Maintenance of Radiometric Calibration Performance of RADARSAT-1

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ABSTRACT

RADARSAT-1, the first Canadian SAR remote sensing satellite, was launched on November 4, 1995. After commissioning, it was put into routine operations on April 1, 1996. Significant effort has been expended in the provision of geometrically and radiometrically calibrated products to users. After calibration, the beams are monitored routinely as part of the Maintenance Phase for image quality. Radiometric accuracy performance is monitored through periodic measurements of the elevation beam pattern of single beams using images of the Amazon rainforest. For some beams, pattern changes have occurred after calibration, but compensation has been made in the processor by recalibrating these beams. This paper describes the overall process of data acquisition, data analysis and recalibration for maintaining calibration accuracy within the *design goal limits* [1].

INTRODUCTION

RADARSAT-1, the first Canadian radar remote sensing earth observation satellite, was launched into orbit on November 4, 1995. Since then, an extensive effort was spent on calibrating the imagery produced by the Synthetic Aperture Radar (SAR) processor which is located at the Canadian Data Processing Facility (CDPF) receiving station near Ottawa. An important requirement of the RADARSAT-1 program was to provide users with radiometrically calibrated imagery. This means that users should be able to extract values of the radar brightness parameter from imagery which are calibrated to within 1 dB across the swath regardless of the terrain imaged. Radiometric calibration of the elevation beam patterns is required in order to achieve the required accuracy.

To achieve the initial calibration of the beams, numerous images were acquired over active transponder sites and over the Amazon rainforest region. The latter set of measurements are routinely used for monitoring the elevation beam pattern measurements. The calibration performance of the RADARSAT-1 system has been reported elsewhere [2]. This paper focuses on the process of maintaining the radiometric calibration performance of the RADARSAT-1 system and describes tools that were developed for such purposes.

APPROACH

The approach used for maintaining radiometric calibration of the RADARSAT-1 system is comprised of the following steps which are depicted in the flowchart given Fig. 1.

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[1] On contract from *Lockheed-Martin Canada.*

