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CRREL

SADARM Captive Flight Tests

35-GHz Ground-Based Radar System Measurements

Joyce A. Nagle

April 1992

For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, *published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.*

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U.S. Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

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35-GHz Ground-Based Radar System Measurements

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Prepared for
ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND
PICATINNY ARSENAL

PREFACE

This report was prepared by Dr. Joyce A. Nagle, Research Physical Scientist, Geophysical Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. The data reported herein have been compiled by CRREL under Contract no. 0311-1164 for the Search and Destroy Armaments (SADARM) PM Office, Army Armament Research, Development and Engineering Command (ARDEC), Picatinny Arsenal, New Jersey.

The millimeter-wave radar measurements of the winter background environment were made by personnel from the Geophysical Sciences Branch of CRREL. The methods for calculating the millimeter-wave radar backscattered power and the normalized radar cross-section were developed by Dr. D.J. McLaughlin, Dr. R.S. Raghavan and N. Allan of the Radar Systems Laboratory at Northeastern University, Boston, Massachusetts, for CRREL. The actual processing of the data was performed by Dr. J.A. Nagle at CRREL.

Data contributions to this publication are in final form and have not been edited. Any questions regarding their content, or requests for additional information, should be directed to the Chief, Geophysical Sciences Branch, USACRREL, 72 Lyme Road, Hanover, New Hampshire 03755-1290.

The author thanks Dr. Steven A. Arcone, Dr. Harold S. Boyne and Gary Koh for their helpful comments.

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INTRODUCTION

Search and Destroy Armaments (SADARM) winter captive flight tests were conducted on Range 37 of Camp Grayling, Grayling, Michigan, from 6–19 March 1990. The test was run jointly by the Joint Munitions Test and Evaluation Program Office (CHICKEN LITTLE JPO), Eglin Air Force Base, Florida, CRREL and the U.S. Army Armament Research, Development and Engineering Command (ARDEC), Picatinny Arsenal, New Jersey.

The captive flight tests provided an opportunity to assess the performance of SADARM sensors flying over appropriate target sets in a winter background environment. Several target configurations were used in a variety of winter conditions, encompassing both moving and stationary targets as well as clean and countermeasured targets and decoys. Ground-based sensor measurements made during the testing period provided data to increase our understanding of the target–background interaction. The captive flight test data and ground-based measurements are essential for an objective analysis of probabilities of detection (P_d) and False Alarm Rates (FAR).*

One of the objectives of the CRREL program was to obtain a comprehensive data base of the background scene for use in developing models of the electromagnetic response of backgrounds in a cold regions environment. Measurements were made using ground-based infrared (IR) and millimeter-wave (MMW) sensors. This report documents the processing of the MMW radar backscatter measurements that were made in conjunction with the SADARM captive flight tests during the period of 8–17 March 1990. The measurements were made by personnel from the Geophysical Sciences Branch of CRREL using a 35-GHz scatterometer system developed by the Microwave Remote Sensing Laboratory, University of Massachusetts at Amherst.

The ground-based measurements were focused on a limited, but representative, area of terrain located on the west side of the Camp Grayling test track. The area, called the Environmental Plot (EP), was approximately 60 × 60 m (Fig. 1). Meteorological measurements and snow observations were also made in the EP and are reported in Boyne et al.* Conditions at other locations along and adjacent to the test track were also measured to show the degree to which the EP represented the overall test site.

MEASUREMENTS

Table 1 gives the times during which ground-based MMW radar measurements were made. The ground-based MMW radar measurements were taken from a 6-m tower located at the south edge of the EP (Fig. 2). Because of the potential for interference between the ground-based radar and the airborne radar, ground-based measurements were made either just prior to or just after the flight tests.

Scenes 1, 2 and 3 are depicted in Figure 1. Scene 1 elevation is from 11–40° and azimuth from 340–20°. It has sparse scrub oak vegetation. Scene 2 elevation is 5–21° and azimuth 317–327°. Its prominent feature is a jack pine in the center of the field of view, with a small scrub oak directly in front of it. Scene 3 elevation is from 20–60° and azimuth from 330–30°. It is devoid of vegetation except very near its edges. The scene numbers in Table 1 are approximate. The actual location of each measurement can be found in Appendices A and B.

A diagram of the 35-GHz scatterometer is shown in

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* **Boyne, H.S., R.E. Bates, F.E. Perron, Jr., J.E. Fiori, S.N. Decato, R.H. Berger, J.A. Mechling, B.G. Harrington, and D.J. Fisk** (1990) SADARM captive flight tests: Data report. USA Cold Regions Research and Engineering Laboratory, Special Report 90-41.

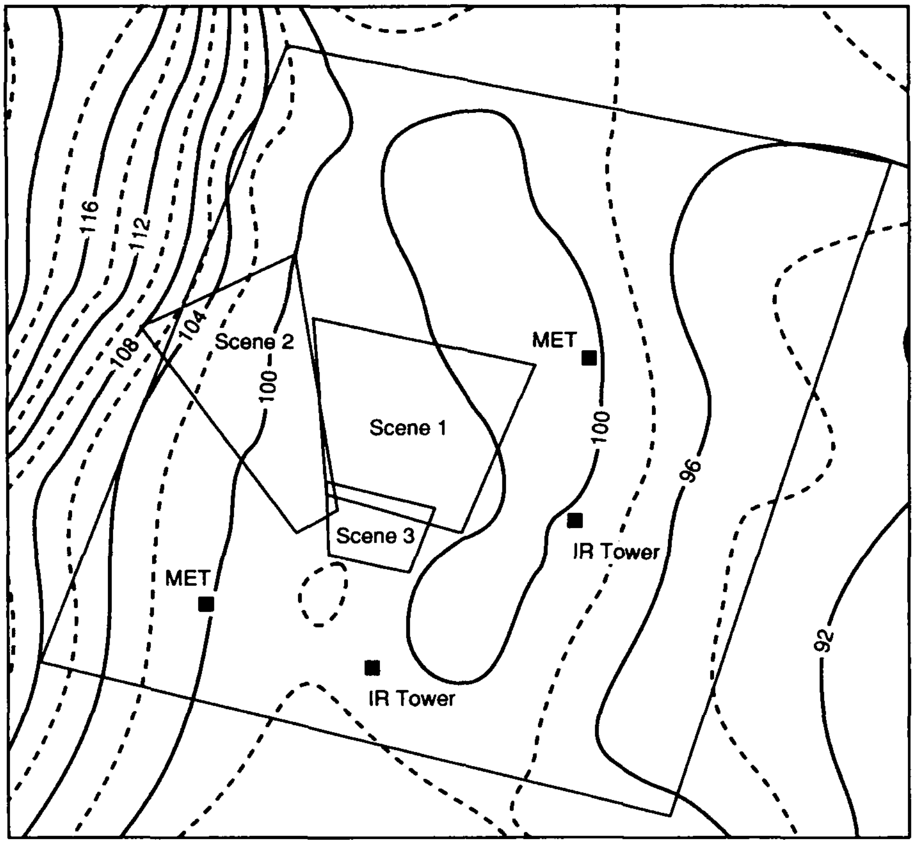


Figure 1. Environmental Plot on Range 37 of Camp Grayling, Grayling, Michigan, showing scenes 1, 2 and 3 (1 in. = 68.57 ft).

Table 1. 35-GHz radar system measurement schedule.

Date	*Julian day*	*Time*	*Polarization*	*Scene*
8 Mar 90	67	1201	HH	1
		1221	VV	1
9 Mar 90	68	1423	VV	1
10 Mar 90	69	1624	HH	1
		1635	HH	1
11 Mar 90	70			
12 Mar 90	71	1114	HH	corner
		1125	VV	corner
		1615	VV	2
		1835	VV	2
		1855	VV	2
		1918	HV	1
		1947	HH	1
		2019	VV	1
13 Mar 90	72	1403	HH	3
		1424	VV	3
		1435	VV	2
		1454	HH	2
		1925	HH	1 & 3
14 Mar 90	73	1457	HH	corner
		1618	HH	2
		1644	VV	2
		1813	VH	2
15 Mar 90	74	1117	HH	3
		1548	VV	3
		1628	HH	3
		1710	HV	3
16 Mar 90	75	1021	VV	3
		1451	HV	2
		1507	HH	2
		1930	HH	2
		1950	HV	2
		2015	VV	2
17 Mar 90	76	601	VV	2
		624	VH	2
		643	HH	2
		1007	HH	1
		1051	VV	1
		1930	VV	1
		1950	HH	1
		2009	HV	1
		2029	HH	2

Figure 2. South tower showing infrared and millimeter-wave sensors.

Figure 3. The system is a digitized FMCW (frequency modulated continuous wave) radar that is stepped over a 300-MHz bandwidth in 256 increments. The output waveform varies from 34.87945 to 35.17945 GHz, with an output power of 7 dBm. A Hewlett-Packard computer provided digital tuning commands to step through the 300-MHz tuning range in 1.53 ms, with a dwell time of 6 μs for each frequency step.

Two 30-cm Cassegrain antennas were oriented parallel to each other on the antenna baseplate and were separated by 0.46 m. The 3-dB **E**-plane antenna beamwidths were 1.9°. The antenna radiation patterns in each of the principal radiating planes, **E**-plane and **H**-plane, of the transmitter and receiver antennas are shown in Figure 4. The antennas were rotated independently to either vertical transmit–vertical receive (VV), vertical transmit–horizontal receive (VH), horizontal transmit–horizontal receive (HH), or horizontal transmit–vertical receive (HV) polarization configurations (Fig. 5).

The radar pedestal was configured to raster-scan in the azimuth over a predetermined angular range and then decrement in elevation prior to the next azimuth scan, resulting in interlacing (Fig. 6). The radar was triggered by a synchronization pulse generated at each 0.5° scan increment (pixel), with exception of 8 March 1991, when a 1.0° scan increment was used. Each of the pulses initiated a radar sweep through the 256 discrete frequen-

* **Stearns, S.D.** (1975) *Digital Signal Analysis*. Rochelle Park, New Jersey: Hayden.

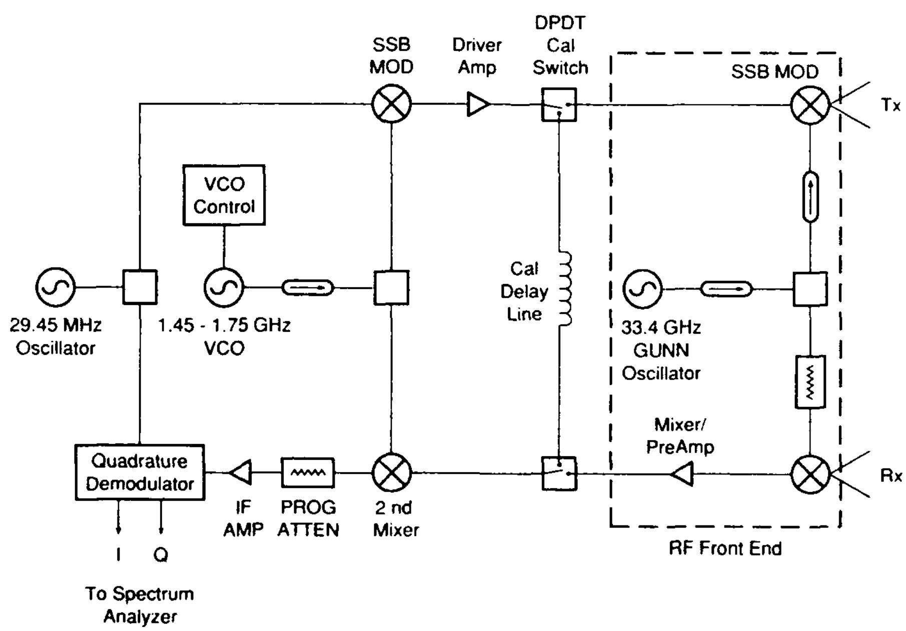
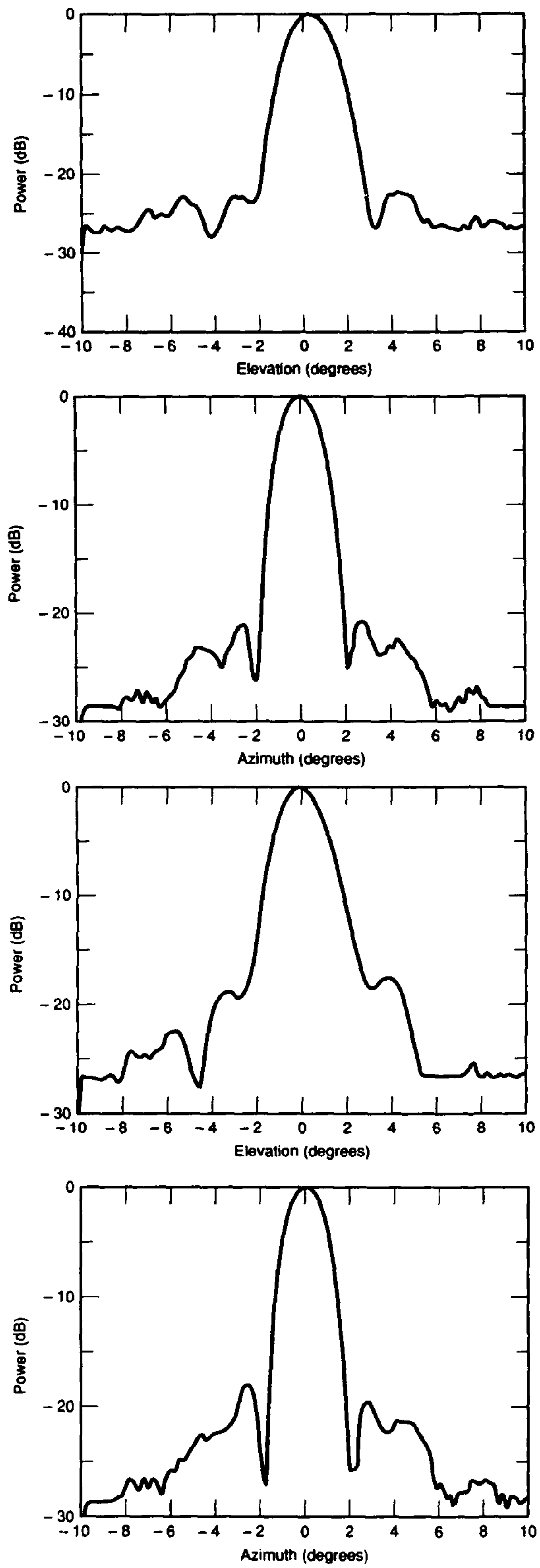


Figure 3. 35-GHz radar system developed by the Microwave Remote Sensing Laboratory, University of Massachusetts at Amherst.



