EXPLORING THE ELEVATION BEAM OVERLAP REGION IN RADARSAT-1 SCANSAR

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ABSTRACT

ScanSAR has become a well-established method of providing high quality wide-swath coverage using SAR from space. The method involves using multiple antenna elevation syntheses from a single antenna to switch between illuminating successive portions of the augmented swath. In switching between beams, the azimuth history of the beam is usually distributed in bursts for the respective elevation beams so that a partial azimuth history is provided. Issues in radiometry, relating to both elevation and azimuth processing are important in ScanSAR. This paper explores the beam seam issue. Using examples from RADARSAT-1, this radiometrically sensitive region is examined for the requirements on accuracy and consistency of the beam patterns. RADARSAT-1 has four ScanSAR modes and can involve 2, 3 or 4 beam ScanSAR operations. Implications on processing and designing ScanSAR systems are given.

1. INTRODUCTION

ScanSAR was first introduced into earth observation with the SIR-C mission [1]. It offers wide-area coverage (300-400 km) at moderate resolution and is ideal for synoptic applications such as coastal surveillance. Figure 1 is a Canadian Ice Service (CIS) ScanSAR image from RADARSAT-1 that illustrates the utility of the mode. RADARSAT-1 [2], launched in 1995, was the first operational satellite to employ this mode. ENVISAT ASAR [3], to be launched in July, 2001, uses the ScanSAR technique for its Wide Swath Mode (WSM).

This mode exploits two complementary properties of advanced SARs: the agility of the formation of the beam in elevation, switching the illuminated area across the swath among several predefined subswaths; and, the ability to process independently associated portions of the azimuth beam spectrum. Each of the subswaths is normally illuminated in a series of alternating 'bursts'of pulses. For a target receiver located near the middle of the ScanSAR swath, the received power in azimuth consists of the burst pattern of each of the beams but proportional in amplitude for each according to the elevation illumination intensity. Figure 2 illustrates this behaviour [4].

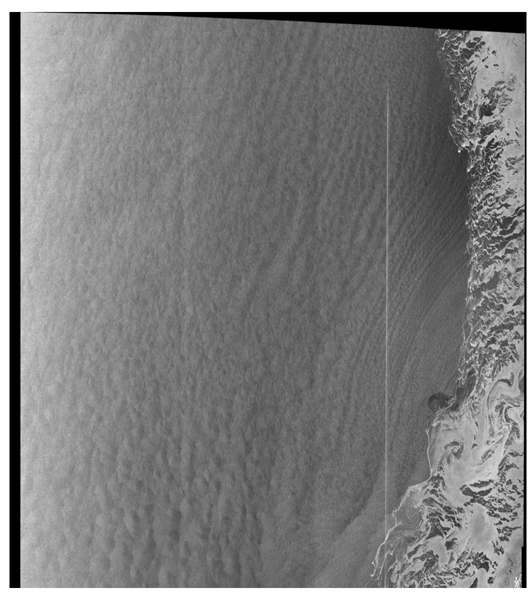

Figure 1. ScanSAR Wide B Image of Sea Ice. ©CSA. A swath over 300 km is captured in four beams.

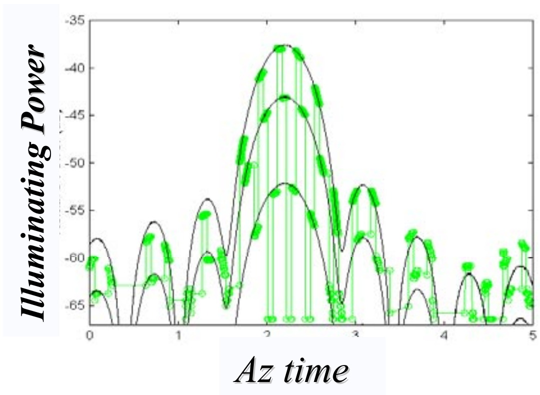

Figure 2. Azimuth Pattern Reception from RADARSAT SCWA. This data was taken from a receiving transponder placed near the intersection of two elevation beams and close enough to a 3rd beam to produce the three traces shown. In green are the burst patterns formed as each elevation pattern is selected.