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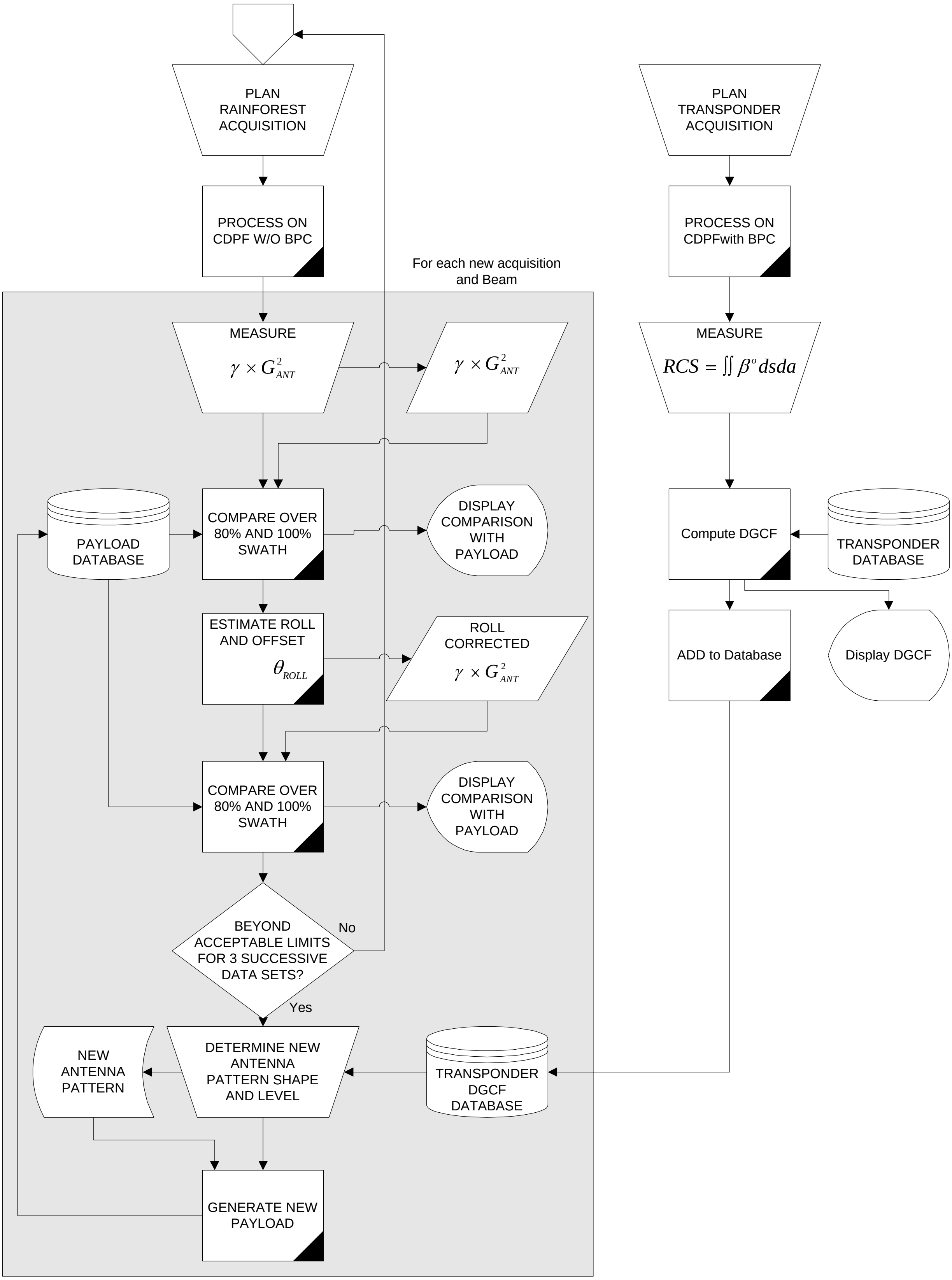

Fig. 1: Flowchart illustrating the steps taken in maintaining radiometric calibration of RADARSAT-1

There are broadly speaking eight steps to maintaining the radiometric calibration of RADARSAT-1 as follows:

1. Acquire raw Amazon data for measurement of Elevation Beam Pattern (EBP).
2. Process Amazon Data without Elevation Beam Pattern Correction (EBPC).
3. Measure EBP from processed image
4. Compute difference pattern without removal of spacecraft roll.
5. Compute difference pattern with removal of spacecraft roll.
6. If necessary, recalibrate the current EBP stored in the processor.
7. Test recalibrated EBP confirming radiometric improvement
8. Replace EBP in payload database with recalibrated EBP.

The following paragraphs briefly describe the steps involved in maintaining radiometric calibration performance of RADARSAT-1.

Step 1: Acquire Raw Amazon Data

The first step is to gather raw data in the Amazon rainforest region, which is noted for its roughly homogeneous radar backscatter properties [3]. In the Maintenance Phase of the RADARSAT-1 program, Amazon data are collected roughly once every two months for all 26 beams. In practice, the data collection process is limited by imaging opportunities of the Amazon region with the spacecraft due to orbital constraints. Typically, imaging opportunities are once every two to three days by any beam. If we are interested in only one particular beam, the opportunities are further reduced, and especially in the case of some narrow fine beams where imaging opportunities may be restricted to roughly once per month.

Acquisitions are routinely scheduled for all calibrated beams to enable identification of those beams which might be experiencing pattern changes due to possible aging effects (e.g. variable phase shifters). Once the problematic beams have been identified, additional acquisitions may be scheduled to confirm changes in the beam pattern. If consistent pattern changes are evident, recalibration of the elevation beam pattern is required to be performed (step 6).