*a. Transmitter **E**-plane.*

*b. Transmitter **H**-plane.*

*c. Receiver **E**-plane.*

*d. Receiver **H**-plane.*

Figure 4. Radiation patterns.

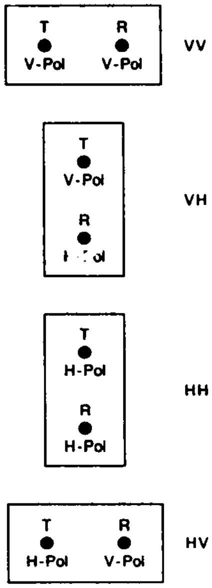


Figure 5. Transmitter (T) and receiver (R) antennas in the VV, VH, HH and HV polarization configurations.

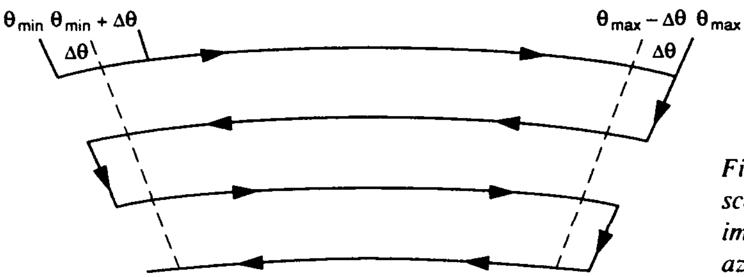


Figure 6. Radar pedestal, configured to raster-scan in azimuth and elevation. The resulting image is interlaced and must be corrected. θ is azimuth angle.

cies. The received signal was down-linked to a quadrature demodulator to extract the in-phase (I) and quadrature (Q) components of the received vector. These data were stored on optical disk for subsequent processing.

The 35-GHz scatterometer system was calibrated using a trihedral corner reflector, with a theoretical radar cross section of 0.9 dB, which was placed 18 m away from the antenna baseplate. The reflector was 9.5 cm on an edge, and was positioned on a tripod so that it was approximately 1.5 m above the snow-covered terrain. The calibration was performed by scanning in the azimuth and elevation in 0.5° increments and recording the I and Q components of the received vector for each sweep of the scans.

DATA PROCESSING

Calculation of backscattered power

For each pixel, a Fast Fourier Transform (FFT) was performed on the 256 samples to convert the data from the frequency domain to the time domain. Prior to performing the FFT, the I and Q components were corrected for the dc offset, and a Hamming weight W_k was applied for each frequency step k to reduce the side lobes

$$W_k = 0.54 - 0.46\ \cos \frac{2\pi k}{(n-1)} \quad (1)$$

where $1 \le k \le n$ and n is the number of frequency steps. The detector output was then expressed as a vector with two orthogonal rectangular components

$$y(f) = I(f) + jQ(f) \quad (2)$$

and a FFT using a decimation-in-time algorithm with bit-reversed ordering was performed.*

The received or backscattered power P_r was calculated as

$$P_r = 10\ log_{10} \left\{ \sum_{i=12\,m}^{128\,m} |A(R_i)|^2 \right\} \quad (3)$$

* **Stearns, S.D.** (1975) *Digital Signal Analysis*. Rochelle Park, New Jersey: Hayden.

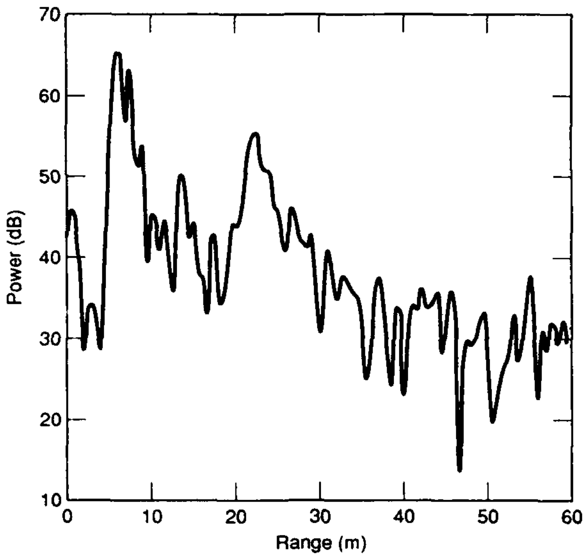


Figure 7. Backscattered power over 60 m of sweep 1 of file 151121.dat. The file is part of image 315117HH.

where $A(R)$ is the amplitude of the transformed output signal as a function of range R. Figure 7 shows the backscattered power over 60 m for the first sweep of file 151121.dat in image 3151117HH (see Appendix A). On the abscissa, time (t) was converted to range since $R = ct$ where c is the speed of light. The maximum range of the transformed data was 128 m, set by the spacing between the adjacent frequency steps. The range resolution in the data was about 50 cm, which was determined by the operating bandwidth. The minimum range was set at 12 m to reject the large peak at 7 m attributable to coupling between the transmitter and receiver antennas. The peak between 21 and 28 m is the backscattered power returned from the terrain within the main lobe of the antenna.

After the backscattered power was calculated for the entire image, the interlacing was corrected so that the sweeps in each scan were ordered from minimum to maximum azimuth angle.

System calibration

The calibration constant for the 35-GHz scatterometer system, K_{system}, was composed of the external calibration constant, $K_{external}$, a correction for system gain variations, $K_{system\ gain}$, and a correction for the antenna beam orientation, $K_{beam\ orientation}$

$$K_{system} = K_{external} + K_{system\ gain} + K_{beam\ orientation}. \tag{4}$$

The external calibration of the 35-GHz scatterometer was accomplished by measuring the return power from a trihedral corner reflector of known radar cross section. Received power, radar parameters, range and radar cross section are related by the radar equation, which was used to determine $K_{external}$. The power received by the antenna, as a result of backscattering from a point target at R, is given by

$$P_r = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4} \tag{5}$$

where P_t = transmitted power
G_t = transmitter antenna gain
G_r = receiver antenna gain
λ = free space wavelength of the transmitted energy
σ = radar cross section of an illuminated target.

Equation 5 can be rewritten as

$$P_r = \frac{K_{external}\ \sigma}{R^4} \tag{6}$$

where

$$K_{external} = \frac{P_t G_t G_r \lambda^2}{(4\pi)^3}. \tag{7}$$

The calibration scene was image 3141618HH (see Appendix A). The sweep with the highest backscattered power return was chosen for the calibration. This sweep was located at –2.0° azimuth and –20.5° elevation in the data file 141636.dat. Figure 8 shows the received power over the range R between 0 and 60 m. The received

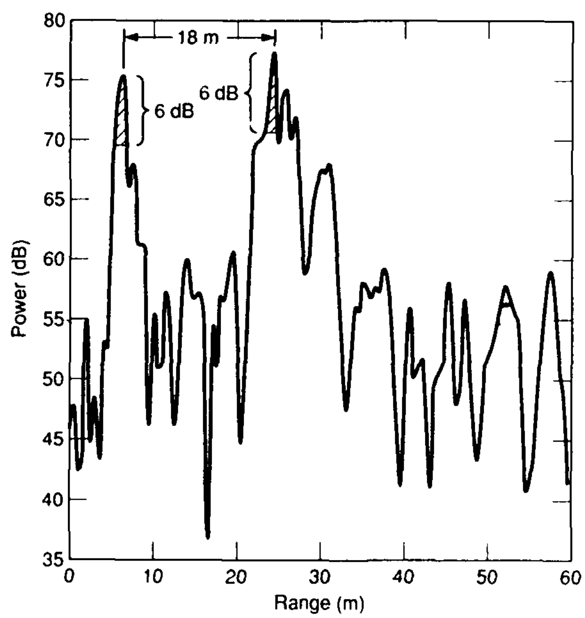


Figure 8. Backscattered power for the calibration scene.

power peak, located at a range of 7 m, is ascribable to signal coupling between the transmitter and receiver antennas. The received power peak, located at a range of 25 m, is attributable to the power backscattered from the trihedral corner reflector. This peak is located 18 m away from the antenna coupling signal. The total backscattered power received from the corner reflector was obtained by integrating between the –6-dB points of the peak (Fig. 8) and was found to be 82.63 dBm. Thus, K_{external} was obtained from eq 6 in logarithmic form

$$K_{\text{external}} = P_r + 4R_{\text{corner reflector}} - \sigma_{\text{corner reflector}} \quad (8)$$

where P_r is 82.63 dBm, $R_{\text{corner reflector}}$ is 18 m or 12.55 dB, $\sigma_{\text{corner reflector}}$ is 0.9 dB and K_{external} is 131.94 dB.

The signal coupling peak at 7 m in Figure 8 was used to monitor the long-term drifts in the gain of the 35-GHz scatterometer. The coupling from the transmitter antenna to the receiver antenna is relatively constant from one azimuth position to the next. The system calibration constant was adjusted to compensate for the relative difference between the antenna coupling signal level observed at the time a particular measurement was made (K_{image}) and the level observed when the system was calibrated ($K_{\text{calibration image}}$). The power level of the coupling signal in the calibration image was obtained by integrating between the –6-dB points of the peak, and $K_{\text{calibration image}}$ was 81.58 dBm. For a particular image, the 7-m peak was integrated between the –6-dB points of the peak for each sweep of the entire image and then averaged to obtain K_{image}. The calibration constant attributable to the system gain was then calculated as

$$K_{\text{system gain}} = K_{\text{image}} - K_{\text{calibration image}}. \quad (9)$$

Equation 5 is for antennas that are collocated. However, the transmitter and receiver antennas were oriented parallel to each other on the antenna baseplate and were separated from each other by 0.46 m. Figure 9 shows the geometry of the corner reflector and the antennas in the calibration scene. Each antenna encountered the corner reflector at an off-boresight angle α_b of

$$\alpha_b = \tan^{-1}\frac{0.23}{18} = 0.732°.$$

Figure 4 shows the transmitter and receiver antenna radiation patterns for the **E**- and **H**-planes. From Figures 4b and 4d, the antenna gains in the **H**-plane were approximately 2.5 dB below the boresight maxima in the direction of the corner reflector. Thus, the calibration constant due to the beam orientation $K_{\text{beam orientation}}$ was 5 dB.

Calculation of the normalized radar cross section

The power backscattered is given by the integral form of the radar equation (eq 5) as

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi)^3} \int\int \frac{\sigma^\circ(x,y) g_t(x,y) g_r(x,y)}{R^4(x,y)}\, dx dy \quad (10)$$

where the limits of integration are determined by the illumination patterns of the transmitter and receiver antennas, $\sigma^\circ(x,y)$ is the normalized radar cross section (NRCS) of the terrain, and $g_t(x,y)$ and $g_r(x,y)$ are the transmitter and receiver antenna gains in the direction of (x,y). Assuming σ° is constant within the limits of integration, the NRCS can be calculated as

$$\sigma^\circ = \frac{P_r}{K_{\text{system}}\, A_w} \quad (11)$$

where K_{system} is given in eq 6 and A_w is the illumination integral

$$A_w = \int\int \frac{g_t(x,y) g_r(x,y)}{R^4(x,y)}\, dx dy. \quad (12)$$

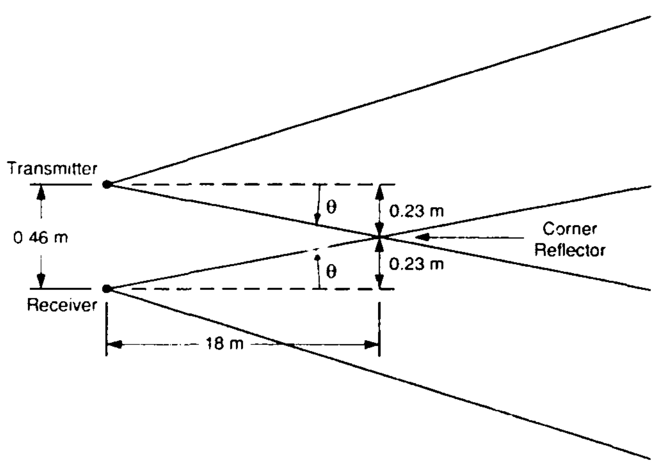


Figure 9. Geometry of the calibration scene. The antennas are separated by 0.46 m and the trihedral corner reflector is located at a distance of 18 m at an off-boresight angle α_b of 0.732°.

