AMM Calibration Report

by Allison Kipple

Alaska SAR Facility

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1 Introduction

Since ST2-L was the first Precision Processor dataset to be calibrated, the calibration of ST2-L involved an extensive amount of debugging and therefore took longer than the other AMM beams. This debugging process forced us to learn (and question) more about the algorithms used in both the processor and our PVS analysis tools. Some bugs also inspired us to add new capabilities to the PVS, allowing us to test parameters that we had previously just assumed to be correct. In all I believe the calibration process at ASF was improved due to the challenges of ST2-L. The primary purpose of this document is to present the AMM calibration results and remaining data quality issues, but I'm also using this opportunity to record the lessons we learned and processes we developed along the way. It's my hope that this effort will improve the quality of future ASF products as well as make the new calibration engineers' lives a little easier. The table of contents should allow everyone to skip to the information most relevant to their particular interests.

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2 The Essence of Calibration

Many people are familiar with calibration in the context of weight scales; you have a set of calibration weights which are each placed on the scale, and the scale is modified until it shows the correct value for each calibration weight. By comparison, ASF's SAR data show how much radar energy was reflected back from objects on the Earth. Our "calibration weights" in this case are corner reflectors and transponders. We know how much radar energy these devices should reflect back to the SAR. If ASF's processed SAR data show different values than what we expected, we tweak the processor until it produces the expected results.

Figure 1. Corner Reflector in ASF's Delta Junction Calibration Array

There are two main calibration categories: radiometric and geometric calibration. Radiometric calibration was briefly described above – the data are radiometrically calibrated when the processor outputs the expected radar cross-section (RCS) values for known targets. There are always slight errors in the radiometric results, however, and the acceptable limits for these errors are specified by the scientists who use SAR data. Causes for these errors include inaccurate satellite attitude determination and less-than-perfect calibration devices. Errors can be reduced when attitude determination methods and calibration devices are made more sophisticated, but this also results in increased program costs. Trade-offs must be specified.

There are also two kinds of radiometric calibration: absolute and relative. Absolute calibration refers to the accuracy of the RCS estimate when compared to the theoretical value. Relative calibration refers to the accuracy of radiometric variations within one image – for example if one device is known to be 1dB lower than another, regardless of their absolute values. For the Antarctic Mapping Mission (AMM), the data were required to have an absolute accuracy of 2 dB and a relative calibration accuracy of 1 dB

Geometric calibration deals with the accuracy of an object's associated latitude and longitude coordinates. AMM specifications stated that the latitude and longitude values output from the Precision Processor should be within 500 m of the actual values.

3 Calibration Process

3.1 Acquire Calibration Data

In order to calibrate the Precision Processor's output, we first needed to request and acquire data of our calibration sites. For AMM we needed data of the Amazon rainforest, the Delta Junction and Kenai calibration arrays, and the Canadian transponders.

3.1.1 Amazon Rainforest Data

The Amazon rainforest is a very homogeneous and stable radar target. In contrast to most other natural targets, it backscatters nearly the same amount of incoming radar regardless of incidence angle or time of year. In fact the total variation of the Amazon's RCS is believed to be only .4 dB. Therefore data of the Amazon rainforest can be used to derive and refine a SAR's antenna pattern (in range). The Amazon data are also used for absolute radiometric calibration since the RCS is so stable. With a gamma0 value of –6.5dB, the Amazon RCS lies near the center of the expected natural RCS range – another characteristic which makes it a good calibration target.

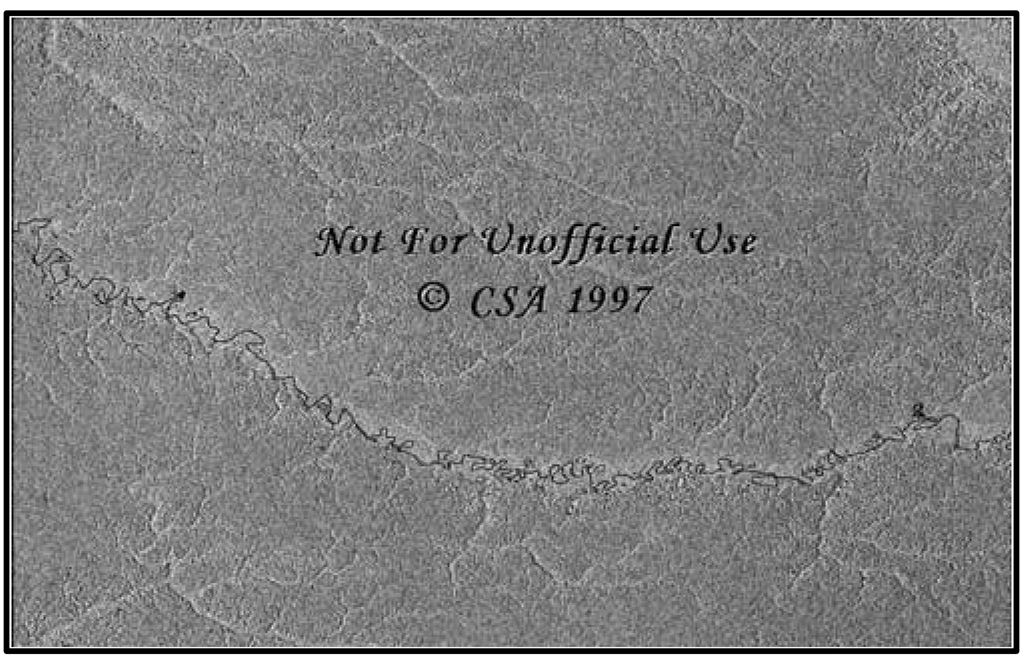


Figure 2. ST2-L Amazon Image 9923_880

We need at least one good ascending and descending pass over a homogeneous section of the Amazon rainforest to accurately calibrate a SAR beam. Obviously the more Amazon data we get, the smaller the averaged errors in our antenna pattern estimation and better resulting calibration will be. We must use the RADARSAT's tape recorder in order to acquire the Amazon data, and generally all tape-recorded data are downlinked to a Canadian station. Delays in getting this data out of Canada and into ASF's data system in turn cause significant delays in the calibration process. During AMM, the Amazon data were either downlinked directly to ASF or meticulously tracked until their arrival at ASF, which was a great help to calibration. For future missions we should also plan more Amazon acquisitions as a buffer, since CSA frequently abandons these acquisitions.

3.1.2 Delta Junction and Kenai Calibration Arrays

During the Antarctic Mapping Mission, ASF deployed corner reflectors and transponders in Delta Junction and Kenai, Alaska. The theoretical RCS of the corner reflectors gives us another absolute radiometric calibration standard to test with, though the reflectors aren't as accurate as the Amazon rainforest and CSA transponders. The bright responses of the corner reflectors and transponders, much brighter than most natural objects, also allows us to test image quality parameters such as: Peak-to-Side-Lobe-Ratio (PSLR), Integrated-to-Side-Lobe-Ratio (ISLR), and resolution.

The locations of the corner reflectors and transponders are well known (GPS survey) and therefore serve as excellent geolocation checkpoints. The lakes around the Delta Junction area can also be used to determine the background radar noise – on a calm day, the lakes reflect nearly all of the signals and therefore their brightness generally indicates background noise.

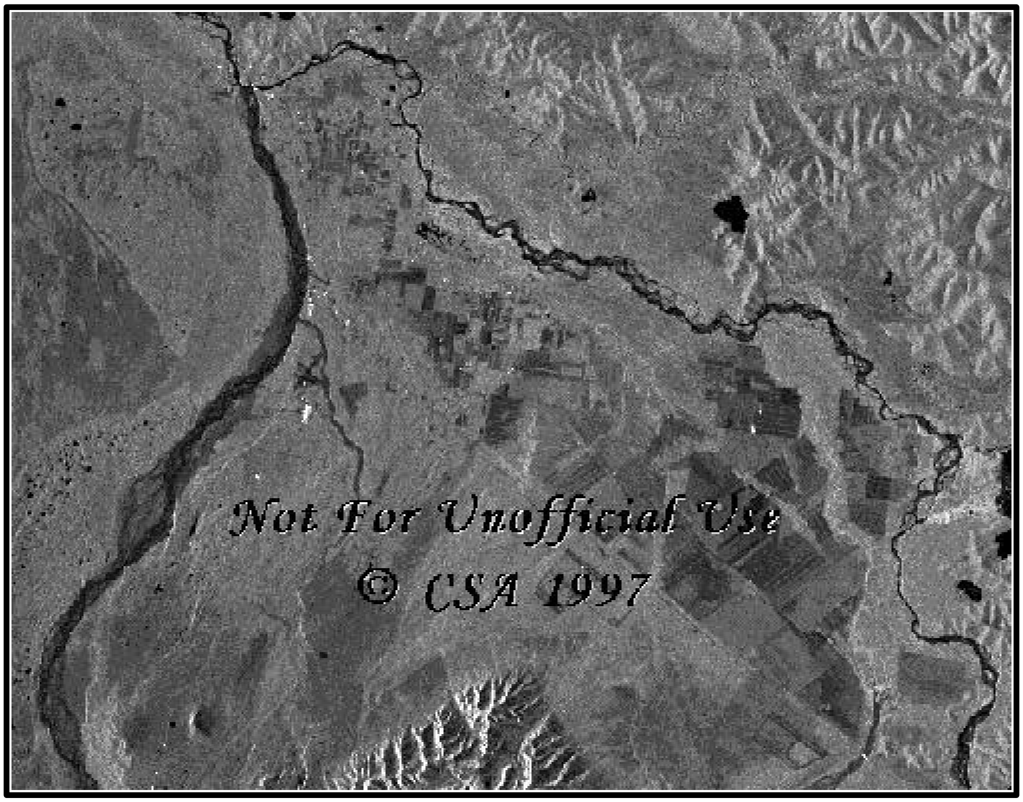


Figure 3. SAR Image of Delta Calibration Array

3.1.3 Canadian Transponders

The Canadian Space Agency utilizes four transponders, which are located in Resolute, Ottawa, Prince Albert, and Fredericton. The CSA calibration team believes that their transponders are stable to within .1dB, an impressive claim. Our much cheaper transponders could never hold to such a standard. Though we aren't certain of the reported .1dB transponder accuracy, we were very pleased when CSA supported us with acquisitions of their transponders during the Antarctic Mapping Mission. Their devices' accuracy was guaranteed to be much better than ours regardless, and the RPT data proved itself to be invaluable during the calibration process.

We ended up using the Amazon rainforest data to derive the AMM beams' antenna patterns and set the absolute radiometric calibration. (The –6.5 dB gamma0 Amazon rainforest value was provided by the SAR CEOS calibration group and has been well defended. Gamma0 = sigma0 – 10*log(cos(incidence_angle)).) We could have calibrated to the Canadian transponders but used the Amazon data to be consistent with our other products. The two methods were consistent to within a few tenths of a dB, as seen in the results section below.

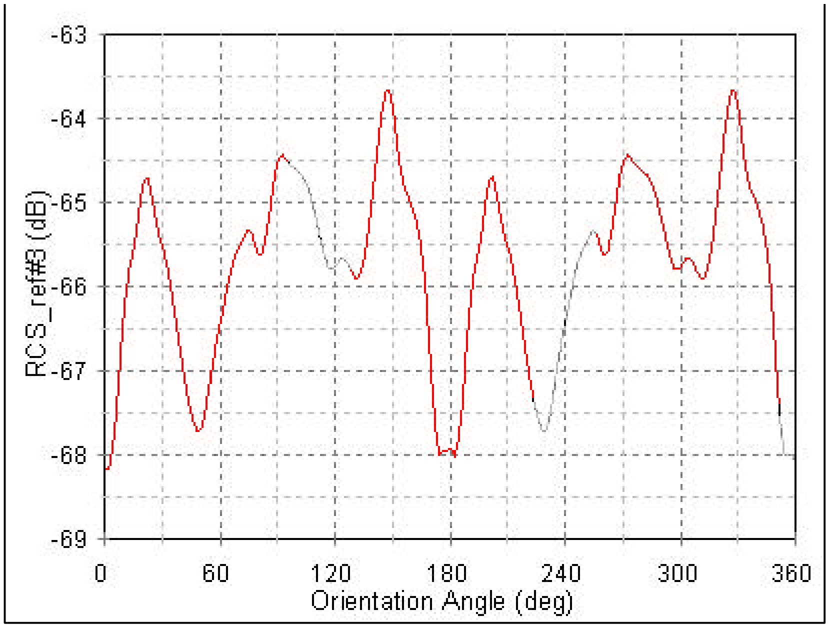
3.1.4 Antarctic Transponders

Two transponders were deployed in Antarctica – one at McMurdo and the other at South Pole station. Unfortunately the McMurdo transponder didn't appear to be working during the Antarctic Mapping

Mission. Perhaps its high-power amplifier became too hot during the summer months and thus became ruined; it is currently being tested at ASF. The South Pole transponder burned out within 30 minutes of being deployed – at an ambient temperature of -110° F – and had to be repaired.

Figure 4. Transponder at South Pole Station

A technician at South Pole station removed the ARC's (Active Radar Calibrator) insulation until it reached a stable temperature. He then replaced the RF-chain with a spare set. The transponder then worked sufficiently during the mission but was just used for geolocation analysis as the transponder's antenna pattern was somewhat bizarre. (At a given incidence angle, the RCS of our transponders varies significantly – up to 4 dB – according to azimuth orientation. There are also sharp peaks and dips in the pattern. I would not recommend using these devices for radiometric calibration , only geometric.)



Figures 5&6. Example plot of RCS vs Orientation (Azimuth) Angle (above); melted South Pole transponder (below).