The partial illumination in azimuth places difficult requirements [5] on the determination of Doppler centroid [6] that can lead to azimuth scalloping when these are not met.

In the across track direction, beam seam artefacts are often an undesirable feature of ScanSAR data [7]. Seams with radiometric discontinuities as low as 0.3 dB can easily be detected [8]. Beam boundary issues stem from a number of critical system parameters areas:

1. Knowledge of the elevation beam shapes,
2. Determination of the relative beam angular placement,
3. The spacecraft attitude: roll, and to a lesser degree yaw, and pitch.

In this paper, we discuss the sensitivity of the interbeam region of RADARSAT-1 ScanSAR and solutions for processing and handling it.

1.1. RADARSAT-1 Beams

RADARSAT-1 can be configured to produce 23 single beam elevation configurations as shown in Figure 3. Typically these swaths are on the order of 100 km in width. There are four ScanSAR modes which combine adjacent overlapping single beams for a combined swath of up to 300 km but with reduced resolution as indicated in Table 1.

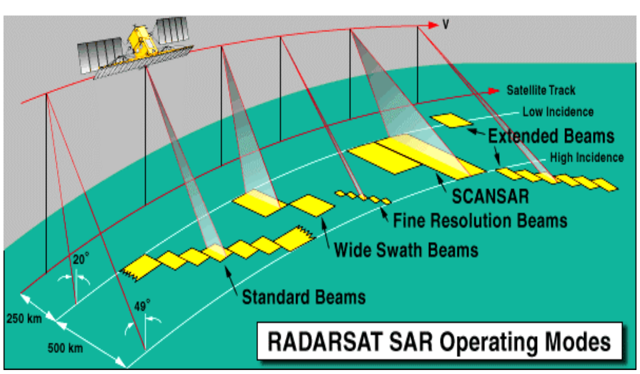

Figure 3. RADARSAT-1 Operating Modes. ©CSA

Table 1. Properties of RADARSAT-1 ScanSAR Modes**.**

Mode	*SCWA*	*SCWB*	*SCNA*	*SCNB*
BEAMS	W1, W2, W3, S7	W1, W2, S5, S6	W1, W2	W2, S5, S6
Swath Width	500 km	500 km	300 km	300 km
Spatial Resolution	100 m	100 m	50 m	50 m
Looks	7	7	4	4
Sampling	50 m	50 m	25 m	25 m
Pixels	10000	10000	12000	12000

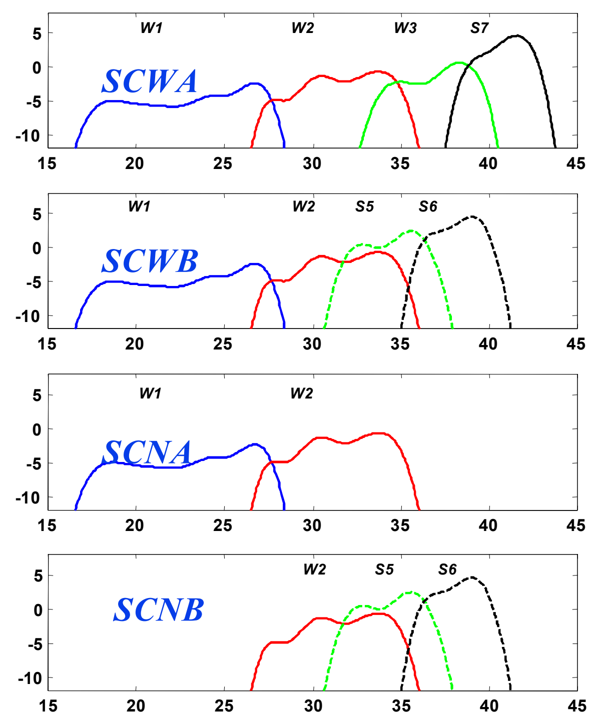

Figure 4. Elevation beam patterns in RADARSAT-1 ScanSAR.

