MILLIMETER - WAVE RADAR SCATTERING FROM TERRAIN: DATA HANDBOOK VERSION 2

Fawwaz T. Ulaby
Thomas F. Haddock

Technical Report 026247-4-T

September, 1990

026247-4-T

MILLIMETER - WAVE RADAR SCATTERING FROM TERRAIN: DATA HANDBOOK, Version 2

Fawwaz T. Ulaby

Thomas F. Haddock

Radiation Laboratory
University of Michigan
Ann Arbor, Michigan

Technical Report 026247-4-T

September, 1990

U.S. Army Research Office

Contract DAAL03-89-K-0056

026247-4-T

MILLIMETER - WAVE RADAR SCATTERING FROM TERRAIN: DATA HANDBOOK, Version 2

Fawwaz T. Ulaby

Thomas F. Haddock

Radiation Laboratory
University of Michigan
Ann Arbor, Michigan

Technical Report 026247-4-T

September, 1990

U.S. Army Research Office

Contract DAAL03-89-K-0056

UNCLASSIFIED MASTER COPY - FOR REPRODUCTION PURPOSES

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE:

3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S):

5. MONITORING ORGANIZATION REPORT NUMBER(S):

6a. NAME OF PERFORMING ORGANIZATION: Radiation Laboratory, University of Michigan, Ann Arbor, Mi 48109

6b. OFFICE SYMBOL *(If applicable)*:

7a. NAME OF MONITORING ORGANIZATION: U. S. Army Research Office

6c. ADDRESS *(City, State, and ZIP Code)*: Ann Arbor, Michigan 48109

7b. ADDRESS *(City, State, and ZIP Code)*: P. O. Box 12211, Research Triangle Park, NC 27709-2211

8a. NAME OF FUNDING / SPONSORING ORGANIZATION: U. S. Army Research Office

8b. OFFICE SYMBOL *(If applicable)*:

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c. ADDRESS *(City, State, and ZIP Code)*: P. O. Box 12211, Research Triangle Park, NC 27709-2211

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE *(Include Security Classification)*: Millimeter-wave Radar Scattering From Terrain: Data Handbook, Version 2.0

12. PERSONAL AUTHOR(S): Thomas F. Haddack and Fawwaz T. Ulaby

13a. TYPE OF REPORT: Technical

13b. TIME COVERED: FROM 1/90 TO 9/90

14. DATE OF REPORT *(Year, Month, Day)*: 1990. September, 15

15. PAGE COUNT: 206

16. SUPPLEMENTARY NOTATION: The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*:

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

This report provides a summary of experimental observations of the radar backscatter from terrain, as reported in the literature. The data is at 35, 94, 140 and 225 GHz, primarily at HH, VV, and HV polarizations. The terrain types observed include dry and wet snow, in-covered ground, trees, grasses, asphalt, gravel, and others.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION: Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL:

22b. TELEPHONE *(Include Area Code)*:

22c. OFFICE SYMBOL:

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

I. INTRODUCTION

Version 1.0 of this Handbook provided plots of millimeter-wave (MMW) radar scattering data for terrain based on measurements made by the University of Michigan's Millimeter-Wave Polarimeter system at 35, 94, and 140 GHz. The present edition, Version 2.0, includes the University of Michigan data as well as data reported by The University of Massachusetts, The University of Kansas, Ohio State University, and data from other institutions.

Most of the data are presented in the form of plots of the backscattering coefficient σ^o versus the incidence angle θ, measured relative to normal incidence, although some plots of σ^o versus time are included also. The radar data are augmented with photographs and close-up observations of the target whenever such information in available in the data source. In some cases, the original data wave reported as a function of depression angle, instead of incidence angle, or in terms of γ, where

$$\gamma = \sigma^o / \cos\theta.$$

For the sake of consistency and in order to make comparison of data more useful, all such data were converted to σ^o versus θ.

No effort will be made in this handbook to provide any analysis of the radar data or to compare the data with model predictions. Instead, a list of relevant publications is given in the bibliography for the interested reader.

PART I. UNIVERSITY OF MICHIGAN DATA

The Millimeter-Wave Polarimeter is a truck-mounted radar system capable of making observations from a 20-m high platform at any incidence angle between 0° (normal incidence) and 80°. In some cases, however, because of truck-access considerations or signal-to-noise limitations, it was not possible to make observations over this entire angular range. Figure I-1 shows a photograph of the system in operation and Figure I-2 shows a close-up of the antenna platform. Table I-1 provides a summary of the system specifications.

The list below provides definitions for the quantities quoted in conjunction with the radar data presented in this part of the Handbook.

TERMINOLOGY

Average Leaf (or Needle) Dimensions - the approximate main axis length of the individual leaves (or needles).

Backscattering Coefficient - radar cross-section per unit area averaged over the illuminated area of the radar footprint, expressed in dB. Also referred to as Sigma-zero or σ^o.

Cut - this term is applied to grasses when they have been cut, and no longer have the natural termination on their blades.

Data set code - the unique alphanumeric sequence describing each data set. Typically it is the date of the measurement, in the sequence YYMMDD, with a numeric suffix if required for uniqueness.

Snow Density - the mass/volume density of undisturbed samples taken from the snowpit.

Snow Depth - the distance from the average top level of the snow to the underlying ground.

Ice Crystal Diameter - the approximate semi-major axis of an individual scatterer. This is typically a statistical quantity, arrived at by examining a number of individual scatterers.

Dry - a material is called "dry" when its moisture content (in the case of soils and vegetations) or its liquid water content (in the case of snow) is within experimental uncertainty of 0 %.

Snow Liquid Water Content (LWC) - the quantity of liquid (non-frozen) water contained in snow, by weight (gravimetric), measured in percent.

Metamorphosed - snow crystals having extensively undergone the natural sublimation process that alters their shape from its original form toward the spherical.

Moisture Content - the percent of water, by mass, contained in a representative sample of soil or vegetation. The measurement consists of weighing a sample in its natural state, and again after drying it in an oven.

Percent Ground Cover - the percent of the ground covered by tree vegetation when viewed from above.

Rough - this term is applied to surfaces which are typically rougher than the natural state in which they are usually found. Often, in the case of soils or snow, it is used to describe a surface that has been artificially roughened.

Smooth - this term is applied to surfaces which are smooth compared to the natural state in which they are usually found. Sometimes it may be used to describe a surface which has been artificially smoothed.

Surface RMS Height - the root-mean-square deviation of the surface height relative to the mean surface

Surface Temperature - the temperature registered by a mercury-bulb thermometer with the bulb just covered by the top layer of the surface.

Tree Density - number of trees per unit area.

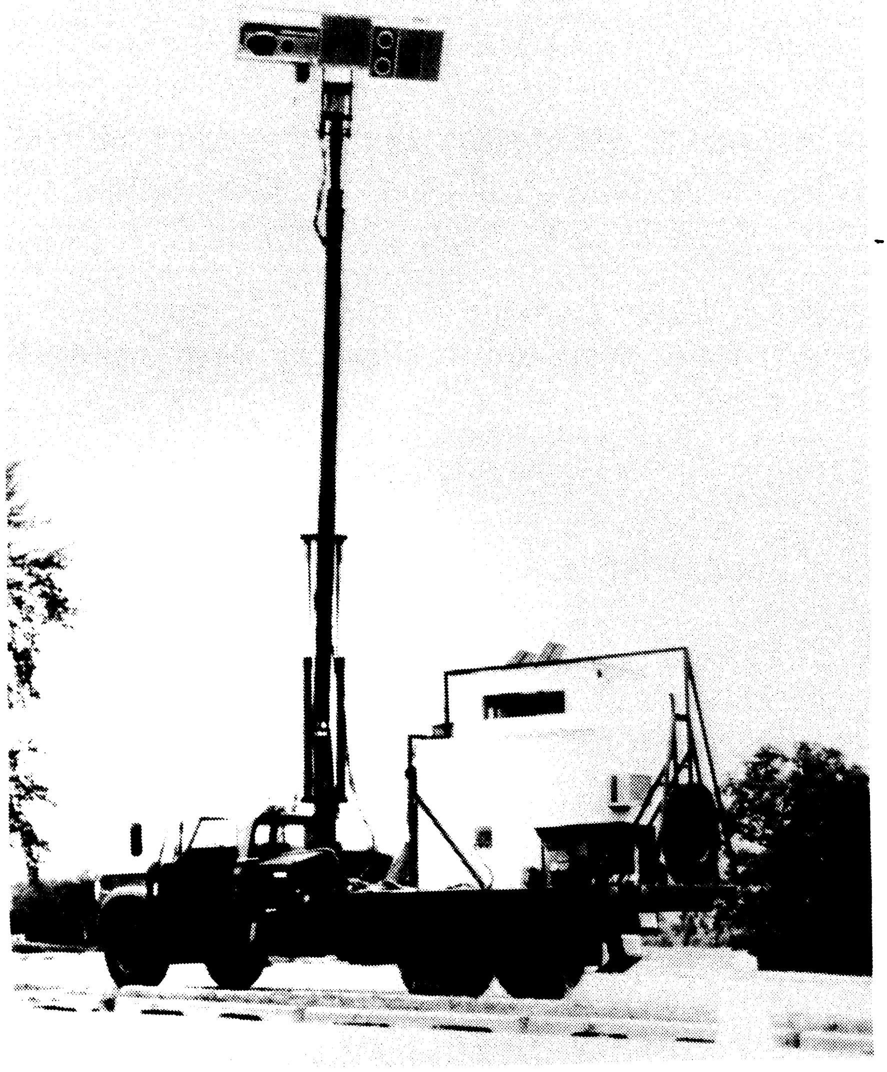


Fig. I-1 Photograph of the Millimeter-Wave Polarimeter system with the boom extended about half way.

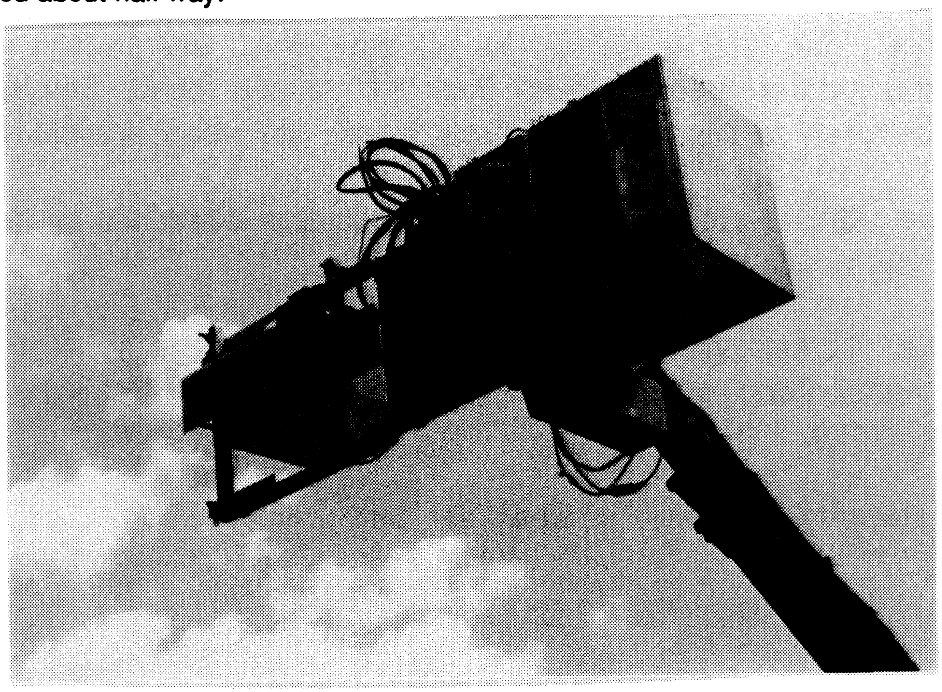


Fig. I-2. Close-up view of the RF sections, showing the 35, 94, and 140 GHz radars on the right side, and radiometers at the same operating frequencies on the left side.

Table I-1. Millimeter-wave Polarimeter system parameters.

FREQUENCIES:	~ 35, 94, 140 GHz		
IF BANDWIDTH:	0 to 2.0 GHz		
TRANSMIT POWER:	35 GHz:	+3 dBm	
	94 GHz:	0 dBm	
	140 GHz:	-4 dBm	
SWEEP RATE:	1 m-sec/freq., 51, 101, 201, 401 freq./sweep		
POLARIZATION:	HH, HV, VV, VH		
INCIDENCE ANGLES:	0 to 70 degrees		
PLATFORM HEIGHT:	3 meters minimum, to 18 meters maximum		
NOISE EQUIV. $\sigma°$:	35 GHz:	-22 dB	
	94 GHz:	-28 dB	
	140 GHz:	-21 dB	
CROSSPOL ISOLATION:	35 GHz:	23 dB	
	94 GHz:	20 dB	
	140 GHz:	10 dB	
PHASE STABILITY:	35 GHz:	~1 degree/hour	
	94 GHz:	~1 degree/minute	
	140 GHz:	~10 to 50 degrees/second	
NEAR FIELD DIST:	35 GHz:	2.7 m	
	94 GHz:	7.3 m	
	140 GHz:	2.7 m	
BEAMWIDTH:	35 GHz:	R: 4.2 deg	T: 4.2 deg
	94 GHz:	R: 1.4 deg	T: 2.8 deg
	140 GHz:	R: 2.2 deg	T: 11.8 deg
ANTENNA DIAMETER:	35 GHz:	R: 6 inches	T: 6 inches
	94 GHz:	R: 6 inches	T: 3 inches
	140 GHz:	R: 3 inches	T: 0.36 inches
SIGNAL PROCESSING:	HP 8510A/8511A based		
OUTPUT PRODUCTS:	-received power verses range -received power verses frequency (at fixed R) -phase and amplitude for each frequency		

2. MMW DATA FOR DRY SNOW

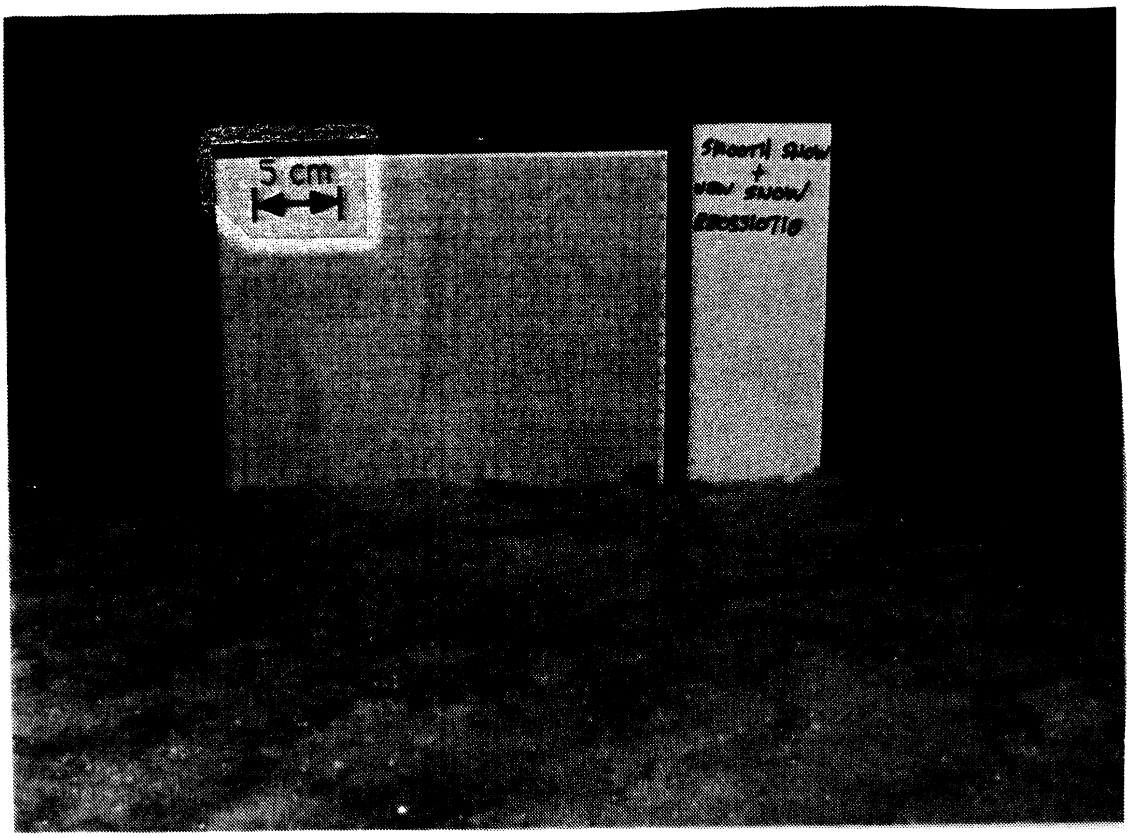
Snow is a very complex target and many of the following data sets could be categorized in several ways. In the interests of simplifying the data organization, and facilitating its use by the reader, the data have been categorized into subsections by their most salient feature.

The following chart is included in order to give a more complete overview of the characteristics of the data:

Data Set Code	A smooth surface	B slightly rough surface	C very rough surface	D heavily metamorphosed	E unmetamorphosed fresh	F small crystal size	G large crystal size
880329 (S)	x			x			x
880329 (SR)		x		x			x
880329 (VR)			x	x			x
890210	x			x			x
890223	x				x	x	
890302 (SM)	x				x	x	
890302 (LG)	x				x		x
890307 (RO)		x			x		x
890307 (SM)	x				x		x

A. Smooth Surface

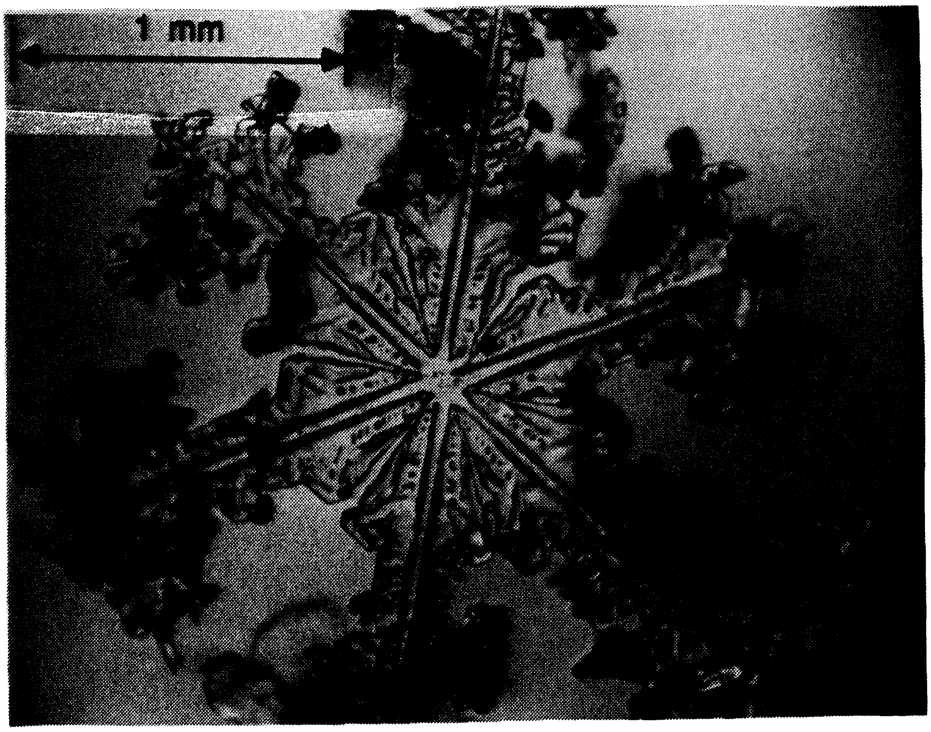
Dry snow
Data set code: 880329(S)
Depth: 20-30 cm
LWC: 0 %
Surface RMS height: 1 cm
Density: 0.3 to 0.4 gm/cm^3
Ice crystal diameter: 1 to 4 mm
Surface temperature: -2.0 C
Description: smooth snow surface



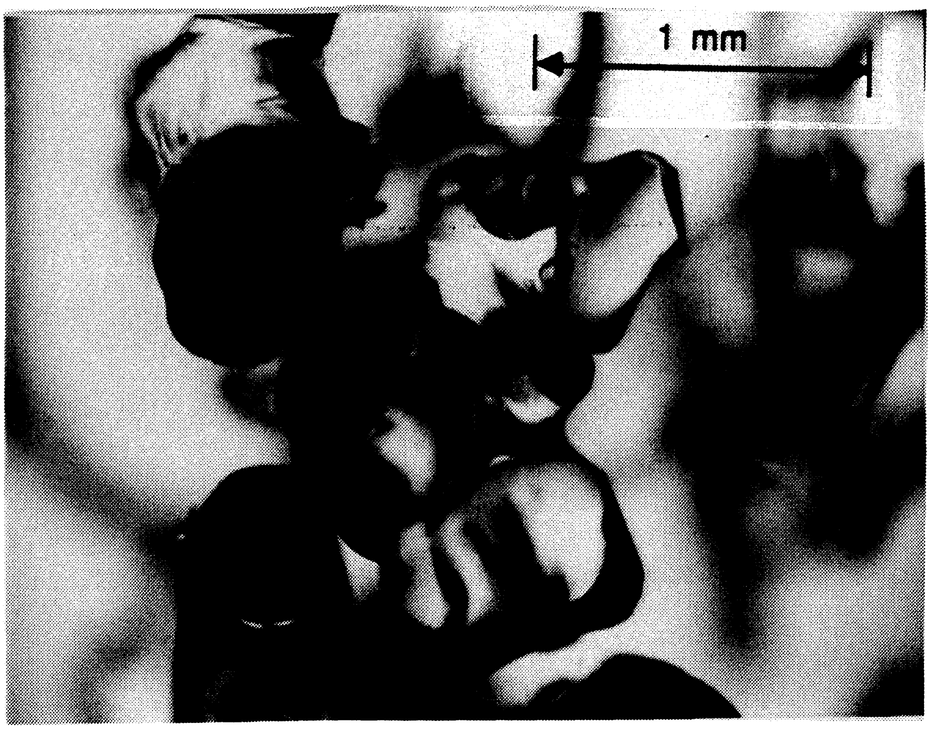
Surface roughness profile with 1 cm grid

MMW DATA FOR DRY SNOW

880329(S)



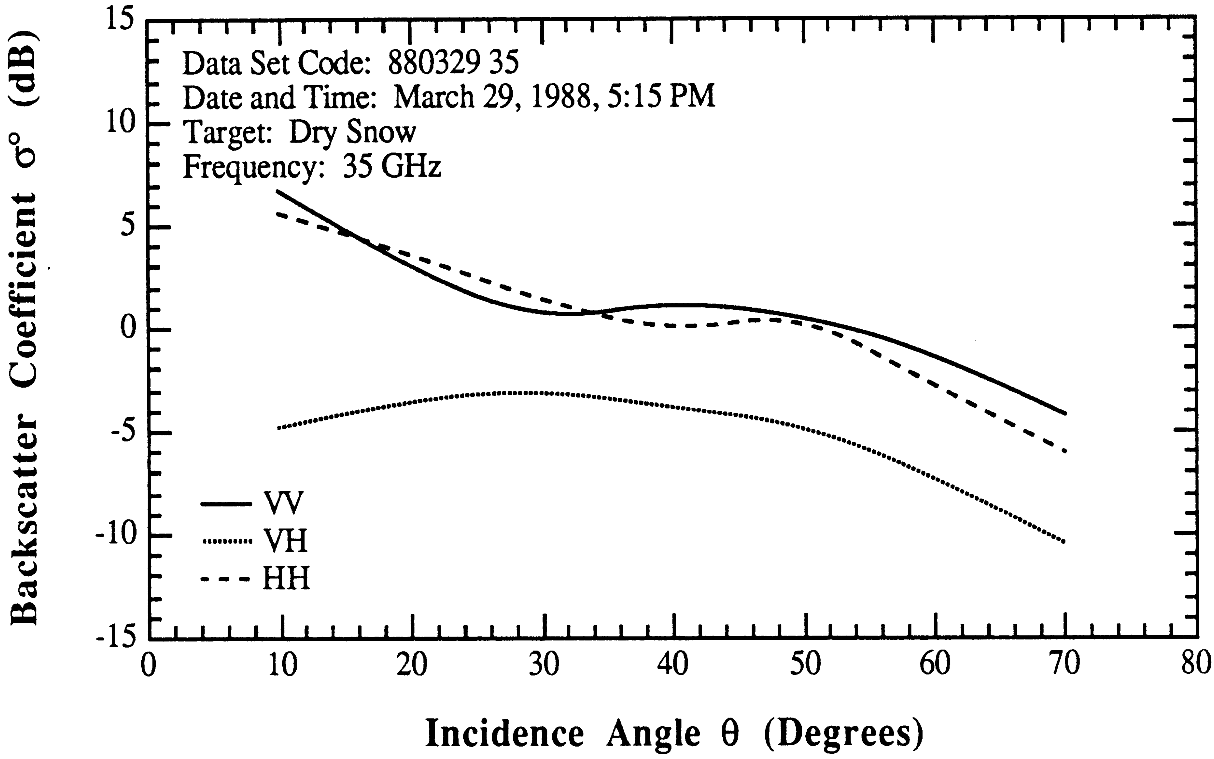
Snow crystal from surface



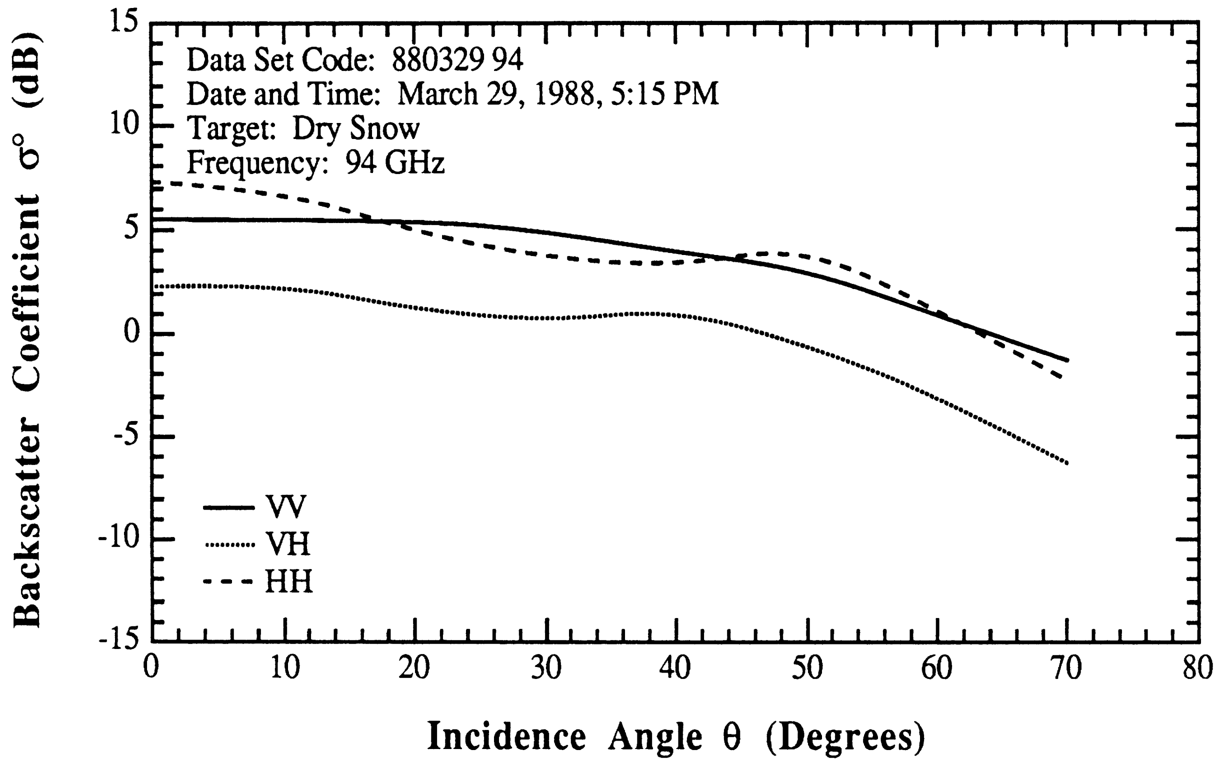
Metamorphosed crystal from middle of snowpack

MMW DATA FOR DRY SNOW

880329(S)



Smooth Snow at Houghton



Smooth Snow at Houghton

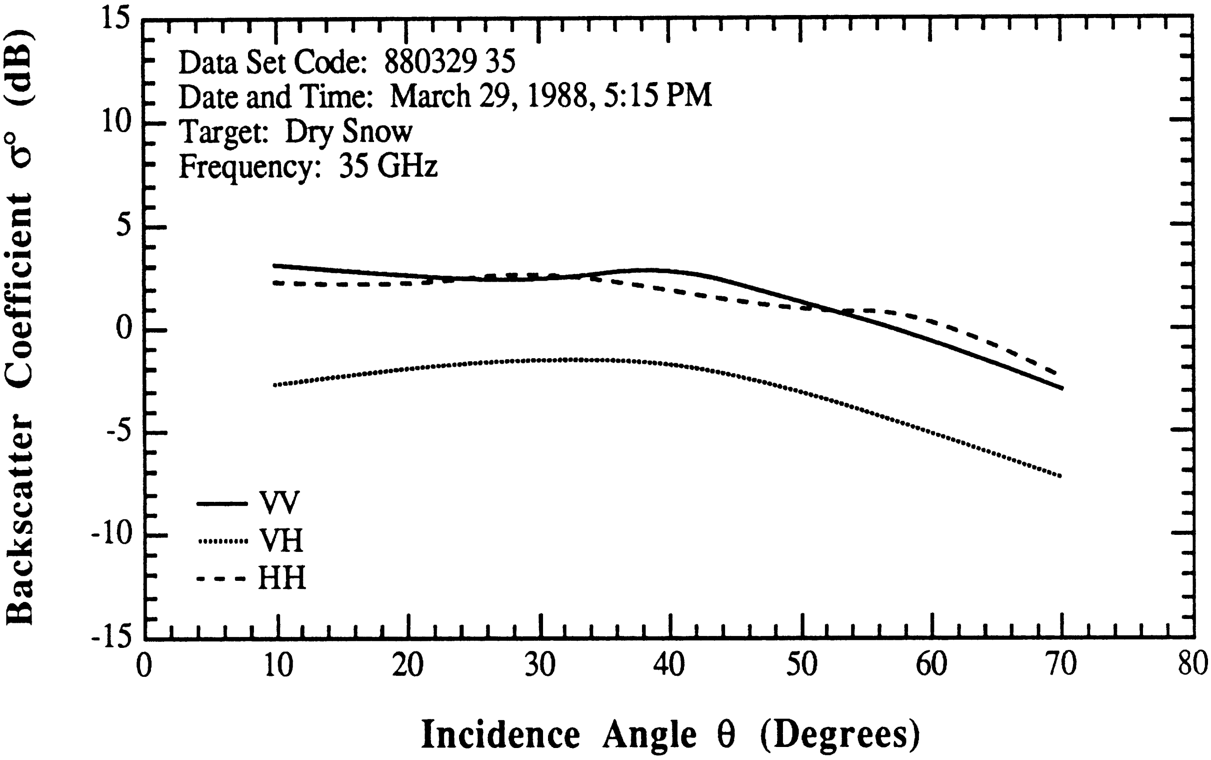
B. Slightly Rough Surface

Dry snow
Data set code: 880329 (SR)
Depth: 20 to 30 cm
LWC: 0%
Surface RMS height: 1 cm
Density: 0.3 to 0.4 gm/cm^3
Ice crystal diameter: 1 to 4 mm
Surface temperature: 0 C
Description: snowpack of highly metamorphosed snow with a slightly rough surface

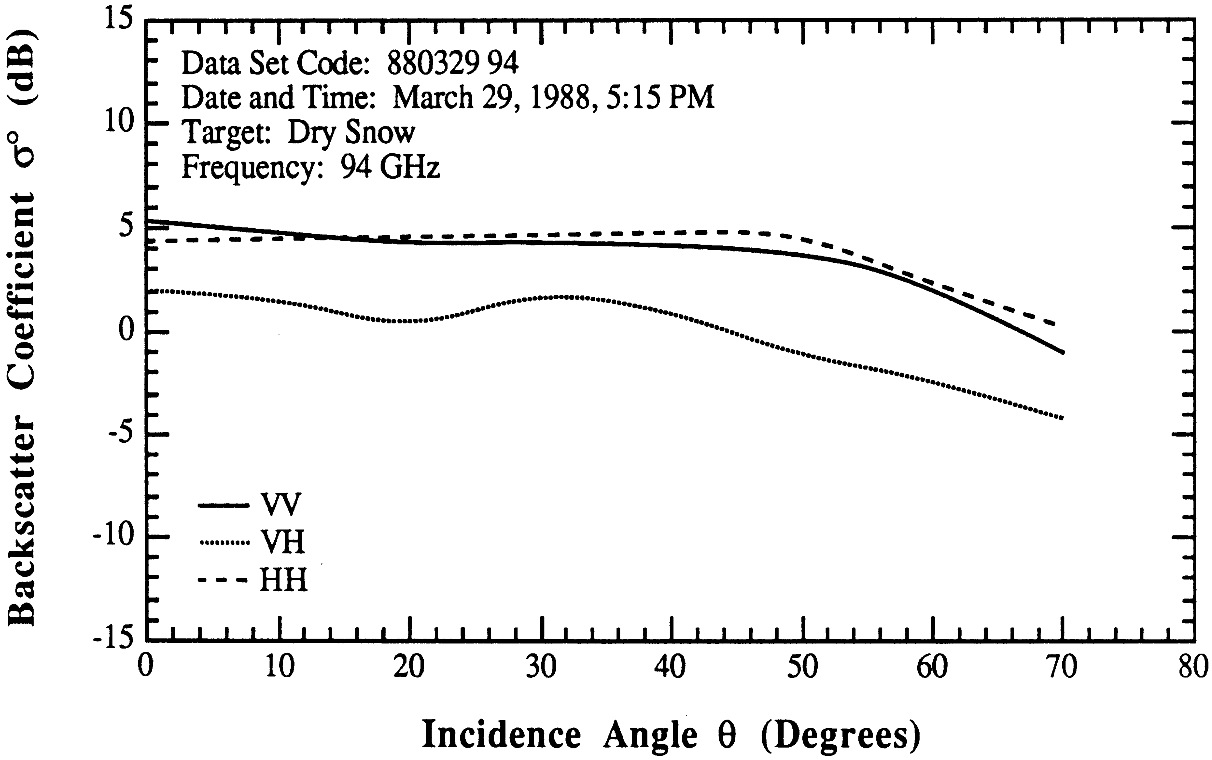
Surface roughness profile with 1 cm grid

MMW DATA FOR DRY SNOW

880329(SR)



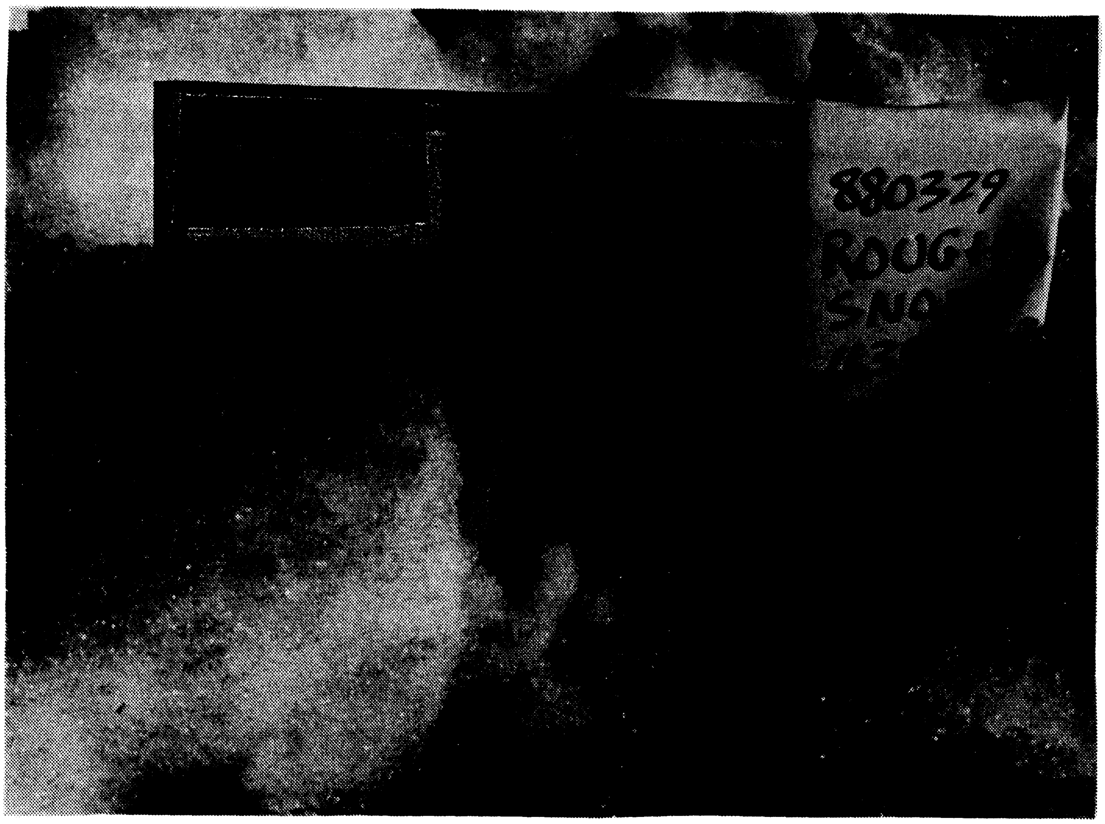
Slightly rough snow at Houghton



Slightly rough snow at Houghton

C. Very Rough Surface

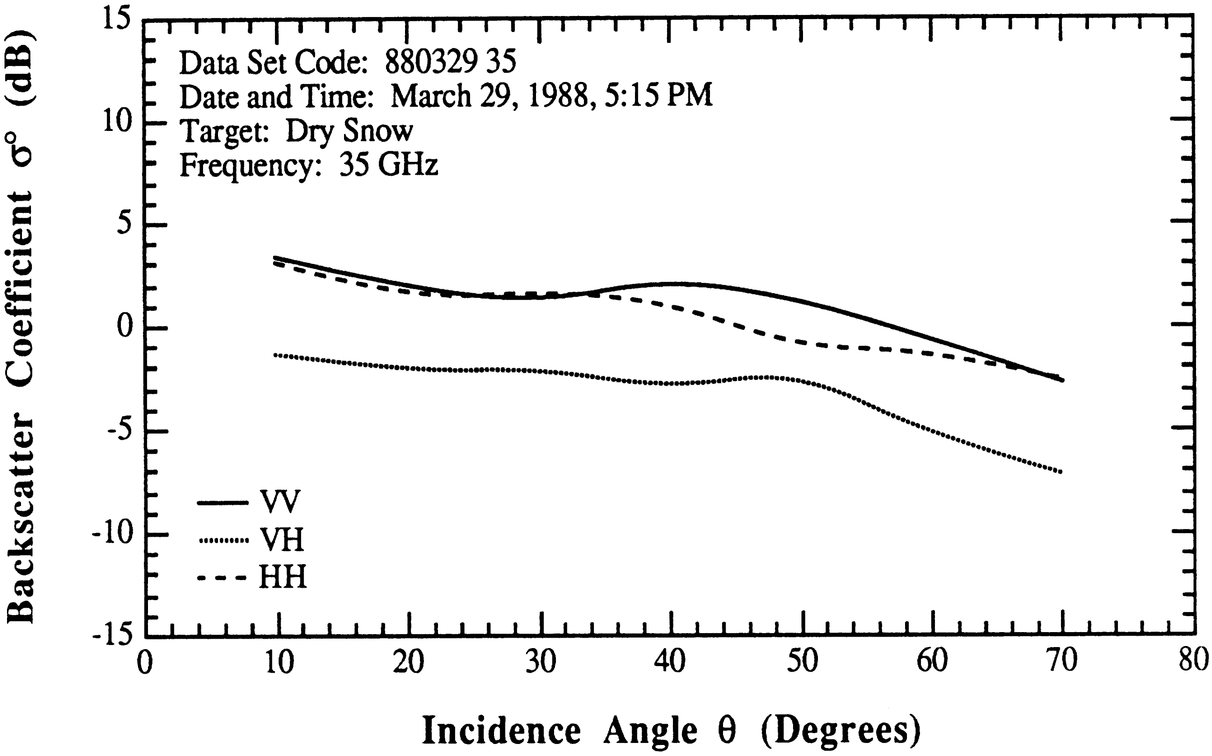
Dry snow
Data set code: 880329(VR)
Depth: 20 to 30 cm
LWC: 0%
Surface RMS height: 4 cm
Density: 0.3 to 0.4 gm/cm^3
Ice crystal diameter: 1 to 4 mm
Surface temperature: 0 C
Description: snowpack of highly metamorphosed snow with a rough surface



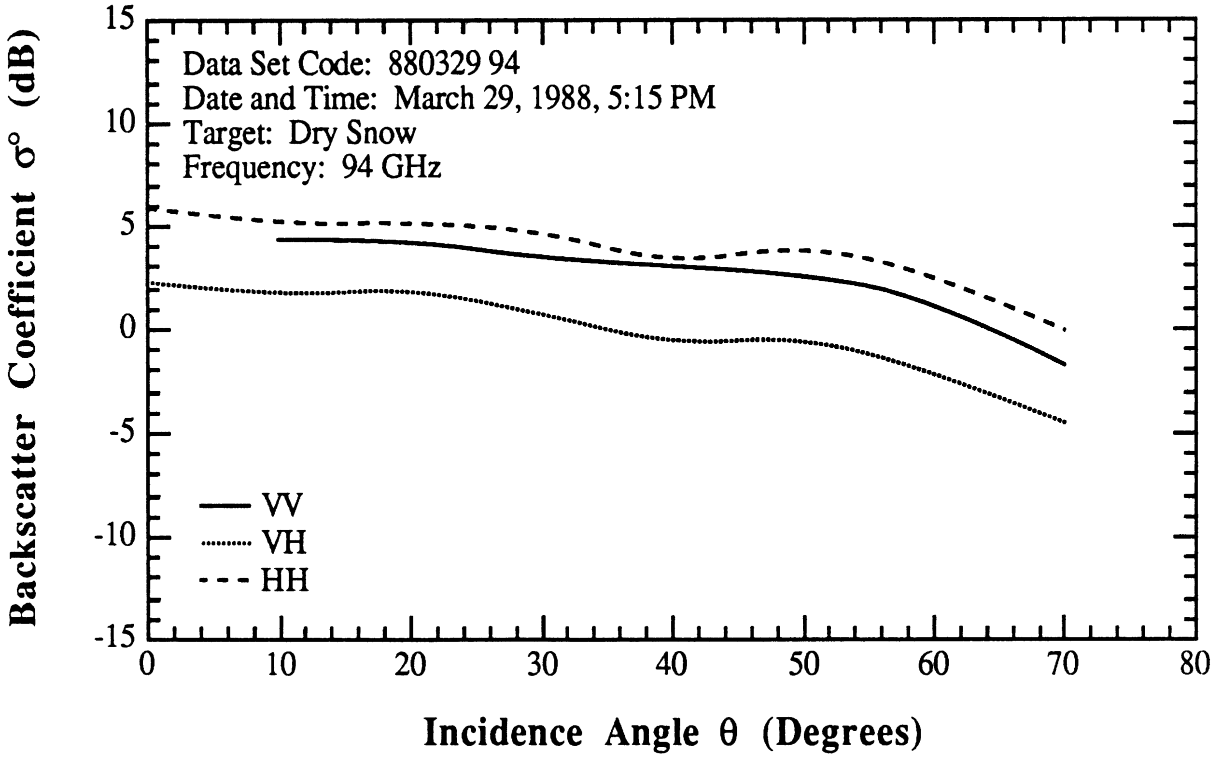
Surface roughness profile with 1 cm grid

MMW DATA FOR DRY SNOW

880329(VR)



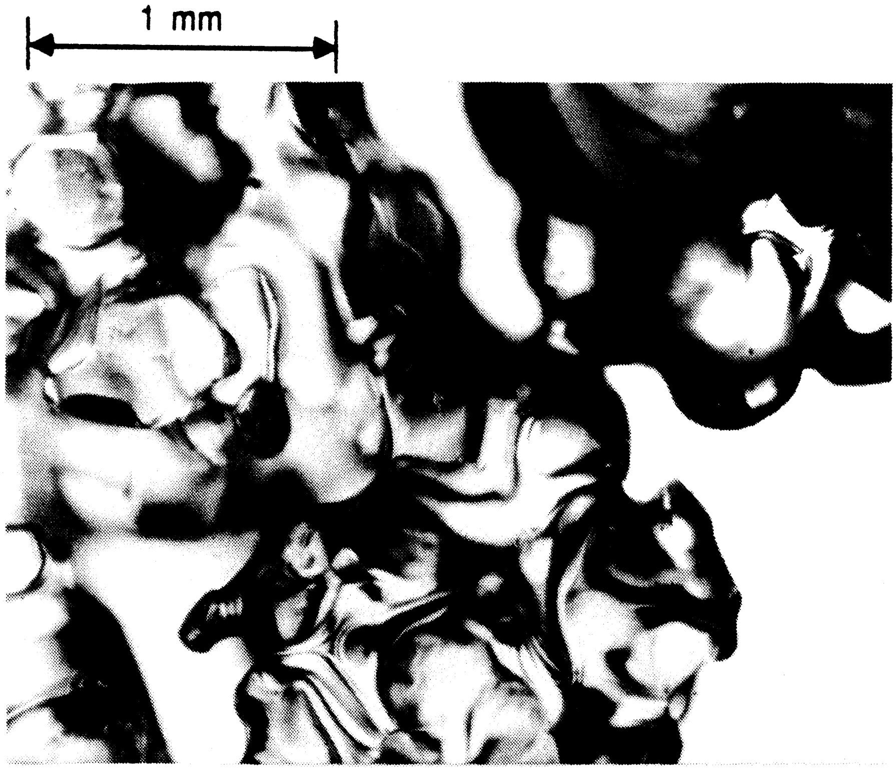
Very rough snow at Houghton



Very rough snow at Houghton

D. Heavily Metamorphosed Snow

Dry snow
Data set code: 890210
Depth: 27 cm
LWC: 0.0 %
Surface RMS height: ~ 1 cm
Density: 0.5 gm/cm^3
Ice crystal diameter: 2 to 4 mm
Surface temperature: -4.8 C
Description: heavily metamorphosed snow