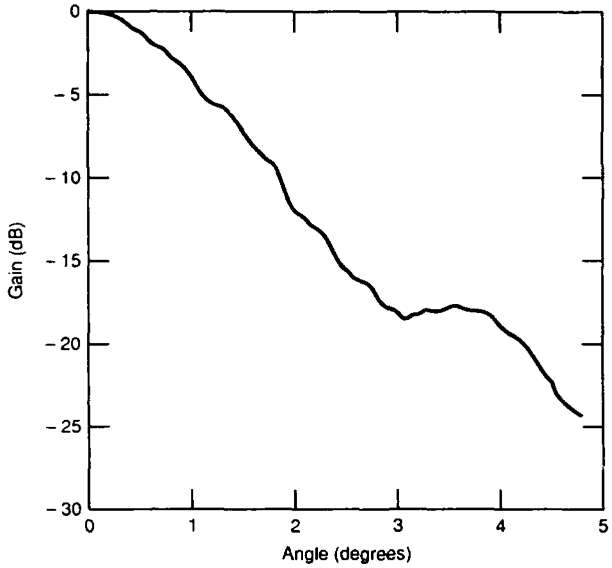


Figure 10. Digitization of the transmitter **E***-plane radiation pattern.*

The antenna beam patterns are not given as analytical functions and, thus, the integral for A_w must be calculated numerically. Since the beam patterns are required in all planes, an assumption was made about the beam patterns in the planes other than the **E**- and **H**-planes. The assumption was that the **E**-plane radiation pattern of the transmitter antenna described the radiation intensity in all planes for both the transmitter and receiver antennas. This plane was chosen because it is broader than the **H**-plane and provided more overlap between the transmitter and receiver antenna patterns. An ellipsoidal beam pattern was not assumed because there is no overlap at the higher grazing angles. This also applies to a Gaussian beam pattern assumption. Consequently, the assumption was made that the **E**-plane radiation pattern was representative of the radiation pattern in all the planes and the three-dimensional beam pattern was just a rotation of the **E**-plane radiation pattern.

Based on this assumption, the transmitter **E**-plane radiation pattern in Figure 4a was digitized to obtain the transmitter and receiver antenna gains. Figure 10 shows the digitized beam pattern. For beam angles greater than 4.9° off-boresight, the gain was assumed to be –27 dB.

The illumination area of the antenna radiation pattern is dependent on the alignment of the antennas and, hence, $\sigma°$ was calculated separately for the VV/HV and HH/VH configurations. Figures 11 and 12 show the geometry of the VV/HV and HH/VH configurations respectively. In these figures, x is the down-range coordinate, y is the cross-range coordinate and z is altitude.

In the polarization configurations with vertical receive (VV and HV), the antennas are in the yz plane (Fig. 11). To compute the integral in eq 12, an expression is required for the angle between the antenna boresight and a radial between the antenna focal point and a point (x_0, y_0) on the xy plane for both antennas. These angles are ω_1 and ω_2 for the receiver and transmitter antennas, respectively, D is the distance between the antennas, h is the height of the antennas above the terrain and θ is the grazing angle. The angles were calculated from the dot product of the two vectors

$$\omega_1 = \cos^{-1}\left(\frac{\mathbf{R}_{b_1} \cdot \mathbf{R}_{p_1}}{|\mathbf{R}_{b_1}|\,|\mathbf{R}_{p_1}|}\right) \tag{13}$$

$$\omega_2 = \cos^{-1}\left(\frac{\mathbf{R}_{b_2} \cdot \mathbf{R}_{p_2}}{|\mathbf{R}_{b_2}|\,|\mathbf{R}_{p_2}|}\right) \tag{14}$$

where $\mathbf{R}_{b1}$ and $\mathbf{R}_{b2}$ are the vectors between the boresight of the receiver and transmitter antennas, respectively, and the ground at the grazing angle θ and $\mathbf{R}_{p1}$ and $\mathbf{R}_{p2}$ are the vectors between the receiver and transmitter

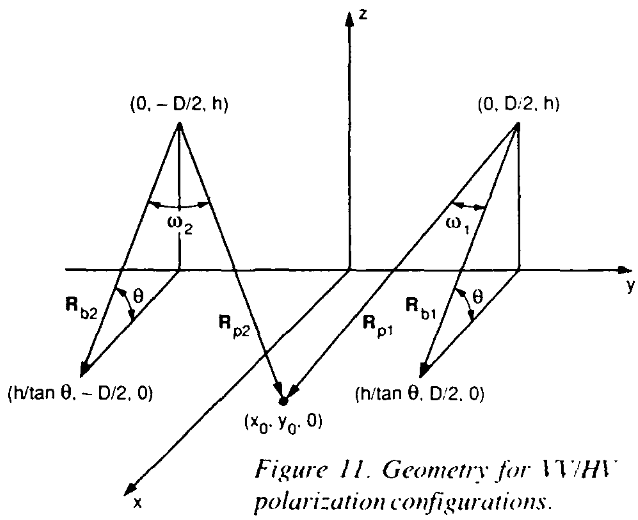


Figure 11. Geometry for VV/HV polarization configurations.

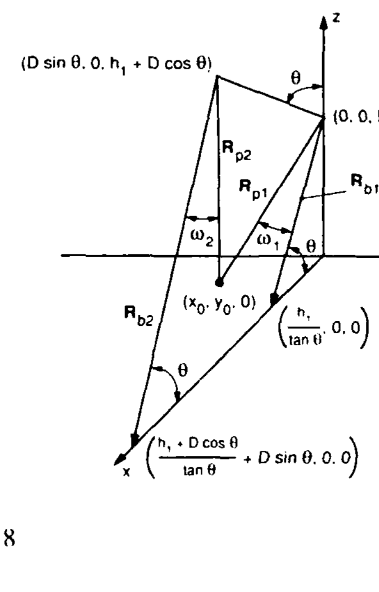


Figure 12. Geometry for HH/VH polarization configurations.

antennas, respectively, and the point (x_0,y_0) on the ground. For the receiver antenna

$$\mathbf{R}_{b_1} = \frac{h}{\tan\theta}\,\hat{\mathbf{x}} - h\hat{\mathbf{z}} \tag{15}$$

and

$$\mathbf{R}_{p_1} = x_0\,\hat{\mathbf{x}} + \left(y_0 - \frac{D}{2}\right)\hat{\mathbf{y}} - h\hat{\mathbf{z}} \tag{16}$$

and the angle between the vectors is

$$\omega_1 = \cos^{-1}\left(\frac{(x_0 + h\tan\theta)\cos\theta}{\left[x_0^2 + \left(y_0 - \frac{D}{2}\right)^2 + h^2\right]^{0.5}}\right). \tag{17}$$

Similarly, for the transmitter antenna

$$\mathbf{R}_{b_2} = \frac{h}{\tan\theta}\,\hat{\mathbf{x}} - h\hat{\mathbf{z}} \tag{18}$$

and

$$\mathbf{R}_{p_2} = x_0\hat{\mathbf{x}} + \left(y_0 + \frac{D}{2}\right)\hat{\mathbf{y}} - h\hat{\mathbf{z}} \tag{19}$$

and the angle between the vectors is

$$\omega_2 = \cos^{-1}\left(\frac{(x_0 + h\tan\theta)\cos\theta}{\left[x_0^2 + \left(y_0 + \frac{D}{2}\right)^2 + h^2\right]^{0.5}}\right). \tag{20}$$

The numerical integration of eq 12 was performed such that the x and y coordinates were incremented over a range where the gain product $g_t(x,y)g_r(x,y)$ was significant. From Figures 4a and 10, it can be seen that the antenna gain was less than 25 dB below the peak for angles ω_1 and ω_2 greater than about 4.9° from boresight. Consequently, angles beyond 4.9° did not contribute to the integrand significantly. For each increment in x and y, ω_1, ω_2 and $R^4(x,y)$ were computed and the integrand was determined.

The limits of integration for the VV and HV polarization configurations were set with the upper bound on x as

$$x_u = \frac{h}{\tan(\theta - \theta_{max})} \tag{21}$$

for $x_u < R_{max}$ (in this case 128 m) and otherwise $x_u = R_{max}$ and the lower bound on x as

$$x_\ell = \frac{h}{\tan(\theta + \theta_{max})}. \tag{22}$$

The upper bound on y was set by

$$y_u = h\,\frac{\tan\theta_{max}}{\sin(\theta - \theta_{max})} - \frac{D}{2} \tag{23}$$

or y_{max} where

$$y_{max} = \sqrt{R_{max}^2 - h^2 - x_\ell^2} \tag{24}$$

if $y_u > y_{max}$. The lower bound on y was such that $y_\ell = -y_u$. The slant range at each increment in x and y was

$$R^2 = x^2 + y^2 + h^2 \tag{25}$$

and the increments in x and y were

$$\Delta x = \frac{x_u - x_\ell}{20} \tag{26}$$

$$\Delta y = \frac{y_u - y_\ell}{20}. \tag{27}$$

In the polarization configurations with horizontal receive (HH and VH), the antennas are in the yz plane (Fig. 12). From Figure 12, the vectors for the receiver antenna are

$$\mathbf{R}_{b_1} = \frac{h_1}{\tan\theta}\,\hat{\mathbf{x}} - h_1\,\hat{\mathbf{z}} \tag{28}$$

and

$$\mathbf{R}_{p_1} = x_0\,\hat{\mathbf{x}} + y_0\,\hat{\mathbf{y}} - h_1\hat{\mathbf{z}} \tag{29}$$

where h_1 is the height of the receiver antenna. The angle between the vectors is

$$\omega_1 = \cos^{-1}\left(\frac{(x_0 + h_1\tan\theta)\cos\theta}{\left[x_0^2 + y_0^2 + h_1^2\right]^{0.5}}\right). \tag{30}$$

Similarly, for the transmitter antenna

$$\mathbf{R}_{b_2} = \frac{(h_1 + D\cos\theta)}{\tan\theta}\,\hat{\mathbf{x}} - (h_1 + D\cos\theta)\,\hat{\mathbf{z}} \tag{31}$$

and

$$\mathbf{R}_{p_2} = (x_0 - D\sin\theta)\,\hat{\mathbf{x}} + y_0\,\hat{\mathbf{y}} - (h_1 + D\cos\theta)\,\hat{\mathbf{z}} \tag{32}$$

and the angle between the vectors is

$$\omega_2 = \cos^{-1}\left(\frac{\left[x_0 - D\sin\theta + (h_1 + D\cos\theta)\tan\theta\right]\cos\theta}{\left[(x_0 - D\sin\theta)^2 + y_0^2 + (h_1 + D\cos\theta)^2\right]^{0.5}}\right). \tag{33}$$

For the HH and VH polarization configurations, the upper bound on x was set as

$$x_u = \frac{h_l}{\tan\left(\theta - \theta_{max}\right)} \tag{34}$$

for $x_u < R_{max}$, and otherwise $x_u = R_{max}$, and the lower bound on x set as

$$x_l = \frac{h_l + D\cos\theta}{\tan\left(\theta + \theta_{max}\right)} + D\sin\theta. \tag{35}$$

The upper bound on y was set by

$$y_u = h_l \frac{\tan\theta_{max}}{\sin\left(\theta - \theta_{max}\right)} \tag{36}$$

or y_{max} where

$$y_{max} = \sqrt{R_{max}^2 - h^2 - x_\ell^2} \tag{37}$$

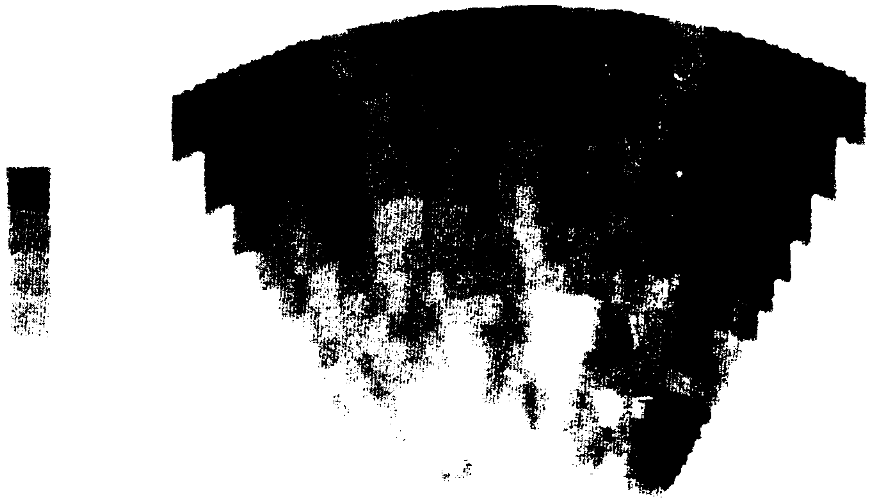
if $y_u > y_{max}$. The lower bound on y was such that $y_\ell = -y_u$. The slant range at each increment in x and y was

$$R^2 = x^2 + y^2 + (h_l + D\cos\theta)^2 \tag{38}$$

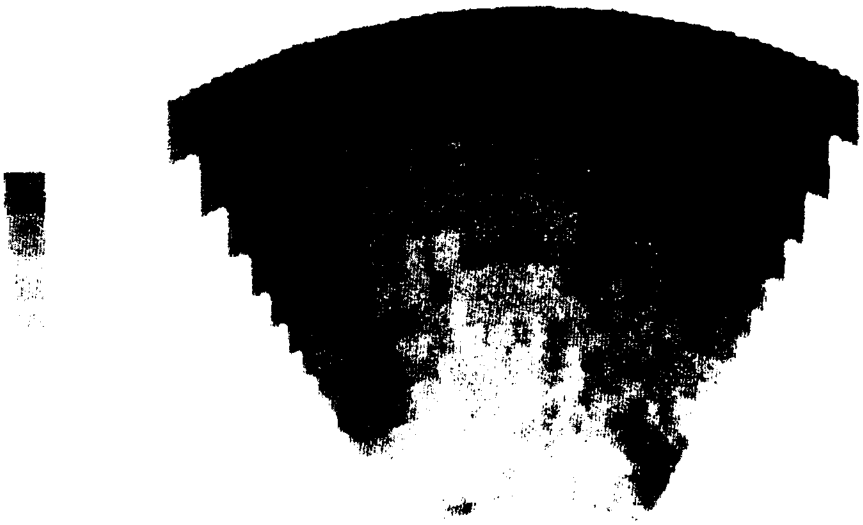
and the increments in x and y were

$$\Delta x = \frac{x_u - x_\ell}{20} \tag{39}$$

$$\Delta y = \frac{y_u - y_\ell}{20}. \tag{40}$$



a. HH polarization.



b. VV polarization.

