RADARSAT-1 Radiometric Performance Maintained in Extended Mission

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ABSTRACT

Since its launch on November 4,1995 and the start of the routine operation on April 1, 1996, RADARSAT-1, the first Canadian SAR remote sensing satellite, provides calibrated data to worldwide users for their intended applications. Significant effort continues to be expended in the provision of radiometrically and geometrically calibrated products generated by the Canadian Data Processing Facility (CDPF). Since the end of the initial Calibration Phase in 1997, both single beams and ScanSAR are monitored routinely as part of the Maintenance Phase for radiometric performance using images of the Amazon Rainforest. In 2002, a major upgrade of the ScanSAR processor completed in CDPF made significant improvements in image quality. Since 1998, calibration measurements indicated changes in the characteristics of several previously calibrated elevation antenna patterns. Compensation for beam pattern changes is made in the processor by re-calibrating these beams. In addition, both single beams and ScanSAR are monitored routinely as part of the Maintenance Phase for image quality performance using images of RADARSAT-1 Precision Transponders (RPTs). On-board, internal calibration of the SAR instrument is also monitored. Software tools are continually developed to improve image quality operational efficiency, and new experiments are being undertaken in the context of the current extended mission. In mid 2002, due to aging considerations for the On-Board Recorder, sites within Canadian mask have been envisioned for their ability to support radiometric analyses, as a potential alternative for the Amazon where images are recorded. From several sites, a Boreal Forest location near Hearst, Ontario, was chosen for testing radiometric measurements, using specific beams to cover the entire range of incidence angles. Tools have also been developed for tracking performance of image quality parameters and radiometric measurements over the Hearst and Amazon regions. In late October 2000, concerns began to rise of the possibility of failure of the Horizon Scanner 1, which would result in operating the spacecraft in a mode known as 'Attitude Determination Method 3' (ADM3), causing a decrease in attitude control performance of spacecraft compared to the current operation in ADM1. Experiments were conducted to better understand the impact on processing and image quality in ADM3 mode. Images were processed successfully with good image quality and no significant impact on processing and radiometry.

1. INTRODUCTION

The Canadian Earth observation satellite RADARSAT-1 was launched on November 4, 1995 and declared operational on April 1, 1996. Since that time, a number of important milestones have been completed and throughout all these major activities, RADARSAT-1 system is still meeting and exceeding its performance specification as set out in [1] and image quality is maintained. In this paper, we are primarily concerned with the performance of the image quality and the calibration using products generated by the Canadian Data Processing Facility (CDPF). The RADARSAT calibration system is described in [2]. Previous publications on RADARSAT-1 performance describing image quality and calibration performance since launch can be found elsewhere in [3]-[4]-[5]-[6]-[7].

2. RADIOMETRIC CALIBRATION AND IMAGE QUALITY PERFORMANCE

The RADARSAT-1 calibration plan is presently undergoing its Maintenance Phase. In this phase, tracking of beam calibration and image quality parameters is performed on a routine basis. Radiometric Accuracy performance is tracked by measuring deviations in measured pattern when compared to the calibrated pattern for any given beam, using images of the Amazon Rainforest. Methodology for elevation beam pattern measurement used for RADARSAT-1 beams has been described elsewhere in [8]. Data are collected for each beam about once every two months depending upon the availability of imaging opportunities in the Amazon Rainforest. Techniques and tools have been developed to measure radiometric deviations both with and without spacecraft roll correction [9]-[10]. From tracking the beam radiometric accuracy performance during the five years of operation and through the current extended mission, it appears that some beams (S1, S2, S3, S4, S6, S7, W1, W2, F4, EXTL1) had radiometric fluctuations that could be attributed to changes in their respective elevation beam patterns. Recalibrations were done for those beams. New payload parameters files containing re-calibrated beam patterns were issued to the CDPF processor as well as to all foreign network station processors (see Table I). Measurements performed after a recalibration indicate improved radiometric accuracy. Fig. 1 shows typical results for relative radiometric accuracy as measured for Beam W1 since its calibration date of February 1997. The beam was re-calibrated in December 1998 and again in July 2001. After re-calibration, the radiometric accuracy performance improved, as indicated by measurements made since August 2001 to date.

