Alaska SAR Facility

RADARSAT Modified Antarctic Mapping Mission

Calibration Plan

Version 2

August 28, 2001
ASF00CAL120-0.6
RWA

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MAMM Calibration Plan

1 Introduction

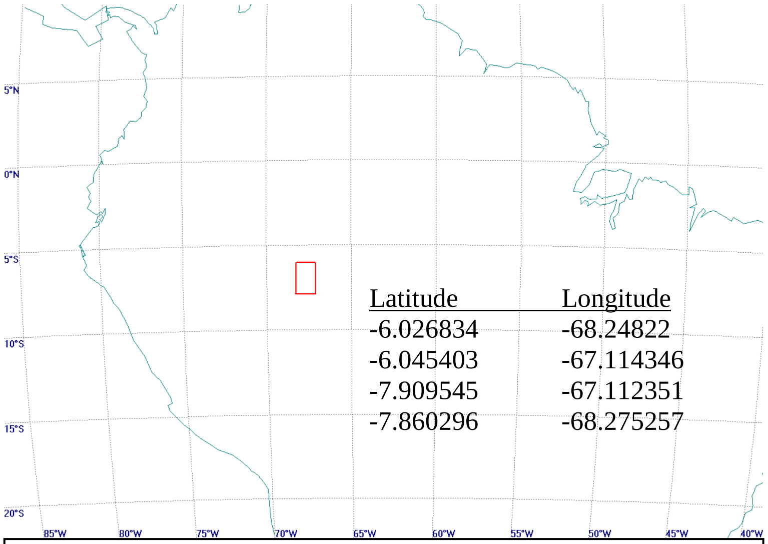
This plan provides an outline of the calibration of the RADARSAT Modified Antarctic Mapping Mission (MAMM) data set. It is intended to be a guide and reference for future MAMM calibration activities.

2 Preparatory Phase

2.1 Calibration data collection

2.1.1 Distributed Target

All Amazon data available for the calibration sites were used. All Amazon calibration data from three calibration sites designated by CSA bounded by the coordinates as shown in Figure 1 was ordered and used where possible. The data was ordered at a rate of 2 beams per cycle, as shown in Table 1.



Latitude	Longitude
-6.026834	-68.24822
-6.045403	-67.114346
-7.909545	-67.112351
-7.860296	-68.275257

Figure 1. Amazon calibration data area

Table 1. Amazon data availability by beam mode.

Beam	*# datatakes to L0*	*# datatakes at ASF*	*# datatakes to be ordered*	*Arrival date of data on order*
ST1	6	11	27	August 27, 2000
ST2	4	11	22	August 27, 2000
ST3	0	8	15	August 3, 2000
ST4	0	11	17	August 3, 2000
ST5	0	15	7	August 3, 2000
ST6	4	7	23	July 10, 2000
ST7	0	13	26	July 10, 2000
EL1	10	10	32	September 20, 2000
F1N	4	4	2	September 20, 2000
F1M	11	11	4	September 20, 2000
F1F	5	5	2	September 20, 2000

2.1.2 Point Target Array

ASF collected repeat cycle data pairs over Delta Junction for ST1, ST2, ST6, ST5 and Extended Low prior to the acquisition. Three repeat cycle acquisitions were acquired for Fine 1. Additional Fine 1 acquisitions were acquired during each of the three cycles in the first acquisition of the mission. In addition, enough data were acquired to yield three ascending and three descending passes for Extended Low and Fine 1. The data is being used to generate and evaluate interferograms independent of the Southern Hemisphere, and to verify geolocation accuracy for the new beams and the new processor.

2.1.3 Noise Data

Noise floor determination requires data with low-backscatter targets, typically calm lakes or ocean. Three sites have been typically used; the Yukon-Kuskokwim Delta, the lake region north of Glennallen, and the Cook Inlet – Prince William Sound region, all in Alaska. Data that had been previously acquired was used where possible. If data was not available, then acquisitions were requested. A minimum of 10 frames per beam mode were planned for, acquired, and used to determine the noise floor.