3.2 Analyze the Calibration Data

3.2.1 Distributed Target Analysis (Amazon Data)

The Amazon images are loaded into the PVS analysis tool. A grid is drawn over the image, and the user de-selects "bad" grid sectors – regions with rivers, mountains, or any other non-homogeneous element.

The PVS then uses the remaining grid elements to estimate the RCS (sigma0) of the image as a function of incidence angle. These data are loaded into a spreadsheet, and the sigma0 values converted into gamma0 values.

Though every scene is unique, the plot of gamma0 versus incidence angle should average out as a nearly flat line for Amazon data. If all of the results slope up or down (or have a similar non-flat shape), the antenna pattern should be shifted or otherwise adjusted to compensate. Note that the antenna pattern is in units of one-way power. So, when we decided to reduce the gain by 12 dB, I added 6 to every element in the antenna pattern. Similarly if the analysis results at 30 degrees elevation are .1 dB too high, you need to add .05 to the antenna pattern element corresponding to 30 degrees to dampen that data appropriately. (The antenna pattern is located in the CALPARMS file, as are several other calibration parameters. See Appendix II.) In sum: use the PVS to determine the sigma0 value vs incidence angle for each suitable Amazon scene; use a spreadsheet to convert those values to gamma0 and calculate the offset from –6.5; determine the average offset per incidence angle from all scenes, and divide those values by 2; convert incidence angle to elevation angle (elev = asin(sin(inc)*radius/(radius + altitude)) where the Earth's radius and spacecraft altitude are given in the metadata); interpolate the offsets for the elevation angles given in the antenna pattern; add the offsets to the antenna pattern files; smooth the antenna pattern, especially at the edges of your offset analysis; resubmit the antenna pattern; reprocess the Amazon data; repeat.

After the noise calibration term has been determined (i.e. a1 - see the noise analysis section below), the Amazon data can also be used to set the linear term (a2). That is, if the plot of gamma0 is not centered around –6.5 dB for Amazon data, a2 can be used to shift all the values up or down. The a2 parameter is used as follows:

sigma0 = 10log(a2 * (DN^2 – a1*n))
gamma0 = sigma0 – 10log(cos(i))

where:

sigma0 and gamma0 are in dB
a1 = calibration noise term
a2 = calibration linear term
DN = average DN value of your selected grid
n = CEOS noise vector, an estimate of noise versus range
i = incidence angle

So, if your gamma0 plot is 1.5 dB higher than it should be:

new_a1 = old_a1 * 10^-.15
new_a1 = .708 * old_a1

3.2.2 Point Target Analysis (Calibration Arrays at Delta and Kenai, CSA Transponders)

Images of the calibration arrays, or similarly of the Canadian transponders, are loaded into the PVS for point target analysis. First the PVS queries the calibration database for field data associated with the image being analyzed. This includes information on the location and pointing angles of each calibration device on the day the image was acquired. (Calibration engineers measure and record the pointing angles when they position the devices for an upcoming pass. Detailed GPS positioning analysis is performed approximately once per year or whenever a reflector is moved. All field data are later recorded in the calibration database.)

The PVS uses an image's geolocation metadata and the known device locations to plot small red boxes on the image, representing where it thinks the calibration devices should be. An image analyst then picks out the actual devices (seen as bright points in the image), and the PVS calculates geolocation errors between the expected and actual locations. The geolocation accuracy for AMM was set at 500 m. The worst RMS geolocation image seen in the Delta imagery was less than 200 m – well within specifications. Many results are much better, some even within 20 meters. It should be remembered, however, that these same Delta images were used to refine the processor's geolocation algorithms in the first place, so the results in Delta *should* be very good. The Kenai data generally showed worse geolocation accuracies than Delta, though they were still well within spec. Geolocation results on some natural ground control points in Antarctica were somewhat worse – around 300m RMS – but still within spec. The difficulty in accurately selecting the Antarctic targets is in part responsible for the larger errors; when the McMurdo antenna could be used as a target, the results were quite good.

The PVS also uses the selected point targets, along with nearby pixels, to determine image quality parameters such as PSLR, ISLR, and resolution. The PSLR and ISLR results are better for the CSA transponders than they are for the corner reflectors. This is due to the fact that for corner reflectors, the sidelobes often blend into the surrounding backscatter. The transponders' brighter response lifts the sidelobes above the surrounding backscatter, however, making their PSLR and ISLR measurements not only more accurate but also improved. In order to further improve the PSLR and ISLR values (i.e., to bring them within spec), JPL weighted the sidelobes down even further. Weighting down the sidelobes has a side effect of worsening resolution, so the resolution estimates are now at the limit of the requirements. (See the results sections below.)

The point targets' RCS values can also be used as a consistency check for absolute radiometric calibration. The corner reflectors' results have a wide error range due to imperfections or bending in the reflectors' sides as well as weather effects (e.g. snow), but their average RCS values should be about 1.8 dB lower than their theoretical values. The theoretical values depend on the predicted versus actual pointing angles and are usually around 46 dB. The theoretical CSA transponder RCS values are as follows: Ottawa, 55.68 dB; Resolute, 55.51 dB; Fredericton, 54.14 dB; Prince Albert, 53.97 dB. When absolute calibration was completed, the CSA transponder results turned out to be a few tenths of a dB higher than their theoretical estimates. SAR experts considered this to be highly consistent and said we should be satisfied with the absolute calibration. Ok!

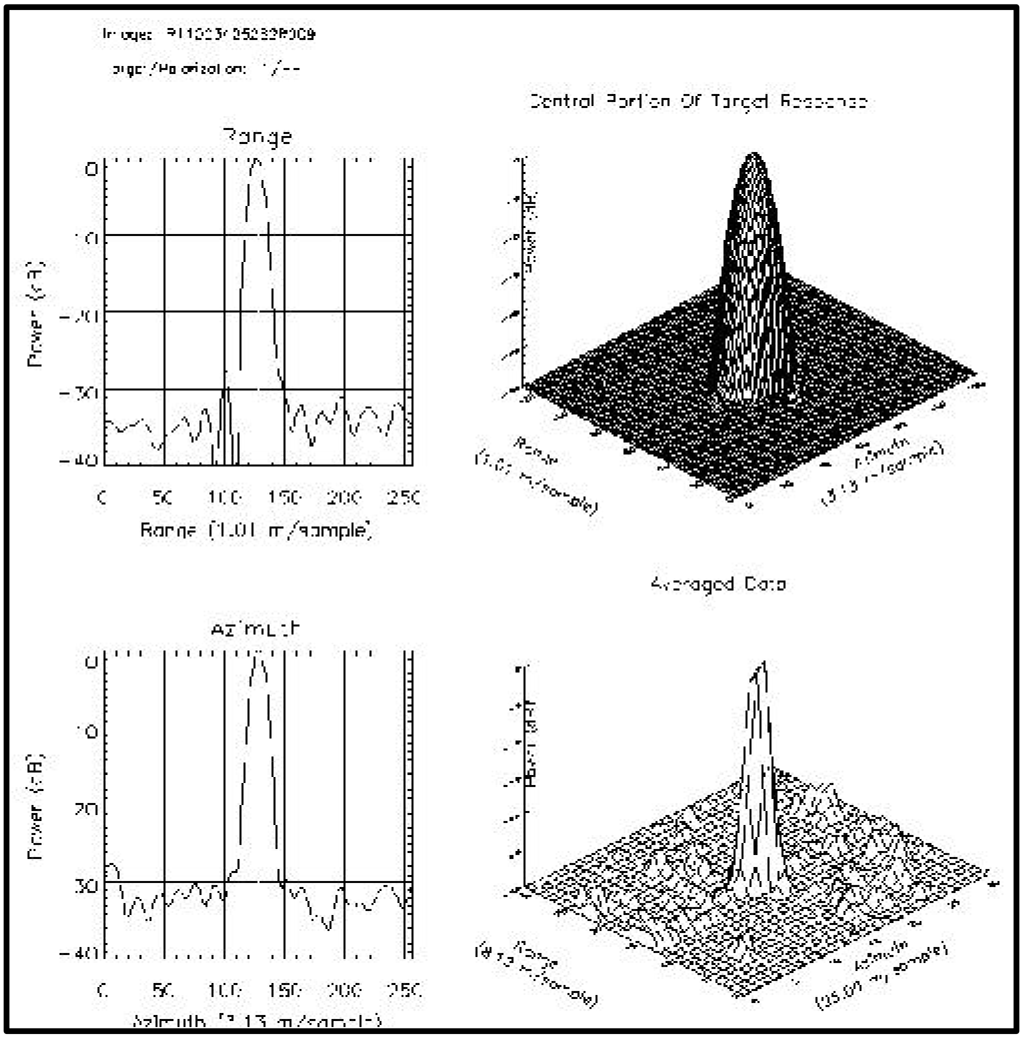


Figure 7. Example Point Target Response

3.2.3 Noise Analysis

In order to perform noise analysis you need an image that contains some very dark regions - regions with a naturally low radar response. There are some fair-sized lakes around our Delta Junction calibration array that we often use for noise analysis. If the lakes are covered with snow or are not smooth (e.g., a windy day), then they cannot be used. After we eliminate unsuitable data, we usually have a couple images per beam that can be used for noise analysis.

To determine the noise floor, you start out by zooming in on a dark lake (using the PVS). Then bring up the ‘Statistics’ window and select a pixel near the darkest region of the lake. Note the DN value of the pixel and the average value of the surrounding pixels. (You can select the number of pixels to be averaged in this process.) Repeat this several times, selecting different points around the lake. Then repeat this process on other dark lakes within the image, and then on dark lakes in other images. The goal of this process is to obtain an average DN value for the regions of lowest backscatter, or similarly a DN estimate for the noise floor. When you are fairly confident in this value, you use it to obtain the calibration noise coefficient (a1) as follows:

DN^2 = a1 * CEOS_NOISE

where:

DN = estimate DN of noise floor
a1 = calibration noise coefficient
CEOS_NOISE = average value of the CEOS noise vector, found in the radiometric data record

It is prudent to check your a1 setting with a naturally low sigma0 image, such as smooth ocean scenes or flat regions of cold, dry snow (e.g., interior Greenland or Antarctica). Perform grid target analysis on the low-sigma0 images and plot the results. If the plot of sigma0 vs incidence angle has a shape that is similar to that of the noise vector versus incidence angle, your a1 setting may be too low. If a1 is too high the PVS will output sigma0 results of –100dB, meaning that it failed at taking the log of a negative number. Note that you can simply change the a1 value in the PVS-generated .hdr file and repeat your grid analysis in order to see the effect of changing a1. (You don't have to run data through the processor again to test different a1 values.) The noise vector data are located in the radiometric data record within the CEOS metadata file. You can use the STEP tool called "metadata" to look at it. (See the ASF homepage at www.asf.alaska.edu for more details.) Note that this step in the calibration process essentially compensates for the application of an antenna pattern in a region where nearly no radar was backscattered, i.e., where no antenna pattern existed in the first place.

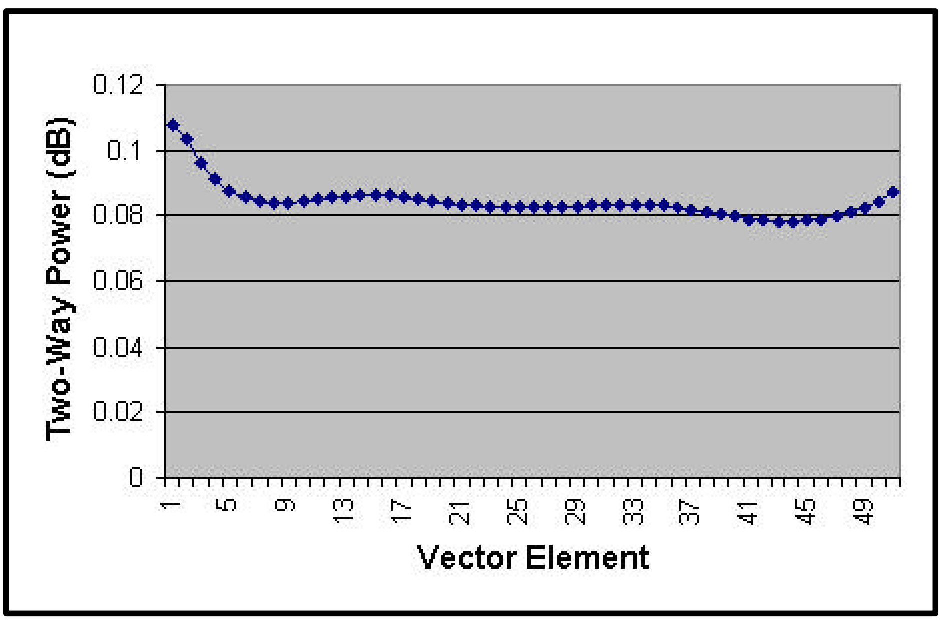


Figure 8. Example ST2-L Noise Vector. Each element represents 32 full-res pixels.

After you set both a1 and a2 appropriately, perform the standard PVS noise analysis – where you select a square region over a dark lake and the PVS calculates the estimate sigma0 of that region. For the left-looking RADARSAT data, the noise floor should range between –20 and –24 dB.