Step 2: Process Amazon data without EPBC

The second step is to process the raw Amazon data as an SGF product without beam pattern correction. This is to enable the beam pattern to be measured from the image product. Processing is performed by the CDPF and the products are copied to exabyte tape for off-line pattern measurement.

Step 3. Measure EBP from Processed Image

The third step is to measure the elevation beam pattern from Amazon scene products. The beam pattern measurement method for scene products has been described elsewhere [4]. Once measured, the test pattern is stored for off-line analysis.

Step 4. Compute Difference Pattern Without Removal of Spacecraft Roll.

In this step, the calibrated and test patterns are compared by computing the difference pattern without removal of spacecraft (S/C) roll. This is to quantify the level of radiometric errors which can be expected from products processed with the current Payload Parameters File (PPR). The calibrated pattern for the desired beam is obtained from the PPR file. The test pattern is obtained from the beam pattern measurement in step 2. The difference function is computed over two regions: the whole beam and the central 80%. Normally the outer edges of the scene are more sensitive to roll variations in the S/C and the two comparisons allow a rough assessment of whether the differences are caused by pattern change or by S/C roll.

In a perfect match, we expect to find a constant difference and the Peak to Peak (P-P) excursion of the curve (difference of the maximum and minimum) is used as a measure of the match of both pattern and S/C roll.

Step 5. Compute Difference Pattern With Removal of Spacecraft Roll.

This step is similar to the previous one except it to compute the difference pattern with removal of spacecraft roll. This is useful to identify any possible pattern changes, either in the electronic boresight and/or the shape when the effect of spacecraft roll is removed. If changes in pattern shape are noticed, more data is acquired and the process is repeated (steps 1-5).

The computation of the optimal roll offset is initiated by a coarse grid search followed by a correlation technique. Typical values for the grid search range from ±0.3 degrees.

When the excursion of the measured antenna pattern from the payload reference pattern is more than 1 dB, for 3 or more consecutive data takes, a new pattern is determined. Otherwise monitoring beam performance continues.

Step 6. If necessary, Recalibrate the Current EBP

When it has been determined that the elevation beam requires recalibration (step 5), it is necessary to identify the approximate date at which the pattern shape changes began to occur. This information is obtained by noting the P-P excursion and central 80% swath deviations in the difference pattern computed without removal of S/C roll determined at step 4. This is taken as the validity date of the updated payload file.

The new antenna pattern calibration is established in two substeps:

- At least three test antenna pattern measurements, ($\left\{\gamma \times G^2_{ANT}\right\}$, are combined to a single smoothed pattern using a tool developed and implemented in MATLAB™. The pattern combination algorithm has been described elsewhere [5].

- The freshly determined smooth pattern is then fitted using least squares analysis [6] to precision transponder measurements taken since the first detected occurrence of pattern departure from specification. This gives the absolute level of the calibration.

Step 7. Test Recalibrated EBP

Repeat the antenna pattern measurement on those Amazon products for which the radiometry was degraded. Using the recalibrated pattern as the reference, repeat steps 2 through 5 comparing the test pattern. The results of the P-P deviations are stored for comparsion with the original values.

The difference pattern without removal of spacecraft roll is verified to be less than about 0.3 dB peak-to-peak deviation across the swath. This confirms that radiometry has indeed improved when comparing the shifted test pattern with the recalibrated pattern.

Step 8. Replace EBP in Processor with Updated EBP.

Issue an updated PPR file containing the recalibrated elevation beam pattern for use by all processing facilities.

EXAMPLE

An illustrative example of the above technique is provided for recalibration of Standard Beam 3 (S3). The software tools have been developed in the IDL 3.6 programming language running under the Sun Solaris 2.6 operating system.

Fig. 2 shows a summary plot of the difference patterns without S/C roll for beam S3 acquired before and after recalibration. Updated results of the P-P deviations (ΔP_{100} and ΔP_{80}) versus time for calibrated beams are reported elsewhere [2].