2.1.4 **Calibration Data Set**

Table 2. Summary of MAMM calibration data.

	ST1	**ST2**	**ST5**	**ST6**	**EL1**	**F1**	
Point Target	R1_10441_160	R1_08183_160	R1_14300_160	R1_13757_160	R1_22889_160	R1_23318_160	
Ascending	R1_19016_160	R1_17101_160	R1_20474_160	R1_22675_160	R1_24018_160	R1_24004_160	
	R1_24846_160	R1_20874_160	R1_25619_160	R1_25519_160	R1_24947_160	R1_24690_160	
				17630_160			
Point Target	R1_10992_290	R1_04332_290	R1_14579_289	R1_13407_290	R1_22797_290	R1_23497_290	
Descending	R1_25298_290	R1_25155_290	R1_20410_290	R1_25312_290	R1_23483_290	R1_24183_290	
	R1_25641_290	R1_25498_290		R1_25655_290	R1_25541_290	R1_25898_290	**F1 Sea Ice**
				17866_290			
Dist. Target	R1_16626_885		R1_25244_884	18895_290	R1_17655_884	R1_17455_885	R1_25229_620
Ascending	R1_26230_885			21296_290	R1_18684_884	R1_20885_885	R1_26015_620
					R1_19713_884	R1_25344_885	R1_26215_621
				R1_20442_885	R1_20056_884	R1_25587_885	
		R1_17748_457					
Dist. Target	R1_17648_466	R1_18434_457	R1_16476_466	R1_20349_466	R1_16519_466	R1_17748_466	
Descending	R1_19263_466	R1_19806_457	R1_17601_466	R1_25837_466	R1_17105_466	R1_18534_466	R1_25253_730
	R1_26123_466	R1_20492_457	R1_22407_456	R1_23679_469	R1_19606_466	R1_20935_465	R1_25353_730
		R1_23136_466	R1_25737_465	R1_18291_465	R1_20978_466	R1_23679_465	R1_25496_730
		R1_23479_466					
		R1_25537_466					
		R1_25880_466					
Noise Floor	R1_18345_153	R1_22189_152	R1_22189_293	R1_22427_293	R1_22797_297	R1_24869_294	
	R1_22003_174	R1_23390_152	R1_23390_293	R1_22826_293	R1_22889_171	R1_25212_294	
		R1_23540_298	R1_23540_157	R1_23169_293	R1_25098_152	R1_25419_152	
		R1_24226_298	R1_24226_157	R1_23875_157		R1_25762_152	
		R1_25834_154	R1_25834_293	R1_24055_293		R1_25862_156	
		R1_25941_298	R1_25941_154			R1_26105_152	
chirp #	2	2	1	1	2	3	

*The acquisition for these sets of data within a beam were repeat orbit geometry for interferometry purposes.

2.2 Maintenance of Point Target Array

ASF currently maintains 12 trihedral corner reflectors in the small farming community of Delta Junction, located approximately 90miles southeast of Fairbanks. These reflectors are used for point target analysis. From the reflection impulse response we can determine geolocation accuracy, Peak to Side Lobe Ratio (PSLR), Integrated peak to Side Lobe Raito (ISLR), and resolution. The calibration technician is responsible to orient the calibration array for the requisite acquisitions. No transponders were used in the Delta Junction array. Necessary maintenance was performed during the summer months prior to the beginning of MAMM. An acquisition schedule of one maintenance trip per cycle per MAMM beam mode was executed.

2.3 Calibration / Validation System

The in-place Product Verification System (PVS) at ASF was deemed not sufficient for data quality checking and calibration of the data being acquired and processed for MAMM. The current calibration system was designed to solely support the JPL Precision Processor (PP). Since the MAMM data is being processed on a Vexcel designed system a new more adaptable calibration system was required.