The beam patterns used in the four ScanSAR modes are illustrated in Figure 4. In the figure, the two-way patterns (in dB) derived from payload 22 [11] are plotted against the beam elevation (in degrees). For common sub-beams of the four ScanSAR modes, the same line type used to designate the same single beam pattern. Note especially the beam overlap regions in each mode.

1.2. Beam Pattern Determination

The elevation beam patterns are supplied to the Canadian Data Processing Facility (CDPF) using a payload file that is indexed with applicability times according to the calibration epoch of the system. The mechanics of determining beam patterns for RADARSAT-1 has been described in [9] and is summarized in Figure 5.

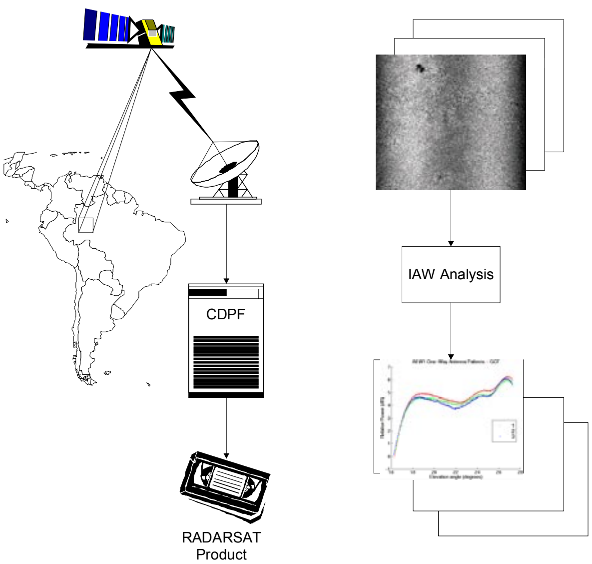

Figure 5. Overview of RADARSAT-1 beam determination. At the left RADARSAT-1 is seen illuminating the Amazon rainforest and received data for the scene are downlinked and processed to imagery products on the CDPF with no antenna pattern correction. At the right, a series of these images are averaged on an Image Analysis Workstation (IAW) to produce profiles which are proportional to the in-orbit beam pattern. These in turn are combined to produce a single smoothed pattern and tails are added from the preflight patterns to extend the edges.

Absolute beam level determination is done by forcing the smoothed pattern provided from the above process with precision transponder [10] data. This process is shown conceptually in Figure 6.

1.3. Relative Beam Placement

As indicated above, each of the single beam patterns is determined independently. This means that any small systematic variations, within the error budget, that may exist between beams is still present. These radiometric offsets, which may be inconsequential for single beam determinations, can be quite significant in ScanSAR.

In addition to (vertical) radiometric offsets between the beams, it is possible to also produce (horizontal) angular offsets because each beam may be captured with different unknown spacecraft

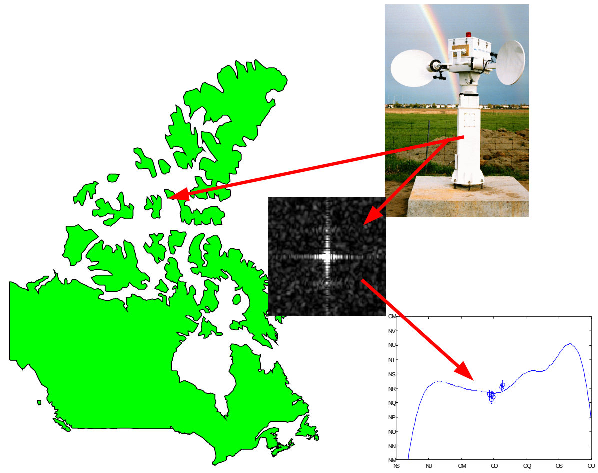

Figure 6. Use of Point Targets for Absolute Calibration. Four widely separated locations (Resolute Bay, Fredericton, Ottawa, and Prince Albert) have precision transponders like the one shown at the top right. These are imaged regularly for each beam and the smoothed beam patterns, derived from the process shown in Figure 5, are shifted to match the well known RCS of the transponders.

