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OFF-NADIR ANTENNA BIAS CORRECTION USING AMAZON RAIN FOREST σ^0 DATA

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TABLE OF CONTENTS

LIST OF TABLES

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LIST OF FIGURES

SUMMARY

The radar response from the Amazon rain forest has been studied to determine the suitability of this region for use as a standard target to calibrate a scatterometer like that proposed for the National Oceanic Satellite System (NOSS). Backscattering observations made by the SEASAT-1 Scatterometer System (SASS) show the Amazon rain forest to be a homogeneous, azimuthally-isotropic, radar target which is insensitive to polarization. The variation with angle of incidence may be adequately modeled as $\sigma^{o}_{(dB)} = a\theta + b$ with typical values for the incidence-angle coefficient, a, from 0.07 - 0.15 dB/deg. Variation of the intercept, b, was from -0.6 to -4.4 dB. A small diurnal effect occurs, with measurements at sunrise being 0.5 dB - 1 dB higher than the rest of the day.

Maximum-likelihood estimation algorithms presented here permit determination of relative bias and true pointing angle for each beam. Specific implementation of these algorithms for the proposed NOSS scatterometer system is also discussed.

Much of the information in this report can be found in the paper by I.J. Birrer, E.M. Bracalente, G.J. Dome, J. Sweet and G. Berthold, "σ^{o} Signature of the Amazon Rain Forest Obtained from the Seasat Scatterometer," IEEE Transactions on Geoscience and Remote Sensing, vol. GE-20, no. 1, January 1982, pp. 11-17.

1.0 INTRODUCTION

The National Oceanic Satellite System Scatterometer (NOSS SCATT) was designed to determine wind vectors on the ocean's surface by measuring radar backscatter from the surface. The SCATT was to be a fan-beam scatterometer utilizing six dual-polarized (V and H) antennas.

To achieve maximum wind-vector accuracy careful cross-calibration between antennas must be performed. This report discusses the development of a calibration technique utilizing measurements of the scattering coefficient σ^O from the Amazon rain forest. A brief discussion is presented of the method used to discriminate rain-forest signals from others. Maps (used to screen Brazil data) generated for this purpose are on a 0.25° x 0.25° grid for locating rivers and a 0.5° x 0.5° grid for identifying vegetation types.

The suitability of the Amazon rain forest for use as a calibration target is shown in Section 4.0. From July to October 1978 numerous backscatter measurements were made by the SEASAT-1 Scatterometer System (SASS). These measurements show the rain forest to be a homogeneous, azimuthally-isotropic radar target which is insensitive to polarization. Variation of σ^O with respect to incidence angle may be adequately modeled with a straight line fit of the form: $\sigma^O_{(dB)} = a\theta + b$, where θ is the angle of incidence (deg.). Measured values for the incidence angle coefficient, a, range from 0.07 - 0.15 dB/deg depending on beam and time of day. Values for the intercept, b, range from -0.6 to -4.4 dB. A small diurnal effect was observed with measurements made at sunrise (0500-0630) being consistently 0.5 - 1.0 dB higher than the rest of the day.

To cross-calibrate the beams on a multibeam scatterometer, two parameters, a relative bias and the true antenna pointing angle, must be determined for each beam. Development of two maximum-likelihood-estimation algorithms to determine these parameters using Amazon rain forest data is discussed in Section 5.0. The first algorithm is used to determine both relative bias and true pointing angle. A second and considerably simpler version is then developed to monitor long-term changes in relative bias due to drift in the instrument gain and transmitter power. Specific processing required to implement these algorithms for the SCATT is also discussed in Section 5.0.

2.0 BACKGROUND

During the SEASAT program, the need for in-flight cross-calibration for antennas from a multibeam scatterometer became apparent. The originally proposed procedure using aircraft underflights proved inadequate. Based on the consistency of σ^0 data over the rain forest obtained during SKYLAB, R.K. Moore of The University of Kansas suggested using the Amazon rain forest data as a means of calibration.

The accompanying map (Figure 1) shows the vast extent of the Amazon rain forest. It includes an area of more than 3,000,000 km^2. Because of its equatorial location, seasonal effects are minimized and vegetation is always present. The region is very flat and uniformly forested except for breaks in the canopy over the Amazon River and its principal tributaries. The predominant climate is hot and humid, with annual precipitation as high as 3000 mm. A slight decrease in rainfall is observed in the large central part of the rain forest during the months of October to December. A similar decrease takes place in the northern part during the months of June to September. In the northwest a more significant decrease in rainfall occurs during May and June with the lowest rainfall in July and August.

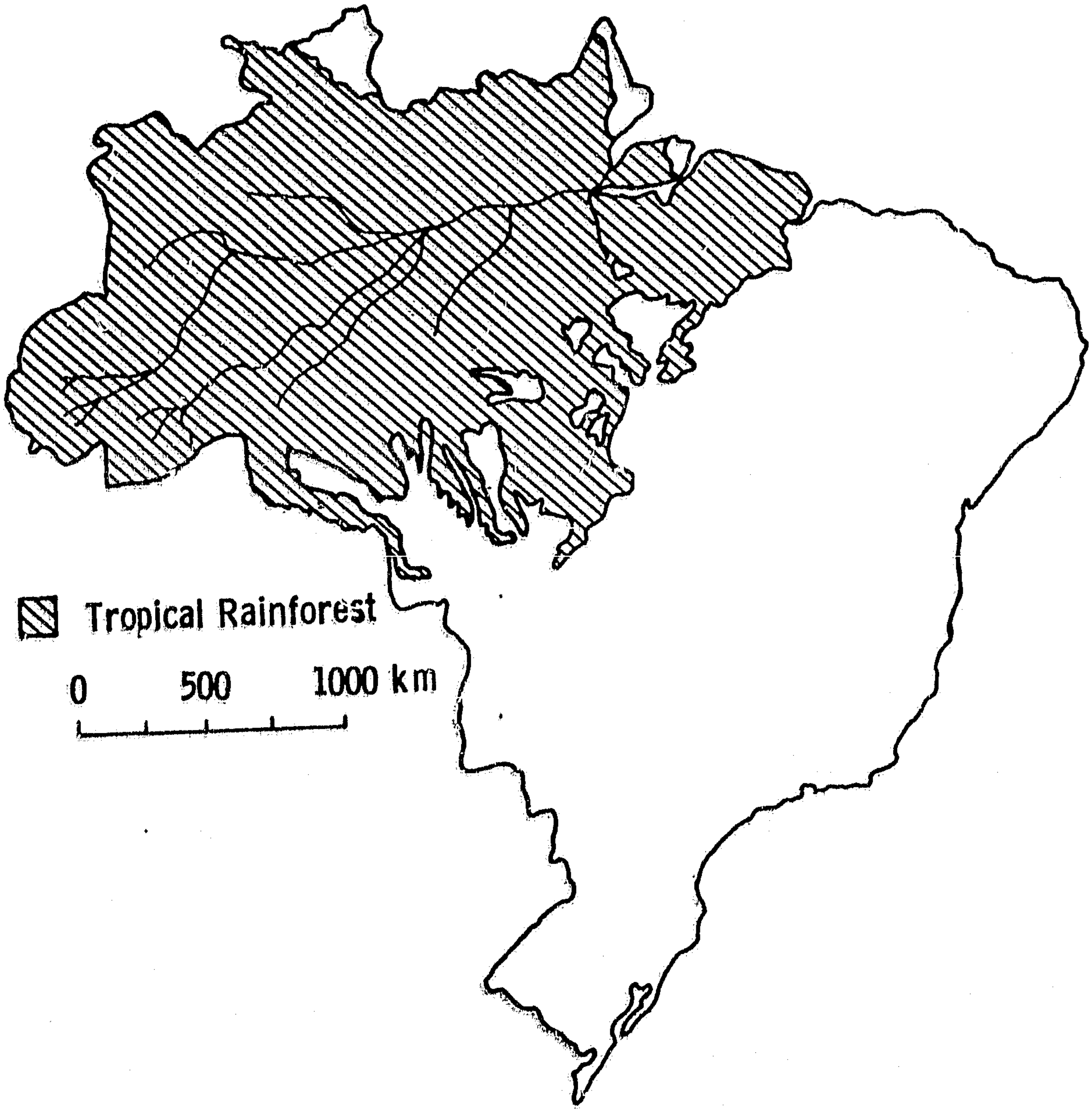


FIGURE 1: Extent of Brazilian Rain Forest

During the SKYLAB SL-2 mission vertical-polarization measurements were made over the Amazon rain forest at incidence angles of 32° to 36°. Figure 2 shows a sample time history taken during one of the SKYLAB passes over the eastern part of the forest. The scattering coefficient was stable with a maximum deviation of about 0.2 dB. For the combined set of SKYLAB measurements the mean value of σ^o was reported as ≈ -5.9 dB with a standard deviation of 1 dB [1,2]. This observed consistency prompted the further investigation using the SEASAT scatterometer.

3.0 DEVELOPMENT OF MAPS USED TO CLASSIFY BRAZIL TARGETS

3.1 Land-Water Map

For the early analysis of SEASAT observations of Brazil, discrimination was achieved by using vegetation maps developed during the SKYLAB program [2]. The 1° x 1° grid available was thought to be adequate. However, as noted in Section 4.2, the presence in the SASS footprint of the Amazon River or one of its principal tributaries markedly lowered the radar cross-section. Since the SCATT was planned to operate with an even smaller footprint, a finer map grid was needed to screen out data contaminated by the presence of rivers.

For NOSS a digitized map was created with a 0.25° x 0.25° grid. The source map was produced by the Department of Cartography of the Brazilian Institute of Geography in 1971. This map of the entire Amazon basin is scaled at approximately 3 inches per degree. The digitized map was created by overlaying grids to subdivide the source map into 0.25° boxes. Codes were then assigned to each box using the following conventions:

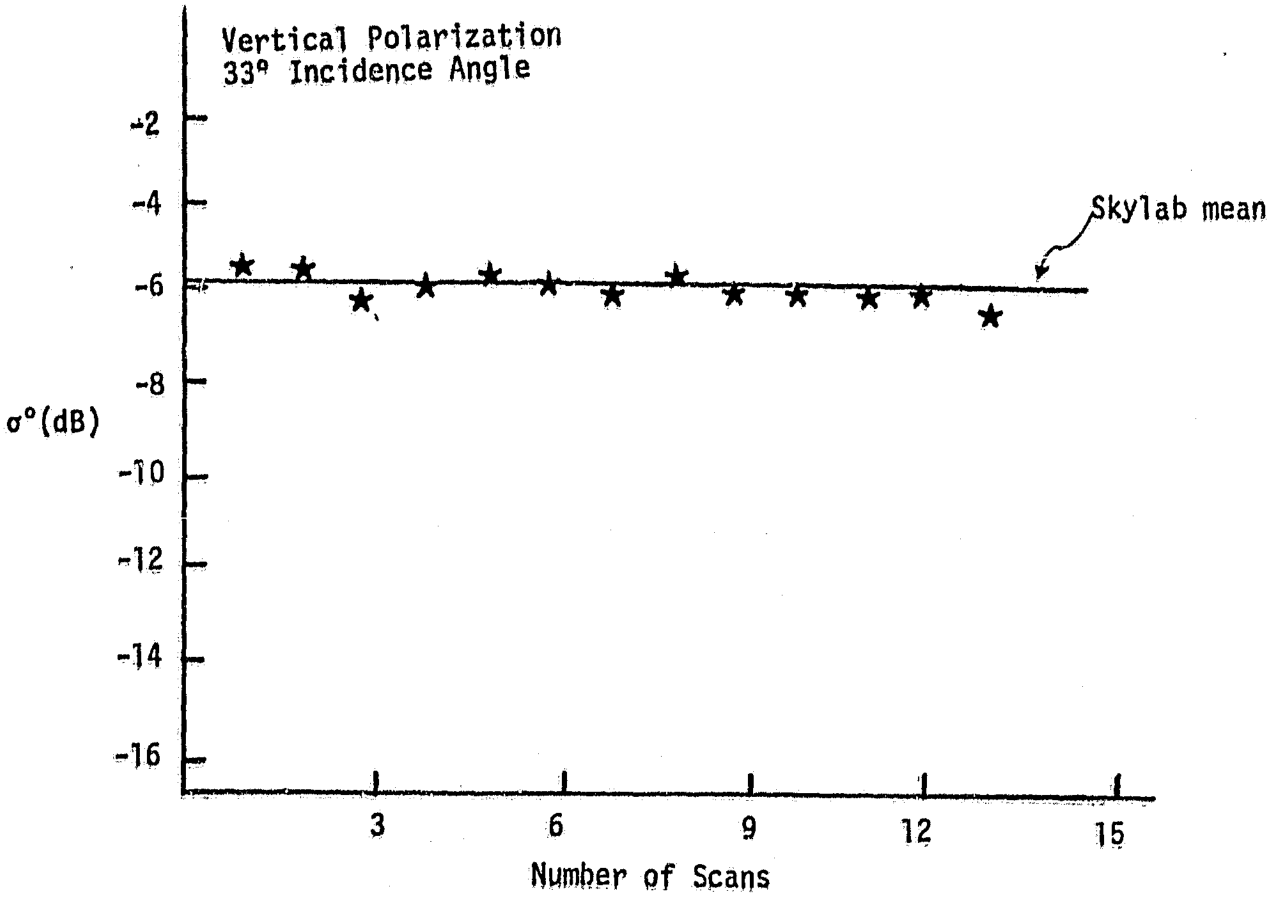


FIGURE 2: Sample SKYLAB Time History over Amazon Rain Forest

0 - flatland only (no significant rivers)

1 - some small rivers but mostly land

2 - large rivers through box

3 - rough terrain

The results of this procedure were then encoded into a computer algorithm. For a given latitude and longitude the algorithm will fetch the code of the box containing the location. This map was tested during the extensive analysis of SEASAT data discussed in Section 4.0.

For NOSS it was envisioned to use the computed location of the center of the Doppler cell for classification. A more careful screening could be performed by using the latitudes and longitudes of the corner points for a particular Doppler cell. Testing to be sure that all four corners showed a "land-only" condition would be a check against overlapping part of a river-filled box.

3.2 Vegetation Map

To further classify Brazilian data a vegetation map for the Amazon basin was produced with a 0.5° x 0.5° grid. Codes were assigned to each box according to the conventions listed in Table 1. Six distinct types of vegetation are found in the Amazon basin. Types 1 and 2 are the forests which are suitable for use as a standard target. Combinations of types were only designated if the dominant vegetation was either type 1 or type 2. Otherwise, they were coded with a 3, 4, 5, or 6, depending on the dominant type.

This map was incorporated into an algorithm similar to the land-water algorithm. For a particular latitude and longitude the code is retrieved for the box containing that location. This algorithm was used during the

TABLE 1
Codes Used in Vegetation Map

Type (Code)	Description	
0	Outside of Brazil Rain Forest	
1	Humid Upper Amazon	
2	Humid Firm Land	
3	Humid Floodlands	
4	Humid Plains	
5	Mountainous Region	
6	Savannah	
7	Combination Types	1,4
8		2,4
9		1,2,4
10		1,2
11		2,6
12		2,4,6
13		1,2,3,6
14		1,6
15		2,3,6
16		2,3
17		1,2,3
18		1,3
19		2,5
20		2,5,6

SASS analysis to remove all data from vegetation types 3,4,5, and 6. A similar approach is recommended for a NOSS-type of system.

4.0 CHARACTERIZATION OF σ^o SIGNATURE USING SEASAT SCATTEROMETER DATA

4.1 The SEASAT-A Scatterometer System (SASS)

The SASS operated using four dual-polarized (V and H) 0.5° x 25° fan-beam antennas. The antennas were pointed 45° from the satellite subtrack to give a "star-like" illumination pattern on the surface [3] (see Figure 3). This configuration provided for pairs of nearly orthogonal measurements of the earth's surface. The SASS instrument transmitted a 100-watt 14.6-GHz signal. The backscattered signal was spread out in frequency due to the Doppler effect. Using 15 parallel channels (each consisting of a Doppler filter, a square-law detector, and a gated integrator), the reflected power

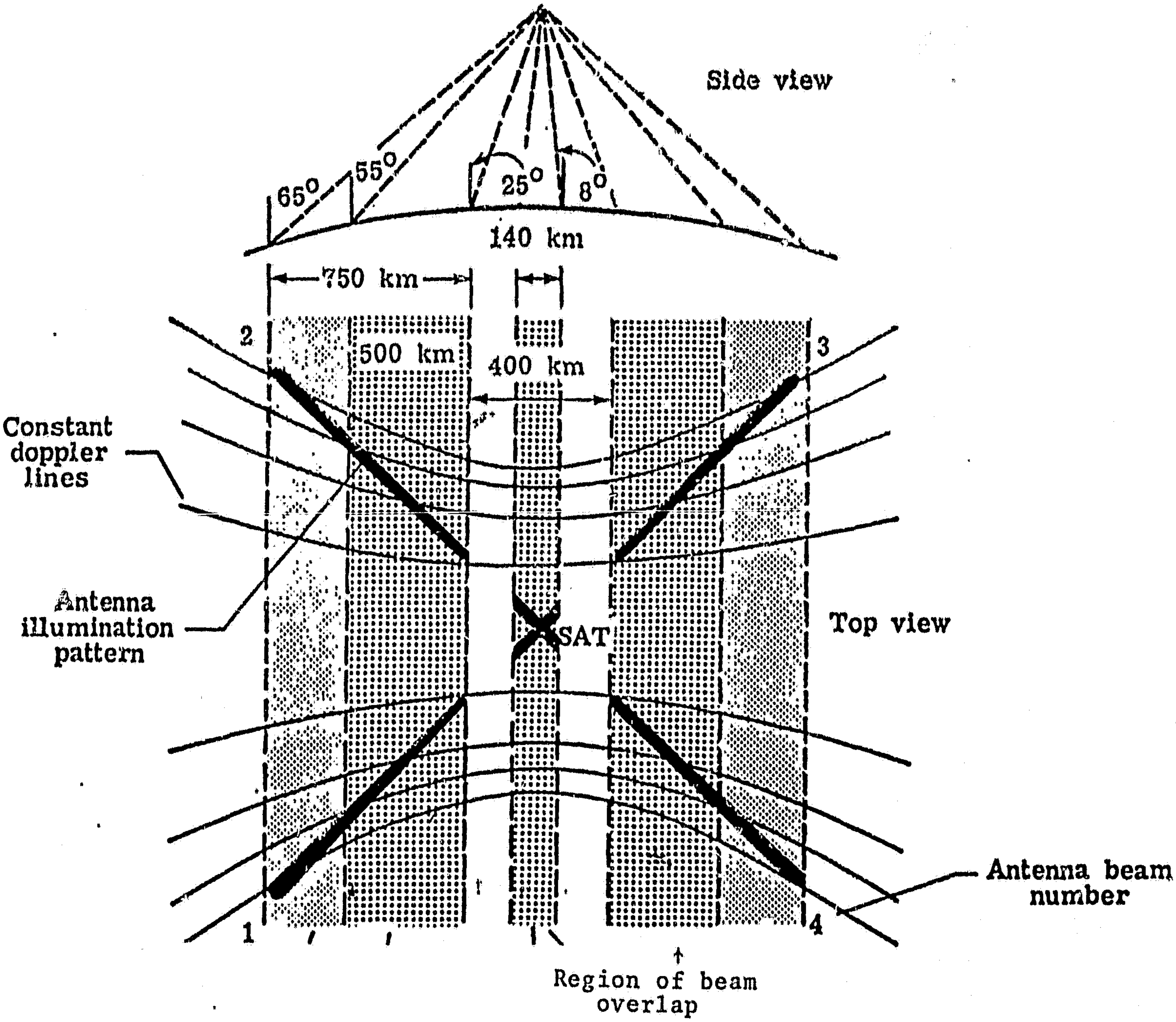


FIGURE 3: SEASAT Scatterometer Swath Coverage

from one antenna was sampled 61 times during a 1.89-sec measurement period. The mean values of the 61 integrated voltage levels of signal plus noise and noise alone from each of the 15 channels were transmitted to the ground. The power reflected from the earth's surface was determined from these voltage pairs, the calibrated gain of the receiver, and the known integration time, as indicated in Figure 4.