3.3 Debug and Update the PVS

Since ST2-L presented us with a different kind of product from a new processor, it tested the PVS analysis tool in new ways and therefore uncovered several bugs. This caused delays in the calibration process as problem reports on the PVS would have to be issued, the cause of the bugs discovered and fixed, new capabilities added, and the updated software delivered. This debugging process didn't affect other beam calibrations nearly as much as it impacted ST2-L, but there are still the occasional bug discoveries. Bugs found in the PVS during the ST2-L calibration include:

- The theoretical corner reflector RCS values weren't being calculated correctly. This was traced to a calculation involving satellite track direction and corner reflector headings: with left-looking data the calculation was offset 180 degrees from the right-looking value. We put a left-looking check in.
- The chirp rate is negative (which is correct and which should be changed in ASF's other data products – mentioned below), but the PVS expected positive values and would crash when it reached the negative value.
- The PVS assumed that the entire noise vector should be interpolated over the swath, whereas the precision processor assumed that each noise element corresponded to 32 pixels. This meant that we ended up with funky noise values in far range at first.
- At first we were not able to pick out the corner reflectors in a full-res image because the brightness scale was set for 8-bit rather than 16-bit data. (Many other items besides the corner reflectors looked bright.) This scaling was changed and our target selection improved dramatically.
- The ability to check the number of looks (statistically) was added after it was realized that the data was approximately 1-look rather than 4.
- The ability to generate a histogram from the data, rather than trusting the metadata histogram, was added.
- The data unexpectedly had leading zeros. The PVS did not account for this so the first element in grid analysis plots would always be wrong. Fix pending, one way or the other.

Thanks to Jay Cable of ASF for fixing these and many other PVS problems in a prompt and friendly manner.

3.4 Update the Calibration Parameter File

The calibration parameter files are used by ASF's SAR processors and contain the antenna pattern description as well as various other image quality and calibration parameters. Currently an archive of these files is located on crom under the ~jason/cal_param_files/rsat1/pp directory (for the precision processor). When a new version of a calibration parameter file is created, that version is uploaded to the IMS, and from there used by the processor. (Scripts recording this activity are located in the same directory.)

As a result of data analysis the calibration files are updated and loaded to the IMS/processor, and the data are then reprocessed and analyzed again. This cycle continues until the product is within specifications. In the case of ST2L, there were also many software deliveries which caused parameters to change and therefore required new calparm files to be submitted. The final step in this process is to enter all of your final PSLR, ISLR, etc. values into the file and change the status flag to "CALIBRATED." (I generally use something like the second-best PSLR and ISLR values and the second-worst resolution values – i.e., eliminate the outliers.) The "CALIBRATED" term will then be shown in the products' CEOS metadata.

Let everybody know the good news, especially user services. (See Appendix 2 for an example calibration parameter file.)

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4. Validation Process

Calibration is only one of many factors to be taken into account before a data set is released. Validation, which includes data quality analysis, also plays a major role. Validation involves checking that other metadata parameters, not only those specifically related to the calibration process, are correct. Historically we have been weak in this area as we were not set up to fully test all metadata parameters. The many metadata problems encountered in the ST2-L calibration process have begun to change that, though; now ASF is ramping up its data quality analysis capabilities. (One example is the DQWG.)

Currently the validation process is rather mundane. There is visual QA – just making sure that there aren’t bands in the image, unaccounted window position changes (e.g., rivers appear to be "broken"), azimuth ambiguities, unexpected leading or trailing zero-fill, noting AGC and other saturation effects, etc. Metadata parameters are then automatically checked against expected ranges, and anomalous results are checked by a human. There is also a quick visual check of several parameters to ensure that they "make sense." Scene center shifts are a common problem.

It is more difficult to monitor the more obscure metadata parameters unless you are performing rather sophisticated post-processing to the data. Steps are being taken such that ASF can more accurately test all metadata parameters.

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5. Data Anomalies & Errors Found Along The Way (Resolved)

5.1 Metadata Anomalies

When the JPL-verified version of ST2-L data arrived at ASF, there were many metadata anomalies. This may be due in part to the fact that the metadata had so few explicit specifications associated with it. Some of the errors were easy to identify, including:

- Chirp rate was zero
- Datatake ID was missing
- Image ID was missing
- Range sample rate was in Hz rather than MHz
- Range pulse length was in seconds rather than microseconds
- Mechanical boresite was zero
- SNR was negative (impossible)
- DC bias was –99, then –7.5 rather than +7.5

We notified people that if these values were wrong, there was a strong possibility that other parameters we didn't regularly check (and which are difficult to judge without more extensive calculations) were also incorrect. Other people did find more metadata problems including:

- Seconds of day truncated (platform position record)
- Noise vector elements were in units of amplitude rather than intensity
- Calibration parameters a1 and a2 were not being adjusted properly in low-gain products
- Far slant range was incorrect (the swath was longer than we had originally expected)
- GHA angle was incorrect

5.2 Image Data & Algorithm Anomalies

Several anomalies which impacted image quality were discovered, including:

- Zero-fill pixels at the leading edge of images. Information on the amount of zero-fill is now included in the CEOS prefix preceding each image line. People still need to update software to account for this (and test that it is correct).
- PRF ambiguities offset the geolocation estimates by 4 km (1 PRF off) and slightly worsened the data's radiometric quality. It took a lot of testing and algorithm refinement to finally reduce the occurrence of this problem. It's still a significant issue for ST7 and EH4. This problem was due in part to the fact that RADARSAT doesn't steer to zero-Doppler, and in part due to the fact that orbit data for RADARSAT's southern travels is not as good as the northern orbit ephemeris.
- 1.3 versus 4 looks. We all felt very small. Fixing this and the item below helped the radiometric calibration – particularly the results with the Canadian transponders which previously had been undersampled and inaccurate.
- PSLR and ISLR were outside of specs (associated in part with error above). Sidelobes were weighted to improve these specs at the cost of resolution. Then EH4's resolution was out of spec, and we had to go backwards a little.
- Incorrect handling of window position changes, specifically in the southern hemisphere (descending?) caused some geolocation offsets.
- The transition between the CSA-derived and JPL-derived sections of the antenna pattern was not smooth and resulted in image banding. The JPL-derived pattern was jagged and required further smoothing to eliminate banding.

5.3 Miscellaneous Anomalies

- Frame centers inconsistent between beams. For ascending Delta coverage we order frame 160 for right-looking data, 162 for ST2-L, and up to 164 for EH4-L. The frames are supposed to be centered at a particular latitude, so this is odd. Is the processor centering according to nadir? It's time and resource consuming to reorder images to get the area you really wanted. This hasn't been fixed.
- There was a problem with the RDS which affected the frame locations, different from that mentioned above. The geolocation was still correct but the frame centers were offset slightly. This required (–s) quite a lot of re-scanning.

6. Anomalies We Must Live With

6.1 Spacecraft Roll

Spacecraft roll errors up to .1 degree are not unusual for the RADARSAT platform. The estimates of roll errors contained in RADARSAT’s downlinked data stream are generally bogus and therefore are not used. If the roll estimates were correct, the antenna pattern could be shifted to account for the errors. For standard beam data, a roll error results in either: reduced brightness near range and increased brightness far range (positive roll), or the opposite for negative roll. For EH4 data the result is increased brightness along range for a positive roll and the opposite for a negative roll. The radiometric offsets caused by roll errors are generally within but near the limit of specifications. Relative radiometric accuracy, for example, could near its limit of 1dB with a .1 degree roll error.

6.2 Ascending, Descending Brightness Difference

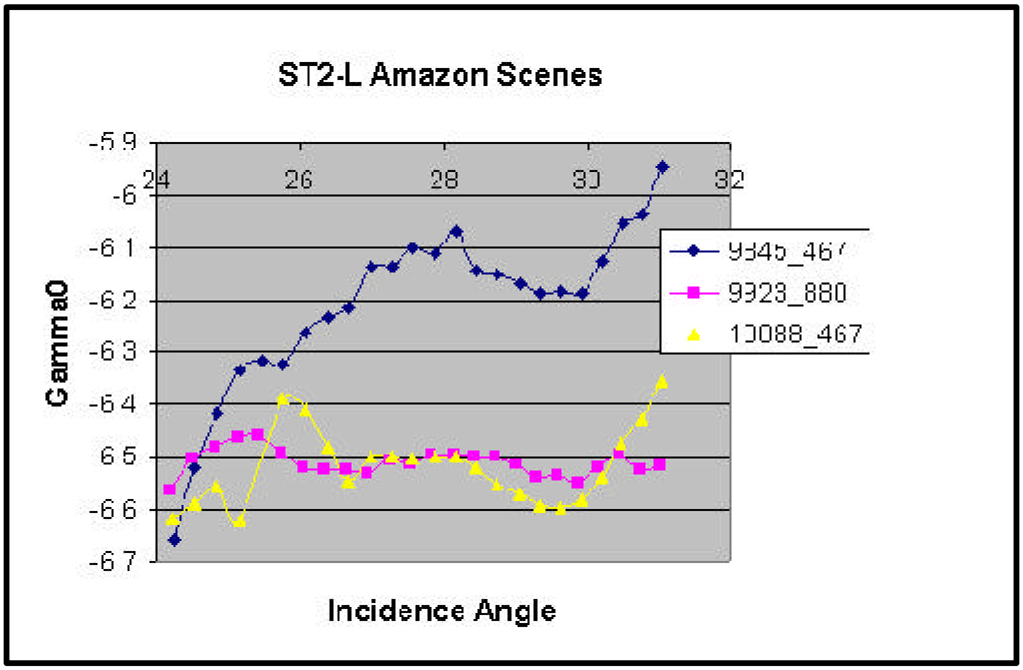
There appears to be a slight brightness difference between ascending and descending data, around a few tenths of a dB. Other random fluctuations between scenes make an automatic radiometric correction for this difference very difficult; it’s not consistent enough. The variations are still within specs, though they will probably show up in the AMM map.

7. ST2-L Calibration Results

The final ST2-L calibration parameters are: a1 = 2.174 * 10^5, a2 = 2.964 * 10 ^ -7. Image quality parameters are as follows:

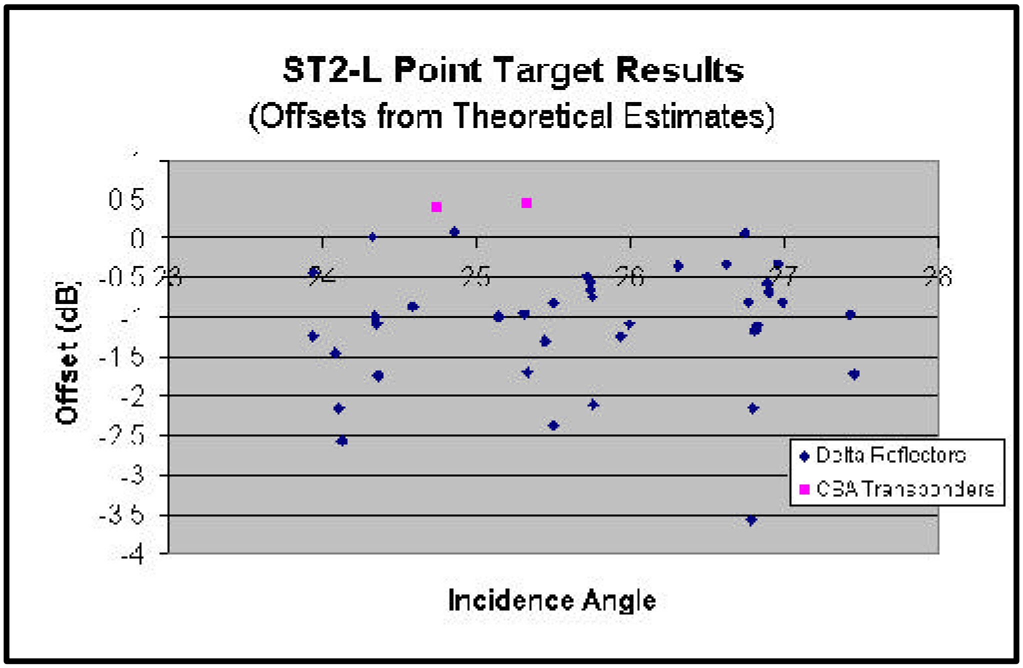
	Measurement	Specifications
Resolution (3 dB), Slant Range:	12 m	12 m
Resolution (3 dB), Azimuth:	34 m	38 m
PSLR Slant Range:	-26 dB	-20 dB
PSLR Azimuth:	-26 dB	-20 dB
ISLR Slant Range:	-20 dB	-13 dB
ISLR Azimuth:	-18 dB	-13 dB
Relative Radiometric Accuracy:	+/- .5 dB	+/- 1 dB
Absolute Radiometric Accuracy: (Roll errors often still within spec)	+/- 1 dB	+/- 2 dB
Number of Looks:	3.9	
Noise Equivalent Sigma0:	-24 dB	
Noise Floor: (7 bits, 1/512th of dynamic range)	100-150 DN	

The following is a plot of gamma0 versus incidence angle for the ST2-L Amazon frames:



Note that two orbits, 9923 and 10088, are within .1 dB of the theoretical –6.5 dB gamma0 throughout the range of incidence angles. Orbit 9845 apparently suffered from a positive roll error, as indicated by the shape of its plot. (Several frames from this orbit were processed, and the sigma0 plot was similar for all frames.) It would be very resource intensive to try to implement an algorithm to correct for such roll errors, given the fact that the roll error estimates downlinked by the spacecraft are bogus. Note that even the frame with the roll error is within specs, however (+/- 1 dB relative, +/- 2 dB absolute radiometric calibration).

The absolute RCS values of the Canadian transponders and ASF corner reflectors were a few tenths of a dB higher than theoretical estimates. (Note that JPL field measurements indicate the corner reflectors should be about 1.9 dB lower than theoretical.) We decided to set the calibration parameters to the Amazon data, however, to be consistent with our right-looking datasets. SAR experts told us that if the Amazon and point target settings agreed to a few tenths of a dB, we should be happy.



Note: We set the gain level such that the noise floor would be quantized to 6 or 7 bits and the reflectors and transponders would require all 16 bits. If anyone ever wants to change the gain setting, they need to specify either the noise quantization or the highest allowable sigma0. We can change the antenna pattern gain to accommodate people, but we do need specifications to go by.