2.3.1 SPROCKET & PTINFO

The Engineering Division of the ASF designed a replacement for PVS called SPROCKET. This new design, when fully implemented, will allow us to analyze generic data types. We will then be able to analyze COTS products as well as the current in-house products. SPROCKET is being built in phases. The first phase, in use now for MAMM, is used to produce the calibration images. PTINFO, a Vexcel product, is then used to perform point target and image quality analysis.

2.4 Validate and Calibrate MAMM Production (SLC) processor

The MAMM Production processor shall be calibrated so that the products meet the science requirements listed in Appendix A. It shall be calibrated using the data sets described in section 2.1.4. The radiometric calibration of the processor shall be centered on the equation listed below which converts digital numbers to the target radar backscatter coefficient σ_0 (in dB).

$$\sigma_0 = 10 \log_{10} [a_2(DN^2 - a_1 N_r)] \qquad \text{(equation 1)}$$

Where DN is the digital number, N_r is the noise offset as a function of range, a_1 and a_2 are adjustable parameters, called the Noise Scale Factor and the Linear Conversion Factor, respectively.

The calibration of this processor shall be deemed complete when no further modification of the processor is needed to meet the scientific requirements listed in Appendix A. This calibration shall be completed by October 10, 2001. Upon delivery of any modifications to the processor the processor in its entirety shall be tested in the same manner as the original calibration so that the modifications do not negatively impact data quality of SLC products. The time required to conduct any such recalibration will directly and proportionally affect the calibration schedule.

3 Acquisition Phase

3.1 Staffing

The Quality Assurance group had a limited role in the acquisition portion of the mission. As specified below, 2 full-time employees (FTE) maximum were required for acquisition support, leaving 2 FTEs to continue with calibration.

3.2 Calibration Device Maintenance

3.2.1 Delta Junction Reflector Array

There was limited maintenance for MAMM during mission. For each beam mode used during MAMM we acquired a repeat geometry pair. The data from these acquisitions was used to monitor data quality and for calibration.

3.3 Amazon data acquisition

At least 1 acquisition per beam of Amazon calibration site data was acquired during the MAMM acquisition phase. If CSA scheduled these acquisitions then we ordered them from CDPF, if not, we shall scheduled the acquisitions.

3.4 Monitoring data

Throughout the mission ASF acquired and analyzed one pass per cycle per MAMM beam mode. This data was analyzed for any quality issues that may have arisen during the mission. Analysis included radiometric anomalies, geolocation, distortion, resolution, PSLR and ISLR. The methodology used was the same as that used for the calibration of the MAMM Production processor.

3.5 Data quality troubleshooting

The Mission Operation Center (MOC) is responsible for the identification and analysis of data quality problems. The Quality Assurance team was available on-call to assist in any data quality issues that arose.

4 Production Phase

4.1 Data Quality

4.1.1 Image Format

The Single Look Complex products shall be in a CEOS format and include a data file and a leader file. The SLC data shall consist of the following beam modes: ST1, ST2, ST6, EL1, and F1. As a contingency the following modes may be used: ST3, ST4, ST5, and ST7.

The Focus SLCs shall be verified to be single look 16-bit signed values. This test shall be performed using a procedure described in further detail in "Microwave Remote Sensing" by Ulaby, Moore and Fung. The histogram of a SAR image with less than 5 looks follows the Rayleigh distribution. The ratio between the standard deviation and the mean amplitude values of a homogeneous area for a single look image should have values very close to 0.52. For several sample images four subsets shall be identified and the ratio between standard deviation and mean value shall be calculated.

The images shall also be processed to zero Doppler, and in the slant range projection, with the time from each range line being the zero Doppler time. The geolocation analysis assumes that the data is deskewed to zero Doppler and projected in slant range, if any of the above were not true there would be large geolocation errors that would not allow us to meet specifications. For example the geolocation tests are performed on an array of corner reflectors in Delta Junction that are distributed throughout the range direction. The image is geolocated using these reflectors and if the products were not deskewed to 0 Doppler there would be noticeable trends in the geolocation errors as a function of range.