Figure 5 shows an enlarged view of one of the 15 Doppler cells synthesized along the beam. As illustrated, the Doppler-cell area is determined by the 0.5° 3-dB beamwidth in the narrow-beam plane and the Doppler filter along the beam. Due to the 1.89-sec measurement time the Doppler cell is smeared in the alongtrack direction to give the resultant cell shown in the lower inset. The integrated Doppler cells are between 16-20 km wide and 50-70 km long.

The frequencies selected for the Doppler filters result in three near-nadir resolution cells (0° - 13° incidence angle) and twelve off-nadir cells (20° - 65° incidence angle). Only the off-nadir measurements were used in this analysis since the near-nadir returns were outside the main antenna beam.

The value of σ^o can be determined by solving the radar equation in the following form:

$$P_R = \frac{P_T \lambda^2 L_S G_0^2}{(4\pi)^3} \int_A \frac{\left(\frac{G}{G_0}\right)^2 \sigma^o h(f)}{R^4} \, dA \qquad (1)$$

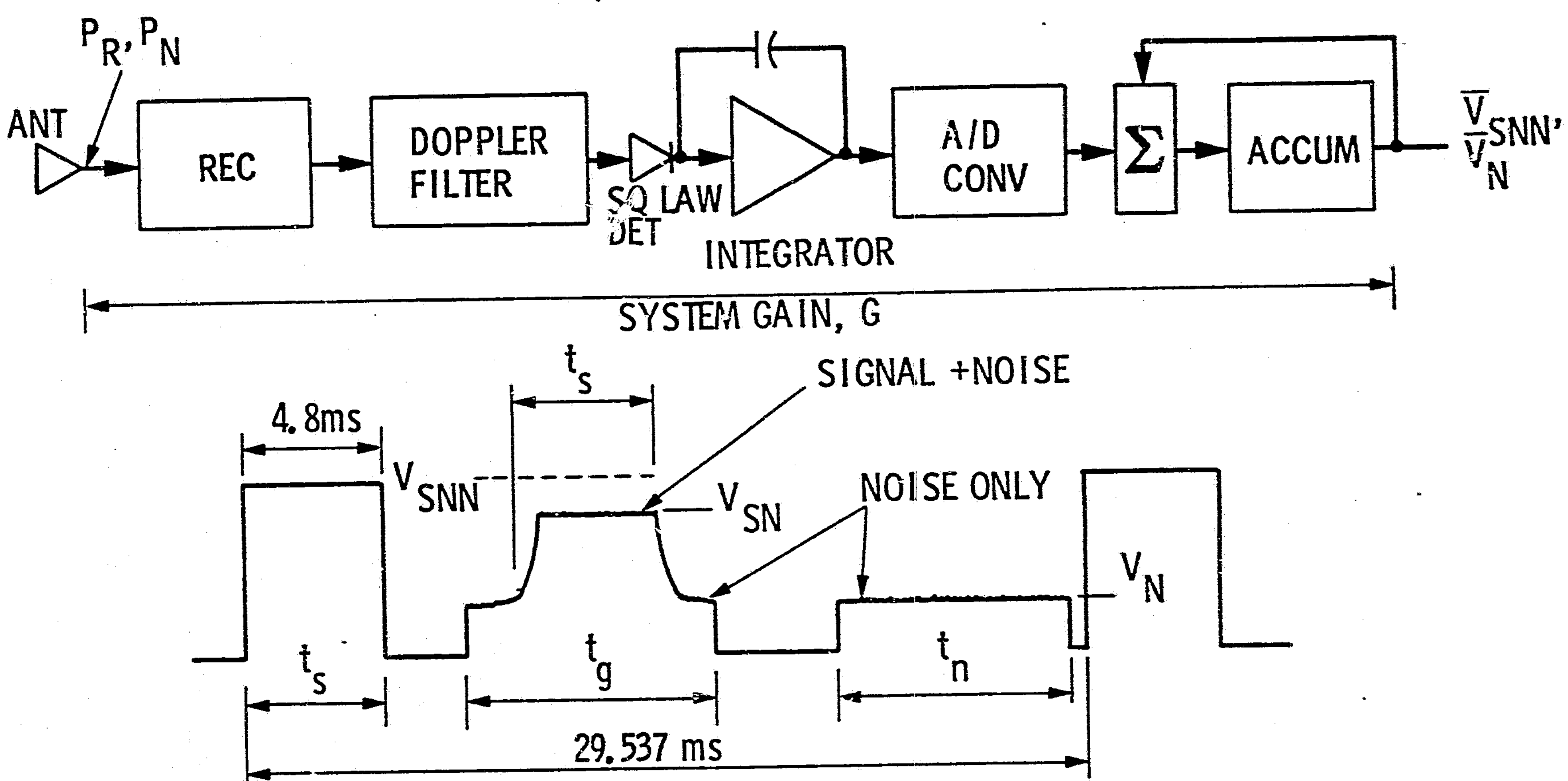
where:

P_R = received power

P_T = transmitted power

λ = transmitted wavelength

L_S = miscellaneous losses



$T_S = 61 \times t_s = 0.2928$ (ALL CHANNELS)

$T_G = 61 \times t_g = 0.345$ TO 0.69

$T_N = 61 \times t_n = 0.4818$ (ALL CHANNELS)

$$V_{SNN} = T_S G (P_R + P_N) + (T_G - T_S) P_N G \quad (1)$$

$$\overline{V}_{SN} = \overline{V}_{SNN} - \frac{T_G - T_S}{T_N} \overline{V}_N \quad (2)$$

$$P_{SN} = \frac{\overline{V}_{SN}}{T_S G} \quad \text{- SIGNAL + NOISE POWER} \quad (3)$$

$$P_N = \frac{\overline{V}_N}{T_N G} \quad \text{- NOISE POWER} \quad (4)$$

$$P_R = \frac{\overline{V}_{SN}}{T_S G} - \frac{\overline{V}_N}{T_N G} \quad \text{- SIGNAL POWER} \quad (5)$$

WHERE:

$$G = \frac{\overline{V}_{SNN} + \overline{V}_N}{P_N (T_G + T_N)} \quad (6)$$

FIGURE 4: Calculation of SASS Received Power

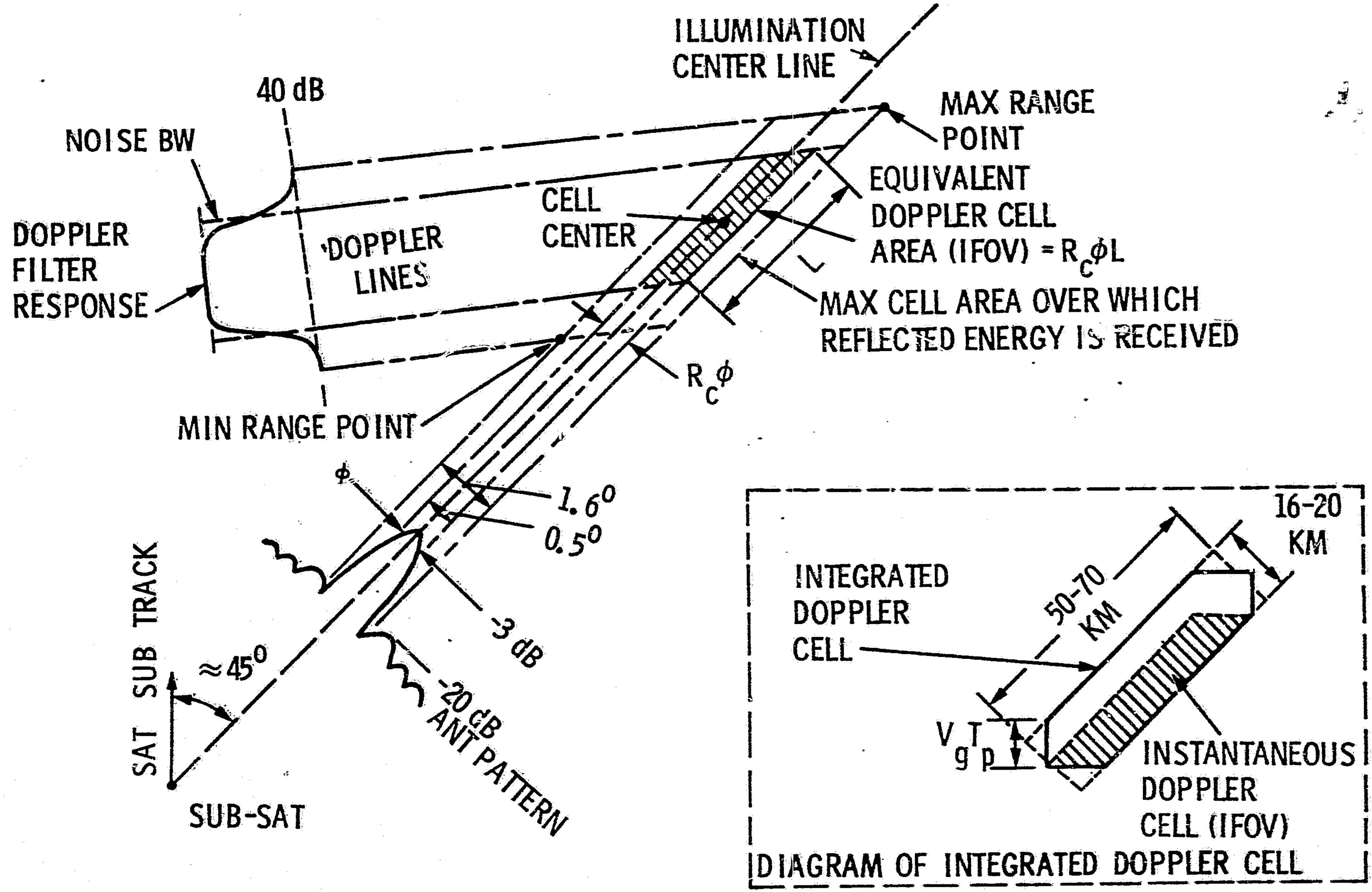


FIGURE 5: Doppler Cell Area Determined by Antenna Pattern and Filter Response

G_0 = peak antenna gain

$\frac{G}{G_0}$ = relative gain at center of cell

$h(f)$ = frequency response of Doppler filter

R = range to cell center

Equation (1) may be solved for σ^o as:

$$\sigma^o = \frac{(4\pi)^3 P_R R^4}{P_T \lambda^2 L_S G_0^2 (\frac{G}{G_0})^2 A} \qquad (2)$$

assuming:

$$h(f) = \begin{cases} 1 & f_\ell < f < f_u \\ 0 & \text{otherwise} \end{cases}$$

where:

$A = L R\phi_A$, where L is the distance on earth's surface from f_ℓ to f_u

f_o = center frequency

B_n = noise bandwidth (Doppler filter)

f_ℓ, f_u = upper and lower Doppler-filter cutoff frequencies

ϕ_A = narrow dimension antenna beamwidth (radians)

$$f_\ell = f_o - \frac{B_n}{2}$$

$$f_u = f_o + \frac{B_n}{2}$$

A particular σ^o is calculated by evaluating equation (2) using measured values for P_R and P_T, values for G_0 and $\frac{G}{G_0}$ obtained from a lookup table, and computed values for R and A [4].

4.2 Target Stability of the Amazon Rain Forest

Initially the SASS data were processed by scientists at NASA Langley Research Center to produce time histories of σ^o over Brazil [4]. Figures

6 and 7 show sample time histories of Beam 1 vertical-polarization measurements made during an orbit identified as Rev 952. The radar-cross-section stability over the Amazon rain forest was similar to that observed during the SKYLAB mission. When the rain forest results are compared with the observations over the ocean, three striking differences are noted: (1) σ^o is consistently higher over the rain forest (except at the smallest incidence angle), (2) σ^o is much more stable over the rain forest, and (3) the variation in σ^o with incidence angle is much less. As can be seen in both Figures 6 and 7, SASS cells which included part of the Amazon or one of its major tributaries were easily identified by the sudden 1-3 dB drop in σ^o.

Since the goal of the research was to determine the Amazon rain forest's suitability as a standard target, tests were made for both temporal and regional stability. Comparing data taken at the same time of day over the same flight line throughout the mission provided a useful test for seasonal effects. Figure 8 shows the results of one of these comparisons. Approximately 10 measurements were averaged at each incidence angle to estimate the mean σ^o. The deviation of the mean σ^o is negligible near the peak antenna gain (θ_i = 44°) except for the September 18 measurements at 40°. This discrepancy may be due to atmospheric attenuation. At the extremes of the incidence-angle range the deviation is less than 0.5 dB. However, due to the short lifetime of SEASAT (99 days, July-October), further research is needed to determine if any seasonal effects exist. The values of the mean σ^o for a particular time of day were compared over numerous flight lines to test for regional effects. No consistent discrepancies were observed over the rain forest. As a result of these tests, the entire SEASAT rain-forest data set was analyzed as a unit.

