow the area of interest (AOI) so that the Image Analyst (IA) can concentrate on significant targets in their theatre of operations. A Request for Information (RFI) from a commander may consist of site monitoring of installations over long periods of time (e.g. reactor sites).

DRDC Ottawa has proposed to use Coherent Target Monitoring (CTM) for change detection and site monitoring using repeat-pass interferometry. By observing the coherence map from sequential coherent pairs, one can discern changes based upon the coherence being lower than the surrounding areas. This may indicate man-made changes (e.g., vehicle tracks, new roads, airfields) or ecological, geological or seasonal changes (e.g., defoliation, landslides, changes in snow/ice cover, etc.). Change detection based upon observation of a loss of coherence is often referred to as Coherent Change Detection (CCD).

CTM is a COTS software program [2] developed by Atlantis Scientific (later Vexcel Canada, then part of Microsoft Canada, and currently part of MDA) initially under contract from CSA as an extension to their EV-InSAR package. CTM was developed specifically for Coherent Target Monitoring, but has been used at DRDC Ottawa in its “Sequential” mode, a capability that was developed specifically for DRDC Ottawa [3]. For the sequential mode, a time sequence of input Single Look Complex (SLC) images is processed as a sequence of adjacent image pairs, which minimizes the time step between each image, and maximizes the scene coherence between each analyzed image pair as compared to regular CTM processing, which pairs all images to a single reference image. This permits productions of a time series of co-registered SLC images and coherence maps for change detection analysis. The software also produces an image of the average backscatter by calculating the mean value of the co-registered and detected images.

Depending upon the time between the coherent pairs (data is not always available on every 24-day repeat cycle of RADARSAT-1) and general changes in the land cover, the overall coherence map may be very good or very poor.

This document briefly introduces CTM, describes the datasets examined, the procedures used, problems arising, and lessons learned in the process. Some representative coherence maps are shown in Annexes A and B. More information on certain procedures appears in Annexes C and D. Some fused CTM products are discussed by Vachon et al. in Annex D of [5].

2 Summary of Data Sets

CTM was used to process five time series of RADARSAT-1 Fine beam mode data:

- 39 F5, ascending scenes from Resolute Bay, NU;
- 22 F2, descending scenes from Kandahar, Afghanistan;
- 17 F4, ascending scenes from Kandahar, Afghanistan;
- Two pairs of F3N scenes from CFB Valcartier, QC; and
- Five F2 and F2N ascending scenes from the Miramar, NU mine site.

The Resolute Bay scenes are a convenient test site, as repeat images are available for all beam modes at this site because it is used by CSA as part of their radiometric calibration program. A radar calibration transponder is located north of the airfield. The scene also includes a village and Arctic terrain. The Kandahar, Afghanistan scenes include desert terrain and represent a current theatre of operations for the CF. The Valcartier scenes were examined to assess detection of wintertime ground operations at CFB Valcartier, while the Miramar site was tested for detection of activity in the Arctic and to demonstrate CCD for a CF initiative to enhance Arctic surveillance.

The datasets are summarized in Table 1 through Table 6. Recall that RADARSAT-1's repeat cycle is 24 days. In the tables, the assessment of coherence is subjective, with poor being mostly zero coherence and excellent being mostly unity coherence. Some pairs were "Not Processed" due to issues noted in Section 5.

Table 1: Resolute (ascending) datasets (Relative Orbit 8.20657).

	Date	Start Time	Stop Time	Beam Mode	Days Since	Coherence
1	2000-09-20	23:53:11	23:53:28	F5		
2	2000-11-07	23:53:09	23:53:26	F5	48	Fair
3	2000-12-25	23:53:10	23:53:27	F5	48	Fair
4	2002-01-13	23:53:39	23:53:56	F5	384	Very Poor
5	2002-03-02	23:52:33	23:52:50	F5	48	Excellent
6	2002-04-19	23:52:34	23:52:51	F5	48	Good
7	2002-07-24	23:52:23	23:52:38	F5	96	Very Poor
8	2002-09-10	23:52:21	23:52:38	F5	48	Excellent
9	2002-10-28	23:52:18	23:52:33	F5	48	Poor
10	2002-11-21	23:52:15	23:52:32	F5	24	Good
11	2003-01-08	23:52:09	23:52:26	F5	48	Good
12	2003-03-21	23:52:02	23:52:19	F5	72	Good
13	2003-06-01	23:51:54	23:52:12	F5	72	Poor
14	2003-09-29	23:51:47	23:52:04	F5	120	Poor
15	2003-11-16	23:51:44	23:52:00	F5	48	Fair
16	2004-03-15	23:51:26	23:51:43	F5	120	Fair
17	2004-08-06	23:51:17	23:51:32	F5	144	Poor
18	2004-08-30	23:51:12	23:51:28	F5	24	Excellent
19	2004-10-17	23:51:13	23:51:28	F5	48	Poor
20	2004-11-10	23:51:10	23:51:27	F5	24	Fair
21	2004-12-04	23:51:09	23:51:25	F5	24	Fair
22	2004-12-28	23:51:05	23:51:21	F5	24	Excellent
23	2005-02-14	23:51:00	23:51:16	F5	48	Good
24	2005-03-10	23:50:57	23:51:12	F5	24	Good
25	2005-04-03	23:50:55	23:51:11	F5	24	Good
26	2005-05-21	23:50:52	23:51:08	F5	48	Poor
27	2005-06-14	23:50:54	23:51:10	F5	24	Poor
28	2005-08-01	23:50:50	23:51:05	F5	48	Good
29	2005-09-18	23:50:46	23:51:01	F5	48	Excellent
30	2005-10-12	23:50:46	23:51:01	F5N	24	Excellent
31	2005-11-29	23:50:42	23:50:58	F5	48	Excellent
32	2005-12-23	23:50:37	23:50:53	F5	24	Excellent
33	2006-01-16	23:50:33	23:50:49	F5	24	Good
34	2006-02-09	23:50:33	23:50:49	F5	24	Fair
35	2006-03-29	23:50:31	23:50:46	F5	48	Fair
36	2006-05-16	22:50:28	23:50:44	F5	48	Good
37	2006-06-09	23:50:30	23:50:46	F5	24	Poor
38	2006-07-03	23:50:24	23:50:40	F5	24	Fair
39	2006-07-27	23:50:26	23:50:41	F5	24	Excellent

Table 2: Kandahar (descending) datasets (Relative Orbit 166.41247).

	Date	Start Time	Stop Time	Beam Mode	Days Since	Coherence
1	2005-08-13	01:31:18	01:31:34	F2F		Not Processed
2	2005-09-06	01:31:18	01:31:34	F2F	24	Not Processed
3	2005-09-13	01:27:08	01:27:23	F4N		Not Processed
4	2005-10-07	01:27:08	01:27:21	F4N	24	Not Processed
5	2006-01-04	01:31:08	01:31:23	F2	120	Not Processed
6	2006-01-28	01:31:03	01:31:19	F2	24	Good
7	2006-03-17	01:31:02	01:31:18	F2	48	Good
8	2006-04-10	01:30:59	01:31:14	F2	24	Good
9	2006-05-04	01:31:02	01:31:17	F2	24	Good
10	2006-05-28	01:30:59	01:31:14	F2	24	Excellent
11	2006-06-21	01:30:59	01:31:14	F2	24	Good
12	2006-07-15	01:30:55	01:31:10	F2	24	Excellent
13	2006-08-08	01:30:55	01:31:11	F2	24	Excellent
14	2006-09-01	01:30:55	01:31:11	F2	24	Excellent
15	2006-09-25	01:30:53	01:31:08	F2	24	Good
16	2006-10-19	01:30:54	01:31:10	F2	24	Good
17	2006-11-12	01:30:52	01:31:07	F2	24	Good
18	2006-12-06	01:30:51	01:31:06	F2	24	Good
19	2006-12-30	01:30:49	01:31:04	F2	24	Fair
20	2007-01-23	01:30:45	01:31:00	F2F	24	Good
21	2007-02-16	01:30:46	01:31:01	F2F	24	Fair
22	2007-03-12	01:30:43	01:30:59	F2	24	Fair

Table 3: Kandahar (ascending) datasets (Relative Orbit 145.08532).

	Date	Start Time	Stop Time	Beam Mode	Days Since	Coherence
1	2006-01-26	13:42:10	13:42:25	F4	24	Not Processed
2	2006-02-19	13:42:10	13:42:25	F4	24	Not Processed
3	2006-03-15	13:42:10	13:42:25	F4	24	Not Processed
4	2006-04-08	13:42:07	13:42:22	F4	24	Not Processed
5	2006-05-02	13:42:09	13:42:24	F4	24	Not Processed
6	2006-05-26	13:42:07	13:42:20	F4	24	Not Processed
7	2006-06-19	13:42:06	13:42:22	F4	24	Not Processed
8	2006-07-13	13:42:02	13:42:17	F4	24	Good
9	2006-08-06	13:42:03	13:42:18	F4	24	Good
10	2006-08-30	13:42:02	13:42:17	F4	24	Fair
11	2006-10-17	13:42:02	13:42:17	F4	48	Good
12	2006-11-10	13:41:59	13:42:14	F4	24	Fair
13	2006-12-04	13:41:58	13:42:13	F4	24	Not Processed
14	2006-12-28	13:41:56	13:42:11	F4	24	Not Processed
15	2007-01-21	13:41:53	13:42:08	F4F	24	Not Processed
16	2007-02-14	13:41:53	13:42:08	F4F	24	Not Processed
17	2007-03-10	13:41:49	13:42:05	F4F	24	Not Processed

Table 4: Miramar (ascending) datasets (Relative Orbit 280.15965).