Figure 13. 35-GHz radar images of scene 1, 8 March 1990.

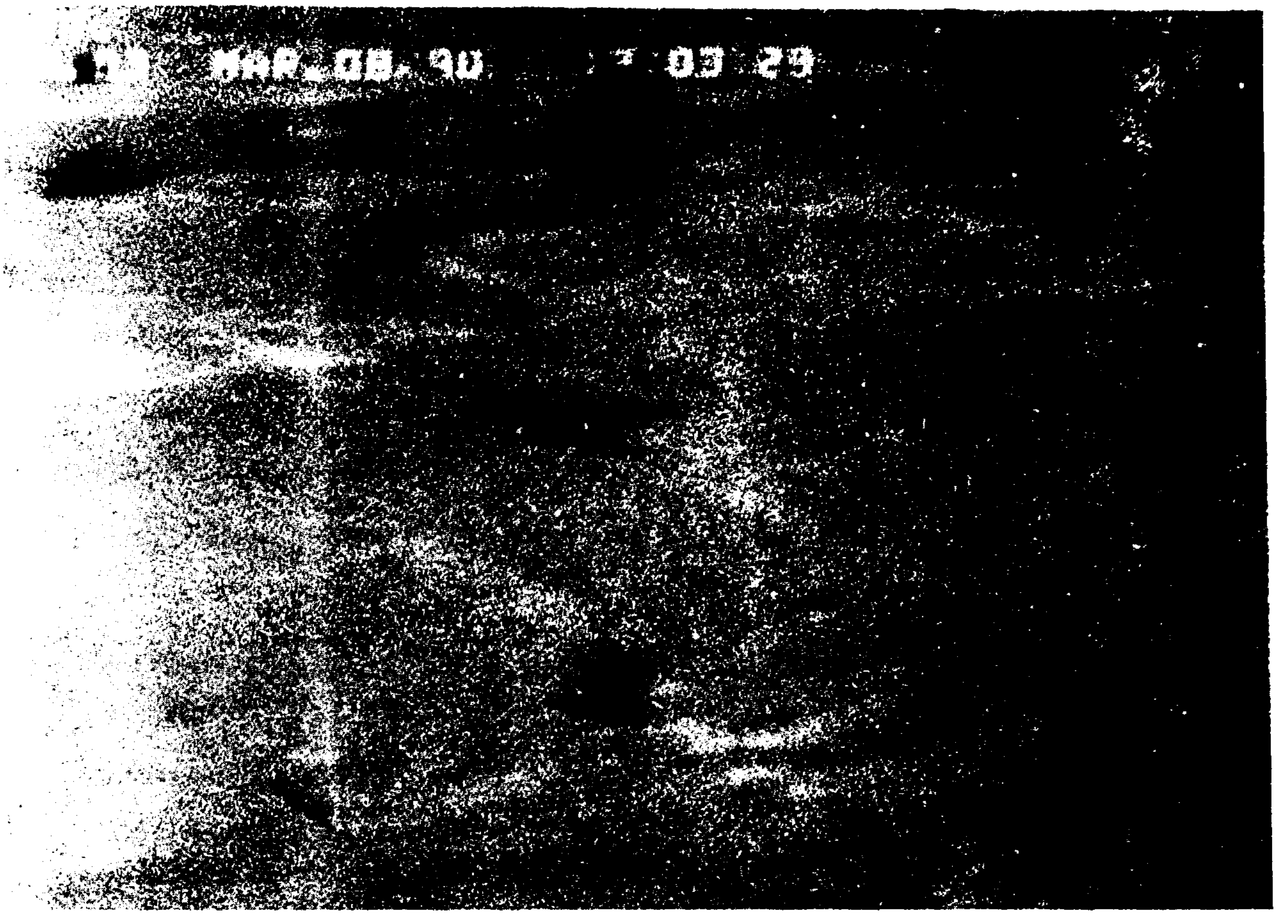


Figure 14. Visible image of scene 1, 8 March 1990.

AVAILABLE DATA

Appendix A contains a list of all the images. The following data are available for each image through the Chief, Geophysical Sciences Branch, CRREL:*

1. The *I* and *Q* components of the received vector for each sweep of the azimuth scans (there is one file for each azimuth scan—at each azimuth angle the radar is swept through 256 frequency steps).
2. The backscattered power corrected for interlacing.
3. The normalized radar cross sections for the image.

An example of the data can be seen in Figure 13. This figure shows scene 1 of the EP. There was full snow cover at the time, as seen in Figure 14, the visible image of the scene. In Figure 14, the prominent features are the small scrub oak bushes. Figure 13 does not show any significant features attributable to the vegetation, but does show some variation at the higher elevation angles owing to snow surface roughness.

In addition, for each image there is an explanation file containing relevant information. The file is called *.README* and hard copies for each image are contained in Appendix B.

A description and listing of the computer programs used to process the data are contained in Appendix C.

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APPENDIX A: IMAGES

Each image is contained in a directory with a name constructed in the following format:

Month Day Hour Minute Polarization

For example, the directory 3081201HH contains the image for March 8, 1990 taken beginning at 1201 hours with HH polarization. (Note: Directory names in MS-DOS do not have the polarizations included. The names are limited by 8 characters. Thus, directory 3081201HH will be 3081201.) The following is a list of all the 35-GHz scatterometer images available:

3081201HH	3141813VH
3081221VV	3151117HH
3091423VV	3151548VV
3101624HH	3151628HH
3101635HH	3151710HV
3121114HH	3161021VV
3121125VV	3161451HV
3121615VV	3161507HH
3121835VV	3161930HH
3121855HV	3161950HV
3121918HV	3162015VV
3121947HH	3170601VV
3122019VV	3170624VH
3131403HH	3170643HH
3131424VV	3171007HH
3131435VV	3171051VV
3131454HH	3171930VV
3131925HH	3171950HH
3141457HH	3172009HV
3141618HH	3172029HH
3141644VV	

Each directory (*image*) contains:

1. An explanation file called *.README* that contains relevant information about each image. This file contains the calibration constant for each image.

2. *n* files containing the in-phase (I) and quadrature (Q) components of the received vector for each sweep of the azimuth scans. There is one file for each azimuth scan; at each azimuth angle the radar is swept through 256 frequency steps. The file names have the following format:

DD HH MM E

where DD is the day in March (8 through 17), HH is the hour of the day (00 through 23), MM is the minute (00 through 59) and E is an extension that is blank for the first file generated at the current minute in time, 1 for the second file, 2 for the third file, etc. Each file corresponding to an azimuth scan has a header followed by 256 pairs of I and Q components for each frequency sweep (or pixel). The header has the following format:

Data type	*Description*
Real	Scan start time (in seconds; used to find relative time difference between scans).
String	ON—if calibration was ON. OFF—if calibration was OFF.
String	Description of measurement scene.
Real	Wind direction (degrees).
Real	Wind speed (m/s).
Real	Minimum elevation angle.
Real	Minimum azimuth angle.
String	Polarization—first letter is the transmitter and second letter is the receiver.
Integer	Number of frequency sweeps in the azimuth scan.
Real	Delay time between frequency sweeps.

3. NRCS subdirectory containing the following:

a. *image*.pow—file containing backscattered power uncorrected for interlacing.

b. *image*.cor—file containing backscattered power corrected for interlacing.

c. *image*.rcs—file containing NRCS for image.

For all images, except 3081201HH and 3081221VV, the sweep with the minimum azimuth angle was the repositioning sweep and was not included in the analysis (see Fig. 6). For images 3081201HH and 3081221VV data were collected at the minimum azimuth angle and no correction for repositioning was necessary.

In some of the images, the number of sweeps in a given scan was less than the number of increments in azimuth angle. For these scans, it was assumed that the missing sweep was at the end of the azimuth scan and the missing data were obtained by averaging the backscattered power, at the corresponding azimuth angle, in the scan above and below the present elevation angle.

APPENDIX B: *.README* FILES

Each image directory has a file called *.README* that contains information about the image. The majority of the information in the *.README* files is contained in the image header of each scan and from field notebooks. An example of a *.README* file is found below:

Directory:	named by data, time and polarization (see Appendix A)
Date:	date image was recorded
Start Time:	starting time of imaging procedure
Scene:	brief description of scene
Min Grazing Angle:	(minimum elevation angle in degrees)
Max Grazing Angle:	(maximum elevation angle in degrees)
Delta Grazing:	increment in grazing angle
Min Azimuth Angle:	minimum azimuth angle in degrees (not corrected for radar repositioning)
Max Azimuth Angle:	maximum azimuth angle in degrees
Delta Azimuth:	increment in azimuth angle
Polarization:	transmitter and receiver antenna polarizations
Sweep Number:	number of frequency sweeps per scan (not corrected for radar repositioning)
Sweep Time:	delay time between frequency sweeps
Calibration Constant:	$K_{\text{final}} = K_{\text{external}} + K_{\text{beam orientation}} + (K_{\text{image}} - K_{\text{calibration image}})$

For Image (for NRCS calculations and image reconstruction)

NROWS =	number of scans per image
NCOLS =	number of sweeps (corrected for radar repositioning)
MIN AZ =	minimum azimuth angle (corrected for radar repositioning)
Notes:	any comments from field notes or data analysis.

Directory	3081201HH
Date	3/8/90
Start Time	1201
Scene	TARGET: SWOE SNOWPACK
Min Grazing Angle	10
Max Grazing Angle	30
Delta Grazing	1.0
Min Azimuth Angle	-30
Max Azimuth Angle	30
Delta Azimuth	1.0
Polarization	HH
Sweep Number	60
Sweep Time	0.3
Calibration Constant	136.94 + (85.90 - 81.58) = 141.26

For Image
NROWS = 21
NCOLS = 60
MIN AZ = -30

10/31/90 The original ASCII files were corrected so that the minimum elevation angle is -10 and the minimum azimuth angle is -30.

Notes: The increment in azimuth and grazing angle for this image is 1.0 degree. The radar was left running while repositioning took place, therefore, no pixels are dropped from the ends of each scan. Consequently, a separate version of PROCESS was used to calculate the received power. The code is in the subdirectory Process under this directory.

Full snow cover; some surface melting.

Directory	3081221VV
Date	3/8/90
Start Time	1221
Scene	TARGET SWOE SNOWPACK
Min Grazing Angle	11
Max Grazing Angle	30
Delta Grazing	1.0
Min Azimuth Angle	-30.0
Max Azimuth Angle	30.0
Delta Azimuth	1.0
Sweep Number	60
Polarization	HH
Sweep Time	0.3
Calibration Constant	136.94 + (84.59 - 81.58) = 139.95

For Image
NROWS = 18
NCOLS = 60
MIN AZ = -30

10/20/90 The polarization for this scene is correct. The *.dat files have been changed to the correct polarization of VV.

Notes: The increment in azimuth and grazing angle for this image is 1.0 degree. The radar was left running while repositioning took place, therefore, no pixels are dropped from the ends of each scan. Consequently, a separate version of PROCESS was used to calculate the received power. The code is in the subdirectory Process under this directory.

The file 81221 could not be converted from binary to ASCII. This file is for an elevation angle of -10 degrees. It was left out of the calculations for NRCS by just skipping over it. Consequently, the starting elevation angle is -11.0 degrees. The interlacing corrections were made with the elevation angle of -10 set with a dummy file. The file 81234.dat is short by a portion of a sweep. Consequently, the whole last pixel was deleted from the data file and an average value was used to replace the missing pixel.

Full snow cover; some surface melting.

Directory	3091423VV
Date	3/9/90
Start Time	1423
Scene	SCENE 1A
Min Grazing Angle	10.0
Max Grazing Angle	30.0
Delta Grazing	0.5
Min Azimuth Angle	-30.0
Max Azimuth Angle	30.0
Delta Azimuth	0.5
Polarization	VV
Sweep Number	120
Sweep Time	0.1
Calibration Constant	136.94 + (82.78 - 81.58) = 138.14

For Image

NROWS = 41
NCOLS = 119
MIN AZ = -29.5

Notes: Wet snow; low overcast with fog; visibility about 0.75 km.

Directory	3101624HH
Date	3/10/90
Start Time	1624
Scene	TARGET: SWOE SNOWPACK
Min Grazing Angle	31.5
Max Grazing Angle	37.5
Delta Grazing	0.5
Min Azimuth Angle	-10.5
Max Azimuth Angle	-4.5
Delta Azimuth	0.5
Polarization	HH
Sweep Number	12
Sweep Time	0.1
Calibration Constant	136.94 + (86.71 - 81.58) = 142.07

For Image

NROWS = 13
NCOLS = 11
MIN AZ = -10.0

Notes: Corner reflector; (6 deg x 6 deg) area scanned; Reflector at about 12 m.

Directory	3101635HH
Date	3/10/90
Start Time	1635
Scene	TARGET: SWOE SNOWPACK
Min Grazing Angle	20
Max Grazing Angle	30
Delta Grazing	0.5
Min Azimuth Angle	-10
Max Azimuth Angle	0.0
Delta Azimuth	0.5
Polarization	HH
Sweep Number	20
Sweep Time	0.1
Calibration Constant	136.94 + (86.88 - 81.58) = 142.24

For Image

NROWS = 21
NCOLS = 19
MIN AZ = -9.5

Notes: Corner reflector; (10 deg x 10 deg) area scanned.

Directory	3121114HH
Date	3/12/90
Start Time	1114
Scene	CORNER ON THERMAX
Min Grazing Angle	42
Max Grazing Angle	48
Delta Grazing	0.5
Min Azimuth Angle	-14.0
Max Azimuth Angle	-8.0
Delta Azimuth	0.5
Polarization	HH
Sweep Number	12
Sweep Time	0.1
Calibration Constant	136.94 + (87.72 - 81.58) = 143.08

For Image
NROWS = 13
NCOLS = 11
MIN AZ = -13.5

Notes: (6 deg x 6 deg) corner reflector scan; reflector on sky at about 8.5 m.