Table I: RADARSAT-1 Payload Parameters Files

FILE #	Submitted	Valid Start Time	Valid End Time	Comments
P0000005.ppr	28-Nov-95	28-Dec-95 23:24:28	28-Feb-96 21:03:41	
P0000006.ppr	28-Feb-96	28-Feb-96 21:03:41	21-May-96 21:36:00	Revised replica_phase_coeff
P0000007.ppr	21-May-96	21-May-96 21:36:00	14-Jun-96 15:34:53	New beam table load
P0000008.ppr	14-Jun-96	14-Jun-96 15:34:53	23-Jul-96 20:06:25	New beam patterns for S1-7, W1-3, F1-5
P0000009.ppr	23-Jul-96	23-Jul-96 20:06:25	25-Sep-96 21:13:05	Refinement of elevation beam patterns and GCF
P0000010.ppr	25-Sep-96	25-Sep-96 21:13:05	27-Nov-96 19:39:39	Beam slot changes for extended high beams
P0000011.ppr	27-Nov-96	27-Nov-96 19:39:39	21-Jan-97 14:35:58	Calibration of beams S1, S2, S3, S4 of CDPF products
P0000012.ppr	21-Jan-97	21-Jan-97 14:35:58	14-Feb-97 17:12:08	EL1 Beam replacing EH1 beam
P0000013.ppr	14-Feb-97	14-Feb-97 17:12:08	02-Jun-97 16:39:46	S5-S7, W1-W3 calibrated, S1, S2, S4 and GCFs upgraded
P0000014.ppr	02-Jun-97	02-Jun-97 16:39:46	12-Aug-97 15:35:51	F1-F5 calibrated, GCFs and TRNLs updated, Relative beam gains adjusted
P0000015.ppr	12-Aug-97	12-Aug-97 15:35:51	08-Sep-97 07:00:00	Calibration upgrade to Beam EL1
P0000016.ppr	08-Sep-97	08-Sep-97 07:00:00	09-Sep-97 07:00:00	Beam EL1 calibrated
P0000017.ppr	08-May-98	09-Sep-97 07:00:00	20-Oct-97 19:00:00	Beam S4 Calibrated for Left-Looking Mode (Antarctic Mapping Mission)
P0000018.ppr	08-May-98	20-Oct-97 19:00:00	21-Apr-98 21:12:32	Copy of Payload 16 with an update of TNRL
P0000019.ppr	23-Dec-98	21-Apr-98 21:12:32	13-Oct-98 20:57:17	Beams F4 and W1 re-calibrated
P0000020.ppr	21-Apr-99	13-Oct-98 20:57:17	10-Dec-98 20:57:17	Beams S3 and S6 re-calibrated
P0000021.ppr	17-Jun-99	10-Dec-98 20:57:17	25-Oct-99 22:00:17	Beams S1 re-calibrated and TNRL updated
P0000022.ppr	15-Feb-00	25-Oct-99 22:00:17	15-Nov-99 10:00:17	Beam EXTL1 re-calibrated
P0000023.ppr	04-May-00	15-Nov-99 10:00:17	17-Apr-00 22:00:17	Beam S7 re-calibrated
P0000024.ppr	19-Jul-00	17-Apr-00 22:00:17	18-Apr-00 23:00:17	Beam W2 re-calibrated
P0000025.ppr	19-Sep-00	18-Apr-00 23:00:17	09-Feb-01 23:00:17	Beam S4 re-calibrated
P0000026.ppr	24-Jul-01	09-Feb-01 23:00:17	27-Aug-01 23:00:17	Beam W1 re-calibrated and ScanSAR relative beam gain adjustment
P0000027.ppr	23-Jan-02	27-Aug-01 23:00:17	02-Nov-01 23:00:17	Beam S2 and EL1 recalibrated with saturation correction
P0000028.ppr	04-Jun-02	02-Nov-01 23:00:17	07-Jun-02 00:00:00	Beam F4 recalibrated
P0000029.ppr	17-Dec-02	07-Jun-02 00:00:00	23-Jul-14 00:00:00	Beam S3 and S7 recalibrated