attitude parameters. With RADARSAT-1, spacecraft roll variation is not monitored directly and linked into the processing. Over most of the swath of single beams, where the beam patterns are relatively flat, this does not normally pose a significant difficulty [11].

1.4. Sensitivity to S/C Roll

In ScanSAR, the consequences are more far reaching because it is the beam edges where the sensitivity to slight changes in roll (>0.01º) is highest that the beams are often stitched together at the boundary. Worse is the fact that the correction for adjacent beams in the overlap region has the opposite sign with the result that a discontinuity often results [7]. Figure 7 further elucidates this challenge.

Several methods of determining the amount of roll have been proposed. The most obvious is from direct ephemeris data, but this is not available for RADARSAT-1. The second is to use a fit of the beam pattern to the shape of the clutter data in the main lobe of the elevation pattern. This has been shown to work well for simple scenes such as the ocean or Amazon rainforest where a simple clutter model is plausible. Finally, the overlap region can be used to estimate roll offset, independent of scene content, by utilizing the common scattering and known beam patterns present there. The quality of the estimate improves with larger overlaps and with better knowledge of the beam pattern itself. We note that this region is known with the least fidelity. When a separate angular displacement for each beam, θ^i which includes roll θ_{roll} ,and relative offset of the beams, θ_o^i is required, the problem is more complex.

$$\theta^i = \theta_{roll} + \theta_o^i \tag{1}$$

In the next section, we discuss the stability of the interbeam pattern measurements.

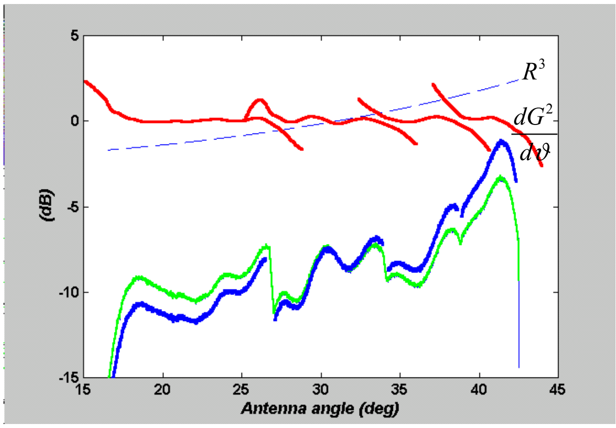

Figure 7 . ScanSAR beam position sensitivity. At top is the R^3 correction range fall off shown as the blue dashed line. The red lines are the slopes of the beam patterns for a 0.1º roll displacement. Below are the beam patterns with and without the R^3 correction. Note in the beam overlap region, the sensitivity to roll is highest but also in opposite directions for adjacent beams.

1.5. Beam Stability

Beam shape and gain stability depend on a number of factors in RADARSAT-1 including the elevation beam phase shifters in the beam forming network. Again the highest sensitivity to stability is along the edges of the beams. In Figure 8, we illustrate this issue for beams W1 and W2. From this example, it is clear that since beam patterns are derived from smoothed versions of data like these, image specific beam patterns will have inherent uncertainties and these are greatest in the overlap regions.

1.6. Summary of Radiometric Issues for ScanSAR

In the subsections above, we have illustrated the issues that affect the radiometry in the interbeam areas of ScanSAR data. Any systematic discontinuity [8] greater than 0.3 dB can easily be detected by a casual observer of a SAR image and is considered to be unacceptable. With RADARSAT-1, we have seen it is very likely that these can easily arise from a number of sources. In the section below, we suggest a methodology which includes ways to mitigate and minimize these effects.