Directory	3121125VV
Date	3/12/90
Start Time	1125
Scene	CORNER ON THERMAX
Min Grazing Angle	42
Max Grazing Angle	48
Delta Grazing	0.5
Min Azimuth Angle	-14.0
Max Azimuth Angle	-8.0
Delta Azimuth	0.5
Polarization	VV
Sweep Number	12
Sweep Time	0.1
Calibration Constant	136.94 + (82.95 - 81.58) = 138.31

For Image
NROWS = 13
NCOLS = 11
MIN AZ = -13.5

Notes: (6 deg x 6 deg) corner reflector scan; reflector on sky at about 8.5 m.

Directory	3121615VV
Date	3/12/90
Start Time	1615
Scene	SCENE 2 (TREE #9)
Min Grazing Angle	5.0
Max Grazing Angle	21.0
Delta Grazing	0.5
Min Azimuth Angle	-42.5
Max Azimuth Angle	-32.5
Delta Azimuth	0.5
Polarization	VV
Sweep Number	20
Sweep Time	0.1
Calibration Constant	136.94 + (82.73 - 81.58) = 138.09

For Image
NROWS = 33
NCOLS = 19
MIN AZ = -42.0

Notes: Video recorder started part way through scene; sunny, warm, breezy; snow melting rapidy; bare ground in front of tr and wet ground.

THERE IS CONFUSION AS TO WHETHER THIS SCENE IS VV. IT MAY BE VH. The NRCS was calculated using the code NRSCV. If the scene turns out to be VH, then the code NRSCH must be used to recalculate the NRCS.

Directory	3121835VV
Date	3/12/90
Start Time	1835
Scene	SCENE 2 (TREE #9)
Min Grazing Angle	5.0
Max Grazing Angle	21.0
Delta Grazing	0.5
Min Azimuth Angle	-42.5
Max Azimuth Angle	-32.5
Delta Azimuth	0.5
Polarization	VV
Sweep Number	20
Sweep Time	0.1
Calibration Constant	136.94 + (84.82 - 81.58) = 140.18

For Image
NROWS = 33
NCOLS = 19
MIN AZ = -42.0

Notes: THERE IS SOME CONFUSION AS TO WHETHER THIS SCENE IS VV. IT MAY BE HH. The current NRCS was calculated using the code NRSCV. If the scene turns out to be HH, then the code NRSCH must be used to recalculate the NRCS.

Directory	3121855HV
Date	3/12/90
Start Time	1855
Scene	Scene 2
Min Grazing Angle	5.0
Max Grazing Angle	21.0
Delta Grazing	0.5
Min Azimuth Angle	-42.5
Max Azimuth Angle	-32.5
Delta Azimuth	0.5
Polarization	HV
Sweep Number	20
Sweep Time	0.1
Calibration Constant	136.94 + (77.15 - 81.58) = 132.51

For Image
NROWS = 33
NCOLS = 19
MIN AZ = -42.0

Notes: THERE IS SOME CONFUSION AS TO WHETHER THIS SCENE IS HV. The current NRCS was calculated using the code NRSCV. If the scene turns out to be VH or HH, then the code NRSCH must be used to recalculate the NRCS.

Directory	3121918HV
Date	3/12/90
Start Time	1918
Scene	SCENE 1 (PATCHY SNOW)
Min Grazing Angle	11.0
Max Grazing Angle	26.0
Delta Grazing	0.5
Min Azimuth Angle	-30.0
Max Azimuth Angle	+20.0
Delta Azimuth	0.5
Polarization	HV
Sweep Number	100
Sweep Time	0.1
Calibration Constant	136.94 + (77.52 - 81.58) = 132.88

For Image
NROWS = 31
NCOLS = 99
MIN AZ = -29.5

Notes: Patchy snow; puddles and wet ground; clear sky.

10/20/90 The polarization for this scene is correct. The *.dat files have been changed to the correct polarization of HV.

12/11/90 The data files for this scene have min. elevation angle of -11.0 and maximum of -26.0. Previously, I had thought they were -5.0 to -20.0 such as in 3121947HH.

Directory	3121947HH
Date	3/12/90
Start Time	1947
Scene	SCENE 1 (PATCHY SNOW)
Min Grazing Angle	5.0
Max Grazing Angle	19.5
Delta Grazing	0.5
Min Azimuth Angle	-30.0
Max Azimuth Angle	20.0
Delta Azimuth	0.5
Polarization	HH
Sweep Number	100
Sweep Time	0.1
Calibration Constant	136.94 + (85.61 - 81.58) = 140.97

For Image
NROWS = 30
NCOLS = 99
MIN AZ = -29.5

Notes: There are only 30 scans in this image. The data file corresponding the the desired maximum grazing angle of 20.0 degrees (file 1220061) was not complete. Therefore, the maximum grazing angle used in the image was 19.5 degrees. This will have no effect on the interlacing correction procedure.

12/11/90 The min. elevation angle in the data files is -5.0. There is a discrepancy with this scene 1 and 3121918HV were the minimum is -11.0.

Directory	3122019VV
Date	3/12/90
Start Time	2019
Scene	Scene 1
Min Grazing Angle	11.0
Max Grazing Angle	26.0
Delta Grazing	0.5
Min Azimuth Angle	-30.0
Max Azimuth Angle	20.0
Delta Azimuth	0.5
Polarization	VV
Sweep Number	100
Sweep Time	0.1
Calibration Constant	136.94 + (83.95 - 81.58) = 139.31

For Image
NROWS = 31
NCOLS = 99
MIN AZ = -29.5

Notes:

Directory	3131403HH
Date	3/13/90
Start Time	1403
Scene	Corner reflector on plate
Min Grazing Angle	45.0
Max Grazing Angle	51.0
Delta Grazing	0.5
Min Azimuth Angle	-26.5
Max Azimuth Angle	-10.5
Delta Azimuth	0.5
Polarization	HH
Sweep Number	32
Sweep Time	0.1
Calibration Constant	136.94 + (81.86 - 81.58) = 137.22

For Image
NROWS = 13
NCOLS = 31
MIN AZ = -26.0

Notes: Corner reflector on aluminum plate; 6 deg x 6 deg scan. File 1314061.dat should have peak refelction.

Directory	3131424VV
Date	3/13/90
Start Time	1424
Scene	Corner reflector on plate
Min Grazing Angle	45.0
Max Grazing Angle	51.0
Delta Grazing	0.5
Min Azimuth Angle	-26.6
Max Azimuth Angle	-10.5
Delta Azimuth	0.5
Polarization	VV
Sweep Number	32
Sweep Time	0.1
Calibration Constant	136.94 + (80.87 - 81.58) = 136.23

For Image
NROWS = 13
NCOLS = 31
MIN AZ = -26.0

Notes: Corner reflector on aluminum plate; 6 deg x 6 deg scan. File 1314271.dat should have peak reflection.

SHOULD MIN AZ BE -26.5 INSTEAD OF -26.6?

Directory	3131435VV
Date	3/13/90
Start Time	1435
Scene	SCENE #2
Min Grazing Angle	5.0
Max Grazing Angle	21.0
Delta Grazing	0.5
Min Azimuth Angle	-42.5
Max Azimuth Angle	-32.5
Delta Azimuth	0.5
Polarization	VV
Sweep Number	20
Sweep Time	0.1
Calibration Constant	136.94 + (81.26 - 81.58) = 136.62

For Image
NROWS = 33
NCOLS = 19
MIN AZ = -42.0

Notes:

Directory	3131454HH
Date	3/13/90
Start Time	1454
Scene	SCENE #2
Min Grazing Angle	5.0
Max Grazing Angle	21.0
Delta Grazing	0.5
Min Azimuth Angle	-42.5
Max Azimuth Angle	-32.5
Delta Azimuth	0.5
Polarization	HH
Sweep Number	20
Sweep Time	0.1
Calibration Constant	136.94 + (81.57 - 81.58) = 136.93

For Image
NROWS = 33
NCOLS = 19
MIN AZ = -42.0

Notes:

Directory	3131925HH
Date	3/13/90
Start Time	1925
Scene	Scene 1 + 3
Min Grazing Angle	11.0
Max Grazing Angle	60.0
Delta Grazing	0.5
Min Azimuth Angle	-30.0
Max Azimuth Angle	20.0
Delta Azimuth	0.5
Polarization	HH
Sweep Number	100
Sweep Time	0.1
Calibration Constant	136.94 + (86.39 - 81.58) = 141.75

For Image
NROWS = 99
NCOLS = 99
MIN AZ = -29.5

Notes: Scene 1 extended down to -60 deg elevation angle. Sky reflector and corner reflector at about -56 deg elevation.

Directory	3141457HH
Date	3/14/90
Start Time	1457
Scene	Bare ground and 2 corners
Min Grazing Angle	53.0
Max Grazing Angle	60.0
Delta Grazing	0.5
Min Azimuth Angle	-30.0
Max Azimuth Angle	30.0
Delta Azimuth	0.5
Polarization	HH
Sweep Number	120
Sweep Time	0.1
Calibration Constant	136.94 + (80.87 - 81.58) = 136.23

For Image
NROWS = 15
NCOLS = 119
MIN AZ = -29.5

Notes: At 1500 hrs scan over corner reflector; at 1501 scan over 0.9 dB reflector.

Directory	3141618HH
Date	3/14/90
Start Time	1618
Scene	Scene 2a
Min Grazing Angle	5.0
Max Grazing Angle	21.0
Delta Grazing	0.5
Min Azimuth Angle	-42.5
Max Azimuth Angle	0.0
Delta Azimuth	0.5
Sweep Number	85
Polarization	HH
Sweep Time	0.1
Calibration Constant	136.94 + (81.60 - 81.58) = 136.96

For Image
NROWS = 33
NCOLS = 84
MIN AZ = -42.0

Notes: File 141636.dat is the file used to determine the absolute calibration constant. The pixel at (-2.0,-20.5) degrees azimuth and elevation was used for the calibation. The file contains a 0.9 dB corner reflector at a range of 18 m.

From R. Berger's notes: Reflectors are 61 feet from tower base; 0.9 dB corner reflector at (-3.25, -19.4); -3.2 dB corner reflector at (-5.6, -19.2); video.

Directory	3141644VV
Date	3/14/90
Start Time	1644
Scene	Scene 2a
Min Grazing Angle	5.0
Max Grazing Angle	21.0
Delta Grazing	0.5
Min Azimuth Angle	-42.5
Max Azimuth Angle	0.0
Delta Azimuth	0.5
Polarization	VV
Sweep Number	85
Sweep Time	0.1
Calibration Constant	136.94 + (80.78 - 81.58) = 136.14

For Image
NROWS = 33
NCOLS = 84
MIN AZ = -42.0

Notes: Reflectors are 61 feet from tower base; 0.9 dB corner reflector at (-3.25, -19.4); -3.2 dB corner reflector at (-5.6, -19.2); video.

Directory	3141813VH
Date	3/14/90
Start Time	1813
Scene	Scene 2 exp + 2 corners
Min Grazing Angle	5.0
Max Grazing Angle	21.0
Delta Grazing	0.5
Min Azimuth Angle	-42.5
Max Azimuth Angle	0.0
Delta Azimuth	0.5
Polarization	VH
Sweep Number	85
Sweep Time	0.1
Calibration Constant	136.94 + (73.73 - 81.58) = 129.09

For Image
NROWS = 33
NCOLS = 84
MIN AZ = -42.0

Notes:

Directory	3151117HH
Date	3/14/90
Start Time	1117
Scene	Bare ground + corners
Min Grazing Angle	25.0
Max Grazing Angle	60.0
Delta Grazing	0.5
Min Azimuth Angle	-30.0
Max Azimuth Angle	30.0
Delta Azimuth	0.5
Polarization	HH
Sweep Number	120
Sweep Time	0.1
Calibration Constant	136.94 + (71.91 - 81.58) = 127.27

For Image
NROWS = 71
NCOLS = 119
MIN AZ = -29.5

Notes: Corners at about 1141 hrs.

Directory	3151548VV
Date	3/15/90
Start Time	1548
Scene	Scene 3a Bare ground
Min Grazing Angle	35.0
Max Grazing Angle	60.0
Delta Grazing	0.5
Min Azimuth Angle	-30.0
Max Azimuth Angle	30.0
Delta Azimuth	0.5
Polarization	VV
Sweep Number	120
Sweep Time	0.1
Calibration Constant	136.94 + (72.64 - 81.58) = 128.00

For Image
NROWS = 51
NCOLS = 119
MIN AZ = -29.5

Notes: Scan at 1615 is of larger corner reflector at 5 m position. Bright sun; temperature in the 70's; very windy.

Directory	3151628HH
Date	3/15/90
Start Time	1628
Scene	Scene 3a bare ground
Min Grazing Angle	35.0
Max Grazing Angle	60.0
Delta Grazing	0.5
Min Azimuth Angle	-30.0
Max Azimuth Angle	30.0
Delta Azimuth	0.5
Polarization	HH
Sweep Number	120
Sweep Time	0.1
Calibration Constant	136.94 + (73.21 - 81.58) = 128.57

For Image
NROWS = 51
NCOLS = 119
MIN AZ = -29.5

Notes: Scan at 1631 may have a person in it.

Directory	3151710HV
Date	3/15/90
Start Time	1710
Scene	Scene 3 bare ground
Min Grazing Angle	35.0
Max Grazing Angle	50.0
Delta Grazing	0.5
Min Azimuth Angle	-30.0
Max Azimuth Angle	30.0
Delta Azimuth	0.5
Polarization	HV
Sweep Number	120
Sweep Time	0.1
Calibration Constant	136.94 + (71.59 - 81.58) = 126.95

For Image
NROWS = 31
NCOLS = 119
MIN AZ = -29.5

Notes: Very windy.