Changes in the characteristics of several previously calibrated elevation antenna patterns have occurred gradually since 1998, as indicated by calibration measurements, in particular W1, S1, S3 and F4. It was known that Variable Phase Shifters (VPS) would experience significant heating during a normal imaging period of up to 28 minutes, and that VPS's near the centre of the antenna aperture would experience more rapid heating than those near to the edge. An experiment was conducted to determine if the change in the elevation antenna pattern was due to the heating or cooling of VPS forming antenna beams. After analysis it was concluded that changes in beam pattern are not due to temperature variations. Long-term performance variability of VPS is probably the cause of these changes [11]. Compensation for beam pattern changes is made in the processor by re-calibrating these beams.

In addition, Image Quality measurement parameters include point target impulse response measures: range and azimuth impulse response widths (IRW), range and azimuth peak sidelobe ratios (PSLR), integrated sidelobe ratio (ISLR), and absolute location error (ALE) using images of RPTs. Fig. 2 through 4 shows the IRW results for all three chirp bandwidths of the RADARSAT-1 system, since the start of the Maintenance Phase, for all single beams. PSLR, ISLR and ALE measurements, each combined for all three chirps, are shown in Fig. 5, 6 and 7.

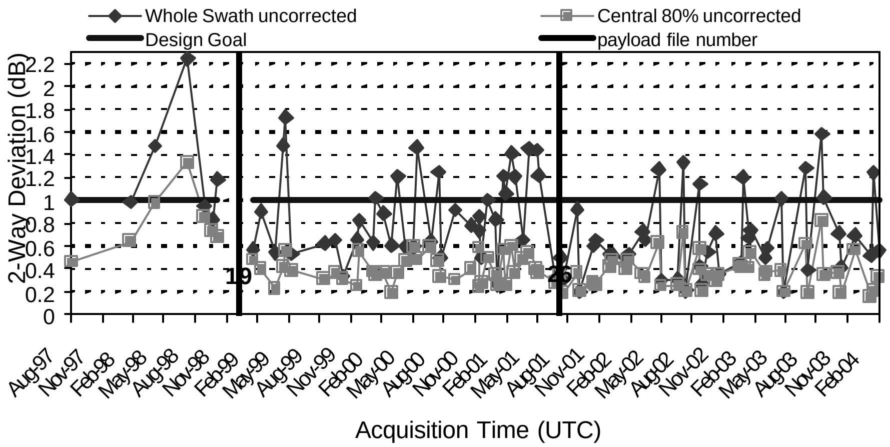

Fig.1: Radiometric Accuracy without correction of spacecraft roll for beam W1

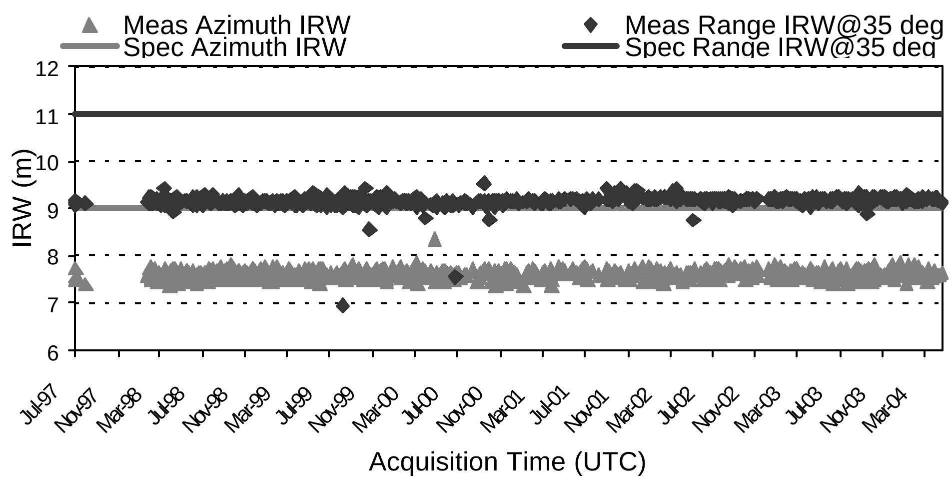

Fig.2: Impulse Response Width for chirp 1 beams (BW=30 MHz)