Fig. 3 shows the pattern analysis results for a product acquired on March 6, 1999 where the radiometry is degraded with PPR file #19. Fig. 4 shows the same product after recalibration. Identified on each plot are the calibrated and original test patterns, the shifted test pattern and the original and shifted difference patterns (upper curves), the spacecraft roll, and the P-P swath deviations for the original and shifted difference patterns.

Comparing Fig. 3 and 4, the improvement is self-evident between the degree to which the shifted test pattern matches the calibrated pattern. The same technique is repeated for other products where radiometry was degraded and radiometry was found to improve, indicating a successful beam recalibration. The payload parameters file was updated to PPR #20 with the recalibrated S3 pattern on April 21, 1999.

Table 1 provides a summary of the PPR files which have been used to date since launch. It is noted that the three most recent PPR files (#19,#20,#21) resulted from recalibration of beams W1, F4, S3, S6 and S1 based on the tools and techniques described here.

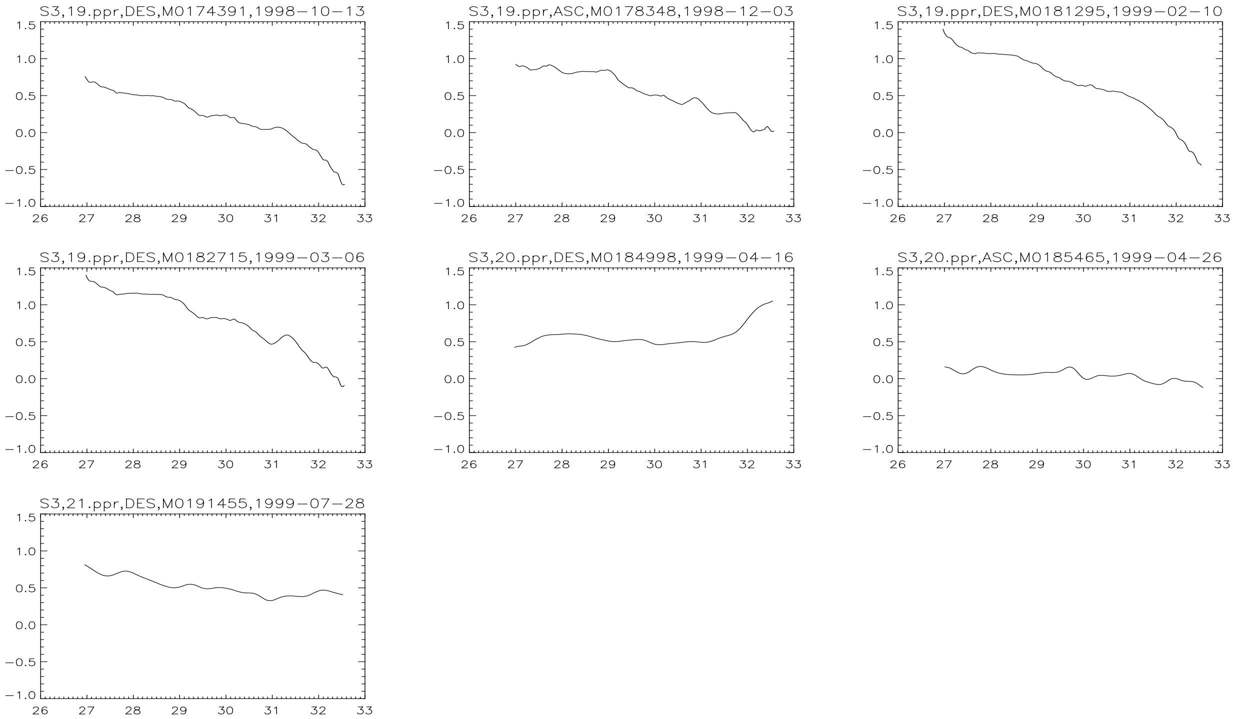

Fig. 2: Two-way difference patterns versus elevation angle without removal of spacecraft roll for beam S3. Amazon data were acquired between October 13, 1998 and July 28, 1999. Beam S3 was recalibrated on April 21, 1999.