2. *A ROBUST SOLUTION*

There are four elements to the solution suggested for the determination and application of antenna pattern corrections to ScanSAR:

1. Simultaneous determination of average antenna patterns for all constituent ScanSAR beams.
2. A single determination of the relative positioning of all constituent ScanSAR beams so determining $\{\theta_o^i\}$ as part of the beam determination process and therefore requiring a single composite roll estimation for each image take.
3. Roll determination using any of the methods described in §1.4.
4. Smoothing of residual interbeam radiometric discontinuities.

A flow chart of the process which performs the first two of these steps is shown in Figure 9.

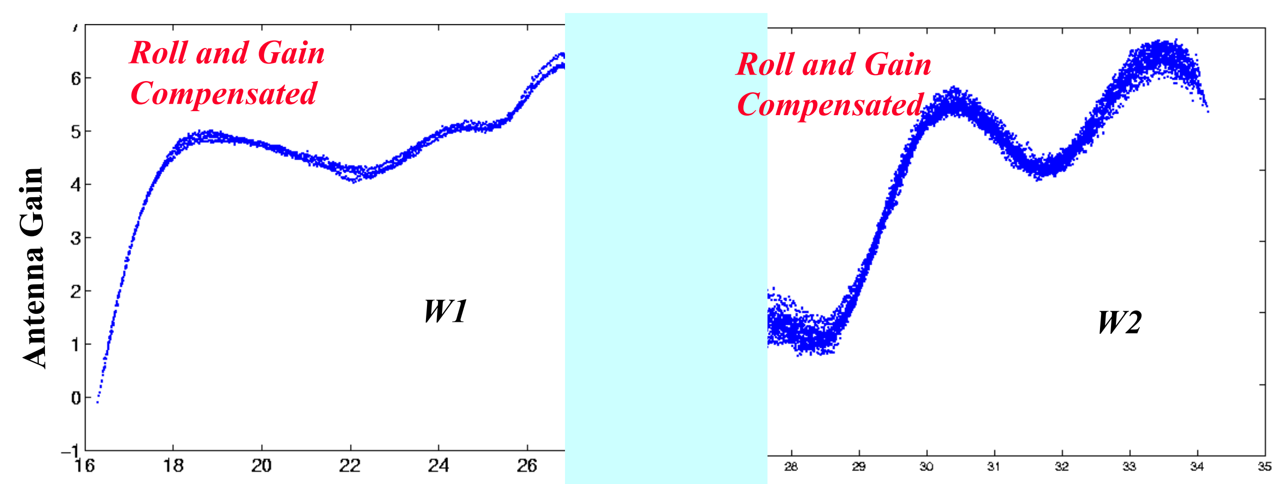

Figure 8. Beam stability in ScanSAR sub-beams W1 and W2. At the left are a set of three one-way antenna pattern determinations for beam W1 and at right are a set of eight determinations for beam W2. In each case the beam patterns have been adjusted for roll and gain changes from either the Amazon backscatter or the system gain of RADARSAT-1 to minimise the apparent shape variations of the patterns. The shaded region in the middle represents the overlap of the two beams when they are combined in several ScanSAR modes. The two-way gain stability in the mainlobe region is approximately ±0.2 dB and in the interbeam region approximately ±0.4 dB.