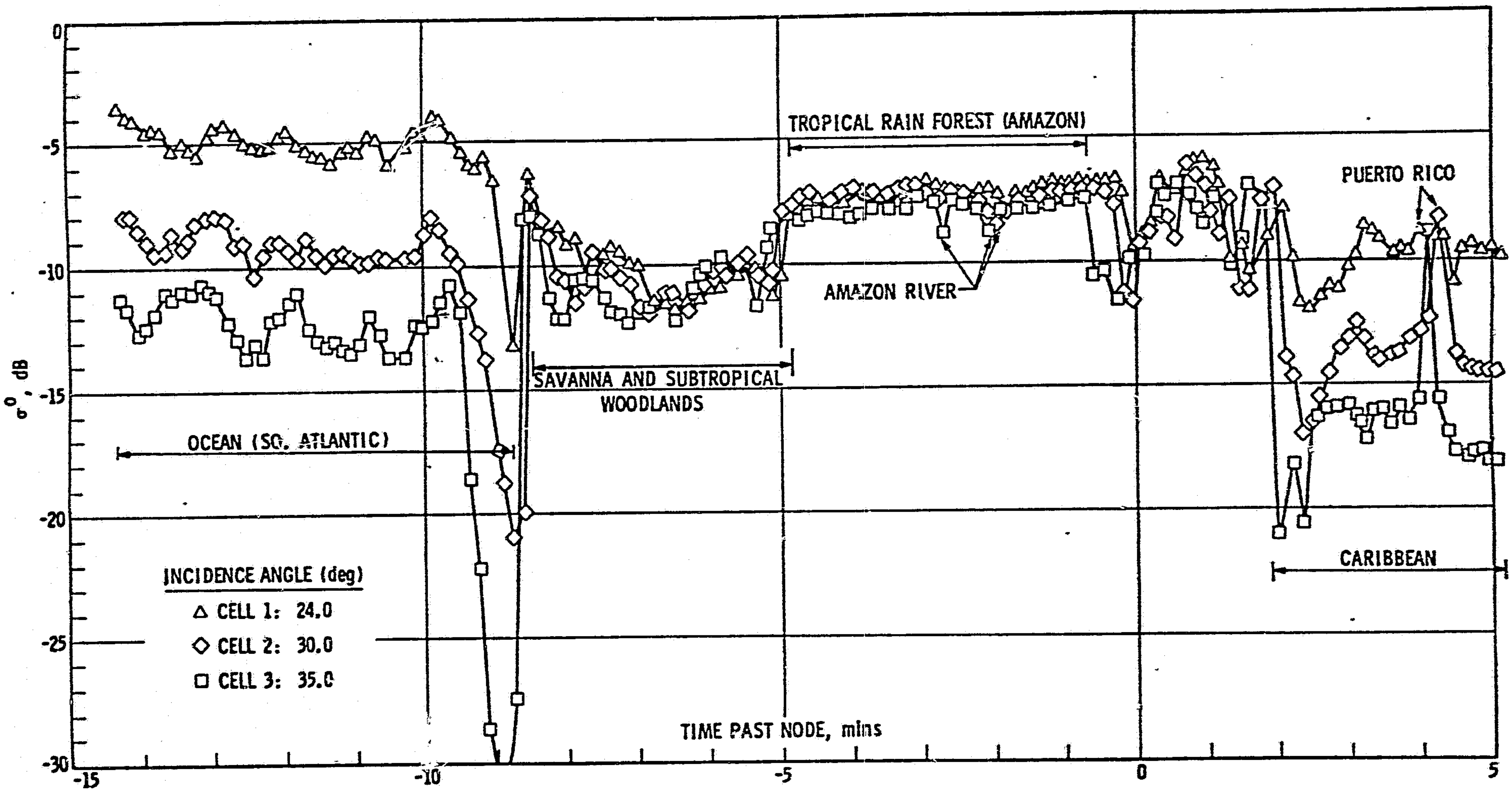


FIGURE 6: σ^0 Time History for Rev 952; V-polarization; Cells 1,2,3

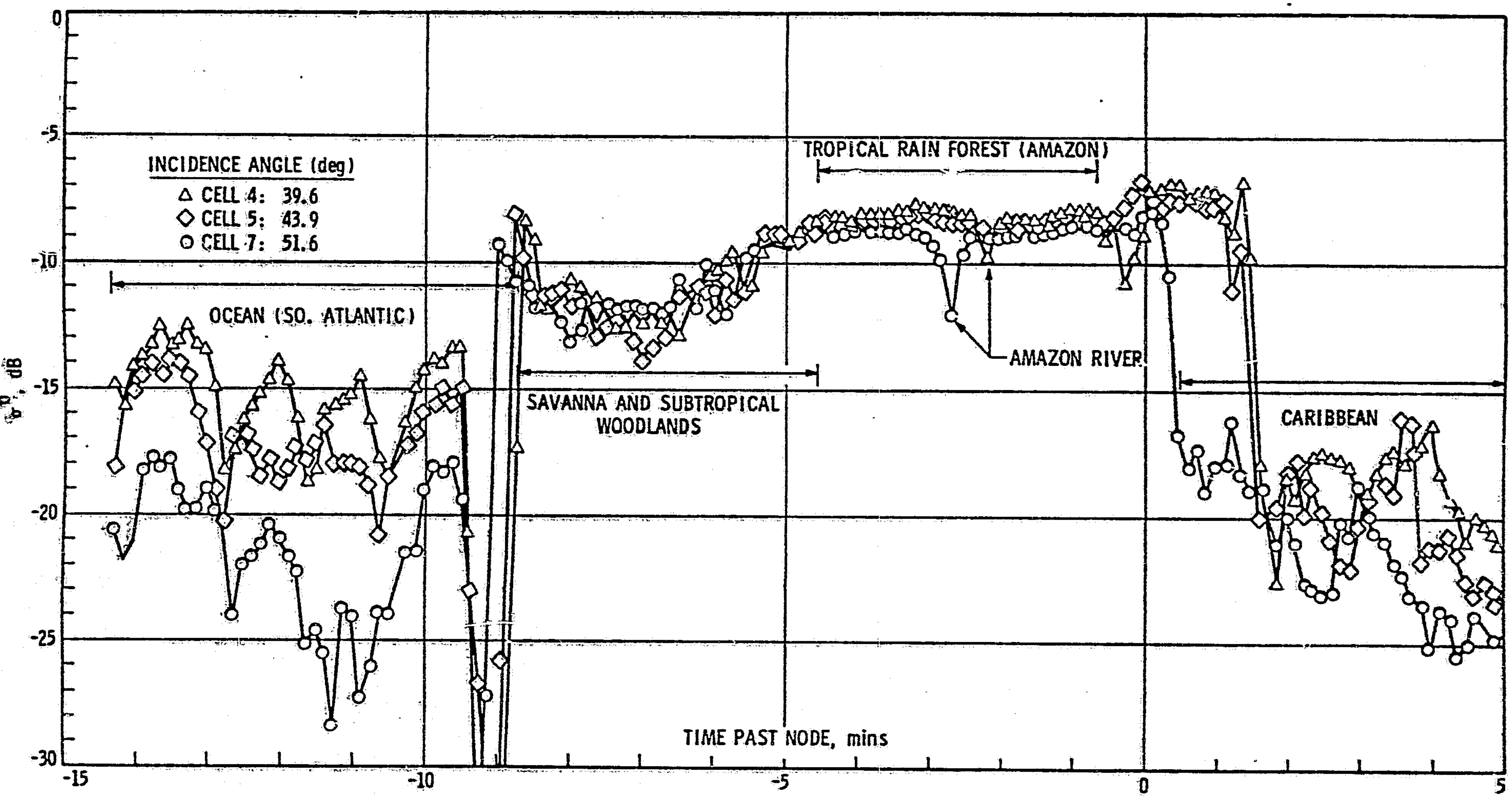


FIGURE 7: σ^{0} Time History for Rev 952; V-polarization; Cells 4,5,7

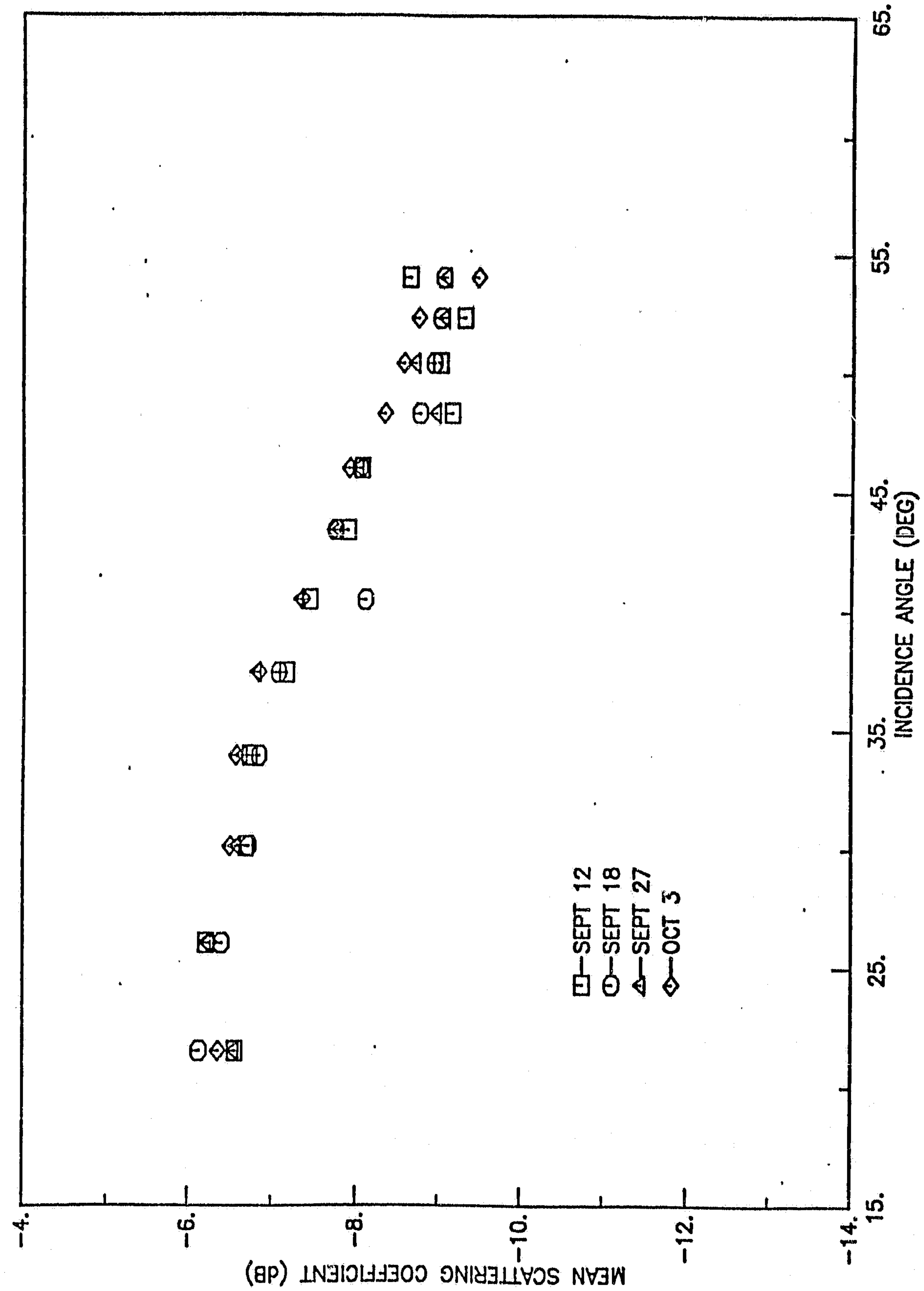


FIGURE 8: Target Stability During SEASAT Mission

4.3 Incidence Angle Dependence and Diurnal Variation

The SASS made measurements over the Amazon rain forest twice daily. During the early part of the mission, the Brazil crossings were between 0500 and 0630 (local time at center of area) and between 1630 and 1830. During the last month of the SEASAT mission, the crossings took place between 0900 and 1200 and between 2100 and 2400. For the subsequent analyses the data were binned by polarization, beam, incidence angle and time of day. Mean values and standard deviations of σ^o were computed for each of these bins.

Plots and regressions of mean σ^o versus incidence angle were made for each beam to describe the small incidence-angle dependence observed in the time histories. The sample sizes for estimation of the means varied approximately from 10 to 100 measurements. Figure 9 shows the results for Beam 4, vertical polarization. The late-morning and nighttime data agree well. The results from Beams 1 and 2 indicate that the late-afternoon measurements were also consistent with the late-morning and nighttime data. On the other hand, the early-morning measurements were from 0.5 to 1.0 dB higher than data at the other times of day.

As can be clearly seen from Figure 9, the basic angular trend is adequately modeled by the equation

$$\sigma^o_{(dB)} = a\theta + b \qquad (3)$$

where θ is the incidence angle. Typical values for the incidence angle coefficient a, as determined from regression analysis, ranged from 0.077 to 0.159 dB/deg depending on beam and time of day.

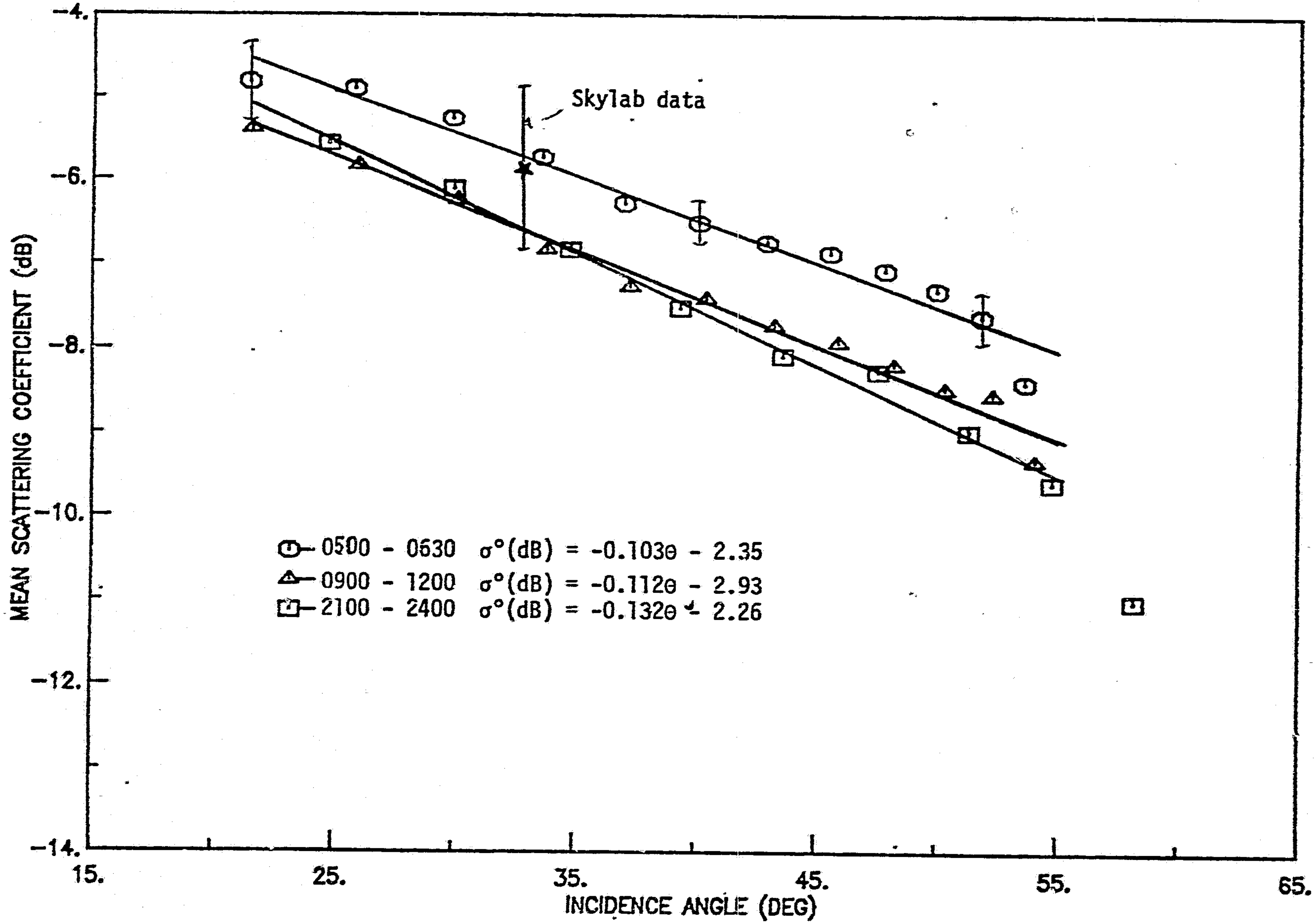


FIGURE 9: Mean σ^o vs Incidence Angle; Beam 4; V-polarization

Equation (3) may be rewritten as

$$\sigma^o_{(real)} = K e^{-\theta/\theta_o} \qquad (4)$$

where:

$$K = e^{\frac{b}{10} \ln 10}$$

$$\theta_o = - \frac{10}{a \ln 10}$$

Table 2 gives a complete summary of the values of a, b, K, θ_o determined by regression using (3)*. From the summary in Table 2 some obvious differences are observed between beams. The data appear to be most consistent in the incidence angle range of 30° - 50°. The four SASS antennas had been cross-calibrated using the eleven Brazil passes available to NASA Langley scientists soon after the SEASAT mission [4]. Good agreement was achieved in the mid-angular range. The remaining differences highlight the need for the more sophisticated cross-calibration algorithm (using all of the SEASAT passes) developed here.

The value of σ^o estimated from the regression fit agrees well with the reported SKYLAB results. The SASS, however, shows much less deviation about the mean. Bars have been drawn on Figure 9 to show the scatter in the measurements. At incidence angles near the nominal pointing angle of 44°, the standard deviations ranged from 0.1 to 0.2 dB. At the extremes of the incidence angle range the standard deviations ranged from 0.3 to 0.6 dB. This

*Both unweighted regressions and regressions weighted by number of cases were tried. Weighted regression results are reported here because they take into account the higher density of measurements in the angular region of greatest measurement accuracy. In most cases the differences in the "a" coefficients between the weighted and unweighted regression were within the errors of the estimated coefficients.

TABLE 2
Regression Parameters for the Incidence Angle Response of SASS Data over Brazil

Model: $\sigma^o_{(dB)} = a\theta + b$

$\sigma^o(\text{real}) = K e^{-\theta/\theta_o}$, where K, θ_o are determined from a, b.

Beam #	Time of day*	a	b	$R^2 \times 100$%	K	θ_o	Data points per regression
1	1	-0.129	-1.75	98	0.669	33.67	72
	2	-0.158	-1.71	99	0.764	27.41	246
	3	-0.112	-2.85	96	0.519	38.68	543
	4	-0.096	-3.69	94	0.428	45.30	551
2	1	-0.077	-3.62	96	0.435	56.31	166
	2	-0.089	-4.08	92	0.391	49.00	518
	3	-0.135	-1.98	98	0.663	32.17	442
	4	-0.155	-1.11	97	0.774	28.09	437
3	1	-0.148	-0.58	93	0.874	29.30	103
	2	-0.156	-1.15	96	0.767	27.91	603
	3+	------	-----	--	-----	-----	---
	4	-0.078	-4.37	96	0.366	55.61	836
4	1	-0.103	-2.35	97	0.582	42.29	140
	2	-0.112	-2.93	97	0.510	38.65	589
	3+	------	-----	--	-----	-----	---
	4	-0.132	-2.26	99	0.595	32.95	538

*Time Code: 1 = 0500-0630
2 = 0900-1200
3 = 1630-1830
4 = 2100-2400

+No data available

%Squared multiple correlation coefficient increase in the standard deviation is probably due to a decrease in measurement precision caused by weaker signals at angles well away from the peak antenna gain, and also may be caused by small beam-pointing-angle errors that have more importance where the antenna gain varies more rapidly with angle.

The regression equations determined from the data were used to estimate values of σ^o at 40° incidence angle which are plotted in Figure 10 as a function of time of day for Beam 2. The early morning return is 0.6 - 0.9 dB higher than at the other times of day. Table 3 summarizes these estimates for all of the beams. When this effect was first noted in the original analysis of the first 11 passes, all of the data had been screened using GOES imagery to eliminate cases containing significant cloud cover. In the present analysis the data were not screened. However, since this was the dry season few of the measurements should have been corrupted.

Initially it was believed that, because of the random orientation of the scatterers in the uniformly vegetated rain forest, the values of σ^o would be insensitive to polarization. While most of the measurements were vertically polarized, enough horizontal polarization data were taken to allow a comparison. On Figure 11 are plots of both V-pol and H-pol data for Beam 1. As expected the results appear to be insensitive to polarization.

No noticeable azimuthal-angle variation was observed in the rain-forest data. This isotropy can be demonstrated by comparing the 0900 - 1200 V-pol data from Beam 2 and Beam 4. While the beams differ 180° in azimuth, the measurements show agreement within 0.1 - 0.2 dB. This may be seen by overlaying Figures 9 and 11.