The ellipsoid used in the processing, along with the corresponding radius values, have been visually identified to exist in the resulting CEOS output products.

ASF test engineers will test the CEOS formatting, unique processing run numbers for images, and the ability to process a sequence of images for one orbit during the testing phase of the system.

Reference FRD specifications: (5.1.1; 5.1.14; 5.1.10; 5.1.11; 5.1.13; 5.1.8; 5.1.9; 5.1.22; 5.1.24; 5.1.25)

4.1.2 Geolocation Accuracy

Geolocation accuracy shall be determined using the Point Target array listed in section 2.2. These reflector locations are known using differential GPS measurements and provide for excellent reference points within an image. Absolute geolocation error is the number of meters that the image differs from the ground truth locations in the range and azimuth directions. Relative geolocation error is the standard deviation of the absolute geolocation errors about the mean. The geolocation shall be calibrated to meet the Science requirement listed in Appendix A.

Geolocation accuracy is determined by comparing the measured locations of the features in the SAR images and the known locations of corner reflectors deployed in Delta Junction. The Delta Junction image is processed to the elevation for a given corner reflector. This elevation parameter is verified by first visually identifying it in the command line execution of the program. Additionally the elevation correction is tested by inputting different elevation values for a single reflector and measuring the effect this has on the geolocation of that reflector.

The image must then be displayed so that one may determine the exact x and y (pixel) coordinates of each reflector. The Sprocket system, designed and developed at ASF, is used for this process. Once the x and y coordinates are known, Vexcel-developed ptinfo tool is used to measure the reflector’s elevation. Ptinfo produces the measured latitude and longitude coordinates from the SAR image for a given reflector.

Use the following formula to determine the geolocation error:

Haversine Formula

Δlat=measured lat - ground truth lat
Δlong=measured long - ground truth long
a=sin^2(Δlat/2)+cos(lat1)*cos(lat2)*sin^2(Δlong/2)
c=2*arcsin(sqrt(a))
Great circle difference = R * c
R (radius of the Earth) = 6360924.0 meters
R was obtained by taking the average of 10 Delta Junction Precision Processor scenes

These steps must be repeated for each corner reflector measured.

Distortion within an image shall be measured by comparing the positional relationships among measured corner reflectors and comparing them to ground truth.

Overall geolocation accuracy error introduced by the processor shall be no greater than 100 meters.

Initial geolocation of Delta Junction images demonstrated across track errors consistent with incorrect slant ranges that put the overall geolocation error outside the 100 meter parameter. Subsequent looks confirmed this to be systemic and empirical data gathered on images of Delta Junction and the McMurdo Ground Station antenna resulted in a determination that subtracting .34 microseconds from the fixed Radar Electronic Delay value of 4.2 microseconds would bring geolocation within specification. Even though 4.2 microseconds is the CSA specified value and they do not acknowledge any changes to that value, further evidence supporting a change in the FOCUS processor was provided by the fact that JPL's Precision Processor (Used in AMM-1) used a fixed value of 3.9 microseconds. The .34 microsecond change was made by Vexcel to the Focus processor and is being used for MAMM level one processing.

Reference FRD specifications: (5.1.7.3; 5.1.7.4; 5.1.12)

4.1.3 Image Quality Analysis

Resolution, defined as the width of the impulse response 3dB down from the peak, Integrated Peak to Side Lobe Ratio (ISLR), and Peak to Side Lobe Ratio (PSLR) will be measured using the Delta Junction reflector array. The science requirements for ISLR, PSLR, and Resolution are shown in Appendix A.

Image quality results are obtained using the Vexcel PTINFO tool. As above in the determination of geolocation accuracy, the image must be processed to L1 and then viewed to identify the exact x and y (pixel) coordinates. These coordinates are input to the PTINFO tool to determine all the image quality statistics for a given point.

For image quality purposes, there were two Delta Junction sites that were not used in the calculation of the statistics. DJR 20-23 are an array of four corner reflector positions used ideally for ScanSAR products. They are physically 8 feet apart and thus return a stronger impulse than a normal reflector, and were not used. DJR 3 was also not used for image quality purposes because it is constructed using an experimental design and does not return as strong or as consistent a response as the other reflectors.