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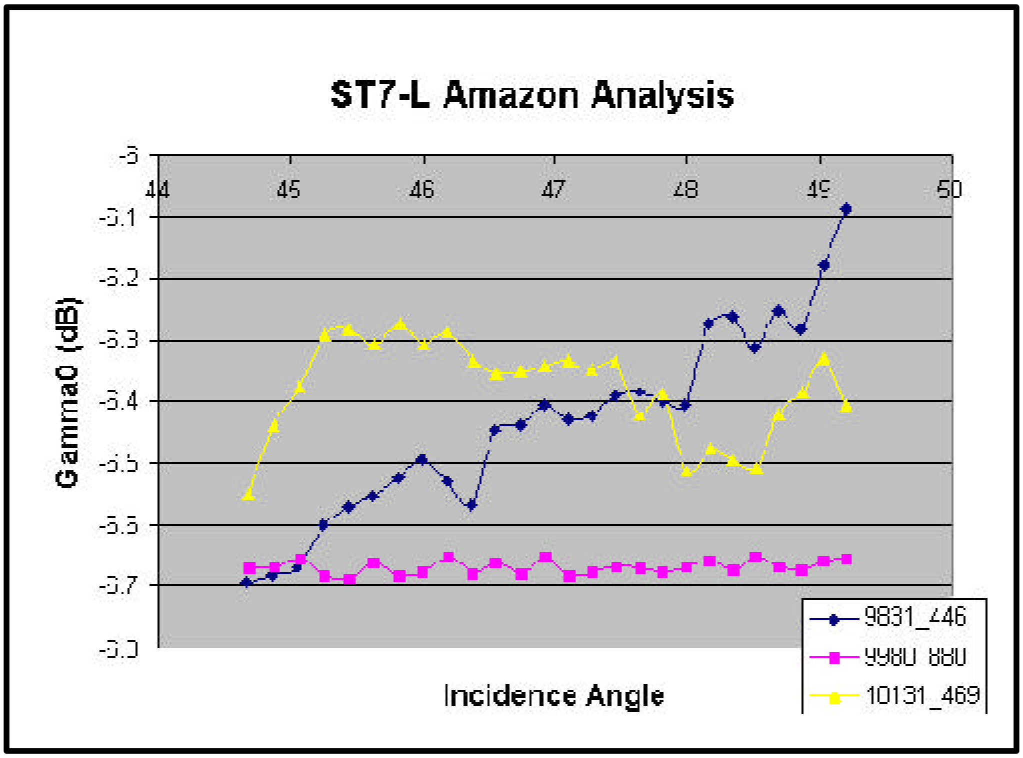
8. ST7-L Calibration Results

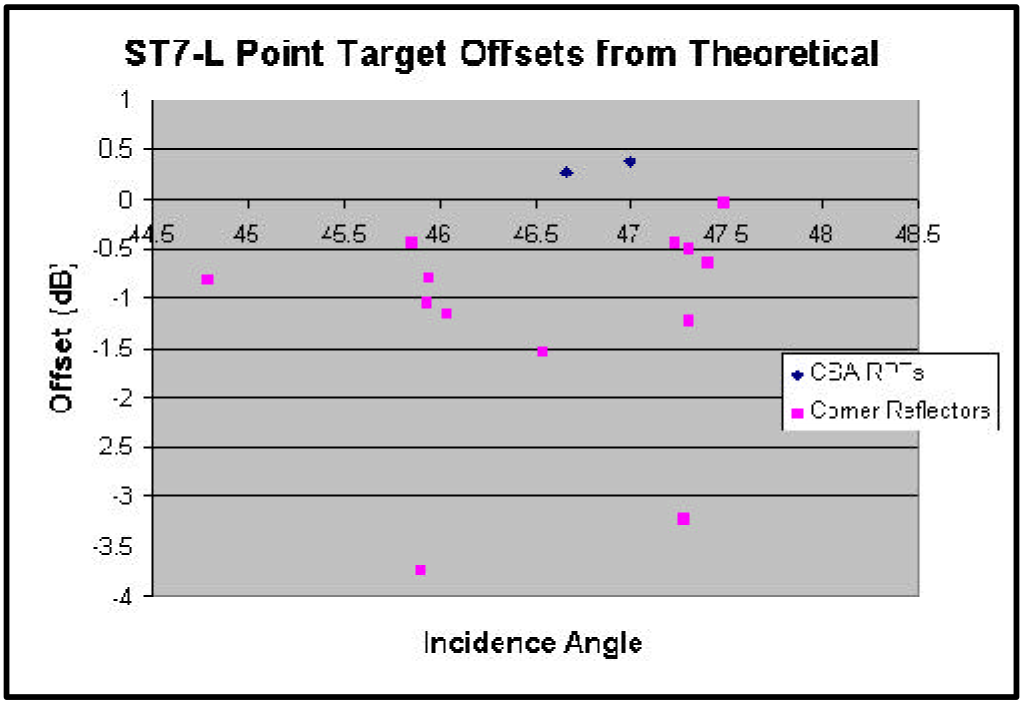
Many of the data quality and other issues raised in sections above apply not only to ST2L but to ST7-L and other left-looking beams as well. Specific ST7-L results follow.



The Amazon results show a brightness difference between ascending and descending datatakes, but the results also show how difficult it would be to automatically correct for such differences. The plot for scene 9831_446 (which covers a more mountainous region) cuts through the other plots and any "correction" to it would cause increased errors at its edges. At any rate, the data are still within the required +/- 1 dB relative and +/- 2 dB absolute radiometric accuracy.

As you can see, we calibrated to scene 9980_880. It's a great scene – very homogeneous. Slight antenna pattern anomalies showed up as bands in this image, whereas other images with greater natural variation weren't affected. Bands were usually caused by spikes in the antenna pattern – spots where the values suddenly went up and down. Smoothing the antenna pattern helped greatly. There were also sudden drop-offs where the JPL-derived antenna pattern merged with CSA's antenna pattern, and these had to be smoothed as well. I would definitely recommend checking antenna patterns in detail and smoothing the patterns when necessary, as part of the calibration process.

The point targets' analysis agreed with the Amazon results to about .3 dB. (The results suggested that the absolute calibration should be set .3 dB lower.) SAR experts I spoke with considered this to be an excellent agreement, so we left it alone. We also wanted to be consistent with the right-looking imagery, which was calibrated using Amazon results. The final ST7-L calibration parameters were: a1 = 2.6 E+05, a2 = 1.28 E-07.



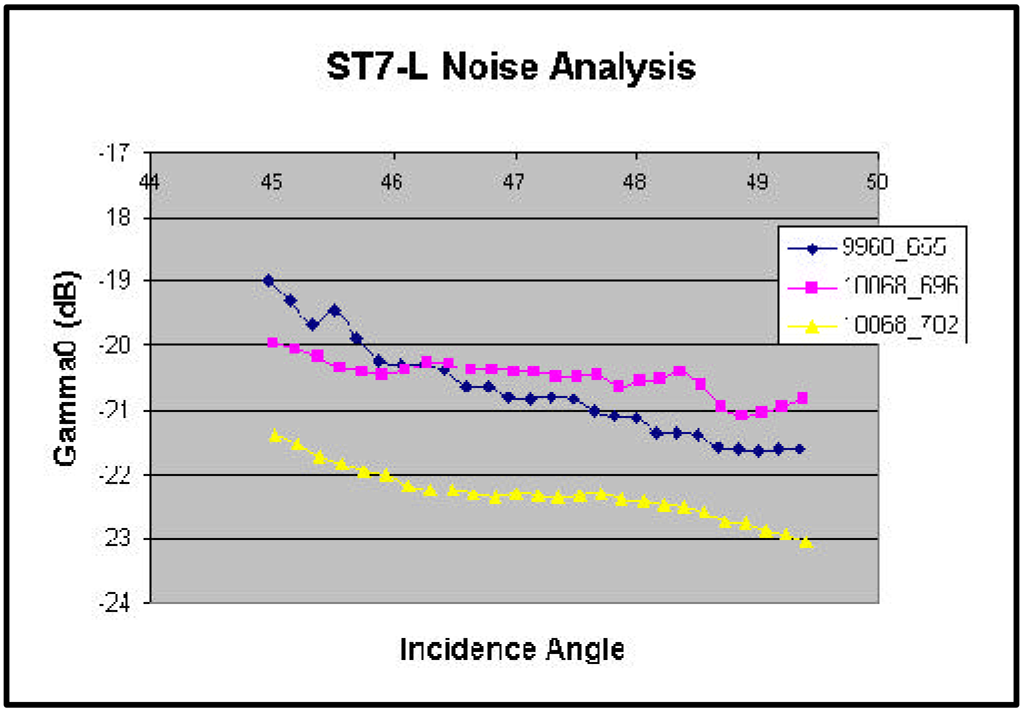
Note that the worst corner reflector measurements were from DJR-16. DJR-16's RCS values have consistently been lower than those of the other corner reflectors, for all left-looking beams. We don't know if this was caused by incorrect positioning (was a vehicle nearby, affecting the compass?) or whether the reflector is damaged in some way.

The following ST7-L image quality parameters were derived from point target analysis:

	Measurement	Specifications
Resolution (3 dB), Slant Range:	18 m	18 m
Resolution (3 dB), Azimuth:	38 m	38 m
PSLR Slant Range:	-30 dB	-20 dB
PSLR Azimuth:	-26 dB	-20 dB
ISLR Slant Range:	-17 dB	-13 dB
ISLR Azimuth:	-19 dB	-13 dB
Relative Radiometric Accuracy:	+/- .6 dB	+/- 1 dB
Absolute Radiometric Accuracy: (Roll errors often still within spec)	+/- 1 dB	+/- 2 dB
Number of Looks:	4	
Noise Equivalent Sigma0:	-24 dB	
Noise Floor:	100-150 DN	

Note that the resolution results are at the limit of specifications. Also, PRF ambiguities remain a problem for ST7-L while ST2-L is nearly free of the ambiguities now. We found a couple ST7-L scenes with PRF ambiguities just within our calibration set. This doesn't bode well for the mapping, as a PRF ambiguity results in a 4 km geolocation offset. Algorithms for reducing ST7-L's PRF ambiguities are currently being tested.

We analyzed several low-backscatter images to ensure that the noise floor was set correctly. (Actually, we were most concerned about setting the noise floor too high, which could cause problems when the RAMS group converted the data to sigma0.) We used several excellent images from the Byrd region of Antarctica; the cold, dry snow there produced a minimal backscatter response, around -24 dB. Some of the results are plotted below.



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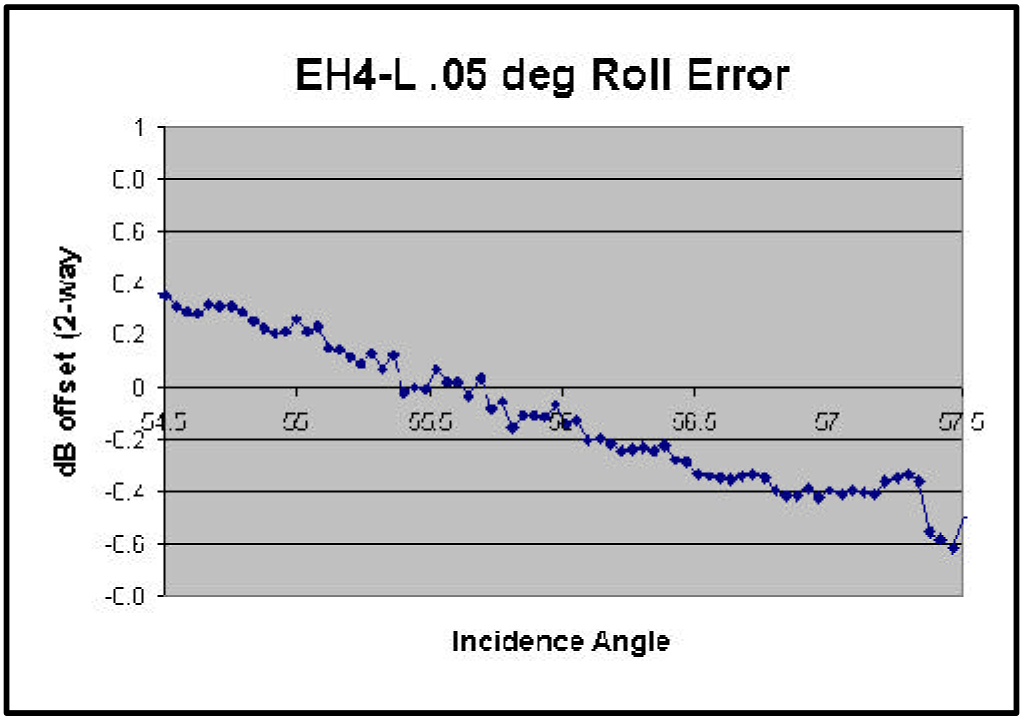
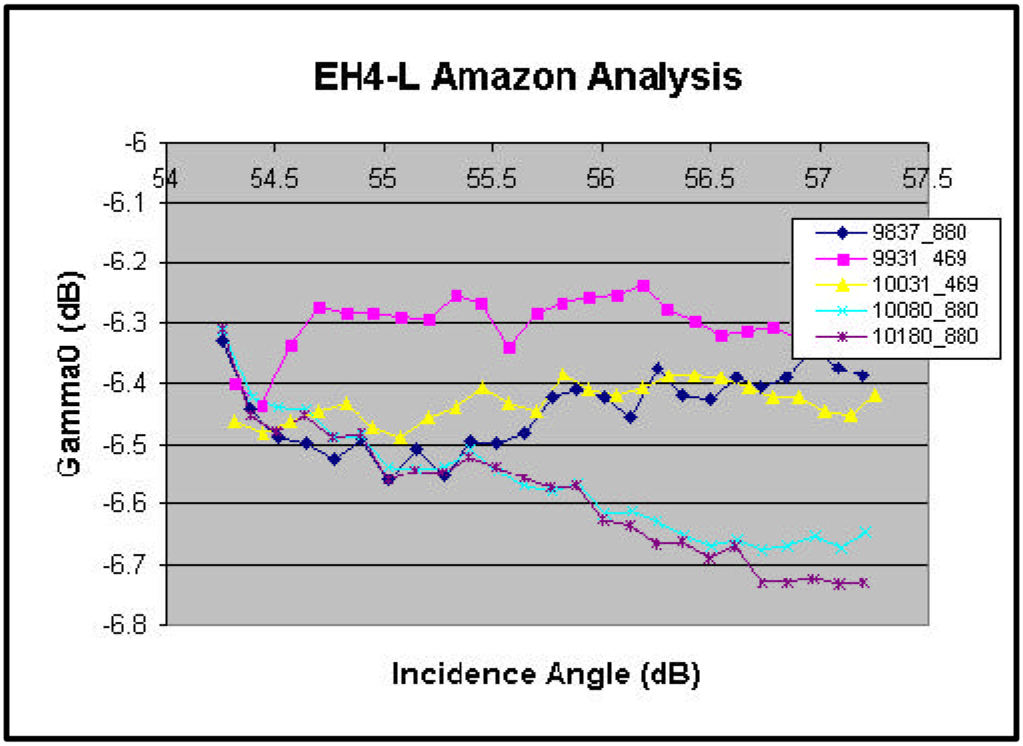
9. EH4-L Calibration Results