	Date	**Start Time**	**Stop Time**	**Beam Mode**	**Days Since**	**Coherence**
1	2006-10-03	00:34:43	00:35:00	F2N		
2	2006-11-20	00:34:44	00:35:01	F2N	48	Very Poor
3	2007-01-07	00:34:46	Not Avail.	F2	48	Poor
4	2007-01-31	00:34:34	00:34:51	F2N	24	Fair
5	2007-02-24	00:34:36	00:34:52	F2	24	Good

Table 5: Valcartier (ascending) datasets (Relative Orbit 64.64009).

	Date	**Start Time**	**Stop Time**	**Beam Mode**	**Days Since**	**Coherence**
1	2007-01-20	22:39:24	22:39:39	F3N		
2	2007-02-13	22:39:24	22:39:39	F3N	24	Very Poor

Table 6: Valcartier (descending) datasets (Relative Orbit 71.88118).

	Date	**Start Time**	**Stop Time**	**Beam Mode**	**Days Since**	**Coherence**
1	2007-02-14	10:49:00	10:49:15	F2		
2	2007-03-10	10:48:56	10:49:12	F2	24	Not Processed

3 Summary of Processing Procedures

The processing procedure that is contained in this section was adapted from a procedure that was initially outlined by N. Tayebi (see Annex C). The run procedure and outputs from a typical run are shown, along with a few screenshots of the CTM software.

1. Load RAW RADARSAT-1 data from CD on a PC using a script **pc25043-RAST\\C:\Data\RADARSAT-1\ingest_RS1.csh** (documented in Annex D) to rename the files from the original naming convention on CD (e.g. dat_01.001) to filenames describing the data (e.g. **RS1_Resolute_A_F5__2000-09-20_RAW.sdf**):

```
dwilson@pc25043-RAST /cygdrive/c/data/RADARSAT-1
$ ingest_RS1.csh
Location (one word; will use this as directory) > Miramar
A or D > A
Beam (max 3 char) > F2N
Date (yyyy_mm_dd) > 2006-11-20
total 399440
-r--r--r--  1 dwilson Domain Users 409004120 Nov 30 22:23 dat_01.001
-r--r--r--  1 dwilson Domain Users     13776 Nov 30 22:23 lea_01.001
-r--r--r--  1 dwilson Domain Users       360 Nov 30 22:23 nul_vdf.001
-r--r--r--  1 dwilson Domain Users       720 Nov 30 22:23 tra_01.001
-r--r--r--  1 dwilson Domain Users      1800 Nov 30 22:23 vdf_dat.001
`e:/scene01/DAT_01.001' -> `./RS1_Miramar_A_F2N_2006-11-20_RAW.sdf'
`e:/scene01/LEA_01.001' -> `./RS1_Miramar_A_F2N_2006-11-20_RAW.slf'
`e:/scene01/NUL_VDF.001' -> `./RS1_Miramar_A_F2N_2006-11-20_RAW.nvf'
`e:/scene01/TRA_01.001' -> `./RS1_Miramar_A_F2N_2006-11-20_RAW.stf'
`e:/scene01/VDF_DAT.001' -> `./RS1_Miramar_A_F2N_2006-11-20_RAW.vdf'
total 1597732
-rwx------+ 1 dwilson Domain Users       360 Oct 16  2006 03Oct06_56959_01.nvol
-rwx------+ 1 dwilson Domain Users 408985302 Oct 16  2006 03Oct06_56959_01.sard
-rwx------+ 1 dwilson Domain Users     13776 Oct 16  2006 03Oct06_56959_01.sarl
-rwx------+ 1 dwilson Domain Users       720 Oct 16  2006 03Oct06_56959_01.sart
-rwx------+ 1 dwilson Domain Users       961 Oct 16  2006 03Oct06_56959_01.txt
-rwx------+ 1 dwilson Domain Users      1800 Oct 16  2006 03Oct06_56959_01.vol
-rwx------+ 1 dwilson Domain Users       360 Jan 16 11:59 07Jan07_58331_01.nvol
-rwx------+ 1 dwilson Domain Users 408966484 Jan 16 13:25 07Jan07_58331_01.sard
-rwx------+ 1 dwilson Domain Users     13776 Jan 16 13:33 07Jan07_58331_01.sarl
-rwx------+ 1 dwilson Domain Users       720 Jan 16 13:33 07Jan07_58331_01.sart
-rwx------+ 1 dwilson Domain Users       956 Jan 16 13:34 07Jan07_58331_01.txt
-rwx------+ 1 dwilson Domain Users      1800 Jan 16 13:34 07Jan07_58331_01.vol
-r--r--r--  1 dwilson Domain Users       360 May 31 17:13 RS1_Miramar_A_F2N_2006-11-20_RAW.nvf
-r--r--r--  1 dwilson Domain Users 409004120 May 31 17:13 RS1_Miramar_A_F2N_2006-11-20_RAW.sdf
-r--r--r--  1 dwilson Domain Users     13776 May 31 17:13 RS1_Miramar_A_F2N_2006-11-20_RAW.slf
-r--r--r--  1 dwilson Domain Users       720 May 31 17:13 RS1_Miramar_A_F2N_2006-11-20_RAW.stf
-r--r--r--  1 dwilson Domain Users      1800 May 31 17:13 RS1_Miramar_A_F2N_2006-11-20_RAW.vdf
-r--r--r--  1 dwilson Domain Users       360 Jan 26 14:25 RS1_Miramar_F2N_2006-11-20_A_RAW.nvf
-r--r--r--  1 dwilson Domain Users 409004120 Jan 26 14:25 RS1_Miramar_F2N_2006-11-20_A_RAW.sdf
-r--r--r--  1 dwilson Domain Users     13776 Jan 26 14:25 RS1_Miramar_F2N_2006-11-20_A_RAW.slf
-r--r--r--  1 dwilson Domain Users       720 Jan 26 14:25 RS1_Miramar_F2N_2006-11-20_A_RAW.stf
-r--r--r--  1 dwilson Domain Users      1800 Jan 26 14:25 RS1_Miramar_F2N_2006-11-20_A_RAW.vdf

Filesystem            Size  Used Avail Use% Mounted on
c:                    233G  210G   24G  91% /cygdrive/c
```

The parameters can also be entered on the command line as:

$ ingest_RS1.csh Miramar A F2N 2006-11-20

The script shows the data on the CD, then proceeds to transcribe it to a subdirectory named by the location parameter. After the files are renamed in this directory, a listing is made and a summary of the free space on the local disk is given as information for the next data ingest.

2. On the PC, "ftp" the data to the workstation **raven**, a Linux server (srv25662-rde). Ncftp (bundled with the popular CYGWIN Unix for Windows package) remembers defaults and gives progress and ETA, but any ftp client would do.

```
dwilson@pc25043-RAST /cygdrive/c/data/RADARSAT-1
$ cd Miramar/
```

```
dwilson@pc25043-RAST /cygdrive/c/data/RADARSAT-1/Miramar
$ ncftp raven
NcFTP 3.1.7 (Jan 07, 2004) by Mike Gleason (http://www.NcFTP.com/contact/).
Resolving raven...
Connecting to 131.136.33.32...

FTP on RDE server
Logging in...

Password requested by 131.136.33.32 for user "dwilson".

    Please specify the password.

Password: *********

Login successful.
Logging in...
Logged in to raven.

Directory successfully changed.
Current remote directory is /home/tz2/dwilson.
ncftp /home/tz2/dwilson > cd data/RADARSAT-1/Miramar
Directory successfully changed.
ncftp ...ata/RADARSAT-1/Miramar > mput RS1_Miramar_A_F2N_2006-11-20_RAW.*
RS1_Miramar_A_F2N_2006-11-20_RAW.nvf:                  360.00 B  351.56 kB/s
RS1_Miramar_A_F2N_2006-11-20_RAW.sdf:                  390.06 MB   22.63 MB/s
RS1_Miramar_A_F2N_2006-11-20_RAW.slf:                   13.45 kB    6.57 MB/s
RS1_Miramar_A_F2N_2006-11-20_RAW.stf:                  720.00 B    0.00 B/s
RS1_Miramar_A_F2N_2006-11-20_RAW.vdf:                    1.76 kB    1.72 MB/s
ncftp ...ata/RADARSAT-1/Miramar > quit
```

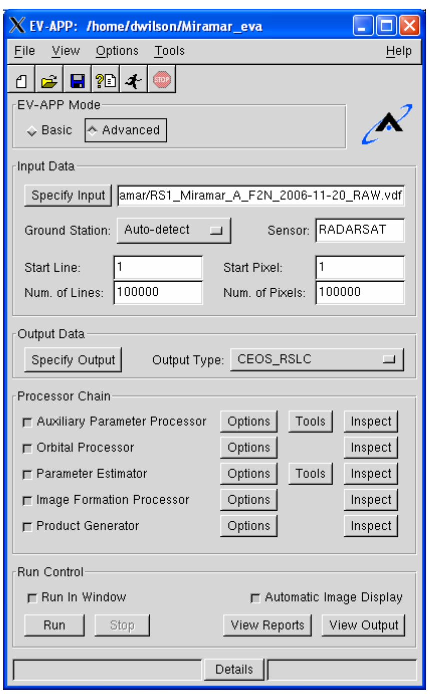
3. On raven, initialize the APP SW [1] using the script **vexcel2006_setup.csh**.

```
dwilson@srv25662-rde:/home/dwilson> source atlantisV3_setup.csh
```