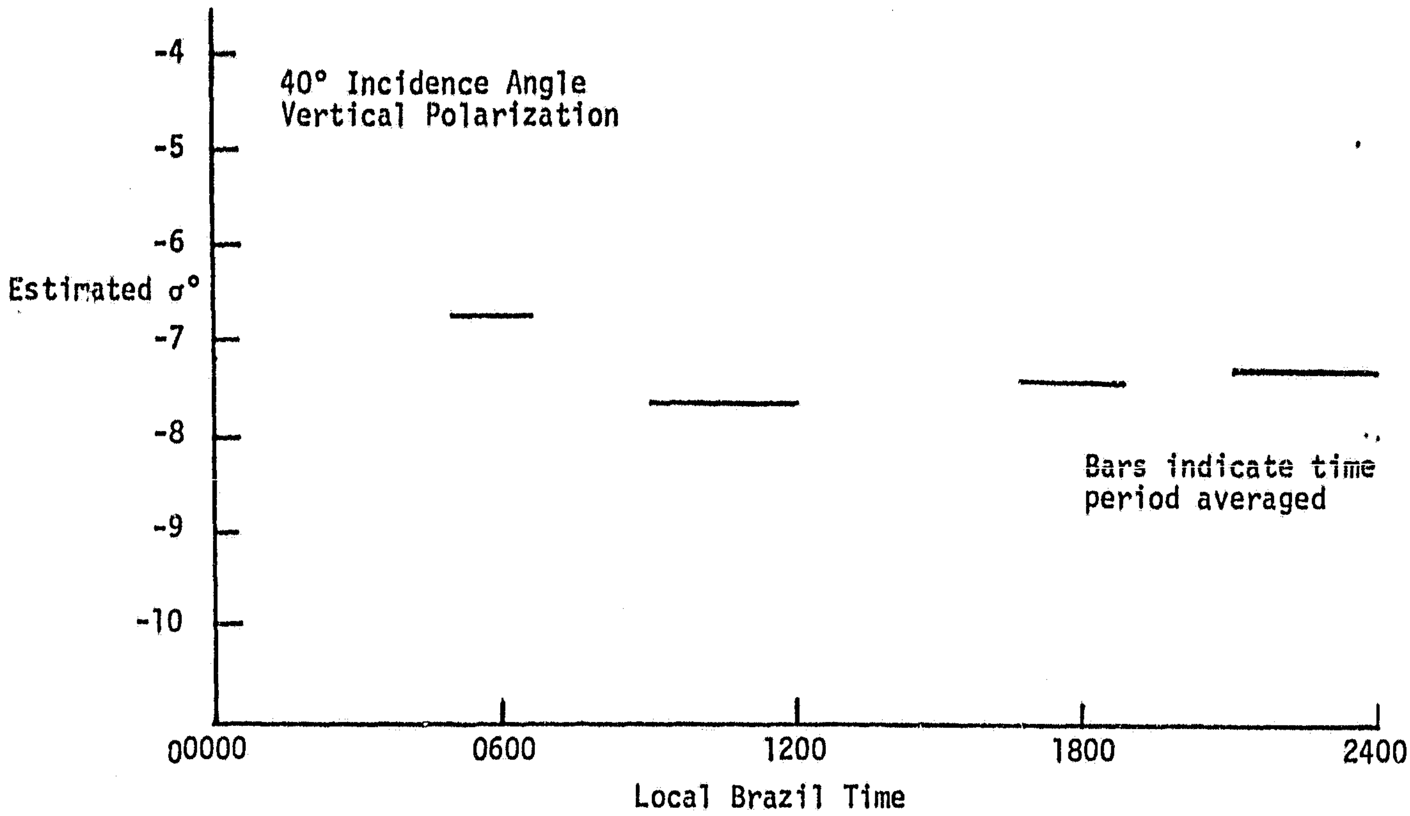


FIGURE 10: Estimated σ^o From Regression Fit

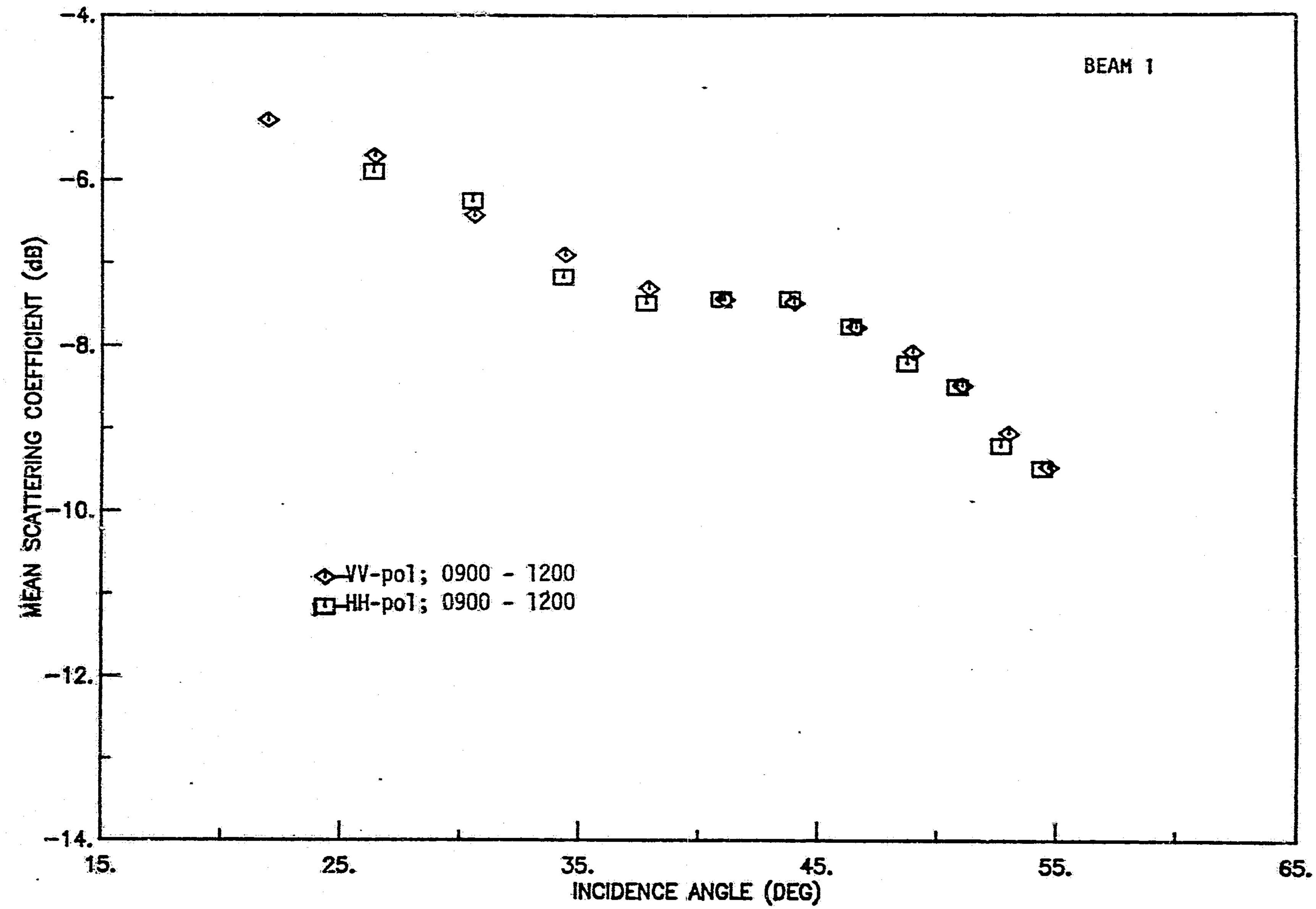


FIGURE 11: Comparison of VV-pol and HH-pol Data, Beam 1

TABLE 3
Summary of Diurnal Effect at 40° Incidence Angle
Vertical Polarization

Time of Day	ESTIMATED SCATTERING COEFFICIENT (dB) Beam 1	Beam 2	Beam 3	Beam 4	Average for All Beams
0500 - 0630	-6.91	-6.70	-6.34	-6.47	-6.60
0900 - 1200	-7.49	-7.62	-7.39	-7.41	-7.48
1630 - 1830	-7.33	-7.40	-----	-----	-7.36
2100 - 2400	-7.53	-7.31	-7.49	-7.54	-7.47

4.4 SEASAT Summary

The data obtained from SEASAT-1 have shown the potential of the Amazon rain forest for use as a standard target. Since the diurnal effects appear to be limited to early morning, data from other times of day could all be used together to build a data base for calibration. The small scatter (0.1 - 0.6 dB) in the mean values of σ^0 indicates the remarkable stability of this region and hence its usefulness as a standard target. A basic characterization of the incidence-angle dependence can be made using a simple straight-line model of $\sigma^0_{(dB)}$ vs θ.

The differences between the regression coefficients shown in Table 2 for the different beams cannot be due to actual σ^0 differences because Beams 1 and 2 covered the same area, as did Beams 3 and 4. Hence these differences must be in antenna patterns or in pointing-angle differences. This points out the need for use of such a "standard target" in future multibeam scatterometers.

5.0 DEVELOPMENT OF OFF-NADIR ANTENNA BIAS CORRECTIONS FOR NOSS

5.1 Description of NOSS Scatterometer System

The NOSS Scatterometer System (SCATT) design is for a second generation fan-beam scatterometer using experience gained from SEASAT (Section 4.1). Figure 12 shows the proposed SCATT ground-track coverage. Besides the four beams used in SASS, two antennas are pointed at 65° from the satellite orbit plane to aid in wind-direction alias removal. All of the antennas are dual-polarized (V and H). The SCATT instrument transmits a 100-watt 14.0-GHz signal. The backscattered signal is Doppler filtered into 60 resolution cells with each cell approximately 10 km x 10 km. The off-nadir bias correction algorithm is to be applied to the outermost 50 Doppler cells of each beam.

5.2 Development of Maximum Likelihood (ML) Algorithms to Estimate Off-Nadir Bias Parameters

During SEASAT analysis, Brazilian rain-forest data were first used to correct for antenna biases in the off-nadir cells. Estimates for relative bias and pointing angle were determined by comparing data from a limited number of passes. For NOSS a formalized algorithm was desired to allow automation of the estimation of these parameters by using all available SCATT rain-forest data. The next subsection (5.2.1) describes in detail the derivation of a maximum likelihood (ML) approach to estimate relative bias and pointing angle.* Once pointing angle is determined, a ML technique may be used periodically to re-estimate relative bias. This algorithm is described in Section 5.2.2.

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*This ML approach is an adaptation of the approach used in the SEASAT Wind Vector Algorithm developed by F.J. Wentz (Remote Sensing Systems, Inc.).

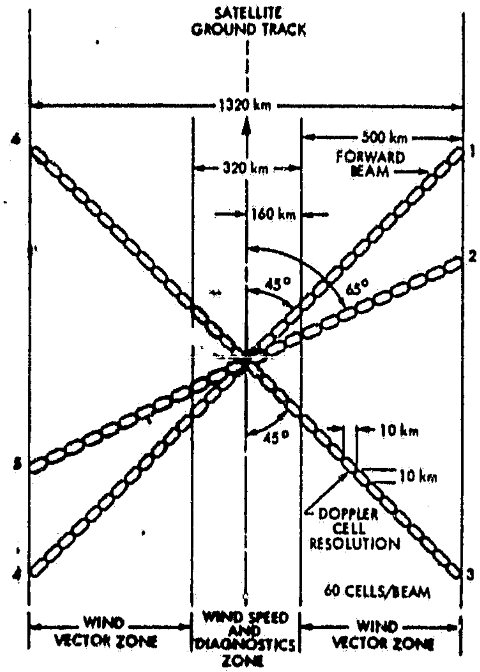

FIGURE 12: Proposed NOSS Footprint

5.2.1 Relative Bias and Pointing Angle Estimation

For an operational system the radar parameters, P_T and G_0 in equations (1) and (2) are specified in the design and carefully measured prior to launch. The relative antenna gain, $\frac{G}{G_0}$, is determined from pre-launch antenna pattern measurements and the specified pointing angle, θ_p. Although P_T is monitored during operation, only relative changes in P_T can be measured. The true absolute value of P_T depends on pre-launch calibrations. However, as was observed with the SASS, the actual values for P_T, G_0 and θ_p after launch can differ from the design values due to errors in the pre-launch calibrations [4].

Effects of these differences at each Doppler cell can be seen by writing equation (1) for both the designed and actual values of P_T, G_0, θ_p and the corresponding σ^o inferred from equation (2). For a given Doppler cell (incidence angle):

$$P_R = \frac{P_{D^T} \lambda^2 G_{D^0}^{\;2} [G/G_0(\theta_{D^p})]^2 \; \sigma^o_D \; A}{(4\pi)^3 \; R^4}$$

where the subscript D refers to the designed values.

$$P_R = \frac{P_{A^T} \lambda^2 G_{A^0}^{\;2} [G/G_0(\theta_{A^p})]^2 \; \sigma^o_A \; A}{(4\pi)^3 \; R^4}$$

where the subscript A refers to actual values.

Equating the above expressions and solving for σ^o_D in terms of σ^o_A yields

$$\sigma^o_D = \frac{\alpha [G/G_0 \; (\theta_{A^p})]^2 \; \sigma^o_A}{[G/G_0 \; (\theta_{D^p})]^2} \tag{5}$$

where $\alpha \triangleq$ relative bias $= \dfrac{P_{A^T} \; G_{A^0}^{\;2}}{P_{D^T} \; G_{D^0}^{\;2}}$

By substituting a standard reference target, σ_S^o at the cell incidence angle, for the value of σ_A^o, the relationship in equation (5) can be used to estimate the relative bias, α, and the actual pointing angle θ_{A^P}. Since the measurements, σ_D^o, are noisy, maximum-likelihood estimation is used to determine α and θ_{A^P}.

Formulation of the maximum-likelihood estimation may be given as: a vector of noisy observations, $\underset{\sim}{z}$, exists which depends probabilistically on a parameter of interest, B. The M.L. estimate of B is then given by the condition

$$f_{\underset{\sim}{z}/B}(\underset{\sim}{z}/B)\Big|_{B = \hat{b}_{ML}(z)} = \text{maximum} \qquad (6)$$

where:

$f_{\underset{\sim}{z}/B}$ is the joint conditional probability density function.

$\hat{b}_{ML}(z)$ is the maximum-likelihood estimate of B.

This approach can be applied to estimate α and θ_{A^P} with the following assumptions:

(1) Radar measurements are independent and may be described as a Gaussian process

(2) The noisy observations, $\underset{\sim}{z}$, are the parameter σ_D^o

(3) The parameter of interest, B, is given by the relation:

$$\frac{\alpha\,[G/G_0\,(\theta_{A^P})]^2}{[G/G_0\,(\theta_{D^P})]^2}\,\sigma_S^o = B(\alpha\ \theta_{A^P})$$

(4) $G/G_0(\theta_P)$ is known from pre-launch measurements.

Applying the above conditions, the conditional probability in expression (6) may be re-written as:

$$f_{\underset{\sim}{\sigma}^o/B}[\{\sigma^o_{\ell D};\ \ell = 1,N\}/B(\alpha,\theta_{Ap})] = \frac{\prod_{\ell=1}^{N} e^{-[\sigma^o_{\ell D} - B(\alpha,\theta_{Ap})]^2/2(\Delta\sigma^o_D)^2}}{\eta} \qquad (7)$$

where:

$$\eta = \prod_{\ell=1}^{N} \sqrt{2\pi(\Delta\sigma^o_D)^2}$$

N = number of measurements

$\Delta\sigma^o_D$ = standard deviation of the measurements.

Since the purpose is to select values of $\hat{\alpha},\hat{\theta}_{Ap}$ that maximize expression (7), several simplifications can be made. The quantity, η, may be ignored since it is not a function of the parameters α,θ_{Ap}. The quantity $\Delta\sigma^o_D$ is assumed to be constant since any changes in the standard deviation of the backscatter measurement as a function of ground track over the rain forest appear to be small. Lastly, the logarithm of the likelihood function may be maximized, since the same values $\hat{\alpha},\hat{\theta}_p$ will maximize both the likelihood function and the log-likelihood function. Therefore, the condition to satisfy is:

$$-1/2 \sum_{\ell=1}^{N} (\sigma^o_{\ell D} - \bar{B})^2 = \max \qquad (8)$$

where $\bar{B} = B(\alpha,\theta_{Ap})$.

Since the function $\bar{G}/\bar{G}_0(\theta_p)$ is stored as a look-up table and very difficult to express analytically, the log-likelihood expression in (8) is maximized in two steps. First a migrating search is performed to approximately center a 3 x 3 matrix about the solution. Then the maximum of a bivariate interpolating polynomial fit to points on this matrix is found to obtain $\hat{\alpha},\hat{\theta}_p$.

The search is done by defining a log-likelihood matriz, $g_{i,j}$, as follows:

$$g_{i,j} = -1/2 \sum_{\ell=1}^{N} [\sigma^o_{\ell D} - B(\alpha_i, \theta_{jp})]^2 \tag{9}$$

where:

$\alpha_i = \alpha_o + i\Delta\alpha;\ i = -1,0,1$

$\theta_{jp} = \theta_{op} + j\Delta\theta_p;\ j = -1,0,1$

Since the actual values for P_T and G_0 should be reasonably close to the design specifications, initially α_o is chosen to be 1.0. Similarly, the design-specified pointing angle, θ_{D^p}, is chosen for the initial value of θ_{op}. Reasonable values for $\Delta\alpha, \Delta\theta_p$ appear to be 0.2 and 1.0 respectively. The values for $g_{i,j}$ are then compared to find the maximum. If the center point, $g_{0,0}$, is not the maximum, a new matrix is formed as follows:

$\alpha_i = \alpha_{max} + i\ \Delta\alpha;\ i = -1,0,1$

$\theta_{jp} = \theta_{p_{max}} + j\ \Delta\theta_p;\ j = -1,0,1$

where:

$\alpha_{max}, \theta_{p_{max}}$ are the α_i, θ_{jp} corresponding to the maximum of the previous matrix.

Searching continues until a matrix is formed which has the maximum at the center.

Estimates for relative bias, $\hat{\alpha}$, and actual pointing angle, $\hat{\theta}_p$, are found by fitting a bi-variate, quadratic interpolating polynomial to the values of $g_{i,j}$. Values of $\hat{\alpha}$ and $\hat{\theta}_p$ which maximize the polynomial are then determined analytically. The interpolating polynomial is of the form:

$$g(\hat{\alpha}, \hat{\theta}_p) = a\beta^2 + b\beta + c\gamma^2 + d\gamma + e\beta\gamma + f \tag{10}$$

where:

$\beta = (\alpha - \alpha_0\ )/\Delta\alpha$

$\gamma = (\hat{\theta}_p - \theta_{\ p}\ )/\Delta\theta_p$

$$a = \frac{g_{-1,0}}{2} - g_{0,0} + \frac{g_{1,0}}{2}$$

$$b = \frac{-g_{-1,0}}{2} + \frac{g_{1,0}}{2}$$

$$c = \frac{g_{0,-1}}{2} - g_{0,0} + \frac{g_{0,1}}{2}$$

$$d = \frac{-g_{0,-1}}{2} + \frac{g_{0,1}}{2}$$

$$e = g_{0,0} - g_{1,0} - g_{0,1} + g_{1,1}$$

$$f = g_{0,0}$$

where $g_{i,j}$ are the values of the likelihood matrix.

The maximum is found by taking the partial derivatives of the interpolating polynomial and setting them equal to zero. When the resultant equations are solved for $\hat{\alpha}$ and $\hat{\theta}_p$ we get

$$\hat{\alpha}_{ML} = \alpha_0 + \frac{\Delta\alpha(ed - 2bc)}{4ac - e^2} \qquad (11a)$$

$$\hat{\theta}_{p_{ML}} = \theta_{p_0} + \frac{\Delta\theta_p(be - 2ad)}{4ac - e^2} \qquad (11b)$$

where a,b,c,d,e are defined as above.