EH4 is an interesting beam, the most unique beam of the set. The beam is more focused, its power more sharply peaked at beam center. The other beams have a nearly flat region at the center of the beam. (See Appendix I for plots of the antenna patterns.) The flat beam center was designed in order to obtain fairly constant power over the imaged swath. However, other requirements specific to EH4, such as maintaining a reasonable amount of backscattered power at high incidence angles and greater distance, made it impractical to generate a flat beam center for EH4.

EH4’s focused beam makes the data more vulnerable to spacecraft roll errors. You can simulate the effects of a roll error by shifting a copy of the antenna pattern over a fixed antenna pattern and then measuring the difference between the two patterns. If you have a perfectly flat antenna pattern, shifting the copy from side to side will generate no differences. On the other hand if you shift a copy of steep line, it will quickly separate from the first line, creating wide gaps in-between. With the ST2-L and ST7-L patterns, the result of shifting is most apparent at the patterns’ edges where the slopes are steep. An example of this effect can be seen in the plot of ST2-L scene 9845_467. The "flat" area of the antenna pattern is affected somewhat because it’s not truly flat, but you can see that the edges (where the antenna pattern drops off steeply) are more affected. Since the EH4-L antenna pattern doesn’t really have a flat section, even slight shifts will result in significant power offsets throughout the scene. For example, the plot below shows that a .05 degree roll error causes nearly 1dB error across the imaged swath.



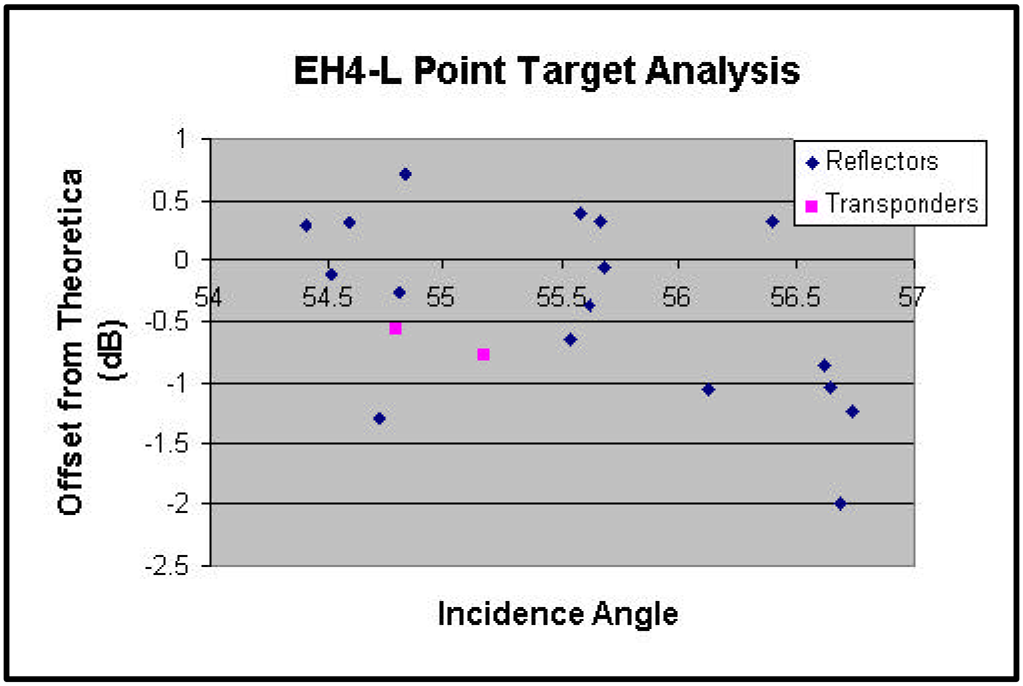
(The plot above simulates an inward roll. If the spacecraft were to roll "up", the result would be a near-mirror image of the above plot. You can visualize that an inward roll would result in moving the high-power section of the beam closer to the spacecraft.) Since RADARSAT experiences spacecraft roll errors up to .1 degree on a fairly regular basis, the effects of roll errors are a major concern for EH4-L calibration. Several of our calibration scenes appeared to have a roll error near .03 degrees – irrelevant for most beams but enough to affect EH4 by a few tenths of a dB. In the calibration process, we attempted to split the difference between the various roll errors to obtain the best fit. However, you can still see the effects of roll errors in the final results.



Note that the data are still within specs. For a large mapping project like AMM, however, the roll error effects will likely show up in the merged product. I don't think you could do much to improve these roll errors, save putting a better attitude determination system on RADARSAT!

In looking at the point target results below, you will notice that the corner reflector offsets are higher than usual while the CSA transponder offsets are quite a bit lower than usual – about 1 dB. Further analysis indicated that both transponder scenes suffered from a PRF ambiguity, and one of the three Delta scenes (10150_285) did as well. All of these scenes appeared to be at –1 PRF. This makes the point target analysis suspect. If three out of five point target scenes had PRF ambiguities, it also seems quite possible that at least one of our Amazon scenes also had a PRF ambiguity. For this reason I believe we should hold off on calling EH4-L calibrated, waiting instead to first see the results of our calibration data at the correct PRF.

JPL just delivered the EH4 azimuth resolution fix a few days ago, so we haven't been able to obtain +1 PRF EH4 data before my termination date. Therefore the final EH4 calibration will need to be done by someone else. It shouldn't be too difficult once the PRF problems are resolved.



I want to make a couple more notes about the point target results. I'm not sure that the transponder results are low only because of a PRF offset. Jason once tested ST2-L data at the correct PRF, +1 PRF, and –1 PRF and found very little RCS difference between the results (.1 dB, if I remember correctly). Maybe there are other reasons. Before the 4-look correction, the transponders' results varied widely. Usually the results were lower than those of the Amazon calibration. We believed this was because the data were undersampled before the 4-look correction. (JPL's recent calculations concluded that the EH4 data is indeed 4-look.) Tom Bicknell also mentioned that if the transponders saturated the SAR, something he considered a definite possibility, then there would be power loss at the receiver and the results would indeed indicate a lower calibration.

Here are the EH4-L image quality parameters, derived from the point target analysis:

	Measurement	Specifications
Resolution (3 dB), Slant Range:	18 m	18 m
Resolution (3 dB), Azimuth:	38 m	38 m
PSLR Slant Range:	-30 dB	-20 dB
PSLR Azimuth:	-27 dB	-20 dB
ISLR Slant Range:	-17 dB	-13 dB
ISLR Azimuth:	-19 dB	-13 dB
Relative Radiometric Accuracy:	+/- .5 dB	+/- 1 dB
Absolute Radiometric Accuracy: (Roll errors often still within spec)	+/- 1 dB	+/- 2 dB
Number of Looks:	4	
Noise Equivalent Sigma0:	-24 dB	
Noise Floor:	~150 DN	

The point targets' geolocation errors were all within 100 m. Note that the Antarctic geolocation errors are generally worse than Delta's, since JPL fits to the corner reflectors' location errors. Therefore we only state that the geolocation errors are within the spec of 500m rms, rather than listing the Delta values. The location estimates of Antarctic targets we've looked at (e.g., the McMurdo antenna) do appear to be within spec.

We again checked the noise floor setting by analyzing some low-backscatter Amazon scenes. The sigma0 plot looked fine.

One final comment about the EH4-L data – you will occasionally notice range ambiguities in coastal EH4-L imagery. Range ambiguities are sensor-related and cannot be accounted for in the processor. Range ambiguities are caused when backscatter from a bright region outside the main swath reaches the spacecraft at the same time the SAR is receiving the primary backscatter from a different pulse. Range ambiguities are often lost in the noise of the primary backscatter. If part of the main swath has a low radar response, however, you will see the range ambiguities there. For example, the Kenai image below shows traces of mountains in the otherwise dark inlet, though the mountains are actually located east of the swath. These range ambiguities rarely have much impact on quantitative radiometric analysis.

Figure 9 (or so). EH4-L Image of the Kenai, Alaska region. Notice range ambiguities in the inlet and the effects of extreme AGC settings on the image as a whole.

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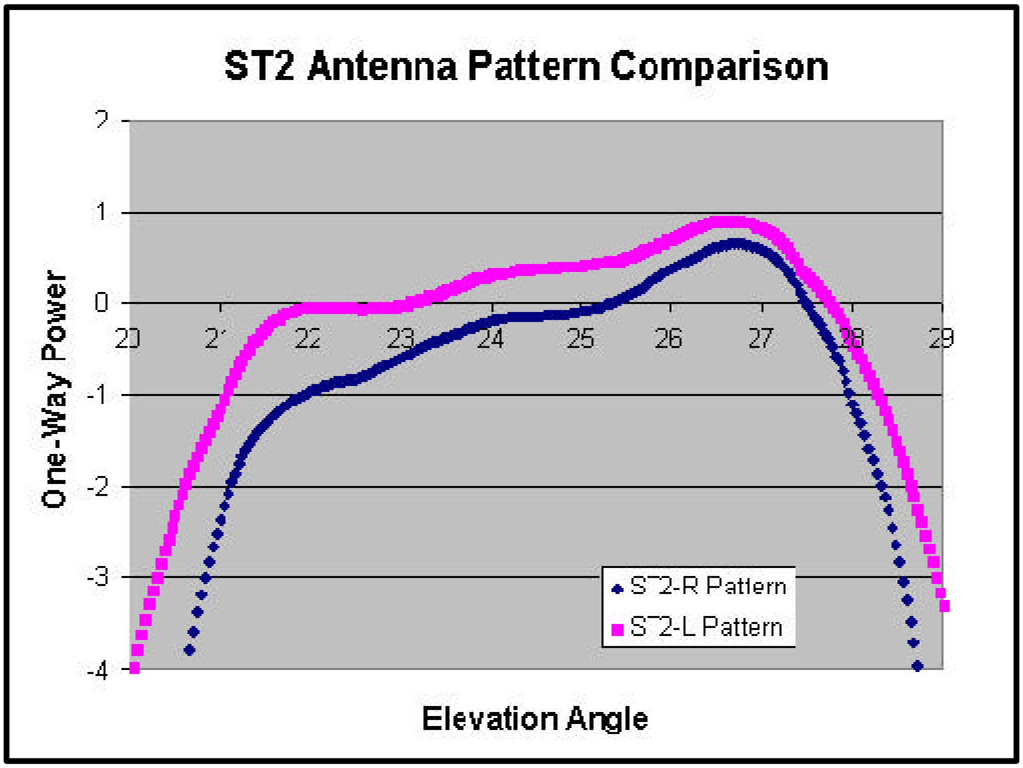
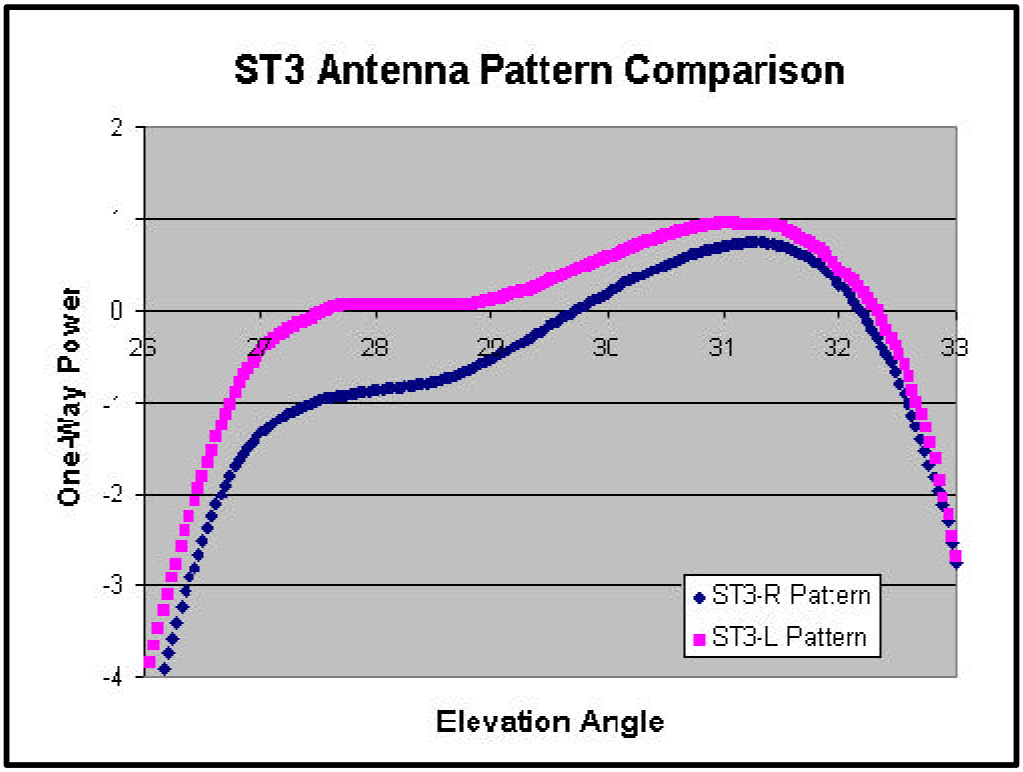
10. ST3-L Calibration Results