The image quality requirements are summarized in the following table:

	St 1	St 2	St 5	St 6	Fn 1	El 1
Resolution, range	11.9	11.9	17.7	17.7	6.8	11.9
Resolution, azimuth	11	11	11	11	11	11
PSLR	-18	-18	-18	-18	-18	-18
ISLR	-10	-10	-10	-10	-10	-10

Reference FRD specifications: (5.1.5)

Further discussion of these measurements is forthcoming.

4.1.4 Radiometric Calibration

The radiometric calibration of a SAR beam mode is an iterative process. An image is first processed using a unity payload parameter (pap) file. The unity pap file contains no corrective gain values. Using this unity L1 image, all targets that produce non-uniform, non-isotropic scattering are masked out, or deselected. These features include rivers, lakes and other topographic features.

For this image, $\gamma°$ for each pixel is determined using:

$$\gamma° = 10 \log [\{(DN^2/A2^2) * \tan \Theta\} - \text{Noise Power}]$$
$$\sigma° = 10 \log [\{(DN^2/A2^2) * \sin \Theta\} - \text{Noise Power}]$$

where DN^2 is the square of the pixel magnitude = $I^2 + Q^2$, Θ = incidence angle, and **A2** = scaling coefficent, which may be range dependent, but is constant for MAMM. $\sigma°$ is given here for reference purposes. Noise Power is the range dependent noise power derived from the noise vector.

CSA provides pap information for a greater range of look angles than is actually imaged by the processor. In order to proceed with calibration, the range of look angles to be used must be determined. First the minimum and maximum look angles imaged are determined. To create a buffer, 0.2 degrees is subtracted from the minimum and added to the maximum, defining the look angle range. The pap file contains 255 correction values. Using the newly defined range, a new beam increment is determined.

A 6th order polynomial is created to match the average look angles and $\gamma°$ values from the images. Extend this polynomial to match the desired look angles in order to predict the $\gamma°$ values for the new look angle range.

Apply the following equation to the polynomial fit $\gamma°$ values:

$$F(\text{look angle})=(\gamma° + 6.5) /2$$

where $\gamma°$ measurements are an average of all the azimuth lines at a given look angle. The desired value for $\gamma°$ is - 6.5 (Which is the γ^0 value of the Amazon calibration sites), and the pap file gains are one way. Thus subtracting –6.5 and dividing the result by 2 will yield the necessary pap file correction.

The correction is then added to the current pap file.

With the new values input into the pap file, the next iteration of the above steps is performed. Subsequent iterations result in a flattening of the antenna pattern.

The requirements to be met are a relative radiometric accuracy of ± 1 dB and an absolute radiometric accuracy of ± 2 dB.

Relative radiometric calibration shall be set so that range dependency of radar cross section shall be no greater than 1dB for similar targets. This calibration accuracy shall exclude the effects of incorrect scene elevation data and spacecraft pointing errors.

Absolute radiometric calibration shall be set so that the mean $\gamma 0$ value for a predetermined area of the Amazon Rainforest is –6.5. This calibration accuracy shall exclude the effects of incorrect scene elevation data and spacecraft pointing errors. The absolute calibration error shall be no greater than 2 dB.

Radiometric linearity shall be measured using two targets with well known
backscatter that have a large backscatter difference (e.g the Amazon and a corner reflector). The difference between theoretical and measured shall be calculated to determine a relative error, or non-linearity of the processor response. This relative error shall then be expressed as a percentage of the theoretical difference.