Final estimates for $\hat{\alpha}$ and $\hat{\theta}_p$ are made by averaging the values of $\hat{\alpha}_{ML}$ and $\hat{\theta}_{p_{ML}}$ obtained for each Doppler cell.

5.2.2 Long-Term Monitoring of Relative Bias

Periodic estimates of the relative bias during the mission will provide a means to correct for long-term drifts in transmitter power. If the pointing angle is not expected to change once $\hat{\theta}_p$ is determined, a simplified version of the algorithm in Section 5.2.1 may be used to estimate relative bias.

In this case the parameter of interest contains only one unknown, the relative bias α. The same procedure followed in Section 5.2.1 is used to solve this one-parameter case with a likelihood vector, g_i, replacing the matrix $g_{i,j}$. The vector is defined as:

$$g_i = -\frac{1}{2} \sum_{\ell=1}^{N} [\sigma^o_{\ell D} - \alpha_i \, \sigma^o_S]^2; \; i = -1,0,1 \qquad (12)$$

where:

$\sigma^o_{\ell D}$ = the NOSS SCATT measurement

σ^o_S = the standard target

α_i = $\alpha_0 + i\Delta\alpha$

α_0 = previously determined relative bias

Vector g_i is then fitted with a quadratic interpolating polynomial of the form:

$$g(\hat{\alpha}) = r\beta^2 + s\beta + t \qquad (13)$$

where:

$$\beta = \frac{(\hat{\alpha} - \alpha_0)}{\Delta\alpha}$$

$$r = \frac{g_{-1}}{2} - g_0 + \frac{g_1}{2}$$

$$s = -\frac{g_{-1}}{2} + \frac{g_1}{2}$$

$$t = g_0$$

g_i = the values of the vector calculated in equation (12).

By differentiating equation (13) and setting the result equal to zero, the maximum likelihood value of $\hat{\alpha}$ is found as:

$$\hat{\alpha}_{ML} = \alpha_0 - \frac{s\Delta\alpha}{2r} = \alpha_0 - \Delta\alpha\left(\frac{g_1 - g_{-1}}{g_{-1} - 2g_0 + g_1}\right)$$

A final estimate of $\hat{\alpha}$ may be determined by averaging the estimates of $\hat{\alpha}_{ML}$ obtained for each Doppler cell.

5.3 Implementation of Off-Nadir Bias Algorithm for NOSS SCATT

The flow chart in Figure 13 shows the relationship between the off-nadir bias algorithm and SCATT data processing. Earth-located σ^o data are screened to locate data over the Amazon rain forest. Then the Amazon map described in Section 3.0 is used to remove measurements that include either the Amazon river or one of its principal tributaries. Remaining rain-forest data are then supplied to the off-nadir bias algorithm.

Actual estimates of the relative bias and pointing angle are performed off-line from the main SCATT processing. This is necessary for two reasons: first, Brazil passes for several days are needed to create a sufficient data base for estimation; second, considerable human interaction and evaluation is needed to interpret the results.

Figure 14 shows a flow chart of the processing required in the off-nadir bias algorithm. Inputs to the algorithms are the SCATT σ^o data from the rain forest and the corresponding brightness temperatures T_B measured by the Large Antenna Multichannel Microwave Radiometer (LAMMR). Co-located LAMMR data are used to flag and remove potential rain-corrupted SCATT measurements. A data base is then created for use with the maximum-likelihood procedure described in Section 5.2. Estimates for relative bias and antenna pointing angle are computed for every combination of beam, cell and polarization. Approximate error bounds are determined using the results of several estimations. The following subsections describe in more detail the processing required.

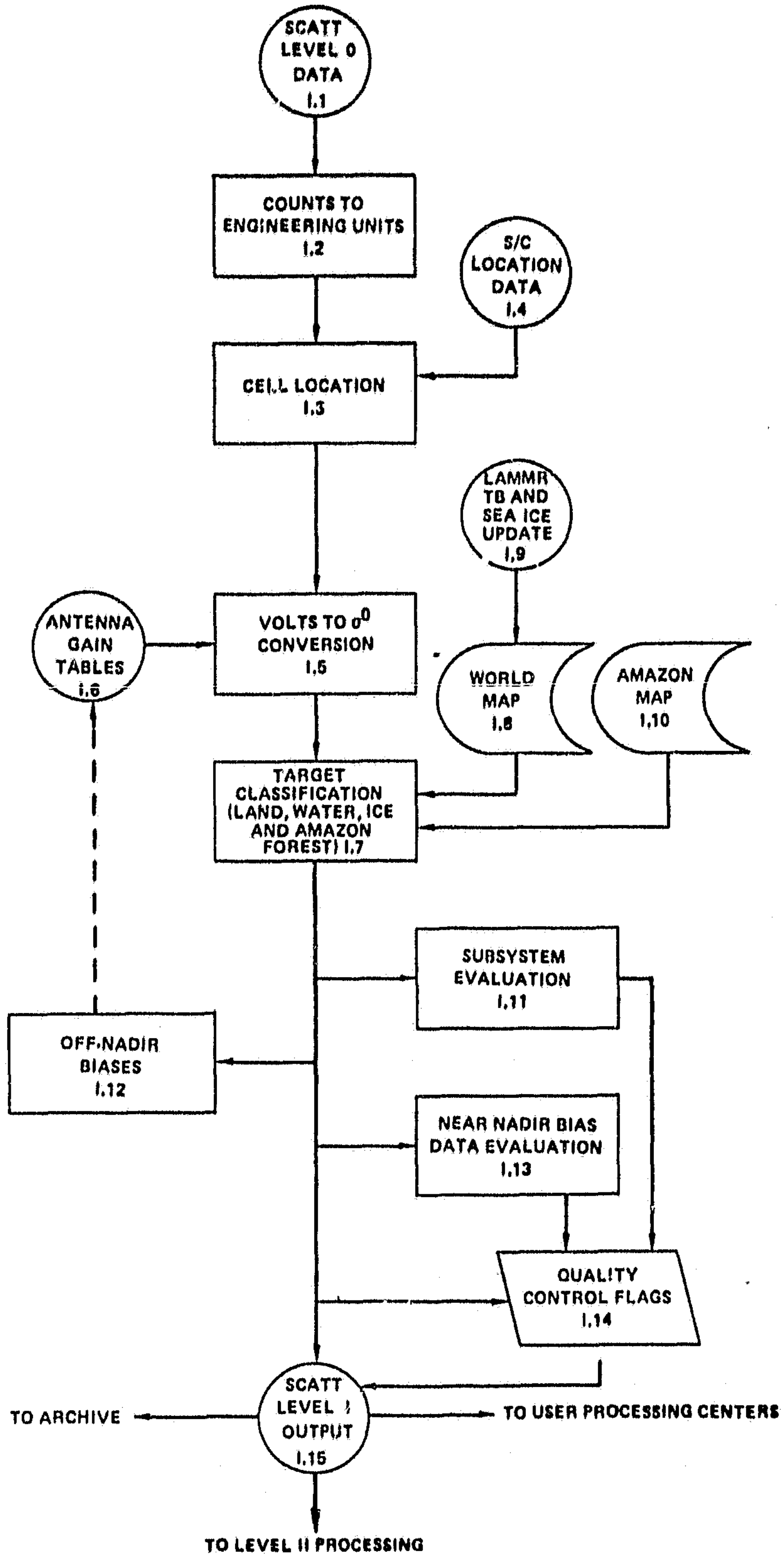

FIGURE 13: Proposed Processing of NOSS Scatterometer (SCATT) Data to Obtain σ^0

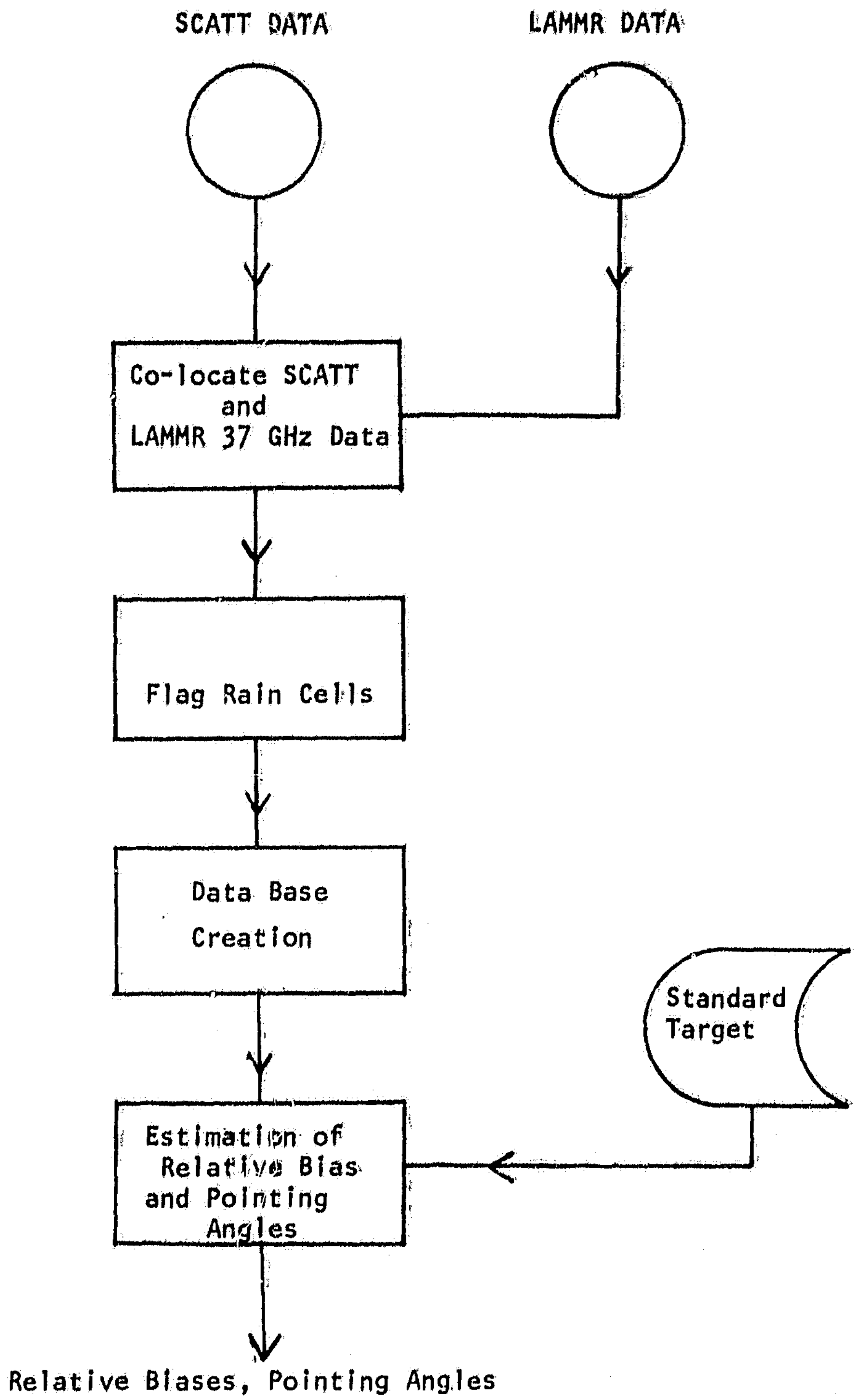

FIGURE 14: Processing Required for Off-Nadir Bias Correction

5.3.1 Co-Location of SCATT and LAMMR

To use LAMMR 37 GHz data to flag rain-corrupted SCATT measurements, T_B measurements must be co-located with individual SCATT σ^o measurements. The input data streams for both SCATT and LAMMR are assumed to be gridded into 50 km blocks and assigned a set of coordinates (i,j). Co-location is accomplished by: first, sorting both LAMMR T_B's and SCATT σ^o's independently by grid coordinates; second, for each coordinate pair (i,j) containing SCATT data the corresponding LAMMR grid point is located. Within the 50 km grid each SCATT cell is matched with the closest LAMMR cell.

5.3.2 Flagging Rain Cells

Co-located LAMMR 37 GHz T_B's are used to flag potential rain-corrupted SCATT cells. The brightness temperature of the Brazilian rain forest is very high due to high emissivity and surface temperature. However, in the presence of rain only the top portion of the rain cloud and not the forest is seen. Hence it is believed that the temperature measured should be lower when rain occurs than in clear sky conditions. Rain flags will be set whenever the measured temperature falls below a fixed cut-off temperature, T_{cut}.

Figure 15 shows the form of the 37 GHz brightness temperature histogram expected from the Amazon rain forest. The lobe at the lower brightness temperature corresponds to measurements made in rain conditions, while the lobe at higher brightness temperature corresponds to clear-sky conditions. A preliminary value for T_{cut} may possible be made from SEASAT radiometer measurements. However, it will be important to make a number of histograms with LAMMR data to confirm the assumed distribution shown in Figure 15 and to properly set T_{cut}.

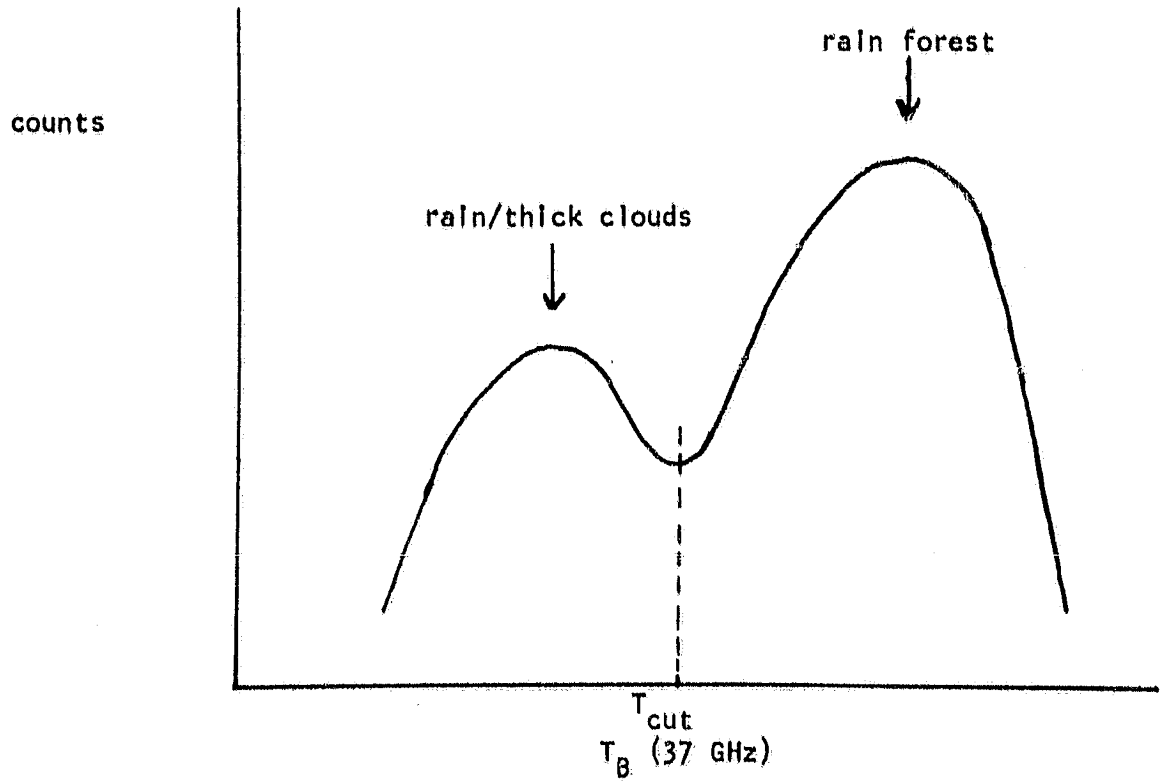

FIGURE 15: Nature of Expected Amazon T_B Distribution

5.3.3 Data Base Creation

Due to the large volume of data produced by the SCATT, estimation of relative bias and pointing angle is performed by using mean σ^o values computed for each pass over Brazil. Individual clear-sky SCATT measurements are grouped by beam, cell number and polarization. At the end of each Brazil pass the mean value, standard deviation, and average incidence angle is computed for each group containing more than twenty measurements. These estimates are also binned by beam, cell number and polarization. Estimation of relative bias and pointing angle takes place when each mean value bin has data from at least 10 passes. Since the bins will fill at different rates depending on the location of the satellite subtrack, provision is made to store up to 20 values in each.

5.3.4 Standard Target Creation

The maximum likelihood procedure described in Section 5.2 requires a standard target, $\sigma_S^o(\theta)$, defined over the entire off-nadir incidence angle range. Determination of σ_S^o will require consistent human evaluation and decision.

Initially plots and regressions of the mean value of σ^o versus incidence angle will be made from the data base described above. These plots and regressions will be compared with SEASAT results described in Section 4.0 and Appendix B. If there is good comparison in trend, the SEASAT model, $\sigma_{dB}^o = a\theta + b$, will be adopted with an appropriate level shift. If the trend of the SCATT data is significantly different, a new model determined from the analysis of several passes may be used. The final procedure used in creating the standard target will be determined once the initial comparisons are made.

5.3.5 Relative Bias and Pointing Angle Estimation

Early in a future mission with the NOSS design will be the implementation of the ML technique to determine both relative bias and pointing angle described in Section 5.2.2. Once a suitable value for pointing angle is determined for each beam, the simplified algorithm described in Section 5.2.3 may be used to monitor long-range transmitter drift. Both of these algorithms can be implemented using the same inputs so switching between algorithms should be trivial.

In this implementation the noisy data, $\sigma^o_{\ell D}$ in equations (8) and (12) are the mean values stored in the data base (Section 5.3.3). Separate estimates will be made for each combination of beam, cell and polarization. Repeated estimates should be made using subsequent data. Final estimates and bounds may be calculated by computing the means and standard deviations.

6.0 CONCLUSIONS AND FUTURE RESEARCH

Detailed analysis of SEASAT scatterometer data has confirmed the suitability of the Amazon rain forest for use as a standard calibration target. A simple straight line model for incidence angle variation appears to be quite adequate. Useful approximations for the model parameters may be determined from the SASS data. The accuracy of these approximations is limited by remaining biases between SASS antennas and the lack of independent rain-forest measurements for absolute calibration.

Maximum-likelihood estimation algorithms have been developed to correct off-nadir antenna biases for spaceborne scatterometers by utilizing rain-forest data. Application of those algorithms for the proposed NOSS scatterometer was straight-forward. Presumably these techniques could be adapted easily for calibrating other future systems.