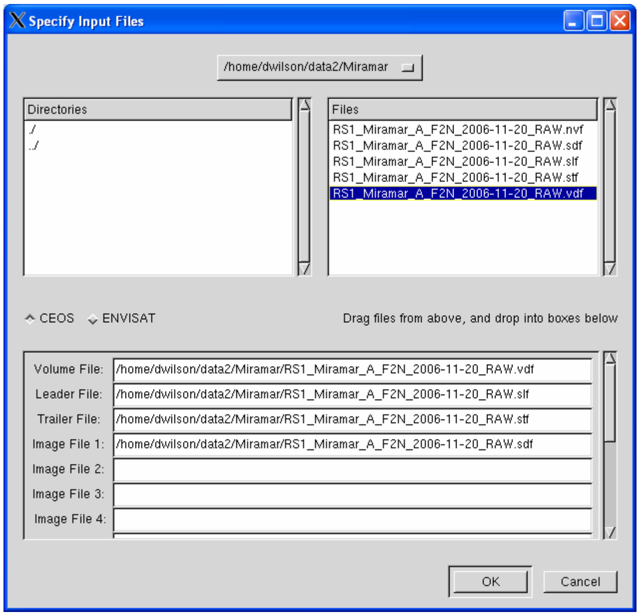
4. Process the RAW data, using EV-**APP "appgui"** (another Vexcel COTS product), into an SLC product.

```
dwilson@srv25662-rde:/home/dwilson> appgui
Loading tools from /usr/local/EarthView3/OpenEV/tools/Tool_DriverList.py
Loading tools from /usr/local/EarthView3/OpenEV/tools/Tool_ShapesGrid.py
Loading tools from /usr/local/EarthView3/OpenEV/tools/Tool_Export.py
```

Select "Advanced".

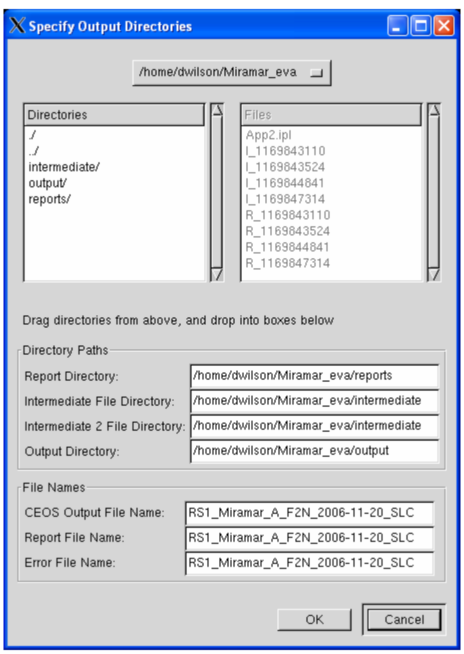


Specify the input files from the directory you ftp'd to by dragging the file names from the "Files" panel to the appropriate "Volume File:" etc.:



Set the input size to an arbitrarily large number of lines and pixels. Appgui will then process the entire image.

Modify the output filenames in the APP GUI to correspond to the input files:



Set up the Output Type to be CEOS_RSLC.

The defaults for APP have been set up so that AGC correction, Replica, Roll correction, Antenna Beam Pattern correction and output to 16-bit (C_int16) integers are all the default values.

Click Run and the software will create the output SLC product in the output directory, in this case Miramar_eva/output.

5. Transfer the SLC files from the APP "output" directory to **TZ**, a Linux workstation (pc25367-ctm), using either an NFS mount of TZ:/home2 or ftp.

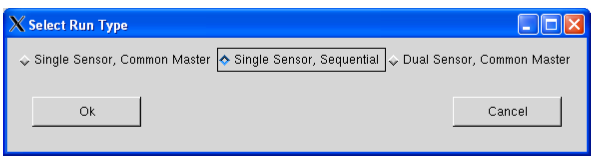
```
> cp Miramar_eva/output/*  /home/tz2/dwilson/data/RADARSAT-1/Miramar/RS1_Miramar_A_F2N_2006-11-20
```

6. Initialize CTM on TZ using the script **vexcel_setup.csh**. See the CTM User Guide [2] for the CTM initialization procedure that creates this script.

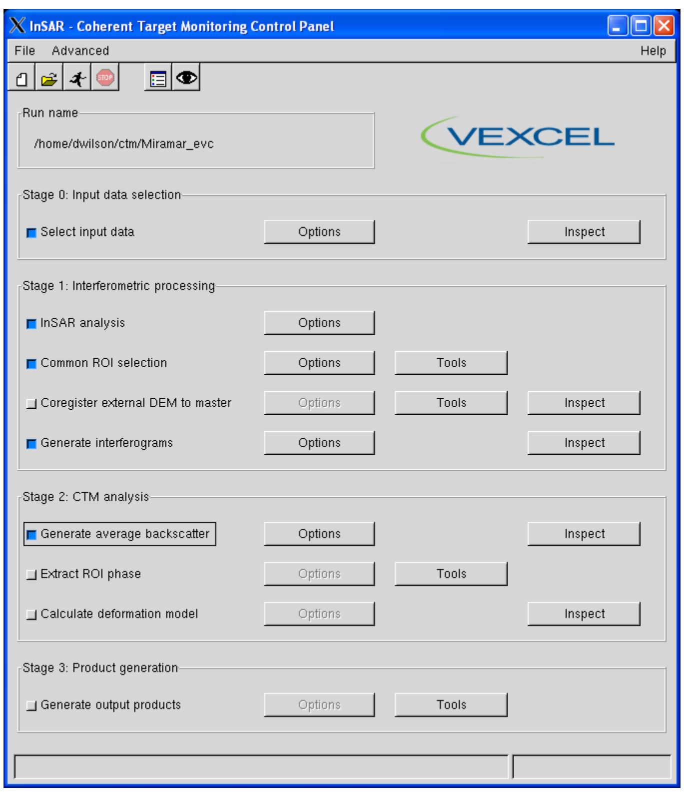
```
[dwilson@pc25367-ctm ~]$ source ~/vexcel_setup.csh
```

7. Start the **ctmgui** and click File > New Run. Specify Sequential mode:

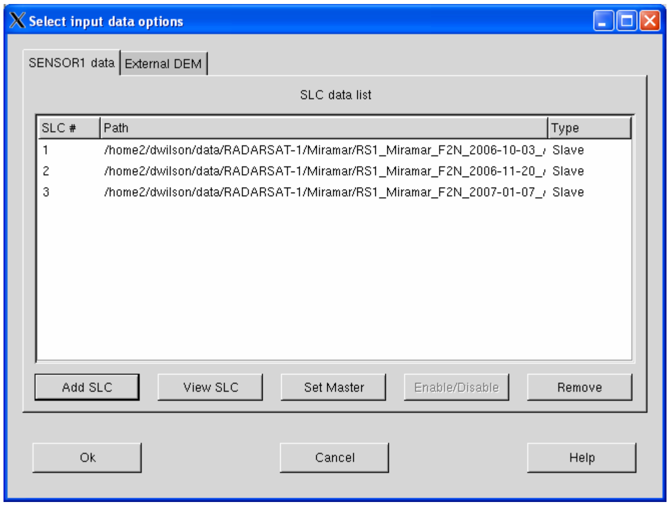
```
[dwilson@pc25367-ctm ~]$ ctmgui
```



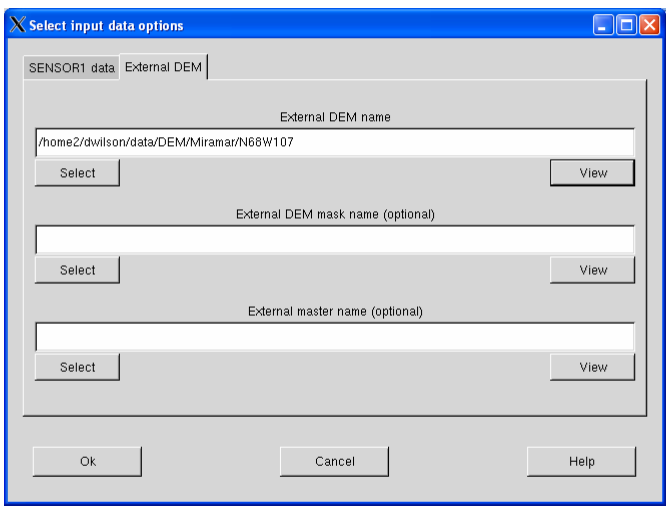
Select all option boxes from Input to Generate average backscatter.



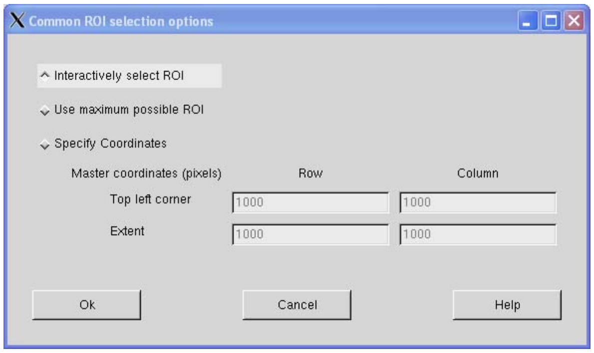
8. Select Input Options and enter all the SLC files in chronological order by clicking Add SLC. One must specify a directory, so the SLC files must be placed in separate directories.