Directory	3161021VV
Date	3/16/90
Start Time	1021
Scene	Scene 3 + corners
Min Grazing Angle	35.0
Max Grazing Angle	60.0
Delta Grazing	0.5
Min Azimuth Angle	-30.0
Max Azimuth Angle	30.0
Delta Azimuth	0.5
Polarization	VV
Sweep Number	120
Sweep Time	0.1
Calibration Constant	136.94 + (84.39 - 81.58) = 139.75

For Image
NROWS = 51
NCOLS = 119
MIN AZ = -29.5

Notes: Corner reflectors at about 8 m only; video. Cloudy, breezy, dry ground.

Directory	3161451HV
Date	3/16/90
Start Time	1451
Scene	Scene 2
Min Grazing Angle	5.0
Max Grazing Angle	21.0
Delta Grazing	0.5
Min Azimuth Angle	-42.5
Max Azimuth Angle	-32.5
Delta Azimuth	0.5
Polarization	HV
Sweep Number	20
Sweep Time	0.1
Calibration Constant	136.94 + (82.65 - 81.58) = 138.01

For Image
NROWS = 33
NCOLS = 19
MIN AZ = -42.0

Notes: Video. Breezy, lots of tree motion.

Directory	3161507HH
Date	3/16/90
Start Time	1507
Scene	Scene 2
Min Grazing Angle	5.0
Max Grazing Angle	21.0
Delta Grazing	0.5
Min Azimuth Angle	-42.5
Max Azimuth Angle	-32.5
Delta Azimuth	0.5
Polarization	HH
Sweep Number	20
Sweep Time	0.1
Calibration Constant	136.94 + (86.61 - 81.58) = 141.97

For Image
NROWS = 33
NCOLS = 19
MIN AZ = -42.0

Notes:

Directory	3161930HH
Date	3/16/90
Start Time	1930
Scene	Scene 2
Min Grazing Angle	5.0
Max Grazing Angle	21.0
Delta Grazing	0.5
Min Azimuth Angle	-42.5
Max Azimuth Angle	-32.5
Delta Azimuth	0.5
Polarization	HH
Sweep Number	20
Sweep Time	0.1
Calibration Constant	136.94 + (86.97 - 81.58) = 142.33

For Image
NROWS = 33
NCOLS = 19
MIN AZ = -42.0

Notes:

Directory	3161950HV
Date	3/16/90
Start Time	1950
Scene	Scene 2
Min Grazing Angle	5.0
Max Grazing Angle	21.0
Delta Grazing	0.5
Min Azimuth Angle	-42.5
Max Azimuth Angle	-32.5
Delta Azimuth	0.5
Polarization	HV
Sweep Number	20
Sweep Time	0.1
Calibration Constant	136.94 + (81.53 - 81.58) = 136.89

For Image
NROWS = 33
NCOLS = 19
MIN AZ = -42.0

Notes:

Directory	3162015VV
Date	3/16/90
Start Time	2015
Scene	Scene 2
Min Grazing Angle	5.0
Max Grazing Angle	21.0
Delta Grazing	0.5
Min Azimuth Angle	-42.5
Max Azimuth Angle	-32.5
Delta Azimuth	0.5
Polarization	VV
Sweep Number	20
Sweep Time	0.1
Calibration Constant	136.94 + (84.07 - 81.58) = 139.43

For Image
NROWS = 33
NCOLS = 19
MIN AZ = -42.0

Notes:

Directory	3170601VV
Date	3/17/90
Start Time	0601
Scene	Scene 2 (MISTING)
Min Grazing Angle	5.0
Max Grazing Angle	21.0
Delta Grazing	0.5
Min Azimuth Angle	-42.5
Max Azimuth Angle	-32.5
Delta Azimuth	0.5
Polarization	VV
Sweep Number	20
Sweep Time	0.1
Calibration Constant	136.94 + (88.27 - 81.58) = 143.63

For Image
NROWS = 33
NCOLS = 19
MIN AZ = -42.0

Notes: Deciduous foliage wet; conifers dry to touch; gentle breeze.

Directory	3170624VH
Date	3/17/90
Start Time	0624
Scene	Scene 2 (DAMP)
Min Grazing Angle	5.0
Max Grazing Angle	21.0
Delta Grazing	0.5
Min Azimuth Angle	-42.5
Max Azimuth Angle	-32.5
Delta Azimuth	0.5
Polarization	VH
Sweep Number	20
Sweep Time	0.1
Calibration Constant	136.94 + (81.81 - 81.58) = 137.17

For Image
NROWS = 33
NCOLS = 19
MIN AZ = -42.0

Notes:

Directory	3170643HH
Date	3/17/90
Start Time	0643
Scene	Scene 2 (DAMP)
Min Grazing Angle	5.0
Max Grazing Angle	21.0
Delta Grazing	0.5
Min Azimuth Angle	-42.5
Max Azimuth Angle	-32.5
Delta Azimuth	0.5
Polarization	HH
Sweep Number	20
Sweep Time	0.1
Calibration Constant	136.94 + (87.47 - 81.58) = 142.83

For Image
NROWS = 33
NCOLS = 19
MIN AZ = -42.0

Notes: Light rain; video.

Directory	3171007HH
Date	3/17/90
Start Time	1007
Scene	Scene 1
Min Grazing Angle	35.0
Max Grazing Angle	60.0
Delta Grazing	0.5
Min Azimuth Angle	-30.0
Max Azimuth Angle	30.0
Delta Azimuth	0.5
Polarization	HH
Sweep Number	120
Sweep Time	0.1
Calibration Constant	136.94 + (88.24 - 81.58) = 143.60

For Image
NROWS = 51
NCOLS = 119
MIN AZ = -29.5

Notes: Corners scanned about 1016-1018 and 1033-1035. Corners not parallel to scan. Video.

12/11/90 THIS IS MOST LIKELY SCENE 3A AND NOT SCENE 1 AS IN THE DATA FILES.

Directory	3171051VV
Date	3/17/90
Start Time	1051
Scene	Scene 1
Min Grazing Angle	35.0
Max Grazing Angle	60.0
Delta Grazing	0.5
Min Azimuth Angle	-30.0
Max Azimuth Angle	30.0
Delta Azimuth	0.5
Polarization	VV
Sweep Number	120
Sweep Time	0.1
Calibration Constant	136.94 + (86.71 - 81.58) = 142.07

For Image
NROWS = 51
NCOLS = 119
MIN AZ = -29.5

Notes: Corner scans at 1101, 1102, 1117, 1118, 11181; video.

12/11/90 THIS IS PROBABLY SCENE 3A AND NOT SCENE 1 LIKE THE DATA FILES SAYS.

Directory	3171930VV
Date	3/17/90
Start Time	1930
Scene	ABVR Scene 1
Min Grazing Angle	50.0
Max Grazing Angle	60.0
Delta Grazing	0.5
Min Azimuth Angle	-30.0
Max Azimuth Angle	30.0
Delta Azimuth	0.5
Polarization	VV
Sweep Number	120
Sweep Time	0.1
Calibration Constant	136.94 + (88.29 - 81.58) = 143.65

For Image
NROWS = 21
NCOLS = 119
MIN AZ = -29.5

Notes: High angle scan; corners frozen up; light snow cover.

Directory	3171950HH
Date	3/17/90
Start Time	1950
Scene	ABVR Scene 1
Min Grazing Angle	50.0
Max Grazing Angle	60.0
Delta Grazing	0.5
Min Azimuth Angle	-30.0
Max Azimuth Angle	30.0
Delta Azimuth	0.5
Polarization	HH
Sweep Number	120
Sweep Time	0.1
Calibration Constant	136.94 + (89.27 - 81.58) = 144.63

For Image
NROWS = 21
NCOLS = 119
MIN AZ = -29.5

Notes: High angle scan; corners frozen up; light snow cover.

Directory	3172009HV
Date	3/17/90
Start Time	2009
Scene	ABVR Scene 1
Min Grazing Angle	50.0
Max Grazing Angle	60.0
Delta Grazing	0.5
Min Azimuth Angle	-30.0
Max Azimuth Angle	30.0
Delta Azimuth	0.5
Polarization	HV
Sweep Number	120
Sweep Time	0.1
Calibration Constant	136.94 + (86.27 - 81.58) = 141.63

For Image
NROWS = 21
NCOLS = 119
MIN AZ = -29.5

Notes: High angle scan; corners frozen up; light snow cover.

Directory	3172029HH
Date	3/17/90
Start Time	2029
Scene	Scene 2 (NEW SNOW)
Min Grazing Angle	5.0
Max Grazing Angle	21.0
Delta Grazing	0.5
Min Azimuth Angle	-42.5
Max Azimuth Angle	-32.5
Delta Azimuth	0.5
Polarization	HH
Sweep Number	20
Sweep Time	0.1
Calibration Constant	136.94 + (89.63 - 81.58) = 144.99

For Image
NROWS = 33
NCOLS = 19
MIN AZ = -42.0

Notes: New snow

APPENDIX C: COMPUTER PROGRAMS

The following computer programs were used to calculate the backscattered power (PROCESS), correct for interlacing (INTER and INTER_2), calculate the calibration constants (CAL), and calculate the normalized radar cross-section (NRCSH or NRCSV).

Program PROCESS

This FORTRAN program, written by J. Nagle, calculates the backscattered power for the 35-GHz radar images. The following is a brief description of the subroutines and functions used in PROCESS:

FFT (FT, FI, K, SIGN)

This subroutine performs a FFT using time decomposition with input bit reversal data in real FR and imaginary FI arrays. The computation is in place, and the output replaces the input. The number of points N must be $N = 2^K$ where K is 8 in this case. The FFT is calculated for SIGN = –1.0 and the inverse FFT is calculated for SIGN = 1.0. This subroutine is called by the main program.

HAM (N, K)

This real function calculates the Hamming weights for a specific frequency step K. N is the total number of frequency steps. This function is called by the subroutine WINDOW.

HEADER (SWPNUM)

This subroutine reads the header off each scan file. The number of sweeps per scan *SWPNUM* is passed back to the main program. This subroutine is called by the main program.

OFFSET (X)

This subroutine calculates the mean of X and subtracts it from each component in the vector. This subroutine is called by the main program.

PIXEL (NSCANMAX, SWPMAX, PT, NSCAN, SWPNUM)

This subroutine locates missing datum in each scan and averages the data in the scans above and below it to replace the missing data. NSCANMAX is the maximum number of scans, SWPMAX is the maximum number of sweeps, PT is the power for each pixel, NSCAN is the number of scans in the image, and SWPNUM is the number of sweeps per scan in the image. This subroutine is called by the main program.

POWER (X, TOT)

This subroutine calculates the backscattered power TOT for the transformed data X. This subroutine is called by the main program.

WINDOW (W)

This subroutine sets up the calculation of the Hamming weights W. This subroutine is called by the main program.

Program INTER

This FORTRAN program, written by J. Nagle, corrects the interlacing in all images except 3081221VV. The even numbered scans are reversed.

Program INTER_2

This FORTRAN program, written by J. Nagle, corrects the interlacing for image 3081221VV only. The first scan in this image was missing so the odd numbered scans are reversed.

Program CAL

This FORTRAN program, written by J. Nagle, integrates between the –6-dB points of the power peak attributable to the coupling between the transmitter antenna and receiver antenna. This program is based on the program PROCESS and uses many of the same subroutines and functions. The program is run on a SUN Sparc Station 1^{+}. The following is a brief description of the subroutines and functions used in CAL:

AVG

This subroutine calculates the average of the integrations between the –6-dB points of the power peak for an entire image. This subroutine is called by the main program.

FFT (FT, FI, K, SIGN)

See PROCESS.

HAM (N, K)

See PROCESS.

HEADER (SWPNUM)

See PROCESS.

LIMITS (POW, MAXPOW, IPOW, IMIN, IMAX)

This subroutine finds the range values over which the –6-dB points of the power peak are integrated. POW is the power values over the entire range, MAXPOW is the maximum power value of the peak, IPOW is the indices of POW that contains the maximum power value, IMIN is the indices of the minimum range value for the peak –6-dB power, and IMAX is the indices of the maximum range value for the peak –6-dB power. This subroutine is called by the subroutine POWER.

OFFSET (X)

See PROCESS.

PIXEL (NSCANMAX, SWPMAX, PT, NSCAN, SWPNUM)

See PROCESS.

POWER (X, TOT)

See PROCESS.

WINDOW (W)

See PROCESS.

Program NRCSH

This PASCAL program calculates the NRCS for HH and VH antenna configurations. The program was written by Nick Allan of Northeastern University and is run on a PC.