For example:
Two targets are processed and the γ°'s are measured to be -6.3 and 47.5 dB. The γ°'s should have been separated by 54.5 dB (theoritical values are –6.5 and 48, respectively), but the measured difference was only 53.8 dB. The relative error (or non-linearity of the processor response) is 0.7 dB out of 54.5 or

$$1 - 0.7/54.5 = 987$$

To achieve a linearity of .97(The upper limit of the MAMM Specification), the error could have been as high as:

$$1 - x/54.5 \quad 97$$

or $x = 1.636$

Reference FRD specifications: (5.1.6; 5.1.7.1; 5.1.7.2)

Due to concerns over changes in RADARSAT-1 antenna patterns, all calibration data over the Amazon calibration site will be acquired from CDPF and stored in our archive. The data will be analyzed for long-term trends using the Precision Processor. Only the data listed in Table 2 will be processed on the Vexcel FOCUS processor, unless significant trends are noted in the beams to be used for MAMM. If trends are noted, then a subset of the Amazon calibration data will be used to update the antenna pattern corrections determined with the standard calibration sets.

4.1.4.1 GAIN

A variety of Antarctic images will be processed to determine that the histograms of the backscatter are reasonably centered. Images with very low return values shall be processed to determine that the noise equivalent σ0 of the data corresponds to a DN value of 32 or greater. In addition, images shall be processed to. maximize the dynamic range while ensuring phase accuracy of one degree for the weakest signals.

The gain can be selected from a fairly simple analysis. For an amplitude value of about 100 (e.g., I = 100 and Q = 0, or I = 70 and Q =71), the I/Q quantization is accurate enough so that the phase quantization error is less than 1 degree.

There is enough dynamic range with 16 bit pixels that the selected gain value is not required to be specific beyond an integer value. It makes sense then, to select an exact gain setting that is easy to remember. If we choose a σ0 value of -20dB (1/100) to be equivalent to an amplitude value (DN) of 100, (because that is the noise floor for FN1), then signals at this level would be quantized to within 1 degree of phase accuracy. The weakest signals (-25 dB noise floor for ST3 thru ST7) would correspond to an amplitude value of about 56 which provides a phase quantization accuracy of about 1 degree. The maximum amplitude value of about 45,000 would correspond to a σ0 of about +33 dB. Saturation can occur at σ0 levels 6 dB below this, due to the speckle effect and the fact that maximum amplitude for some phase values (e.g. 0 and 90) is 32K.

Determination & implemention of the gain setting: Since we needed a DN of 100 to produce a –20dB σ0, we know that the scaling calibration coefficient (A2) is exactly 1000. Empirical data was gathered to determine the correct fixed gain value to meet the requirement.

The gain is set during processing by use of a look-up table. Gain value for the whole table is set to 60 dB **(gain value = 20log(A2))** to achieve the fixed gain recommended above. (The table is RSAT1.LUT in /usr/people/3dsar/3dsar/version/config/sensors on the lzp's. There are actually 18 tables in the file. There are six application types and three pixel types. Each table contains 255 values covering the look angle range of all the beams.) Look-up table # 12 in the LUT file on lzp4 is currently set to 60 dB. This table corresponds to a target type of "MIXED" and for complex pixels (PIXEL_TYPE = CI16).

The script that performs the level 1 processing calls the CEOSConvert program. To use this table the call must have the following flags set.

-rad LUT

-lut MIXED

In our testing, these items were selected in the CEOSConvert GUI.

Reference FRD specifications: (5.1.15, 5.1.16)

4.1.4.2 PHASE

The purpose of the phase error test is to determine if the Focus processor will meet the 10-degree relative phase error requirement for MAMM processing. The method is to process a section of

SAR telemetry to a complex product, then process the same section of telemetry data 1000 lines later in the stream. In order to remove any Doppler centroid differences, the along-track (time-dependent) coefficients of the Doppler polynomial will be manually set to zero prior to the processing. The resulting images can then be co-registered and the phase components compared. Any phase differences found can be attributed directly to the processor. In order to remove any modulus ambiguities, the phase difference image should be calculated using the following steps:

Given $v1_{x,y}$ denotes phase of image 1 at pixel x, line y
$v2_{x,y}$ denotes phase of image 2 at pixel corresponding to pixel x, line y of image 1

Then, the phase difference, $diff_{x,y}$, is

```
$diff_{x,y} = v1_{x,y} – v2_{x,y}$
while ($diff_{x,y} < -\pi/2$) $diff_{x,y} = diff_{x,y} + \pi$
while ($diff_{x,y} > \pi/2$)  $diff_{x,y} = diff_{x,y} – \pi$
```

A histogram will be created using 100 bins corresponding to –90 to +90 degrees of difference. The RMS error will then be calculated using this histogram and the actual mean.