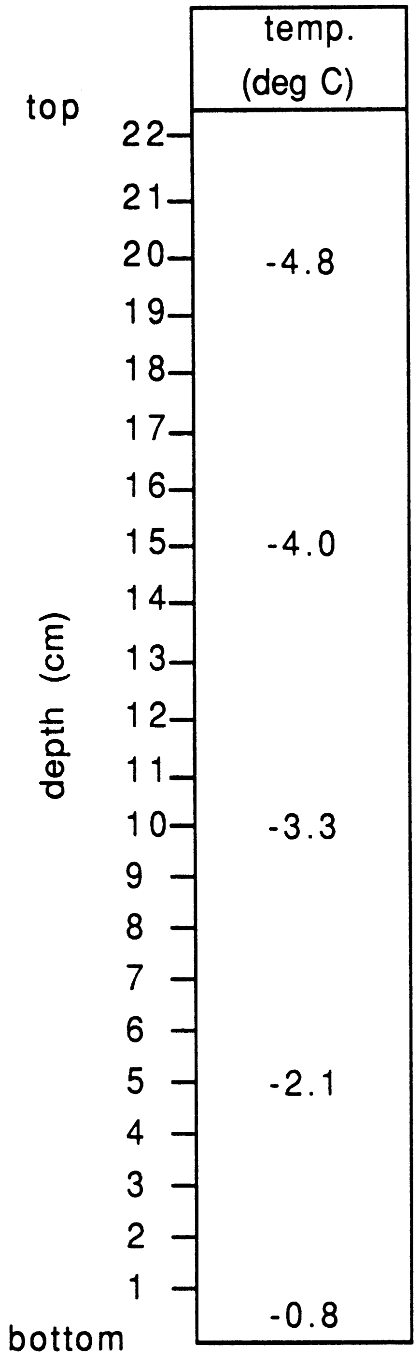


Metamorphosed crystal from top of the snowpack

MMW DATA FOR DRY SNOW

890210

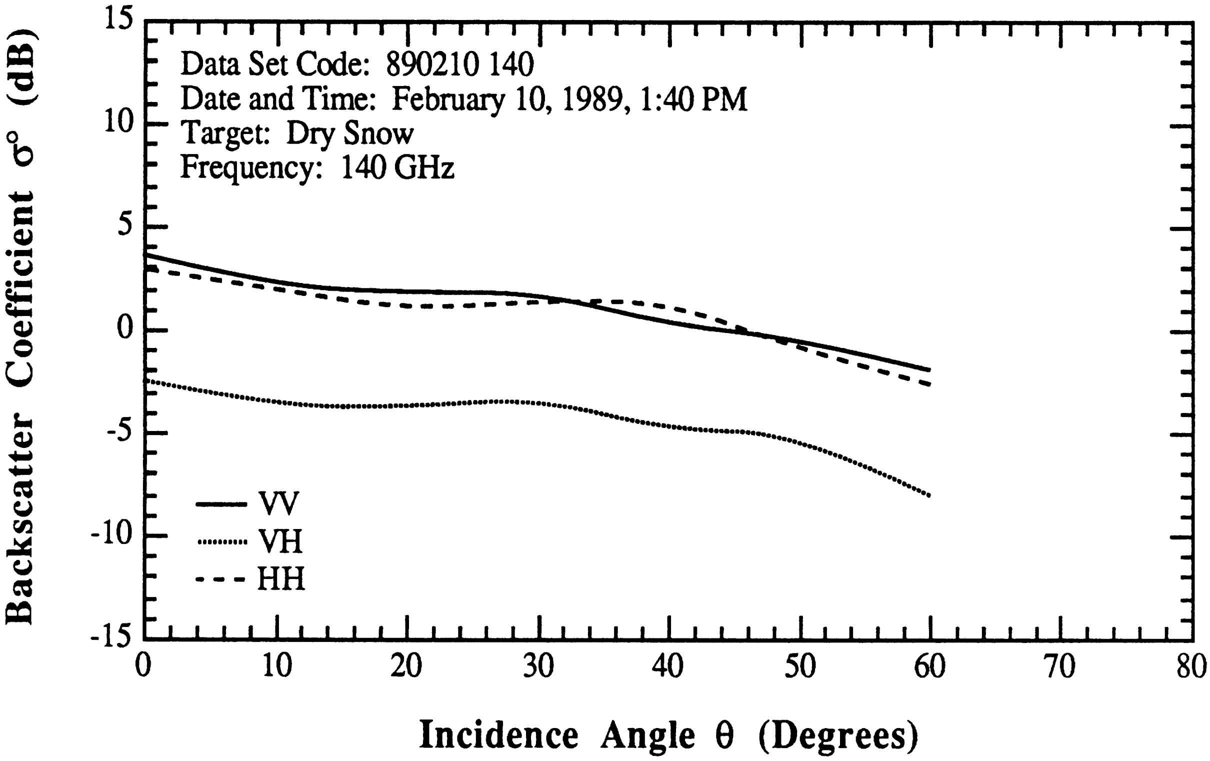
SNOW PIT PROFILE FOR 890210



air temperature: -4.4 C

MMW DATA FOR DRY SNOW

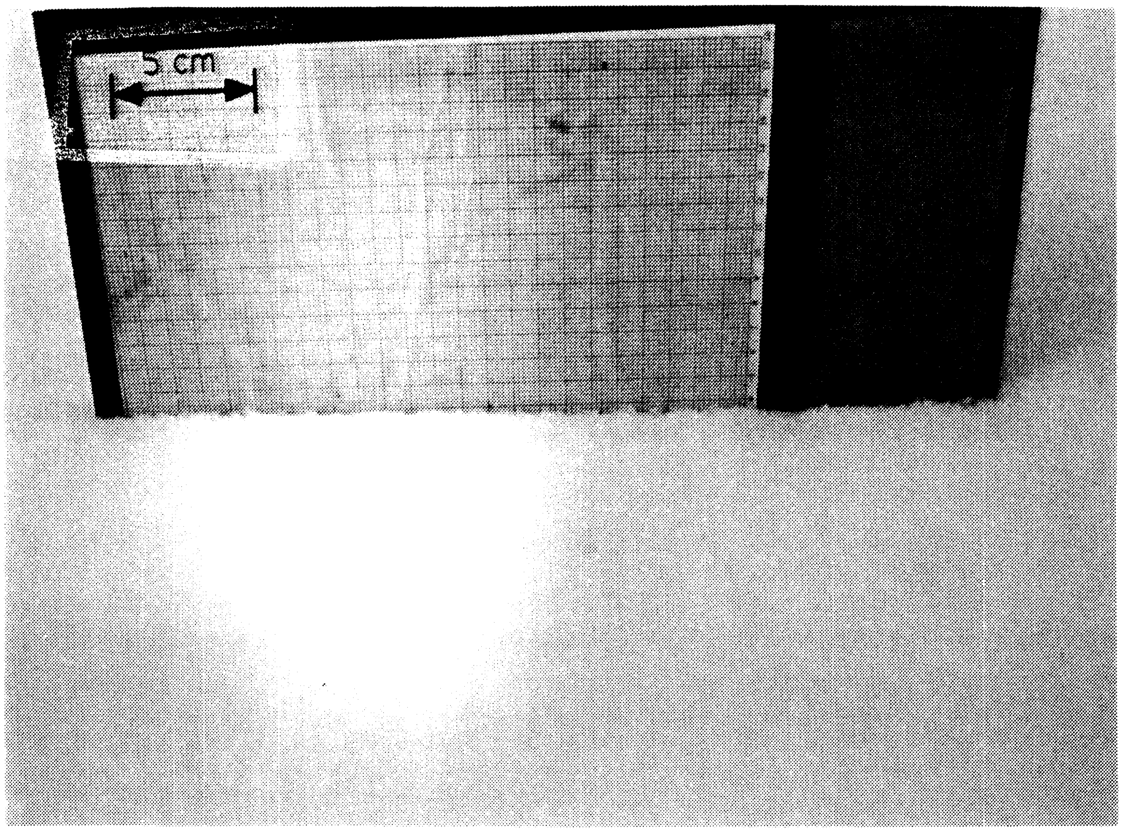
890210



Snow at Brighton

E. Unmetamorphosed Fresh Snow

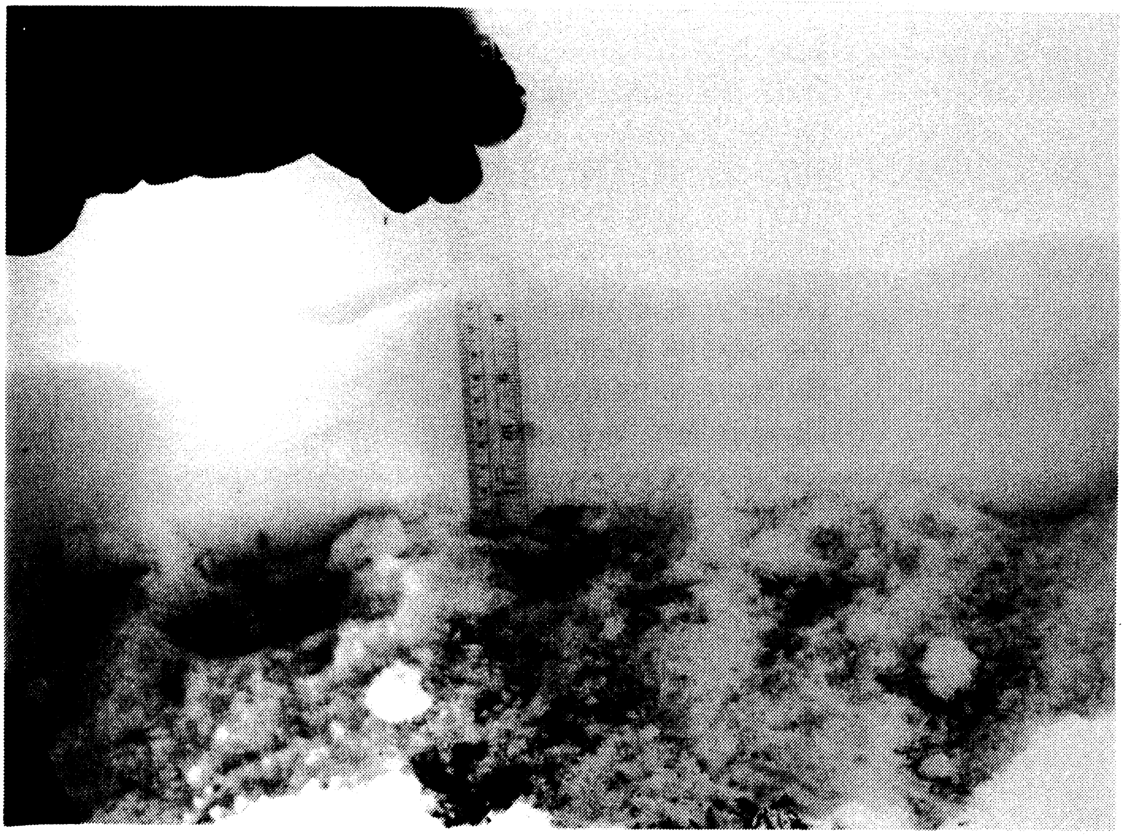
Dry snow
Data set code: 890223
Depth: 12 cm
LWC (at 2:15 PM): 0 %
LWC (at 3:52 PM): 0 %
Surface RMS height: 1.4 mm
Density: 0.2 g/cm^3
Ice crystal diameter: 1 to 2 mm
Surface temperature: -7 C
Description: dry unmetamorphosed snow



Surface roughness profile with 1 cm grid

MMW DATA FOR DRY SNOW

890223

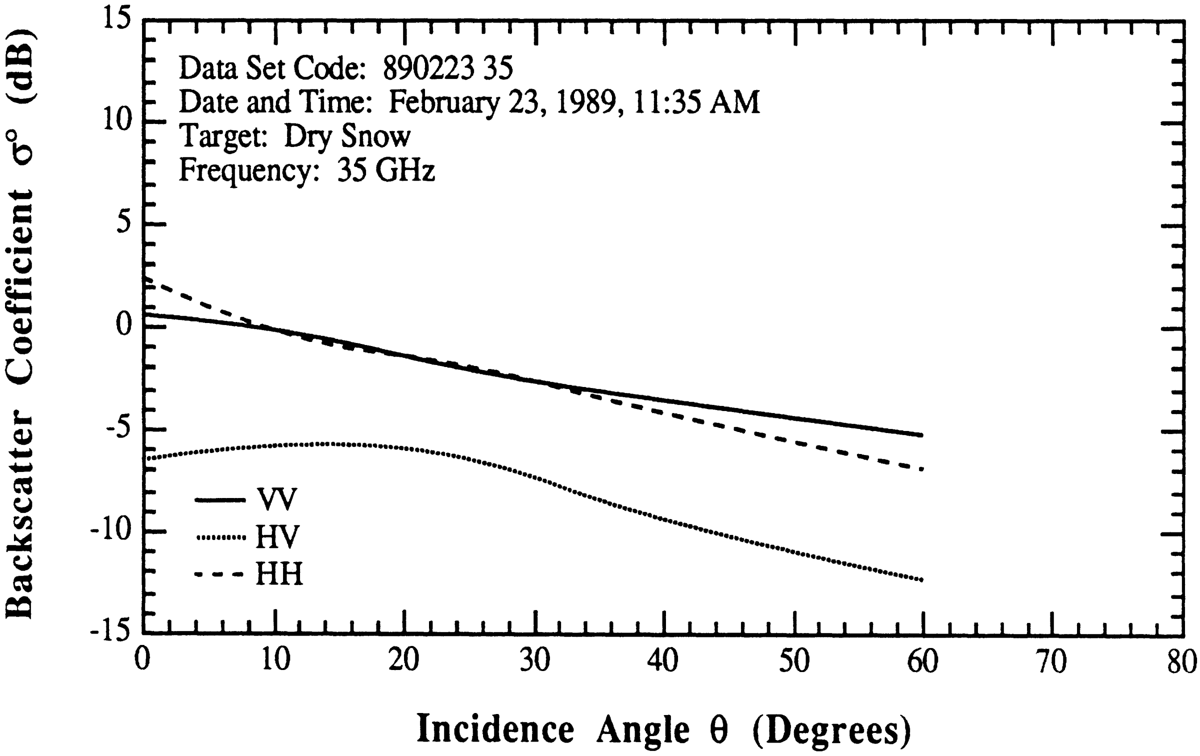


Snow pit

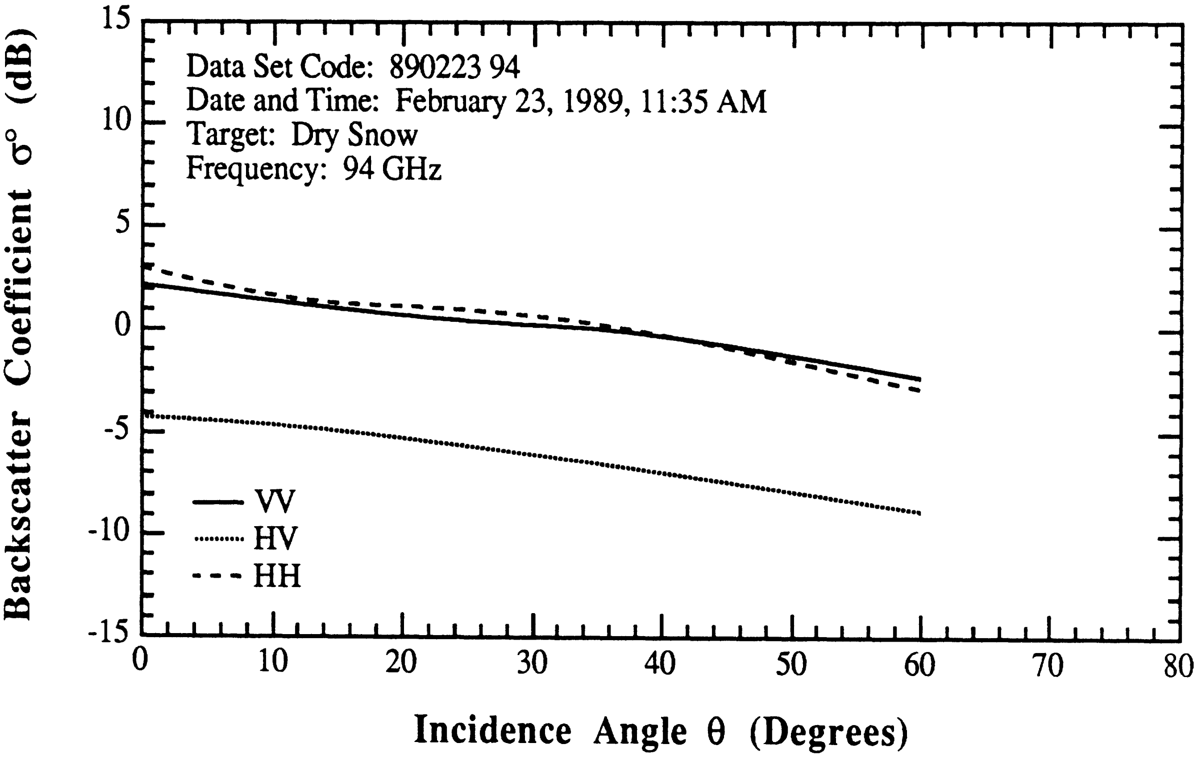
Data collection scene

MMW DATA FOR DRY SNOW

890223



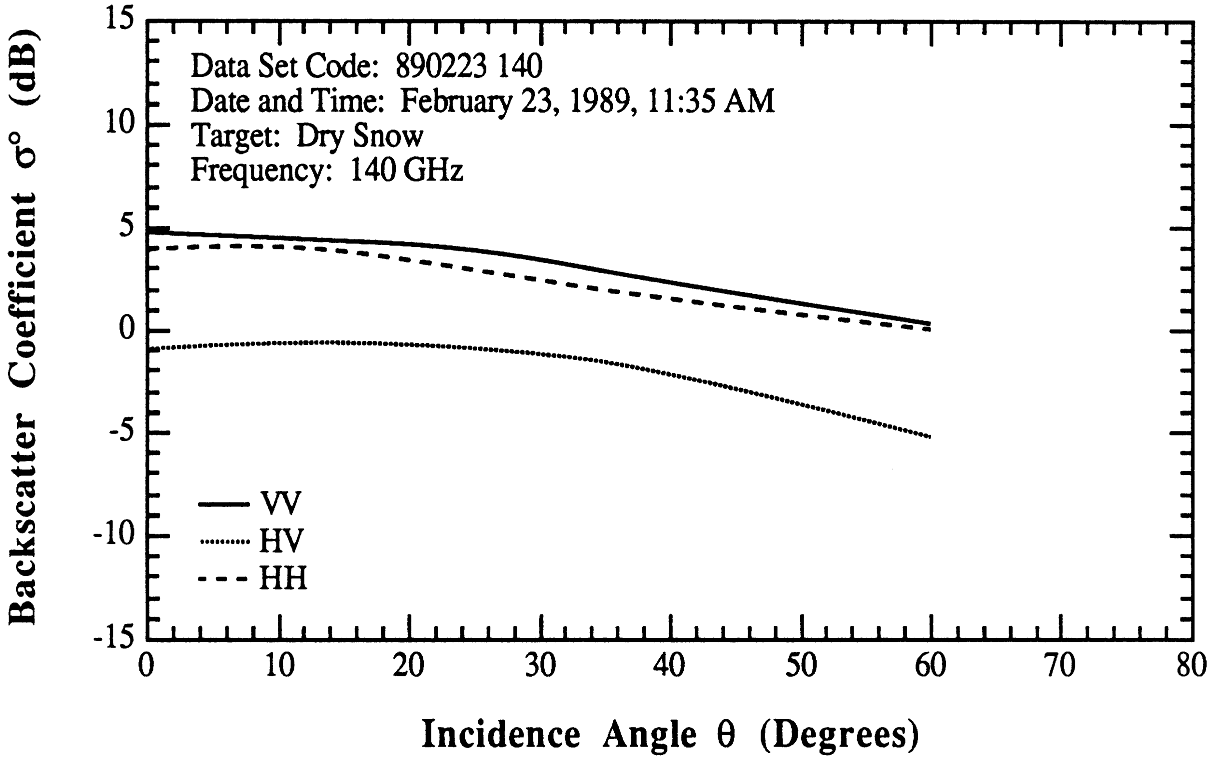
Dry snow at Brighton



Dry snow at Brighton

MMW DATA FOR DRY SNOW

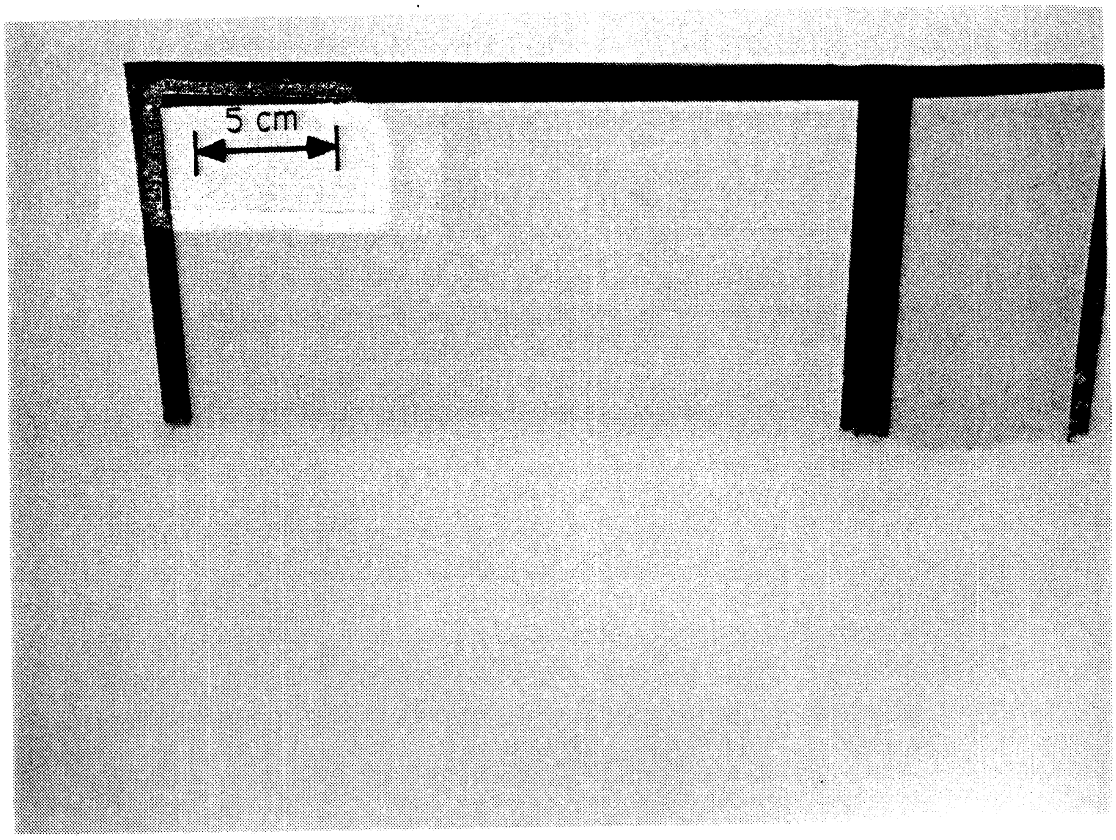
890223



Dry snow at Brighton

F. Small Crystal Size

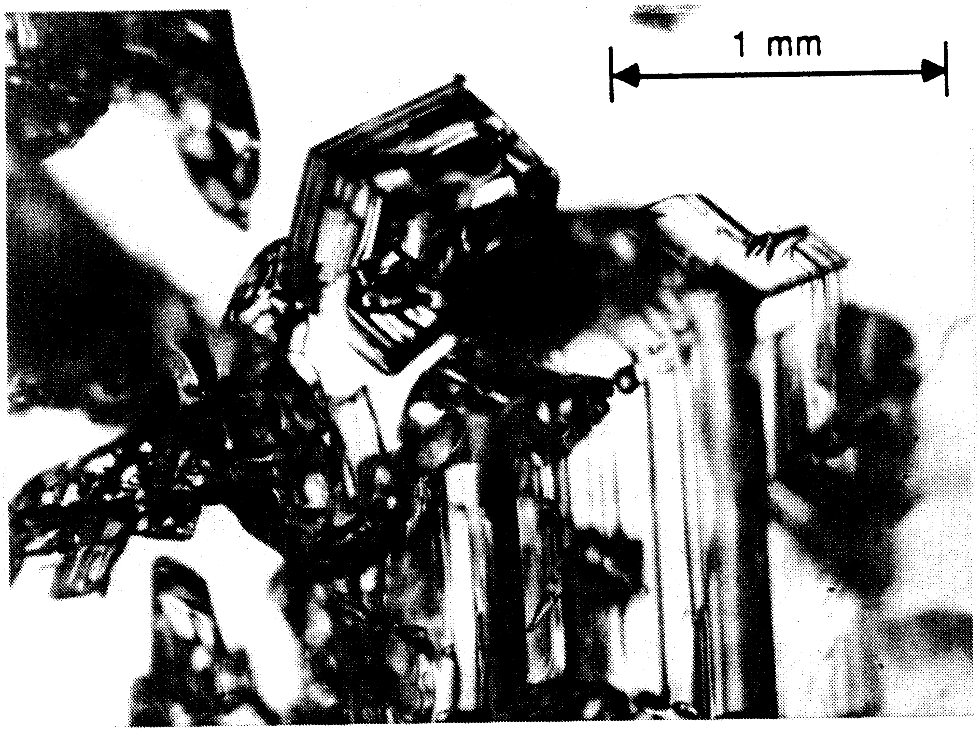
Dry snow
Data set code: 890302(sm)
Depth: 10 cm
LWC: 0 %
Surface RMS height: 0.15 cm
Density: 0.1 to 0.2 gm/cm^3
Ice crystal diameter: 1 mm
Surface temperature: -5 C
Description: smooth snow surface



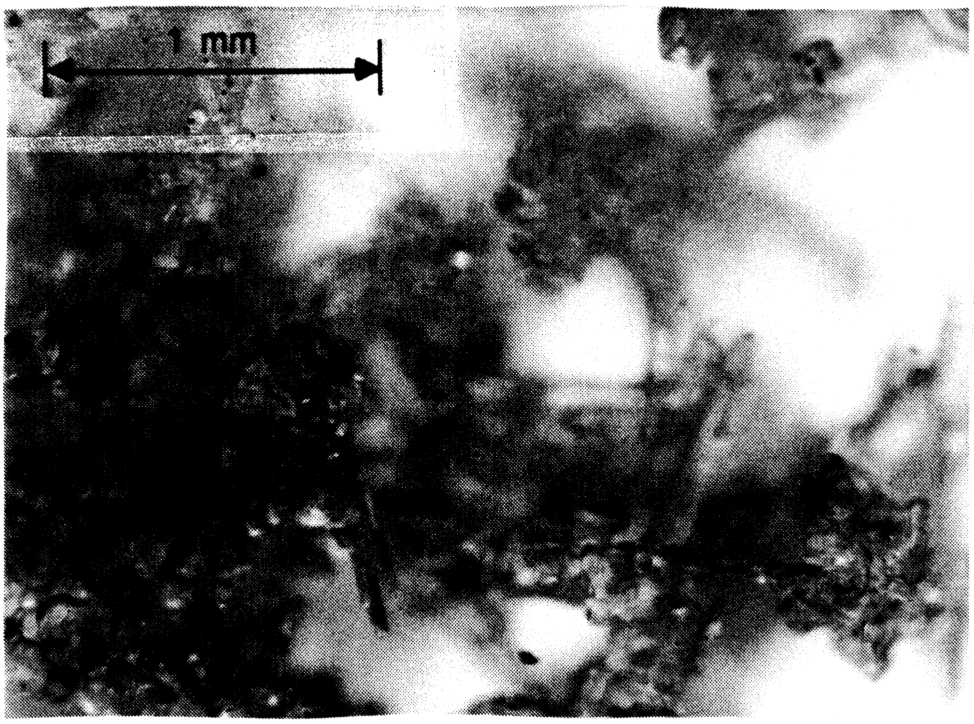
Surface profile with 1 cm grid

MMW DATA FOR DRY SNOW

890302(SM)



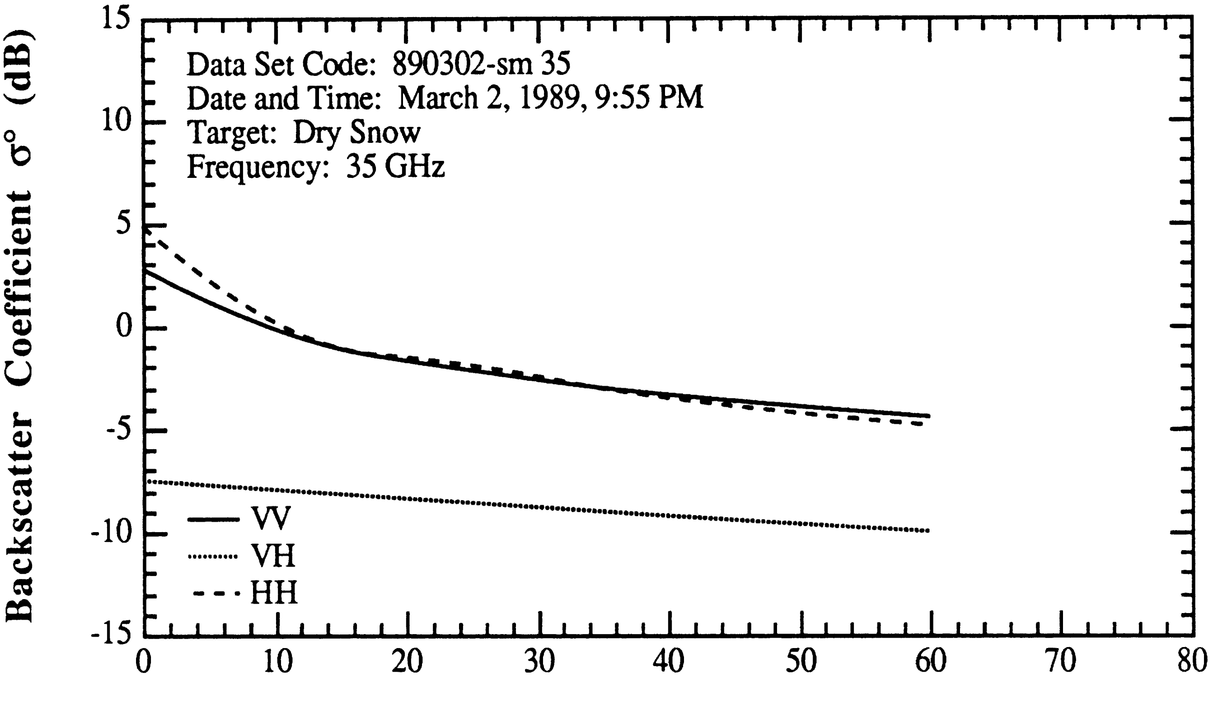
Snow crystals from surface



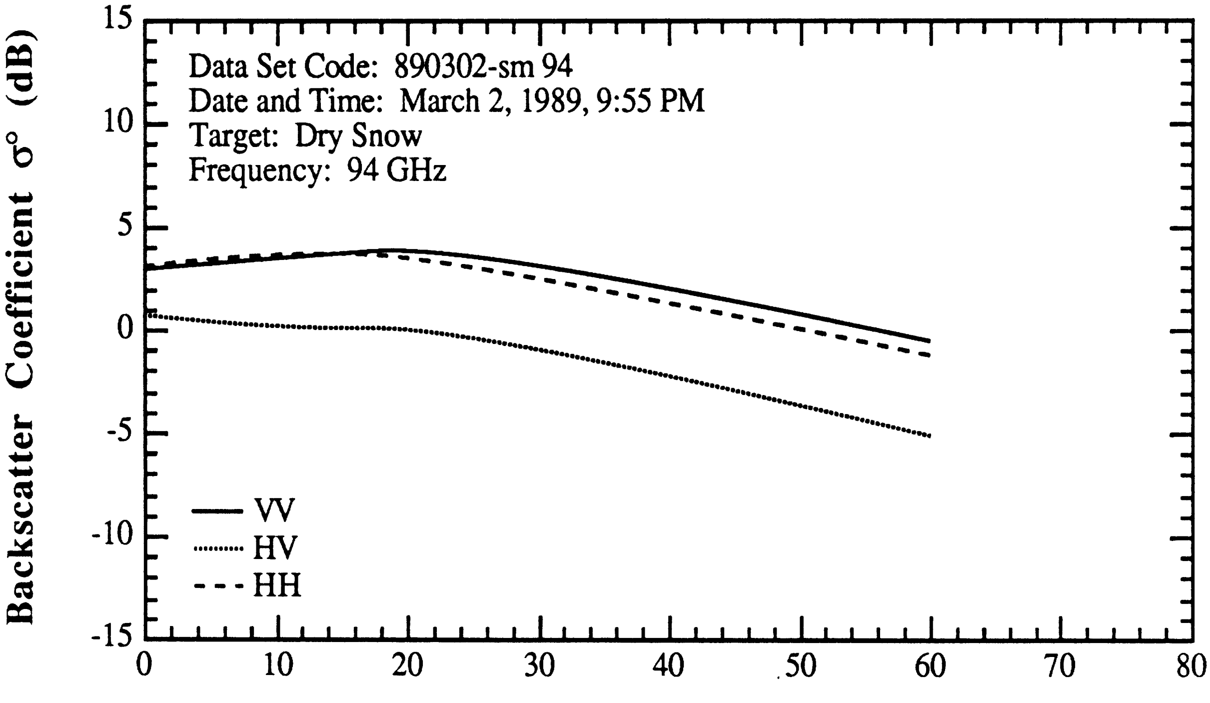
Snow crystals from bottom of snowpack

MMW DATA FOR DRY SNOW

890302(SM)



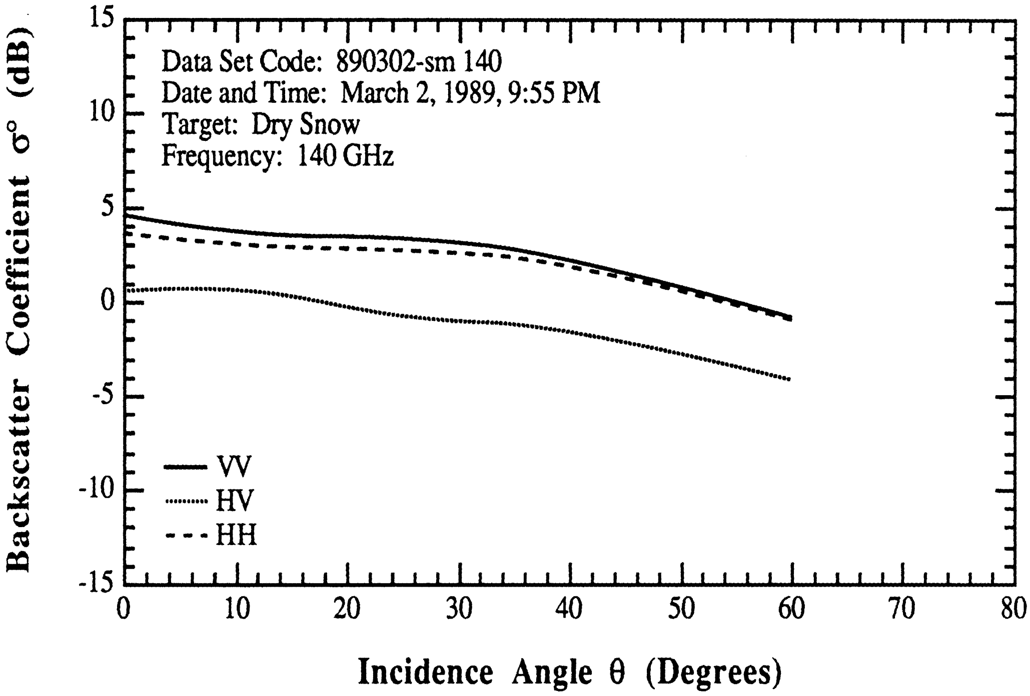
Incidence Angle θ (Degrees)
Small snow crystals at Brighton



Incidence Angle θ (Degrees)
Small snow crystals at Brighton

MMW DATA FOR DRY SNOW

890302(SM)

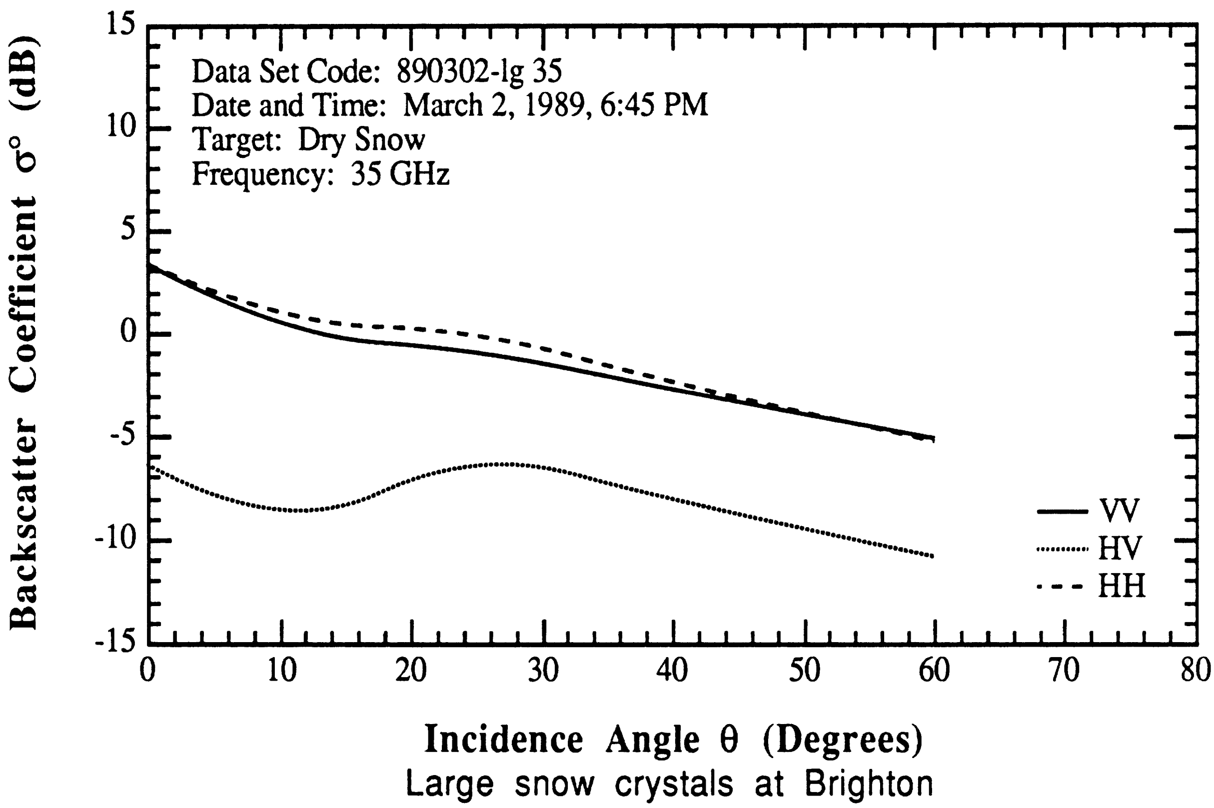


Small snow crystals at Brighton

G. Large Crystal Size

Dry snow
Data set code: 890302(Lg)
Depth: 10cm
LWC: 0%
Surface RMS height: 0.15cm
Density: 0.1 to 0.2 gm/cm^3
Ice crystal diameter: 2 to 2.5 mm
Surface Temperature: -5 C
Description: fresh smooth snow surface

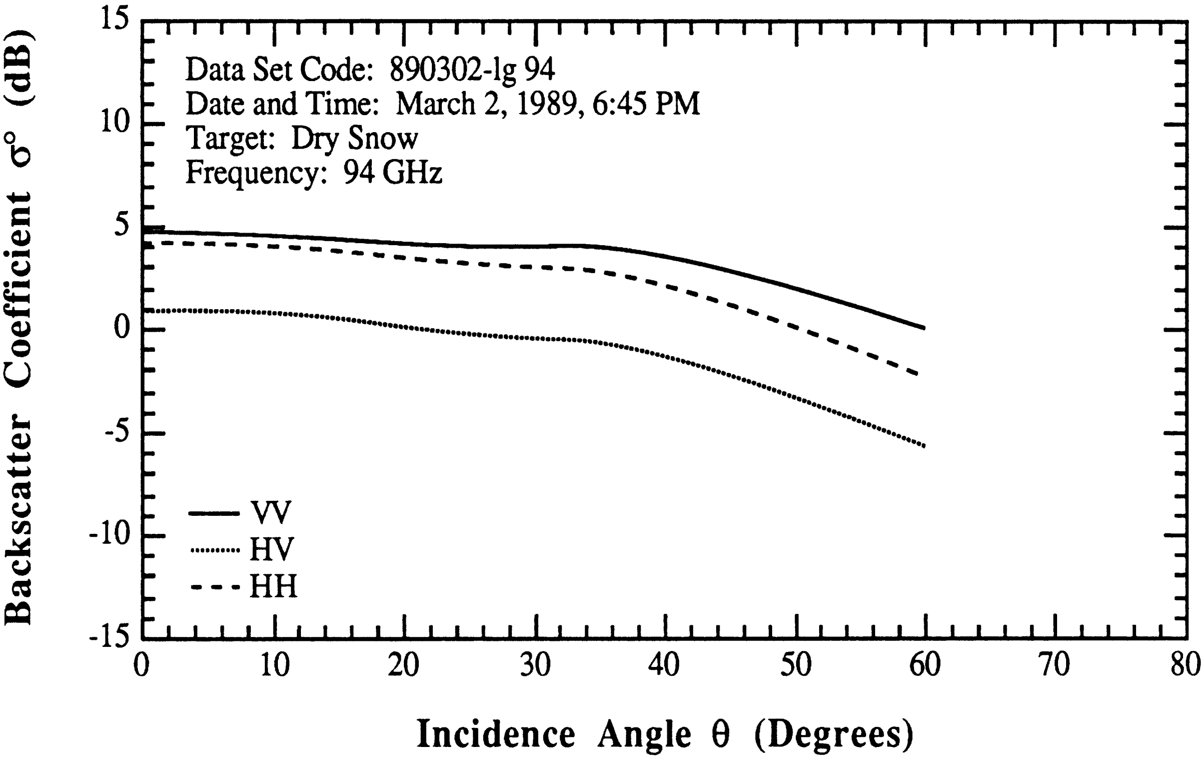
890302(LG)



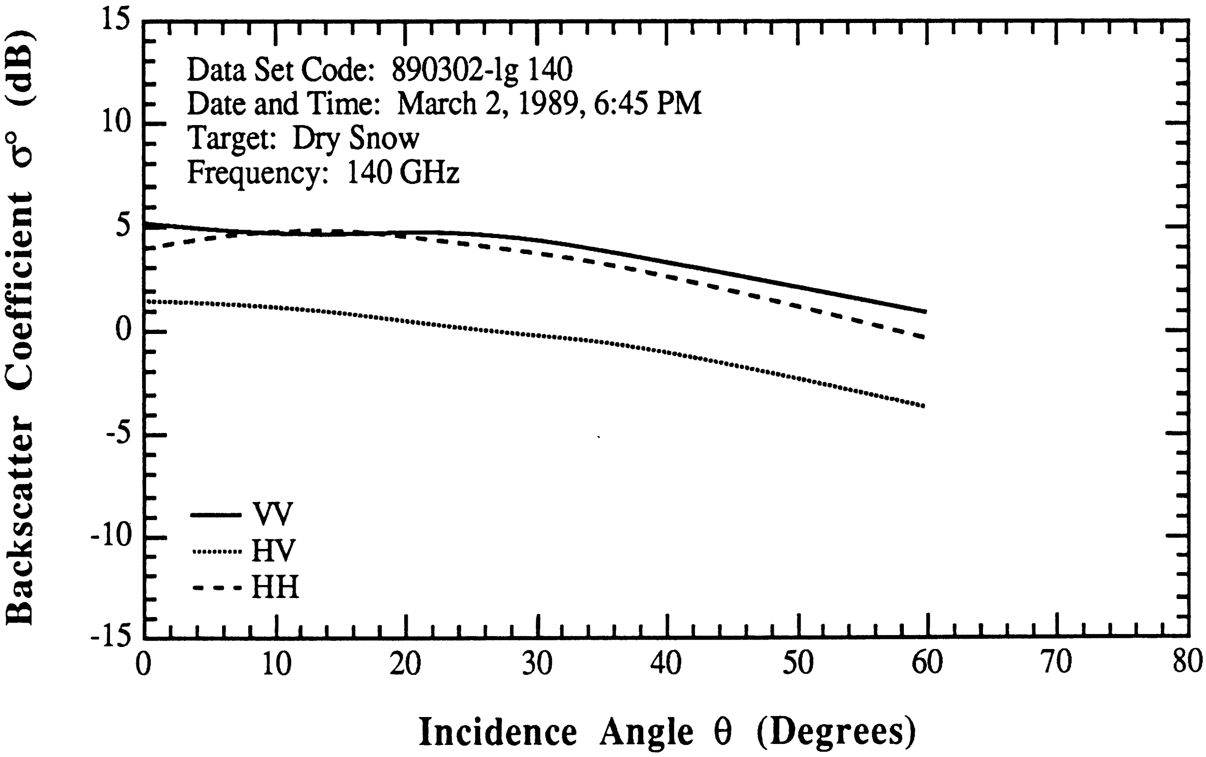
Large snow crystals at Brighton

MMW DATA FOR DRY SNOW

890302(LG)