Three important areas of research need to be undertaken to extend the usefulness of Amazon rain forest data to correct off-nadir antenna biases. First, measurements must be made throughout the year to determine the existence of any seasonal effects. The SEASAT measurements were made during only the dry season. Second, research needs to be done to confirm the proposed algorithm to screen out data corrupted by thick clouds and rain. The multifrequency radiometer measurements made with the NIMBUS 7 satellite could potentially contribute valuable information in both of these areas. Third, a calibration program using aircraft overflights is needed to better determine the absolute value of σ^0.

REFERENCES

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APPENDIX A

```
CBRZLND                    LAND/WATER ROUTINE FOR BRZILIAN RAIN FOREST
C
      SUBROUTINE LDBRZL
C
C     PURPOSE
C
C         THIS ROUTINE LOADS THE LAND WATERMAP
C
       INTEGER ARRAY(6,10,64),CODE
       REAL GLAT(6)/2.,0.,-2.,-4.,-6.,-8./
       REAL GLON(10)/74.,72.,70.,68.,66.,64.,
     &   62.,60.,58.,56./
       REAL LAT,LONG
C
C                                READ LAND/WATER MAP
C
       DO 10 I=1,6
       DO 10 J=1,10
       READ(01,900) (ARRAY(I,J,K),K=1,64)
 900  FORMAT(4X,8I8)
 10   CONTINUE
C
      RETURN
C
      ENTRY LNDH20(TLAT,TLONG, CODE)
C
C
C     PURPOSE
C
C         THIS ROUTINE FETCHES A LAND/WATER CODE
C         CORRESPONDING TO AN INPUT LATITUDE AND
C         LONGITUDE
C
C     INPUT ARGUMENTS
C
C         TLAT            *          LATITUDE (DEG)
C         TLONG           *          EAST LONGITUDE (DEG)
C
C     OUTPUT ARGUMENT
C
C         CODE            *          LAND/WATER CODE
      LAT = TLAT
      LONG = TLONG
C
      LONG = 360.0 - LONG
       ILAT = IFIX( (2.-LAT)/2. ) + 1
       JLON = IFIX( (74.-LONG)/2. ) + 1
       ITEP = IFIX( (GLAT(ILAT) - LAT)/0.25 )
       JTEP = IFIX( (GLON(JLON) - LONG)/0.25) + 1
       KELE = ITEP*8 + JTEP
       CODE = 1 + ARRAY(ILAT,JLON,KELE)
      RETURN
       END
 BRZVEG        VEGETATION CODE ROUTINE FOR BRAZILAIN AREA
```

```
      SUBROUTINE LDVEG
C
C     PURPOSE
C
C             THIS ROUTINE LOADS THE VEGETATION MAP
C
      INTEGER VEGTBL(5,3,64),VGCODE
C
      REAL LAT,LNG
C
      REAL VLAT(3)/2.0,-2.0,-6.0/
C
      REAL VLNG(5)/74.0,70.0,66.0,62.0,58.0/
C
C                                  READ VEGETATION MAP
C
      DO 10 I = 1,5
      DO 10 J = 1,3
      READ(02,900)(VEGTBL(I,J,K),K=1,64)
 10   CONTINUE
 900  FORMAT(4X,8I5)
C
      RETURN
CVEGCD COMPUTE CORRECT VEGETATION CODE
C
      ENTRY VEGCD( TLAT,TLNG, VGCODE )
C
C     PURPOSE
C
C             THIS ROUTINE INPUTS A LATITUDE AND A
C             LONGITUDE.  WITH THESE A VEGETAION
C             CODE IS DETERMINED
C
C     INPUT ARGUMENTS
C
C         TLAT          *        LATITUDE (DEG)
C         TLONG         *         EAST LONGITUDE(DEG)
C
C     OUTPUT ARGUMENT
C
C         VGCODE        *        VEGETATION CODE
C
      LAT = TLAT
      LNG = TLNG
C                                  CONVERT TO WEST LONGITUDE
C
      LNG = 360.0 - LNG
C
C                                  DETERMINE VEGETATION CODE
C
      ILAT = IFIX( (2.0 - LAT) / 4.0) + 1
      ILNG = IFIX( (74.0 - LNG) / 4.0) + 1
C
      INDEXX = IFIX( (VLAT(ILAT) - LAT) / 0.5)
      INDEXY = IFIX( (VLNG(ILNG) - LNG) / 0.5) + 1
```

```
      INDEXZ = INDEXX * 8 + INDEXY
C
      VGCODE = VEGTBL(ILNG,ILAT,INDEXZ)
C
      RETURN
      END
```

0	0	0	0	0	0	0	0	00000010
0	0	0	0	0	0	0	0	00000020
0	0	0	0	0	0	0	0	00000030
0	0	0	0	0	0	0	0	00000040
0	0	0	0	0	0	0	0	00000050
0	0	0	0	0	0	0	0	00000060
0	0	0	0	0	0	0	0	00000070
0	0	0	0	0	0	0	0	00000080
0	0	0	0	0	0	0	0	00000090
0	0	0	0	0	0	0	0	00000100
0	0	0	0	0	0	0	0	00000110
0	0	0	0	0	0	2	2	00000120
0	0	0	0	0	2	2	0	00000130
0	0	0	0	0	0	0	0	00000140
0	0	0	0	0	0	0	0	00000150
0	0	0	0	0	0	0	0	00000160
0	0	0	0	0	0	0	0	00000170
0	0	0	0	0	0	0	0	00000180
0	0	0	0	0	1	1	2	00000190
2	2	2	1	0	0	0	0	00000200
0	0	0	2	0	0	0	0	00000210
1	1	1	2	0	0	0	0	00000220
0	0	0	2	2	2	2	0	00000230
0	0	1	1	1	1	2	2	00000240
0	0	0	2	2	2	0	0	00000250
0	0	0	2	2	0	0	0	00000260
2	0	0	0	2	0	0	0	00000270
2	2	2	1	2	0	0	0	00000280
0	1	2	2	2	0	0	0	00000290
0	0	2	2	0	0	0	0	00000300
0	0	2	0	0	0	0	0	00000310
2	2	2	2	0	0	0	0	00000320
0	0	0	0	0	0	0	0	00000330
0	0	0	0	0	0	0	0	00000340
0	0	0	0	0	0	0	0	00000350
0	0	0	0	0	0	0	0	00000360
0	0	0	0	0	0	0	0	00000370
0	0	0	0	0	0	0	0	00000380
0	0	0	0	0	0	0	2	00000390
0	0	0	0	0	0	0	0	00000400
2	0	0	0	0	0	0	0	00000410
2	0	0	0	0	0	0	0	00000420
0	0	1	0	0	0	1	0	00000430
0	0	0	0	0	0	1	2	00000440
2	0	0	0	0	0	0	2	00000450
0	0	0	0	0	0	0	0	00000460
1	0	1	1	0	0	0	0	00000470
2	0	0	2	0	0	0	0	00000480
0	0	0	2	2	0	1	1	00000490
0	0	2	2	1	1	1	1	00000500
0	0	2	1	0	0	0	0	00000510
0	0	2	0	1	0	0	0	00000520
2	2	2	0	0	0	0	0	00000530
2	2	1	0	0	0	0	0	00000540
1	2	0	0	0	0	0	0	00000550

2	2	0	0	0	0	0	0	00000560
3	0	0	0	0	0	0	0	00000570
3	3	3	0	0	0	0	0	00000580
3	3	3	3	0	0	3	3	00000590
0	0	3	3	3	3	3	3	00000600
0	0	0	0	0	3	3	3	00000610
0	0	0	0	0	0	0	0	00000620
0	0	0	0	1	0	0	1	00000630
0	0	0	0	0	0	0	2	00000640
0	0	3	3	3	3	3	0	00000650
3	3	3	3	3	3	0	0	00000660
3	3	3	3	0	0	0	0	00000670
3	3	3	3	0	0	0	0	00000680
0	3	3	0	2	0	0	0	00000690
0	0	0	0	2	0	0	0	00000700
0	0	0	0	2	0	0	0	00000710
0	0	0	0	2	0	0	0	00000720
0	0	0	0	0	0	0	0	00000730
0	0	0	0	0	0	0	0	00000740
0	0	0	0	0	0	0	0	00000750
0	0	0	0	0	0	0	0	00000760
0	0	0	0	0	0	0	0	00000770
0	0	0	0	0	0	0	2	00000780
0	0	0	0	0	1	0	2	00000790
0	0	0	0	0	2	0	2	00000800
1	0	0	0	0	0	0	0	00000810
2	2	0	0	0	0	2	2	00000820
0	2	0	0	0	0	2	2	00000830
0	0	0	0	0	0	0	0	00000840
2	1	0	0	0	0	0	0	00000850
2	2	0	0	0	0	0	0	00000860
0	2	2	0	0	0	0	0	00000870
0	0	2	2	0	0	0	0	00000880
0	0	0	0	0	0	2	0	00000890
0	0	0	0	0	0	2	2	00000900
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0	0	0	0	0	0	0	0	00000020
0	0	0	0	0	0	0	0	00000030
0	0	0	0	0	0	0	0	00000040
0	0	0	0	0	0	0	0	00000050
0	0	0	0	0	0	0	0	00000060
0	0	0	0	0	0	0	0	00000070
0	0	0	0	0	0	0	0	00000080
0	0	0	0	0	0	0	0	00000090
0	0	0	0	0	0	0	0	00000100
0	0	0	0	0	0	0	0	00000110
0	0	0	0	0	0	0	0	00000120
0	0	0	0	0	0	0	0	00000130
0	0	0	0	7	7	7	7	00000140
0	0	0	0	1	1	1	1	00000150
0	0	0	0	1	1	1	1	00000160
0	0	0	0	10	10	10	10	00000170
0	0	0	0	8	8	8	8	00000180
0	0	0	0	8	8	8	8	00000190
0	0	0	0	8	8	8	8	00000200
0	0	0	0	8	8	8	8	00000210
0	0	0	0	8	8	8	8	00000220
0	0	0	0	2	2	8	8	00000230
0	0	0	0	2	2	2	2	00000240
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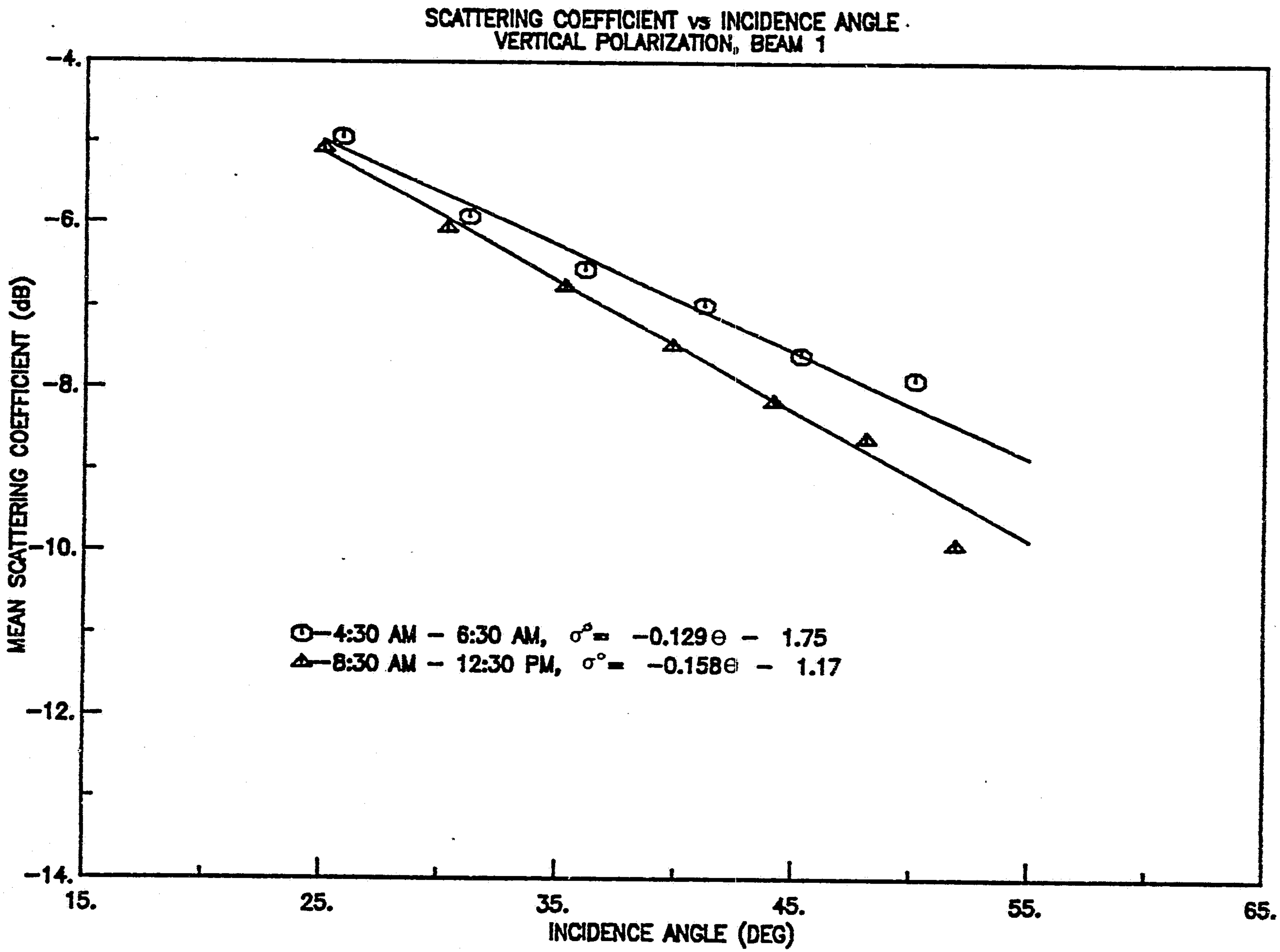
1	1	1	1	1	1	1	0	00000260
1	1	1	1	1	1	1	0	00000270
1	1	1	1	1	1	1	1	00000280
1	1	1	1	1	1	1	1	00000290
1	1	1	1	1	1	1	1	00000300
0	7	1	1	1	1	1	1	00000310
0	7	7	7	7	7	7	7	00000320
1	1	1	1	1	7	7	7	00000330
1	1	1	1	7	4	4	4	00000340
7	7	7	7	7	7	7	1	00000350
7	7	7	7	7	1	1	7	00000360
7	7	1	1	1	1	1	9	00000370
7	1	1	1	1	1	7	8	00000380
1	1	1	1	1	7	9	2	00000390
1	1	10	10	9	8	2	2	00000400
10	2	2	8	8	2	2	2	00000410
8	8	8	8	2	2	2	2	00000420
8	2	2	2	2	2	2	2	00000430
2	2	2	2	2	8	8	8	00000440
2	2	2	2	2	8	11	11	00000450
2	8	8	2	8	8	11	11	00000460
8	8	8	8	8	8	2	2	00000470
2	2	8	2	8	2	2	2	00000480
0	0	0	2	2	2	11	2	00000490
0	0	2	2	2	2	2	11	00000500
2	2	2	2	2	2	2	11	00000510
10	2	2	2	2	2	2	2	00000520
1	18	16	16	16	16	16	16	00000530
1	18	13	13	15	15	16	16	00000540
1	1	14	17	16	16	16	3	00000550