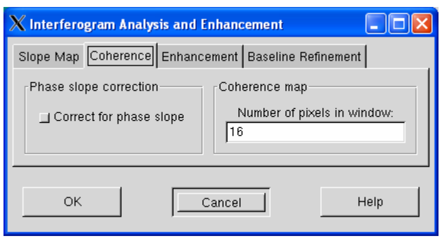
9. Select the DEM tab and enter the directory containing the DEM file. See Annex E for creating merged DEMs using MicroDEM and asctodem.



10. Select the Region of Interest (ROI):

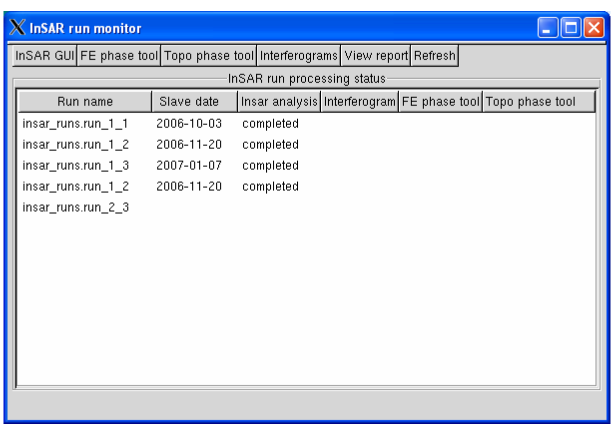


11. For this study we used a 4x4 re-sampling kernel, so that the Insar Analysis > All Sensors > Enhanced Interferogram Phase > Coherence tab parameter **Kernel** ("Number of pixels in window") had to be reset from 144 to 16. This has been set as the current default.



Be careful to close the InSAR Control Panel that was opened here, and not the CTM Control Panel, as they look very similar.

12. Click the Run button to start processing. To monitor the progress of the runs, click the InSAR Run Monitor button.



13. Examine the output products using, for example, the auto-cycle tool in IA Pro [4].

4 Description of Saved Data Sets

1. Raw RADARSAT-1 Data

   The Raw RADARSAT-1 data (almost all processed by RSI) are archived in the CSIAPS Archive (metadata) and the original CDs are stored in the cabinet in Room 227. They are also listed in the RDE Access database.

2. Resolute A SLC Data

   This set of 16+23=39 SLC images constitutes 17.5 (NT) + 16.3 (DJW) = 33.8 GBytes and is stored on a set of 7 DVDs in Room 233.

3. Resolute 2000 A Dataset

   The CTM output of slave and coherence images (15 pairs) constitutes 22.1 GBytes and is stored on a set of 5 DVDs in Room 233.

4. Resolute 2004 A Dataset

   The CTM output of slave and coherence images (22 pairs) constitutes 22.1 GBytes and is stored on a set of 5 DVDs in Room 233.

5. Kandahar A Dataset

   This set of 11+17 SLC images constitutes 11.5 (NT) + 5.7 (DJW) = 17.2 GBytes and is stored on a set of 4 DVDs in Room 233. The CTM output of slave and coherence images constitutes 7.9 GBytes and is stored on another set of 2 DVDs in Room 233.

6. Kandahar D Dataset

   This set of 18 images (17 pairs) constitutes 17.0 GBytes of data and is stored on a set of 4 DVDs in Room 233. The CTM output of slave and coherence images constitutes 22.1 GBytes and is stored on another set of 5 DVDs in Room 233.

7. Miramar Dataset

   This set of 3 SLC images (2 pairs) constitutes 2.1 GBytes of data. The CTM output of slave and coherence images constitutes 279 MBytes and all of this is stored on a single DVD in Room 233.

8. Valcartier Dataset

   This set of 3 SLC images (2 pairs) constitutes 2.2 GBytes of data. The CTM output of slave and coherence images constitutes 2.2 Gbytes and all of this is stored on a single DVD in Room 233.

5 Problems Encountered

1. A low-frequency sinusoidal coherence pattern appeared in some of the Kandahar Ascending runs (Annex B, Figure 6). There is an intensity variation with a sinusoidal pattern across the image (sometimes range oriented, sometimes azimuth oriented). In this case, the pattern appears to have approximately one cycle. The pattern does not appear in every image, just 3 out of 5. This problem is under investigation by Vexcel Canada at the time of writing and there is currently no mitigation procedure. Note: a few of the Kandahar Ascending scenes were processed in spite of this problem because we have been waiting for a fix for over a year.

2. Sinusoidal coherence pattern in an identical image pair (Annex B, Figure 7). By accident, an image was renamed with the same name as the next image in the series, resulting in two identical images being processed as a pair. Rather than the coherence being perfect, a sinusoidal pattern emerged, but the axis was roughly horizontal and there were approximately 7 cycles in the coherence along the azimuth of the image.

3. Difficulty in removing or reordering input images.

4. Difficulty in restarting the CTM software in the case of failure. A failure might be an error message because of a missing file, for example, or the software might go into an infinite loop, checking for some prerequisite for a step, but never executing the code to generate the prerequisite. This can sometimes be mitigated by using the UNIX command “touch” on the master and/or slave files in the recipe directory.

5. Modifications made to IAPro to ease display of CTM data:

    a. Sorting the AOI directory list;

    b. Increasing the length of the AOI Control filename; and

    c. Enabling specification of input filenames on the command line (not yet available on Linux).

6. Several image artefacts (dropouts) were observed in slave images (Annex B, Figure 8).

7. A script, ctm_display.csh, was written to gather the data from the MFF2 files created by CTM and convert them to a directory of GeoTiff files, renaming them so that they are in numerical order (e.g. coherence_run_01_02.tif). Overlays are created using gdal_translate and gdaladdo. Gdal_translate will translate between any of the standard file formats known to GDAL (pronounced “goo-dal”), the Geospatial Data Abstraction Library, but is used here only to convert from the full resolution file to a one-half resolution file for the overlay. Gdaladdo adds the rest of the overlays internally to the “.ovr” file. There is a registration bug in CTM and it is necessary to copy the georef file from the 1_1 run to all the other runs in this script, so that the images are co-registered.

8. Several artefacts were note in the DEMs that appear as linear edges (Annex B, Figure 9).

9. Several artefacts were noted in coherence maps, related to the images extending past the edge of the DEM (Annex B, Figure 10), or perhaps to dropouts in one of the constituent images (Annex, Figure 11).

6 Recommendations and Lessons Learned

1. Be very careful setting up the CTM software, as it is tedious to redo if images are out of order or a member of a sequence has to be replaced. Also, don't move the input data (change directories or rename) or you will have to restart the complete run.

2. Clear the decks when running CTM. It can use up to 8 GBytes of disk space per pair for Fine mode SLC images. It appears to have trouble when disk space is limited (grinds exceedingly slowly).

3. A script was created to ingest RS-1 (RSI format) data from CD on the PC and rename it from the non-descriptive default filenames (e.g. dat_01.001) to filenames describing the data (e.g. **RS1_Resolute_A_F5__2000-09-20_RAW.sdf**).

4. Set up the defaults for APP on raven to process using AGC correction, Replica, Roll correction, Antenna Beam Pattern correction and output to 16-bit (C_int16) integers.

5. If the user chooses "Interactively select ROI", the selection window will appear part way through the processing, when the SW has determined the overlap of all the images. If processing time is not an issue (overnight run), then "Use maximum possible ROI" can be chosen, however there is a suspicion that, with large numbers of images the SW may get confused and get into an infinite loop. Interactive is recommended. Start the SW early enough that the ROI selection can be completed and the SW does not wait in that step overnight.

6. Note that the CTM SW is sensitive to foreign files being created in its tree (e.g. run_m_n/images/azimuth_filtered_slave/georef was renamed to *.bad and caused CTM to hang).

7. When the command line SW modification is made to IAPro on Linux, the script will be modified to start IAPro and load all the images.

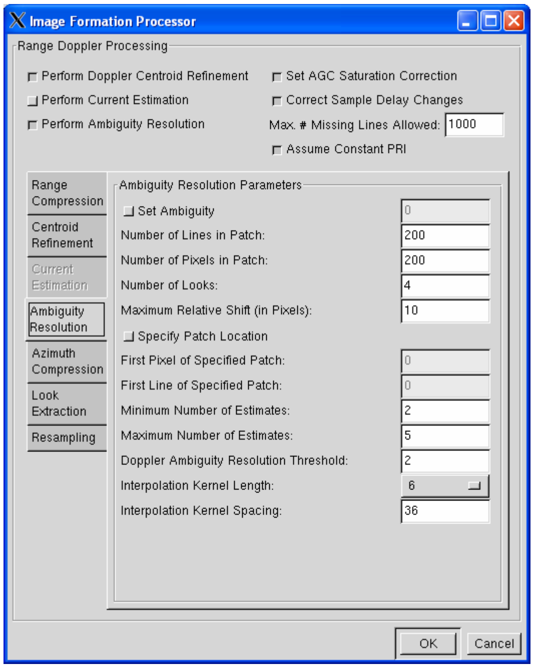
8. DEMs are of varying quality and usually do not span the whole area of interest and must be merged together using MicroDEM and K. Mattar's program on pigpen called asctodem. A DEM comprising sheets 058Ge, 058Gw, 058Fe, 058Fw, 068He and 068Ee was created to cover the whole of Cornwallis Island for the Resolute scenes.

9. Problems were encountered when processing the Kandahar A scenes, but the ROI was adjusted to below the top of the DEM at 32°N, but this did not solve the coherence banding problem.

10. The Kandahar DEM contains some artefacts. An image pair was processed without the DEM, and the coherence artefacts mentioned as item 1 in the previous Section, were not reduced, eliminating these DEM artefacts as a possible cause.