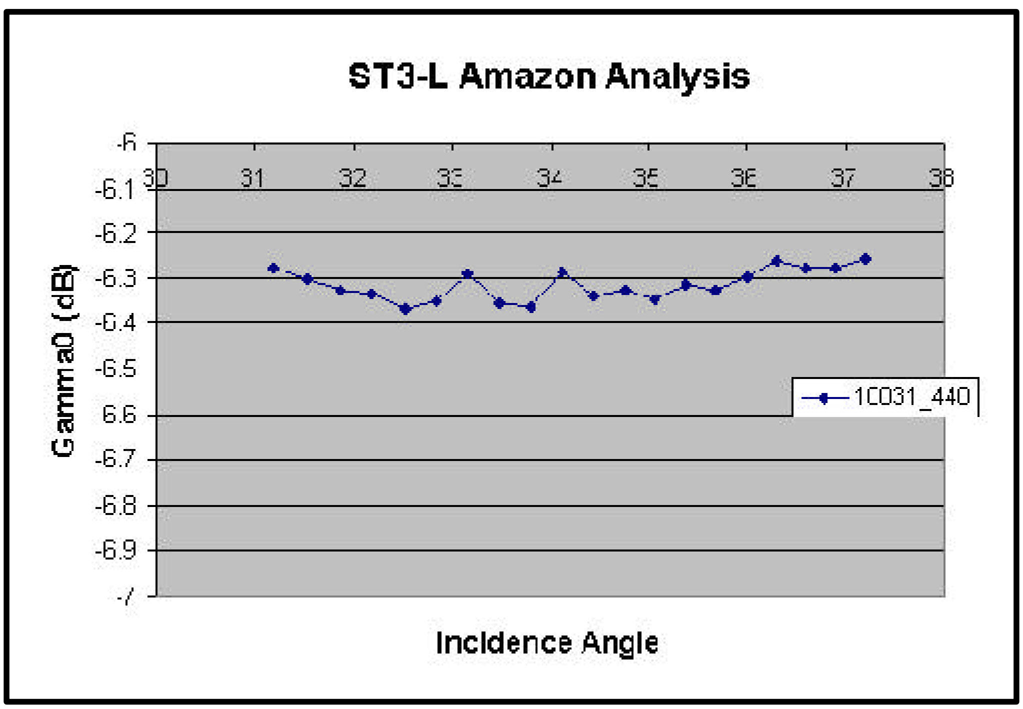
In case you're curious about the order of these chapters, ST3-6L were calibrated in parallel after analysis (and associated debugging) of ST2, ST7, and EH4 was complete. Calibration of these beams was easier once a process was in place. Though these beams were not as important as the first three and therefore generally did not have as many calibration scenes to work from, I believe the results turned out fairly well.

In the sections above I mentioned things like "smoothing the JPL-derived antenna pattern" or "where the JPL and CSA antenna patterns merge." Usually JPL provides ASF with an antenna pattern when JPL verifies, or synonymously delivers, a beam. JPL usually obtains an original antenna pattern from the appropriate flight agency and then makes its own improvements on it, using results from Amazon data analysis. Then the ASF calibration department does some final tweaking before the data are released to users. Such was the general process for ST2-L, ST7-L and EH4-L. We derived the antenna patterns for ST3-6L, however, in part because JPL was so busy with other things. We started out with the right-looking beams and modified them as described in the "Distributed Target Analysis" section. Same process, just tweaking on a larger scale. I thought you might be interested in seeing the differences between the right-looking and left-looking beams, so below you'll see a plots of the ST2 (JPL-derived) right- and left-looking antenna patterns as well as the ST3 antenna patterns. (The left-looking plots were shifted down to provide a better comparison.)





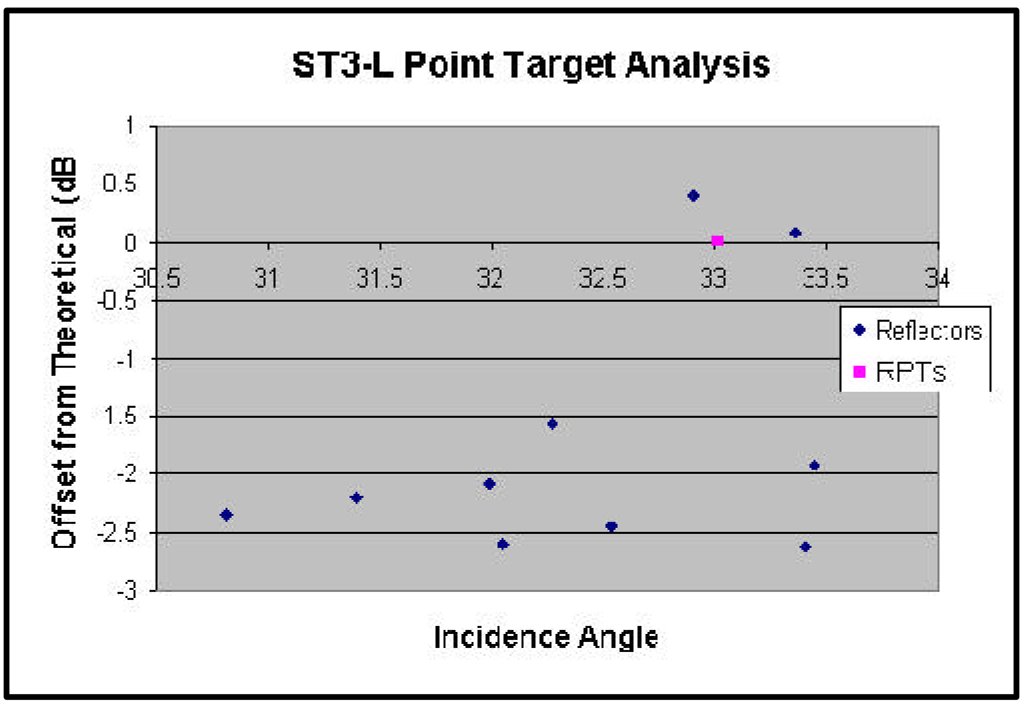
Now for the specific ST3-L calibration results. The calibration parameters turned out to be: a1 = 2.0 E+05, a2 = 1.8 E-07. The Amazon plot follows:



Though the Amazon plot looks good, I called ST3-L the "unlucky beam" because of the poor quality of its calibration acquisitions. There was only one Amazon orbit, and each frame in that orbit had undesirable features – clear-cutting, hills, large flood areas, etc. Each image was unique in its own bad way. It was especially difficult to calibrate the far range. I finally chose just a few select areas from scene 440, a scene which overall was pretty horrible but which had a streak of homogeneous forest across its middle. The other frames agreed very well with this calibration for the first 5/6 or so of the image but disagreed at the edge (only by a couple tenths of a dB though). The terrain was such that the far-range differences looked correct, and I didn't see any far-range banding or anomalies in any other calibration images so I think the pattern is fine.

Since we only have one Amazon orbit, we don't have the statistics to know whether this orbit might be affected by spacecraft roll. That is to say, conceivably we could have calibrated to a spacecraft roll. The rest of our calibration frames, including homogenous ice scenes, look just fine though – no visible brightness differences at the edges that I've come to expect from roll errors. So again, I think the pattern is fine.

You may notice that I set the Amazon calibration to –6.3 rather than –6.5 dB. I did this in part because the point target analysis suggested that the absolute calibration should be higher, and in part because the offset is in line with the ascending/descending offsets seen for other beams (+.2 dB for descending, -.2dB for ascending). The point target results are still lower than those for other beams, even after the offset. I don't have a ready explanation for this, except to say that the differences are small and the data still appear to be within spec – and also that one should consider the Number of Looks estimate for this beam as compared to the others.



Here are the image quality parameters for ST3-L:

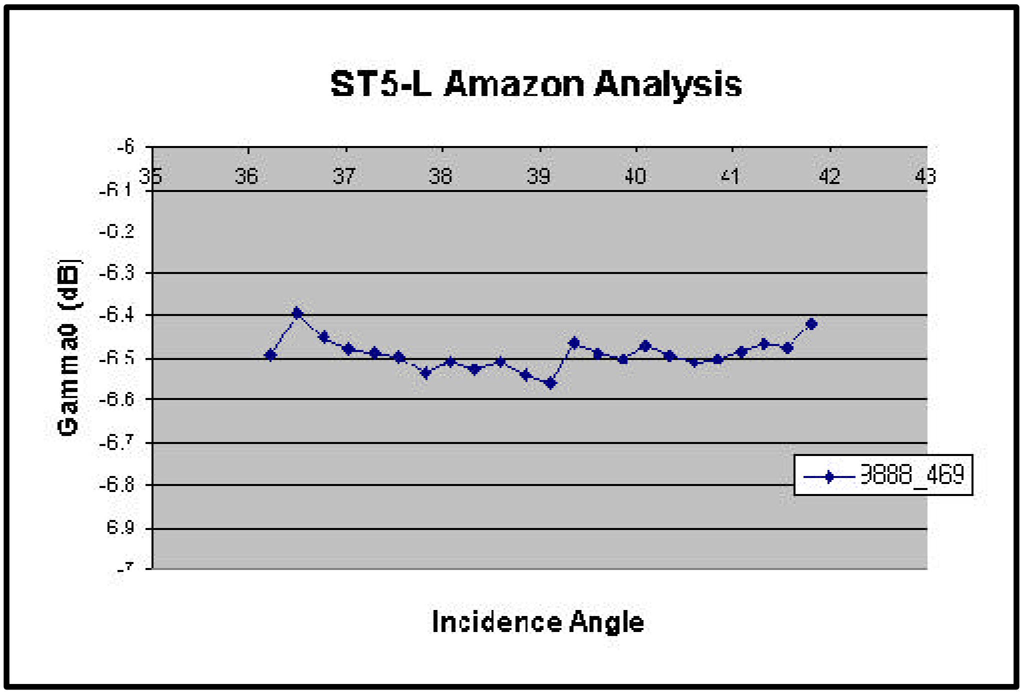
	Measurement	Specifications
Resolution (3 dB), Slant Range:	18 m	18 m
Resolution (3 dB), Azimuth:	35 m	38 m
PSLR Slant Range:	-27 dB	-20 dB
PSLR Azimuth:	-26 dB	-20 dB
ISLR Slant Range:	-16 dB	-13 dB
ISLR Azimuth:	-17 dB	-13 dB
Relative Radiometric Accuracy:	+/- .5 dB	+/- 1 dB
Absolute Radiometric Accuracy: (Roll errors often still within spec)	+/- 1 dB	+/- 2 dB
Number of Looks:	4.7	
Noise Equivalent Sigma0:	-24 dB	
Noise Floor:	100-150 DN	

11. ST4-L Calibration Results

12. ST5-L Calibration Results

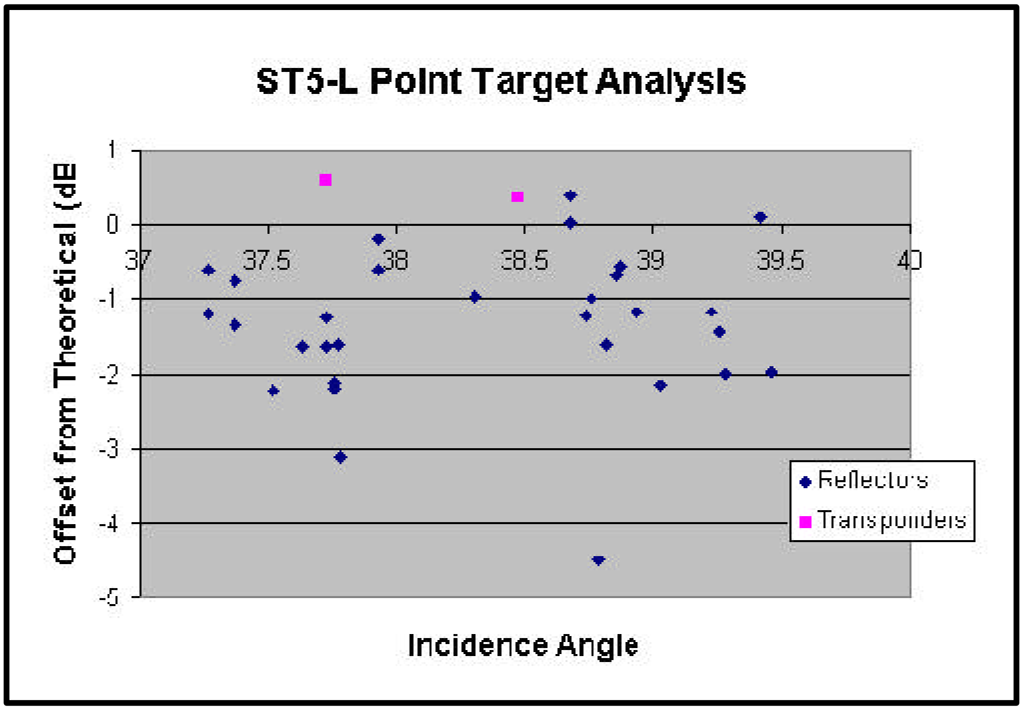
Unfortunately we only had one ST5-L orbit to use for calibration. Fortunately that orbit did contain some nice Amazon scenes. I calibrated to the best scene, 9888_469, in part because it revealed antenna pattern anomalies which the others didn't. I reprocessed several other frames to make sure that their sigma0 plots were not adversely affected by the calibration to 9888_469. All scenes were within .2 dB of the frame

469 results, and all plots looked flat. Unfortunately we don't have a good way to tell if the Amazon orbit suffered from a spacecraft roll error, meaning that there's a possibility we calibrated to a spacecraft roll. I looked at several homogeneous scenes of ice which didn't show the effects of a roll error, however, so I believe that the antenna pattern is fine.