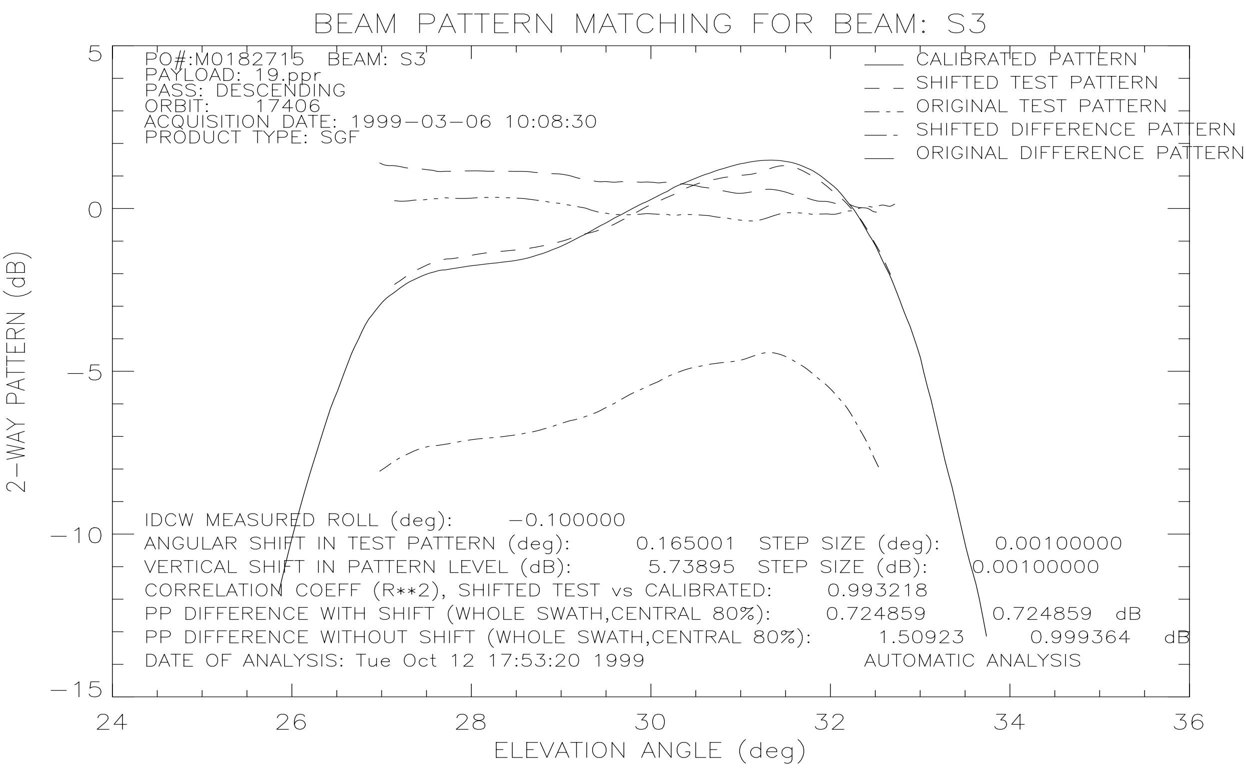

Fig. 3: Beam pattern matching results for beam S3, product M0182715, before recalibration.