11. The SLC data were not processed to the WGS84 datum because all previous data had been processed to the default datum (i.e., IUGG_75).

12. Occasionally images produced by APP have an azimuth ambiguity error (e.g. Resolute_2006-05-16). These are easily spotted, as the geo-referenced image is placed several kilometers up or down in the along-track direction. The remedy is to re-process in the APP, setting the ambiguity number to a different integer value. Try plus or minus 1; for example, in the case of the 2006-05-16 image it was set to zero. An alternative is to increase the "Patch" area that the APP uses to estimate the Doppler ambiguity, or ultimately, changing the location of the patch to a less "difficult" area of the image using the GUI:



13. If the CTM software hangs ("stop", "exit" or clicking the window's "X" button doesn't work), it may be necessary to kill the process using "kill –HUP <pid>", getting the pid of the lowest process in the tree from "ps –ef". This is usually "dmake" which is "defunct". If this does not clear everything, work your way up from the bottom.

14. A trick suggested by A. Giles of Vexcel Canada for restarting CTM after a crash is to use the Unix command "touch" on the slave or master file in xxx_evc/insar_runs/run_m_n/recipe to force it to re-do that step. This makes it appear that the file has changed and the CTM software will attempt to re-process it.

References

[1] EarthView Advanced Precision Processor (APP) for SAR, Version 3.2: User's Guide. Vexcel Canada, Nepean, Ont., Canada. 2006.

[2] EarthView InSAR/CTM, Version 3.2: User Guide. Vexcel Canada, Nepean, Ont., Canada. 2006.

[3] Hughes, W., and Giles, A. (2007). Sequential CTM. DRDC Ottawa CR 2007-118, Defence R&D Canada – Ottawa.

[4] Secker, J., Walter, G. and Espesset, A. (2005). Image Analyst Pro: A New Multi-Sensor Imagery Exploitation System for Geospatial Intelligence. DRDC Ottawa TR 2005-219. Defence R&D Canada – Ottawa.

[5] Vachon, P.W., Secker, J., and Werle, D. (2007). Remote sensing in support of Arctic intelligence: Development of sensor selection rules for CSIAPS. DRDC Ottawa TM 2007-109, Defence R&D Canada – Ottawa.

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Annex A A Selection of Coherence Maps from CTM

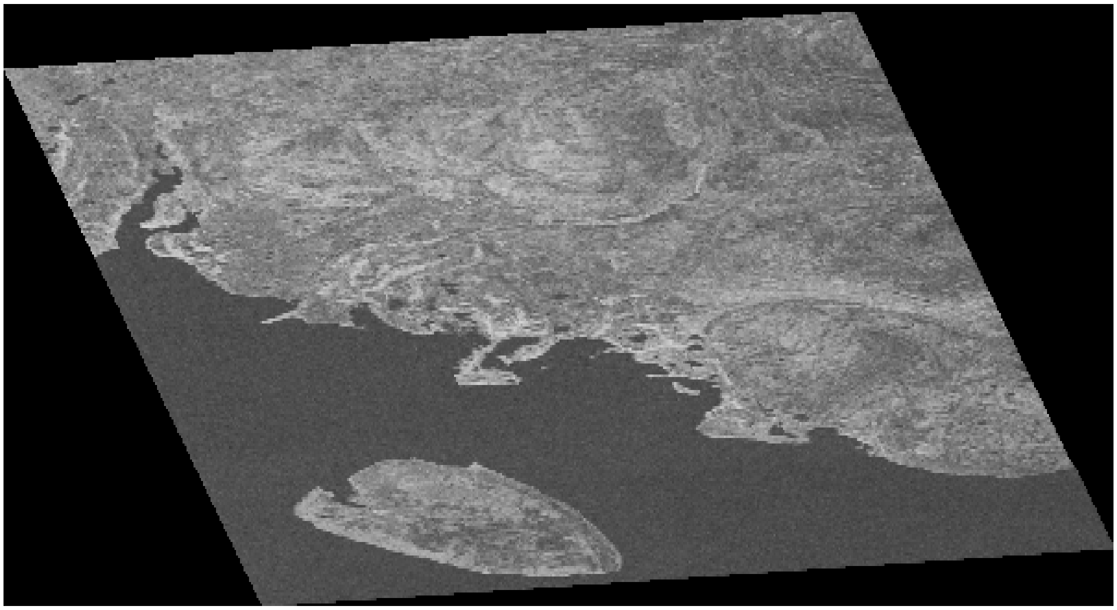

Figure 1: Representative coherence map for Resolute (2002-07-24 and 2002-09-10), F5.

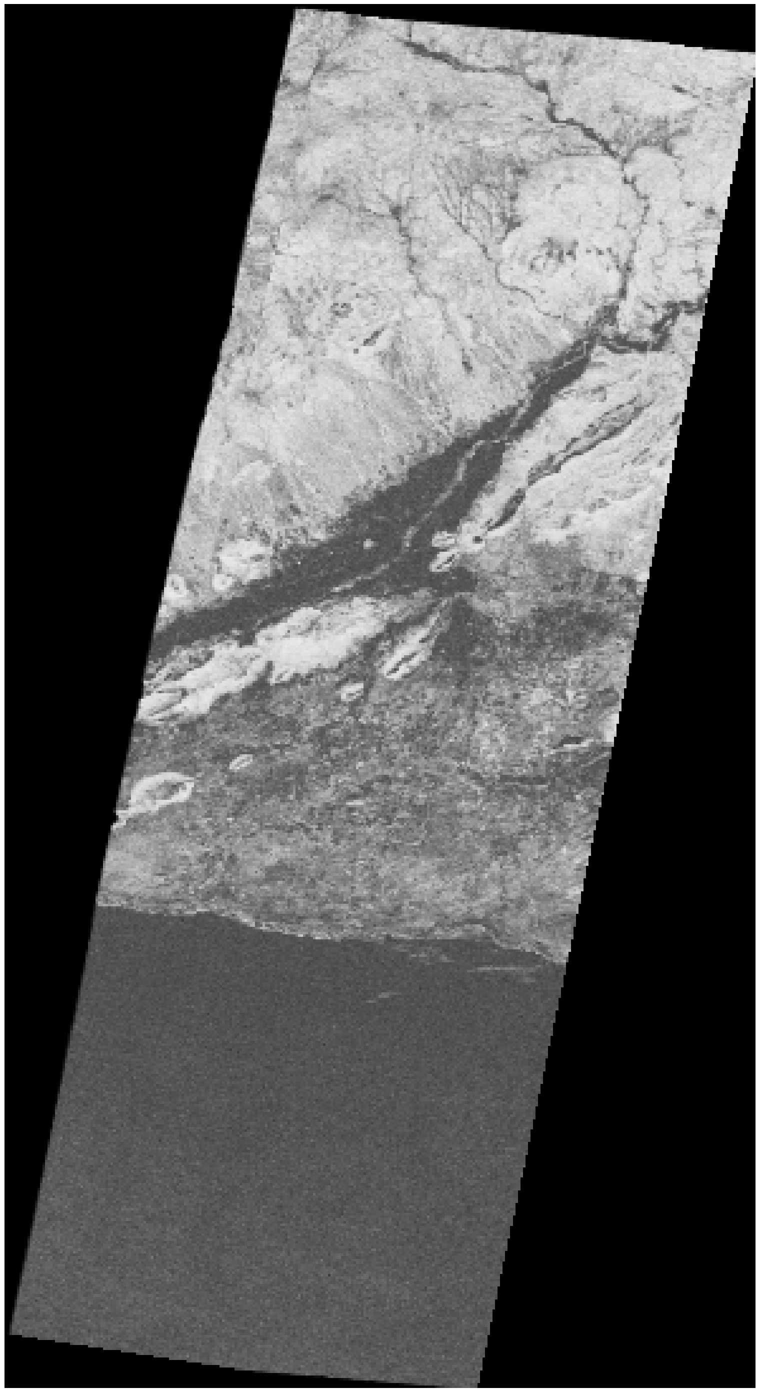

Figure 2: Representative coherence map for Kandahar (2006-05-04 and 2006-05-28, descending), F2.