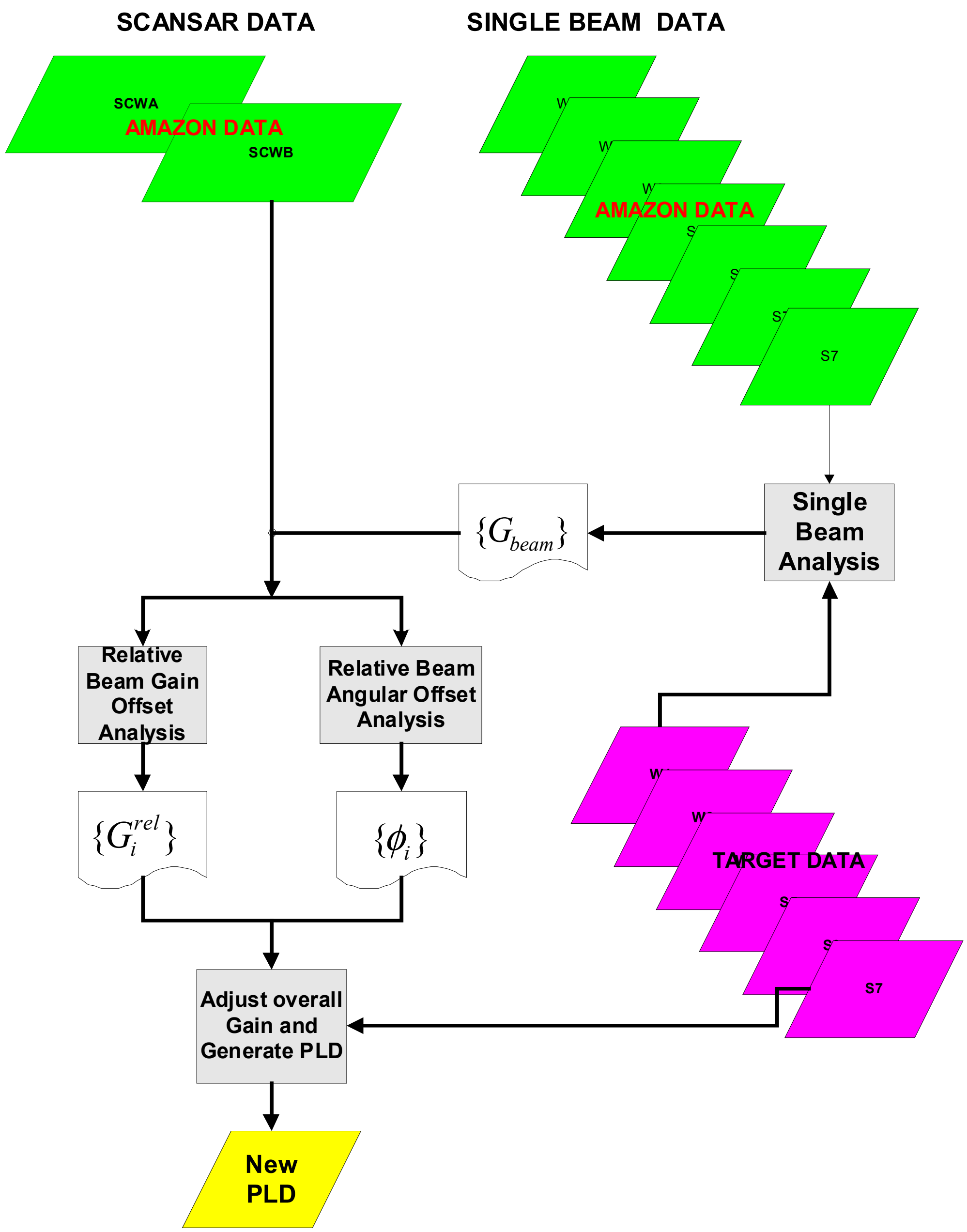

Figure 9. Flow diagram showing analysis scheme for a composite determination of the ScanSAR beam patterns. In this scheme, at the top right, using the traditional analysis tools available for RADARSAT-1 beam pattern analysis, the single beam patterns are determined at the right as per the procedures described in Figures 5 and 6 to form the beam pattern shapes shown as $\left\{G_{beam}\right\}$. In addition, ScanSAR composite beams are also taken of the Amazon and shown on the top left. Relative beam gain and position analysis is then done on each of the prototype shapes against the measured ScanSAR patterns containing these beams and a set of relative gains $\left\{G_i^{rel}\right\}$ and offsets $\left\{\phi_i\right\}$ for each of the constituent beams is determined. These are, in turn, statistically weighted and averaged and fitted *as an ensemble* to determine a payload file (PLD) that has both the relative beam gains and positions correct as well as an absolute level that matches the point target results when fitted against the whole set of beams at one time. Figure 10 is an example of the fitting process for absolute level determination.