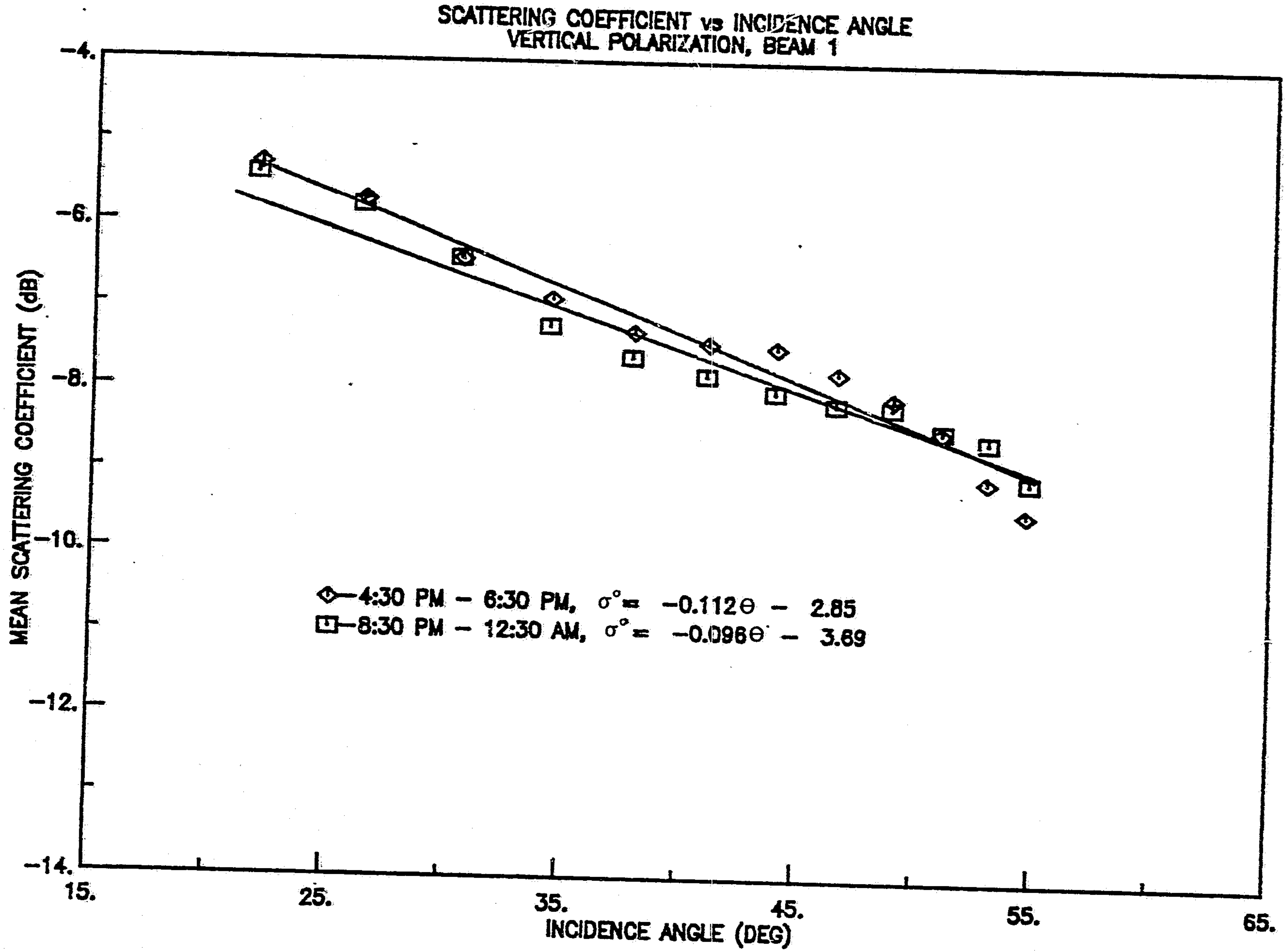
7	7	1	10	2	2	2	2	00000560
7	7	9	2	2	2	2	2	00000570
7	4	4	7	2	2	2	2	00000580
8	8	8	8	2	8	8	8	00000590
8	8	8	8	8	8	8	8	00000600
2	8	2	8	8	8	8	8	00000610
8	8	2	8	8	8	8	8	00000620
8	2	8	8	8	2	8	8	00000630
8	8	8	8	8	8	8	11	00000640
2	2	2	8	2	2	11	12	00000650
2	2	8	8	2	2	12	8	00000660
8	8	8	8	11	11	8	11	00000670
8	8	11	11	11	11	8	11	00000680
2	2	11	11	11	8	8	11	00000690
11	11	11	11	12	12	2	11	00000700
11	11	11	2	11	11	2	11	00000710
2	11	11	11	2	2	2	2	00000720
2	8	2	2	11	0	0	0	00000730
11	8	2	2	11	11	11	11	00000740
12	12	11	11	2	2	2	2	00000750
12	11	11	2	2	2	2	2	00000760
8	2	2	2	2	2	2	2	00000770
8	2	2	2	2	2	2	2	00000780
15	16	2	2	2	2	2	2	00000790
16	16	2	2	2	2	2	2	00000800
2	16	16	2	2	2	2	2	00000810
2	2	2	2	11	2	2	8	00000820
8	8	8	12	12	4	4	4	00000830
8	4	8	8	8	4	4	8	00000840
8	8	8	8	8	8	8	11	00000850
8	8	12	12	8	8	12	11	00000860
11	11	12	12	12	12	11	11	00000870
12	8	12	11	11	2	2	2	00000880
8	12	11	11	11	2	2	2	00000890
11	11	11	11	11	2	2	2	00000900
11	11	11	2	11	2	2	2	00000910
11	2	2	2	11	11	2	2	00000920
11	11	2	2	2	11	11	2	00000930
11	11	2	2	2	2	2	2	00000940
11	2	2	2	2	2	2	2	00000950
2	2	2	2	2	2	2	2	00000960
11	11	2	11	2	2	2	2	00000970
2	2	2	2	2	2	2	2	00000980
2	2	2	11	2	2	2	2	00000990
2	2	11	11	11	2	2	2	00001000
2	2	11	2	2	2	2	2	00001010
2	2	11	2	2	11	2	2	00001020
2	2	2	2	2	11	11	11	00001030
8	8	2	8	8	11	11	11	00001040
8	8	8	8	8	8	8	12	00001050
4	4	4	8	2	2	12	8	00001060
4	4	8	2	2	2	2	2	00001070
8	8	8	2	2	2	2	2	00001080
2	2	2	2	2	2	2	2	00001090
11	11	11	2	2	2	2	2	00001100

11	2	2	2	2	2	2	2	00001110
2	2	2	2	2	2	2	2	00001120
2	2	2	2	2	2	2	2	00001130
2	2	2	2	2	2	2	2	00001140
2	2	2	2	2	2	2	2	00001150
11	11	11	11	2	2	2	2	00001160
11	11	11	11	11	11	11	2	00001170
2	2	19	20	20	11	2	2	00001180
2	11	11	19	19	19	19	2	00001190
2	11	2	2	19	19	19	2	00001200

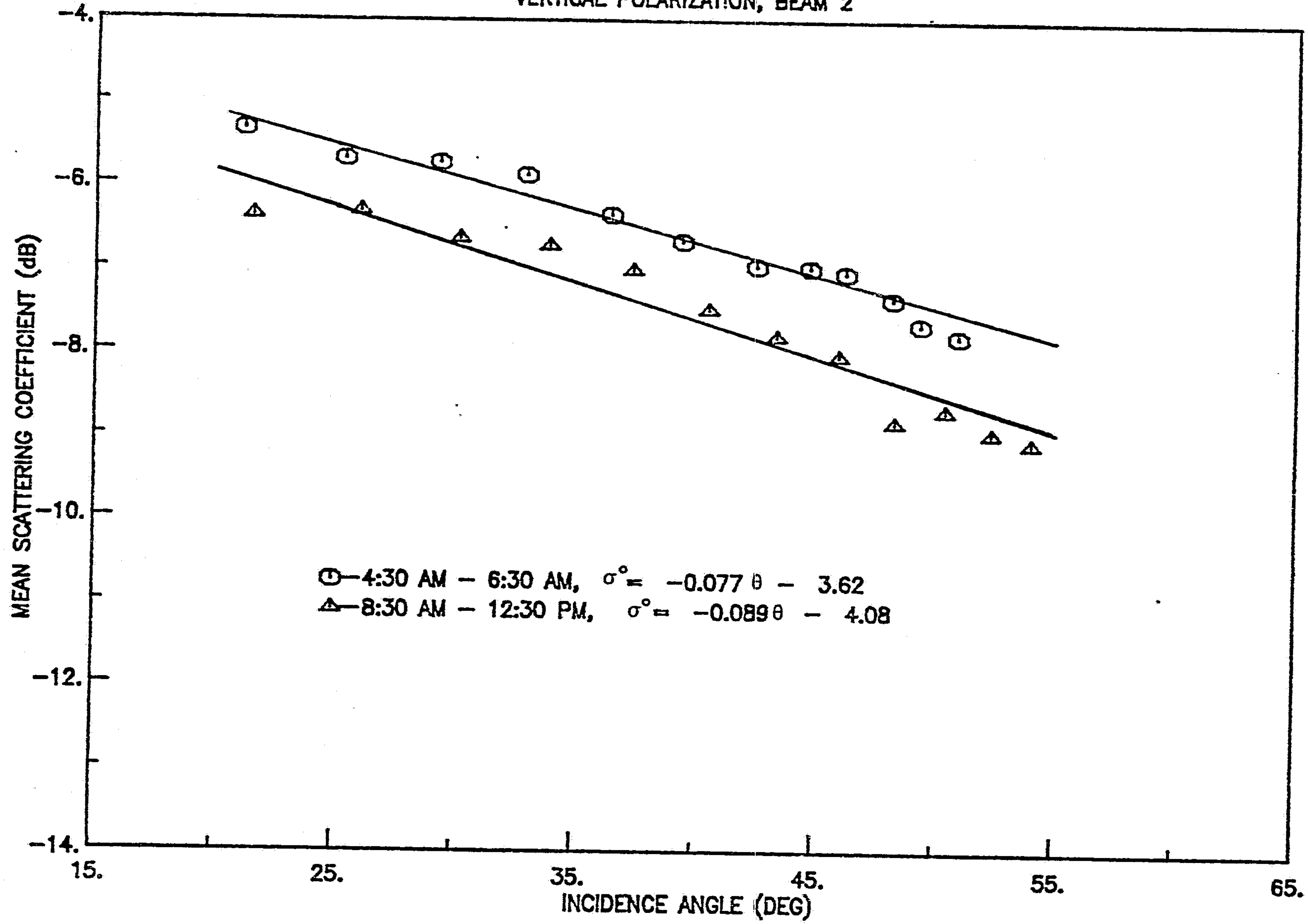
APPENDIX B

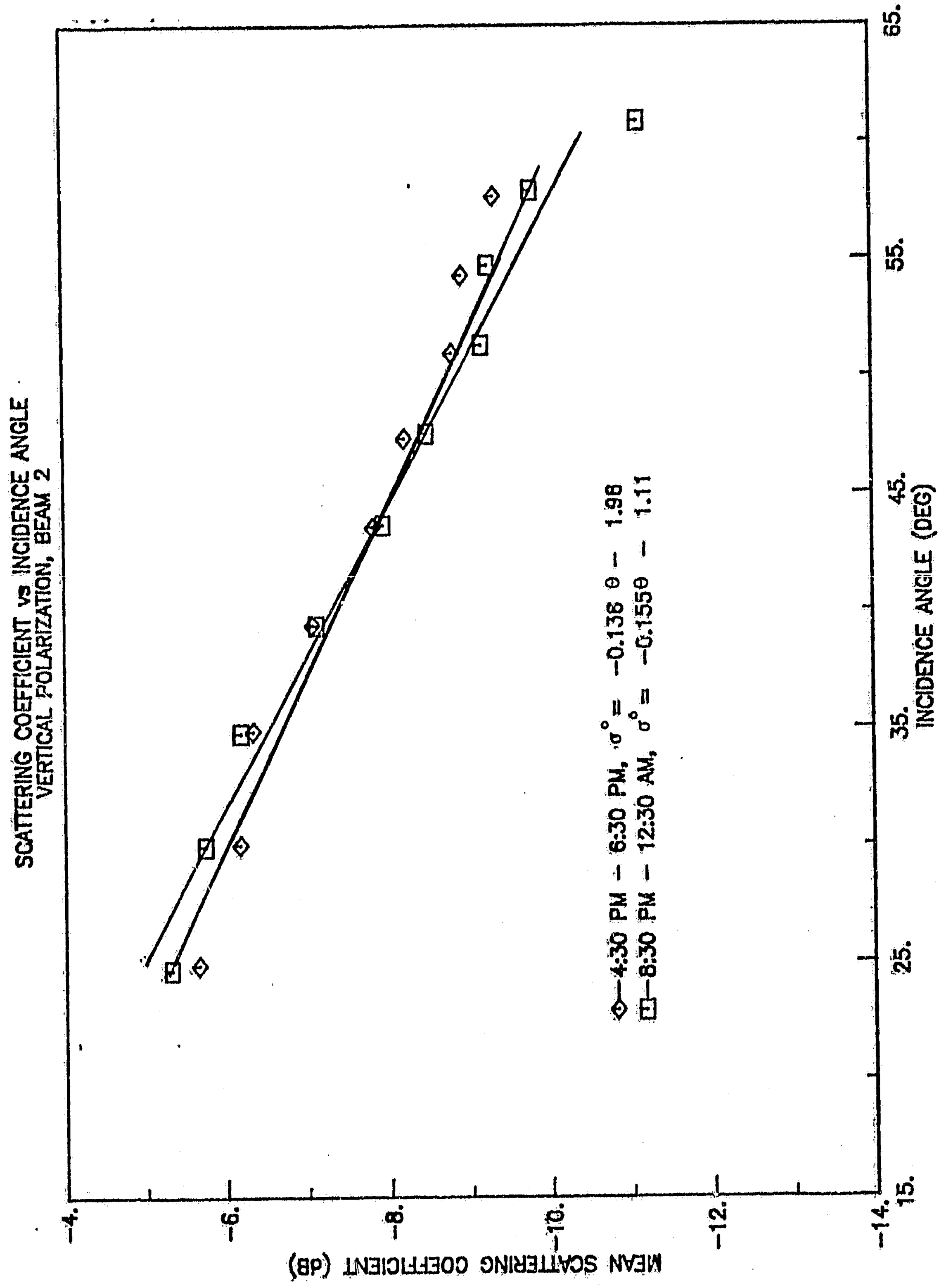
PLOTS OF INCIDENCE ANGLE VARIATIONS
FOR BEAM 1, 2, 3

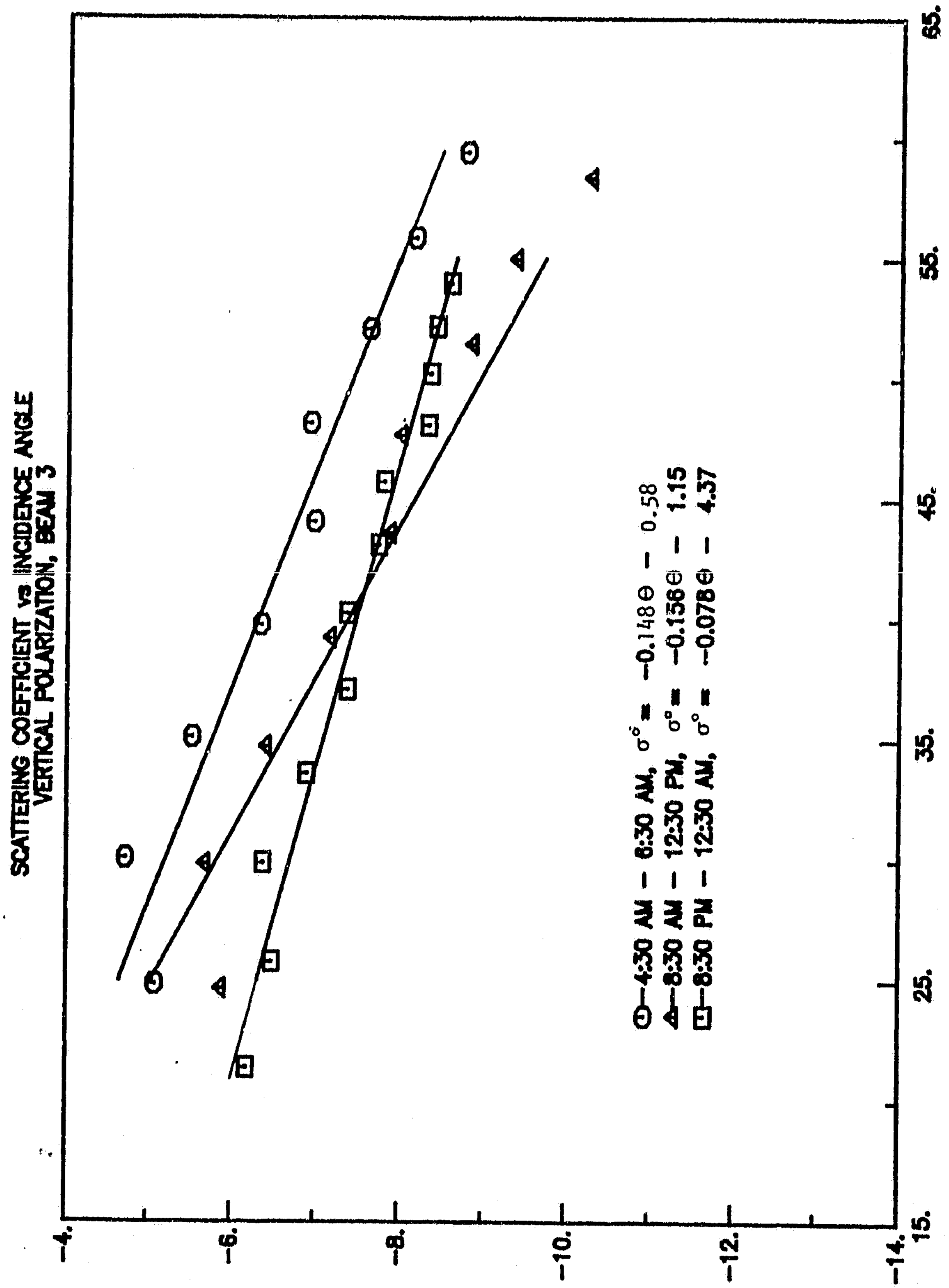

SCATTERING COEFFICIENT vs INCIDENCE ANGLE
VERTICAL POLARIZATION, BEAM 1
MEAN SCATTERING COEFFICIENT (dB)
-4.
-6.
-8.
-10.
-12.
-14.
15.
25.
35.
45.
55.
65.
INCIDENCE ANGLE (DEG)
4:30 AM - 6:30 AM, σ° = -0.129θ - 1.75
8:30 AM - 12:30 PM, σ° = -0.158θ - 1.17


SCATTERING COEFFICIENT vs INCIDENCE ANGLE
VERTICAL POLARIZATION, BEAM 1
MEAN SCATTERING COEFFICIENT (dB)
-4.
-6.
-8.
-10.
-12.
-14.
15.
25.
35.
45.
55.
65.
INCIDENCE ANGLE (DEG)
4:30 PM - 6:30 PM, σ° = -0.112Θ - 2.85
8:30 PM - 12:30 AM, σ° = -0.098Θ - 3.69

SCATTERING COEFFICIENT vs INCIDENCE ANGLE
VERTICAL POLARIZATION, BEAM 2




SCATTERING COEFFICIENT vs INCIDENCE ANGLE
VERTICAL POLARIZATION, BEAM 2
◇—4:30 PM – 6:30 PM, σ° = −0.136 θ – 1.98
⊡—8:30 PM – 12:30 AM, σ° = −0.155θ – 1.11
MEAN SCATTERING COEFFICIENT (dB)
INCIDENCE ANGLE (DEG)
-4.
-6.
-8.
-10.
-12.
-14.
15.
25.
35.
45.
55.
65.


SCATTERING COEFFICIENT vs INCIDENCE ANGLE
VERTICAL POLARIZATION, BEAM 3
⊖—4:30 AM – 8:30 AM, σ° = −0.148θ – 0.58
△—8:30 AM – 12:30 PM, σ° = −0.156θ – 1.15
⊡—8:30 PM – 12:30 AM, σ° = −0.078θ – 4.37
-4.
-6.
-8.
-10.
-12.
-14.
15.
25.
35.
45.
55.
65.

APPENDIX C

NOSS ALGORITHM SPECIFICATION SHEETS

SUBMODULE

IDENTIFICATION	TITLE
1.12.1	Co-location of SCATT with LAMMR T_B's Over the Amazon
1.12.2	Rain Flags
1.12.3	Data Base Creation
1.12.4	Relative Target Creation
1.12.5	Relative Antenna Gain Interpolation
1.12.6	Standard σ^o Interpolation
1.12.7	Relative Gain Table and Antenna Pointing Angle Corrections
1.12.8	Long Range Monitoring of Relative Biases

I. SUBMODULE REFERENCE NO. 1.12.1

II. SENSOR: SCATT

III. ORIGINATOR/PHONE: E.M. BRACALENTE, I.J. BIRRER/804-827-3631, 913-864-4836

IV. SUBMODULE TITLE: SCATT-LAMMR 37 GHz Colocation over the Amazon

V. SUBMODULE FUNCTION: This algorithm colocates the LAMMR brightness temperatures at 37 GHz with the SCATT data over the Amazon.