Program NRCSV

This PASCAL program calculates the NRCS for VV and HV antenna configurations. The program was written by Nick Allan of Northeastern University and is run on a PC.

```
c PROCESS.FOR
c
c This FORTRAN-77 program calculates the power spectrum for a 35 GHz mmw radar image.
c
c Written by Joyce Nagle  August 1990

      Program PROCESS

      Integer NSCANMAX, SWPMAX
      Parameter (NSCANMAX=200, SWPMAX=200)

      Real POW
      Real IR(256), MAG_IQ(256), QR(256), W(256)
      Real PT(NSCANMAX,SWPMAX)

      Integer ACTUAL, NSCAN, SWPNUM
      Integer I, J, K, L

      Complex*8 IQ(256)

      Character*30 DUMMY
      Character*60 DFILE

c Initialize
c Open file with all file names

      Open (Unit=50, Name='DIR.OUT', Status='OLD')

c Open output data file

      Open (Unit=60, Name='POWER.OUT', Status='UNKNOWN')

c For each file

      Read (50, *) NSCAN

      Do 10 I = 1, NSCAN

c Count the actual number of sweeps in each scan
c Rezero the counter

      ACTUAL = 0

c Read file name

      Read (50, '(a)') DUMMY
      DFILE = '/data/nagle/radar/35GHz/'//DUMMY
      print *, DFILE
      Open (Unit=51, Name=DFILE, Status='OLD')

c Read header from file and find number of sweeps

      Call HEADER ( SWPNUM )

c Calculate Hamming weights

      Call WINDOW ( W )

c For each sweep set up vectors with i,q pairs
```

```
      Do 20 J = 1, SWPNUM

        Do 30 K = 1, 256
         Read (51, *, End=100) IR(K)
         Read (51, *) QR(K)
 30      Continue

        ACTUAL = ACTUAL + 1

c  The first sweep in each scan is ignored because the antenna is moved at the end of each sweep
c  by delta azimuth angle to reposition it for the next sweep.  So in order to line up the sides only
c  the pixels from the (minimum azimuth angle + delta  azimuth angle) to the maximum azimuth
c  angle is considered.  This is all done prior to correcting for interlacing.

        If ( J .gt. 1 )  Then

c  Subtract DC offset from the (i,q) values

         Call OFFSET ( IR )
         Call OFFSET ( QR )

c  Multiply by Hamming weights

         Do 40 L = 1, 256
          IR(L) = IR(L) * W(L)
          QR(L) = QR(L) * W(L)
 40       Continue

c  Calculate FFT
c  This FFT uses a decimation-in-time algorithm with bit-reversed ordering.

         Call FFT ( IR, QR, 8, -1.0 )

c  Create complex (i,q) where iq = i + jq and j = sqrt(-1)

         Do 50 L = 1, 256
          IQ(L) = CMPLX(IR(L),QR(L))
 50       Continue

c  Calculate absolute value of the ffted (i,q) pairs

         Do 60 L = 1, 256
          MAG_IQ(L) = CABS(IQ(L))
 60       Continue

c  Calculate the received power

         Call POWER ( MAG_IQ, POW )

           PT(I,J-1) = POW

         End If   ! only pixels 2 to sweep number

         Go To 20

  100     PT(I,J-1) = -99999.0

  20   Continue

       Write (*, '("  Actual sweep number:  ", i3)')  ACTUAL
```

```
  Close (Unit=51)

10 Continue

 Call PIXEL ( NSCANMAX, SWPMAX, PT, NSCAN, SWPNUM )

 Do I = 1, NSCAN
  Do J = 1, SWPNUM-1
   Write (60, *)  PT(I,J)
  End Do
 End Do

 End
```

```
c This subroutine for FFT came from Don Albert

      SUBROUTINE FFT(FR,FI,K,SIGN)
C  REFERENCE STEARNS, DIGITAL SIGNAL ANALYSIS
C  FFT USING TIME DECOMPOSITION WITH INPUT BIT REVERSAL
C  DATA IS IN FR(REAL) AND FI(IMAGINARY) ARRAYS.
C  COMPUTATION IS IN PLACE, AND OUTPUT REPLACES INPUT.
C  NUMBER OF POINTS MUST BE N=2**K
C  FR(N) AND FI(N) MUST BE DIMENSIONED IN MAIN PROGRAM.
C  CALCULATES FFT FOR SIGN= -1.0, INV FFT FOR SIGN= 1.0
      REAL*4 FR(256),FI(256)
      N=2**K
      MR=0
      NN=N-1
      DO 2 M=1,NN
      L=N
    1 L=L/2
      IF(MR+L.GT.NN)GO TO 1
      MR=MOD(MR,L)+L
      IF(MR.LE.M) GO TO 2
      TR=FR(M+1)
      FR(M+1)=FR(MR+1)
      FR(MR+1)=TR
      TI=FI(M+1)
      FI(M+1)=FI(MR+1)
      FI(MR+1)=TI
    2 CONTINUE
      L=1
    3 IF(L.GE.N) GO TO 5
      ISTEP=2*L
      EL=L
      DO 4 M=1,L
      A=SIGN*3.1415926535*FLOAT(1-M)/EL
      WR=COS(A)
      WI=SIN(A)
      DO 4 I=M,N,ISTEP
      J=I+L
      TR=WR*FR(J)-WI*FI(J)
      TI=WR*FI(J)+WI*FR(J)
      FR(J)=FR(I)-TR
      FI(J)=FI(I)-TI
      FR(I)=FR(I)+TR
    4 FI(I)=FI(I)+TI
      L=ISTEP
      GO TO 3
    5 CONTINUE
      IF(SIGN.LT.0.0) RETURN
      DO 6 I=1,N
      FR(I)=FR(I)/FLOAT(N)
    6 FI(I)=FI(I)/FLOAT(N)
      RETURN
      END
```

```
c Real function HAM

c This real function applies a Hamming window.

c Written by Joyce Nagle  August 1990

   Real Function HAM ( N, K )

   Integer N, K

   Real PI

   PI = ACOS(-1.0)

   HAM = 0.54 - 0.46 * COS(2.0*K*PI/(N-1))

   Return
   End
```

```
c Subroutine HEADER

c This subroutine pulls the headers off the files.

c Written by Joyce Nagle  August 1990

    Subroutine HEADER ( SWPNUM )

    Real AZ_ANG, EL_ANG, SWPTIM, TMEAS, WNDDIR, WNDSPD

    Integer SWPNUM

    Character CAL*3, POL*2, TARGET*30

    Read (51, *)    TMEAS
    Read (51, '(a)') CAL
    Read (51, '(a)') TARGET
    Read (51, *)    WNDDIR
    Read (51, *)    WNDSPD
    Read (51, *)    EL_ANG
    Read (51, *)    AZ_ANG
    Read (51, '(a)') POL
    Read (51, *)    SWPNUM
    Read (51, *)    SWPTIM

    Return
    End
```

```
c Subroutine OFFSET

c This subroutine calculates the mean and subtracts from
c each component in the vector.

c Written by Joyce Nagle  August 1990


      Subroutine OFFSET ( X )

      Real MEAN, SUM
      Real X(256)

      Integer I

      SUM = 0.0

c Calculate the mean

      Do 10 I = 1, 256
        SUM = SUM + X(I)
   10 Continue

      MEAN = SUM / 256.0

c Subract the mean from each component

      Do 20 I = 1, 256
        X(I) = X(I) - MEAN
   20 Continue

      Return
      End
```

```
c Subroutine PIXEL

c When a scan is short it is assumed that the missing data is for
c the pixel(s) at the end of the scan. To obtain a value for the
c missing pixel, the power in the scan above and below it are
c averaged.

c Written by Joyce Nagle  October 1990


   Subroutine PIXEL ( NSCANMAX, SWPMAX, PT, NSCAN, SWPNUM )

   Integer NSCAN, NSCANMAX, SWP, SWPMAX, SWPNUM
   Integer COL, I, J

   Real PT(NSCANMAX,SWPMAX)

c Decrease the sweep number by 1. The image is reduced by the first pixel in
c each scan to account for movement of antenna to new position at the end of
c each scan.

   SWP = SWPNUM - 1

   Do 10 I = 1, NSCAN

    Do 20 J = 1, SWP

     If ( PT(I,J) .lt. 0.0 ) Then

c There has not been a correction for interlacing. Therefore, the pixels
c in successive scans are reversed in index order.

      COL = SWP - J + 1

      If ( I .eq. 1 ) Then
       PT(I,J) = PT(I+1,COL)
      Else If ( I .gt. 1 .and. I .lt. NSCAN ) Then
       PT(I,J) = ( PT(I-1,COL) + PT(I+1,COL) ) / 2.0
      Else If ( I .eq. NSCAN ) Then
       PT(I,J) = PT(I-1,COL)
      End If

     End If

 20  Continue

 10 Continue

   Return
   End
```

```
c Subroutine POWER

c This subroutine calculates the received power spectrum.

c Written by Joyce Nagle  August 1990

      Subroutine POWER ( X, TOT )

      Integer I, MAX, MIN

c Integrate from 12 m to 116 m
      Parameter ( MIN=12, MAX=116 )

      Real TOT, X(256)

      TOT = 0.0

c Sum power over range desired.  The min and max in meters and are multiplied by 2 because
c the resolution is 50 cm.  So if the min=12 meter then 12*2 corresponds to the 24th subscript
c index.

      Do 10 I = 1, 256
        If ( I .gt. MIN*2 .and. I .lt. MAX*2 )  Then
          TOT = TOT + X(I)*X(I)
        End If
   10 Continue

      TOT = 10.0 * LOG10(TOT)

      Return
      End
```

```
c Subroutine WINDOW

c This subroutine calculates the Hamming's weights.

c Written by Joyce Nagle  August 1990

   Subroutine WINDOW ( W )

   Real W(256)
   Real HAM
   Integer K

   Do 10 K = 1, 256
    W(K) = HAM( 256, K )
 10 Continue

   Return
   End
```

```
c Program INTER

c This program corrects interlacing for the 35GHz images in the directory
c /data/nagle/radar/35GHz.

c Written by J. Nagle 12.12.90 based on Pascal program INTER
c written by Nick Allan at Northeastern University.

      program inter

      integer   i, j, ncols, nmax, nrows
      parameter (nmax=200)
      real      x(nmax,nmax)
      character dir*27, dummy*9, fname*60

      dir = '/data/nagle/radar/35GHz/'

       write (*, '(//"  Program INTER")')

       write (*, '("    Enter image name:  ",$)')
      read (*, '(a)')  dummy
      fname = dir//dummy//'/NRCS/'//dummy//'.pow'
      open (unit=50, file=fname, status='old')

      fname = dir//dummy//'/NRCS/'//dummy(1:7)//'.cor'
      open (unit=60, file=fname, status='unknown')

       write (*, '("    Enter number of rows:  ",$)')
      read (*, *)  nrows

       write (*, '("    Enter number of columns:  ",$)')
      read (*, *)  ncols

      print *, fname

      do i = 1, nrows
       do j = 1, ncols
        read (50, *)  x(i,j)
       end do
       if ( mod(i,2) .ne. 0 )  then
        do j = 1, ncols
         write (60, *)  x(i,j)
        end do
       else
        do j = ncols, 1, -1
         write (60, *) x(i,j)
        end do
       end if
      end do

      close (unit=50)
      close (unit=60)

      end
```

```
c This FORTRAN-77 program calculates the relative calibration constant for a 35 GHz mmw radar
c image. The leakage is integrated over the +/- 6 dB power peak for the signal coupling.

c Written by Joyce Nagle Oc    -- 1990

      Program CAL

      Real IR(256), MAG_IQ(256), QR(256), W(256)

      Integer actual, NFILES, SWPNUM
      Integer i, J, K, L

      Complex*8 IQ(256)

      Character*30 DUMMY
      Character*60 DFILE

c Initialize
c Open file with all file names

      Open (Unit=50, Name='DIR.OUT', Status='OLD')

c For first sweep only

      Read (50, *) NFILES

      Do i = 1, nfiles

c Count the actual number of sweeps in each scan
c Rezero the counter

       actual = 0

c Read file name

       Read (50, '(a)') DUMMY
       DFILE = '/data/nagle/radar/35GHz/'//DUMMY
       write (*,'(a)') DFILE
       Open (Unit=51, Name=DFILE, Status='OLD')

c Read header from file and find number of sweeps

       Call HEADER ( SWPNUM )

c Calculate Hamming weights

       Call WINDOW ( W )

c For each sweep set up vectors with i,q pairs

       Do J = 1, SWPNUM

        Do K = 1, 256

        Read (51, *, end=100) IR(K)
        Read (51, *) QR(K)
       end do

       actual = actual + 1
```

```
c The first sweep in each scan is ignored because the antenna is moved at the end of each sweep
c  by delta azimuth angle to reposition it for the next sweep.  So in order to line up the  sides only
c  the pixels from the (minimum azimuth angle + delta azimuth angle) to the maximum azimuth
c  angle is considered. This is all done prior to correcting for interlacing.

c        If ( J .eq. 5 )  Then
       If ( J .gt. 1 )  Then

c  Subtract DC offset from the (i,q) values

        Call OFFSET ( IR )
        Call OFFSET ( QR )

c  Multiply by Hamming weights

        Do L = 1, 256
         IR(L) = IR(L) * W(L)
         QR(L) = QR(L) * W(L)
        end do

c  Calculate FFT
c  This FFT uses a decimation-in-time algorithm with bit-reversed ordering.

        Call FFT ( IR, QR, 8, -1.0 )

c  Create complex (i,q) where iq = i + jq and j = sqrt(-1)

        Do L = 1, 256
         IQ(L) = CMPLX(IR(L),QR(L))
        end do

c  Calculate absolute value of the ffted (i,q) pairs

        Do L = 1, 256
         MAG_IQ(L) = CABS(IQ(L))
        end do

c  Calculate the received power

        Call POWER ( MAG_IQ )

       end if

 100    continue

      end do   ! j

      write (*, '("  Actual sweep number:  ", i3)')  actual

      end do   ! i

 c  Average

      Call AVG

      Close (Unit=51)
      Close (Unit=60)

      End
```

```
c Subroutine AVG

c This subroutine calculates the average of the relative calibration constants.