Reference FRD specifications: (5.1.10).

4.1.4.3 Determination of the noise floor

To determine the noise floor, targets that have low DN values, e.g. bodies of calm water, are selected. If we assume that the areas of the lowest DN values have no signal return then the resulting DN values are a product of noise.

For this testing areas in the Prince Williams Sound of Alaska, the Yukon-Kuskokwim river delta and the North Slope of Alaska were used. The values that were obtained from this testing ranged by several dB and were not as consistent as we had hoped. Therefore it was determined that the thermal noise value given by CSA should be used after subtracting out the antenna pattern correction applied in the processing. The values are listed in the CEOS product and simply need their effects removed and then the noise constant can be subtracted from the data.

The format for the noise vector given below is consistent with the metadata format in the Vexcel par files. The vector is appended to the end of the *slc.par file. The new noise_vector block will have the form:

```
noise_vector {
  noise_value_1: -23.5
  noise_value_2: -23.4
  noise_value_3: -23.2
  ...
  noise_value_255: -26.7
}
```

To improve readability, the noise values are in dB. Subtracting them will require computing the power (exp (noise_value/10). The first value shall correspond to the noise at the first range image sample, the second value to range sample 33, the third to 65, etc. The last sample would then correspond to sample 8128. The maximum number of image pixels occurs for real time fn1 and is 7720.

The noise value as a function of range for $\sigma 0$ products is given by:

n(r) = n_ref + 30*log(r/r_ref) - 2*G(r) + 10*log(sin(inc_angle))

where n_ref is the thermal noise reference level for the beam mode/bandwidth
r is the slant range
r_ref is the reference slant range = 951000 m
G(r) is the one way antenna power gain as a function of range

The values needed (except for G(r)) for the noise calculation are found in the *slc.par file.

The value for n_ref is: thermal_noise_ref_level

The slant range to the first pixel is contained in the value: near_range_slc

The slant range for each subsequent array value is found from the par value for the pixel spacing: PixelSpacing

r = near_range_slc + (array_number - 1)*32* PixelSpacing

To find G(r), the antenna pattern must be interpolated, and converted to a function of slant range from its native function of elevation angle. The pattern is contained in the leader file (in the radiometric compensation record).

In order to interpolate the gain pattern, the look or elevation angle for the given slant range must be determined. The radius of the earth and incidence angle are needed for this calculation.

The earth radius at the image center may be found from the latitude, major and minor earth axes, and must be adjusted for terrain height.

rad = minor*sqrt(1+tan^2(lat))/sqrt((minor/major)^2 + tan^2 (lat)) + terrain_height

where the latitude is from the par value: scene_center_latitude and the axes and terrain height are in the earth model block

```
earth_model {

        major: 6378140.000000
        minor: 6356755.000000
        terrain_height: 0.000000}
```

The platform_altitude h is also needed. It is found from the par file value and must also be adjusted for terrain height:

h = platform_altitude - terrain_height

Now the incidence angle can be found from

inc_angle = arccos((h^2- r^2+2*rad*h)/2*r*rad)

and the look angle is

look_angle = arcsin(sin(inc_angle)*rad/(r + h))

Now we have the look angle for each range value and the gain table can be interpolated to determine the value for each range. The table has 255 values. The angle for the center value (128) and the angle increment are provided as data items in the table. These data items are at the end of the table in the leader file.

The incidence angle has also been determined to calculate the final term in the equation.