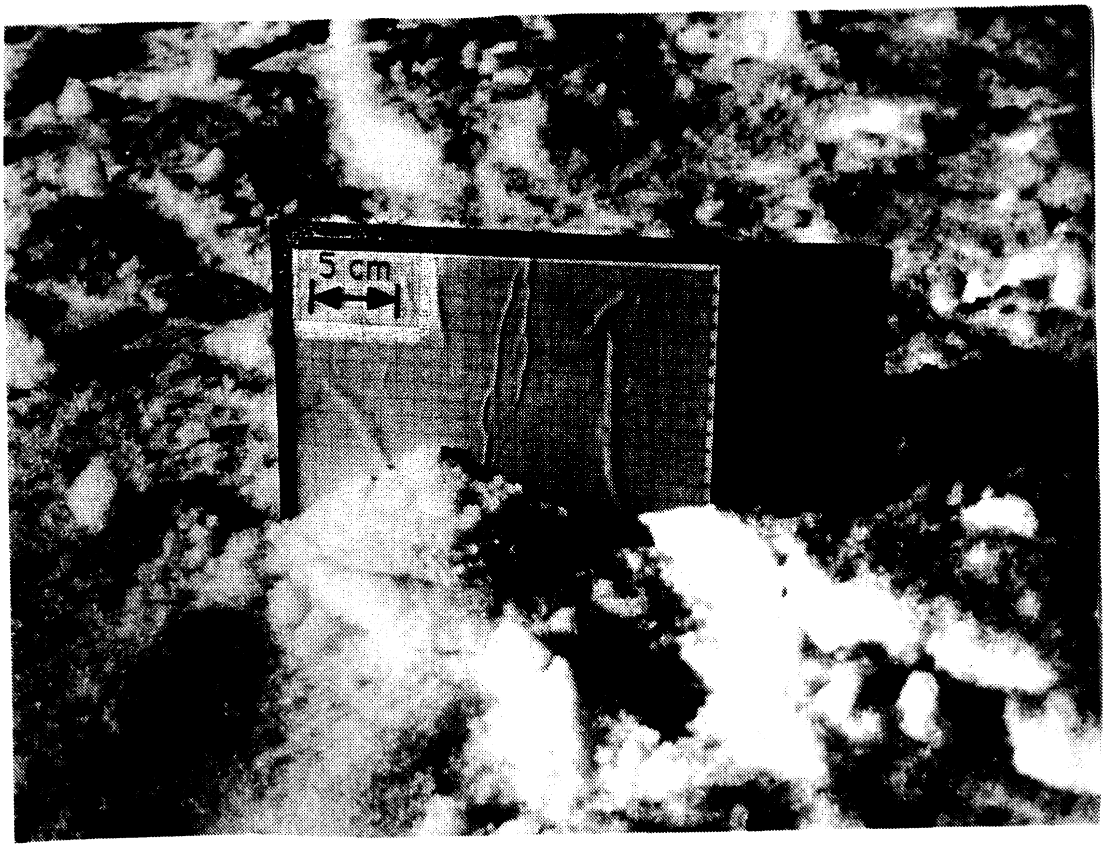
Large snow crystals at Brighton



Large snow crystals at Brighton

H. Large Crystal Size with Rough Surface

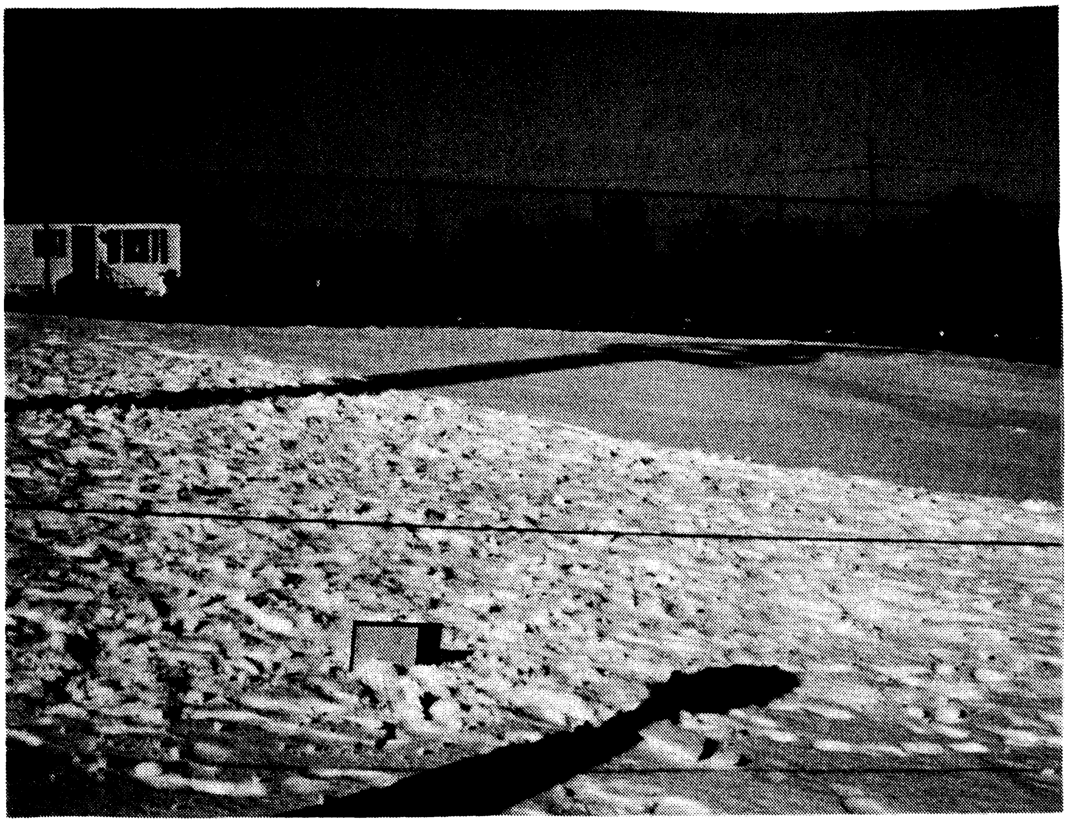
Dry snow -
Data set code: 890307(ro)
Depth: 10 cm
LWC: 0 %
Surface RMS height: 1.17 cm
Density: 0.4 gm/cm^3
Ice crystal diameter: 2 to 4 mm
Surface temperature: -10 to -12 C
Description: dry, slightly metamorphosed snow



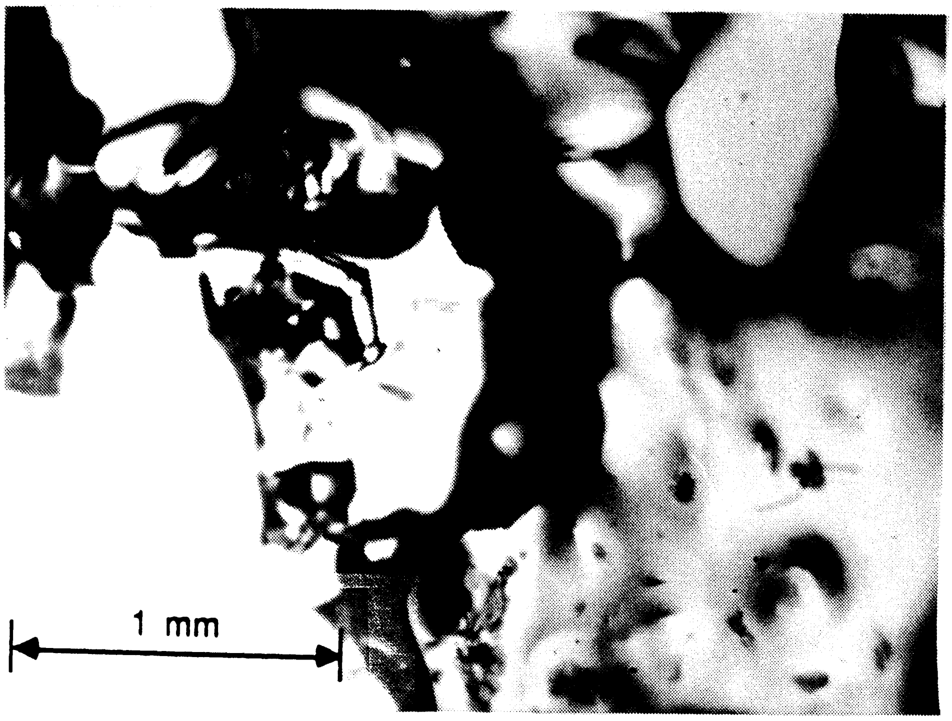
Surface roughness profile with 1 cm grid

MMW DATA FOR DRY SNOW

890307(RO)



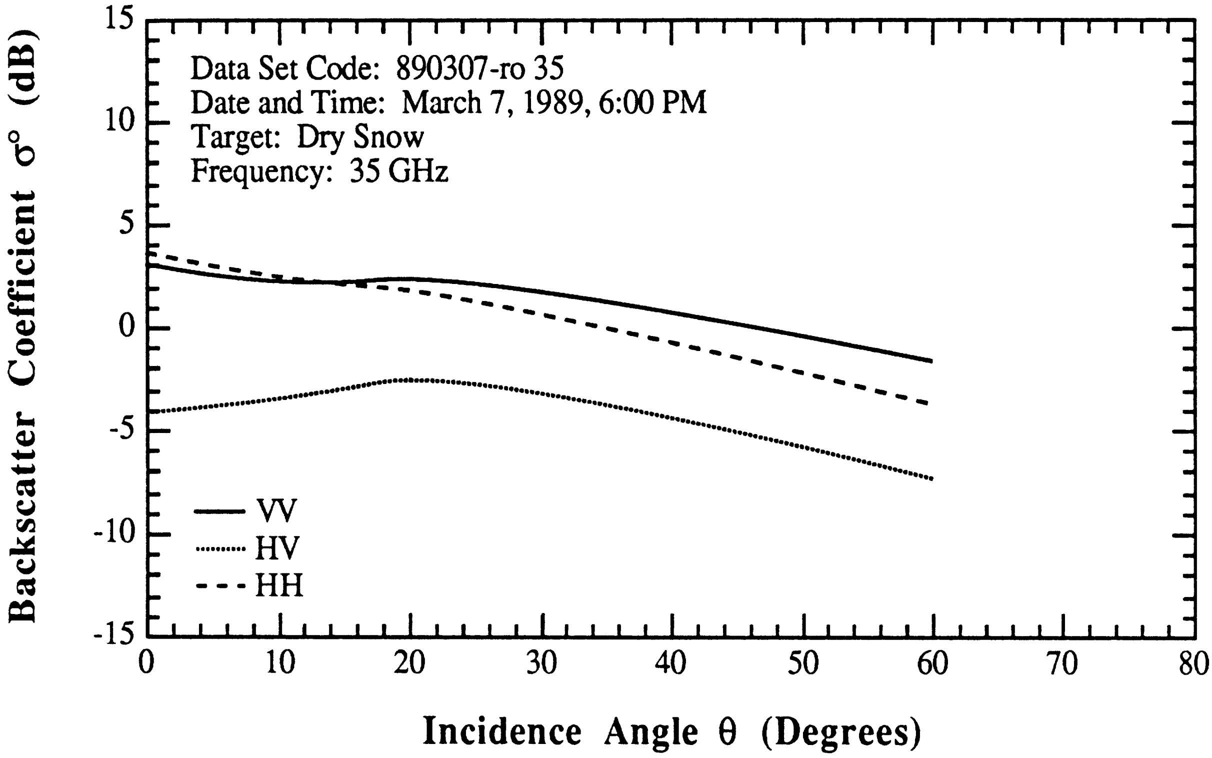
Data collection scene



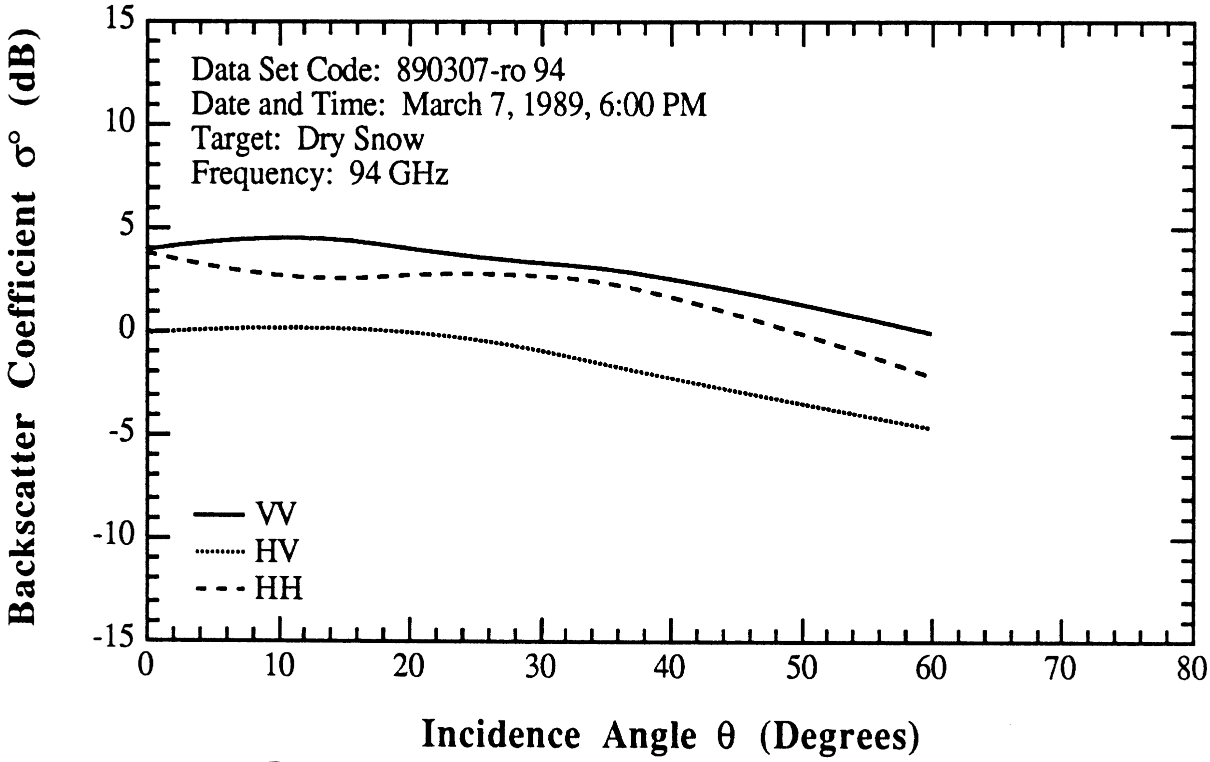
Snow crystals from surface

MMW DATA FOR DRY SNOW

890307(RO)



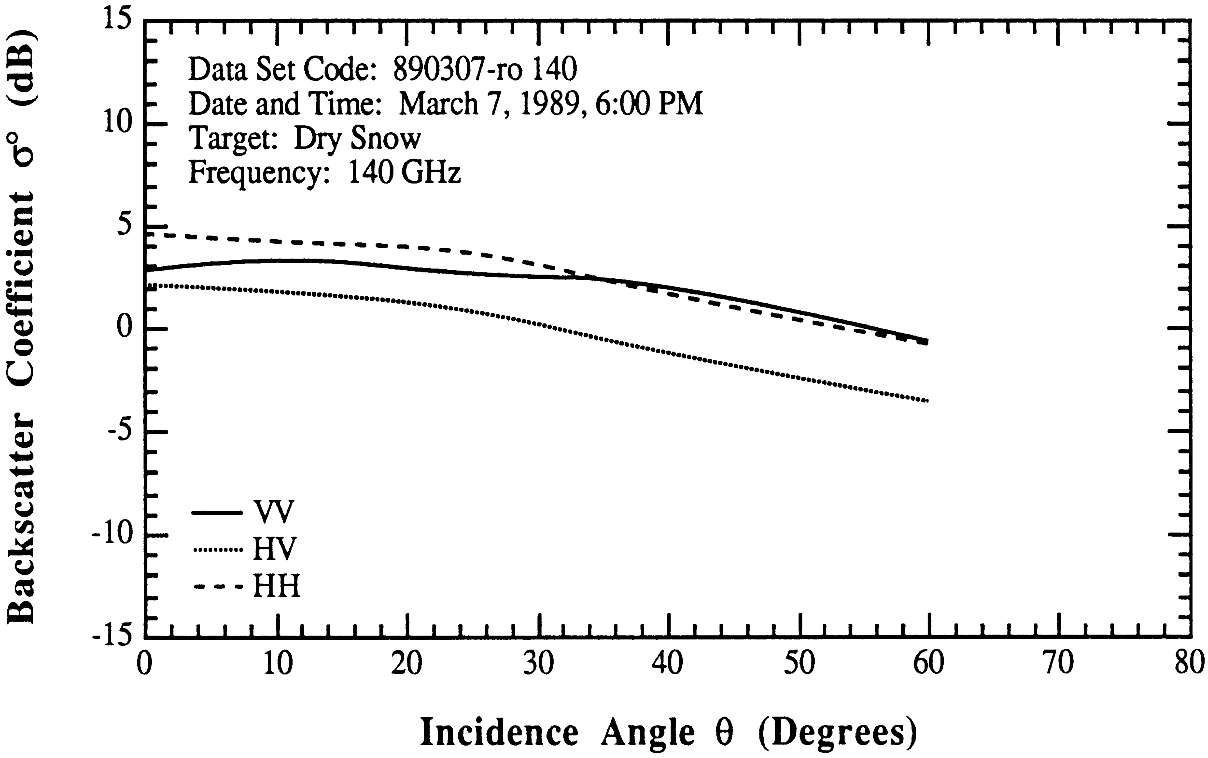
Dry rough metamorphosed snow at Brighton



Dry rough metamorphosed snow at Brighton

MMW DATA FOR DRY SNOW

890307(RO)



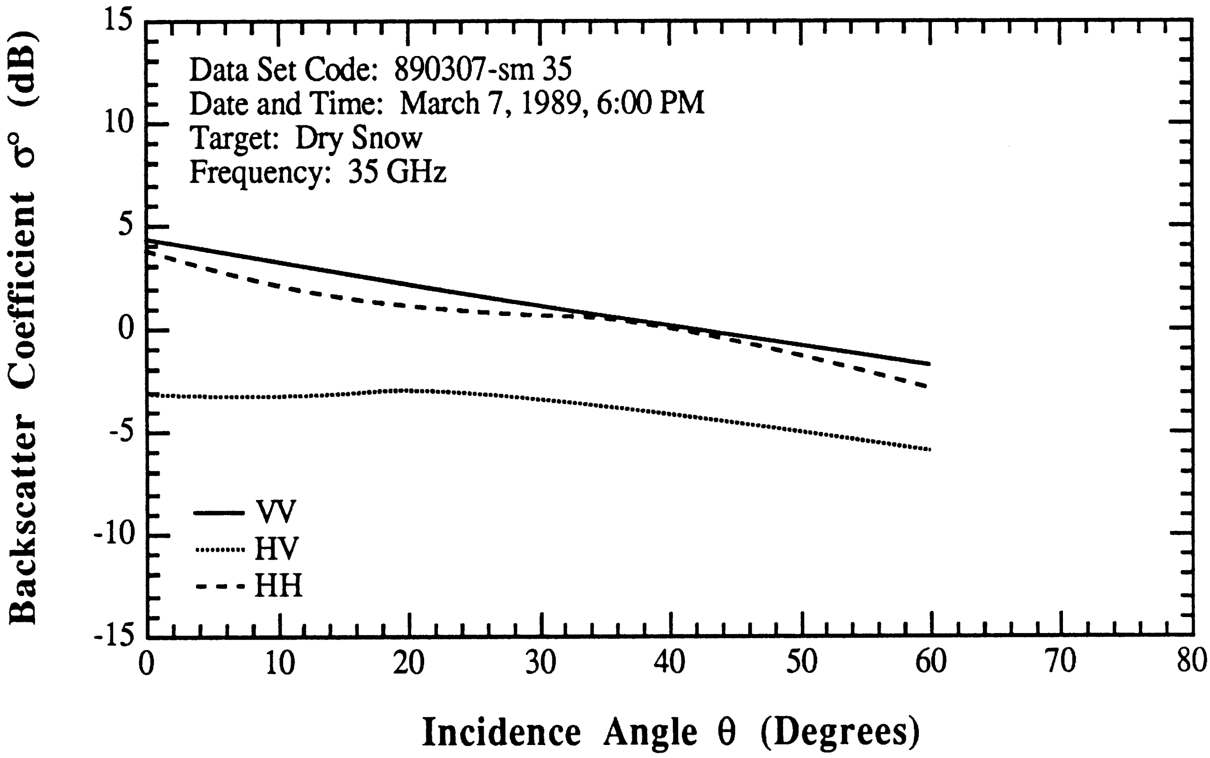
Dry rough metamorphosed snow at Brighton

I. Large Crystal Size with Smooth Surface

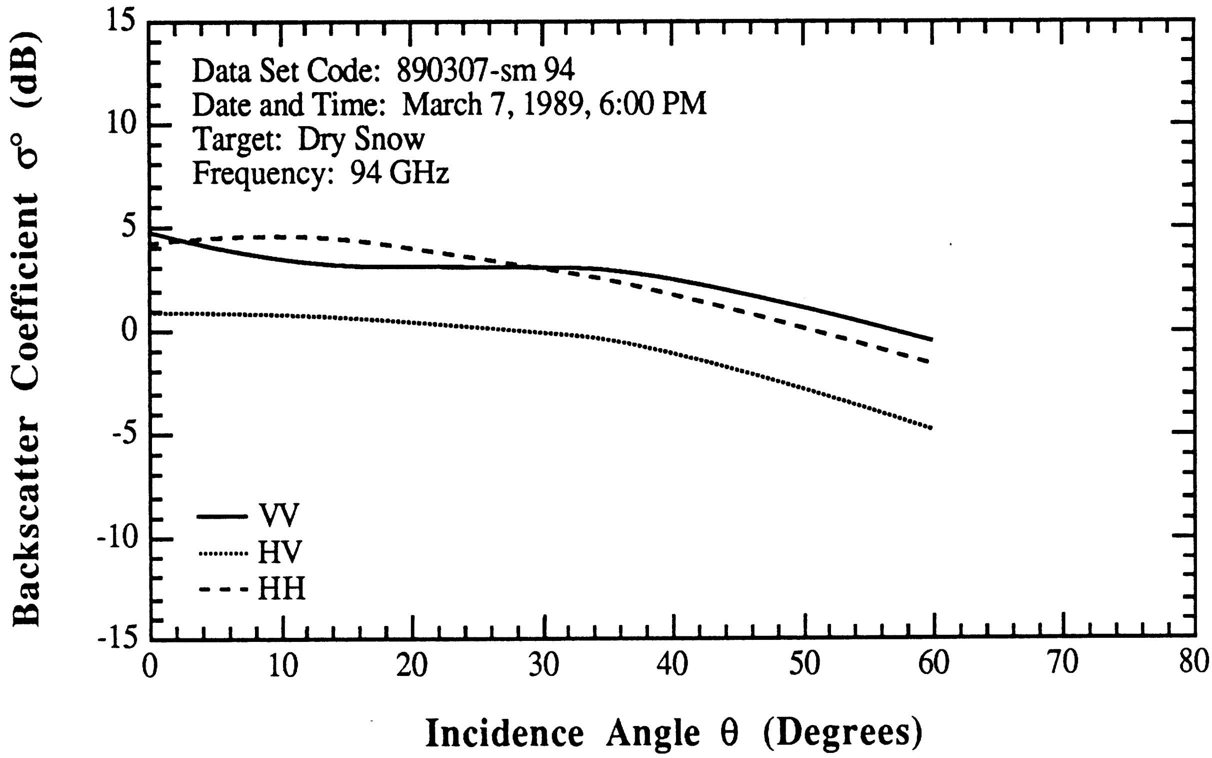
Dry snow
Data set code: 890307 (Sm)
Depth: 10 cm
LWC: 0 %
Surface RMS height: 0.28 cm
Ice crystal diameter: 2 to 4 mm
Density: 0.4 gm/cm^3
Surface temperature: -10 to -12 C
Description: dry slightly metamorphosed snow

MMW DATA FOR DRY SNOW

890307(SM)



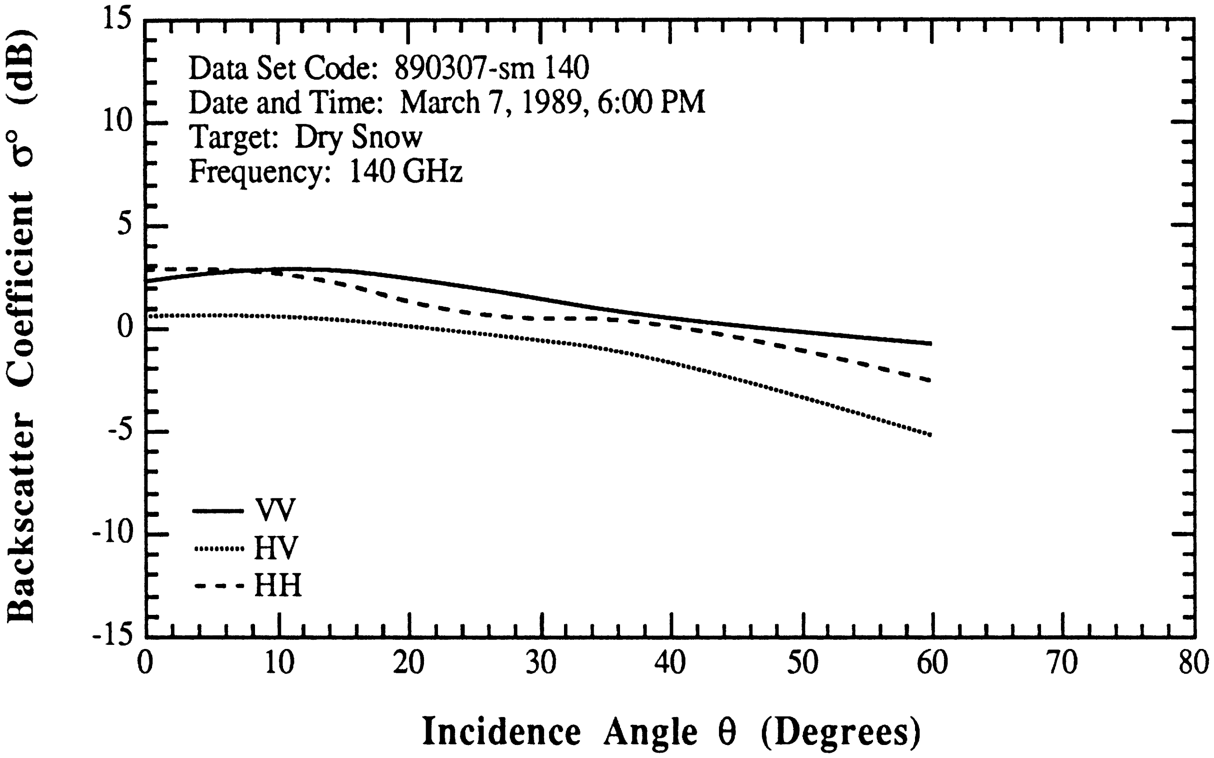
Dry smooth metamorphosed snow at Brighton



Dry smooth metamorphosed snow at Brighton

MMW DATA FOR DRY SNOW

890307(SM)



Dry Smooth metamorphosed snow at Brighton

3. MMW DATA FOR WET SNOW

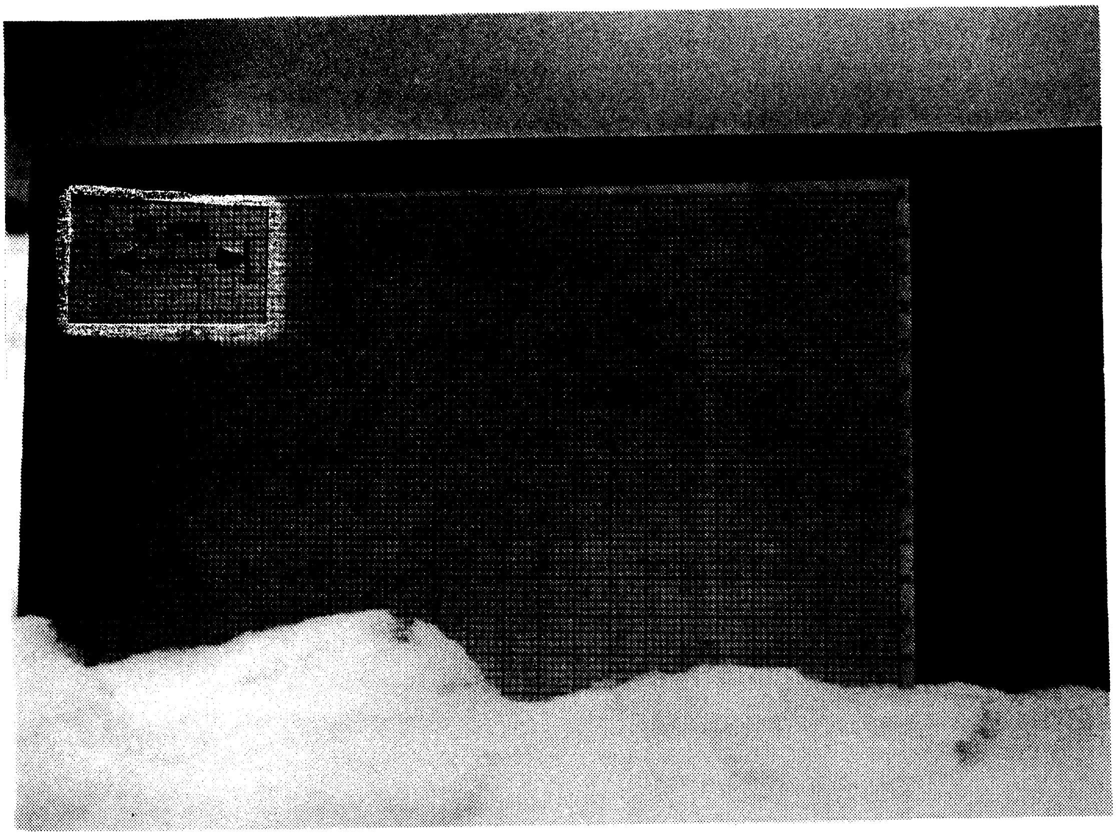
As in the previous chapter on Dry Snow, the following chart is included in order to give a more complete overview of the characteristics of the data:

	manmade wet	slightly wet with smooth surface	wet w/ smooth surface	very wet with rough surface	very wet with smooth surface
Data Set Code	A	B	C	D	E
890220		x			
890309 (vw w/ rs)				x	
890221			x		
890309 (vw w/ ss)					x
890215	x				

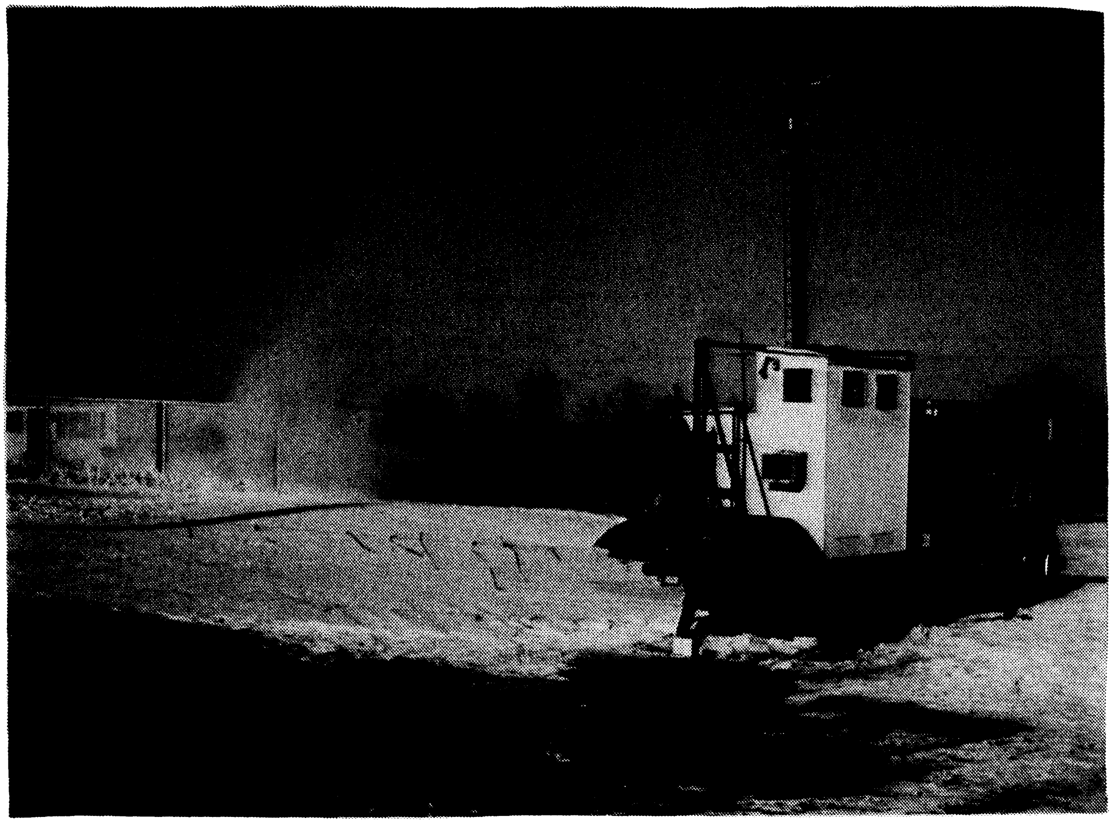
A. Manmade Wet Snow

Wet snow
Data set code: 890215
Depth: 27 cm
LWC: (at 3:25 PM): 8.82 %
Surface RMS height: 1.6 cm
Density: 0.48 gm/cm^3
Ice crystal diameter: 2 to 4 mm
Surface temperature: 0.0 C
Description: manmade wet snow

Snowmaking scene



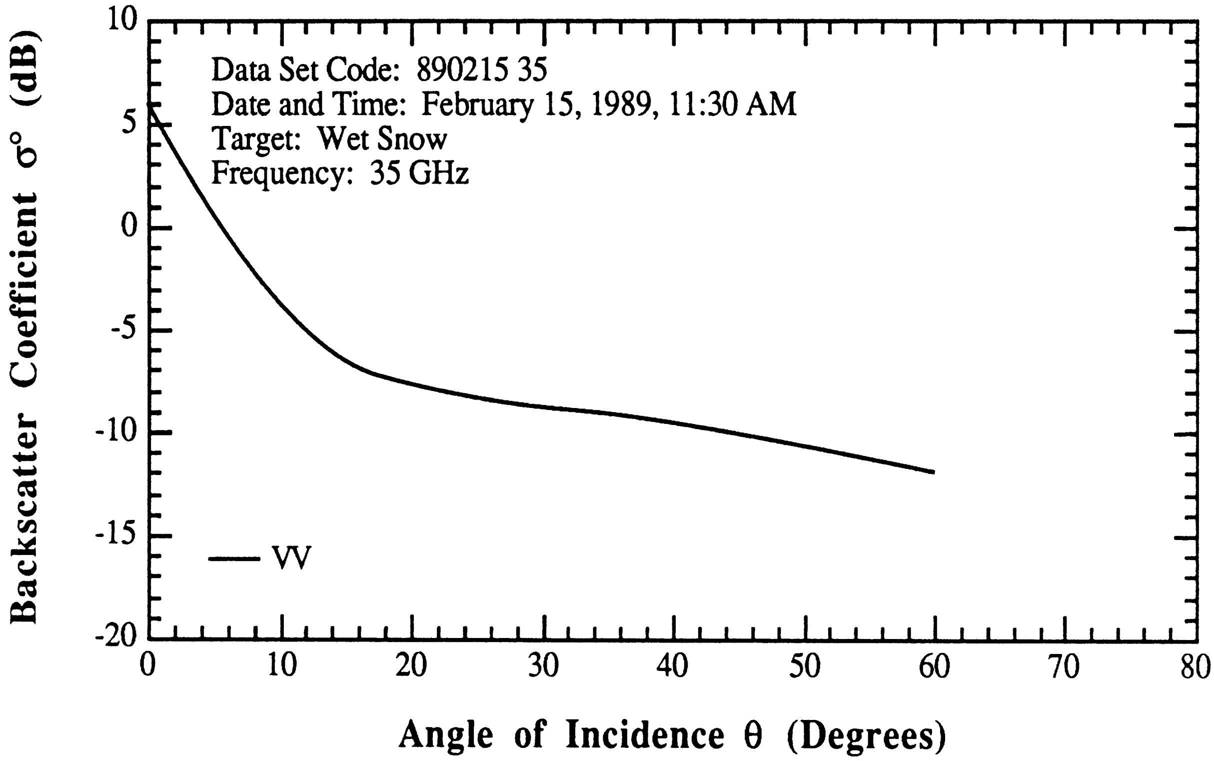
Surface roughness profile with 1 cm grid



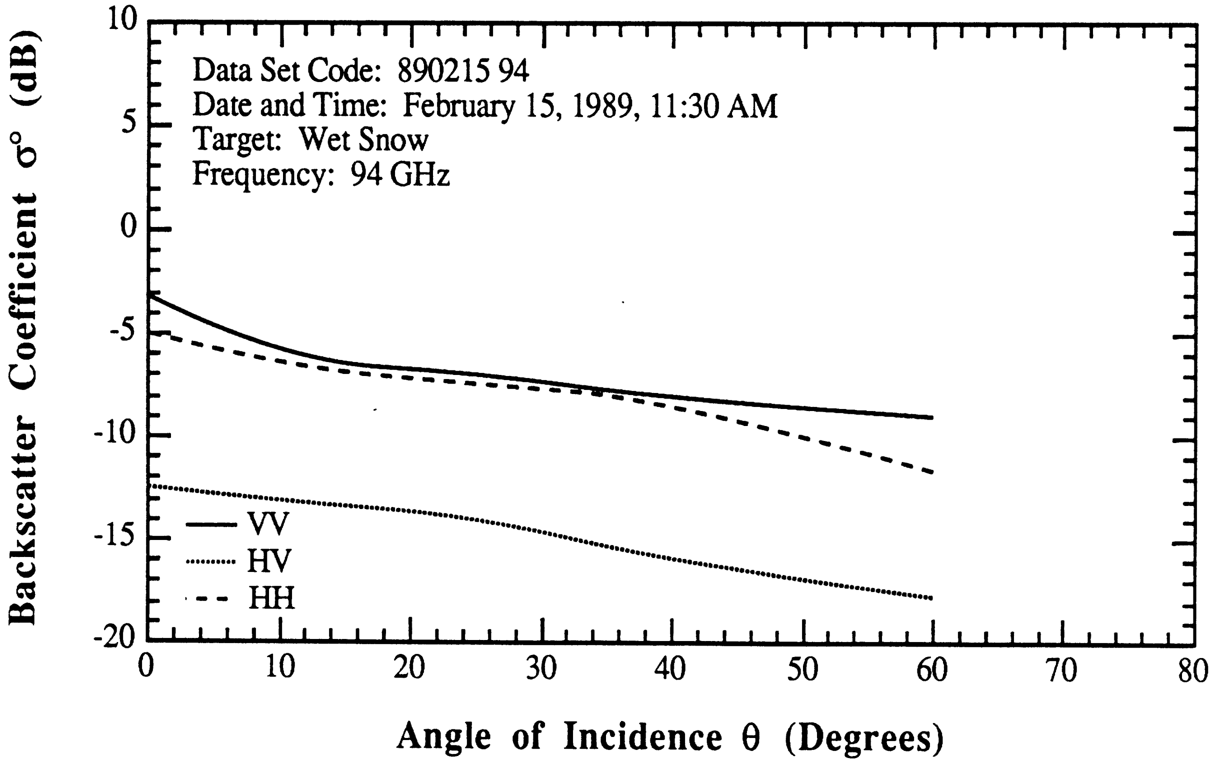
Data collection scene

MMW DATA FOR WET SNOW

890215



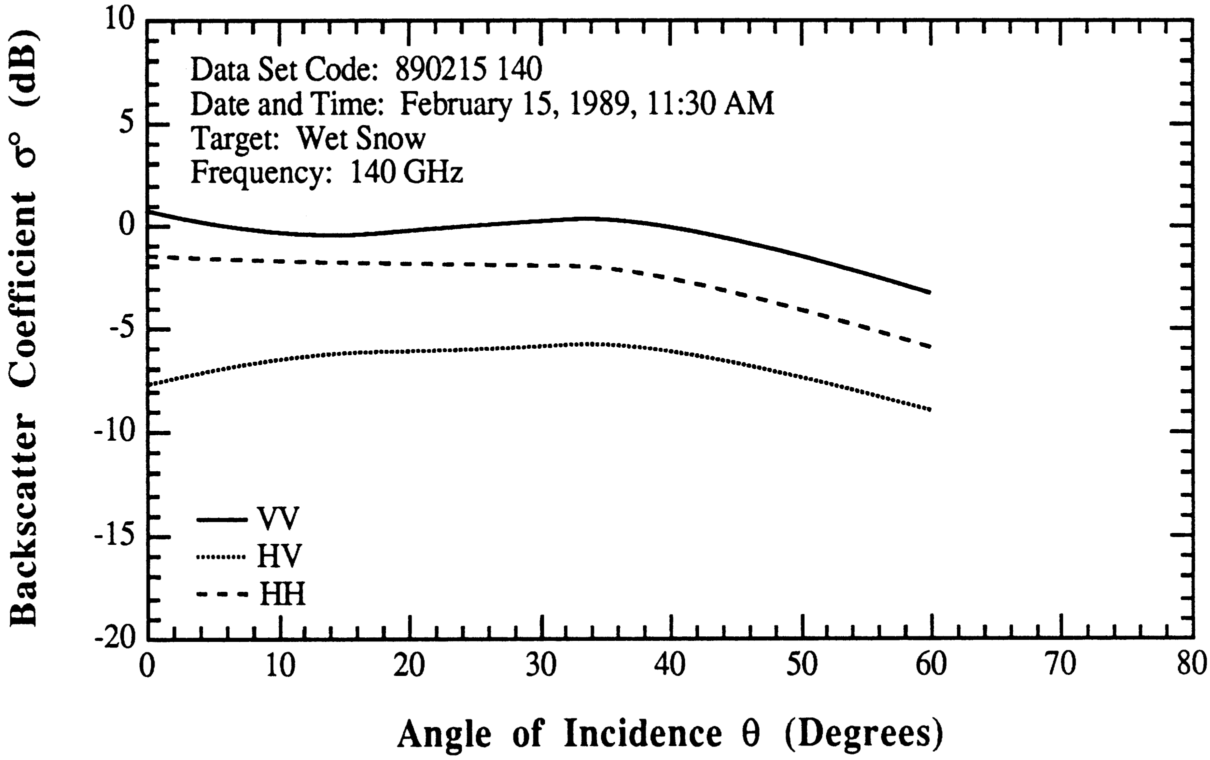
Wet Snow at Brighton



Wet Snow at Brighton

MMW DATA FOR WET SNOW

890215

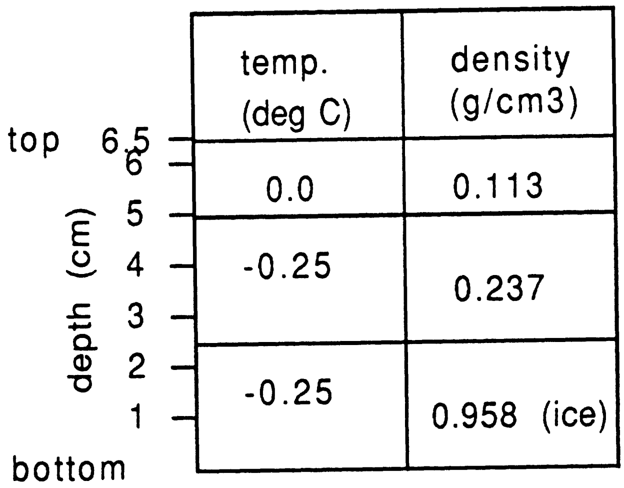


Wet Snow at Brighton

B. Slightly Wet Snow with Smooth Surface

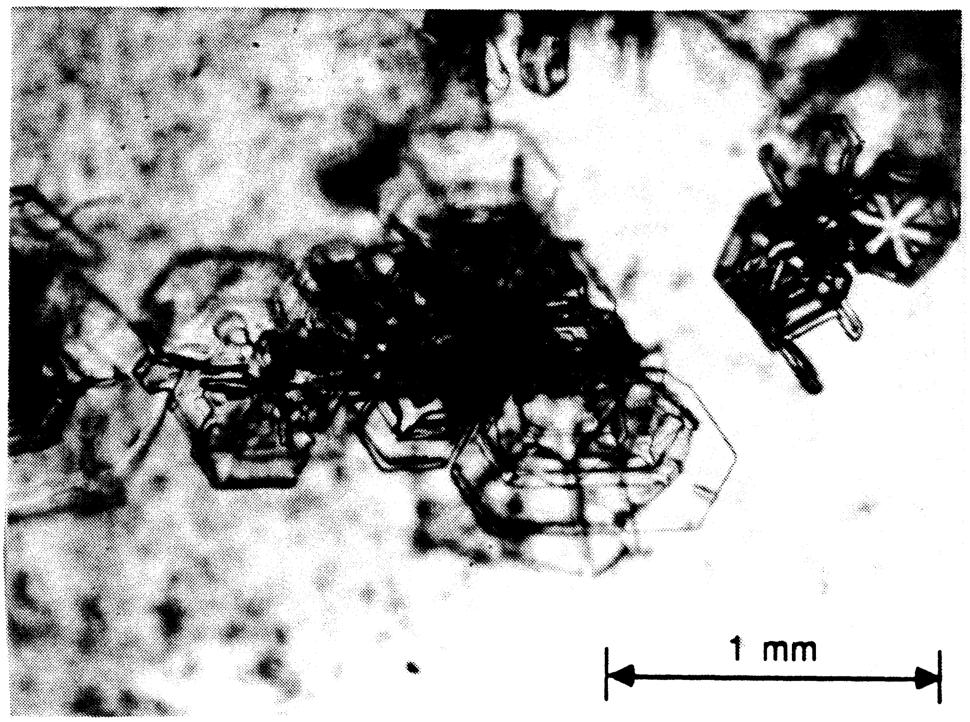
Data set code: 890220
Depth: 6.5 cm
Liquid Water Content: 1.9%
Surface RMS height: 0.11 cm
Density: 0.1 to 1.0 gm/cm^3
Ice crystal diameter: 1 to 2 mm
Surface temperature: 0.0 C
Description: smooth, wet natural snow