Here are the ST5-L image quality parameters, derived from the point target analysis:

	Measurement	Specifications
Resolution (3 dB), Slant Range:	18 m	18 m
Resolution (3 dB), Azimuth:	35 m	38 m
PSLR Slant Range:	-28 dB	-20 dB
PSLR Azimuth:	-27 dB	-20 dB
ISLR Slant Range:	-16 dB	-13 dB
ISLR Azimuth:	-17 dB	-13 dB
Relative Radiometric Accuracy:	+/- .5 dB	+/- 1 dB
Absolute Radiometric Accuracy: (Roll errors often still within spec)	+/- 1 dB	+/- 2 dB
Number of Looks:	4	
Noise Equivalent Sigma0:	-24 dB	
Noise Floor:	100-150 DN	



The point target analysis looked quite good – consistent with the other beams. Again the CSA transponder results suggested that the calibration should be set a few tenths of a dB lower. DJR-16 is again responsible for the lowest offsets.

The calibration parameters for ST5-L are as follows: a1 = 2.0 E+05, a2 = 1.89 E-07.

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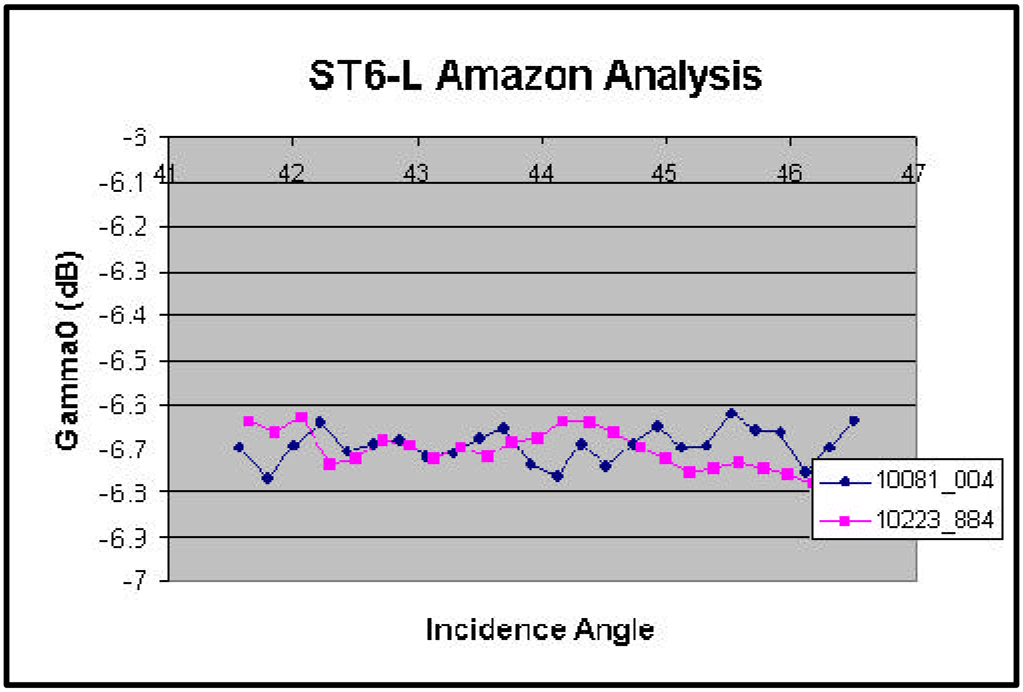
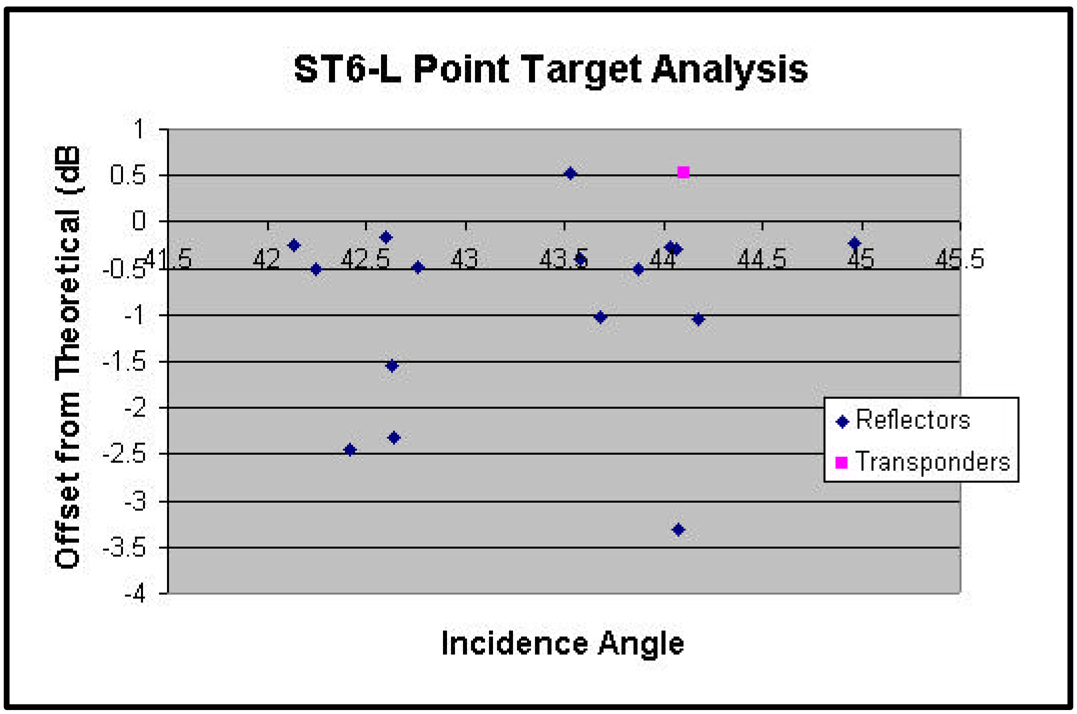
13. ST6-L Calibration Results

We had two ascending Amazon orbits for ST6-L. Both orbits were fairly good, and as you can see the results from the two orbits were very consistent. You may notice that I set the Amazon's absolute calibration at –6.7 dB rather than the usual –6.5 dB. I did this because the transponder and corner reflectors' results were a little higher than they were for the other beams. Also, in Amazon results where there is a clear ascending/descending difference, the ascending data are generally around –6.7 dB while the descending data congregate around –6.3 dB. Since the Amazon scenes appear to be well within spec otherwise, it seemed that adjusting the calibration to fit the other beams wouldn't hurt and may help. Well, that's my long-winded justification anyway.

The calibration parameters for ST6-L are: a1 = 3.0 E+05, a2 = 2.79 E-07.





The following ST6-L image quality parameters were derived from point target analysis:

	Measurement	Specifications
Resolution (3 dB), Slant Range:	18 m	18 m
Resolution (3 dB), Azimuth:	35 m	38 m
PSLR Slant Range:	-31 dB	-20 dB
PSLR Azimuth:	-28 dB	-20 dB
ISLR Slant Range:	-16 dB	-13 dB
ISLR Azimuth:	-17 dB	-13 dB
Relative Radiometric Accuracy:	+/- .5 dB	+/- 1 dB
Absolute Radiometric Accuracy: (Roll errors often still within spec)	+/- 1 dB	+/- 2 dB
Number of Looks:	4	
Noise Equivalent Sigma0:	-24 dB	
Noise Floor:	100-150 DN	

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14. Acknowledgements

I’d like to thank Ruth Duerr for her efforts to get me hired at ASF and for continued moral support, to Jason Williams for the opportunity to work on some challenging projects like this one, to Carl Wales for encouraging young upstarts like me along their career paths, and to ASFers in general for their friendship and encouragement.

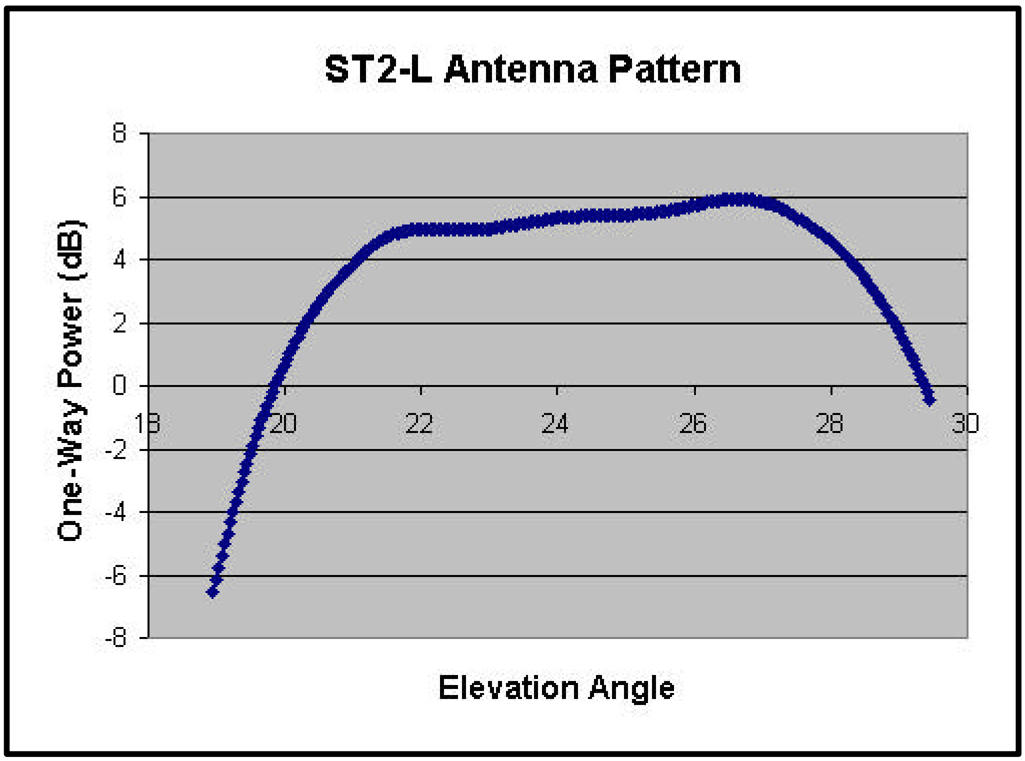
Thanks to Tom Bicknell for patiently and unselfishly (knowledge is power, remember?!) tutoring me on SAR theory and processing techniques over the past few years, and for maintaining a sense of humor and

outward calm during the most stressful times.

Thanks to Barb Hurst-Cushing and the operators in the control room for getting my numerous orders through, and for dealing with us pesky calibration folks in general.

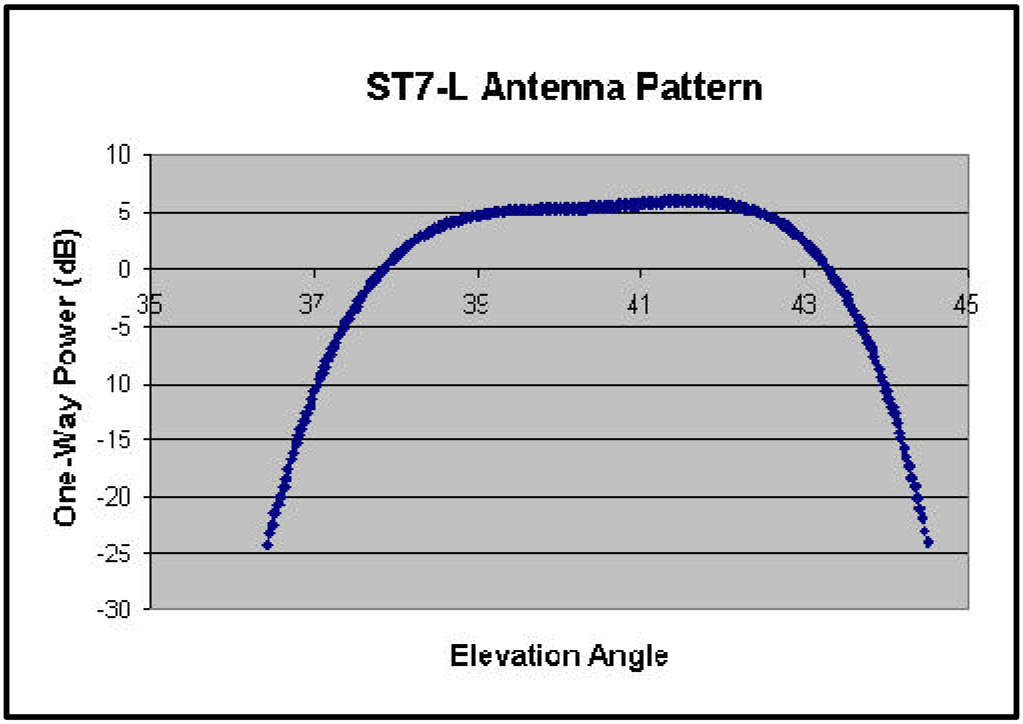
Best wishes in AMM-II!