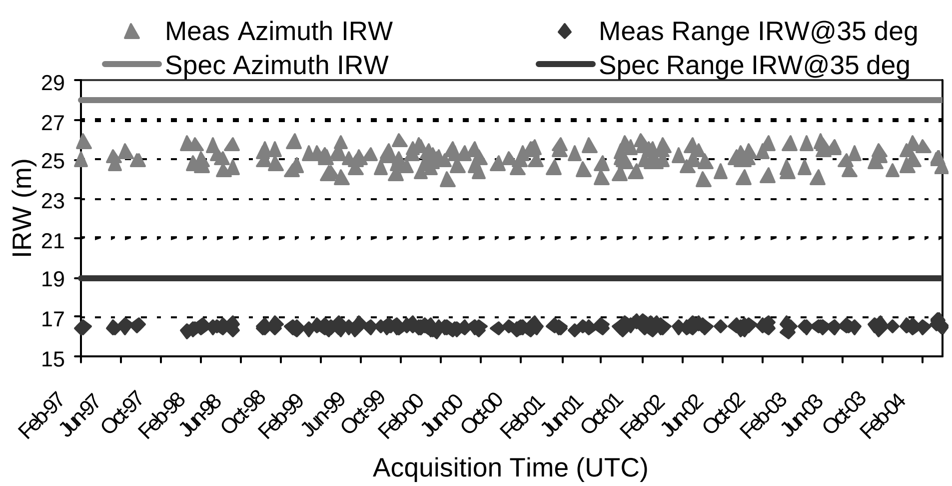

Fig.3: Impulse Response Width for chirp 2 beams (BW=17.28 MHz)

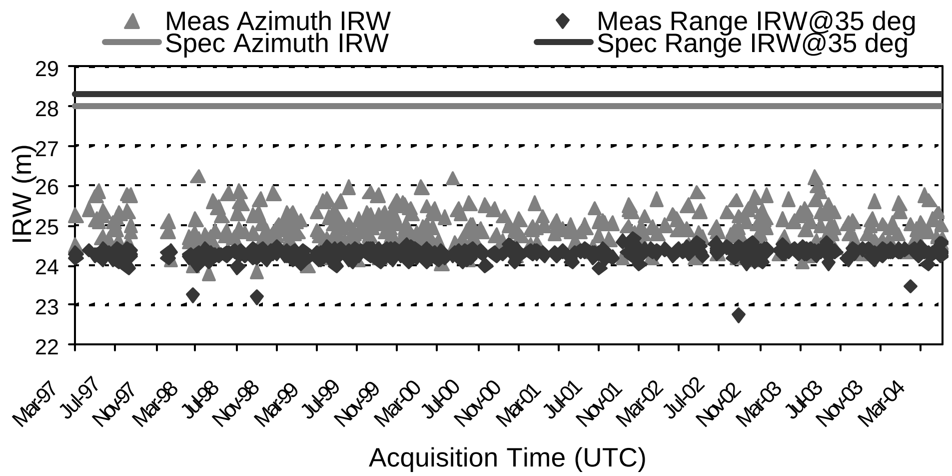

Fig.4: Impulse Response Width for chirp 3 beams (BW=11.58 MHz)