SNOW PIT PROFILE FOR 890220



air temperature: 1.1 C

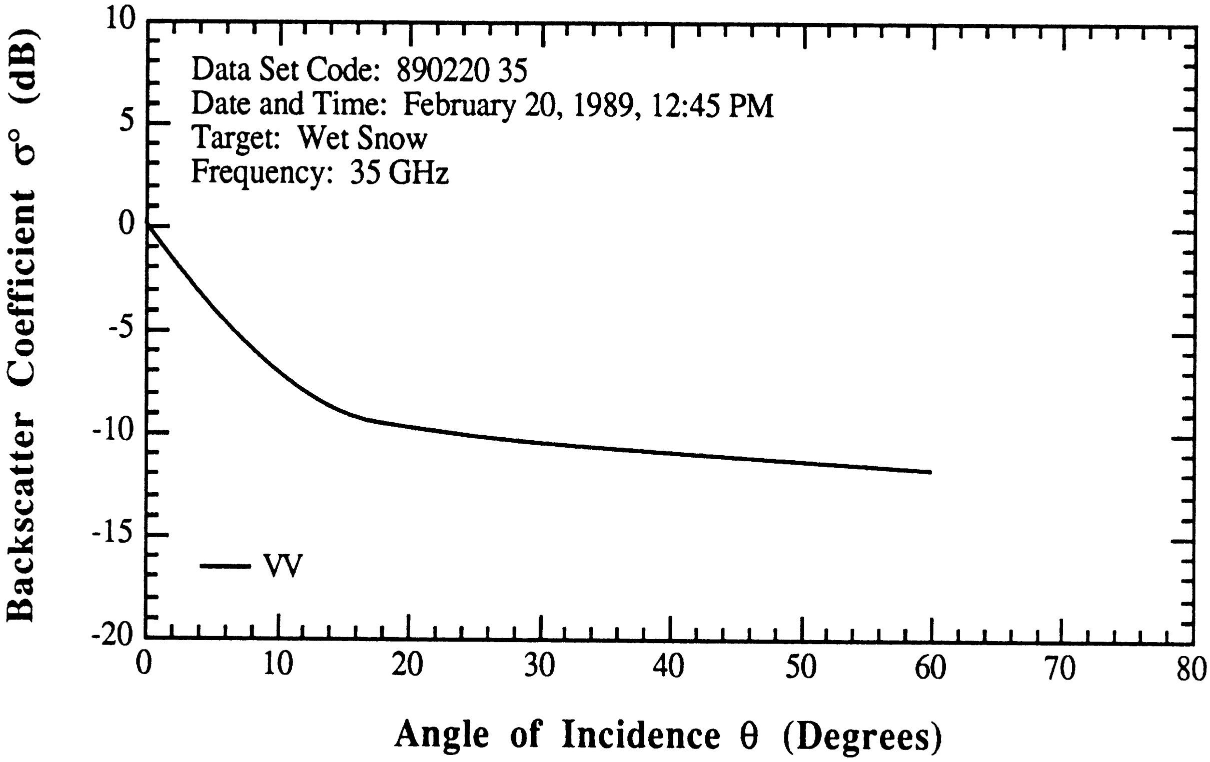
Data collection scene



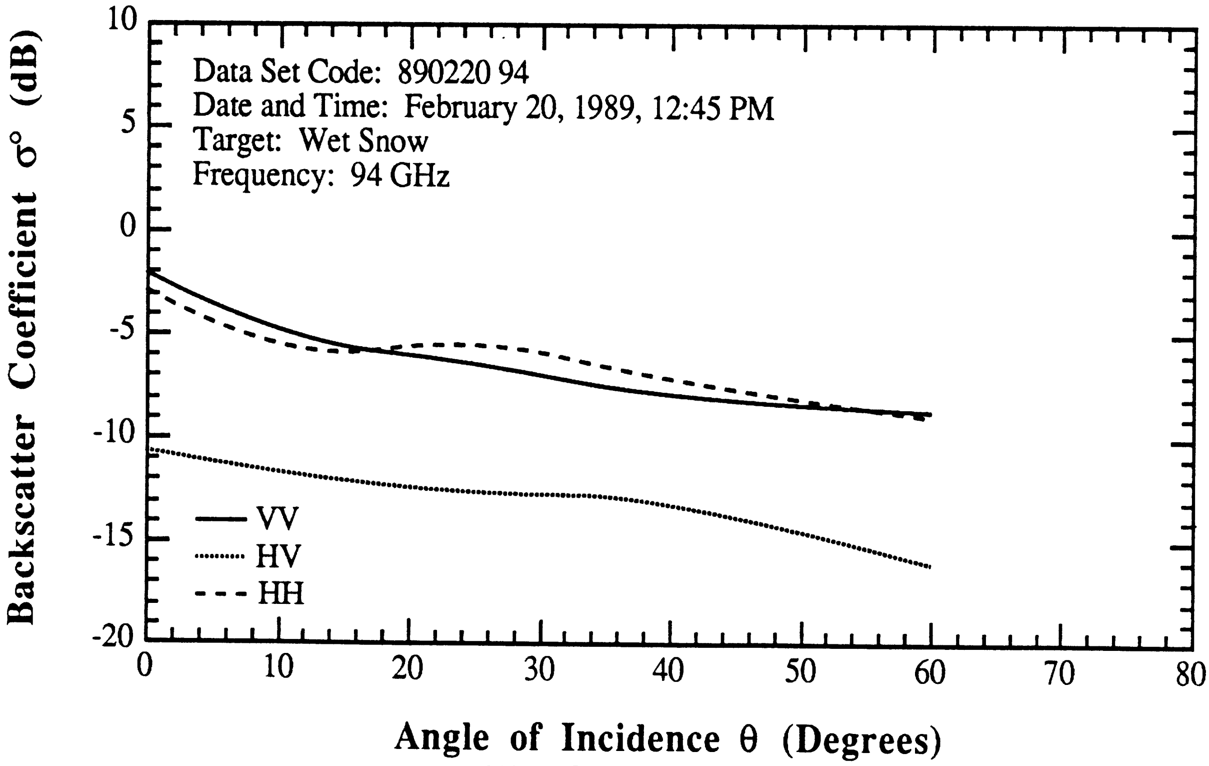
Snow crystals from surface

MMW DATA FOR WET SNOW

890220



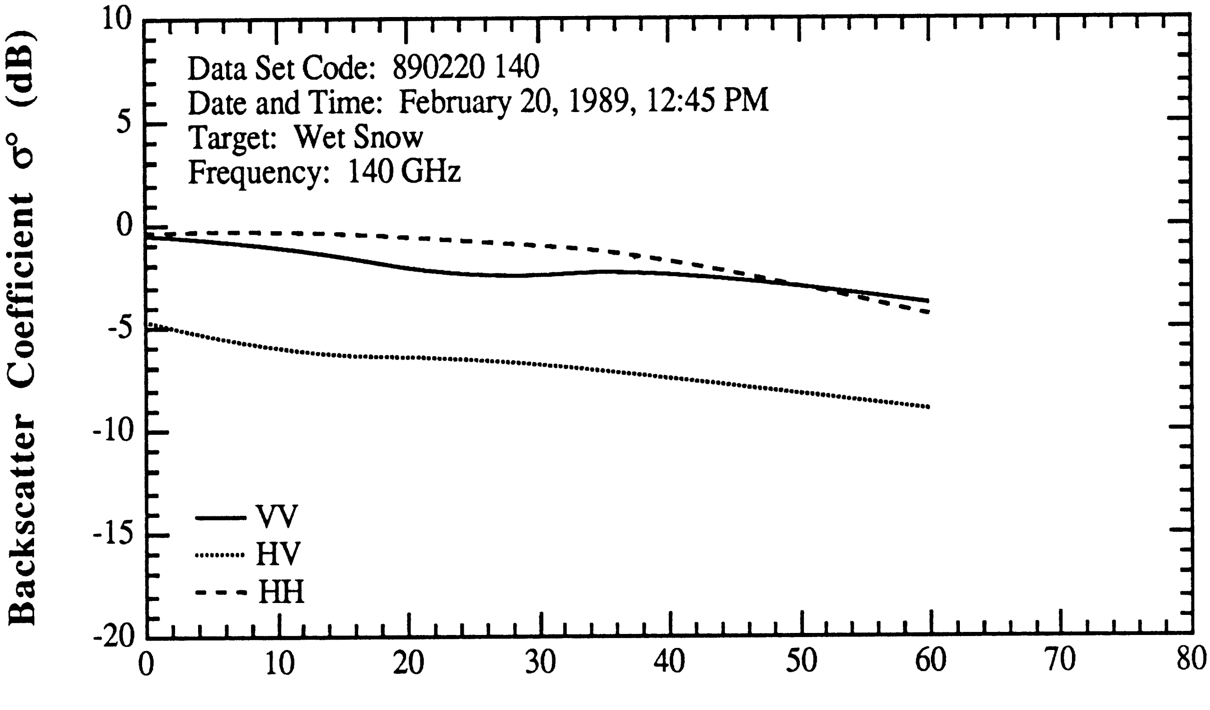
Wet Snow at Brighton



Wet Snow at Brighton

MWW DATA FOR WET SNOW

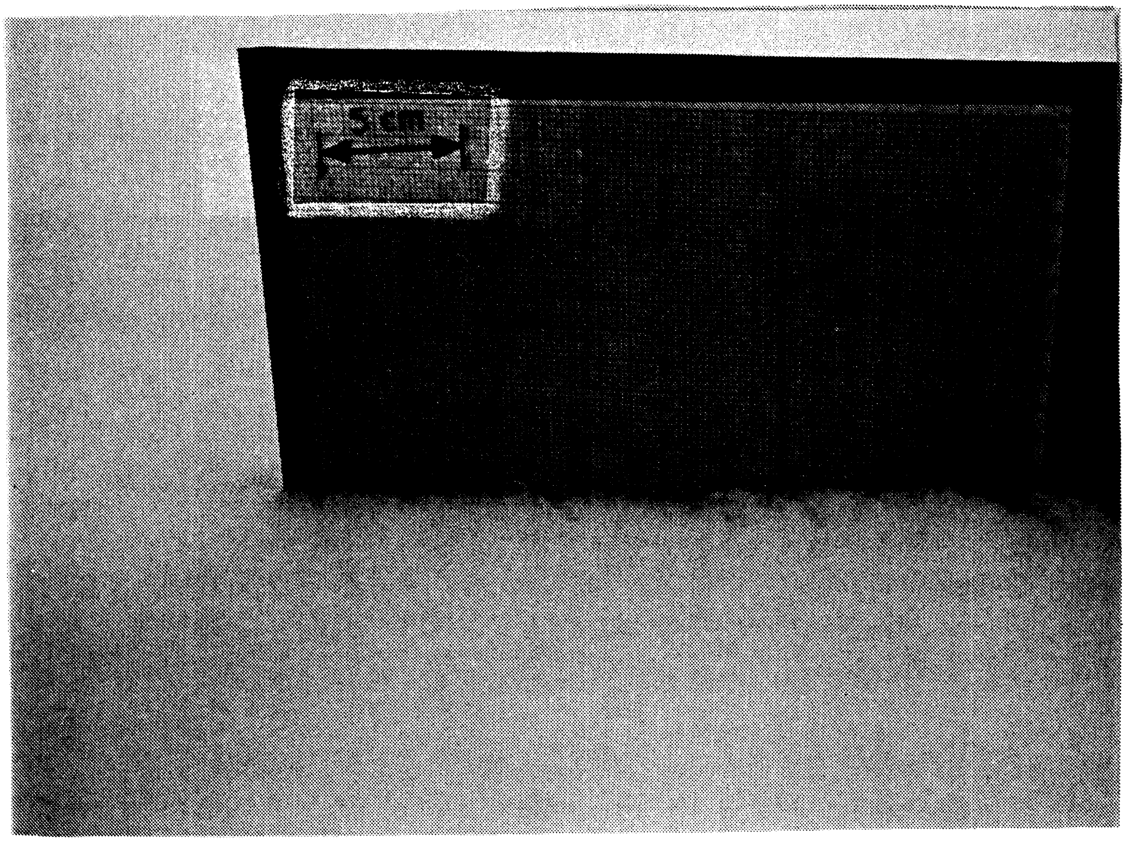
890220



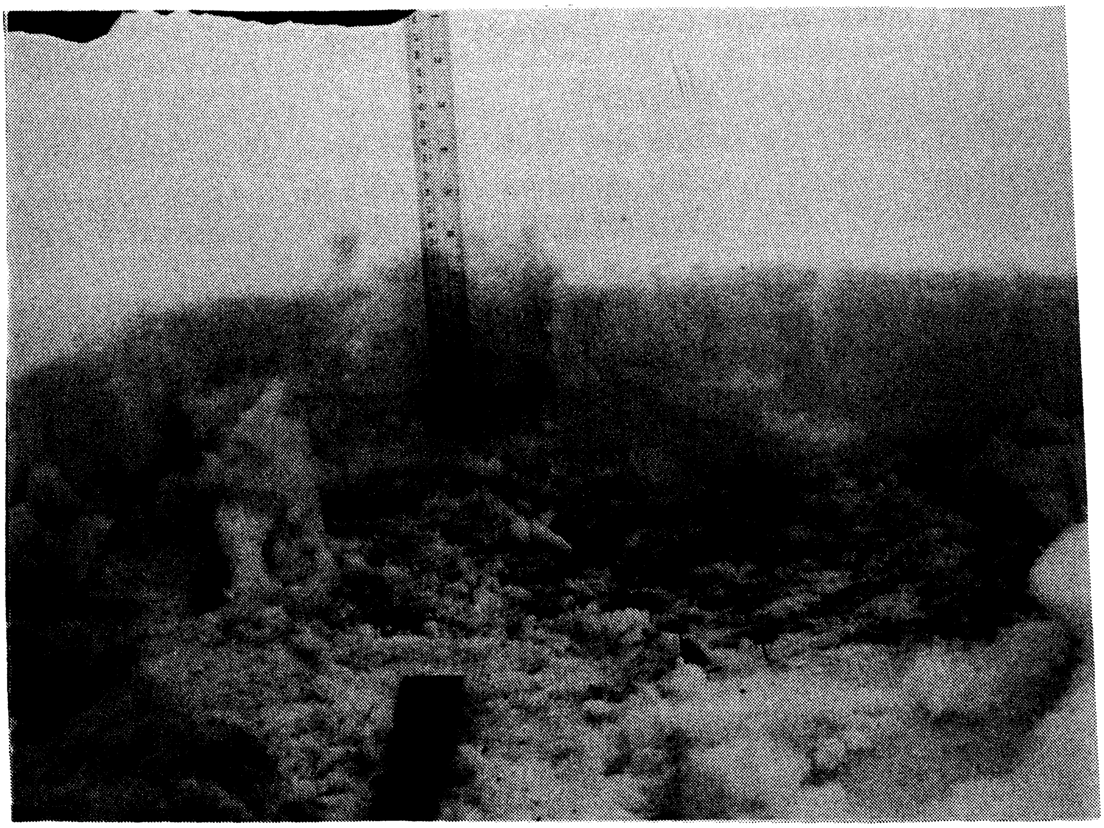
Wet Snow at Brighton

C. Wet Snow with Smooth Surface

Wet snow
Data set code: 890221
LWC (at 12:48 PM): 4.53 %
LWC (at 1:20 PM): 5.50 %
LWC (at 3:08 PM): 6.57 %
Depth: 13.5 cm
Surface RMS height: 0.22 cm
Ice crystal diameter: 1 mm
Density: 0.13 gm/cm^3
Surface temperature: 1.0 C
Description: smooth, wet natural snow



Surface roughness profile with 1 cm grid

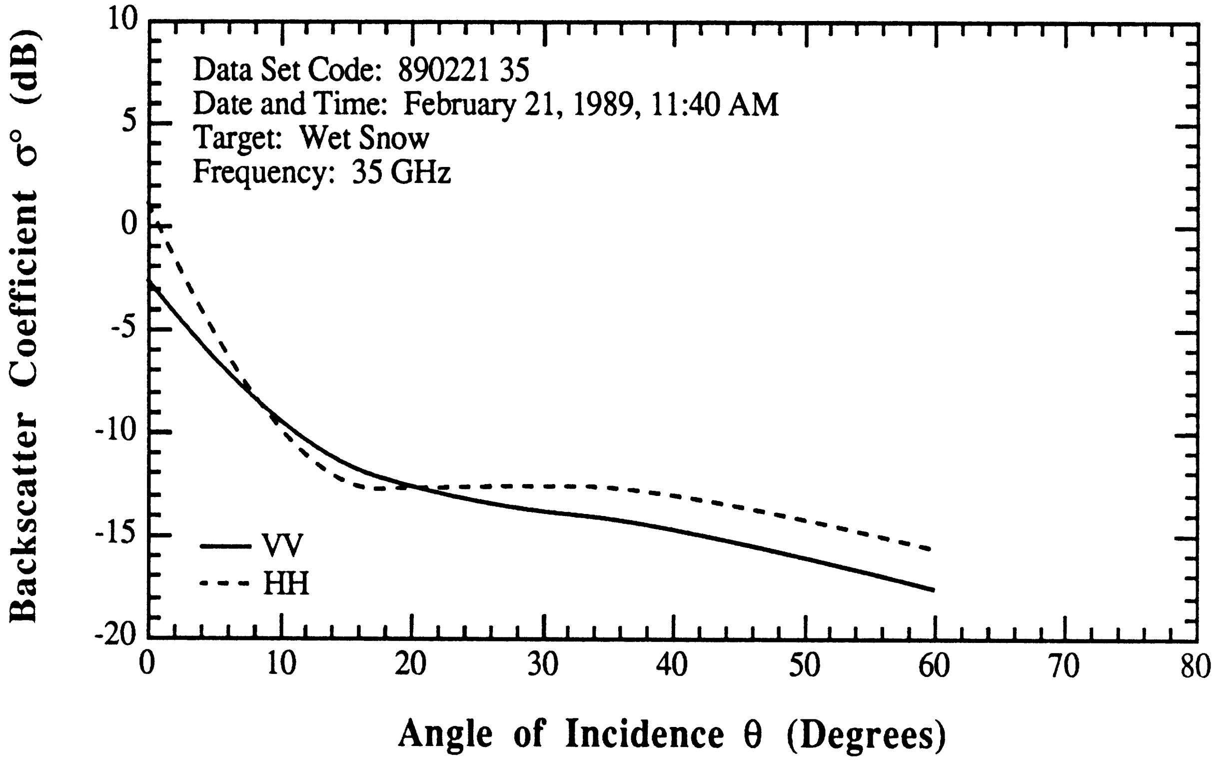


Snow pit

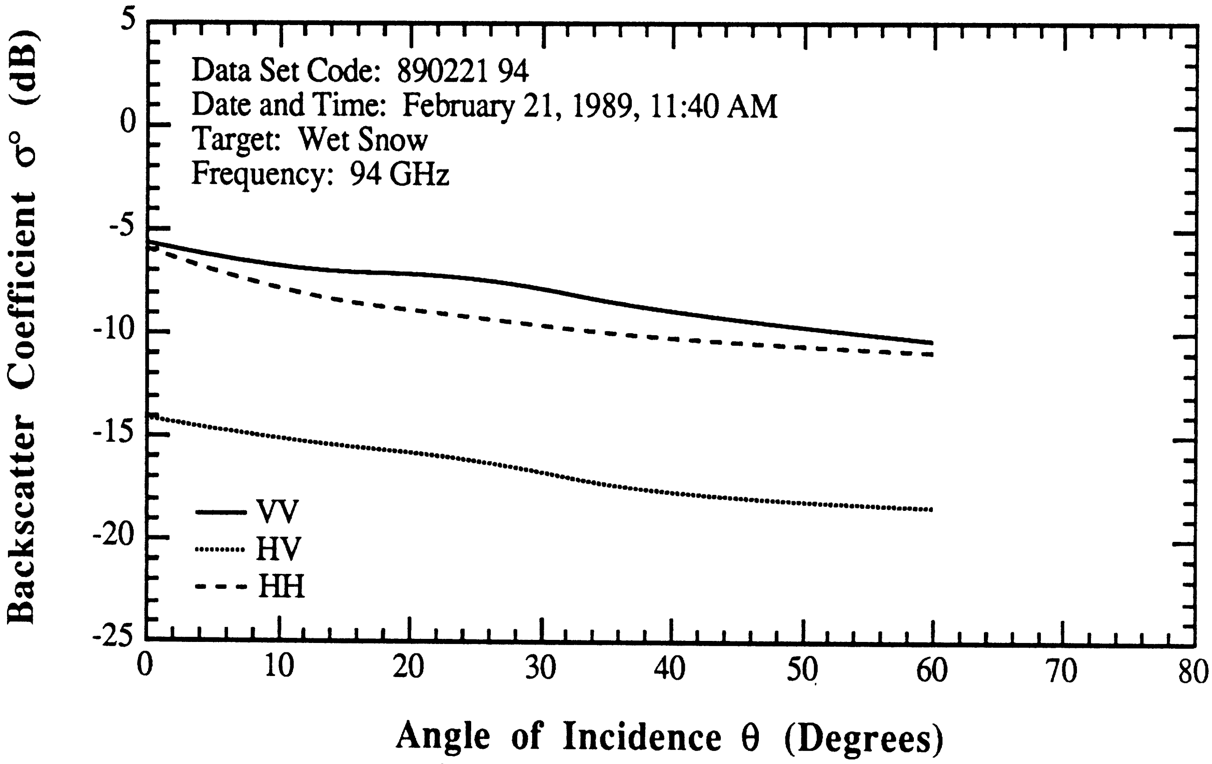
Data collection scene

MMW DATA FOR WET SNOW

890221



Wet Snow at Brighton

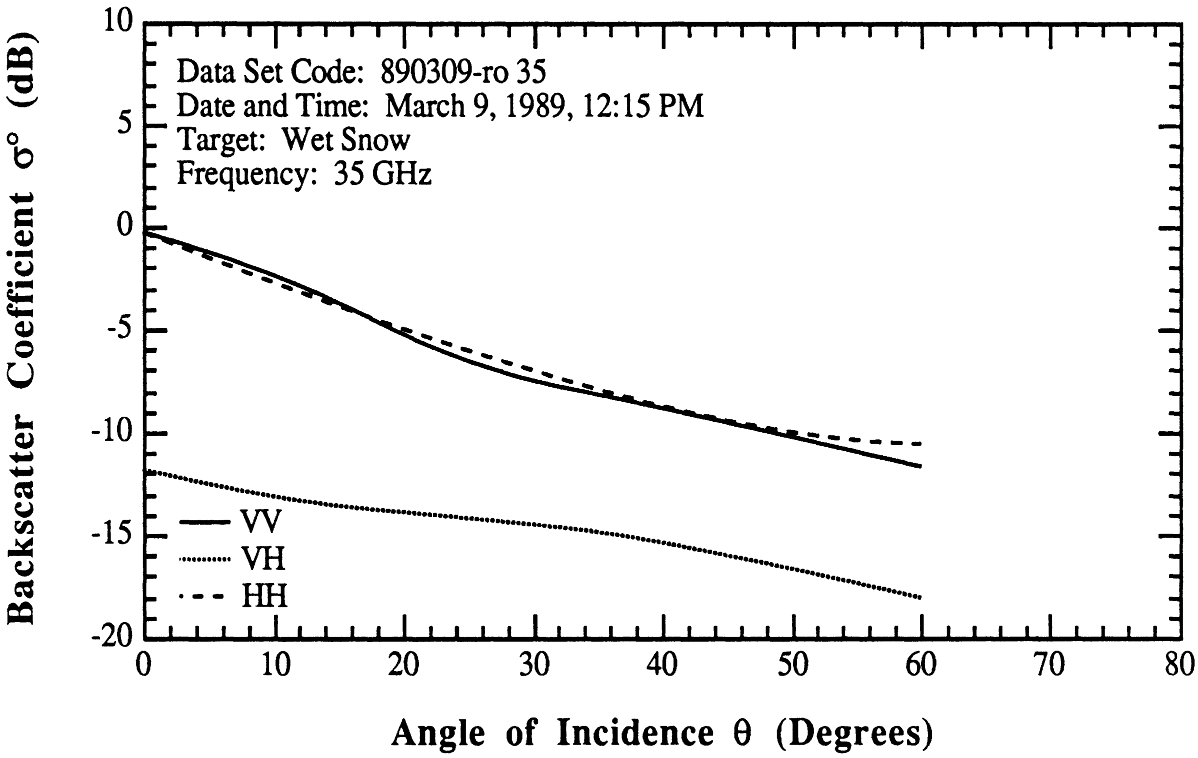


Wet Snow at Brighton

G. Very Wet Snow with Rough Surface

Wet snow
Data set code: 890309(RO)
Depth: 4.0 cm
LWC (at 2:30 PM): 16.89 %
LWC (at 3:09 PM): 15.47%
Surface RMS height (sample 1): 1.36 cm
Surface RMS height (sample 2): 1.78 cm
Surface RMS height (sample 3): 1.79 cm
Surface RMS height (sample 4): 2.29 cm
Density: 0.42 gm/cm^3
Ice crystal diameter: 2 to 4 mm
Surface temperature: 4 to 6 C
Description: rough, wet snow

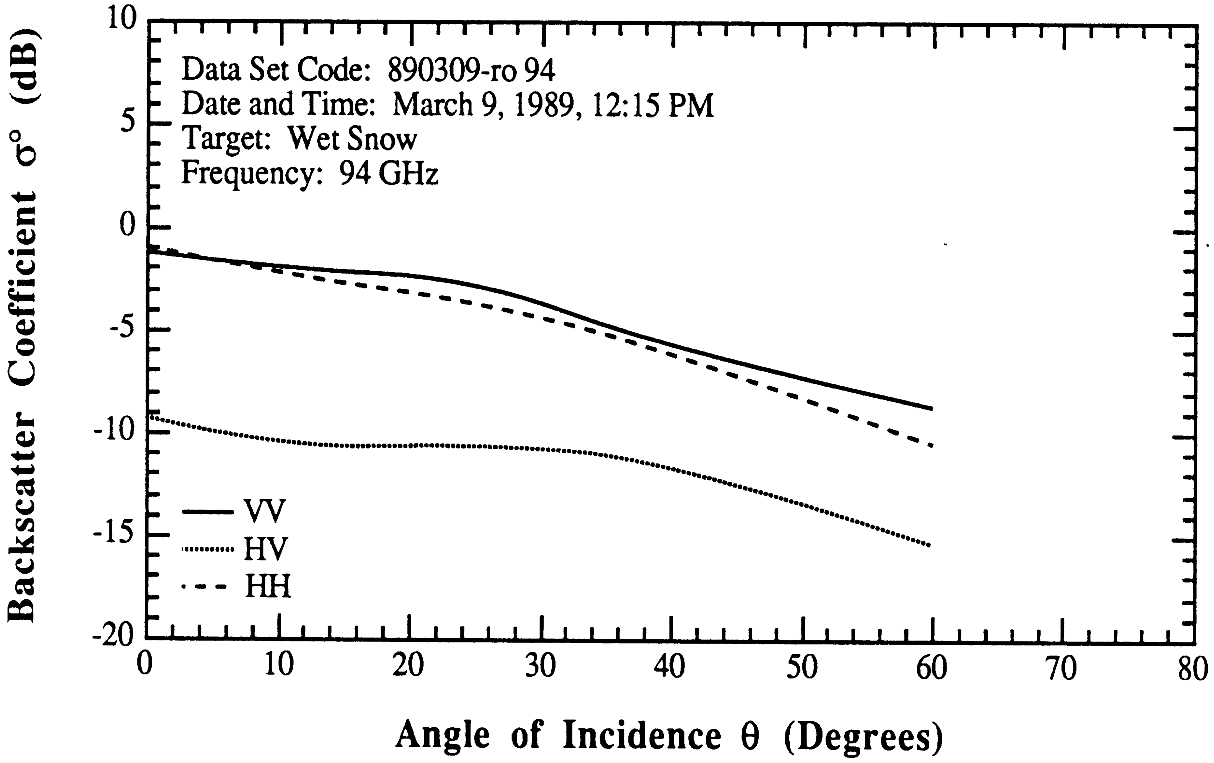
890309(RO)



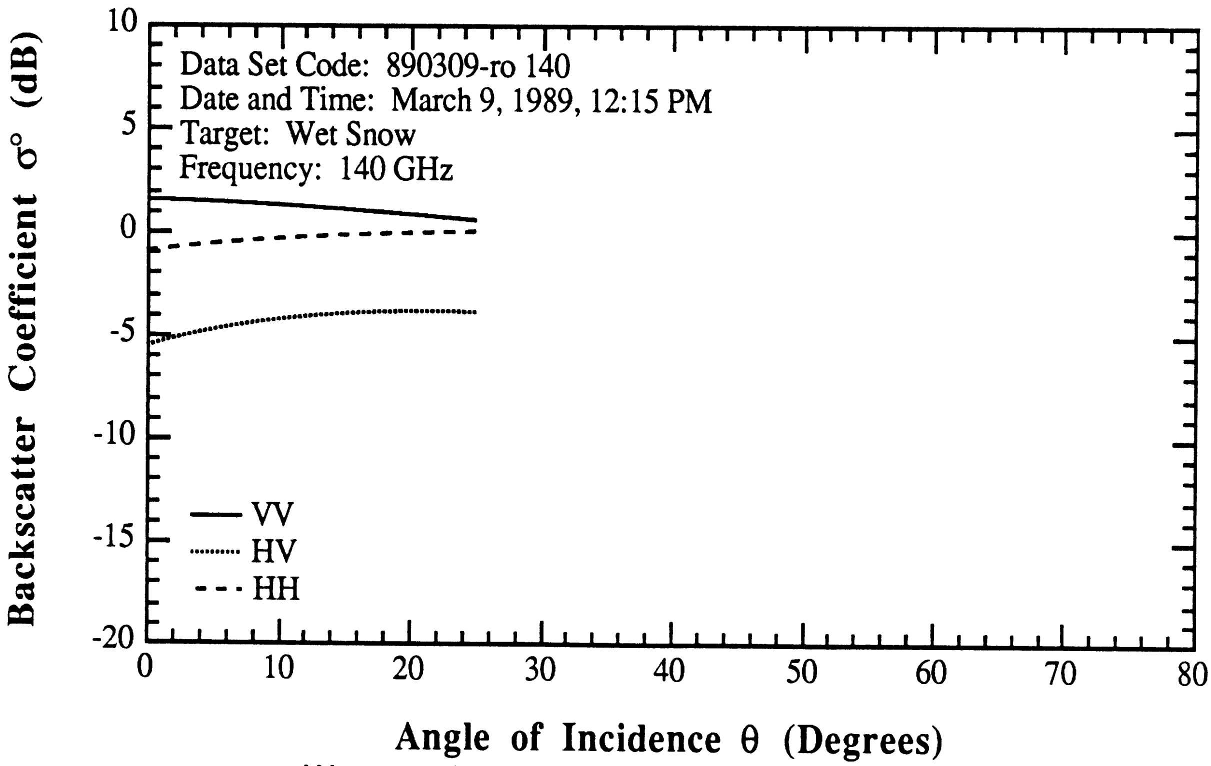
Wet rough metamorphosed snow at Brighton

MMW DATA FOR WET SNOW

890309(RO)



Wet rough metamorphosed snow at Brighton

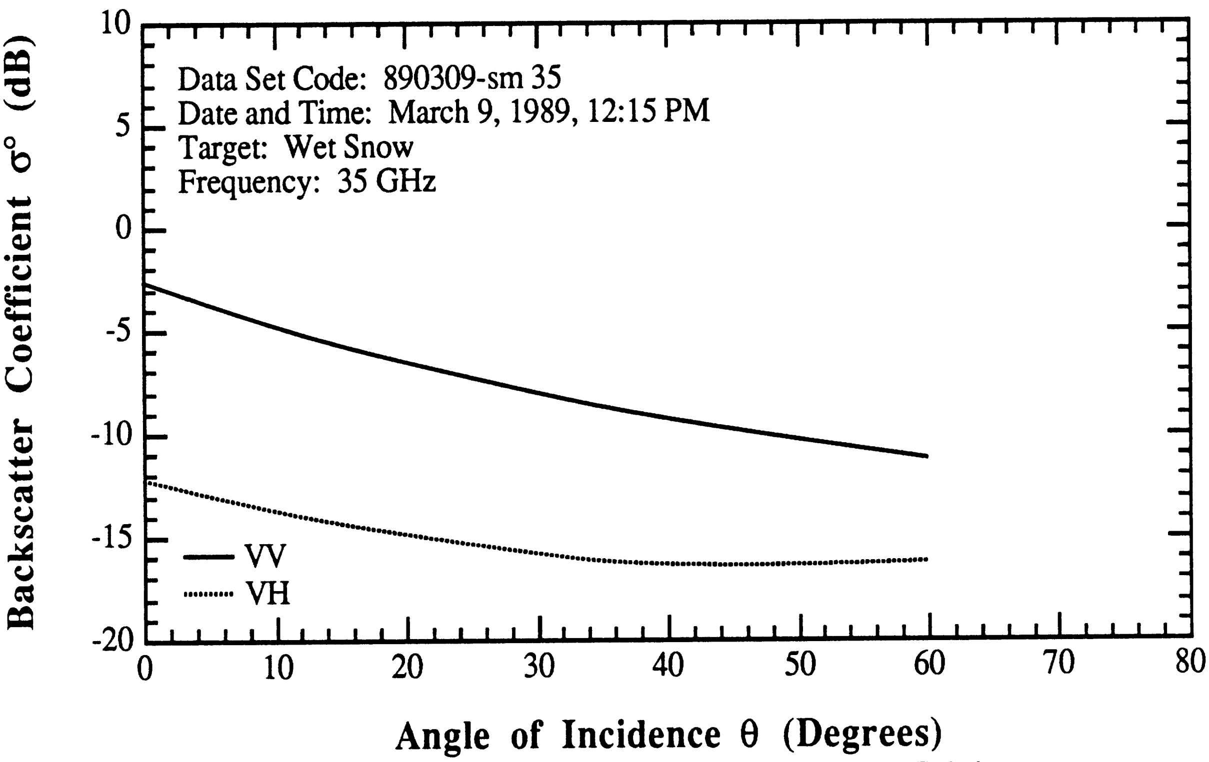


Wet rough metamorphosed snow at Brighton

E. Very Wet Snow with Smooth Surface

Data set code: 890309(SM)
Depth: 4.0 cm
LWC (at 2:30 PM): 16.89 %
LWC (at 3:09 PM): 15.47 %
Surface RMS height: 0.30 cm
Density: 0.42 gm/cm^3
Ice crystal diameter: 2 to 4 mm
Surface temperature: 4 to 6 C
Description: wet, smooth snow

890309(SM)

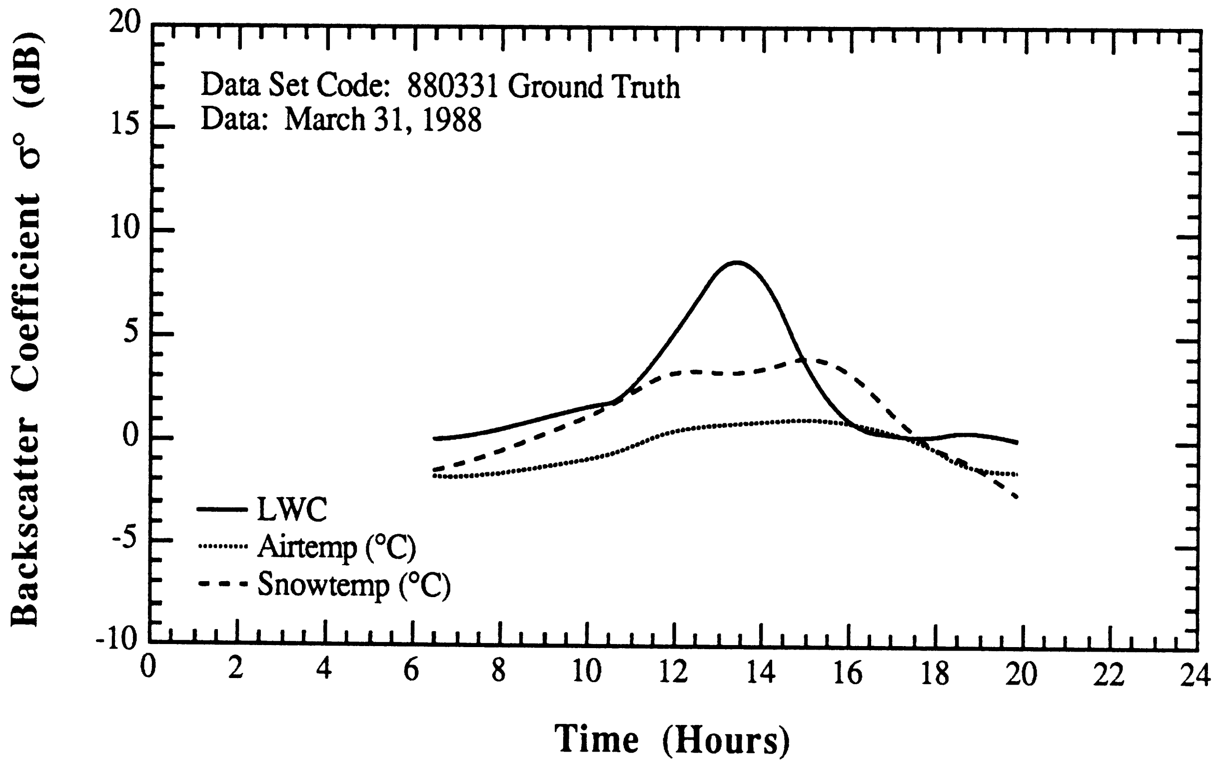


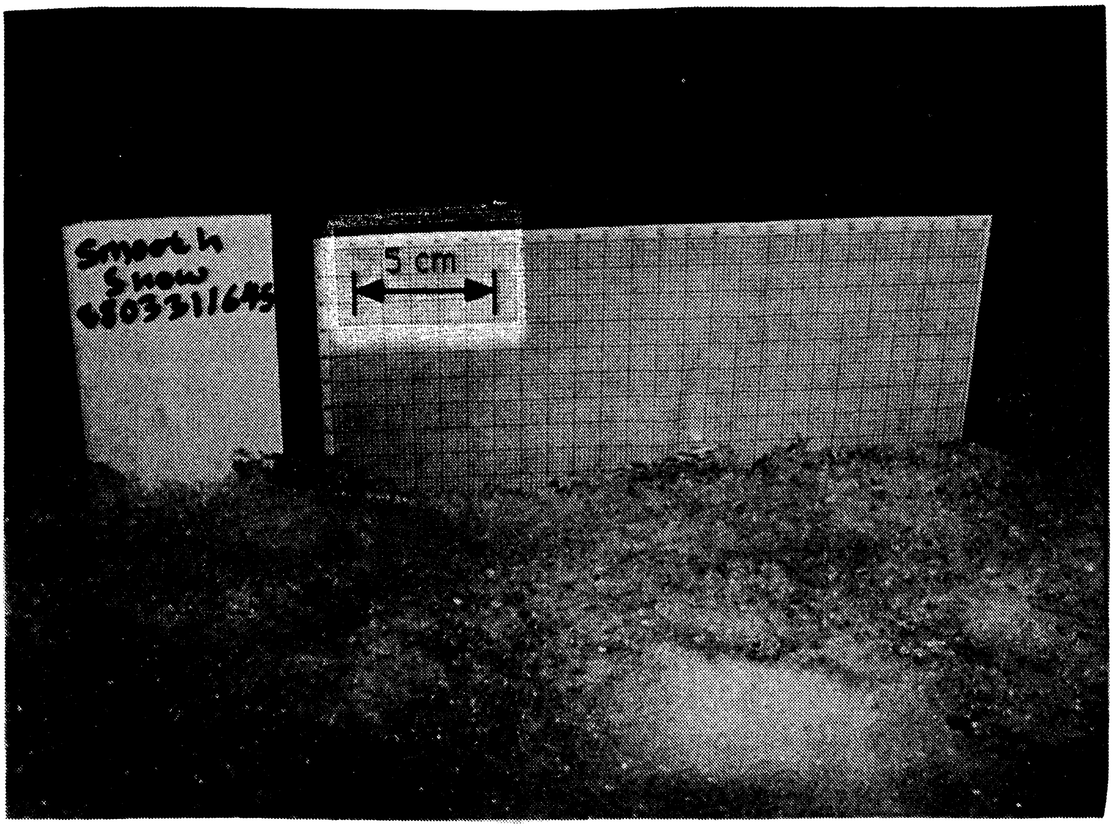
Wet smooth metamorphosed snow at Brighton

4. MMW DIURNAL DATA FOR SNOW

A. 31 March 1988

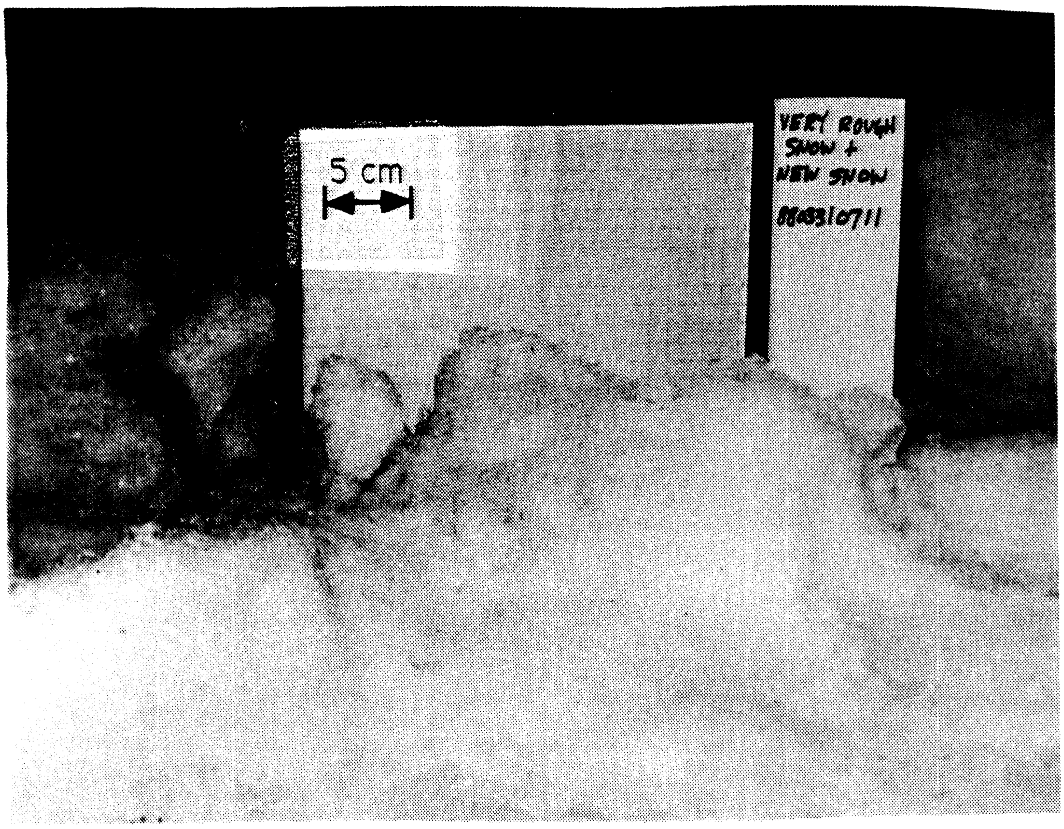
Snow
Data set code: 880331
Depth: ~ 71 cm
LWC: 0 to 10.2 %
Smooth surface RMS height: 0.49 cm
Slightly rough surface RMS height: 0.88 cm
Very rough surface RMS height: 1.98 cm
Density: surface: 0.39
15 cm depth: 0.50 gm/cm^3
30 cm depth: 0.54 gm/cm^3
45 cm depth: 0.53 gm/cm^3
60 cm depth: 0.58 gm/cm^3
71 cm depth (ground): 0.65 gm/cm^3
Ice crystal diameter: 0.5 to 1mm
Surface temperature: -2.7 C to 4.5 C
Description: metamorphosed snow divided into three sections, one natural surface (smooth), and two with roughened surfaces.