In doing the analysis, we take advantage of the fact that beam W2 is common to all RADARSAT ScanSAR modes and can be used to normalize both roll and gain variations during the fitting process. The diagram of course could be adapted for other shape determinations including taking the average shapes for each beam obtained from ScanSAR acquisitions themselves.

The key point is however that in this process, we treat the ScanSAR beams as an ensemble for gain and relative angular position. This means that all beams will be relatively calibrated to a high degree and no biases should be apparent between adjacent beams.

Once the beam patterns have been so determined, they can be applied to a new scene after roll determination. Because of limitations to this process and stability of the beam patterns as noted in §1.4 and 1.5, some residual will remain and these can be dealt with by a smoothing process.

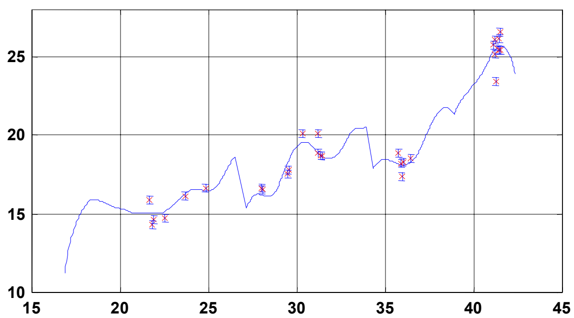

Figure 10. Ensemble point target fitting analysis for SCWA.

The smoothing process developed by RSI takes advantage of the known beam boundary locations and their extents. It takes advantage of the fact that most scenes will contain some reasonably homogeneous regions which intersect these boundaries and therefore can be used to derive a smoothing kernel to apply to the rest of the image. An example of the result of such a process on the image presented in Figure 1 is shown in Figure 11.

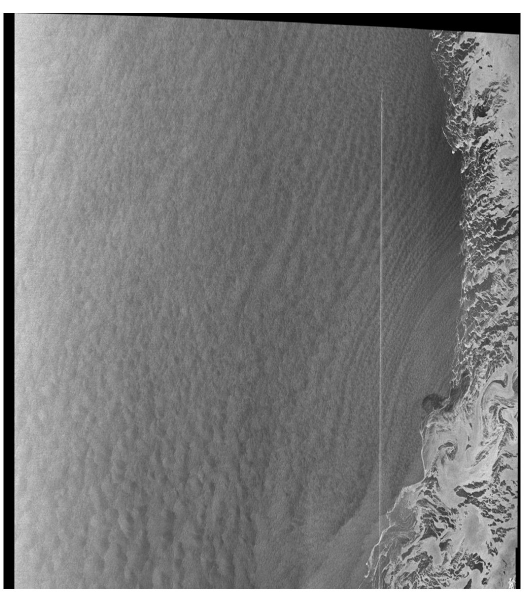

Figure 11. Corrected SCWB image using boundary edge smoothing. ©CSA

3. CONCLUSIONS

In this paper we have outlined some new considerations for the improvements of ScanSAR image radiometry over the beam seams. By careful determination of beam pattern gains and angular offsets from ensemble measurements for all the sub-beams which form the ScanSAR composite, systematic effects can be minimized. Because of inherent uncertainties (knowledge and stability) in both of the elevation patterns and spacecraft attitude, it will be not always be possible to eliminate visible artefacts. An additional step involving smoothing can be used to further reduce these undesirable effects.

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