4.1.4.4 Doppler

Metadata checks to determine if the following are true shall be performed:

> Doppler processing bandwidth set to the desired Hz as per the chop files received from OSU.

By design, the processor uses a single polynomial that provides for a Doppler variation across track but not along track.

Reference FRD specifications: (5.1.5; 5.1.20)

4.1.4.5 Radiometric Calibration Error Propagation

If we take σ^0 in fractional (non-dB) units, then its equation can be written as:

$$\sigma^0 = a_2 (DN^2 - a_1 N_r)$$

The major terms for the propagation of error for the conversion of Digital Numbers (DNs) to the backscatter coefficient σ^0 is given by equation 2 below:

$$S_{\sigma 0}^2 = (DN^2 - a_1 N_r)^2 S_{a2}^2 + (2a_2 DN)^2 S_{DN}^2 + (a_2 N_r)^2 S_{a1}^2$$

Where S_{a2} is the standard deviation in a_2, S_{DN} is the standard deviation in DN, and S_{a1} is the standard deviation in a_1. The dominant term in the measurement of S_{a2} (if calibration is done correctly) is the error inherent in the target, typically taken as 1 standard deviation = 0.5 dB for the Amazon. Determination of S_{a1} is taken directly from Equation 3, where the mean a_1 as well as S_{a1} are measured from the statistics of the data.

There are two significant points to be noted from the error propagation analysis. The user determines S_{DN} based on the number of samples and images used. There is a diminishing return on the number of samples used as the standard deviation due to scatter in the users data becomes much smaller than the error in the measure of the Amazon distributed target. Also, as measurements approach the noise floor, the standard deviation in a_2 term contribution decreases, while the contribution of the standard deviation in a_1 term increases dramatically. Therefore, as targets become darker, the error due to the noise floor increases, and at some point the products will not meet science specification, especially very close to the noise floor. The Parameters S_{a1} and S_{a2} will be determined, along with an analysis of errors close to the noise floor, and included in the calibration report.

4.2 Final Release

The MAMM processor shall be calibrated and released for production processing of the final beam mode by October 10, 2001. The calibration will be deemed final upon completion of an external Calibration Review given by the Quality Assurance staff of ASF. This Calibration Review shall consist of a presentation of our calibration methods and results for the entirety of the MAMM mission.

4.3 MAMM Calibration Report

The MAMM Calibration report shall be published by ASF following successful calibration of the processor, within 1 month of the completion of the calibration review.

5 Calibration schedule

OCT 10, 2001: Calibration of FN1, ST6, ST2, ST1, EL1, ST5, and ST7 complete
NOV 7, 2001: MAMM calibration review
DEC 7, 2001: MAMM calibration report due.

Appendix A *(some of the figures in this table (the original) do not match figures in a similar table for resolution, ISLR, and PSLR in the Image Quality section. I have a due out to reconcile this)*

Science Requirements – Single Look Complex Products

	ST1	**ST2**	**ST6**	**EL1**	**F1**
Resolution, Range	9.5 m	9.5 m	13.6 m	9.5 m	5.4 m
Resolution, Azimuth	6.0 m	6.0 m	6.0 m	6.0 m	6.0 m
PSLR, Range	-15.5 dB	-15.5 dB	-15.5 dB	-15.5 dB	-15.5 dB
PSLR, Azimuth	-15.5 dB	-15.5 dB	-15.5 dB	-15.5 dB	-15.5 dB
ISLR, Range	-10.9 dB	-10.9 dB	-10.9 dB	-10.9 dB	-10.9 dB
ISLR, Azimuth	-10.9 dB	-10.9 dB	-10.9 dB	-10.9 dB	-10.9 dB
Phase error	10 deg	10 deg	10 deg	10 deg	10 deg
Geolocation	100 m	100 m	100 m	100 m	100 m
Distortion (in 100km)	50 m	50 m	50 m	50 m	50 m
Radiometric, relative	1 dB	1 dB	1 dB	1 dB	1 dB
Radiometric, absolute	2 dB	2 dB	2 dB	2 dB	2 dB