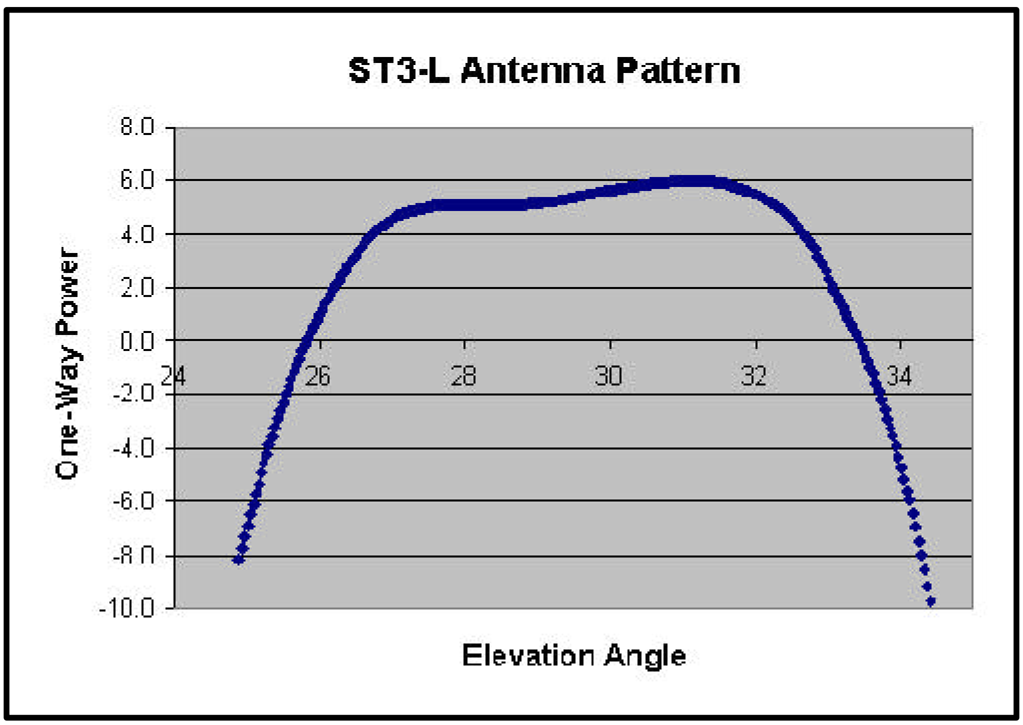
Appendix I. Example Antenna Patterns

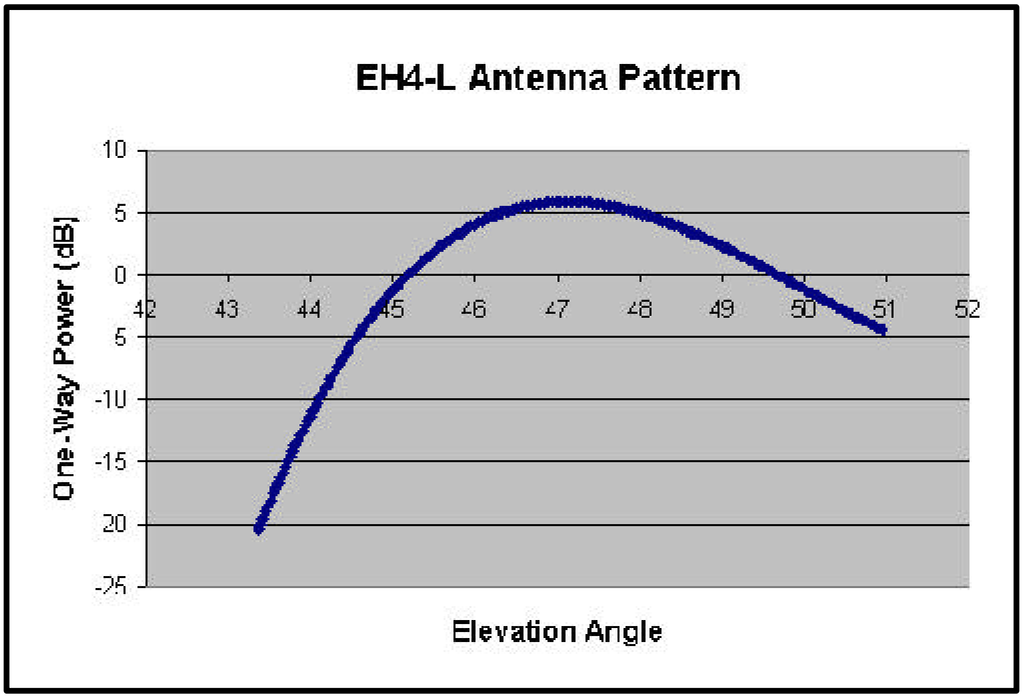


The value of each point is detailed in the calibration parameters file,

as seen in Appendix II (an example ST2-L file).


ST7-L Antenna Pattern
One-Way Power (dB)
10
5
0
-5
-10
-15
-20
-25
-30
35
37
39
41
43
45
Elevation Angle


ST3-L Antenna Pattern
One-Way Power
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
24
26
28
30
32
34
Elevation Angle



Appendix II. Example Calibration Parameters File

```
OBJECT = CAL_PARAM
OBJECT = COMMON_HEADER
TIME = "1998-120T15:00:00.000"
MSG_TYPE = "CAL_PARAM"
DESTINATION = "IMS"
SOURCE = "PVS"
NUMBER_OF_RECORDS = 2
END_OBJECT = COMMON_HEADER
OBJECT = CATALOG_METADATA
FILE_NAME = "PP0ST2015.CALPARMS"
PVS_FILE_TYPE = "CAL_PARAM"
MODE = "ST2"
SENSOR_ID = "RSAT-1-C - -HH"
CENTER_GMT = "362:23:24:28.000"
SYS_ID = "PREC"
VALID_START_TIME = "1997-254T00:00:01.000"
VALID_END_TIME = "1997-298T23:59:59.999"
FILE_CREATION_TIME = "1998-120T15:00:00.000"
END_OBJECT = CATALOG_METADATA
OBJECT = DETAILED_METADATA
OBJECT = PVS_OBJ
REL_RADIO_ACC = 1.00
PVS_ROLL = -99.0000000
CAL_STATUS = "UNCALIBRATED"
CAL_COMMENT = "Radiometric calibration in process, use with care."
END_OBJECT = PVS_OBJ
OBJECT = CALIB_FAC
NOISE_FACT = 4.891E+05
LINEAR_CONV_FACT = 1.635E-07
OFFSET_CONV_FACT = 0.0000000
```

```
IM_ABSCOEF = -99.00
END_OBJECT = CALIB_FAC
OBJECT = NOISE_EST
NT_IMG_NOISE = -24.00
NT_IMG_STDEV = -99.00
NT_CEOS_NOISE = -24.00
NT_DELTA = 0.00
END_OBJECT = NOISE_EST
OBJECT = IM_QUALITY
CD_ISLR_RNG = -14.00
CD_ISLR_AZM = -16.00
CD_PSLR_RNG = -20.00
CD_PSLR_AZM = -20.00
RNG_RES = 20.00
AZI_RES = 32.00
RNG_AMBIG = -30.00
AZI_AMBIG = -20.00
END_OBJECT = IM_QUALITY
OBJECT = GEO_ANALYSIS
ORI_ERR = -99.0000000
DIS_SKEW = 0.500000000
CRT_SCALE = 0.100000000
ALT_SCALE = 0.100000000
CRT_LOCERR = 100.0000000
ALT_LOCERR = 280.0000000
ISO_RATIO = -99.0000000
END_OBJECT = GEO_ANALYSIS
OBJECT = ANTPTN_OBJ
OPR_NAME = "jason"
ANTPTN_SOURCE = "PP0ST20002.ANT"
ANTPTN = "PP0-1998-049"
AZ_PEAK_COEF0 = 0.0000000e+00
AZ_PEAK_COEF1 = 0.0000000e+00
AZ_PEAK_COEF2 = 0.0000000e+00
PATTERN_DATE = "1998-050T09:40:09.000"
MODE = "ST2"
BEAMCTR = 24.2236843
ELEV_INCR = 0.041176
FIRST_ELEV = 18.953157
NO_REC = 256
```


ELEVANG_VEC =

19.0355091,	18.9531571,	18.9943331,	
19.1590366,	19.0766850,	19.1178608,	
19.3237419,	19.2002125,	19.2413883,	19.2825642,
19.4884453,	19.3649178,	19.4060936,	19.4472694,
19.6531487,	19.5296211,	19.5707970,	19.6119728,
19.8178539,	19.6943245,	19.7355003,	19.7766762,
19.9825573,	19.8590298,	19.9002056,	19.9413815,
20.1472607,	20.0237331,	20.0649090,	20.1060848,
20.3119659,	20.1884365,	20.2296124,	20.2707882,
20.4766693,	20.3531418,	20.3943176,	20.4354935,
20.6413727,	20.5178452,	20.5590210,	20.6001968,
20.8060760,	20.6825485,	20.7237244,	20.7649002,
20.9707813,	20.8472538,	20.8884296,	20.9296055,
21.1354847,	21.0119572,	21.0531330,	21.0943089,
21.3001900,	21.1766605,	21.2178364,	21.2590122,
21.4648933,	21.3413658,	21.3825417,	21.4237175,
21.6295967,	21.5060692,	21.5472450,	21.5884209,

21.7943001,	21.6707726,	21.7119484,	21.7531242,
21.9590054,	21.8354778,	21.8766537,	21.9178295,
22.1237087,	22.0001812,	22.0413570,	22.0825329,
22.2884140,	22.1648846,	22.2060604,	22.2472363,
22.4531174,	22.3295898,	22.3707657,	22.4119415,
22.6178207,	22.4942932,	22.5354691,	22.5766449,
22.7825241,	22.6589966,	22.7001724,	22.7413483,
22.9472294,	22.8237000,	22.8648777,	22.9060535,
23.1119328,	22.9884052,	23.0295811,	23.0707569,
23.2766380,	23.1531086,	23.1942844,	23.2354603,
23.4413414,	23.3178139,	23.3589897,	23.4001656,
23.6060448,	23.4825172,	23.5236931,	23.5648689,
23.7707481,	23.6472206,	23.6883965,	23.7295723,
23.9354534,	23.8119240,	23.8530998,	23.8942776,
24.1001568,	23.9766293,	24.0178051,	24.0589809,
24.2648621,	24.1413326,	24.1825085,	24.2236843,
24.4295654,	24.3060379,	24.3472137,	24.3883896,
24.5942688,	24.4707413,	24.5119171,	24.5530930,
24.7589722,	24.6354446,	24.6766205,	24.7177963,
24.9236774,	24.8001480,	24.8413239,	24.8825016,
25.0883808,	24.9648533,	25.0060291,	25.0472050,
25.2530861,	25.1295567,	25.1707325,	25.2119083,
25.4177895,	25.2942619,	25.3354378,	25.3766136,
25.5824928,	25.4589653,	25.5001411,	25.5413170,
25.7471962,	25.6236687,	25.6648445,	25.7060204,
25.9119015,	25.7883720,	25.8295479,	25.8707237,
26.0766048,	25.9530773,	25.9942532,	26.0354290,
26.2413082,	26.1177807,	26.1589565,	26.2001324,
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26.5707169,	26.4471893,	26.4883652,	26.5295410,
26.7354202,	26.6118927,	26.6530685,	26.6942444,
26.9001255,	26.7765961,	26.8177719,	26.8589478,
27.0648289,	26.9413013,	26.9824772,	27.0236530,
27.2295341,	27.1060047,	27.1471806,	27.1883564,
27.3942375,	27.2707100,	27.3118858,	27.3530617,
27.5589409,	27.4354134,	27.4765892,	27.5177650,
27.7236443,	27.6001167,	27.6412926,	27.6824684,
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29.2059822,	29.0824528,	29.1236286,	29.1648045,
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GAIN_VEC =
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(-6.5372500,	-6.1604400,	-5.7838297,	-4.3373299,
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-2.7401714,	-2.4471111,	-2.1624441,	-0.8592448,
-1.6176252,	-1.3571458,	-1.1044049,	0.0487189,
-0.6215062,	-0.3910351,	-0.1676769,	0.8476481,
0.2583022,	0.4612212,	0.6576209,	1.5468402,
1.0314441,	1.2091479,	1.3809018,	2.1551330,
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2.8004069,	2.9153631,	3.0258980,	3.5162950,
3.2341731,	3.3321409,	3.4261451,	3.8559589,
3.6027000,	3.6854651,	3.7646971,	4.2291970,
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4.3115211,	4.3684870,	4.4348900,	4.7077260,
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4.9378530,	4.9465820,	4.9560781,	4.9552391,
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4.9572120,	4.9615099,	4.9631259,	4.9514680,
4.9676840,	4.9446940,	4.9623910,	4.9479450,
4.9506030,	4.9317520,	4.9518870,	4.9654419,
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2.4634140,	2.3160701,	2.1645739,	1.3427620,
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1.1651258,	0.9829302,	0.7961149,	-0.2092536,
0.4083972,	0.2073806,	0.0015160,	-0.4249852)

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OBJECT = AZM_BEAM_OBJ
AZM_INCR = 0.0013890
NO_REC = 701
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0.0093750,	0.0090625,	0.0087500,	0.0084375,
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```
0.0000000 END_OBJECT = AZM_BEAM_OBJ

END_OBJECT = DETAILED_METADATA

END_OBJECT = CAL_PARAM

END
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