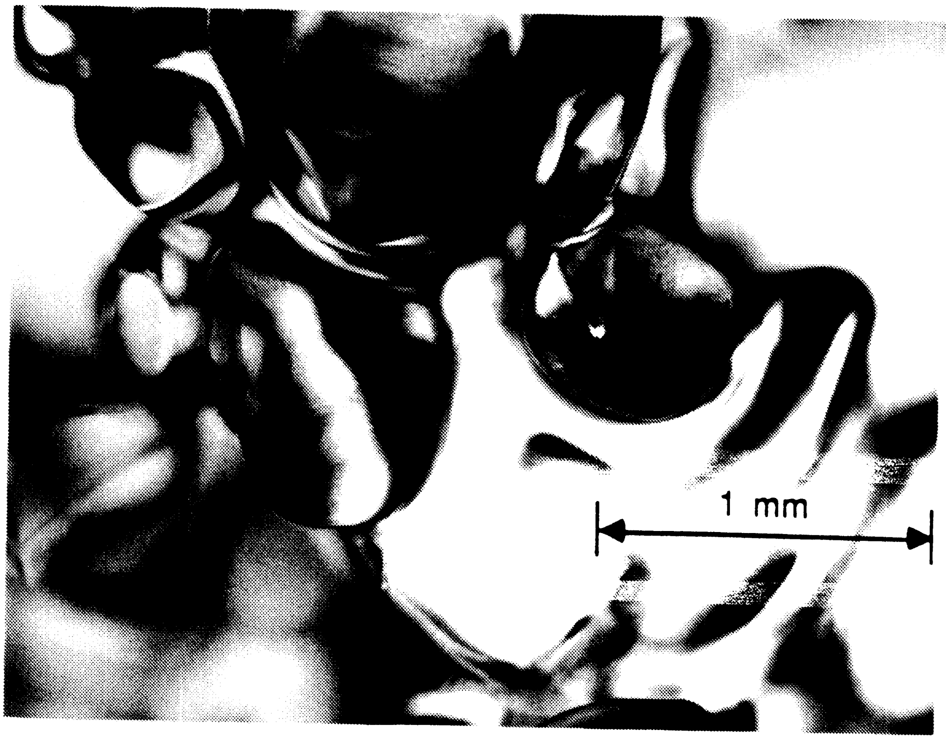


Surface roughness profile of smooth snow with 1 cm grid

Surface roughness profile of slightly rough snow with 1 cm grid



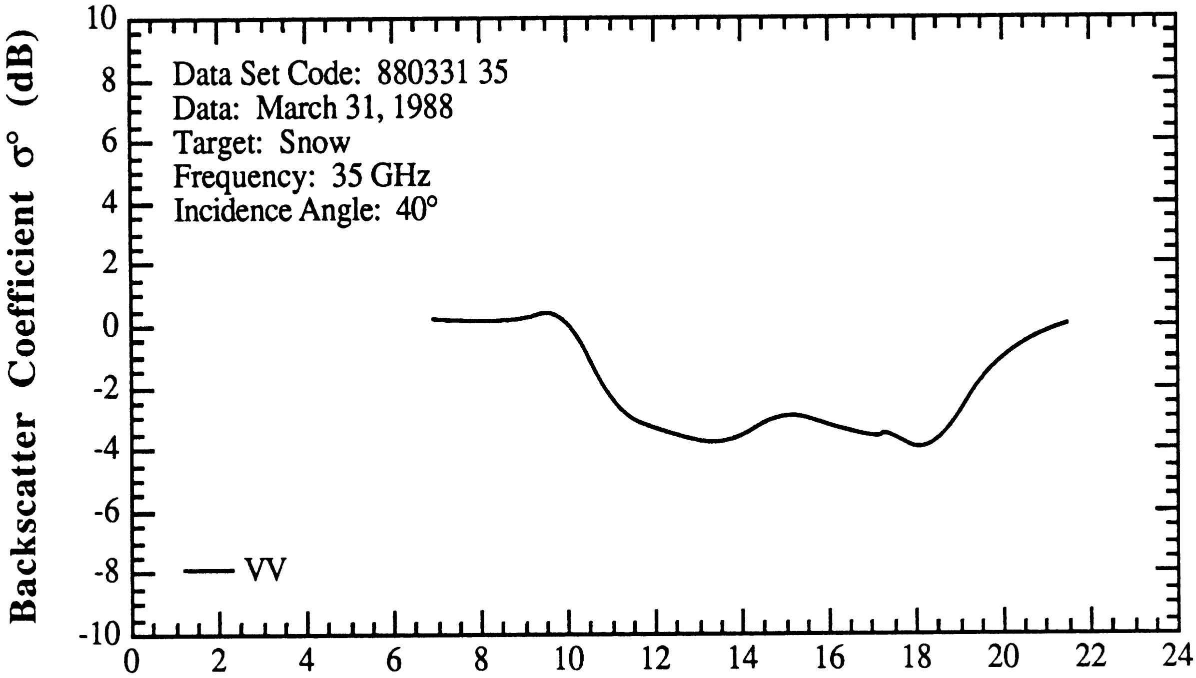
Surface roughness profile of very rough snow with 1 cm grid



Snow crystals from surface

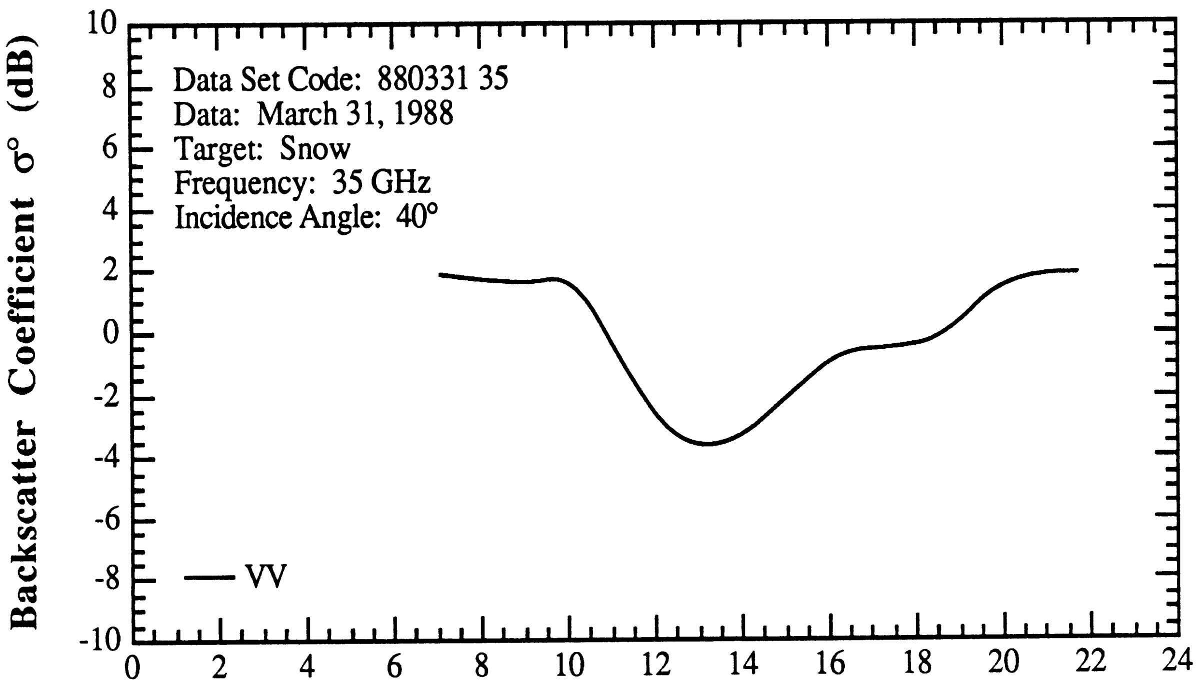
MMW DIURNAL DATA FOR SNOW

880331



Time (Hours)

Houghton snow with smooth surface

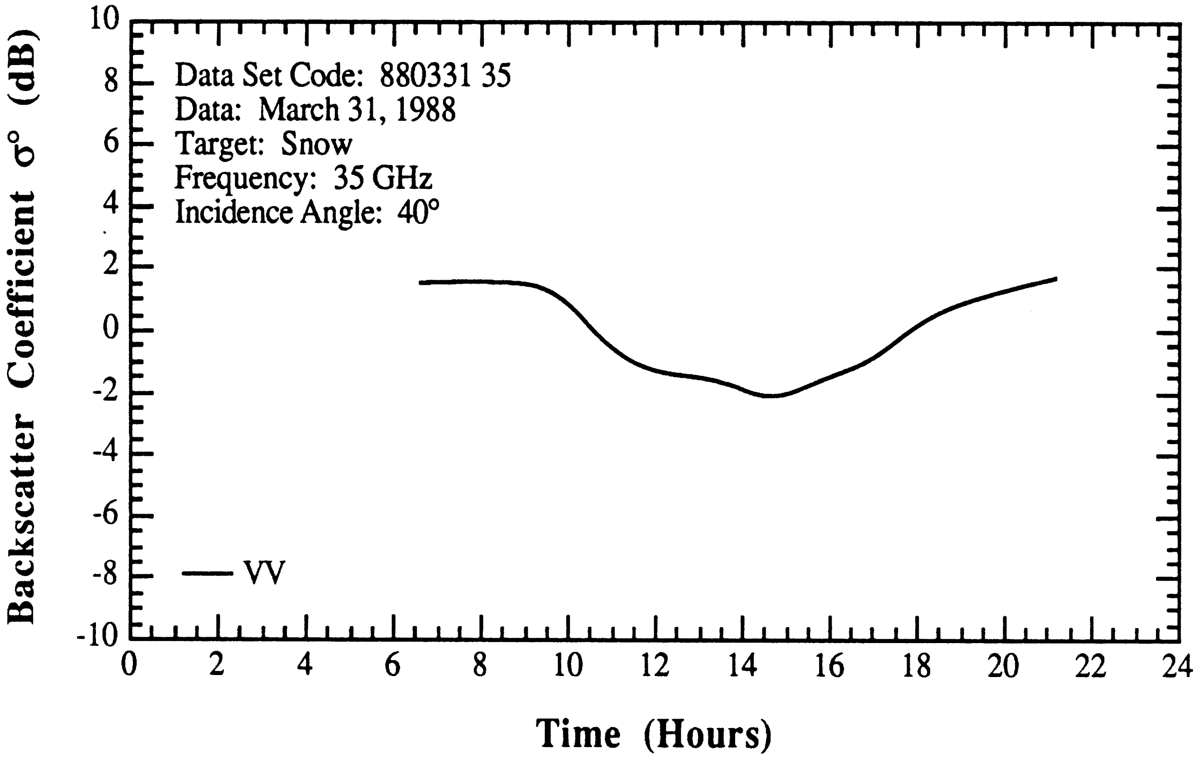


Time (Hours)

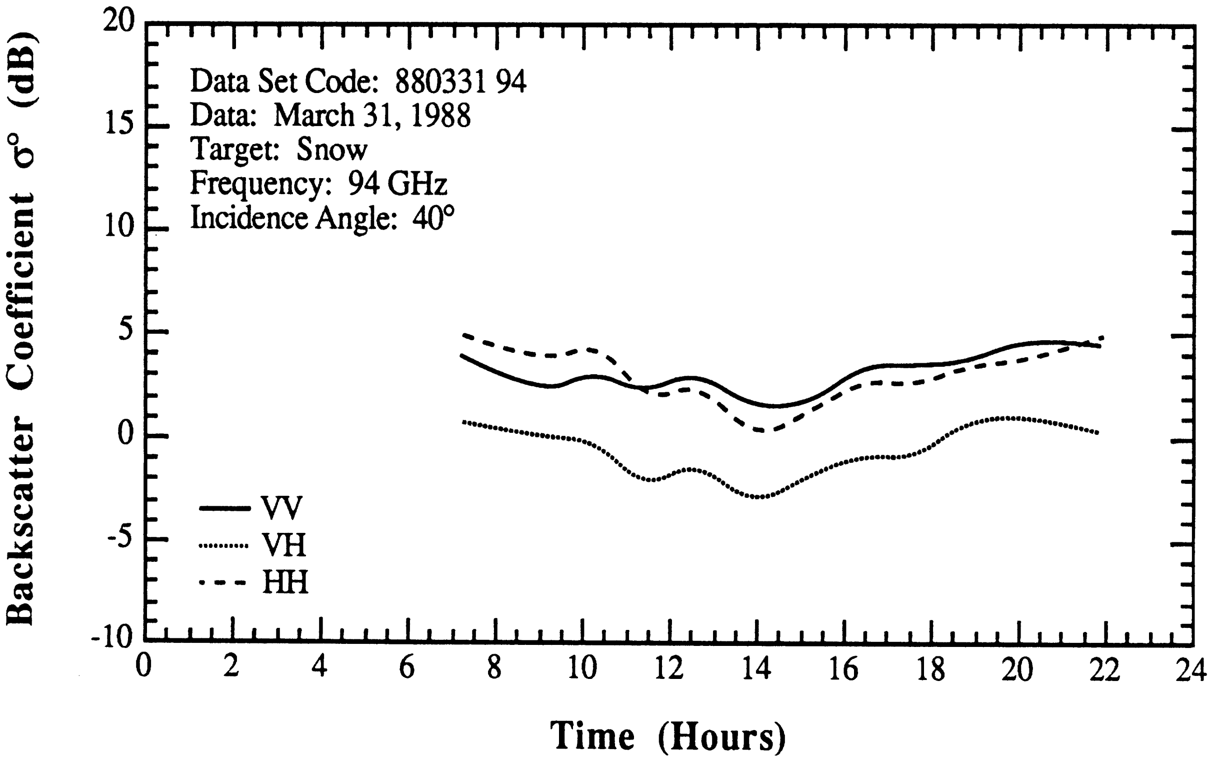
Houghton snow with slightly rough surface

MMW DIURNAL DATA FOR SNOW

880331



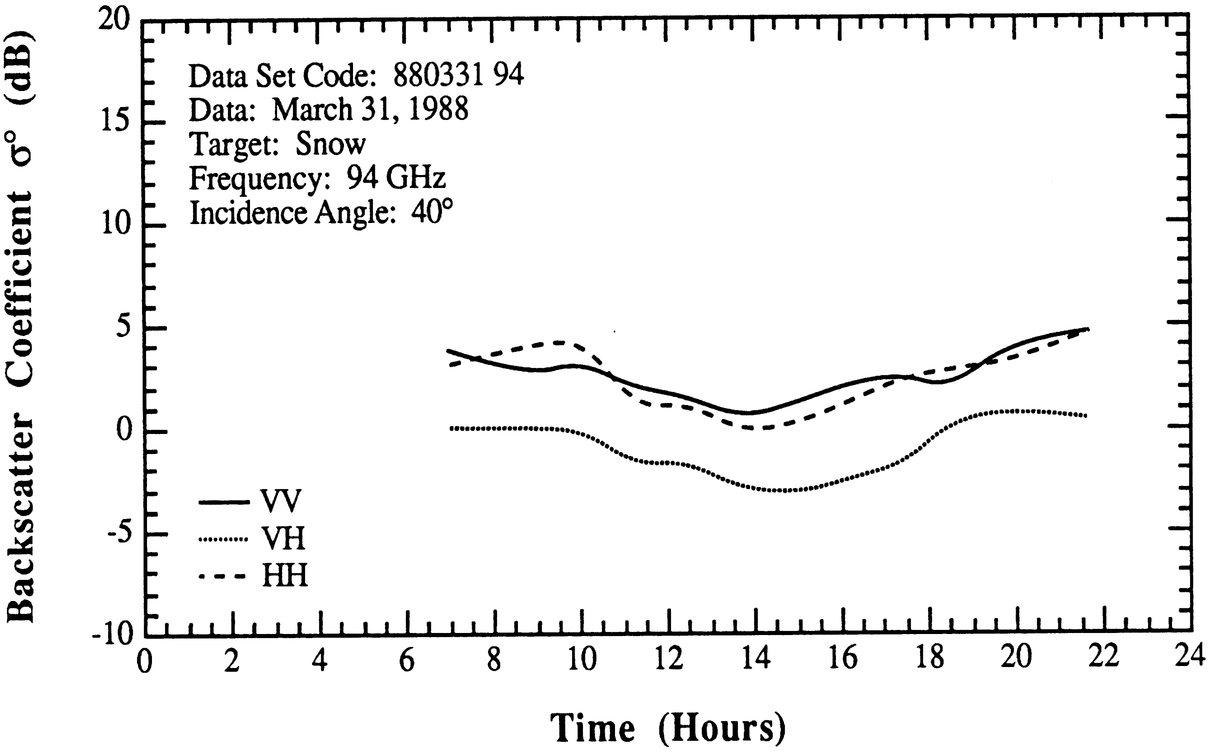
Houghton snow with very rough surface



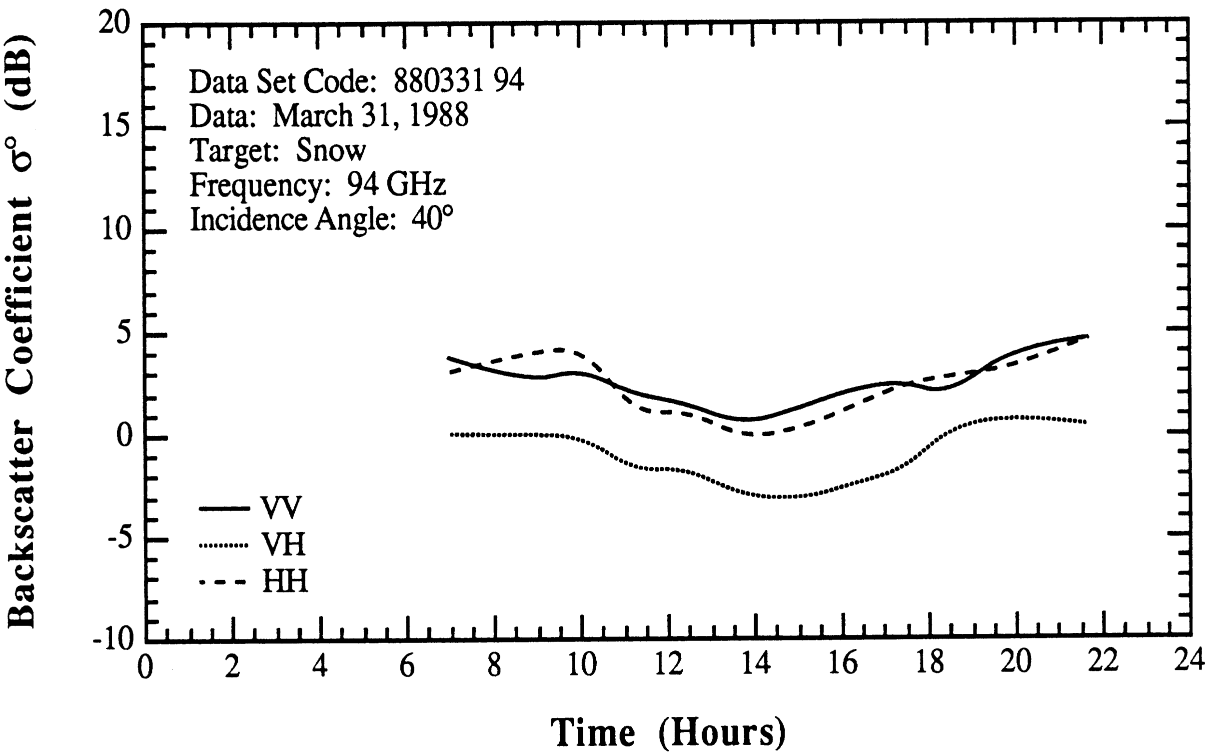
Houghton snow with smooth surface

MMW DIURNAL DATA FOR SNOW

880331



Houghton snow with slightly rough surface



Houghton snow with very rough surface

B. 27 February, 1989

Snow
Data set code: 890227/28
Depth: 9.5 cm
LWC: 0 to 5 %
Surface RMS height: 0.1 cm
Density: 0.31 gm/cm^3
Ice crystal diameter: 1 mm
Surface temperature: 0.0 C to -9.0 C
Description: partially metamorphosed snow

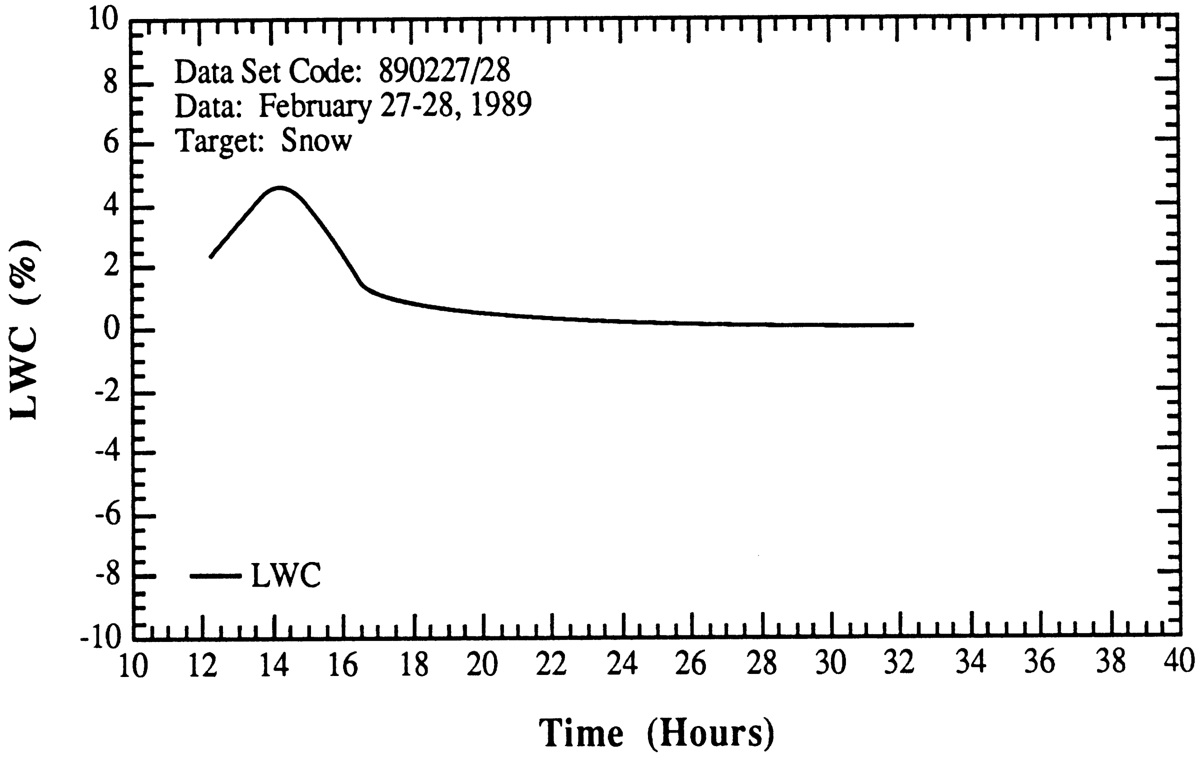
890227/28

SNOW PIT TEMPERATURE PROFILE (°C)

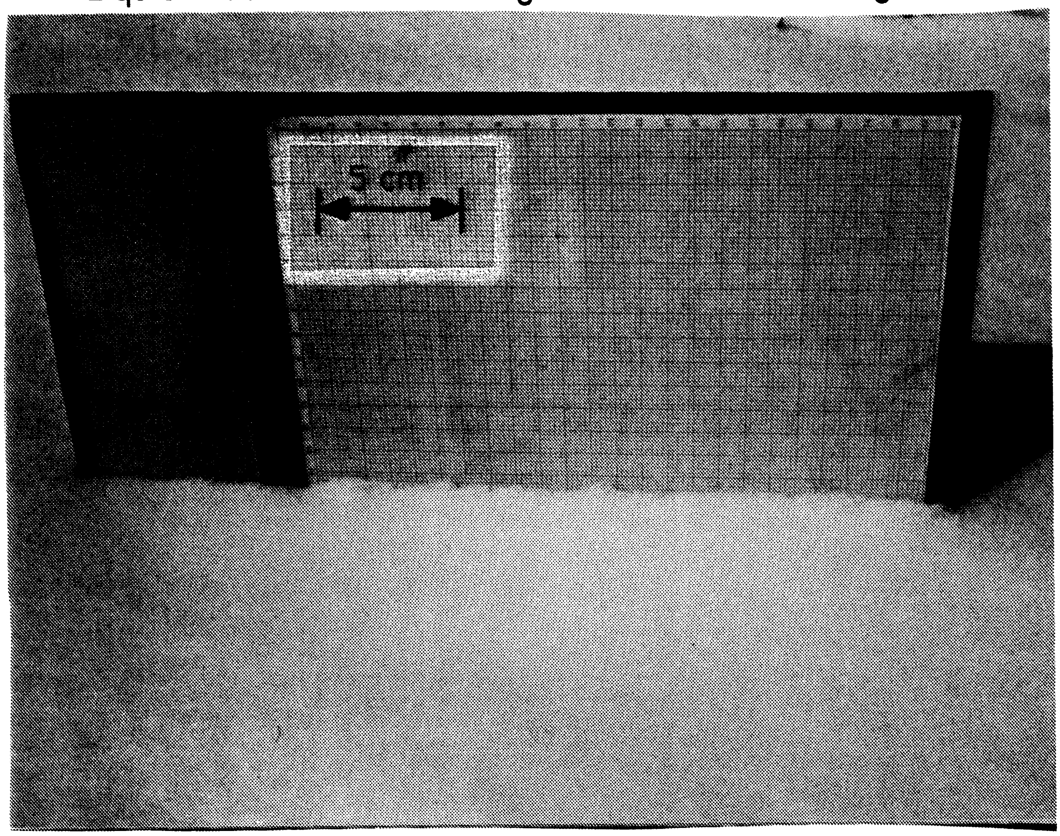
Time	depth (cm)	1400	1445	1540	1655	1800	1900	2100	2302	0100	0300	0500	0605	0803
Top	9.5			0.0	-2.0	-4.0	-3.5	-6.5	-6.5	-6.3	-8.5	-9.0	-7.5	-7.0
	8	0.0	0.0											
	5	-0.6	-0.3	-0.3	-0.5	-1.1	-4.0	-5.5	-5.5	-4.0	-5.0	-6.5	-4.5	-5.7
bottom		-0.6	-0.7	-0.6	-1.0	-0.6	-3.6	-4.0	-4.0	-3.5	-4.5	-5.5	-3.5	-3.8
air temp		-3.5	-3.3	-3.0	-3.2	-5.1	-8.5	-8.0	-6.8	-6.5	-10.	-11.	-9.2	-7.0

MMW DIURNAL DATA FOR SNOW

890227/28



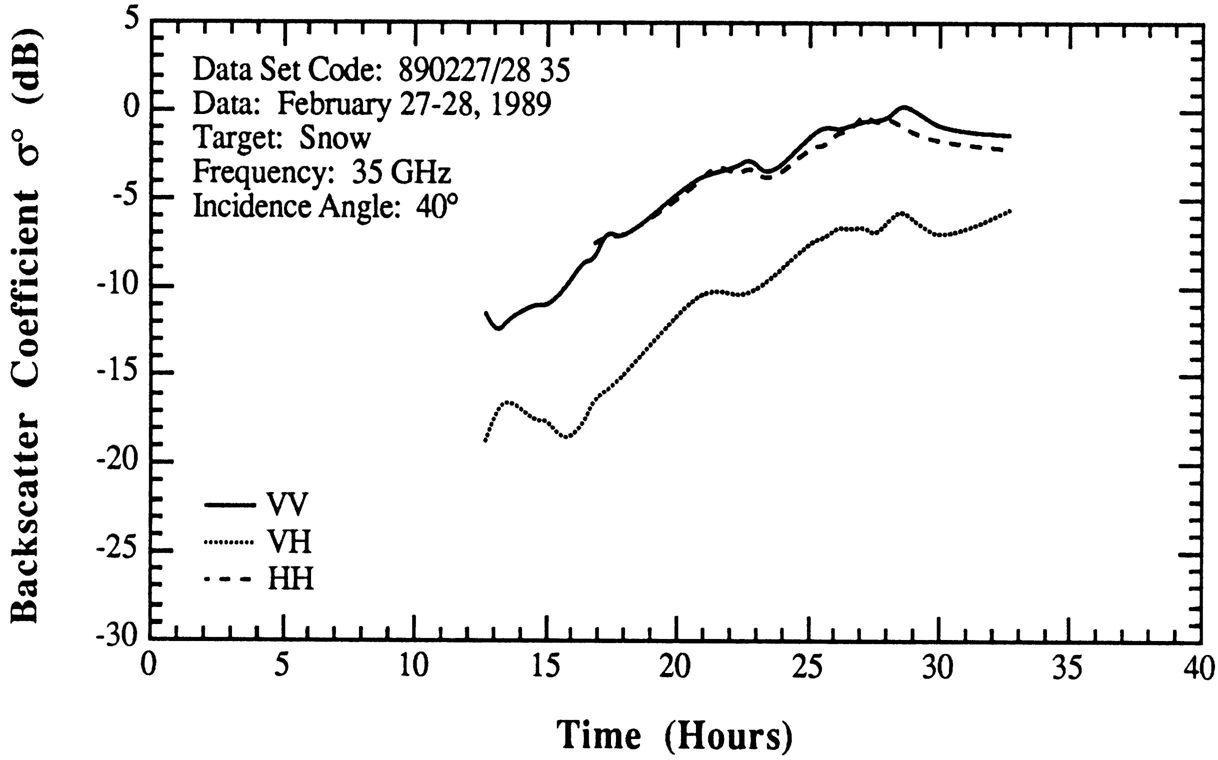
Liquid water content during snow diurnal at Brighton



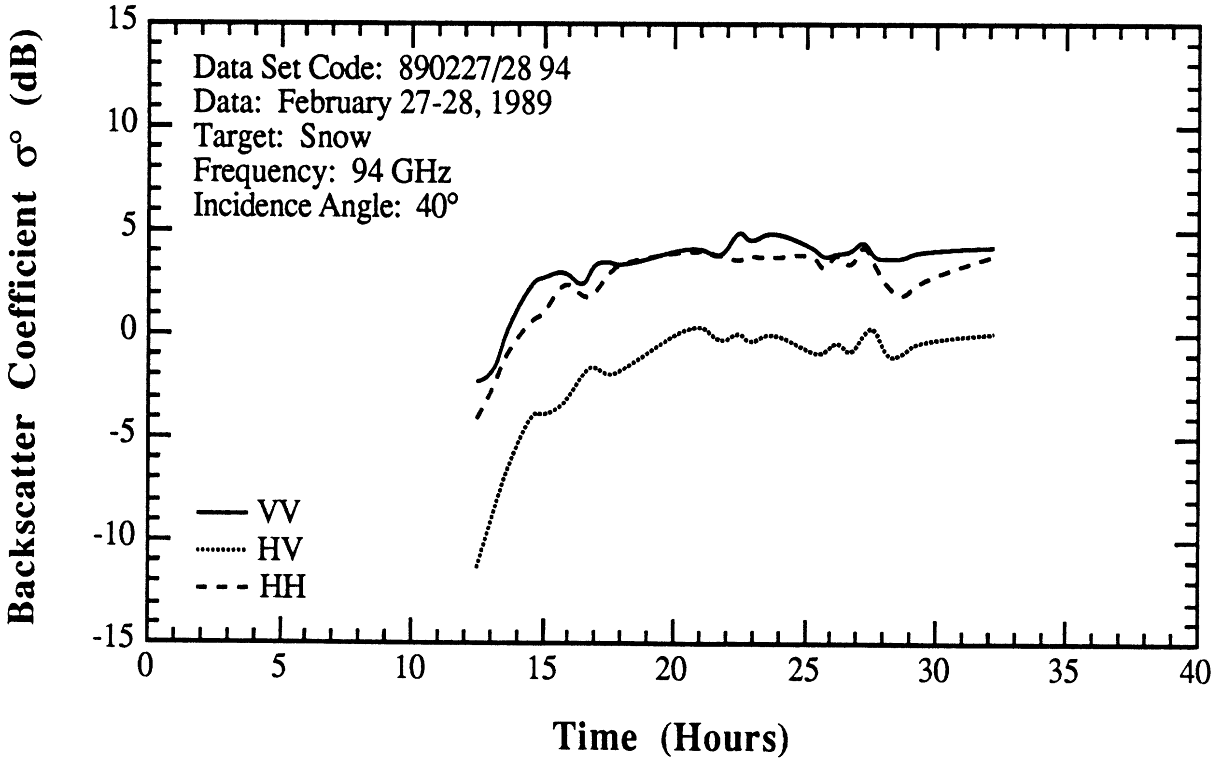
Surface roughness profile with1 cm grid

MMW DIURNAL DATA FOR SNOW

890227/28



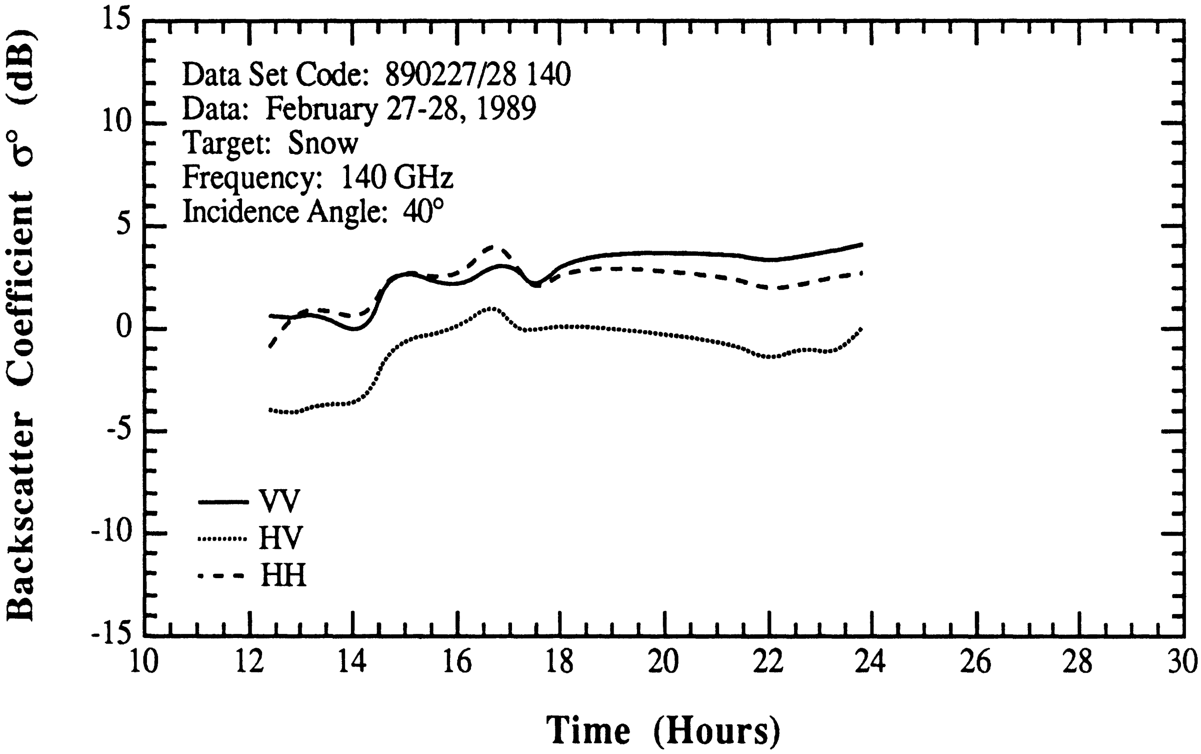
Snow diurnal at Brighton



Snow diurnal at Brighton

MMW DIURNAL DATA FOR SNOW

890227/28



Snow diurnal at Brighton

C. 2 March, 1989

Snow
Data Set code: 890302
Depth: 10 cm
LWC: 0%
Surface RMS height: 0.15 cm
Density: 0.1 to 0.2 gm/cm^3
Ice crystal diameter: 2 to 2.5 mm
Surface temperature: -4 C to -5 C
Description: partially metamorphosed snow

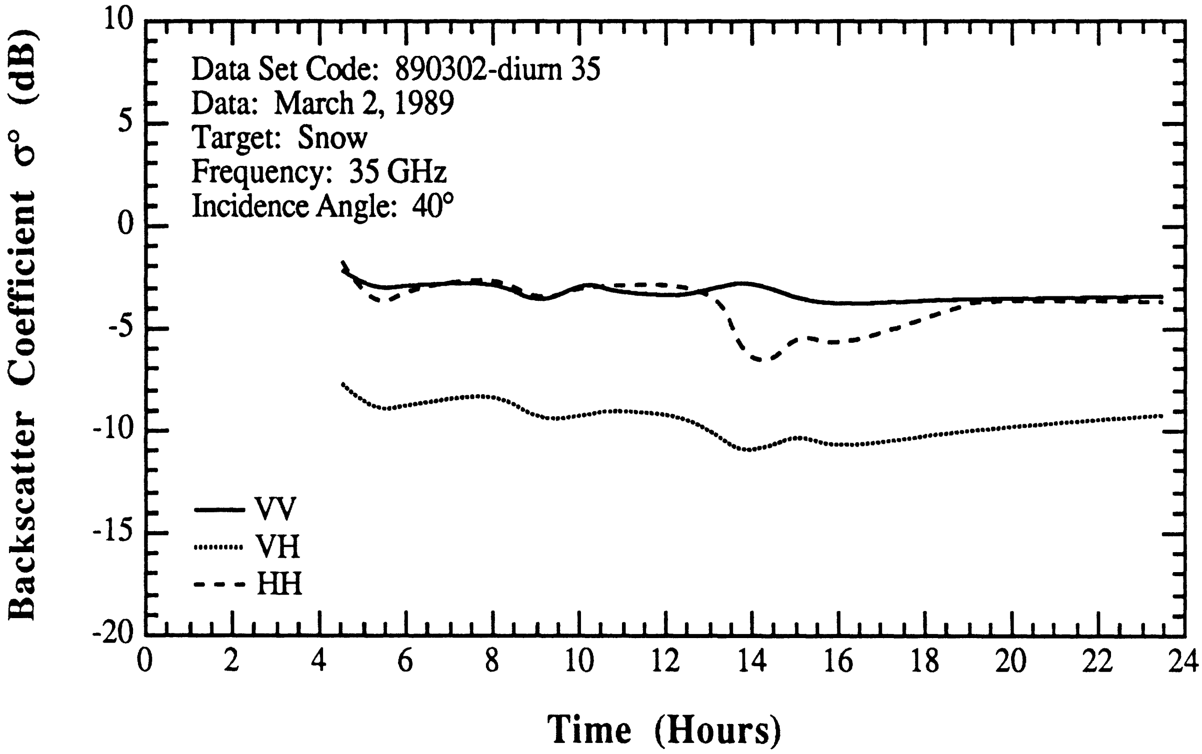
SNOW PIT TEMPERATURE PROFILE (°C)

Time / depth (cm)	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600
Top 10	-4.0	–5.0	-5.0	-5.0	-5.0	-4.0	-4.0	-3.0	-3.0	-2.0	-2.0	-2.0	-1.9
5	-7.0	-7.0	-6.0	-6.0	-6.0	-5.0	-4.0	-3.0	-3.0	-1.5	-1.0	-1.8	-1.7
1 bottom	-13.0	-11.0	-10.0	-10.0	-8.5	-6.0	-4.0	-1.0	-1.0	-0.5	-0.0	-1.5	-1.5
air temp	-15.0	-13.5	-13.0	-12.0	-10.0	-6.0	-5.0	-5.0	-5.0	-3.5	-4.0	-4.5	-5.0

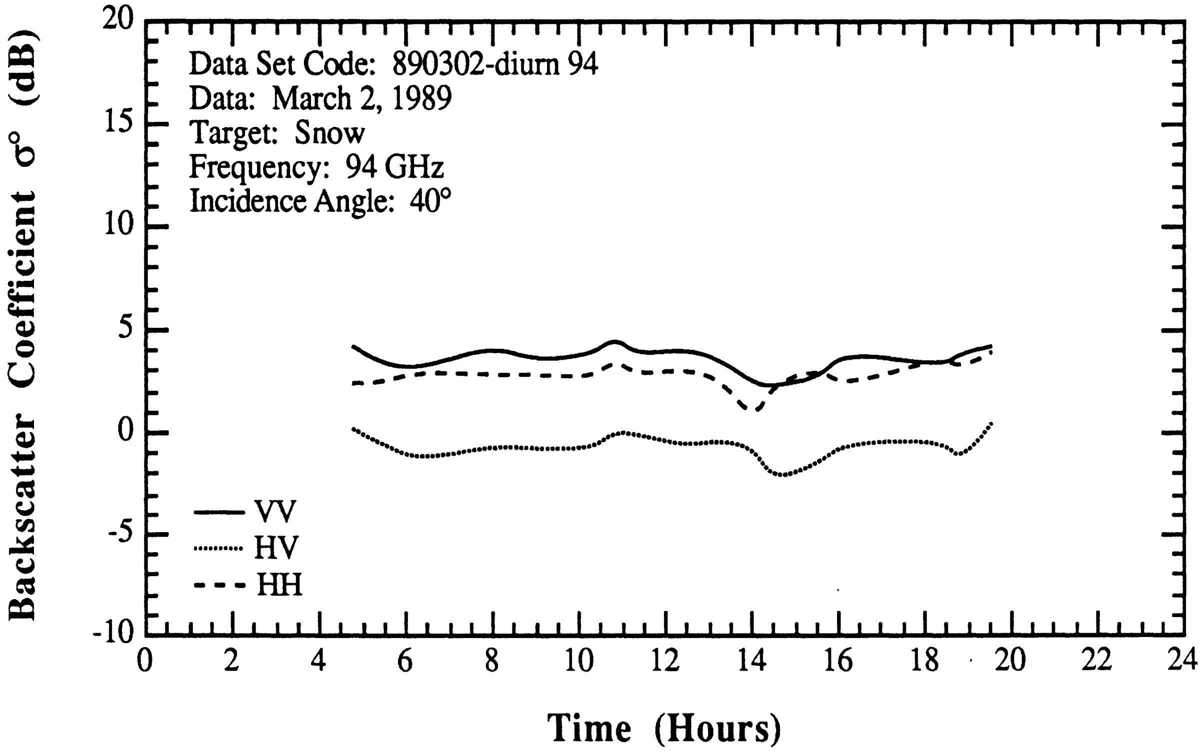
Time / depth (cm)	1700	1800	1900	2100	1400	1500	1600	1700	1800	1900	2100
Top 10	-2.8	-3.7	-4.0	-5.0	-2.0	-2.0	-1.9	-1.9	-3.7	-4.0	-5.0
5	-2.3	-2.7	-3.1	-3.5	-1.0	-1.8	-1.7	-1.7	-2.7	-3.1	-3.5
1 bottom	-1.8	-2.0	-2.2	-2.5	-0.0	-1.5	-1.5	-1.5	-2.0	-2.2	-2.5
air temp	-5.5	-6.0	-6.5	-7.5	-4.0	-4.5	-5.0	-5.0	-6.0	-6.5	-7.5

MMW DIURNAL DATA FOR SNOW

890302



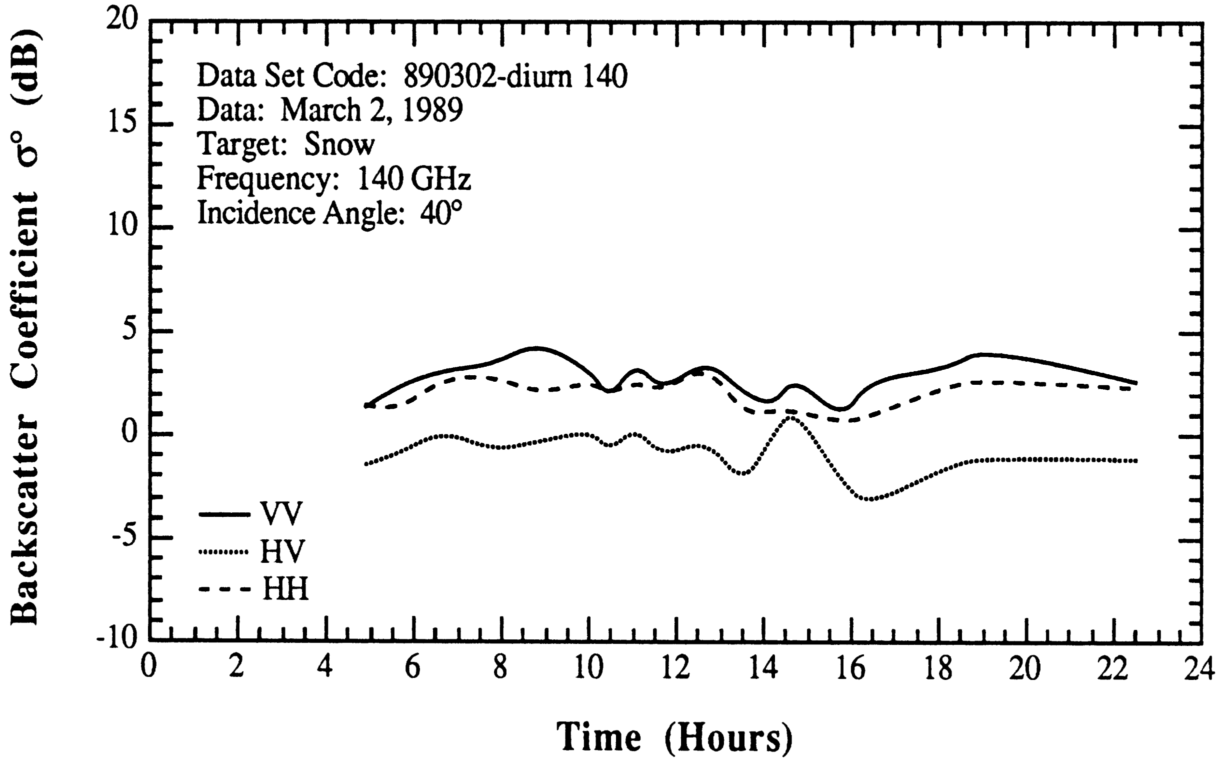
Snow diurnal at Brighton



Snow diurnal at Brighton

MMW DATA FOR SNOW

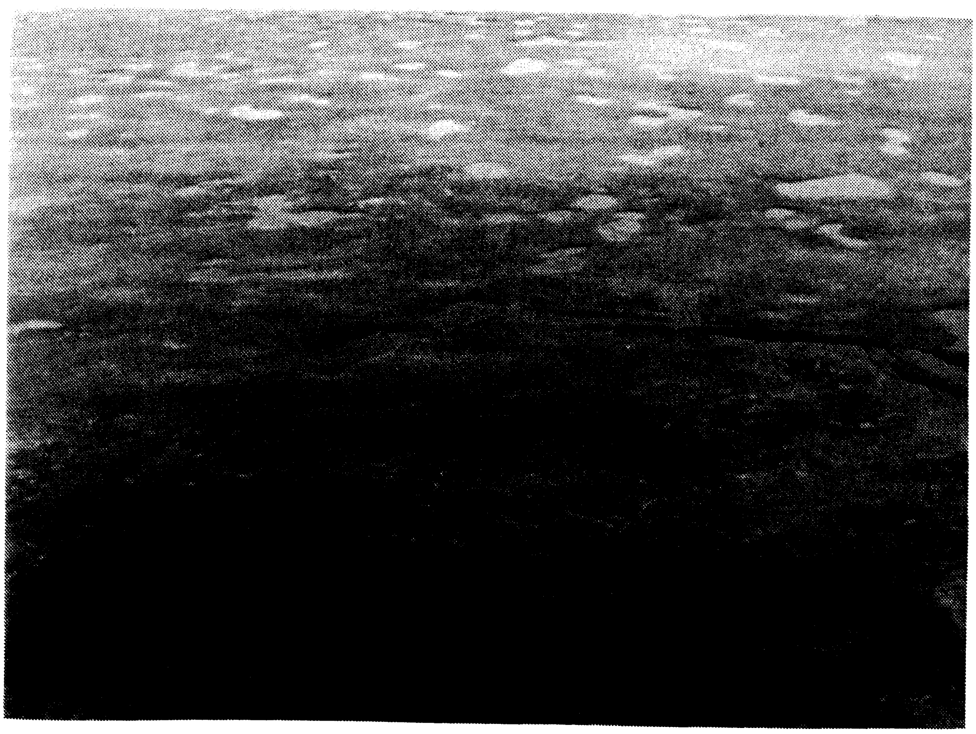
890302



Snow diurnal at Brighton

5. MMW DATA FOR ICE-COVERED GROUND

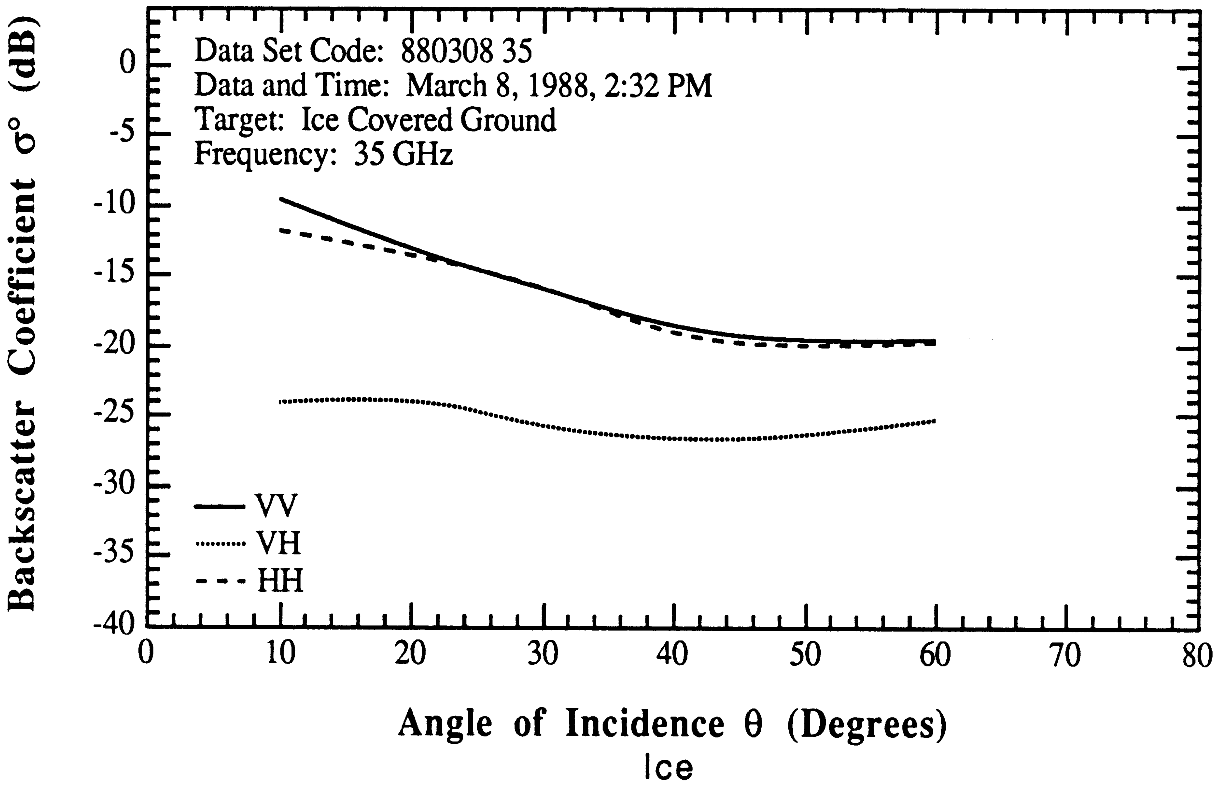
Data set code: 880308
Depth: 3 to10 cm
Surface RMS height: 1 mm
Surface temperature: 0 C
Description: ice formed by the freezing of sheet-flooded terrain, about 10% of the surface was covered by pools of water