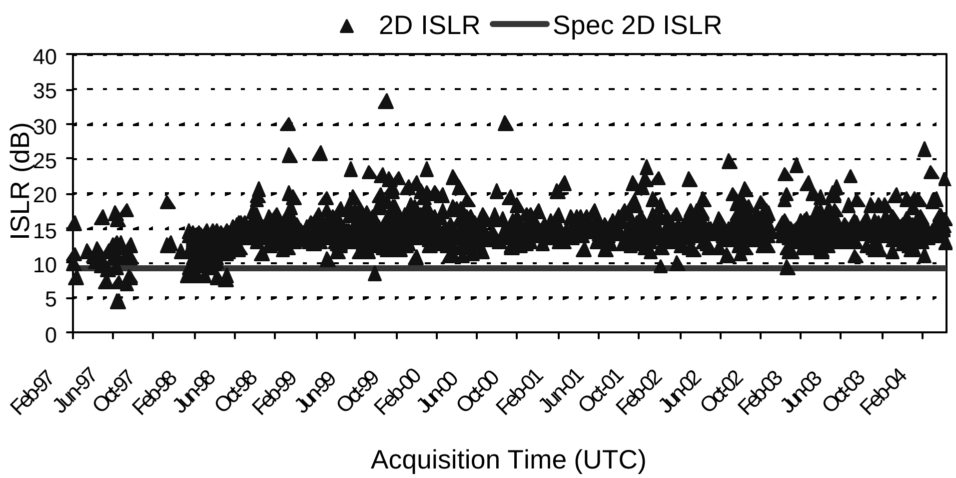

Fig.5: Integrated SideLobe Ratio for all beams

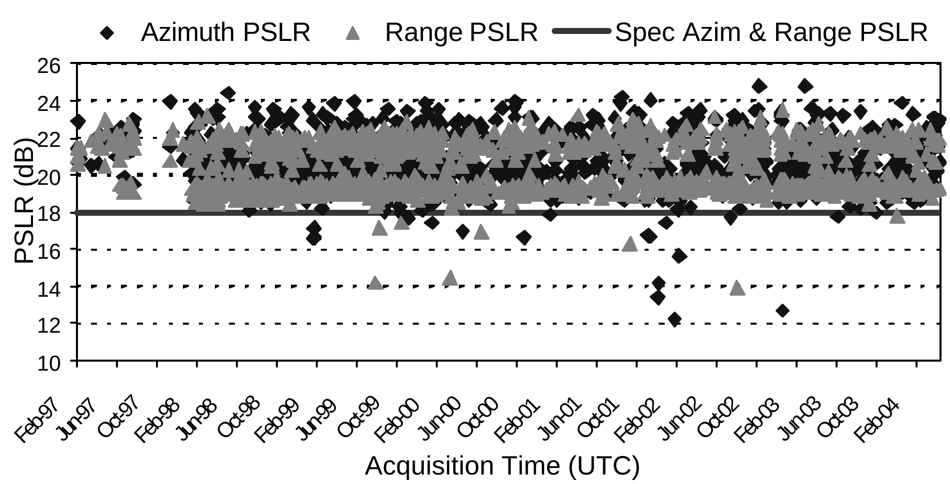

Fig.6: Peak SideLobe Ratio for all beams

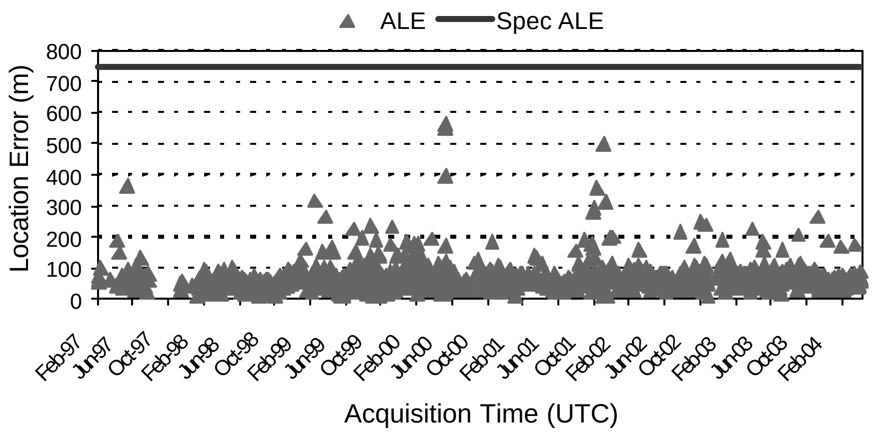

Fig.7: Absolute Location Error for all beams

All measurements for these time-history plots demonstrate a very good stability of the RADARSAT-1 image quality and that it is meeting or exceeding its performance specification during and beyond its design lifetime. In parallel, special purpose software tools have been developed to track performance of these image quality parameters. Other tools and scripts have also been implemented to facilitate and simplify the specific planning and submission of the image quality and calibration imaging requests.