c Written by Joyce Nagle  October 1990

   Subroutine AVG

   Integer I, ICOUNT, NMAX
   Parameter (NMAX=15000)

   Real cal, sum, x

   Rewind (Unit=60)

   ICOUNT = 0
   SUM = 0.0

   Do I = 1, NMAX
     Read (60, *, End=10)  X
     ICOUNT = ICOUNT + 1
     SUM =SUM + X
   End Do

10 cal = sum / icount

   write (*, '("  Calibration Constant  ", f7.2)') cal

   End
```

```
c Subroutine LIMITS

c This subroutine finds the range values over which the -6 dB power is integrated.

c Written by Joyce Nagle  December 1990.

      subroutine limits ( pow, maxpow, ipow, imin, imax )

      integer i, imax, imin, ipow
      real    maxpow, pow(256), pow6

c Find the maximum power minus 6 dB point.

      pow6 = maxpow - 6.0

      i = ipow
      do while ( pow(i) .ge. pow6 )
       imin = i
       i = i - 1
      end do

      i = ipow
      do while ( pow(i) .ge. pow6 )
       imax = i
       i = i + 1
      end do

      return
      end
```

```
program nrcsh;

{ This program calculates the NRCS for the HH and VH polarizations. }
{ The program was written by N. Allan and modified by J.A. Nagle}

uses crt;

const
  height_1=7.77;

  d=0.46;

var
  fname                    : string;
  inter                    : text;
  nrcs                     : text;
  i,j                      : integer;
  angle,Aw,sigma,power     : real;
  start_angle              : real;
  increment_angle          : real;
  gain                     : array [0..78] of real;
  nrows, ncols             : integer;
  cal                      : real;

function log(n:real) : real;
begin
  log := ln(n)/ln(10);
end;

function sine(n:real) : real;
begin
  sine:= sin(n*2*pi/360)
end;

function atan(n:real) : real;
begin
  atan:= 360*arctan(n)/(2*pi)
end;

function tan(n:real) : real;
begin
  tan:= sin(n*2*pi/360)/cos(n*2*pi/360)
end;

function cosine(n:real) : real;
begin
  cosine:= cos(n*2*pi/360)
end;

function arcosine(n:real):real;
begin
  arcosine:= 360*(pi/2-arctan(n/sqrt(1-sqr(n))))/(2*pi);
end;
```

```
procedure integrate;
const
  ang_max=4.9;
  limit=128;
var
  k,l,gain_index_1,gain_index_2                 : integer;
  x,y,g1,g2,delta_x,delta_y                     : real;
  x_u,x_l,omega_1,omega_2,R_squared,y_u,y_l,y_max  : real;
begin

  { integration limits }

  x_u:=height_1/tan(angle-ang_max);
  if x_u > limit then
    x_u:=limit;
  x_l:=(height_1+d*cosine(angle))/tan(angle+ang_max)+d*sine(angle);
  y_u:=(height_1*tan(ang_max))/sine(angle-ang_max);
  y_max:=sqrt(sqr(limit)-sqr(height_1)-sqr(x_l));
  if y_u > y_max then
    y_u:=y_max;

  { increments in x and y }
  delta_x:=(x_u-x_l)/20;
  delta_y:=y_u/10;

  { initialize }

  Aw:=0;

  { integration }

  for k:=19 downto 0 do
    for l:=-9 to 10 do
    begin
      x:=x_l+delta_x*k;
      y:=delta_y*l;
      R_squared:=sqr(x)+sqr(y)+sqr(height_1+d*cosine(angle));
      omega_1:=arcosine((x+height_1*tan(angle))*cosine(angle)/sqrt(sqr(x)
+sqr(y)+sqr(height_1)));
      omega_2:=arcosine((x-d*sine(angle)+(height_1+d*cosine(angle))
*tan(angle))*cosine(angle)/sqrt(sqr(x-d*sine(angle))+sqr(y)+sqr(height_1
+d*cosine(angle))));
      if sqrt(R_squared) <= limit then
      begin
        if omega_1 <= ang_max then
          gain_index_1:=abs(round(omega_1*78/ang_max))
        else
          gain_index_1:=78;
        if omega_2 <= ang_max then
          gain_index_2:=abs(round(omega_2*78/ang_max))
        else
          gain_index_2:=78;
        g1:=gain[gain_index_1];
        g2:=gain[gain_index_2];
          Aw:=Aw+g1*g2*delta_x*delta_y/sqr(R_squared);
        end;
      end;
  end;
```

```
begin

  writeln (' ');
  write ('Enter input file: ');
  readln (fname);
  assign (inter, fname);
  reset (inter);

  write ('Enter output NRCS file: ');
  readln (fname);
  assign (nrcs, fname);
  rewrite (nrcs);

  write ('Enter number of rows: ');
  readln (nrows);

  write ('Enter number of columns (correct for antenna positioning): ');
  readln (ncols);

  write ('Enter minimum grazing angle: ');
  readln (start_angle);

  write ('Enter increment in grazing angle: ');
  readln (increment_angle);

  write ('Enter calibration constant: ');
  readln (cal);
  cal := -cal;

  clrscr;

  gain[78]:=0.0022;
  gain[77]:=0.0030;
  gain[76]:=0.0038;
  gain[75]:=0.0043;
  gain[74]:=0.0050;
  gain[73]:=0.0060;
  gain[72]:=0.0066;
  gain[71]:=0.0078;
  gain[70]:=0.0089;
  gain[69]:=0.0098;
  gain[68]:=0.0105;
  gain[67]:=0.0112;
  gain[66]:=0.0120;
  gain[65]:=0.0126;
  gain[64]:=0.0138;
  gain[63]:=0.0151;
  gain[62]:=0.0155;
  gain[61]:=0.0158;
  gain[60]:=0.0158;
  gain[59]:=0.0162;
  gain[58]:=0.0166;
  gain[57]:=0.0162;
  gain[56]:=0.0158;
  gain[55]:=0.0155;
  gain[54]:=0.0155;
  gain[53]:=0.0151;
  gain[52]:=0.0148;
  gain[51]:=0.0145;
  gain[50]:=0.0141;
```

```
gain[49]:=0.0155;
gain[48]:=0.0158;
gain[47]:=0.0162;
gain[46]:=0.0178;
gain[45]:=0.0200;
gain[44]:=0.0229;
gain[43]:=0.0240;
gain[42]:=0.0251;
gain[41]:=0.0275;
gain[40]:=0.0295;
gain[39]:=0.0316;
gain[38]:=0.0398;
gain[37]:=0.0447;
gain[36]:=0.0490;
gain[35]:=0.0501;
gain[34]:=0.0562;
gain[33]:=0.0603;
gain[32]:=0.0631;
gain[31]:=0.0776;
gain[30]:=0.0955;
gain[29]:=0.1202;
gain[28]:=0.1259;
gain[27]:=0.1413;
gain[26]:=0.1514;
gain[25]:=0.1698;
gain[24]:=0.1995;
gain[23]:=0.2138;
gain[22]:=0.2512;
gain[21]:=0.2630;
gain[20]:=0.2754;
gain[19]:=0.2951;
gain[18]:=0.3162;
gain[17]:=0.3981;
gain[16]:=0.4365;
gain[15]:=0.4898;
gain[14]:=0.5129;
gain[13]:=0.5495;
gain[12]:=0.6026;
gain[11]:=0.6166;
gain[10]:=0.6457;
gain[9]:=0.7244;
gain[8]:=0.7586;
gain[7]:=0.7943;
gain[6]:=0.8710;
gain[5]:=0.9226;
gain[4]:=0.9550;
gain[3]:=0.9772;
gain[2]:=0.9977;
gain[1]:=1.0000;
gain[0]:=1.0000;
for i:=1 to nrows do
begin
   writeln ('working row ',i);
  angle:=start_angle+(i-1)*increment_angle;
  integrate;
  for j:=1 to ncols do
  begin
    readln (inter,power);
    sigma:=cal+power-10*log(Aw);
    writeln (nrcs,sigma);
```

```
    end;
  end;
  close (inter);
  close (nrcs);
end.
```

```
program nrcsv;

{ This program calculates the NRCS for the VV and HV polarizations. }
{ The program was written by N. Allan and modified by J.A. Nagle }

uses crt;

const
  height=8;


  d=0.46;

var
  fname                     : string;
  inter,nrcs                : text;
  i,j                       : integer;
  angle,Aw,sigma,power      : real;
  start_angle               : real;
  increment_angle           : real;
  gain                      : array [0..78] of real;
  nrows, ncols              : integer;
  cal                       : real;

function log(n:real) : real;
begin
  log := ln(n)/ln(10);
end;

function sine(n:real) : real;
begin
  sine:= sin(n*2*pi/360)
end;

function atan(n:real) : real;
begin
  atan:= 360*arctan(n)/(2*pi)
end;

function tan(n:real) : real;
begin
  tan:= sin(n*2*pi/360)/cos(n*2*pi/360)
end;

function cosine(n:real) : real;
begin
  cosine:=cos(n*2*pi/360)
end;

function arcosine(n:real):real;
begin
  arcosine:=360*(pi/2-arctan(n/sqrt(1-sqr(n))))/(2*pi);
end;
```

```
procedure integrate;
const
  ang_max=4.9;
  limit=128;
var
  k,l,gain_index_1,gain_index_2              : integer;
  x,y,delta_x,delta_y,g1,g2                  : real;
  x_l,x_u,omega_1,omega_2,R_squared,y_u,y_max   : real;
begin

  { integration limits }

  x_u:=height/tan(angle-ang_max);
  if x_u > limit then
    x_u:=limit;
  x_l:=height/tan(angle+ang_max);
  y_u:=height*tan(ang_max)/sine(angle-ang_max)-d/2;
  y_max:=sqrt(sqr(limit)-sqr(height)-sqr(x_l));
  if y_u > y_max then
    y_u:=y_max;

  { increments in x and y }

  delta_x:=(x_u-x_l)/20;
  delta_y:=y_u/10;

  { initialize }

  Aw:=0;

  { integration }

   for k:=19 downto 0 do
    for l:=-9 to 10 do
    begin
      x:=x_l+delta_x*k;
      y:=delta_y*l;
      R_squared:=sqr(x)+sqr(y)+sqr(height);
      omega_1:=arcosine((x+height*tan(angle))*cosine(angle)/sqrt(sqr(x)
+sqr(y-d/2)+sqr(height)));
      omega_2:=arcosine((x+height*tan(angle))*cosine(angle)/sqrt(sqr(x)
+sqr(y+d/2)+sqr(height)));
      if sqrt(R_squared) <= limit then
      begin
        if omega_1 <= ang_max then
          gain_index_1:=abs(round(omega_1*78/ang_max))
        else
          gain_index_1:=78;
        if omega_2 <= ang_max then
          gain_index_2:=abs(round(omega_2*78/ang_max))
        else
          gain_index_2:=78;
        g1:=gain [gain_index_1];
        g2:=gain [gain_index_2];
       Aw:=Aw+g1*g2*delta_x*delta_y/sqr(R_squared);
     end;
   end;
end;
```

```
begin

  write ('Enter input file: ');
  readln (fname);
  assign (inter, fname);
  reset (inter);

  write ('Enter output NRCS file: ');
  readln (fname);
  assign (nrcs, fname);
  rewrite (nrcs);

  write ('Enter number of rows: ');
  readln (nrows);

  write ('Enter number of columns (correct for antenna positioning): ');
  readln (ncols);

  write ('Enter minimum grazing angle: ');
  readln (start_angle);

  write ('Enter increment in grazing angle: ');
  readln (increment_angle);

  write ('Enter calibration constant: ');
  readln (cal);
  cal := -cal;

  clrscr;

  gain[78]:=0.0022;
  gain[77]:=0.0030;
  gain[76]:=0.0038;
  gain[75]:=0.0043;
  gain[74]:=0.0050;
  gain[73]:=0.0060;
  gain[72]:=0.0066;
  gain[71]:=0.0078;
  gain[70]:=0.0089;
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  gain[68]:=0.0105;
  gain[67]:=0.0112;
  gain[66]:=0.0120;
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  gain[62]:=0.0155;
  gain[61]:=0.0158;
  gain[60]:=0.0158;
  gain[59]:=0.0162;
  gain[58]:=0.0166;
  gain[57]:=0.0162;
  gain[56]:=0.0158;
  gain[55]:=0.0155;
  gain[54]:=0.0155;
  gain[53]:=0.0151;
  gain[52]:=0.0148;
  gain[51]:=0.0145;
  gain[50]:=0.0141;
  gain[49]:=0.0155;
```

```
gain[48]:=0.0158;
gain[47]:=0.0162;
gain[46]:=0.0178;
gain[45]:=0.0200;
gain[44]:=0.0229;
gain[43]:=0.0240;
gain[42]:=0.0251;
gain[41]:=0.0275;
gain[40]:=0.0295;
gain[39]:=0.0316;
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gain[31]:=0.0776;
gain[30]:=0.0955;
gain[29]:=0.1202;
gain[28]:=0.1259;
gain[27]:=0.1413;
gain[26]:=0.1514;
gain[25]:=0.1698;
gain[24]:=0.1995;
gain[23]:=0.2138;
gain[22]:=0.2512;
gain[21]:=0.2630;
gain[20]:=0.2754;
gain[19]:=0.2951;
gain[18]:=0.3162;
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gain[11]:=0.6166;
gain[10]:=0.6457;
gain[9]:=0.7244;
gain[8]:=0.7586;
gain[7]:=0.7943;
gain[6]:=0.8710;
gain[5]:=0.9226;
gain[4]:=0.9550;
gain[3]:=0.9772;
gain[2]:=0.9977;
gain[1]:=1.0000;
gain[0]:=1.0000;

for i:=1 to nrows do
begin
  writeln ('working row ' ,i);
  angle:=start_angle+(i-1)*increment_angle;
  integrate;
  for j:=1 to ncols do
  begin
    readln (inter,power);
    sigma := cal + power-10*log(Aw);
```

```
      writeln (nrcs,sigma);
    end;
  end;
  close (inter);
  close (nrcs);
end.
```

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12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

Search and Destroy Armaments (SADARM) winter captive flight tests were conducted in Grayling, Michigan, from 6–19 March 1990 to assess the performance of SADARM sensors flying over appropriate target sets in a winter background environment. Several target configurations were used in a variety of winter conditions, including both moving and stationary targets as well as clean and countermeasured targets and decoys. Ground-based millimeter wave radar and infrared measurements made during the testing period provided data to increase our understanding of target–background interaction. This report contains the methods used to reduce and calibrate the ground-based 35-GHz radar data. Each scene imaged is described and a discussion is presented of the methods used to calculate the backscattered power and NRCS and to calibrate the radar.

14. SUBJECT TERMS

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