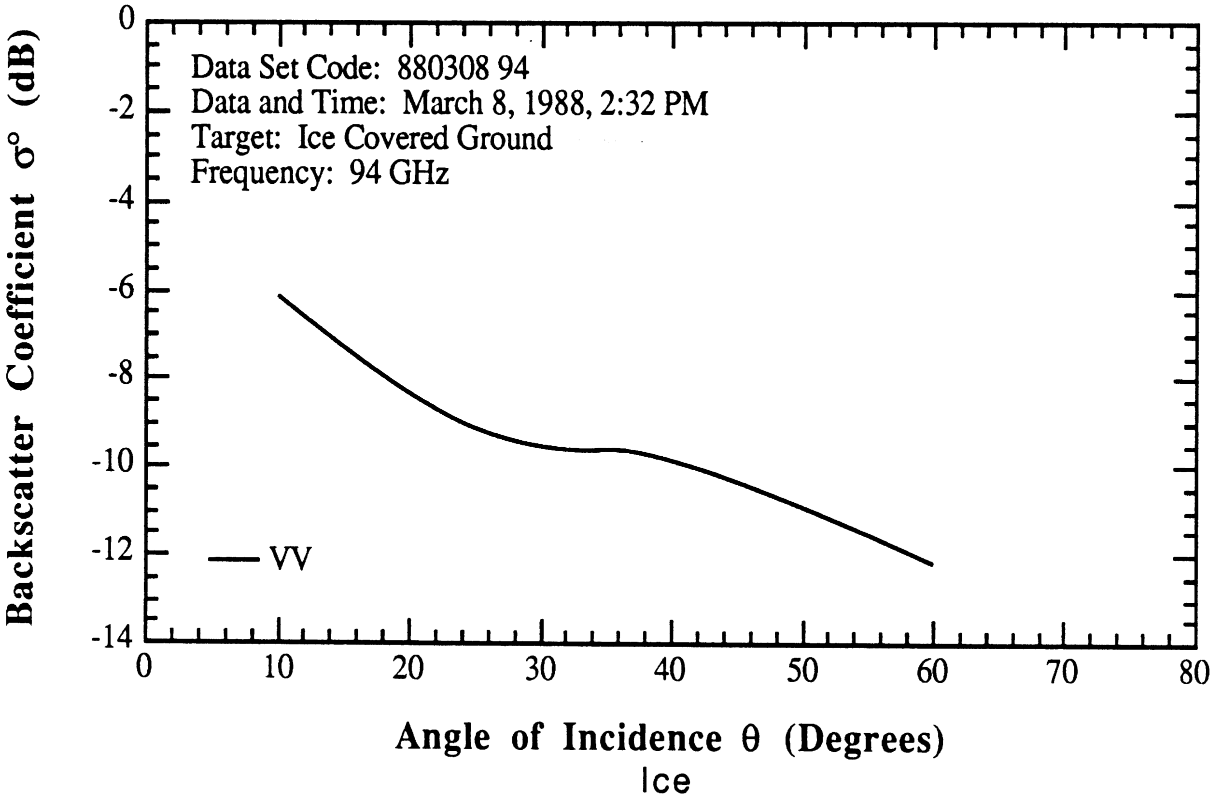


Ice covered ground

MMW DATA FOR ICE-COVERED GROUND

880308

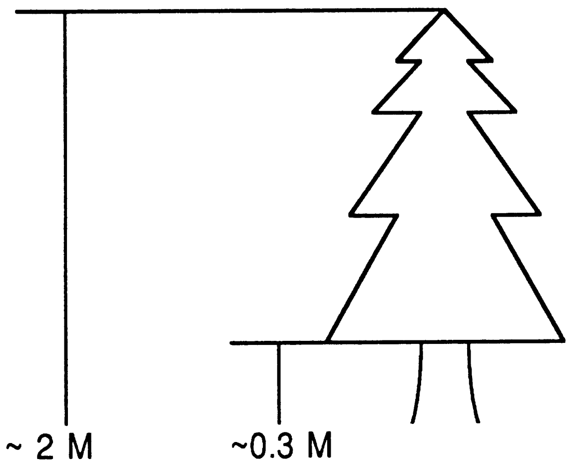




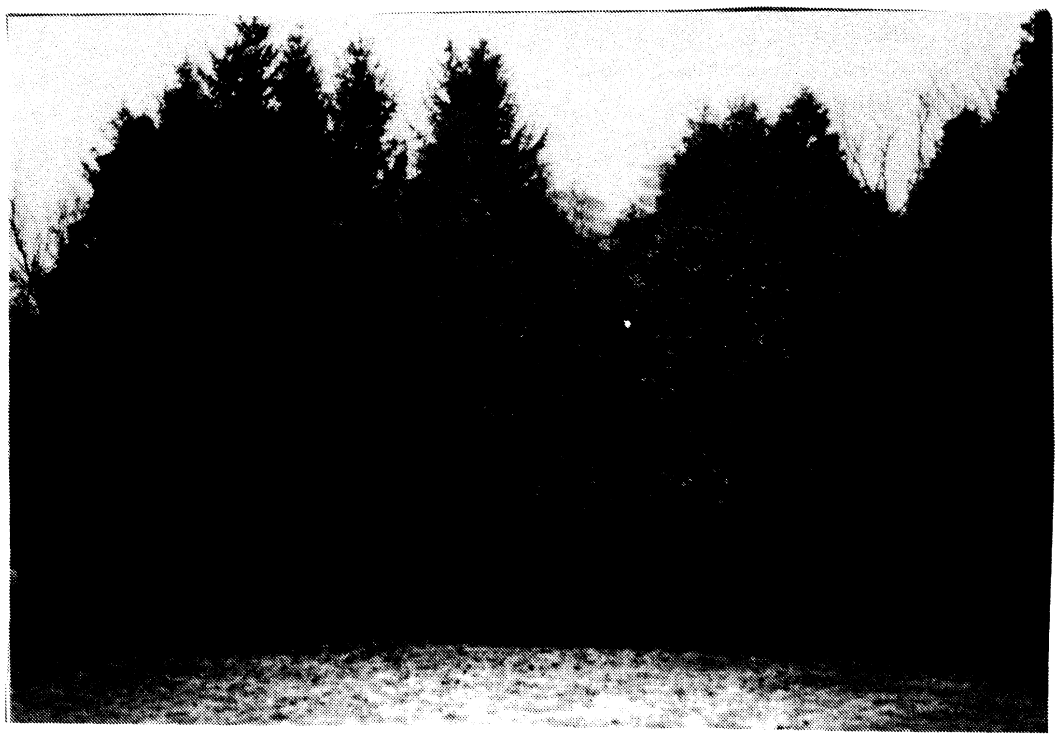
6. MMW DATA FOR TREE CANOPIES

A. Cedar Trees

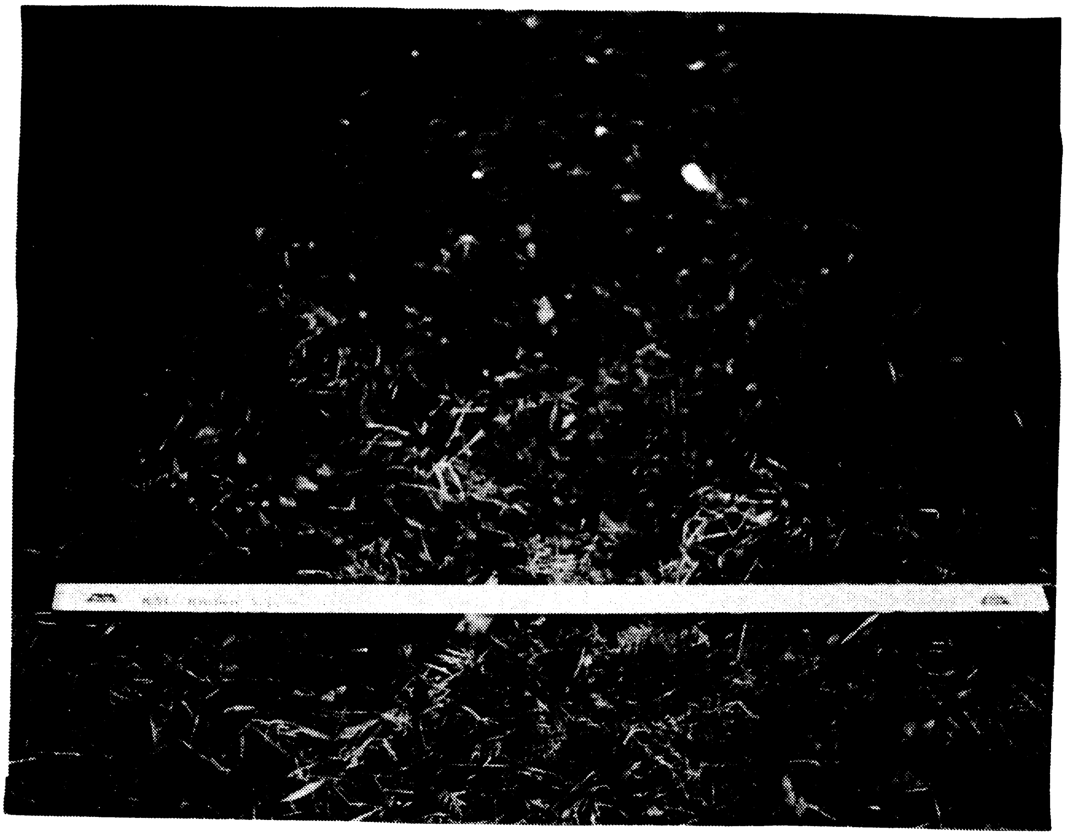
Cedar trees
Data set code: 871111
Tree density: 0.07 trees/m^2
Average leaf (or needle) dimensions: ~ 2 to 3 cm
Leaf moisture content: ~ 70 %
Ground cover moisture content: ~ 35 %
Percent vegetation cover: 90 %
Percent cover of undergrowth: 100%
Moisture content of undergrowth: 35%
Description: Stand of mature oak trees over low ground cover



871111



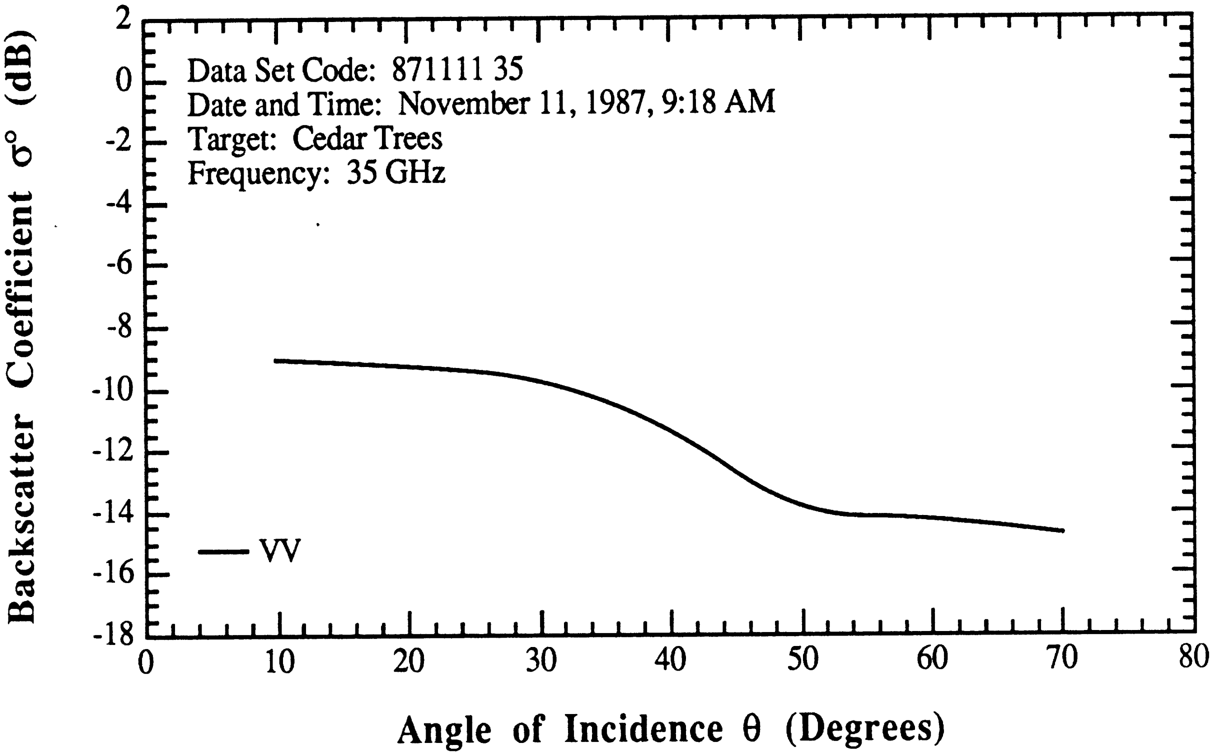
Needles of Cedar trees



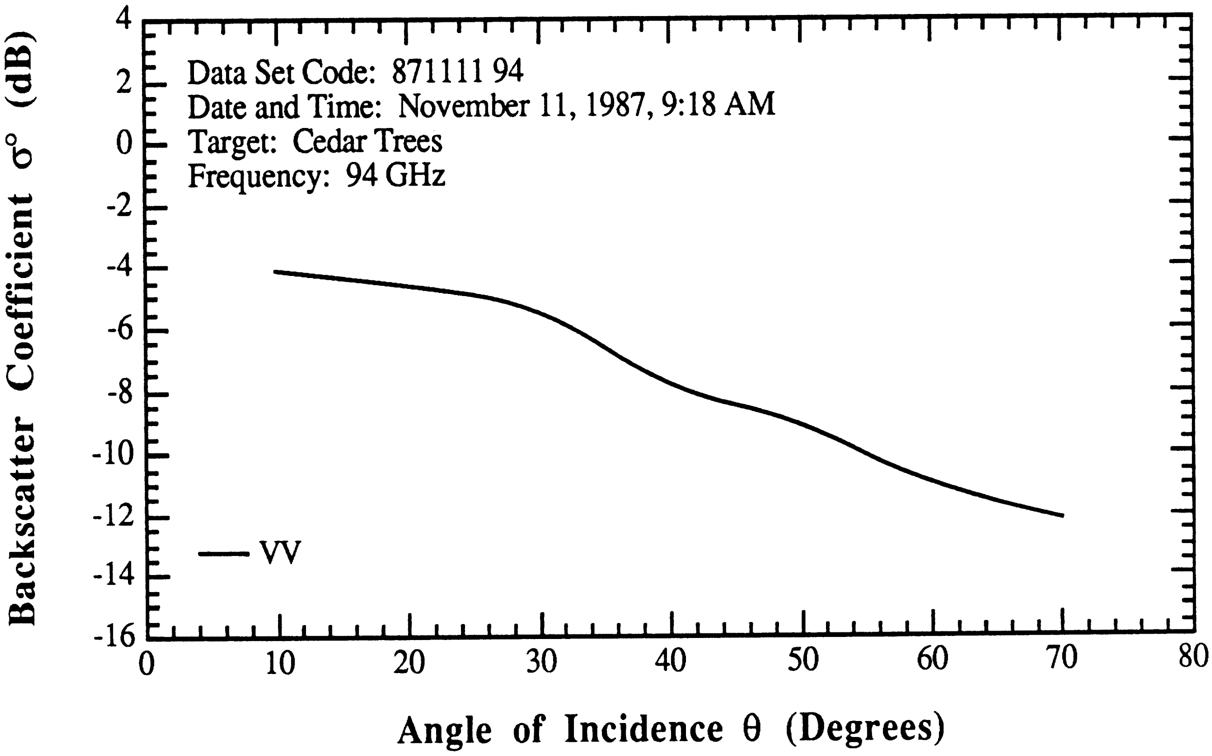
Ground cover beneath Cedar trees

MMW DATA FOR TREE CANOPIES

871111



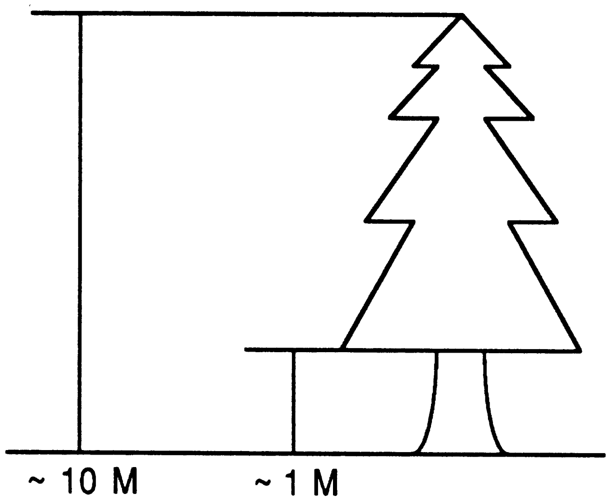
Cedars at Arboretum



Cedars at Arboretum

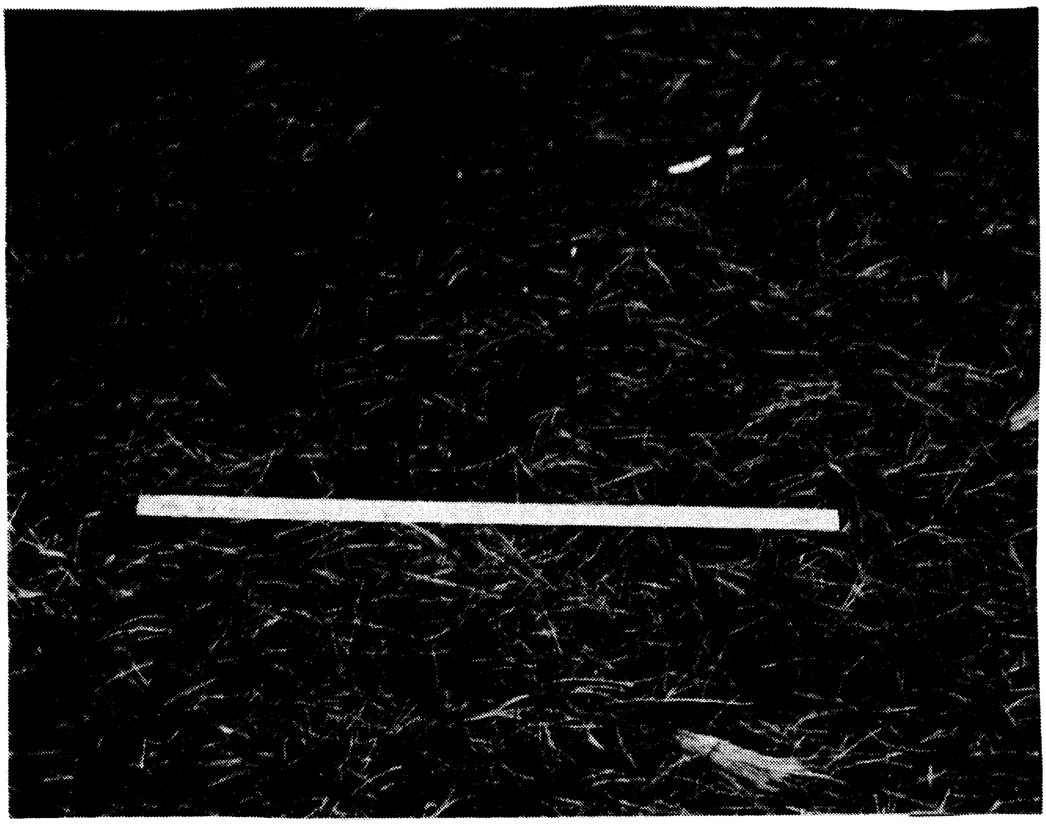
B. Red Pine

5 -11 November, 1987
Data set code: 871105
Tree density: 0.14 trees/m^2
Average leaf (or needle) dimensions: 10 to 15 cm
Leaf moisture content: ~70 %
Percent vegetation cover: 90 %
Percent cover of undergrowth: 100%
Moisture content of undergrowth: 35%
Description: Stand of mature red pines over dry, fallen needles



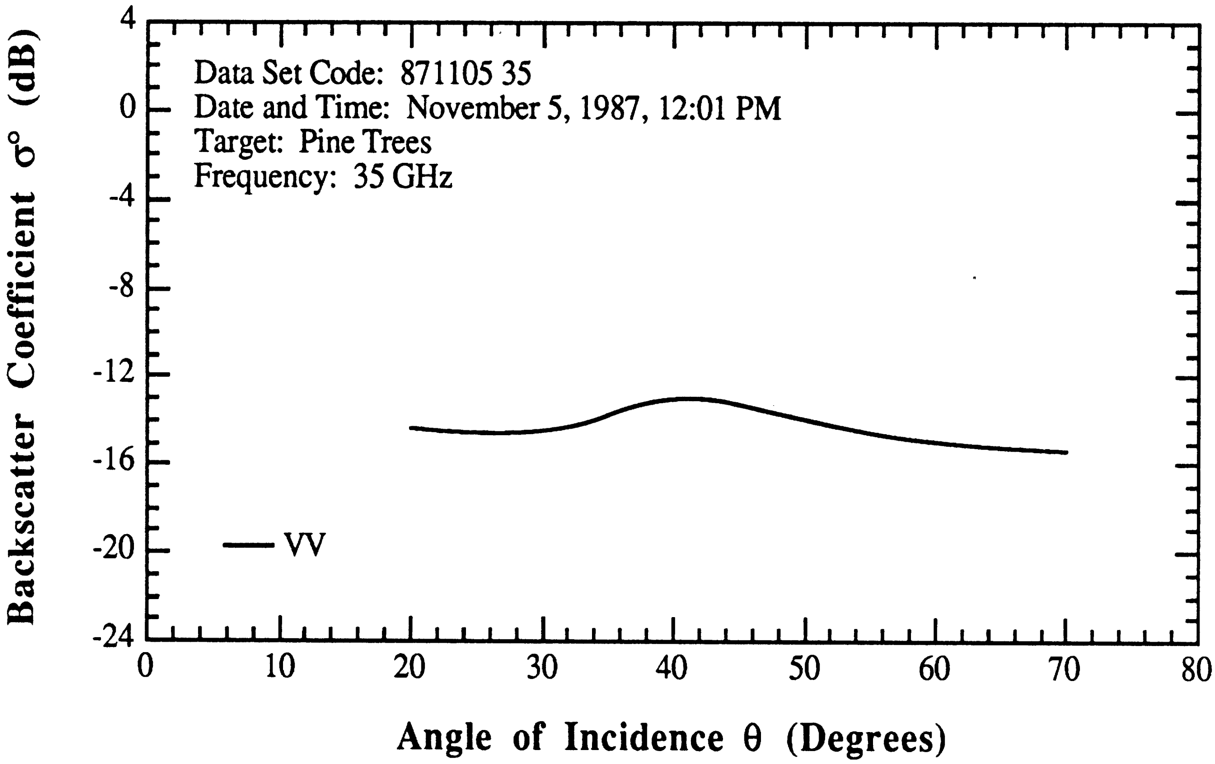
Red pines

Needles of Red Pines



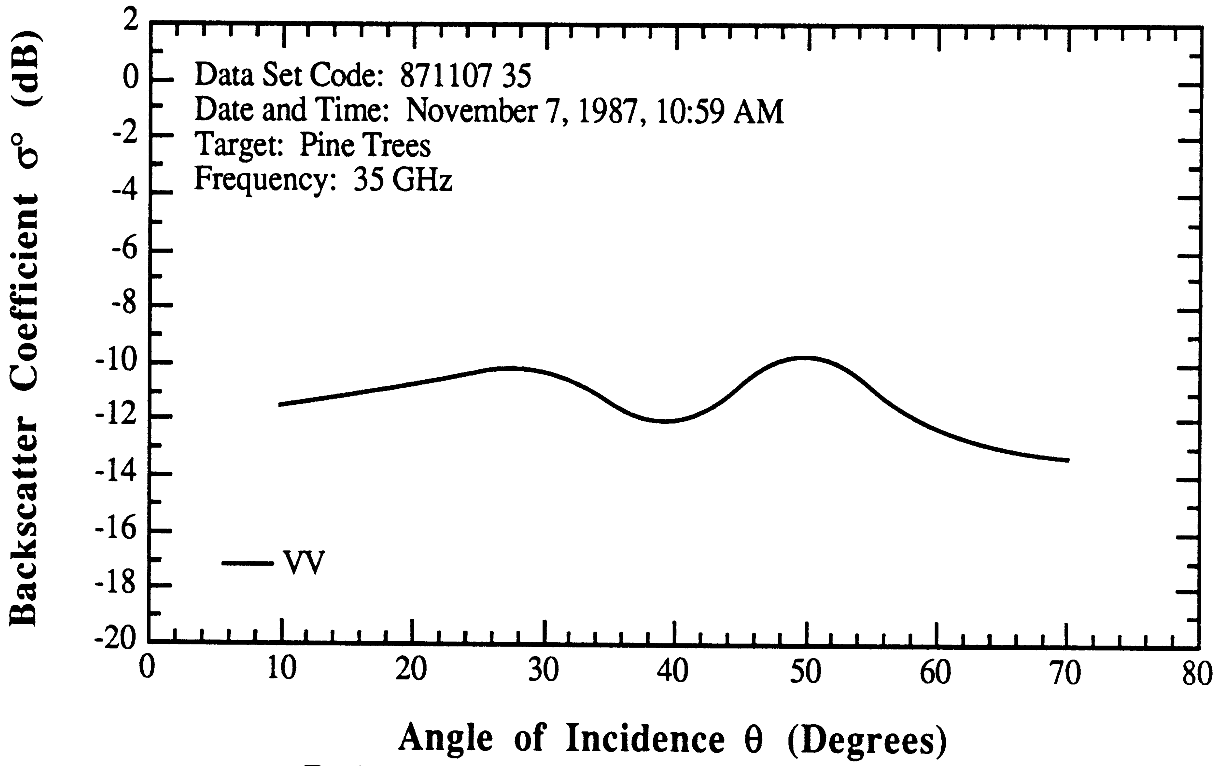
Ground cover beneath Red Pines

871105



Red Pines at Arboretum (5 November, 1987)

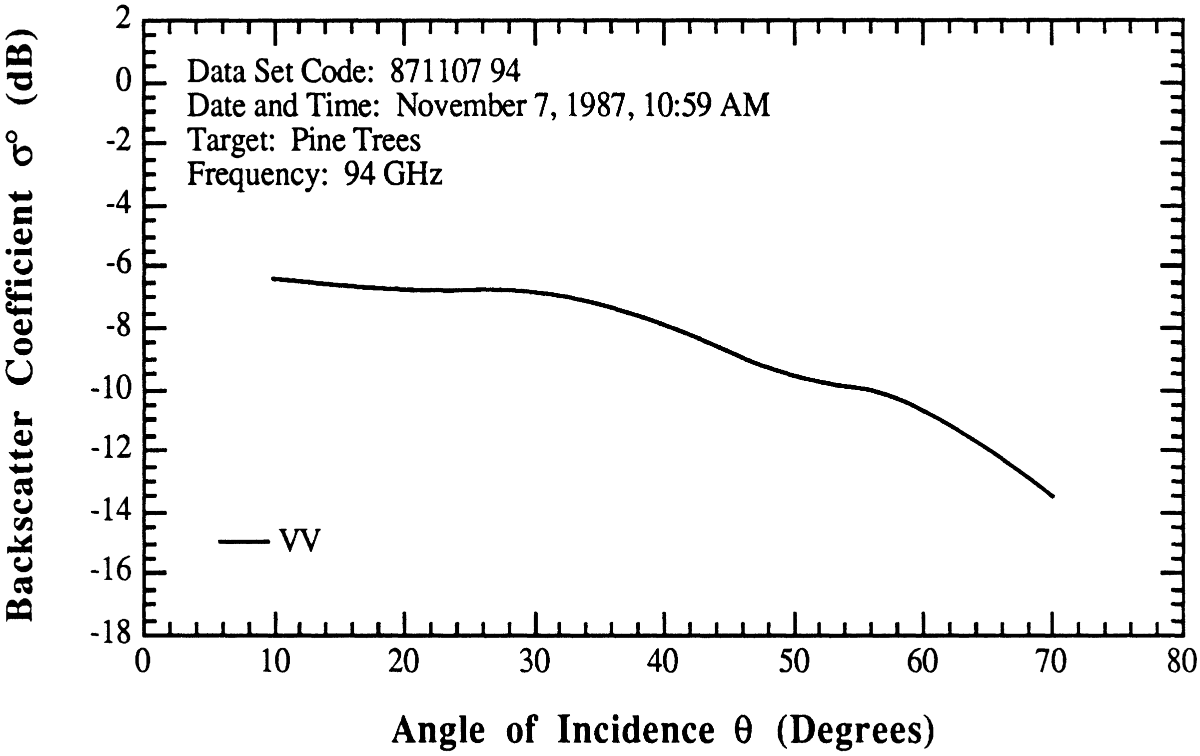
871107



Red Pines at Arboretum (7 November, 1987)

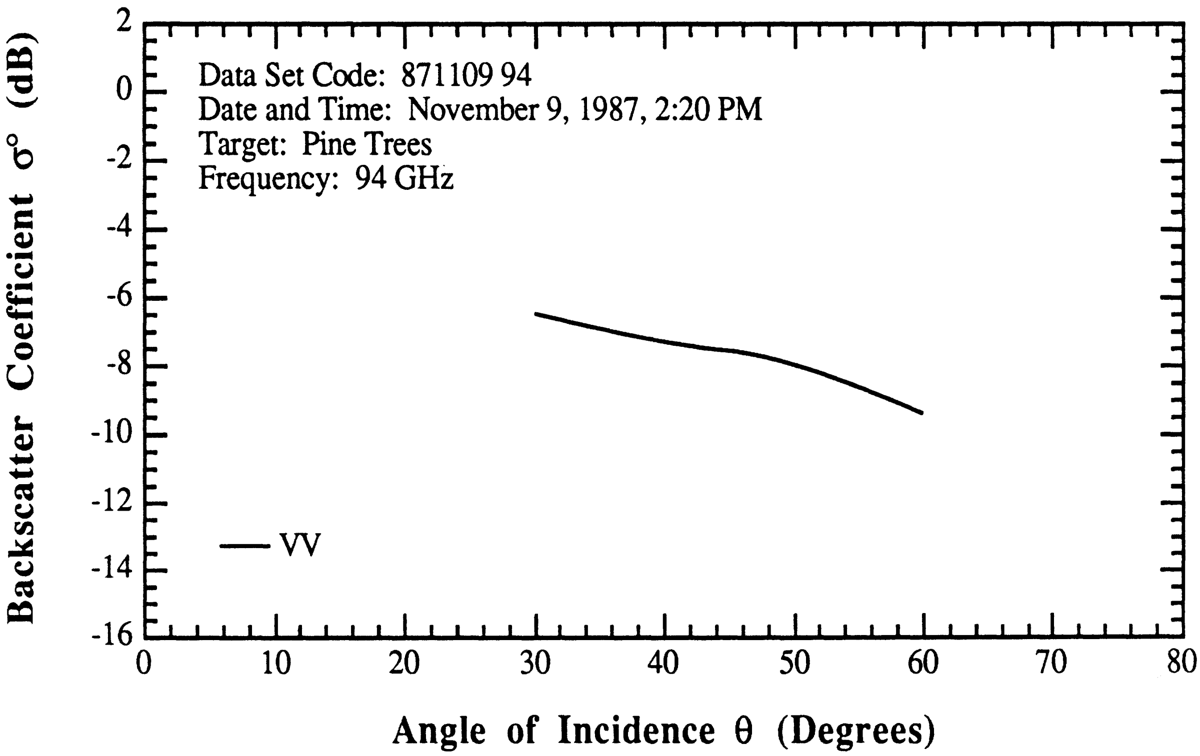
MMW DATA FOR TREE CANOPIES

871107



Red Pines at Arboretum (7 November, 1987)

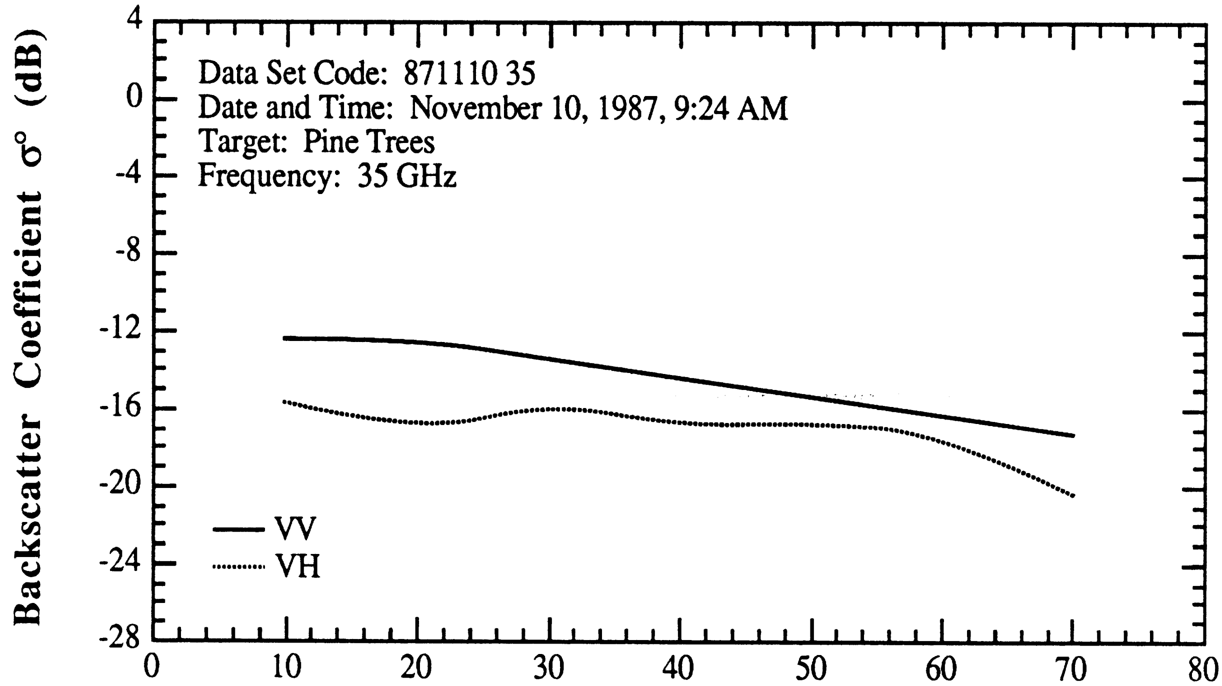
871109



Red Pines at Arboretum (9 November, 1987)

MMW DATA FOR TREE CANOPIES

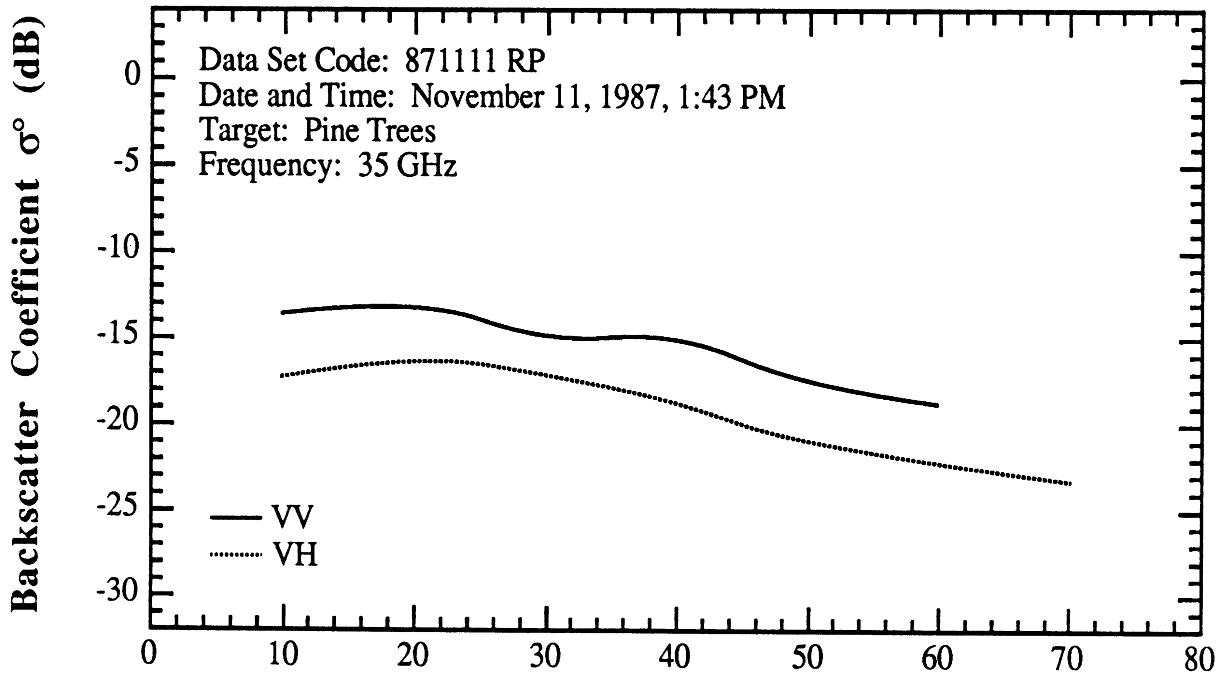
8-71110



Angle of Incidence θ (Degrees)

Red Pines at Arboretum (10 November, 1987)

871111

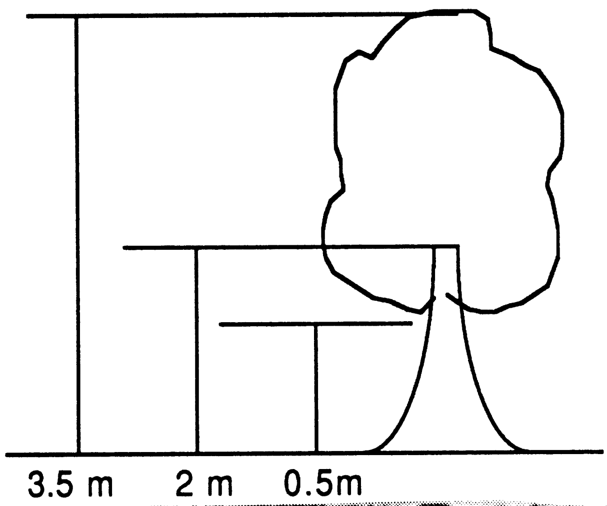


Angle of Incidence θ (Degrees)

Red Pines at Arboretum (11 November, 1987)

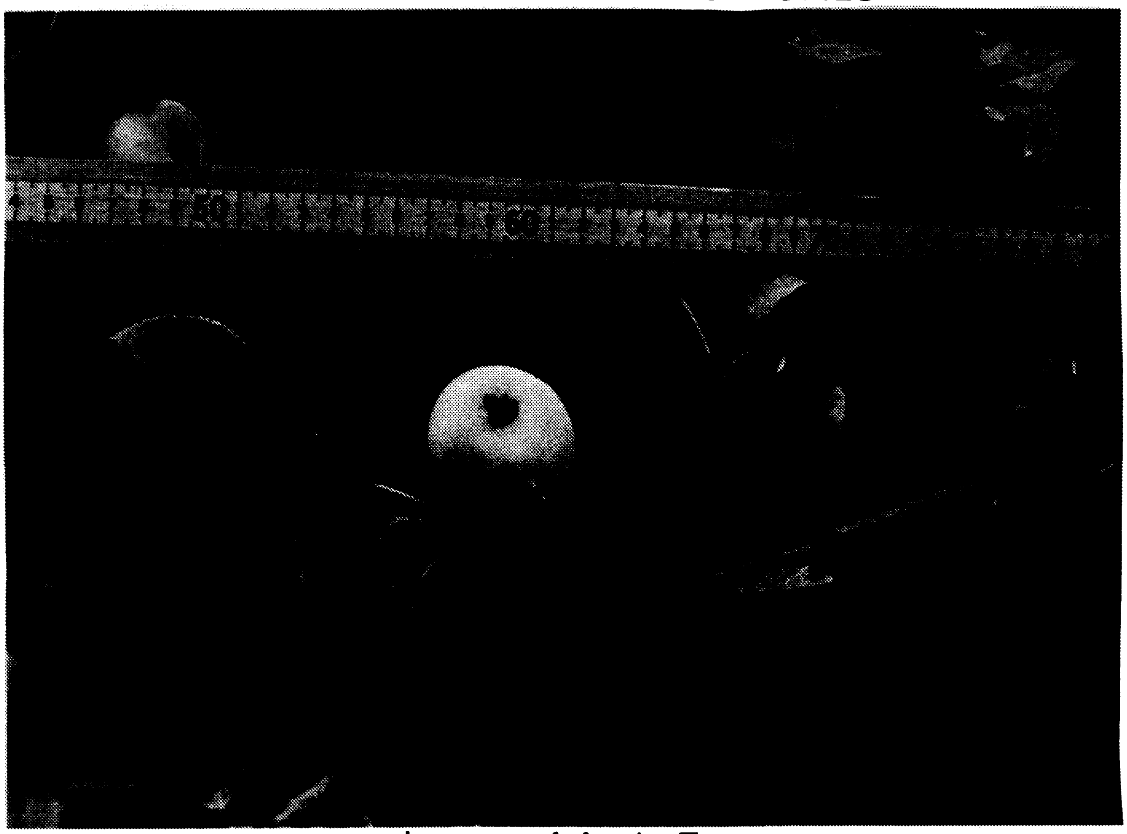
C. Apple Trees

Data set code: 880811
Tree density: 0.1 trees/m^2
Average leaf (or needle) dimensions: 4 by 8 cm
Leaf moisture content: ~80 %
Percent vegetation cover: 90%
Percent cover of undergrowth: 100%
Moisture content of undergrowth: 80%



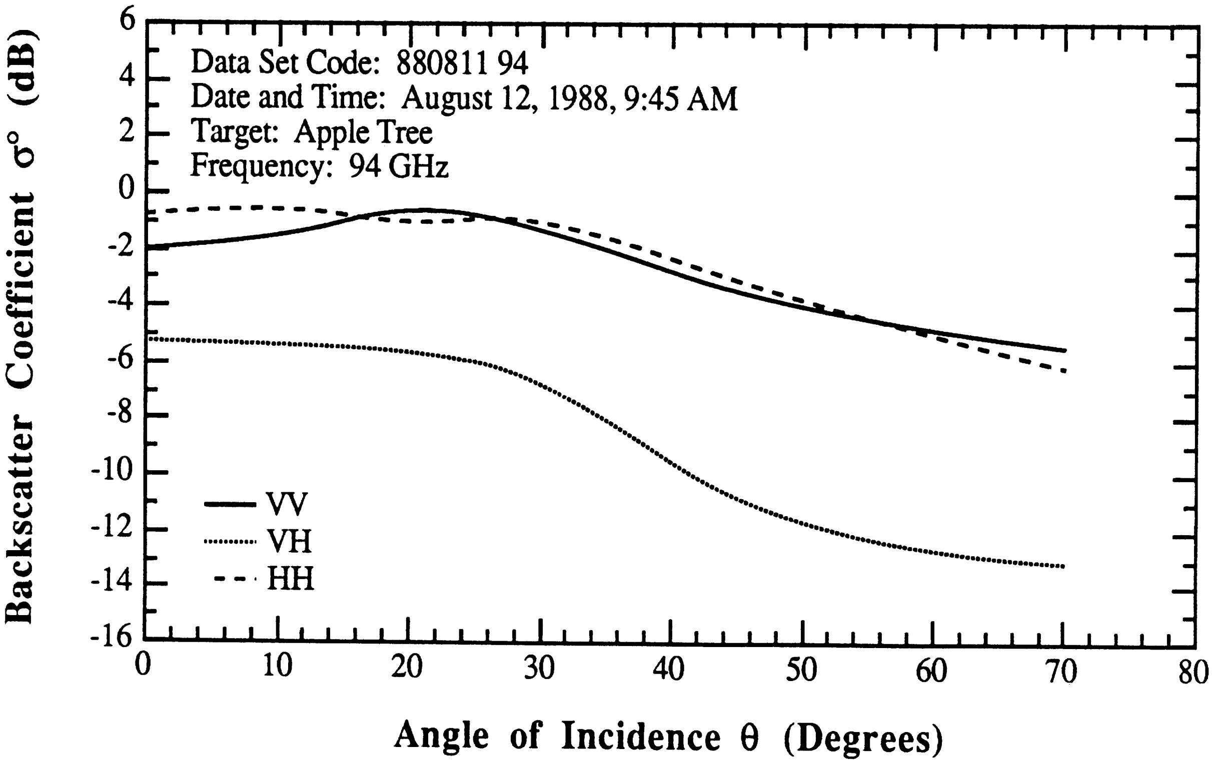
Apple tree

MMW DATA FOR TREE CANOPIES



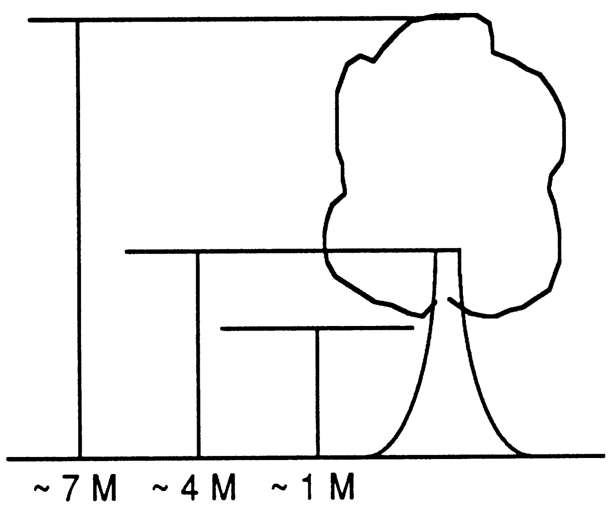
Leaves of Apple Tree

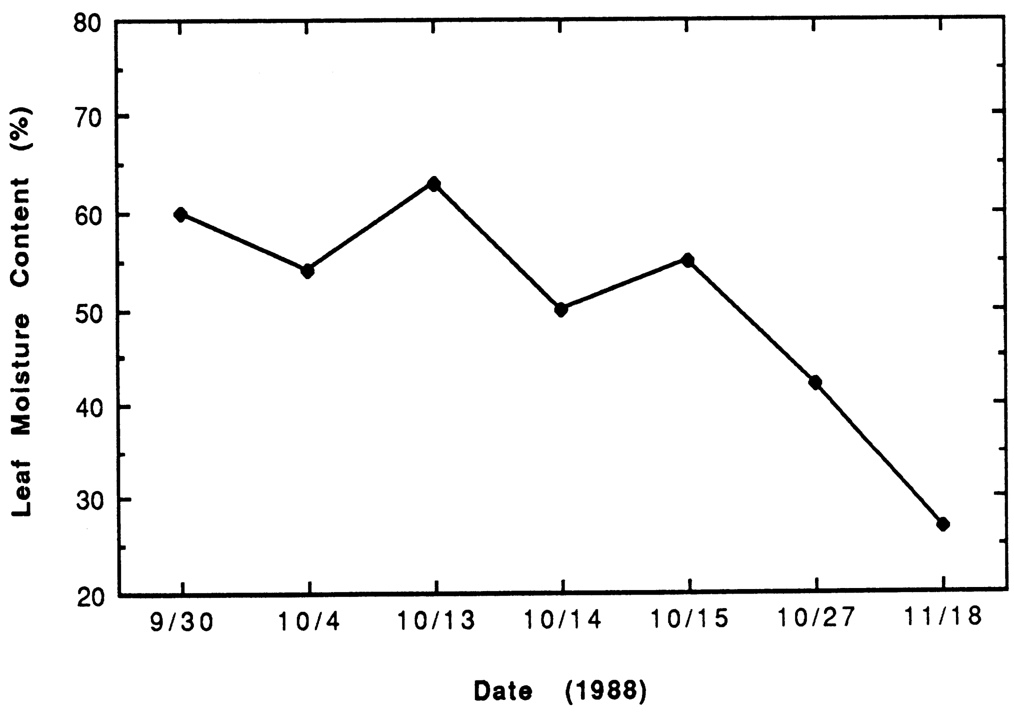
880811



D. Bur Oak

Bur Oak (Quercus macrocarpa)
Data set code: 880930-1027
Tree density: 0.09 trees/m^2
Average leaf (or needle) dimensions: 8 by 12 cm
Moisture content of undergrowth: ~ 70%
Percent cover of undergrowth: 100%
Percent vegetationcover: 95%
Description: Stand of mature oak trees over low ground cover