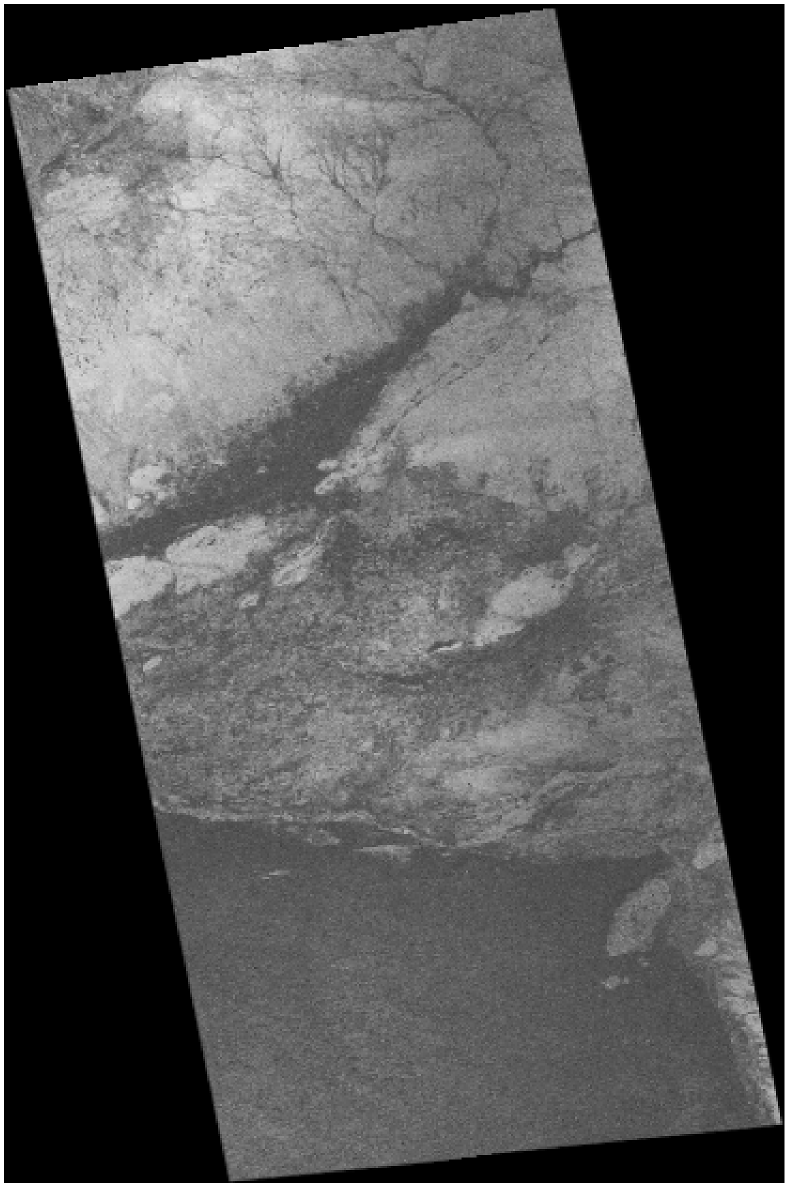

Figure 3: Representative coherence map for Kandahar (2006-06-19 and 2006-017-13, ascending), F4.

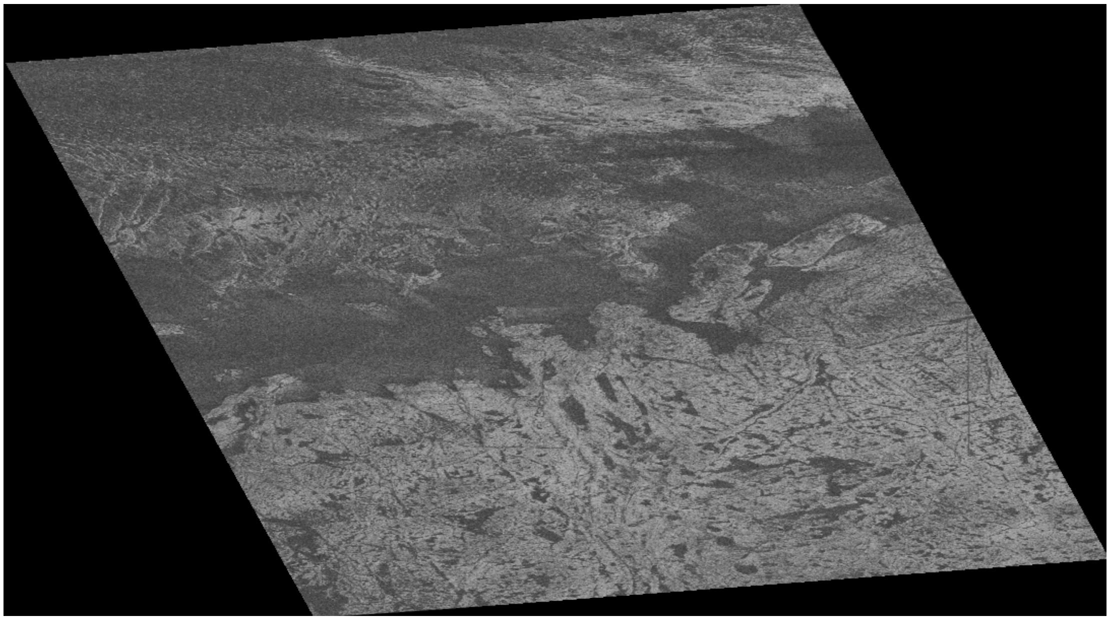

Figure 4: Representative coherence map for Miramar (2007-01-31 and 2007-02-24), F2.

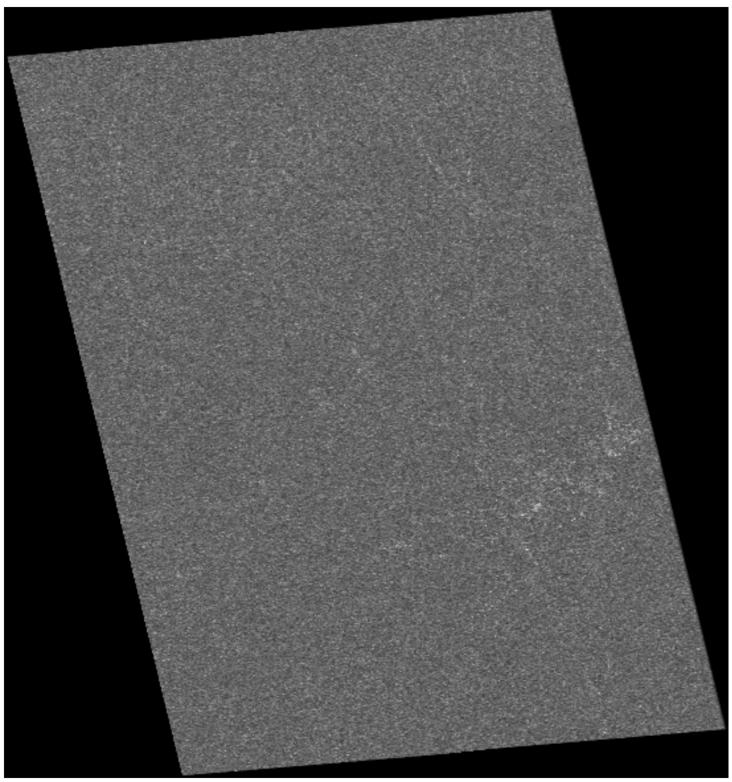

Figure 5: Coherence map for Valcartier (2007-01-20 and 2007-02-13, ascending), F3N.

Annex B A Few Problem Cases

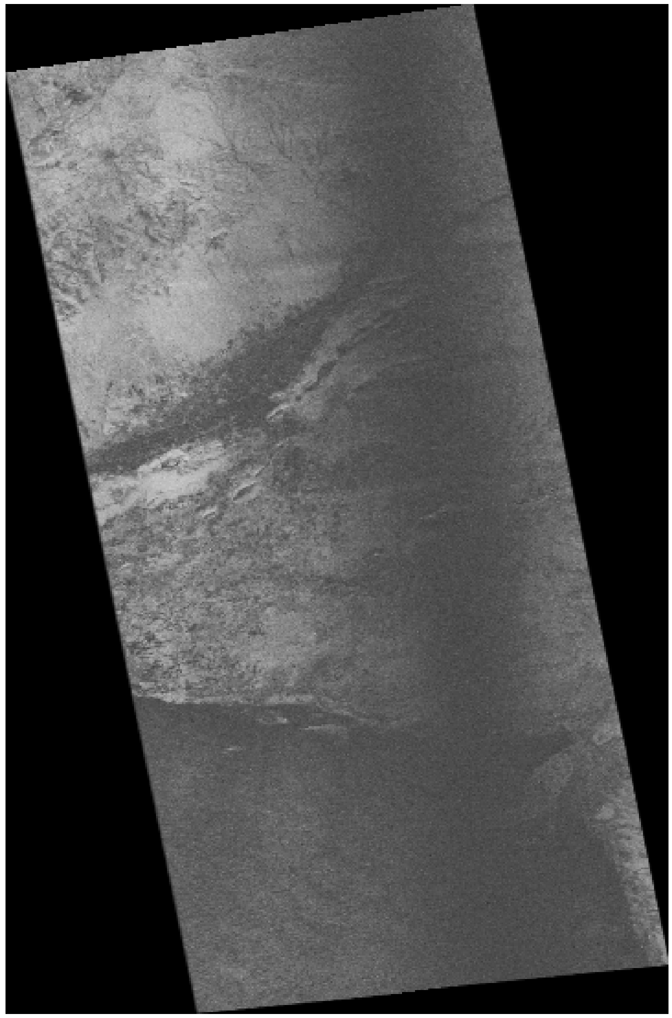

Figure 6: Example of sinusoidal pattern in an ascending pass coherence map for Kandahar (2006-10-17 and 2006-11-10), F4.

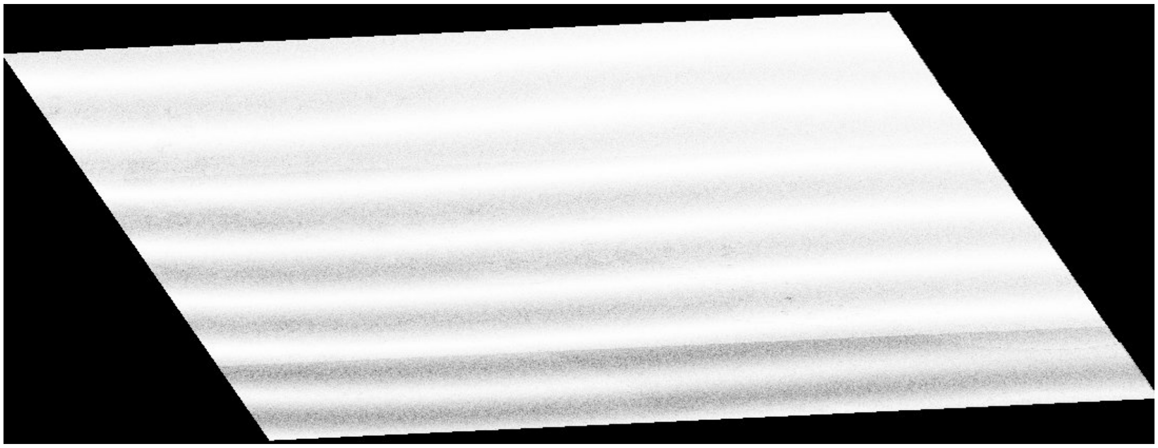

Figure 7: Sinusoidal pattern in a coherence map made from a single image (expected to be white).