3. SCANSAR CALIBRATION

Effective February 1, 1999, all ScanSAR images generated by the CDPF are radiometrically calibrated. A major upgrade of the ScanSAR processor in CDPF was done in 2002. This upgrade provides remarkable improvements in image quality, with elimination of processing problems such as scalloping, location error due to PRF ambiguity, visibility of beam boundary and Automatic Gain Control (AGC) error.

Based on a limited set of Amazon Rainforest data, it is found that the worst-case absolute accuracy is ±1.35 dB, and relative accuracy is 2.7 dB within any image or between any two images. Users will most typically have imagery with radiometric accuracy of ±1 dB, or better in absolute level (2 dB or better in relative level). An example of γ° for a ScanSAR-Wide-B image of the Amazon Rainforest is shown in Fig. 8. It should be noted that a constant γ° of 6.5 dB was used for the Amazon Rainforest for all ScanSAR incidence angles as the reference in calibrating ScanSAR modes. After issuance of Payload Parameter File 22, some gain differences have been observed at the beam boundaries. This problem has been solved by adjusting relative gain between constituent single beams (i.e. beams W1, W2, W3, S5, S6, S7) for all four ScanSAR modes and a new payload file (#26) has been issued. Fig. 9 shows an example of ScanSAR image over Eastern United-States.