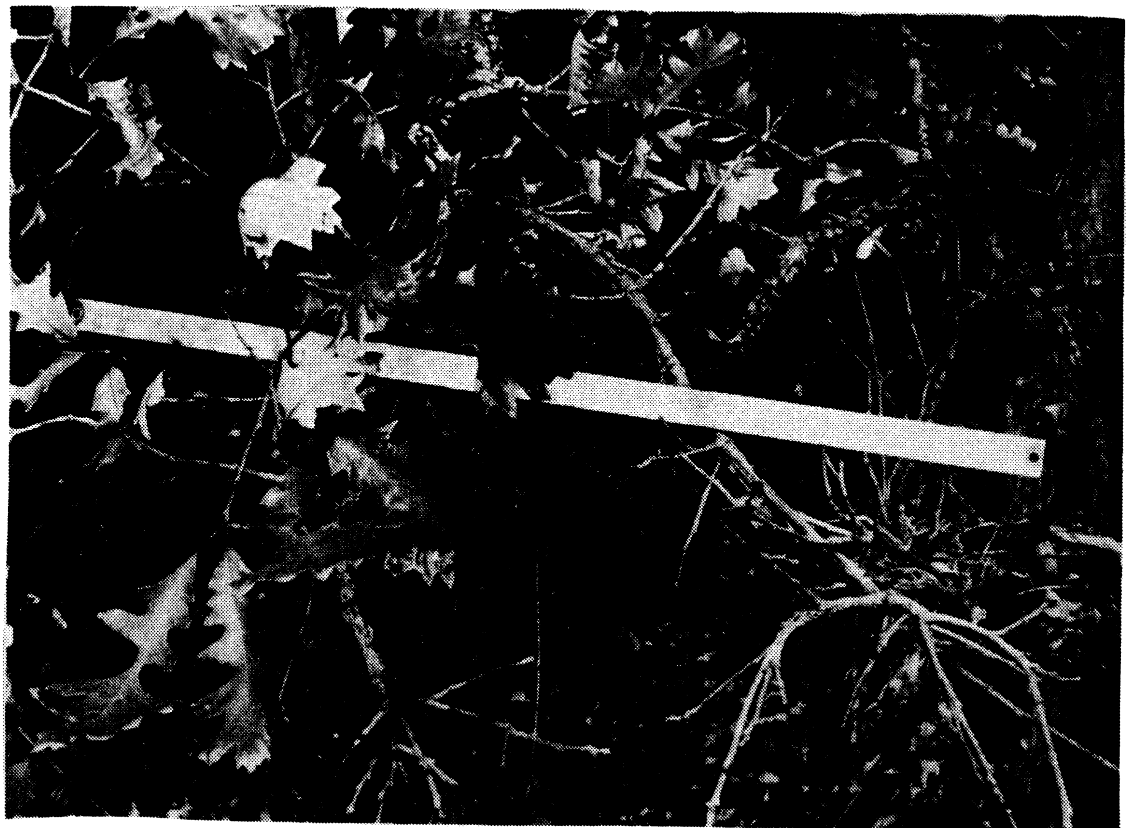




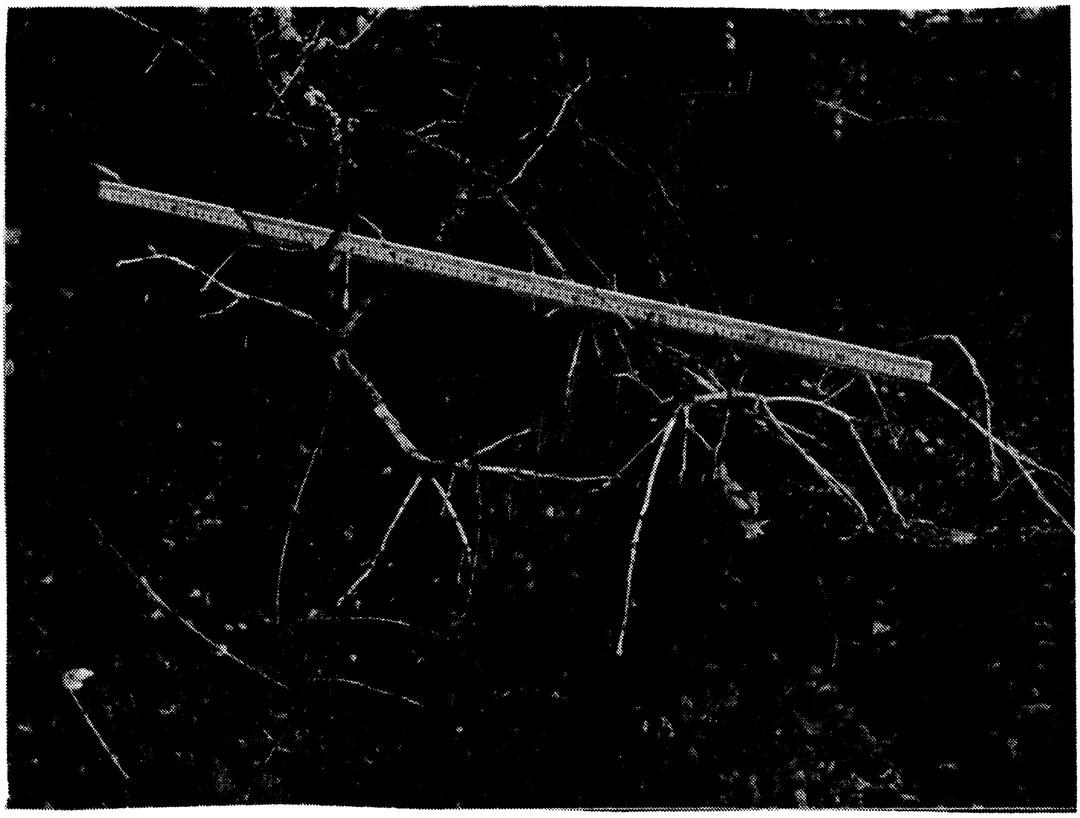
MISSING
PAGE

MISSING
PAGE

Bur oaks at Botanical Gardens -- 881015



Leaves of Bur oaks at Botanical Gardens -- 881015

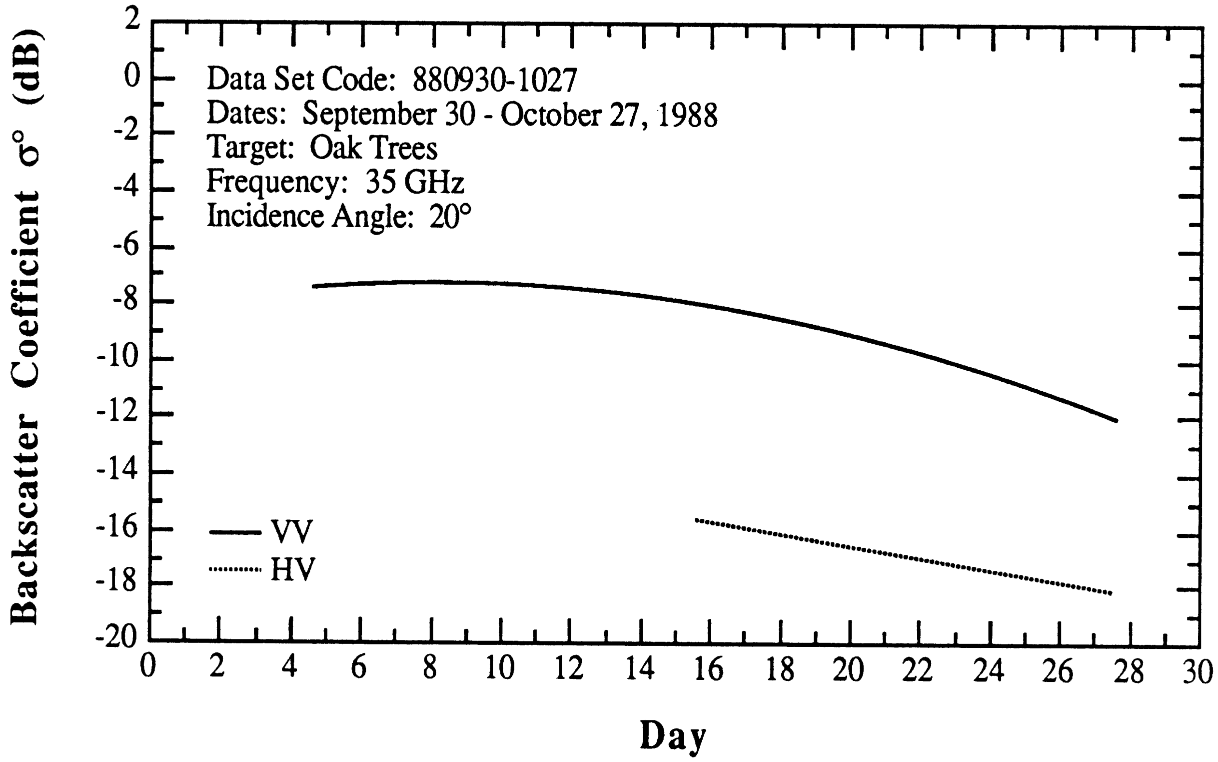


Leaves of Bur oaks at Botanical Gardens -- 881027

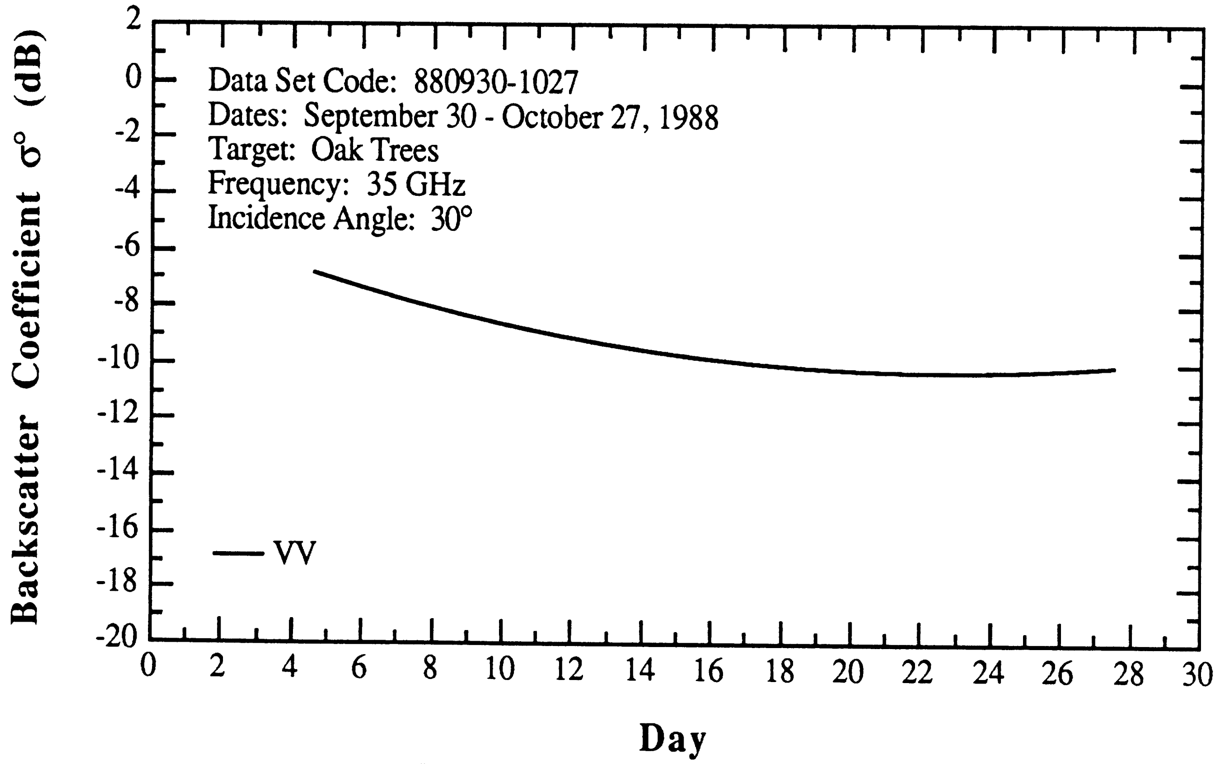
Ground cover beneath Bur oaks at Botanical Gardens -- 881027

MMW DATA FOR TREE CANOPIES

880930-1027



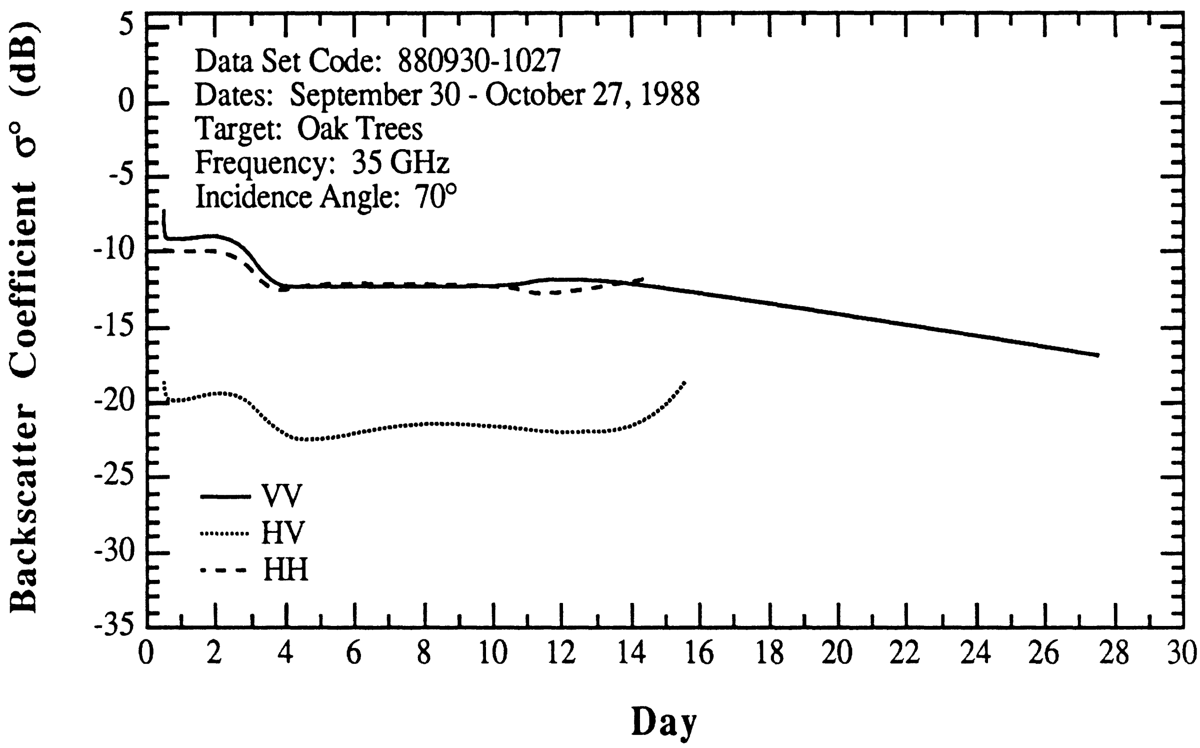
Bur Oaks (Quercus Macrocarpa)



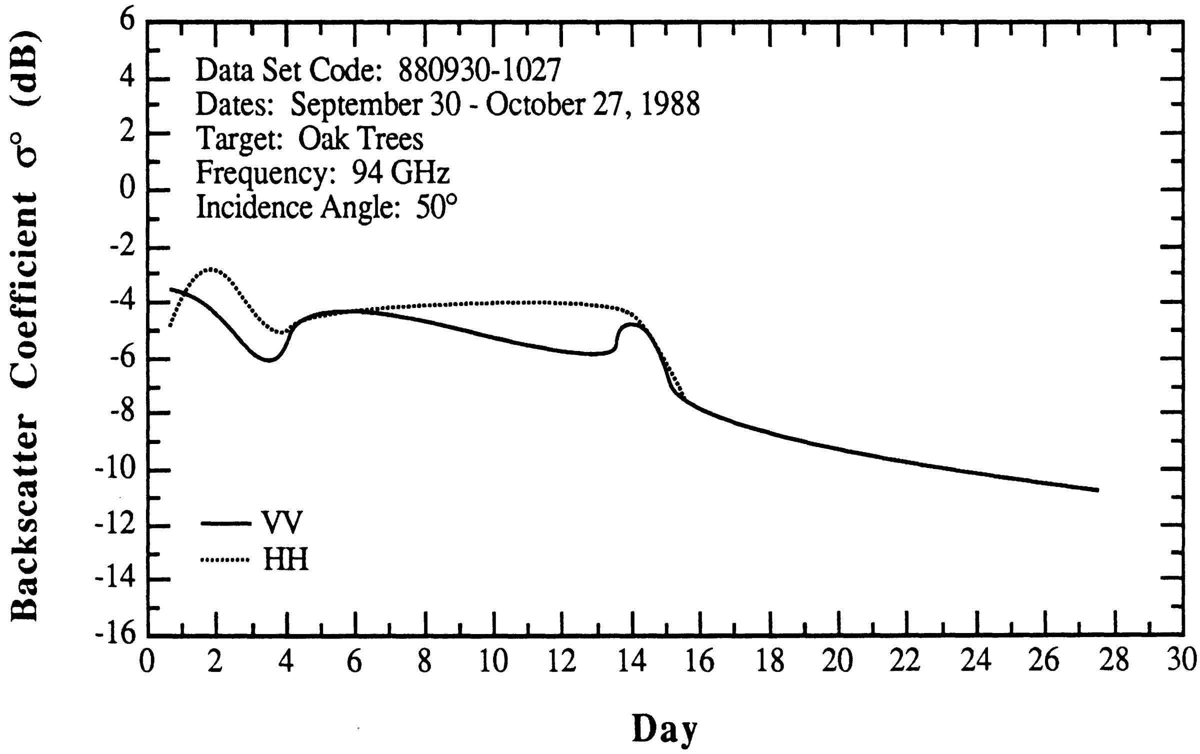
Bur Oaks (Quercus Macrocarpa)

MMW DATA FOR TREE CANOPIES

880930-1027



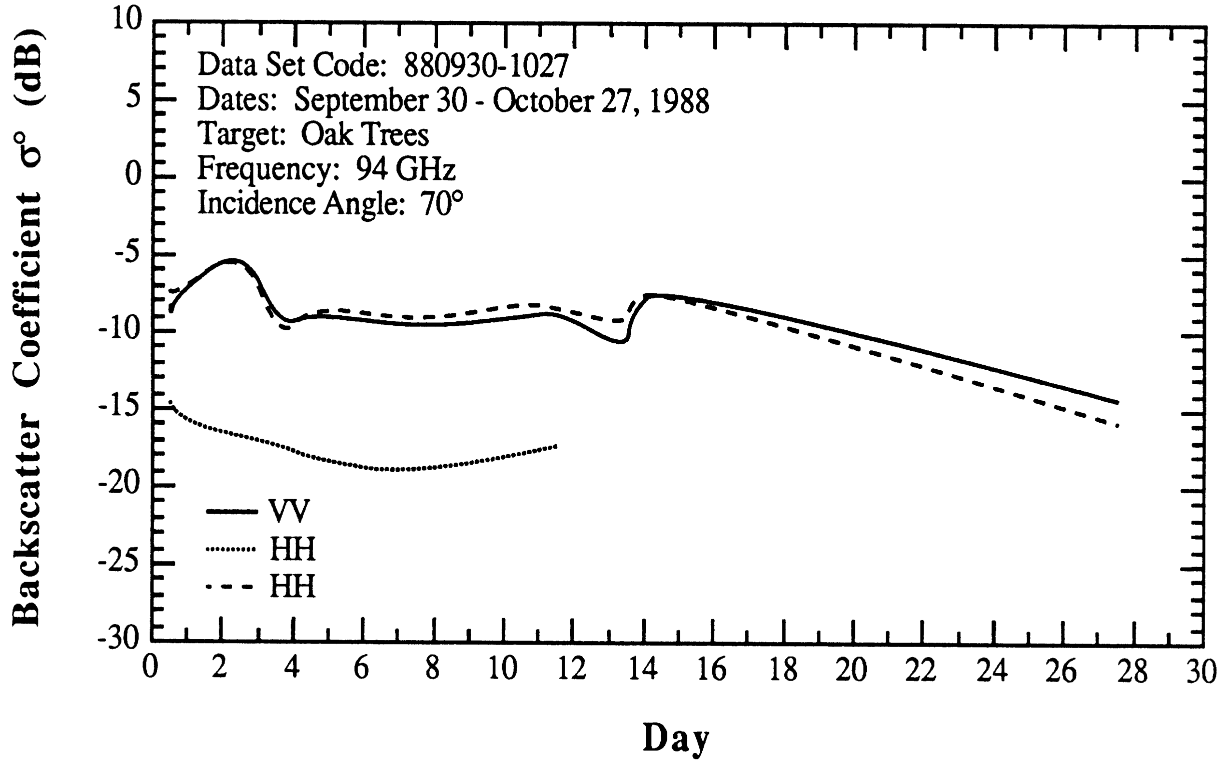
Bur Oaks (Quercus Macrocarpa)



Bur Oaks (Quercus Macrocarpa)

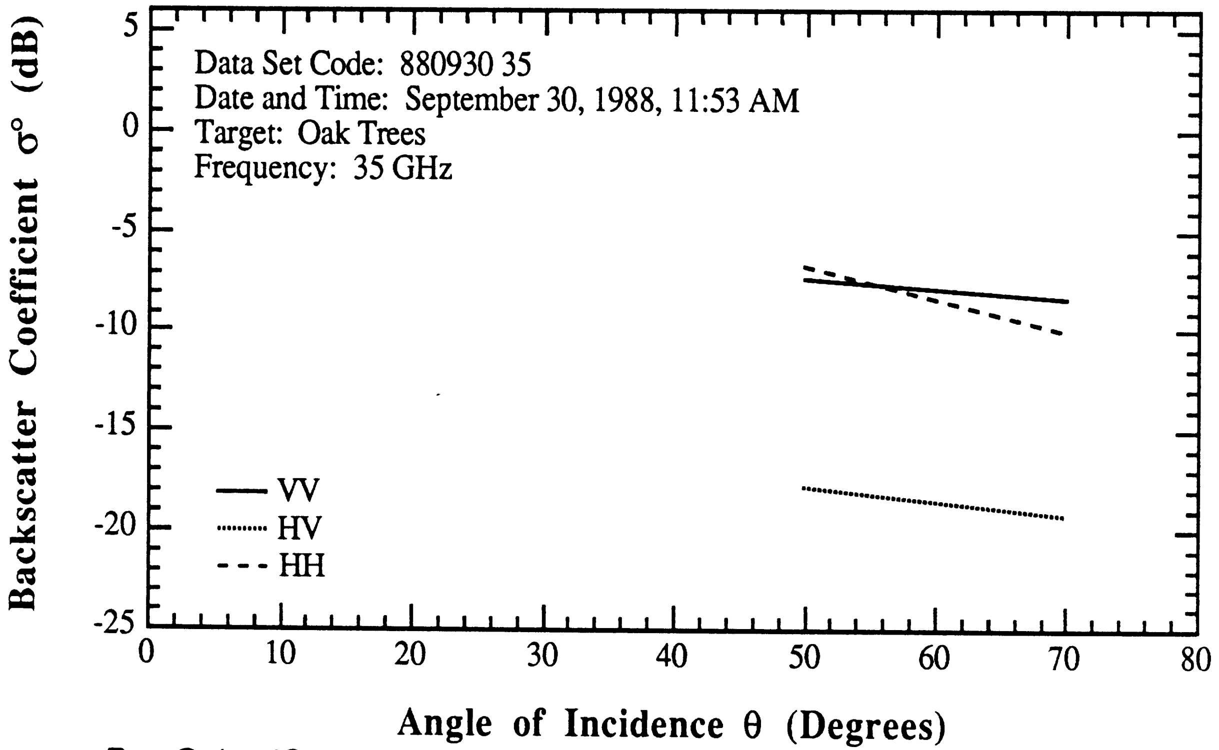
MMW WAVE DATA FOR TREE CANOPIES

880930-1027



Bur Oaks (Quercus Macrocarpa)

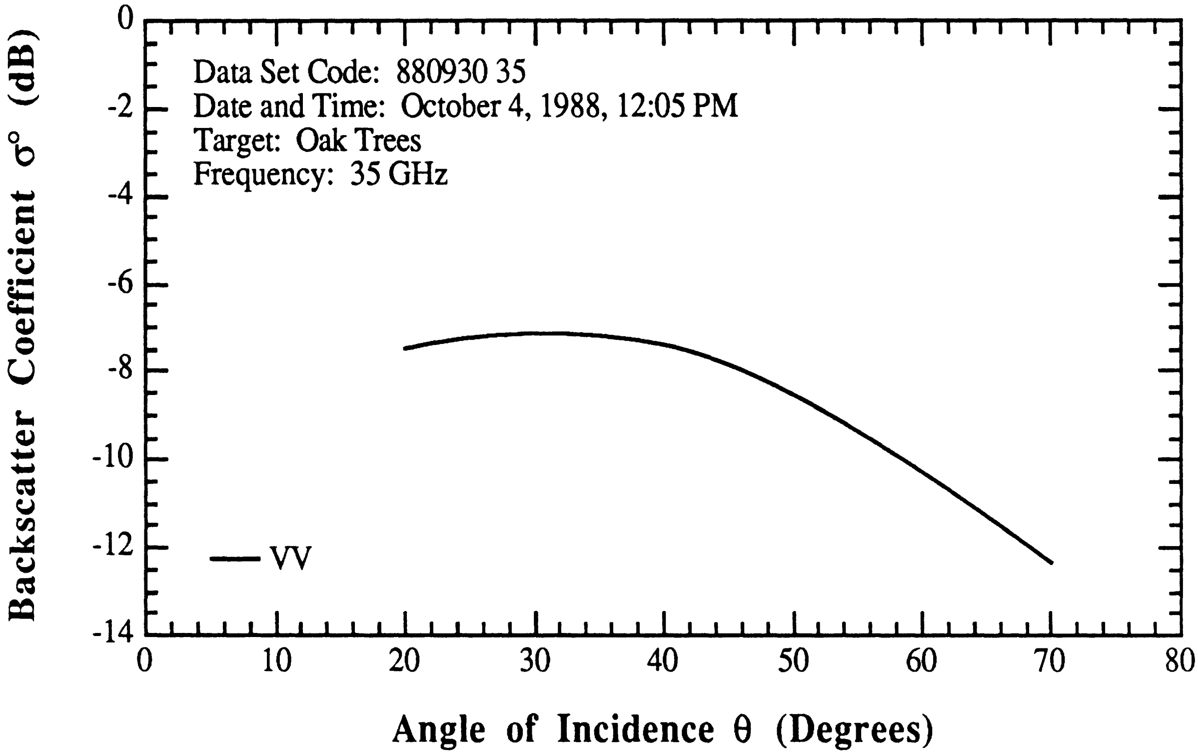
880930



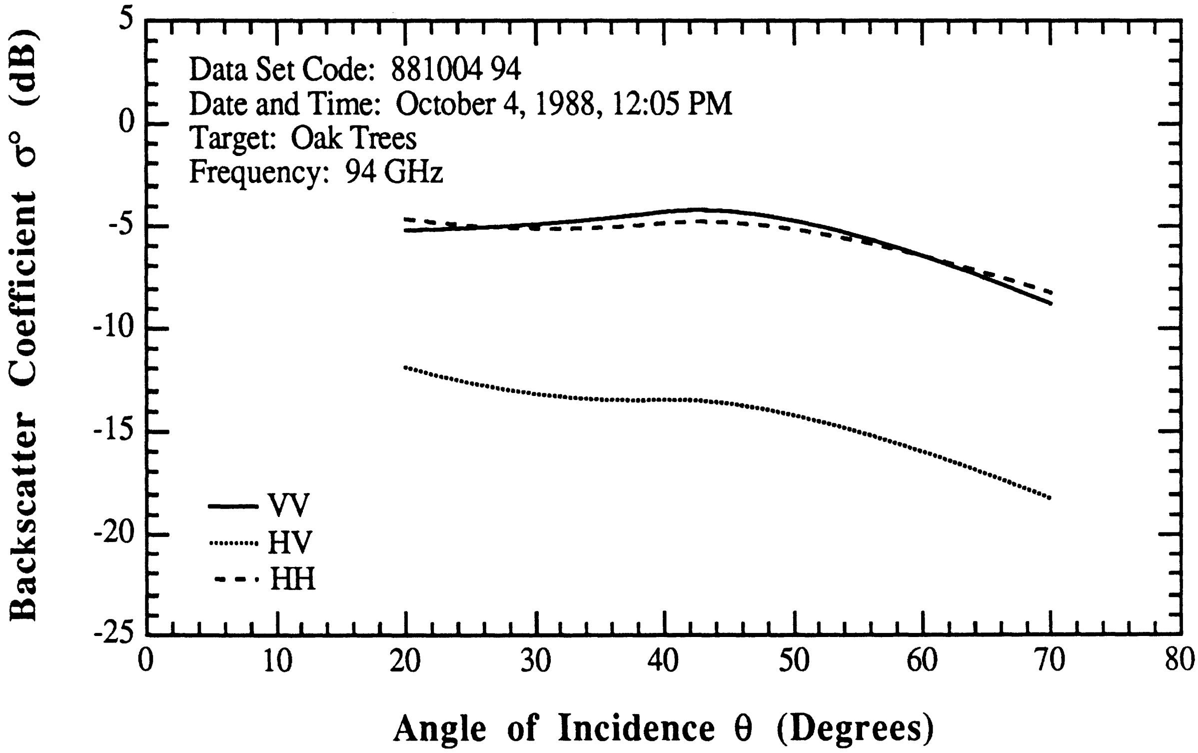
Bur Oaks (Quercus Macrocarpa) Leaf Moisture Content = 59.7%

MMW WAVE DATA FOR TREE CANOPIES

881004



Bur Oaks (Quercus Macrocarpa)

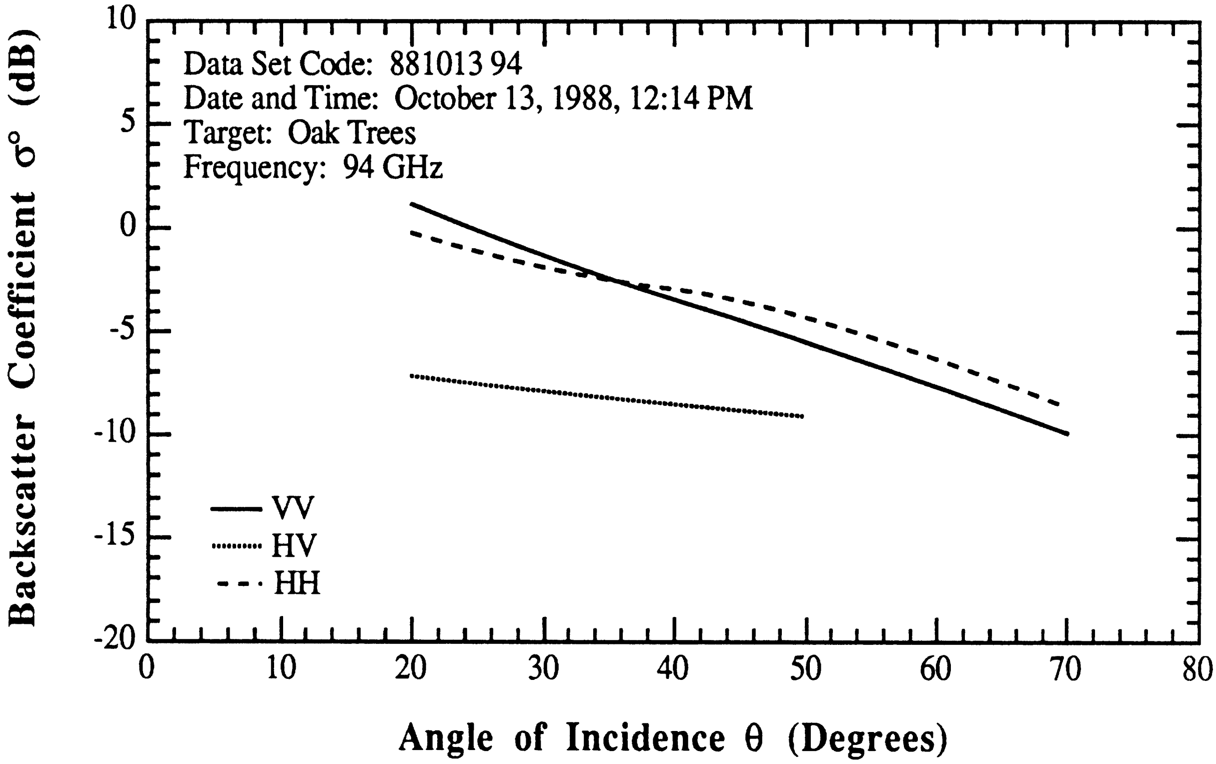


Bur Oaks (Quercus Macrocarpa)

Leaf Moisture Content = 54.2 %

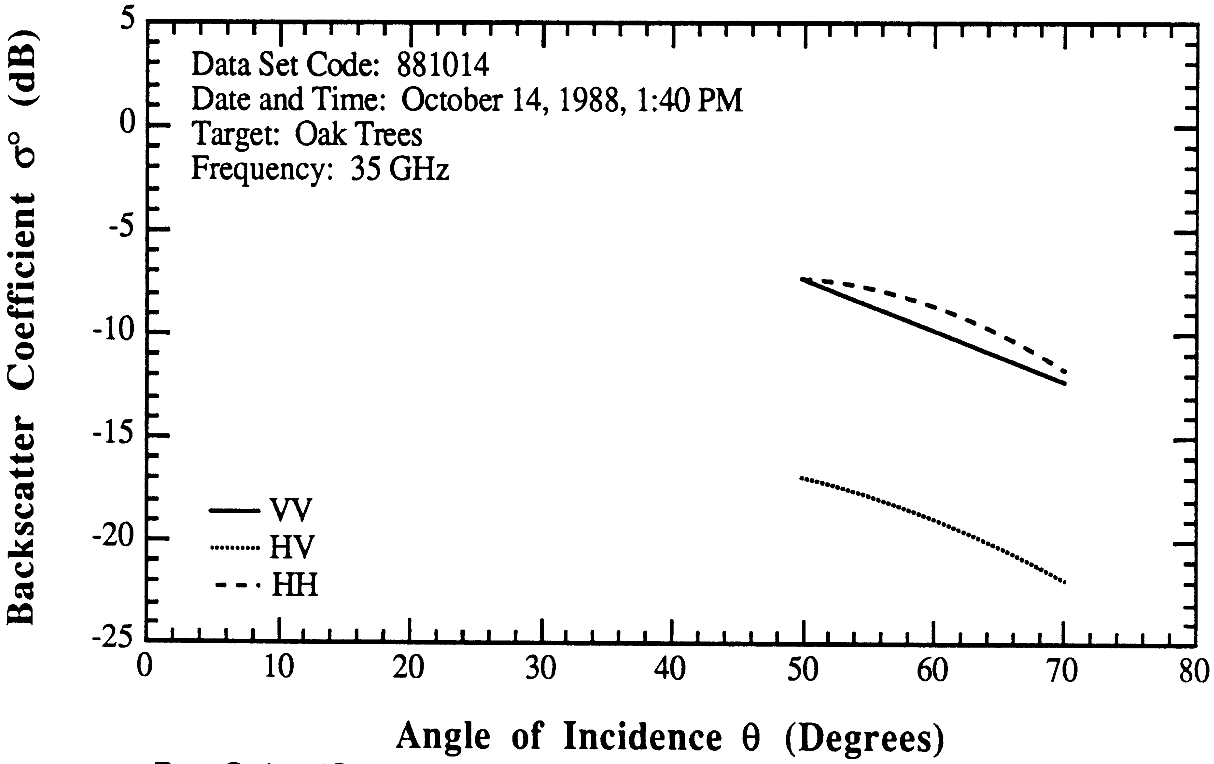
MMW DATA FOR TREE CANOPIES

881013



Bur Oaks (Quercus Macrocarpa) Leaf Moisture Content = 63.4%

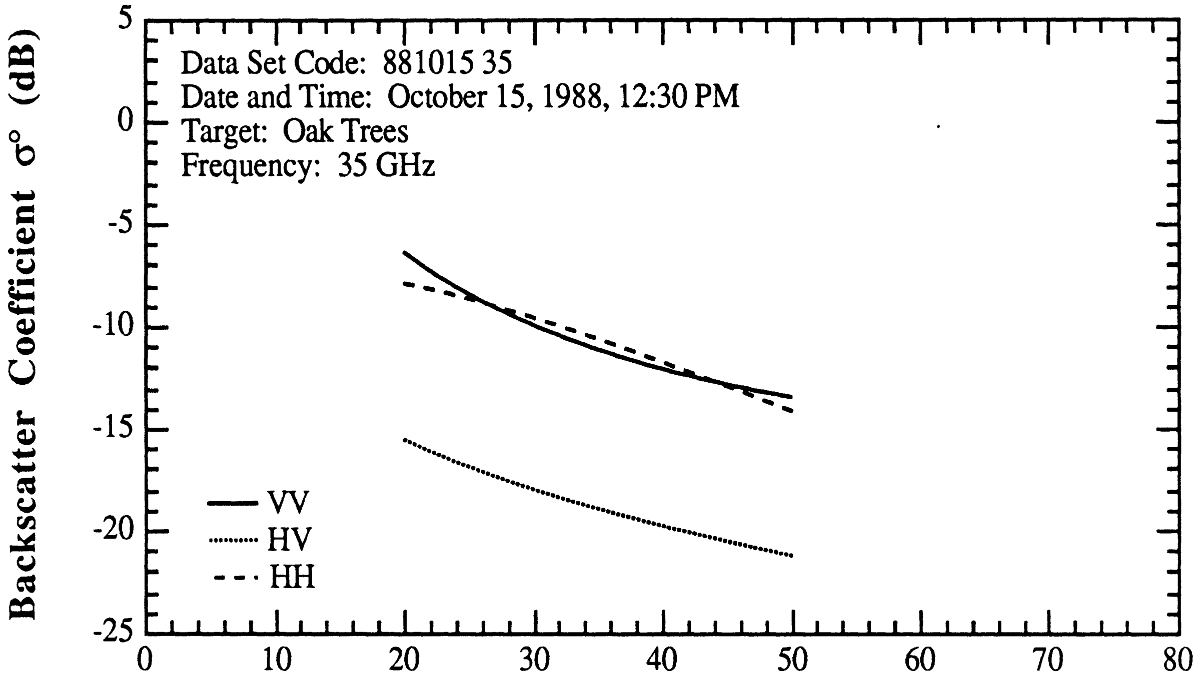
881014



Bur Oaks (Quercus Macrocarpa) Leaf Moisture Content = 50.1%

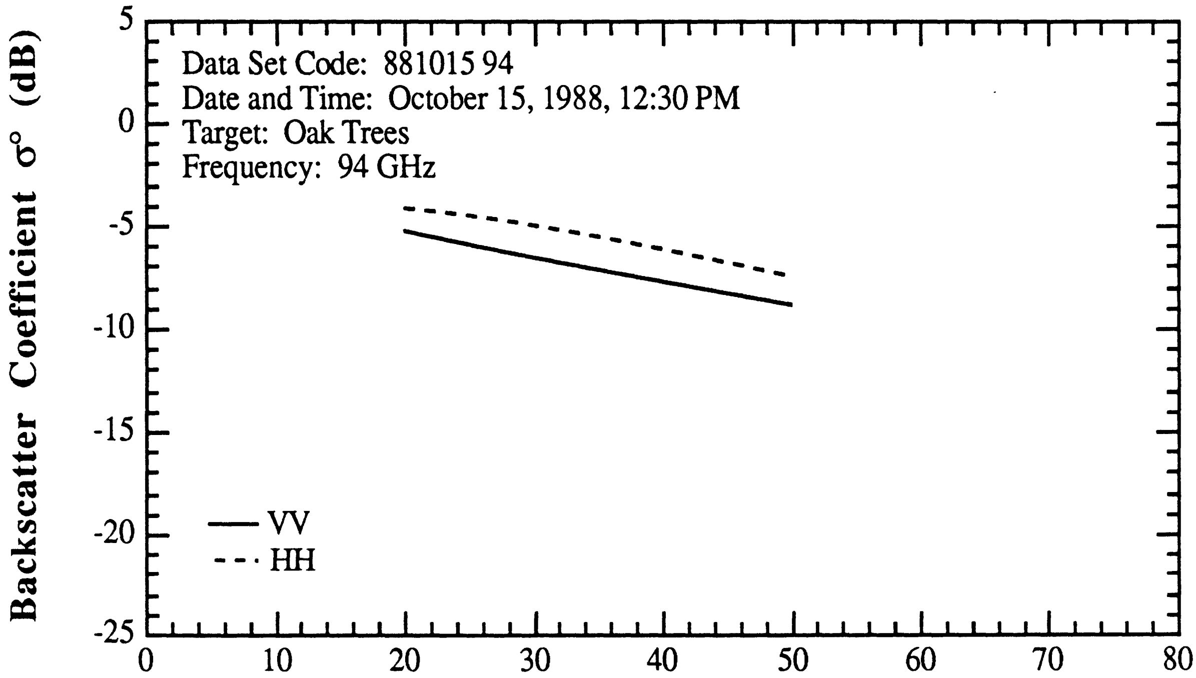
MMW DATA FOR TREE CANOPIES

881015



Angle of Incidence θ (Degrees)

Bur Oaks (Quercus Macrocarpa)

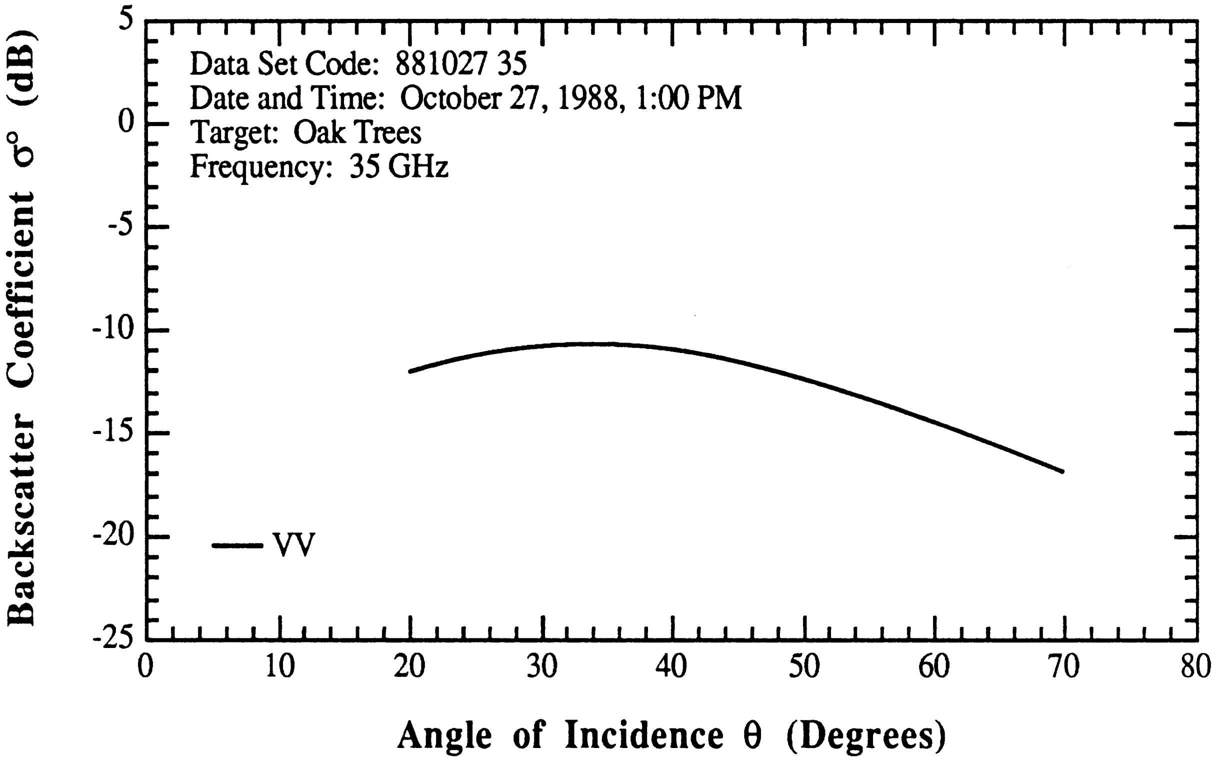


Angle of Incidence θ (Degrees)

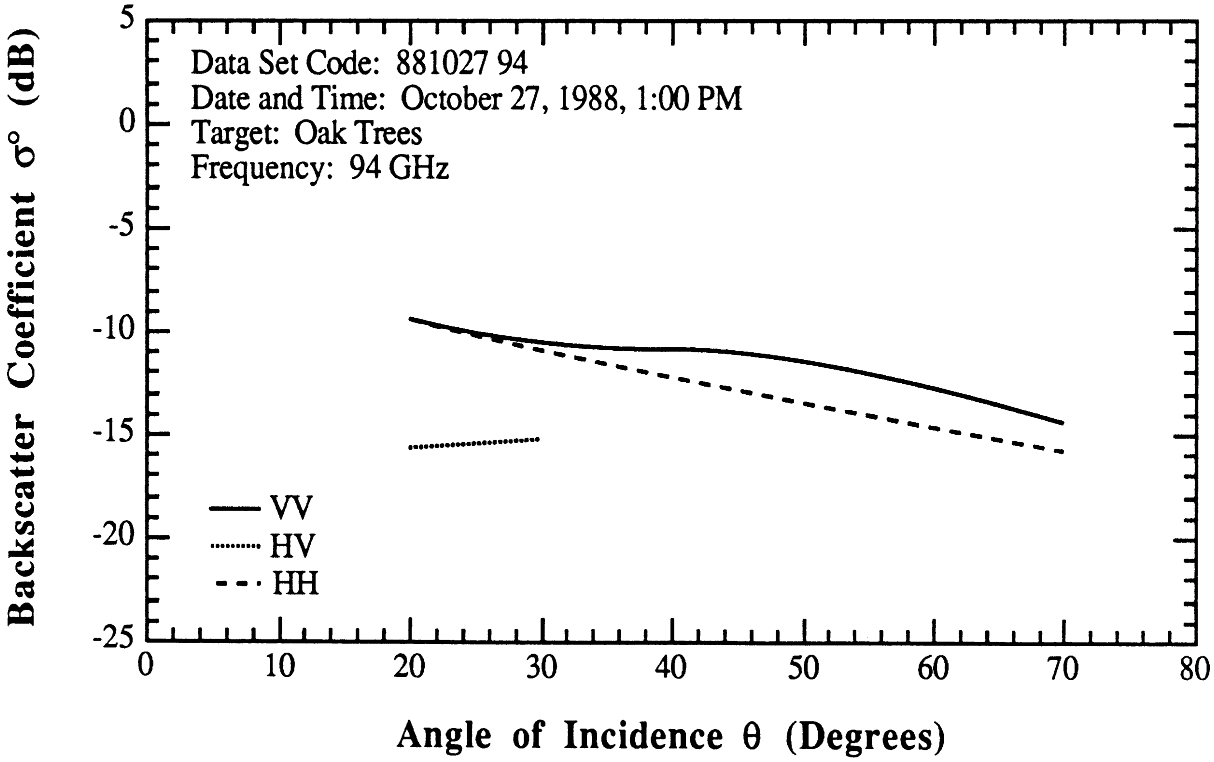
Bur Oaks (Quercus Macrocarpa) Leaf Moisture Content = 55.2%