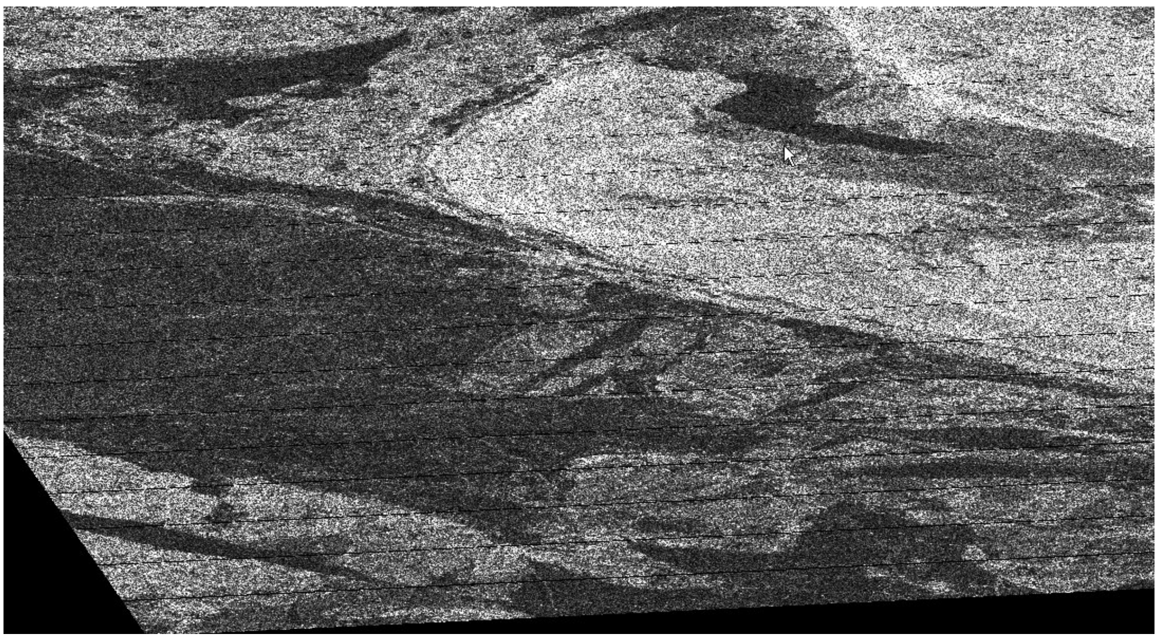

Figure 8: Range-ward dropouts in a Resolute slave image.

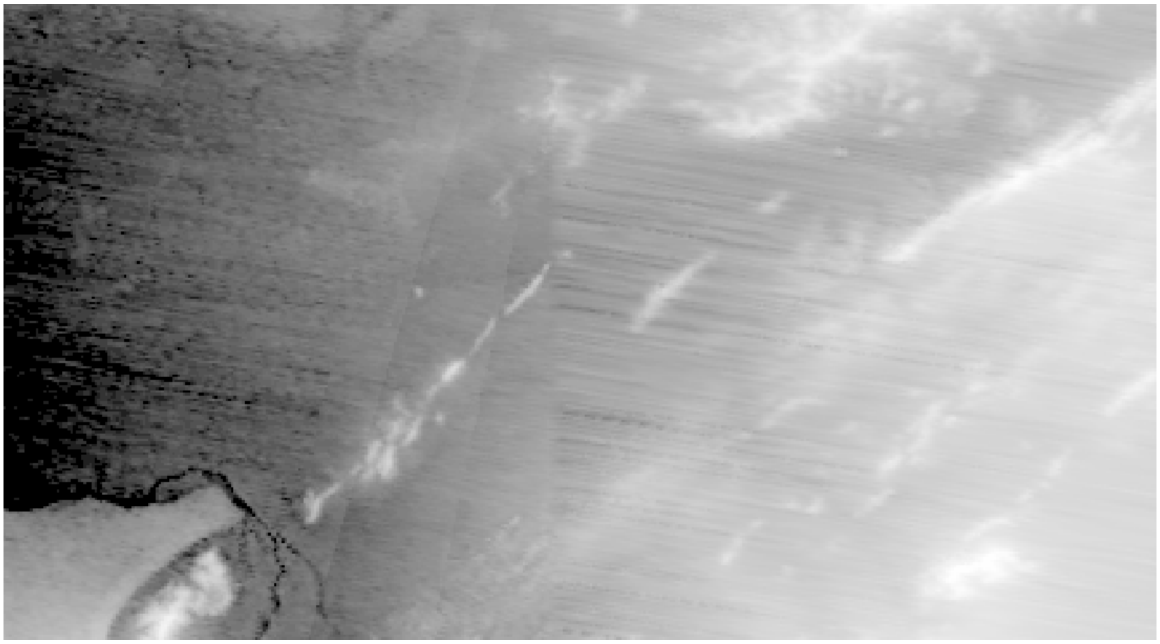

Figure 9: Enhanced portion of the Kandahar DEM showing linear artefacts.

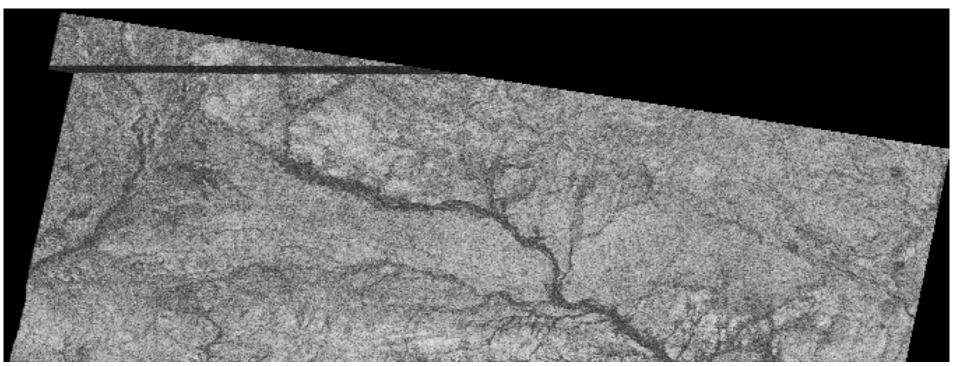

Figure 10: Artefact in a Kandahar coherence map corresponding to the edge of northern extent of the available DEM.

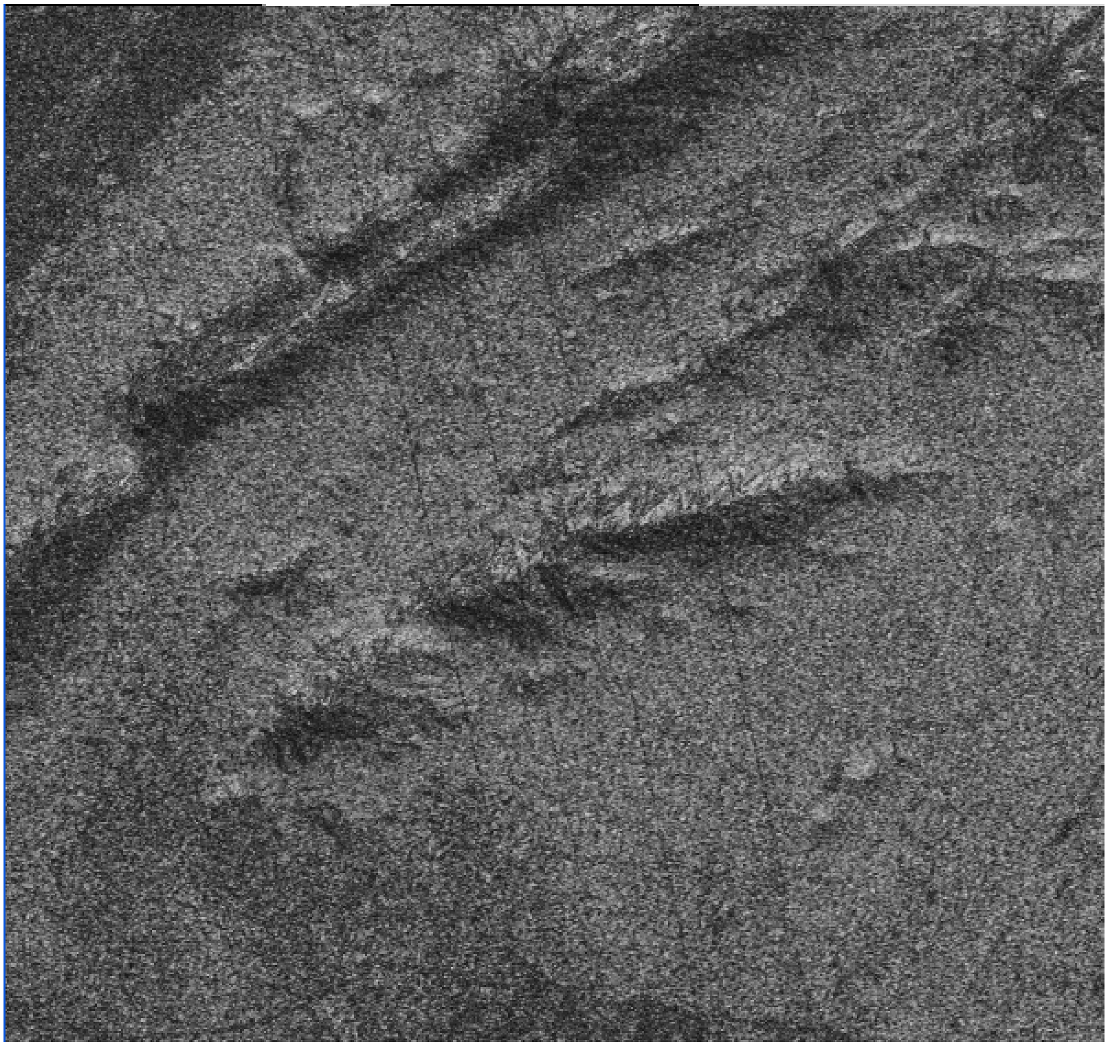

Figure 11: Azimuth-oriented gaps in coherence map for Kandahar (2006-06-19 and 2006-07-13, ascending), F4.