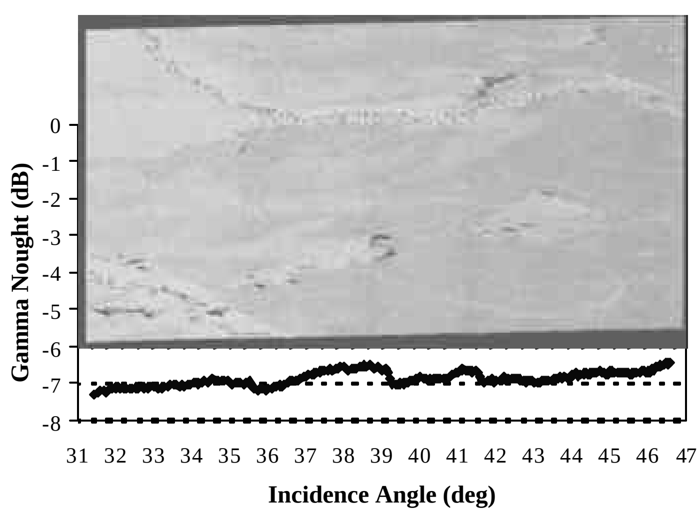

Fig. 8: Gamma nought for SCNB Ascending Pass, 18-Jan-2004

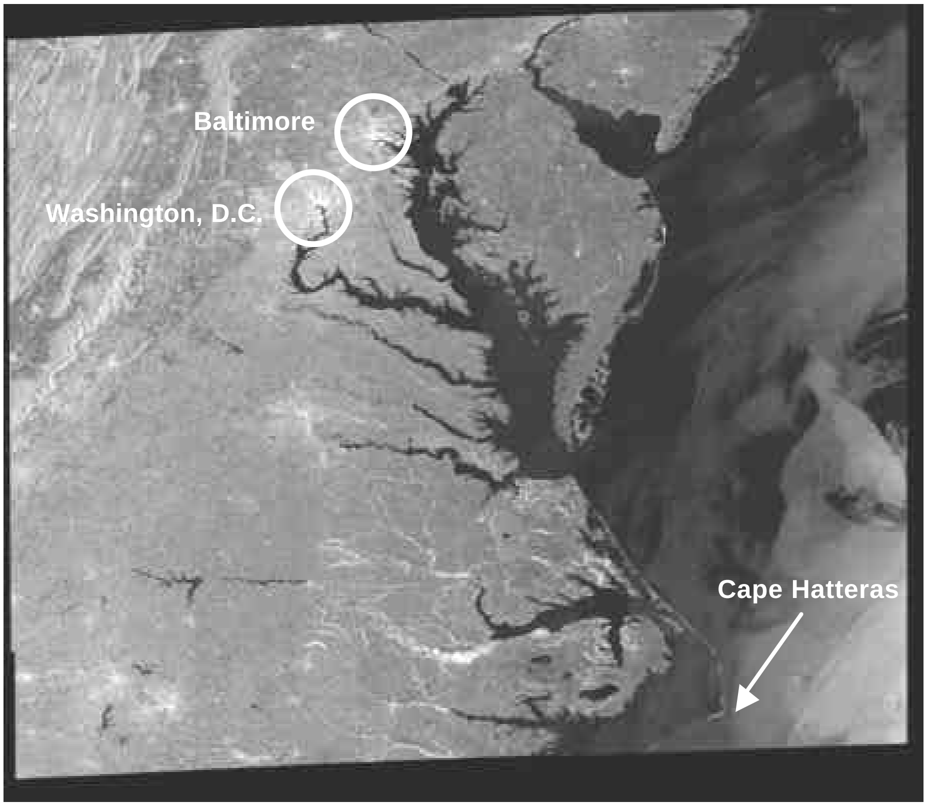

Fig. 9. Radarsat-1 ScanSAR Wide B, 8-March-2002 (orbit 33098)

4.INTERNAL CALIBRATION

RADARSAT-1 incorporates on-board internal calibration for tracking gain variations of the receiver subsystem components: mixer, IF, video circuit, limiter and low noise amplifier. Acquired at transmit pulse times, derived auxiliary telemetry is transmitted to the ground processor together with the radar signal data allowing the processor to compensate for gain variation. Other tracking signals are acquired during pre and post image operation for off-line special processing [2]. In early 1999, a series of annual tests have been initiated to verify the linearity of the internal calibration, which covers a large dynamic range. Repeated in late 2000/early 2001, February 2002 and November 2003, the series of tests show very similar results; no consistent trends were detected which would indicate any degradation of the SAR instrument gain [12].

5. ATTITUDE DETERMINATION METHOD 3 (ADM3) EXPERIMENT

The RADARSAT Attitude Control System's primary and most accurate method, Attitude Determination Method one (ADM1), uses a sun sensor (SS1) and a horizon scanner (HS1) for orientation data. An alternate horizon scanner (HS2) severely degraded in performance in beginning of the operational phase. In late October 2000, slightly less than five years after the launch of Radarsat-1, concerns began to rise of the possibility of failure of the horizon scanner (HS1). This condition would result in reduced attitude control of the spacecraft with operation of the sun and magnetometer attitude sensors, known as 'Attitude determination method 3' (ADM3).

Considerable effort has been expended in 2001 to test and to align the backup ADM3 with the primary ADM1. In pursuing this objective, an experiment was designed towards characterizing attitude performance (in terms of pitch, yaw and roll) by forcing the spacecraft in the ADM3 configuration for a single orbit, then reverting back to the nominal ADM1 configuration (i.e., sun sensor + horizon scanner). Such results could be useful for calibration of the attitude sensors, particularly if the spacecraft is forced into routine operation in ADM3.

Four flight test campaigns have been conducted by RADARSAT-1 Flight Dynamics personnel during the experiment to gather representative data of ADM3 operation, and to test modifications to ADM3 control parameters. These experiments were also conducted to gain a better understanding of impact on processing and image quality when operating the spacecraft in ADM3 mode [13]. A total of 69 images were acquired at different parts of orbit over three planned events and multiple orbits (January 2001, May 2001 and December 2001/January 2002). Images were processed successfully with good image quality.

A roll attitude estimation method was developed by adapting the existing methodology used for elevation pattern measurement based on Amazon images following a method suggested in [14]. This method involves changing the range-dependent correction factor used in the final step of the pattern measurement, based on changes in the SAR antenna elevation beam profile in radar imagery of ocean and moderately homogeneous distributed targets, as described in [13]. In the proposed method, the scattering law for other target classes is modeled and residual shape anomalies are attributed to spacecraft roll. Roll attitude is achieved by performing the following steps:

- measuring γ° pattern from the processed image;
- deriving the β° over the same incidence angle range;
- replacing the β° LUT used for Amazon region with the modified β° LUT.
- with the modified β° LUT in place, the final step is to measure the one-way beam pattern. The roll is obtained by making the difference between the calibrated and test boresights.