VI. INPUTS:

(1) SCATT data over the Amazon (50 km data blocks)

(2) LAMMR brightness temperatures at 37 GHz over the Amazon (50 km data blocks)

VII. OUTPUTS: SCATT data vector with colocated LAMMR T_B's appended to data vector.

VIII. AUXILIARY DATA: TBD

IX. EXCEPTIONS: TBD

X. PROCESSING REQUIRED: TBD

XI. COMMENTS: Since the calculation of brightness temperatures is a level II computation and this is a LEVEL I SCATT algorithm, provision must be made to feed back the LAMMR T_B's to this algorithm on a non-real time basis. The input data stream for both the SCATT and the LAMMR is assumed to be in 50 km data blocks and will be assigned subgrid coordinates (i,j). For these coordinates the following procedure could be used for colocation:

(a) Sort the LAMMR and SCATT independently by grid coordinates into two row ordered lists as follows:

$$\text{LAMMRLIST} = T_{b_{1,1}}, T_{b_{1,2}}, T_{b_{1,3}} \ldots T_{b_{1,N}}, T_{b_{2,1}}, T_{b_{3,2}} \ldots T_{b_{M,N}}$$

$$\text{SCATT LIST} = \text{SCATT}_{1,1}, \text{SCATT}_{1,2}, \ldots \text{SCATT}_{1,Q}, \text{SCATT}_{2,1}, \text{SCATT}_{2,2} \ldots \text{SCATT}_{P,Q}$$

where $T_{b_{i,j}}$ is the 37 GHz brightness temperature of grid coordinate i,j

$\text{SCATT}_{i,j}$ is the scatterometer data vector at grid coordinate i,j

(b) Colocate SCATT and LAMMR data by simply moving down the lists in parallel. For each $SCATT_{i,j}$ append the corresponding $T_{b_{i,j}}$. If more than one brightness temperature exists, choose the closest.

I. SUBMODULE REFERENCE NO: 1.12.2

II. SENSOR: SCATT

III. ORIGINATOR/PHONE: E.M. Bracalente, I.J. Birrer/804-827-3631, 913-864-4836

IV. SUBMODULE TITLE: RAIN FLAG

V. SUBMODULE FUNCTION: Set a rain flag if the LAMMR brightness temperature at 37 GHz is below a critical value, T_{cut}, to indicate the possibility of rain.

VI. INPUTS:

LAMMR T_B's at 37 GHz colocated with SCATT cells (Submodule 1.12.1)

VII. OUTPUTS:

Rainflag (RFLAG)

VIII. AUXILIARY DATA: TBD

IX. EXCEPTIONS: TBD

X. PROCESSING REQUIRED:

(a) If T_{B37} is less than T_{cut}, then RFLAG = 1 (true), otherwise RFLAG = Ø (false).

XI. COMMENTS:

(a) This procedure may be designed to handle a cell at a time or all of the cells for a particular beam.

(b) The value of T_{cut} must be determined experimentally from LAMMR data. This could be done by plotting a histogram of LAMMR data over the Amazon taken on the first several passes. An initial guess for T_{cut} will be provided based on SeaSat-SMMR data.

I. SUBMODULE REFERENCE NO: I.12.3

II. SENSOR: SCATT

III. ORIGINATOR/PHONE: E.M. Bracalente, I.J. Birrer/804-827-3631, 913-864-4836

IV. SUBMODULE TITLE: DATA BASE CREATION

V. SUBMODULE FUNCTIONS: This module creates a data base of SCATT data over the Amazon rain forest. Data that is not flagged for rain (Submodule I.12.2) is sorted by beam, polarization, cell no. At the end of each pass over Brazil, the mean NRCS, standard deviation of NRCS, average incidence angle, and average antenna broadbeam angle for each combination of beam, cell, and polarization are computed. These results along with the number of points in each bin are stored in a semi-permanent fashion (tape, disk) for later processing.

Plots of mean NRCS ($\overline{\sigma^o}$) versus cell no. are made for any combination of beam, polarization, etc. for which data exists.

VI. INPUTS:

SCATT data over Amazon.

Rain Flag. (Submodule I.12.2)

VII. OUTPUTS:

Key Parameters	No. of Parameters
Mean NRCS ($\overline{\sigma^o}$)	600*
Standard Deviation $\Delta\sigma^o$	600*
Count (N)	600*
Average Incidence Angle $\overline{\theta}$	600*
Average Broadbeam Antenna Angle $\overline{\varepsilon}$	600*
Pointer (P)	600

*Temporary data storage must be sufficient to store results from up to 20 passes or approximately 60,600 parameters.

VIII. AUXILIARY DATA: None

IX. EXCEPTIONS: If there are less than ≈ 20 points within a bin, no processing is performed.

X. PROCESSING REQUIRED:

(a) Sort data by beam (i), cell(j), polarization(k) (see note 1).

(b) At the end of each pass, for each combination of i,j,k where there are more than 20 values, compute

$$\ell = P_{i,j,k}$$

$$\overline{\sigma^o}_{i,j,k,\ell} = \frac{1}{N_{i,j,k}} \sum_{n=1}^{N_{i,j,k}} \sigma^o_{i,j,k,n}$$

$$\Delta\sigma^o_{i,j,k,\ell} = \left(\frac{\sum_{n=1}^{N_{i,j,k}} (\sigma^o_{i,j,k})^2 - N_{i,j,k}\, \overline{\sigma^o}_{i,j,k,\ell}}{N_{i,j,k} - 1} \right)^{1/2}$$

$$\overline{\theta}_{i,j,k,\ell} = \frac{1}{N_{i,j,k}} \sum_{n=1}^{N_{i,j,k}} \theta_{i,j,k,n}$$

$$\overline{\varepsilon}_{i,j,k,\ell} = \frac{1}{N_{i,j,k}} \sum_{n=1}^{N_{i,j,k}} \varepsilon_{i,j,k}$$

$$P_{i,j,k} = P_{i,j,k} + 1$$

where $N_{i,j,k}$ is the number of points in each i,j,k bin.

(c) Plot $\overline{\sigma^o}$ versus cell number (j) for different combinations of beam (i) and polarization (k)

X. COMMENTS:

(1) Semi-permanent storage should be provided for all of the input SCATT and LAMMR data over the Amazon.

(2) σ^o are assumed to be in ratio form.

(3) Well-written computer code should only need to store running sums during each pass and not all of the data values.

Note 1: Other sorting parameters may be required.

I. SUBMODULE REFERENCE NO. 1.12.4

II. SENSOR: SCATT

III. ORIGINATOR/PHONE: E.M. Bracalente, I.J. Birrer/804-827-3631, 913-864-4836

IV. SUBMODULE TITLE: Relative target creation

V. SUBMODULE FUNCTION: This submodule takes the summary Amazon data (Means and Standard deviations) and creates a table of $\sigma^o(\theta)$ at 1° incidence angle steps for the off-nadir incidence angle data of the SCATT. This submodule will require considerable human interaction off-line.

VI. INPUTS:

Mean, Standard deviations, average incidence angles from submodule 1.12.3. Plots of σ^o versus cell no. from submodule 1.12.3.

VII. OUTPUT:

Table of NRCS in one degree steps over the off-nadir incidence angle range for both H and V polarizations.

VIII. AUXILIARY DATA: TBD

IX. EXCEPTIONS: TBD

X. PROCESSING REQUIRED: Since this task will require consistent human evaluation and decision, it will not be possible initially to fully automate this procedure. The following steps are envisioned at this point:

(a) Compare data from each polarization and beam with SeaSat Brazil model (or other models of Brazil if available). This will be done by:

(1) Examining the plots from Submodule 1.12.3.

(2) Regressing Mean NRCS (σ^o) against the general model $\sigma^o = F(\theta)$ determined from SeaSat.

(b) If the results from (a) show a good fit with SeaSat model (except for a level shift), the SeaSat model will be adopted as the standard target. (Level shifted, if necessary). The beam which best fits the SeaSat model for each polarization will be used to determine the level shift.

(c) If the data from the SCATT is best modeled by a different function than was used with the SeaSat, this model may be chosen to generate the standard table.

XI. COMMENTS:

(1) The exact approach taken will probably be determined from a preliminary analysis of a few passes.

(2) If there is good agreement with the SASS model or a satisfactory new model developed, it may be possible to automate the procedure.

I. SUBMODULE REFERENCE NO: 1.12.5

II. SENSOR: SCATT

III. ORIGINATOR/PHONE: E.M. Bracalente, I.J. Birrer/804-827-3631, 913-864-4836

IV. SUBMODULE TITLE: Relative Antenna Gain Interpolation

V. SUBMODULE FUNCTIONS: Use a three-point interpolation to determine the relative antenna gain at the input incidence angle.

VI. INPUTS:

Mean incidence angle $(\overline{\theta})$ and mean antenna broadbeam antenna angle $(\overline{\varepsilon})$ corresponding to each θ and value of pointing angle θ_{n^p}

VII. OUTPUT:

Relative antenna gain $G/G_o(\overline{\theta})$

VIII. AUXILIARY DATA:

to table of relative gain values in Module 1.6

IX. EXCEPTIONS: TBD

X. PROCESSING REQUIRED:

(a) $\varepsilon = \overline{\varepsilon} + (\theta_p - \theta_{n^p})$

(b) Find ε_I, the integer smaller than ε

$Z = \theta$

(c) $P = \varepsilon - \varepsilon_I$

(d) $G/G_o(Z) = \frac{P(P-1)}{2} G(\varepsilon_I - 1) + (1-P^2) G(\varepsilon_I) + \frac{P(P+1)}{2} G(\varepsilon_I + 1)$

where G/Go(Z) is the relative gain at an incidence angle of Z degrees.

XI. COMMENTS: TBD

I. SUBMODULE REFERENCE NO: I.12.6

II. SENSOR: SCATT

III. ORIGINATOR/PHONE: E.M. Bracalente, I.J. Birrer/804-827-3631, 913-864-4836

IV. TITLE: Standard σ^o Interpolation

V. SUBMODULE FUNCTIONS: Use a three-point interpolation to determine the standard NRCS of the Amazon rain forest at the input incidence angle.

VI. INPUT: Incidence angle (θ)

VII. OUTPUT: Standard NRCS σ_A^o

VIII. AUXILIARY DATA:

Tabular form of standard radar target

or

Tabular form of relative target from Submodule I.12.4.

IX. EXCEPTIONS: TBD

X. PROCESSING REQUIRED:

(a) Find θ_I the largest integer smaller than θ

(b) $P = \theta - \theta_I$

(c) $\sigma_A^o(\theta) = \frac{P(P-1)}{2}\,\sigma^o(\theta_I - 1) + (1 - P^2)\sigma^o(\theta_I) + \frac{P(P+1)}{2}\,\sigma^o(\theta_I + 1)$

where $\sigma^o(Z)$ is the NRCS of the Amazon rain forest at an incidence angle of Z degrees.

XI. COMMENTS: TBD

I. SUBMODULE REFERENCE: 1.12.7

II. SENSOR: SCATT

III. ORIGINATOR/PHONE: E.M. Bracalente, I.J. Birrer/804-827-3631, 913-864-4836

IV. SUBMODULE TITLE: Relative Gain and Antenna Pointing Angle Corrections

V. SUBMODULE FUNCTIONS: This submodule is designed to provide an output to be used to verify and locate possible errors in the relative gain table (Module 1.6) and in the antenna pointing angle estimates. A maximum likelihood process will be applied using the means and standard deviations determined in Submodule 1.12.3 to estimate values for the antenna gain bias and pointing angle for each combination of beam, cell, and polarization. Average biases and pointing angle for each beam and polarization are also computed.

VI. INPUTS:

(1) Mean σ^o, standard deviation of σ^o, and average incidence angle for the Amazon rain forest passes (Submodule 1.12.3 outputs).

VII. OUTPUTS:

Key Parameters	No. of parameters
Antenna biases $(\hat{\alpha})$	600
Pointing angles $(\hat{\theta}_p)$	600
Average biases $(\overline{\alpha})$	12
Average Pointing angles $(\overline{\theta}_p)$	12

VIII. AUXILIARY DATA: Nominal Pointing Angle, (θ_p) $\Delta\alpha$, $\Delta\theta_p$

IX. EXCEPTIONS: TBD

X. PROCESSING REQUIRED:

For each combination of beam (i), cell (j), and polarization (k) perform the following algorithm (i x j x k = 600 times).

(a) $\alpha_o = 1.0$, $\theta_o p = \theta p$ (the nominal pointing angle)

(b) Determine a 3 x 3 matrix, $g_{m,n}$ as follows:

$$\alpha_m = \alpha_o + m\,\Delta\alpha;\ m = 1,0,1$$

$$\theta_n p = \theta_o p + n\,\Delta\theta p;\ n = -1,0,1$$

$$g_{m,n} = \frac{-1}{2} \sum_{\ell=1}^{10} \left\{ \overline{\sigma^o}_{i,j,k,\ell} - \alpha_m \frac{[G/G\emptyset(\theta_n p)]^2}{[G/G\emptyset(\theta_p)]^2} \sigma^o_A \right\}^2$$

where

$G/G\emptyset$ ( ) is the output of Submodule 1.12.5 at $\overline{\theta}_{i,j,k,\ell}$

σ^o_A ( ) is the output of Submodule 1.12.6 at $\overline{\theta}_{i,j,k,\ell}$

$\overline{\sigma^o}$ and $\overline{\theta}$ are the output of Submodule 1.12.3

(c) Search the matrix $g_{m,n}$ for the maximum value $g_{mmax,nmax}$

If mmax = nmax = 0 go to (d);

otherwise $\alpha_o = \alpha_{mmax}$

$\theta_o p = \theta p_{nmax}$

repeat (b)

(d) Compute the constants of a bivariate interpolating polynomial for g.

$$a = \frac{g_{1,0}}{2} - g_{0,0} + \frac{g_{1,0}}{2}$$

$$b = \frac{-g_{-1,0}}{2} + \frac{g_{1,0}}{2}$$

$$c = \frac{g_{0,-1}}{2} - g_{0,0} + \frac{g_{0,1}}{2}$$

$$d = \frac{-g_{0,-1}}{2} + \frac{g_{0,1}}{2}$$

$$e = g_{0,0} - g_{1,0} - g_{0,1} + g_{1,1}$$

$$f = g_{0,0}$$

where $g_{m,n}$ are the points of the 3 x 3 matrix

(e) Solve for antenna bias, pointing angle

$$\hat{\alpha}_{i,j,k} = \alpha_0 + \frac{\Delta\alpha(ed - 2bc)}{4ac - e^2}$$

$$\hat{\theta p}_{i,j,k} = \theta_0 p + \frac{\Delta\theta_p(be - 2ad)}{4ac - e^2}$$

(f) Compute average parameter over each beam and polarization

$$\overline{\alpha}_{i,k} = 1/50 \sum_{j=1}^{50} \hat{\alpha}_{i,j,k}$$

$$\bar{\theta}_p = \frac{1}{50} \sum_{j=1}^{50} \hat{\theta}_{p_{i,j,k}}$$

XI. COMMENTS:

(1) It is assumed that this processing must take place only for the outer 50 cells.

(2) Initial values for $\Delta\alpha$,$\Delta\theta p$ are 0.2 and 1.0 respectively.

(3) A test should be made to tell if there are at least ≈ 10 elements in each beam, cell, polarization bin of the input data before this submodule is called. The bins are set to handle up to 20 elements to allow for the varying rates of filling. (On the long term average the bins will fill at the same rate). After the first 10 levels are processed by this submodule, further data from 1.12.3 may be stored over this data. This test can be performed by interrogating $P_{i,j,k}$ of Submodule 1.12.3.

(4) Mean σ^o and standard deviation of σ^o should be in ratio form.

I. SUBMODULE REFERENCE NO: 1.12.8

II. SENSOR: SCATT

III. ORIGINATOR/PHONE: E.M. Bracalente, I.J. Birrer/804-827-3631, 913-864-4836

IV. SUBMODULE TITLE: Long-Term Monitoring of Relative Biases

V. SUBMODULE FUNCTION: Given the value of the pointing angle for each beam and polarization, compute the relative bias for each of the cells in that beam; also, provide long term checks for both biases and antenna patterns.

VI. INPUTS:

(1) Mean NRCS ($\overline{\sigma^o}$) and average incidence angles for the Amazon rain forest passes (SUBMODULE 1.12.3 outputs)

(2) Previously determined average pointing angles ($\overline{\theta}_p$) for each beam (i) and polarization (k) (Submodule 1.12.7 outputs).

(3) Initial guess for relative biases - outputs from either submodule 1.12.7 ($\overline{\alpha}$) or some first guess (e.g., 1.0).

VII. OUTPUTS

Key Parameter	No. of Parameters
Antenna bias ($\hat{\alpha}$)	600
Average biases ($\overline{\alpha}$)	12

VIII. AUXILIARY DATA: Standard radar target, or output from Submodule 1.12.4, $\Delta\alpha$

IX. EXCEPTIONS: TBD

X. PROCESSING REQUIRED:

For each combination of beam (i), cell (j) and polarization (k) perform the following algorithm (i x j x k = 600 times).

(a) $\alpha_o = \hat{\alpha}_{i,j,k}$ if available; otherwise $\alpha_o = 1.0$.

(b) Determine a 3 element vector, g_m, as follows:

$$\alpha_m = \alpha_o + m\Delta\alpha;\ m = 1,0,1$$

$$g_m = -\frac{1}{2} \sum_{\ell=1}^{10} ([\overline{\sigma^o}_{i,j,k,\ell} - \alpha_m \sigma^o_A])^2$$

where $\sigma^o_A(\ )$ is the output of submodule 1.12.6 at $\overline{\theta}_{i,j,k,\ell}$

$\overline{\sigma^o}$ and $\overline{\theta}$ are the output of sumbodule 1.12.3

(c) $$\hat{\alpha}_{i,j,k} = \alpha_0 - \Delta\alpha\left(\frac{g_1 - g_{-1}}{g_{-1} - 2g_0 + g_1}\right)$$

(d) $$\bar{\alpha}_{i,k} = \frac{1}{50}\sum_{j=1}^{50} \hat{\alpha}_{i,j,k}$$

XI. COMMENTS:

(1) It is assumed that this processing will take place only for the outer 50 cells of the Scatt Beams.

(2) Initial value for $\Delta\alpha$ is 0.2

(3) As in Submodule 1.12.7, a test must be made to be sure that there are 10 elements in each bin. (For further details see Submodule 1.12.7 see XI 3).

(4) Mean σ^0 and standard deviation of σ^0 must be in ratio form.