Annex C Original Processing Procedure Developed by N. Tayebi

<u>CTM Workstation V.3.2</u>

This is a brief document on the setup for CTM V 3.2. It describes the procedure for a Single Sensor, Sequential Run. For detailed information please refer to the user manual.

In Linux, an environment has to be defined for CTM commands. The user is required to use the following command line to create the required environment in the terminal window:

source vexcel_setup.sh

This command executes all the commands in the shell. At this point, just like other software packages, the user simply enters the name of the application which will launch the graphical user interface (GUI):

ctmgui

After launching the GUI, the user can either start a new run or load an old run. Simply select the File menu. “New run” and “Load run” are listed in this menu. The user should be able to select the desired directory at this point.

In the case of a new run, after selecting the directory and run name, a new window should appear. This window allows the user to select the type of run. The options are as follows:

Single Sensor, Common Master
Single Sensor, Sequential
Dual Sensor, Common Master

In this document, only Single Sensor, Sequential is discussed. However, the set up for Single Sensor, Common Master is very similar.

The user must select input image files for the run. Simply press “options” and a new window should appear which allows the input files to be selected. In the Sensor1 data window, the user can select the SLC image files. Note that only SLC products can be used for any CTM run. For a sequential run, there is no need to select a master image, as the program automatically selects the first image as master for the initial run. In the External DEM window, select the External DEM name from the directory in which the DEM file is stored.

The next step is the setup for the *InSAR analysis.* After turning on the *InSAR analysis*, the *option* button should be selected. This option allows changes to parameters and settings in the InSAR runs. If there are any changes that have to be made to the runs, it is strongly suggested that they be done for all the images, for consistency.

To change the coherence window size, select *All Sensors and Methods* from the *InSAR Analysis options* window to make changes for all the image pairs and then select *All Runs*. At this point the

EV-InSAR GUI will open. In the *Enhanced Interferogram Phase* option of the InSAR GUI window, the Coherence button will allow the user to make changes to the number of pixels in the window. The kernel size suggested is 16 (4X4) and the default value is 144 (12X12). In this version of CTM, it is suggested to use the default parameters for the entire run. Select OK and exit InSAR. The changes will be saved by the program.

The next step is turning the *Common ROI Selection* option on in CTM GUI. A new window should open and allow the user to select the area of interest.

The next options to be turned on are: *Coregister external DEM to master*, *Generate Interferogram*, and *Generate Average backscatter*. For these options, just use the default parameter values.

At this stage, the setup is complete and the run button should be selected. The time required for each CTM run depends on the region of interest (ROI), the size of each image, and the number of images in the run.

Errors:

The user can select the *InSAR run monitor* from the tool bar to see the processing steps. In case of any error, the image pair causing the problem should be highlighted in this window. This window allows the user to follow the processing procedure in CTM.

Output files:

After the CTM run is complete, the user may view the results. It is recommended that the image files be opened in another application such as *IA Pro* for viewing. Note that the images are in MMF2 format.

To view the *Average Backscatter* image, go to "/images" directory of the CTM run.

To view the coregistered images for each pair, the user must select the "/insar_runs" directory. In this directory, all the possible pairs are listed and they each have a separate directory. To view the master image, select the "/1_1" directory and then select "/extracted_master". To view the coregistered slave images, select the desired run (for example: "/1_2" for the first and second image.) and then select the "azimuth_filtered_slave" directory. Viewing the coherence images is the same as above.

Due to a bug in the CTM system, the slave images are not coregistered properly. To solve this issue, the user should replace all the "georef" files of the runs with the "georef" file from the "1_1" or master run.

Example of a CTM run directory (CTM_13:42_evc):

Average Backscatter image:
CTM_13:42_evc
    -->images
        -->average_backscatter

Extracted Master:
CTM_13:42_evc
-->insar_runs
-->run_1_1
-->images
-->extracted_master

Coregistered Slave:
CTM_13:42_evc
-->insar_runs
-->run_2_3
-->images
-->azimuth_filtered_slave

Coherence:
CTM_13:42_evc
-->insar_runs
-->run_2_3
-->images
-->coherence

Annex D pc25043-RAST\\C:\Data\RADARSAT-1\ingest_RS1.csh

```
#!/bin/tcsh
#
#    Ingest RS-1 data from CD and name it reasonable
#
#    $1 = Location (or ask)
#    $2 = A or D (or ask)
#    $3 = Beam (or ask)
#    $4 = Date (or ask)

#
#    DJW       2006-11-07          Original
#    DJW       2007-03-07          Rearrange fields: A/D after location

if ( $1 == "" ) then
     echo -n "Location (one word; will use this as directory) > "
     set location = $<
else
     set location = $1
endif

if ( $2 == "" ) then
        echo -n "A or D > "
        set AorD = $<
else
     set AorD = $2
endif

if ( $3 == "" ) then
        echo -n "Beam (max 3 char) > "
        set beam = $<
else
     set beam = $3
endif
if ( $%beam == 2 ) then
     set beam = ${beam}_
endif

if ( $4 == "" ) then
        echo -n "Date (yyyy_mm_dd) > "
        set date = $<
else
     set date = $4
endif

cd e:/scene01

ls -l

if ( ! -d c:/data/RADARSAT-1/$location ) mkdir c:/data/RADARSAT-1/$location
cd c:/data/RADARSAT-1/$location

cp -v --reply=query  e:/scene01/DAT_01.001   ./RS1_${location}_${AorD}_${beam}_${date}_RAW.sdf
cp -v --reply=query  e:/scene01/LEA_01.001   ./RS1_${location}_${AorD}_${beam}_${date}_RAW.slf
cp -v --reply=query  e:/scene01/NUL_VDF.001  ./RS1_${location}_${AorD}_${beam}_${date}_RAW.nvf
cp -v --reply=query  e:/scene01/TRA_01.001   ./RS1_${location}_${AorD}_${beam}_${date}_RAW.stf
cp -v --reply=query  e:/scene01/VDF_DAT.001  ./RS1_${location}_${AorD}_${beam}_${date}_RAW.vdf

ls -l
echo ""
df -h .
echo ""
```

List of symbols/abbreviations/acronyms/initialisms

A	Ascending
AGC	Automatic Gain Control
AOI	Area of Interest
APP	Advanced Precision Processor
CCD	Coherent Change Detection
CD	Compact Disk
CF	Canadian Forces
CFB	Canadian Forces Base
COTS	Commercial Off the Shelf
CSA	Canadian Space Agency
CTM	Coherent Target Monitoring
D	Descending
DEM	Digital Elevation Model
DRDC	Defence R&D Canada
DVD	Digital Video Disk
ETA	Estimated Time of Arrival
F#	RADARSAT-1 Fine Beam Mode #
F#F	RADARSAT-1 Fine Beam Mode # Far
F#N	RADARSAT-1 Fine Beam Mode # Near
ftp	File Transfer Protocol
GDAL	Geospatial Data Abstraction Library
GUI	Graphical User Interface
IA	Image Analyst
MDA	MacDonald, Dettwiler and Associates
PC	Personal Computer
R&D	Research & Development
RFI	Request for Information
ROI	Region of Interest
SAR	Synthetic Aperture Radar
SLC	Single Look Complex
SW	Software

TZ	The name of the Linux machine at DRDC Ottawa on which CTM is run

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Coherent Target Monitoring (CTM) is COTS software that was developed to detect the rate of land subsidence by using Synthetic Aperture Radar (SAR) repeat-pass interferometry applied to persistent scatterers in the scene. DRDC Ottawa has proposed to use the CTM software to produce a time-series of accurately co-registered SAR images and coherence maps that may be used for both non-coherent and coherent change detection. This capability within the CTM software was improved by DRDC Ottawa developing Sequential CTM, whereby the images in the time series are co-registered sequentially in a pair-wise manner. This report documents testing of the Sequential CTM software and includes the time series of RADARSAT-1 Fine mode images that have been processed, as well as processing procedures, some results, and problems that arose. Test sites include Resolute Bay, NU, Kandahar, Afghanistan, CFB Valcartier, and the Miramar, NU mine site.

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SAR; InSAR; coherence; coherent change detection; CCD; coherent target monitoring; CTM

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