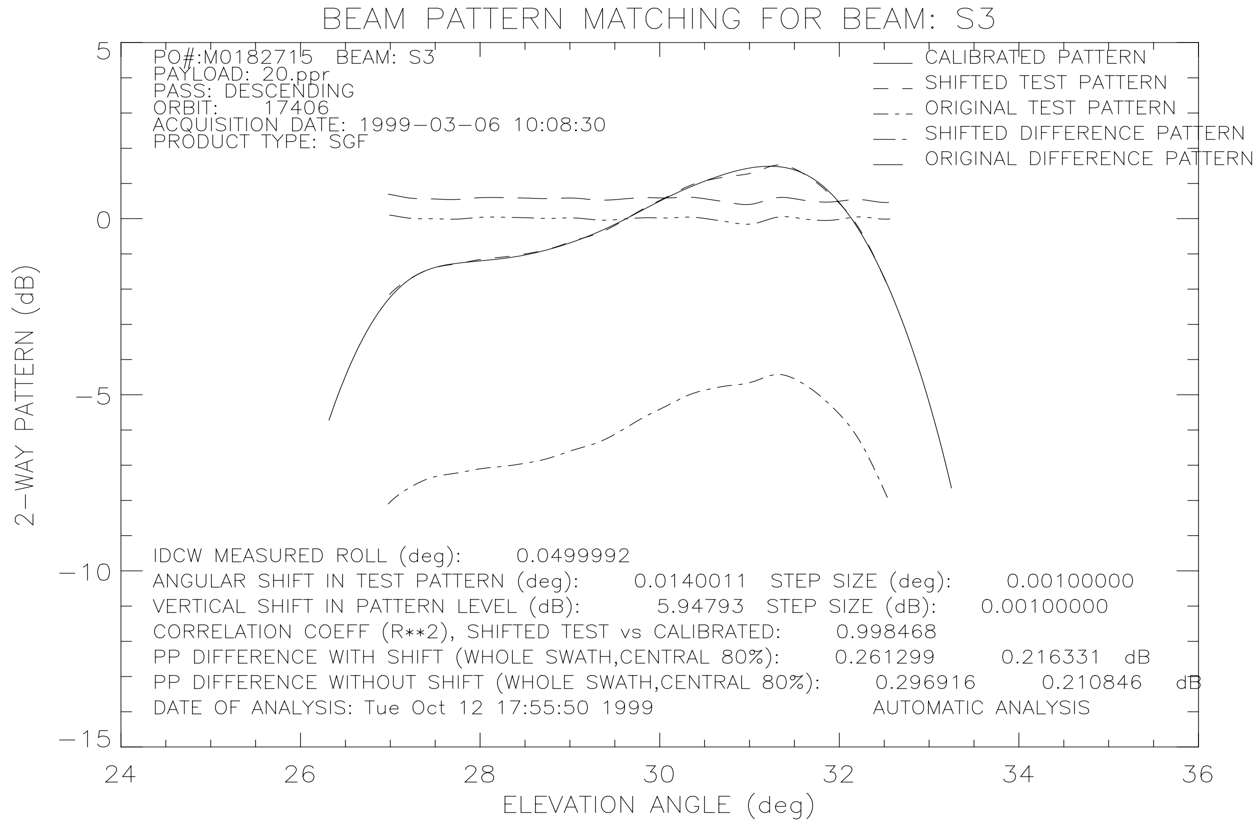

Fig. 4. Beam pattern matching results for beam S3, product M0182715, after recalibration.

DISCUSSION

Caution must be exercised to check that the pattern matching achieved at the edges is good, i.e., the beam edges of the shifted test pattern and the calibrated pattern should overlap each other. When there is a large pattern change even with removal of S/C roll, it may be concluded that the beam recalibration is required. In the recent example of beam S3, the P-P deviations in the roll corrected difference pattern (0.7 dB) were indicative of the comparable elevation pattern shape. The contribution of the S/C roll in the whole swath P-P deviation is the difference with and with out roll correction (1.5 – 0.7 = 0.8 dB). After recalibration, the deviations in the difference are significantly reduced (0.2 dB).