The radar brightness parameter β° is related to γ° via the following equation, where θ is the incidence angle, in radians:

$$g^\circ = b^\circ \tan q \qquad (1)$$

A second attitude estimation method has also emerged using SAR imaging as a basis for independently measuring S/C attitude errors, using measurements of the radar signal Doppler data. The series of ADM3 flight tests has allowed these methods to be validated by comparison with ACS ADM1 results. Doppler is very insensitive to roll errors, that is why roll error was measured using the elevation beam correlation method. For the last test, the range of attitude errors observed was from –0.255 to 0.180 degrees for roll, from –0.895 to 1.005 degrees for pitch and from –0.313 to 0.128 degrees for yaw.

6. BOREAL FOREST RADIOMETRIC TEST

Due to aging consideration for the On-Board Recorder (OBR) and since Amazon images used for calibration performance are recorded, alternative sites within Canadian mask are being explored for their ability to support radiometric analyses in case of an OBR failure. Several sites in the Boreal Forest and in the Tundra/Taïga belt have been selected. From preliminary results, the most homogeneous site in the group, near Hearst, Ontario, was chosen for testing. Radiometric measurements covering the whole range of incidence angle are performed using the elevation pattern measurement method, which was developed by adapting the existing methodology used for Amazon images analyses [15]. Some results, as shown in Fig. 11, are very encouraging and the experiment will continue further to determine if the Boreal Forest is a suitable region for supporting radiometric analysis.

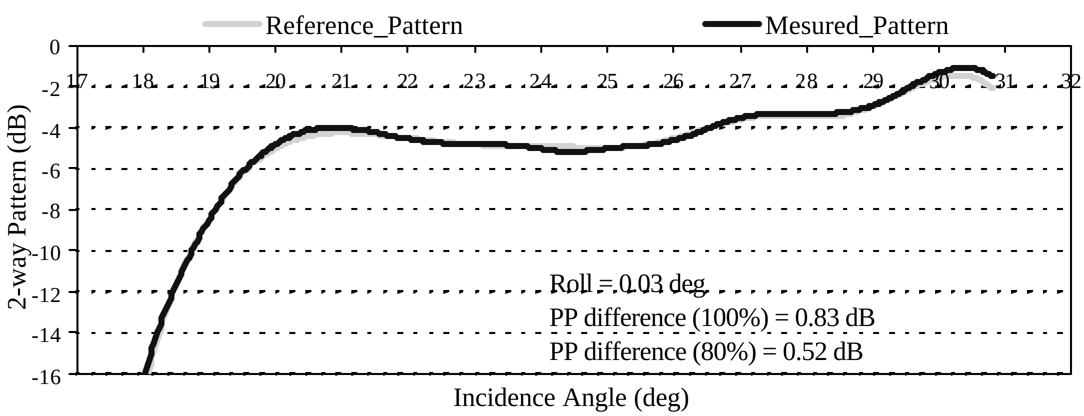

Fig. 11. Pattern Comparison for M0363850 (W1 Asc over Hearst Region on 23 March 2004).

Updated weather data is being adjoined to the analysed datasets. The compiled results, including snow on the ground (winter), humidity levels (summer) and precipitation conditions at time of acquisition, will assist in evaluating seasonal averages of the cyclic γ° measurements performed on the region.

7. CONCLUSION

The RADARSAT-1 radiometric performance and image quality have continued to consistently excel from the early Maintenance Phase to present, in the third year of extended mission. Measured results indicate image quality performance is maintained better than specification. Over the years, tests and experiments results have been used to improve the system performance. The methodology developed for maintaining calibration will also be beneficial for future SAR remote sensing missions. In the context of the present mission extension, the radiometric experiment over Boreal forest as well as the image quality assessment in ADM3 increases the level of confidence towards the future of RADARSAT-1 imagery.

8. REFERENCES

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