CONCLUSION

The pattern matching technique has been used to detect small changes in the elevation beam pattern of al1 calibrated beams of the RADARSAT-1 system, which are routinely monitored as part of the Maintenance Phase. Tools have been developed for monitoring and evaluating the pattern shape changes and for generating an updated calibrated beam pattern which is used for pattern correction by the SAR processor. The tools and techniques described here can be easily adapted to future Earth Observation Systems designed to produce radiometrically calibrated products for the user community.

REFERENCES

[1] "RADARSAT System Specification", *CSA Document RSCSA-SP0002,* Rev.C, 1996.

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[3] R.K. Hawkins, *et al.,* "Stability of Amazon Backscatter at C-Band: Spaceborne SAR Results from ERS-2 and RADARSAT-1", this proceedings.

[4] T.I. Lukowski, *et al.,* "RADARSAT Elevation Antenna Pattern Determination," *Proc. IGARSS '97*, vol. 3, Singapore, pp. 1382-1384, 1997.

[5] K.P. Murnaghan, R.K. Hawkins, and T.I. Lukowski, "Combination Procedure for RADARSAT Antenna Pattern Determination," *Proc. Canadian Symposium on Remote Sensing*, Calgary, 1998.

[6] R.K. Hawkins and S.K. Srivastava, "The Radiometric Error Budget of RADARSAT-1", this proceedings.

RADARSAT PAYLOAD FILES				
Payload #	**Submitted**	**Valid Start Time**	**Valid End Time**	**Comments**
05	28-Nov-95	1995-12-28 23:24:28	1996-02-28 21:03:41	
06	28-Feb-96	1996-02-28 21:03:41	1996-05-21 21:36:00	Revised replica_phase_coeff
07	21-May-96	1996-05-21 21:36:00	1996-06-14 15:34:53	New beam table load
08	14-Jun-96	1996-06-14 15:34:53	1996-07-23 20:06:25	New beam patterns for S1-7, W1-3, F1-5
09	23-Jul-96	1996-07-23 20:06:25	1996-09-25 21:13:05	Refinement of elevation beam patterns and GCF
10	25-Sep-96	1996-09-25 21:13:05	1996-11-27 19:39:39	Beam slot changes for extended high beams
11	27-Nov-96	1996-11-27 19:39:39	1997-01-21 14:35:58	Calibration of beams S1, S2, S3, S4 of CDPF products
12	21-Jan-97	1997-01-21 14:35:58	1997-02-14 17:12:08	EL1 Beam replacing EH1 beam
13	14-Feb-97	1997-02-14 17:12:08	1997-06-02 16:39:46	S5-S7, W1-W3 calibrated, S1, S2, S4 and GCFs upgraded
14	02-Jun-97	1997-06-02 16:39:46	1997-08-12 15:35:51	F1-F5 calibrated, GCFs and TRNLs updated, Relative beam gains adjusted
15	12-Aug-97	1997-08-12 15:35:51	1997-09-08 07:00:00	Calibration upgrade to Beam EL1
16	08-Sep-97	1997-09-08 07:00:00	1997-09-09 07:00:00	Beam EL1 calibrated
17	8-May-98	1997-09-09 07:00:00	1997-10-20 19:00:00	Beam S4 Calibrated for Left-Looking Mode (Antarctic Mapping Mission)
18	8-May-98	1997-10-20 19:00:00	1998-04-21 21:12:32	Copy of Payload 16 with an update of TNRL
19	23-Dec-98	1998-04-21 21:12:32	1998-10-13 20:57:17	Beams F4 and W1 recalibrated
20	21-Apr-99	1998-10-13 20:57:17	1998-12-10 20:57:17	Beams S3 and S6 recalibrated
21	17-Jun-99	1998-12-10 20:57:17	2014-07-23 00:0:00	Beams S1 recalibrated and TNRL updated

Table 1. Radarsat-1 Payload Parameters Files Used Since Launch.