MMW WAVE DATA FOR TREE CANOPIES

881027



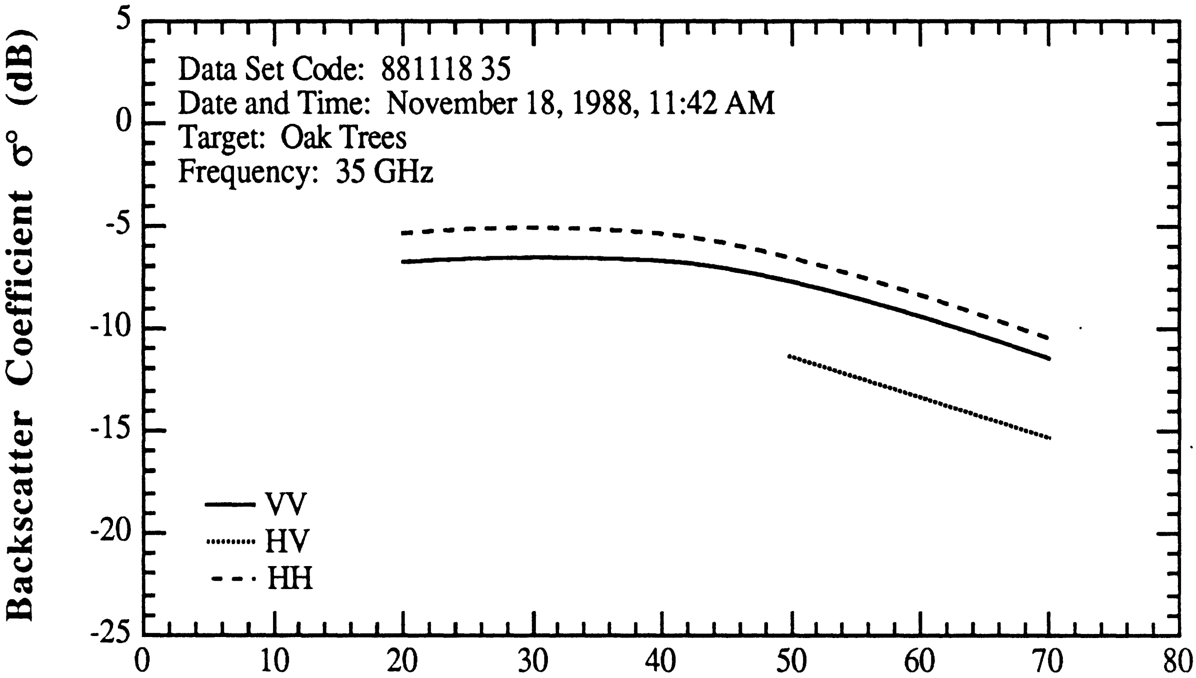
Bur Oaks (Quercus Macrocarpa)



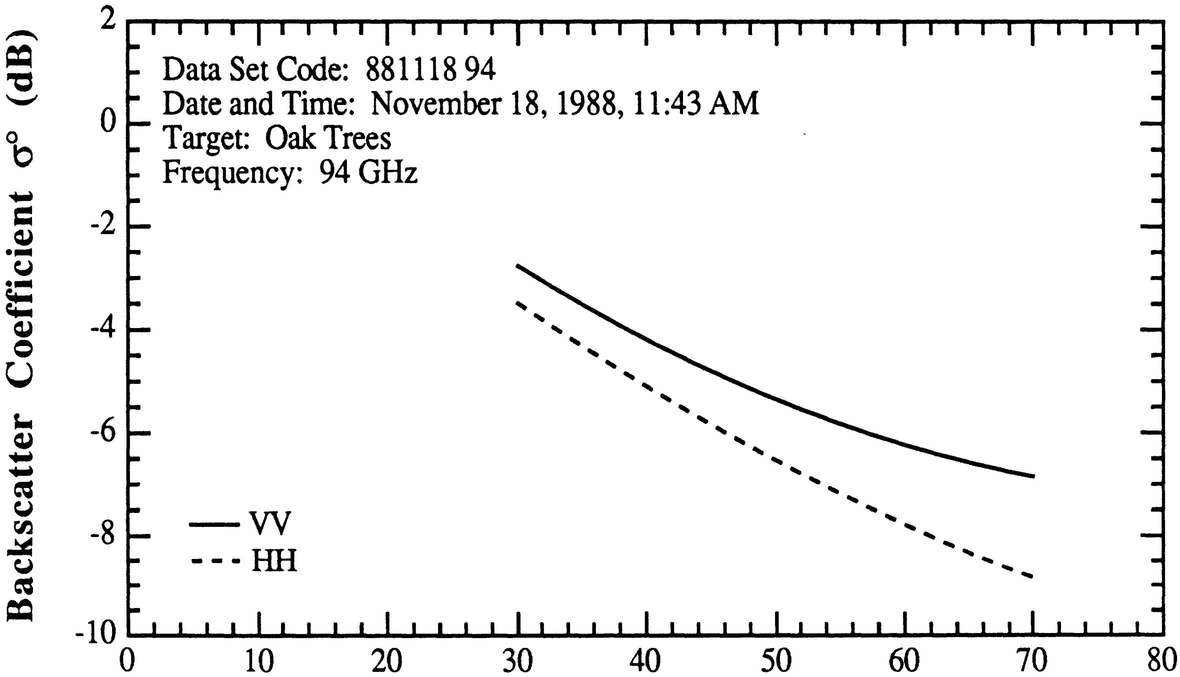
Leaf Moisture Content = 42%

MMW WAVE DATA FOR TREE CANOPIES

881118



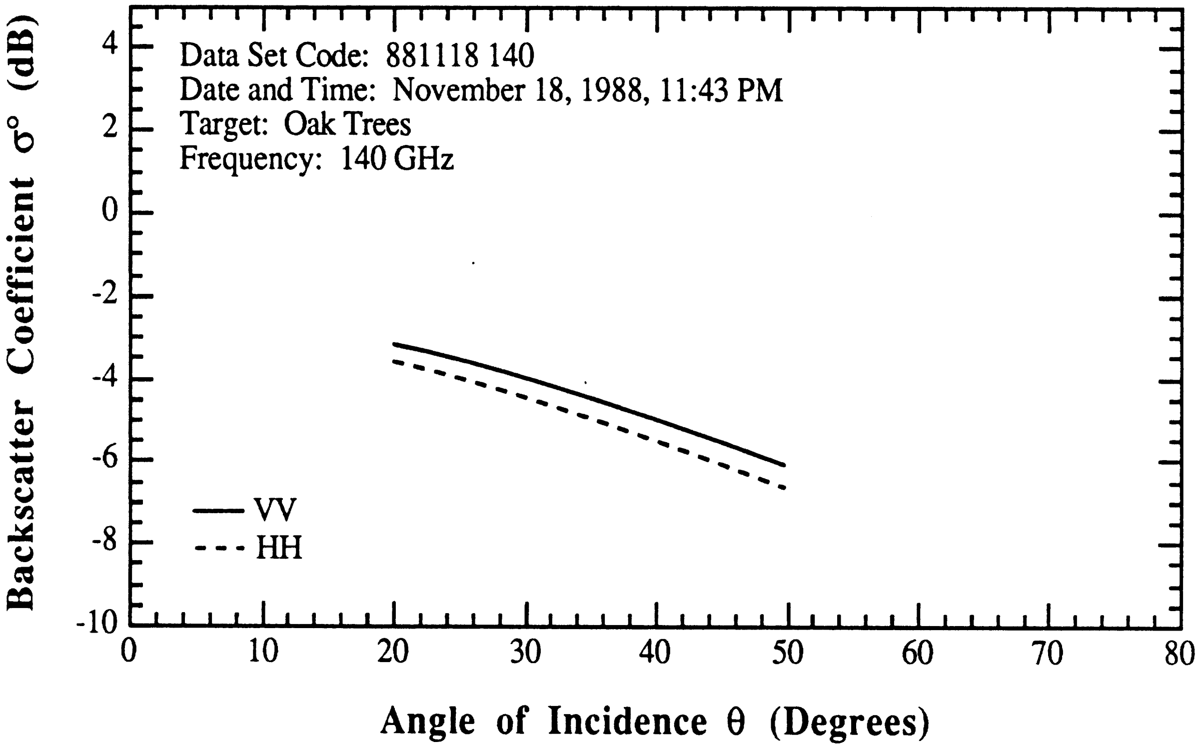
Angle of Incidence θ (Degrees)
Bur Oaks (Quercus Macrocarpa)



Angle of Incidence θ (Degrees)
Bur Oaks (Quercus Macrocarpa) Leaf Moisture Content = 27%

MMW DATA FOR TREE CANOPIES

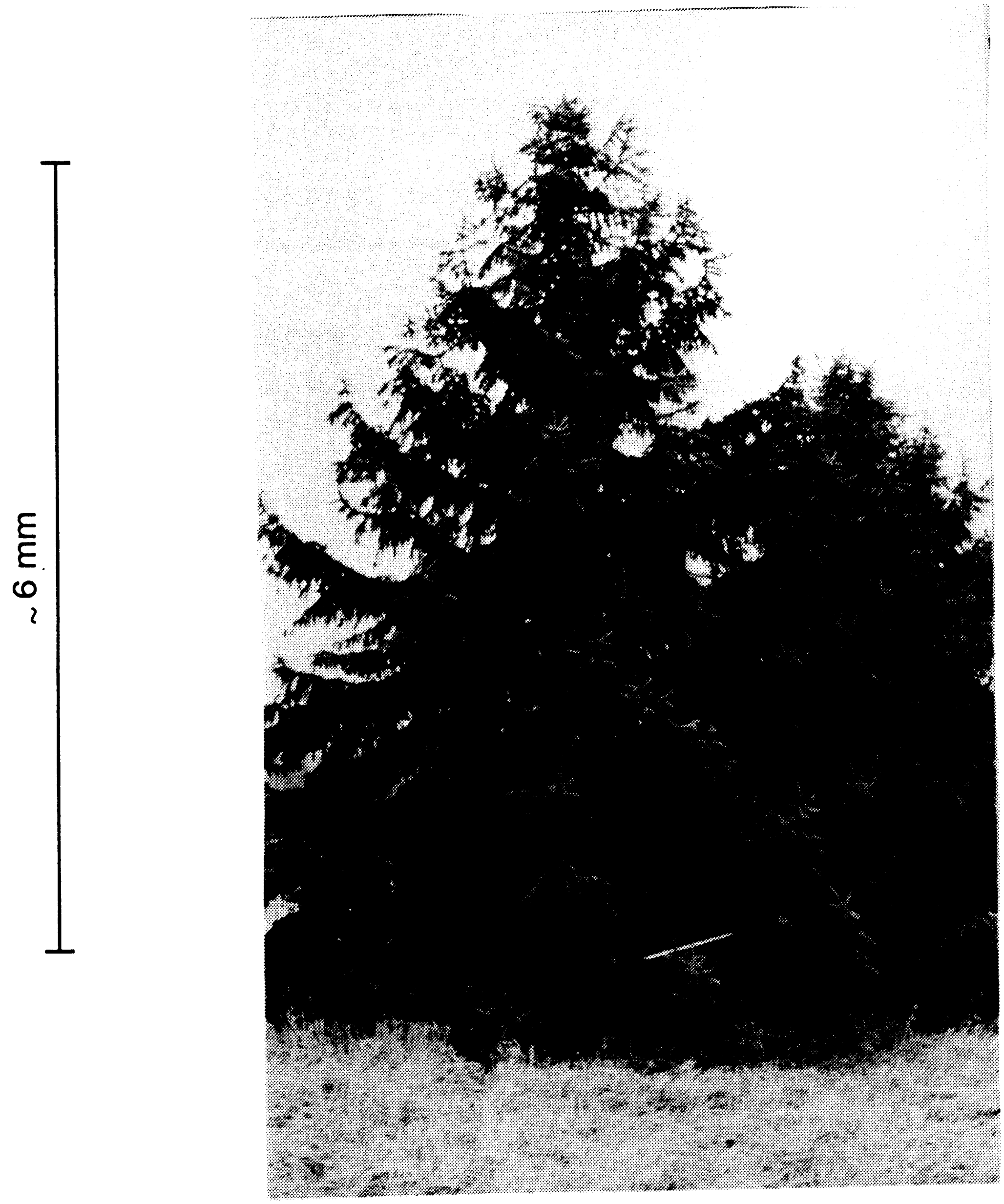
881118



Bur Oaks (Quercus Macrocarpa) Leaf Moisture Content = 27%

E. Spruce Trees

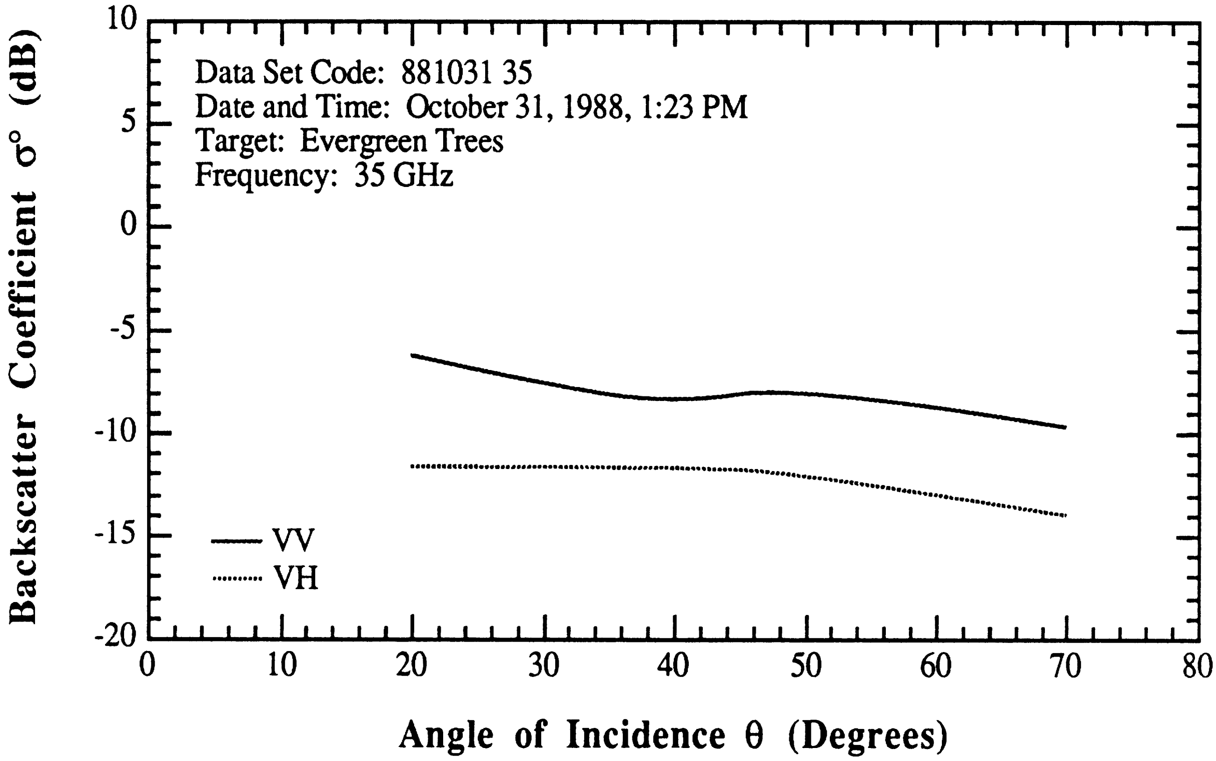
Spruce (Picea abies)
Data set code: 881031/881122
Tree density: 0.03 trees/m^2
Average needle dimensions: 2 cm
Leaf moisture content: 53.1%(881031); 56% (881122)
Percent vegetation cover (est.): 80 %
Percent cover of undergrowth: 100%
Moisture content of undergrowth:35%
Description: stand of mature spruce trees with weedy ground cover



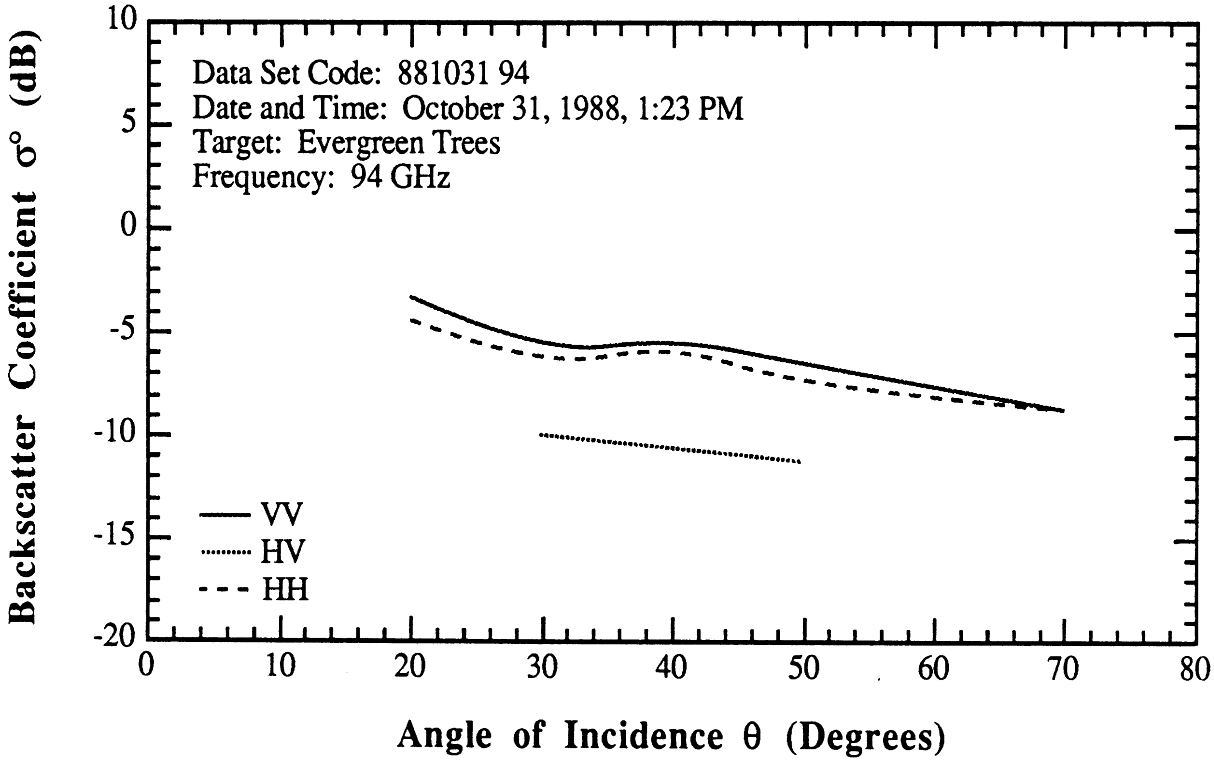
Spruce trees

MMW DATA FOR TREE CANOPIES

881031



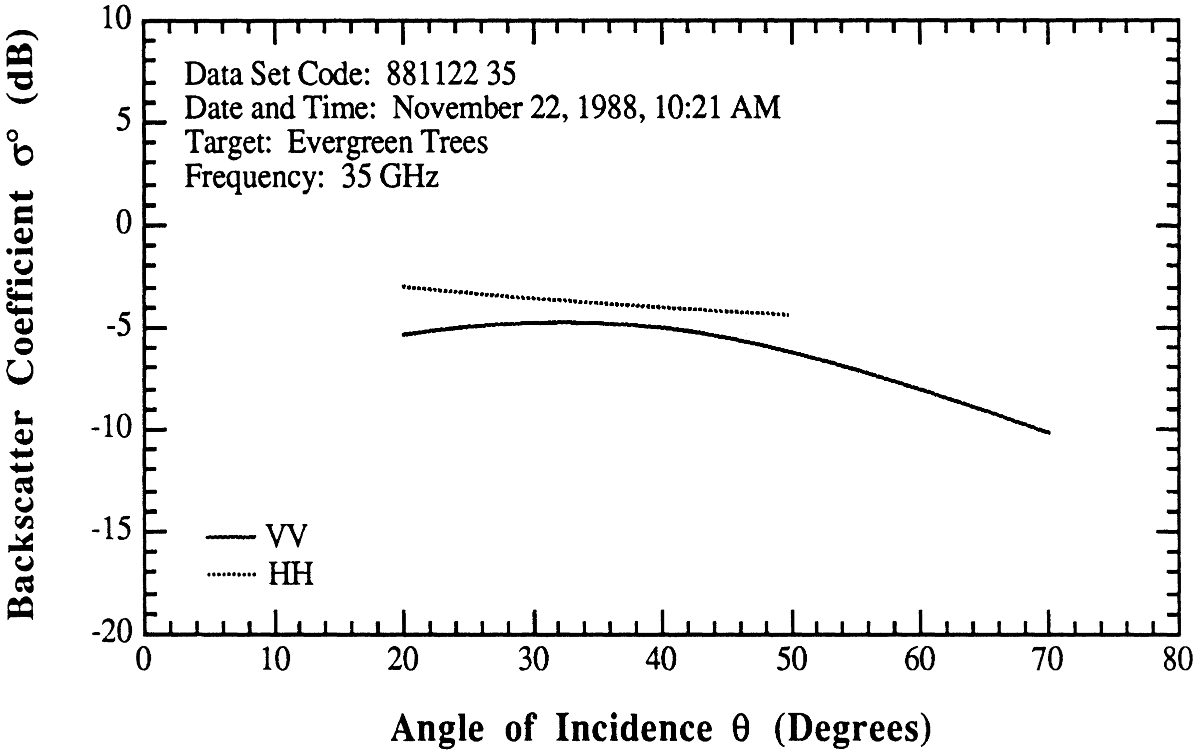
Norway Spruce (Picea Abies)



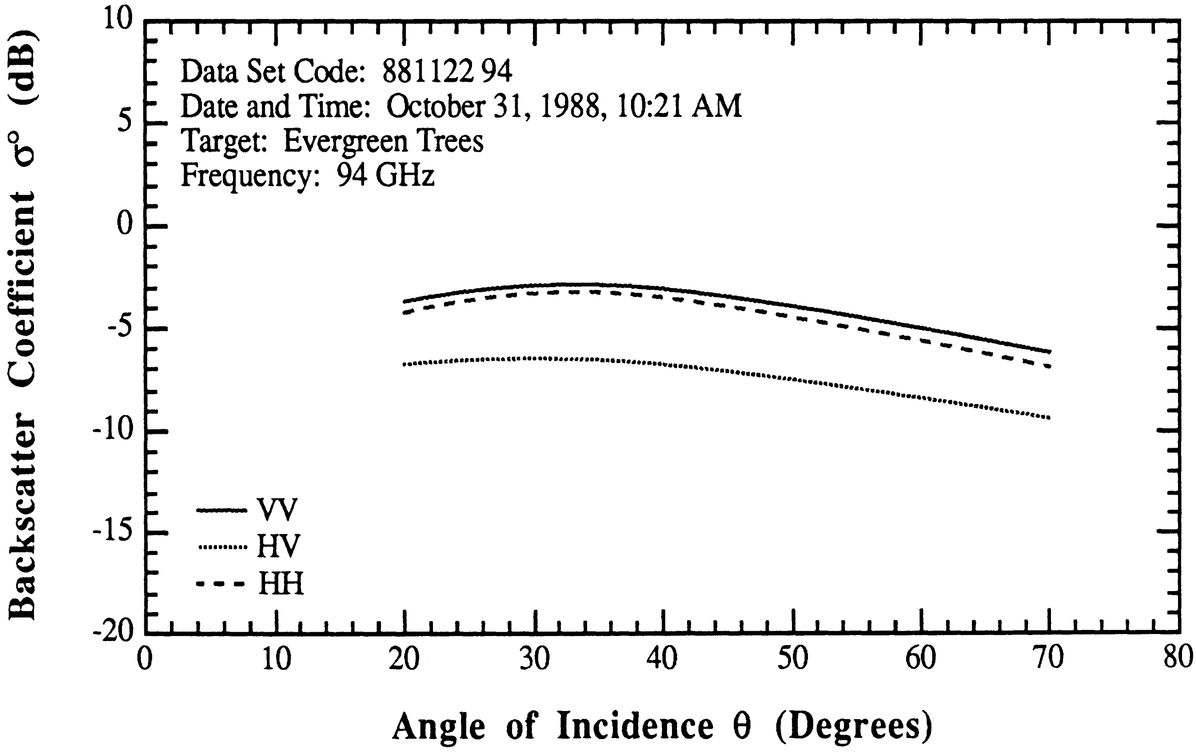
Norway Spruce (Picea Abies)

MMW DATA FOR TREE CANOPIES

881122



Blue Spruce & Norway Spruce (Picea Puryens & Picea Abies)



Blue Spruce & Norway Spruce (Picea Puryens & Picea Abies)

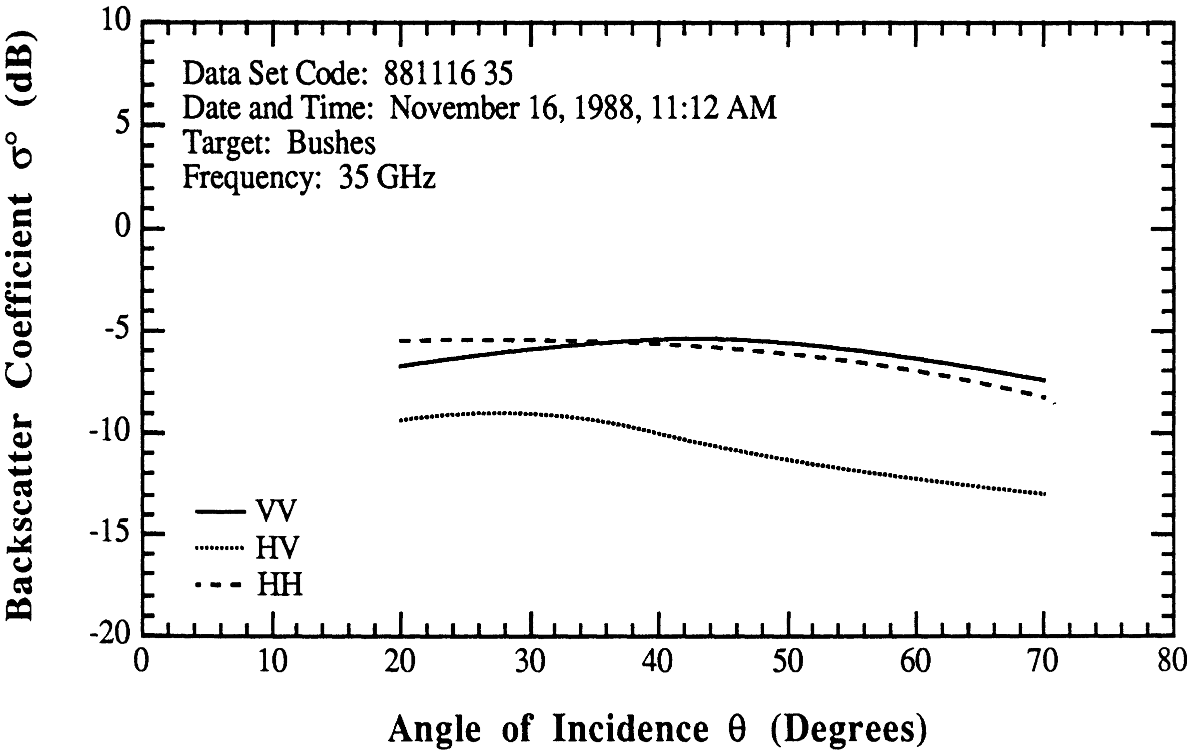
F. White Cedar Bushes

White Cedar bush (Thuja occidentalis)
Data set code: 881116
Height: 3 m
Density: 80 %
Average leaf (or needle) dimension: 5 cm
Leaf moisture content: 56 %
Percent vegetation cover: 80 %
Percent cover of undergrowth: 50%
Description: dense stand of White cedar bushes

White Cedar bush

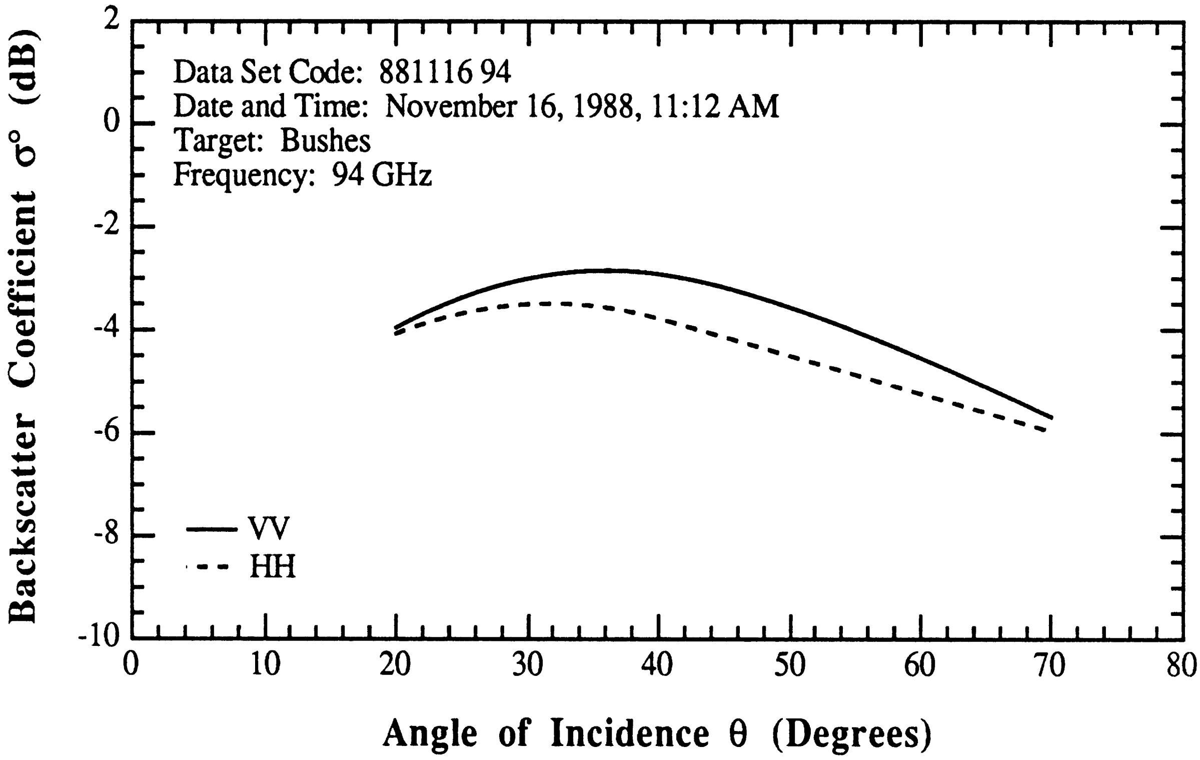
Close-up view of branches of White Cedar Bush

881116

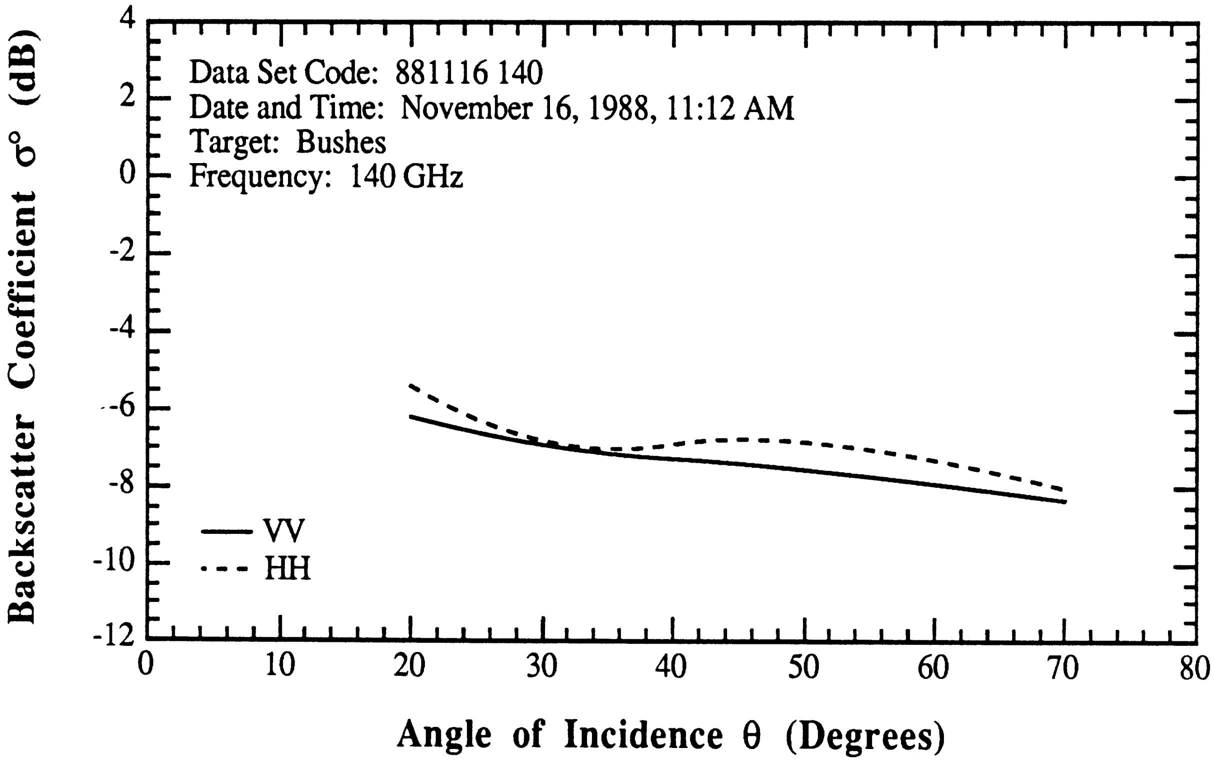


White Cedar at Botanical Gardens (Thuja Occidentalis)

881116



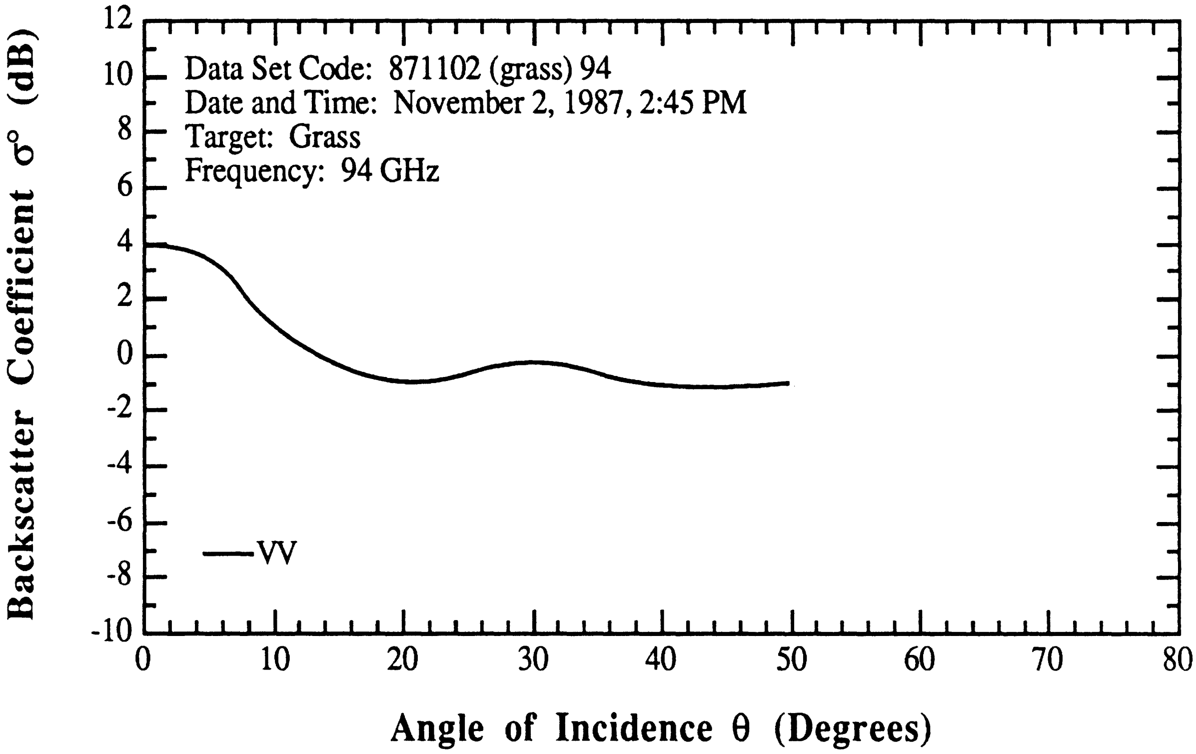
White Cedar at Botanical Gardens (Thuja Occidentalis)



White Cedar (Thuja Occidentalis)

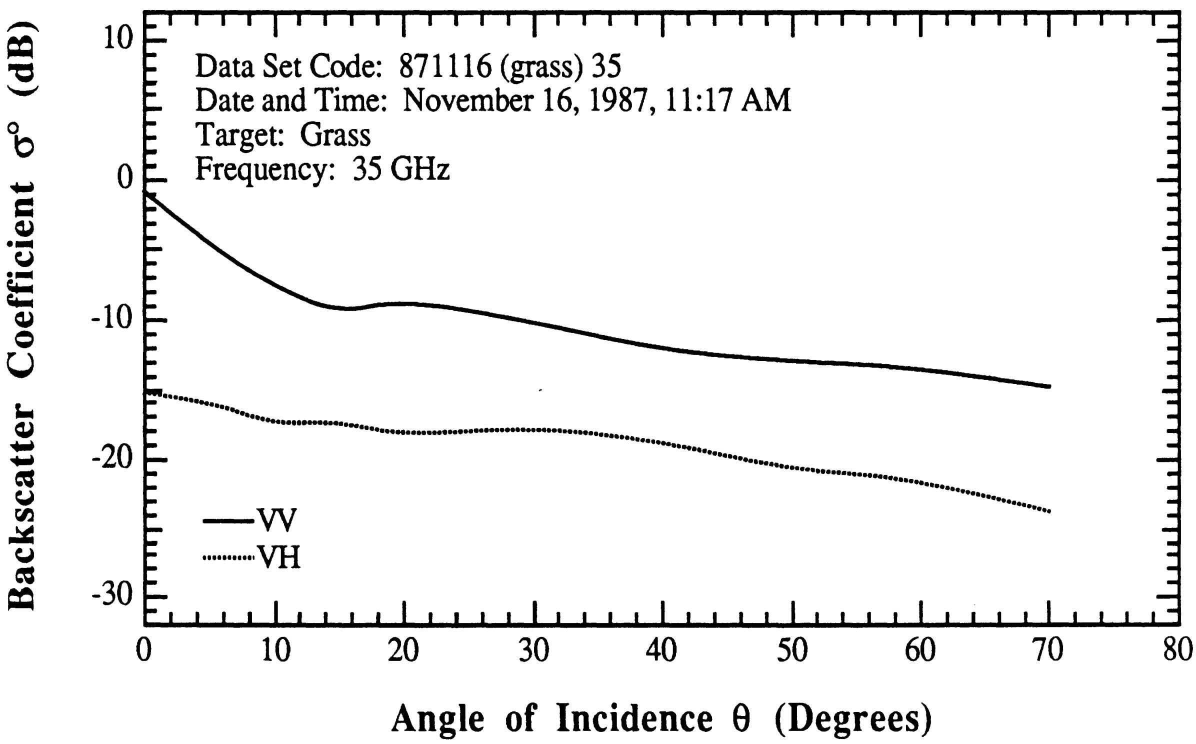
VII. MMW DATA FOR GRASSES

871102



Cut grass with wet surface (Height = 10 cm)

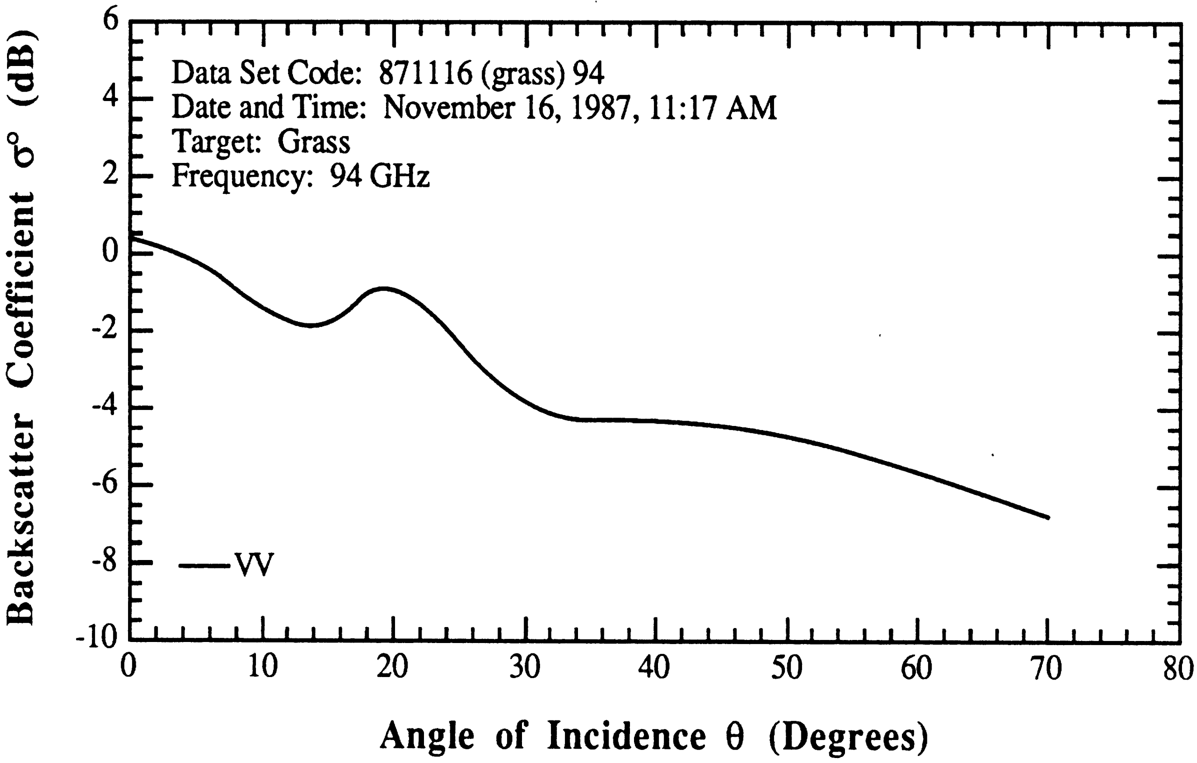
871116



Cut grass at North Campus (Height = 5cm)

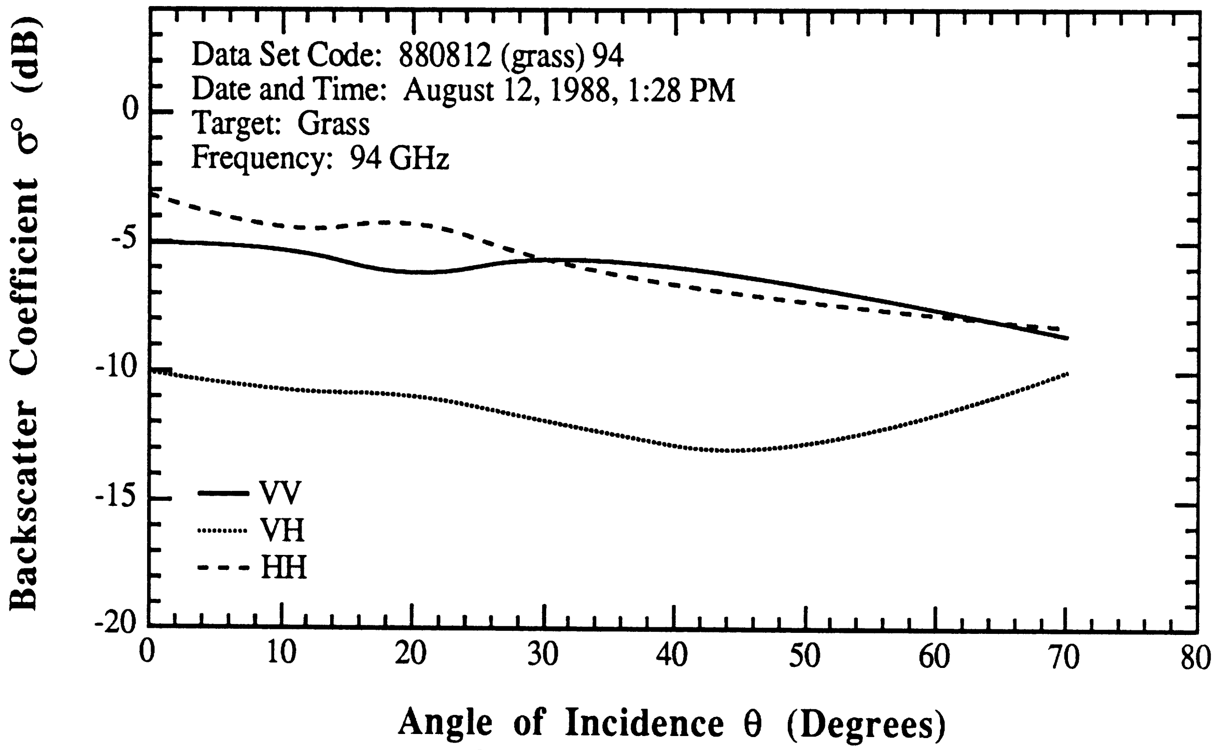
MMW WAVE DATA FOR GRASSES

871116



Cut Grass at North Campus (Height = 5 cm)

880812



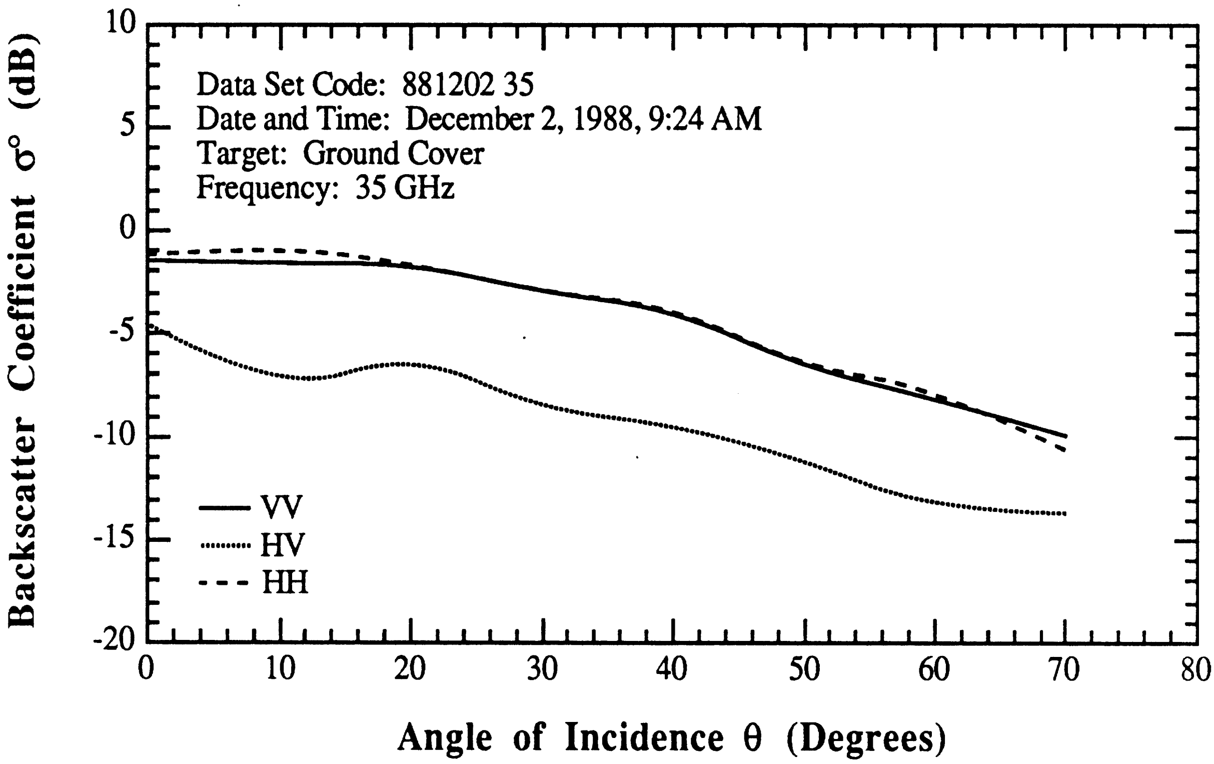
Cut Grass (Height = 6 cm)

Tall Grass (Amaranthus)
Data set code: 881202
Grass Moisture Content: 37.6%
Height: 50 cm
Description: uncut

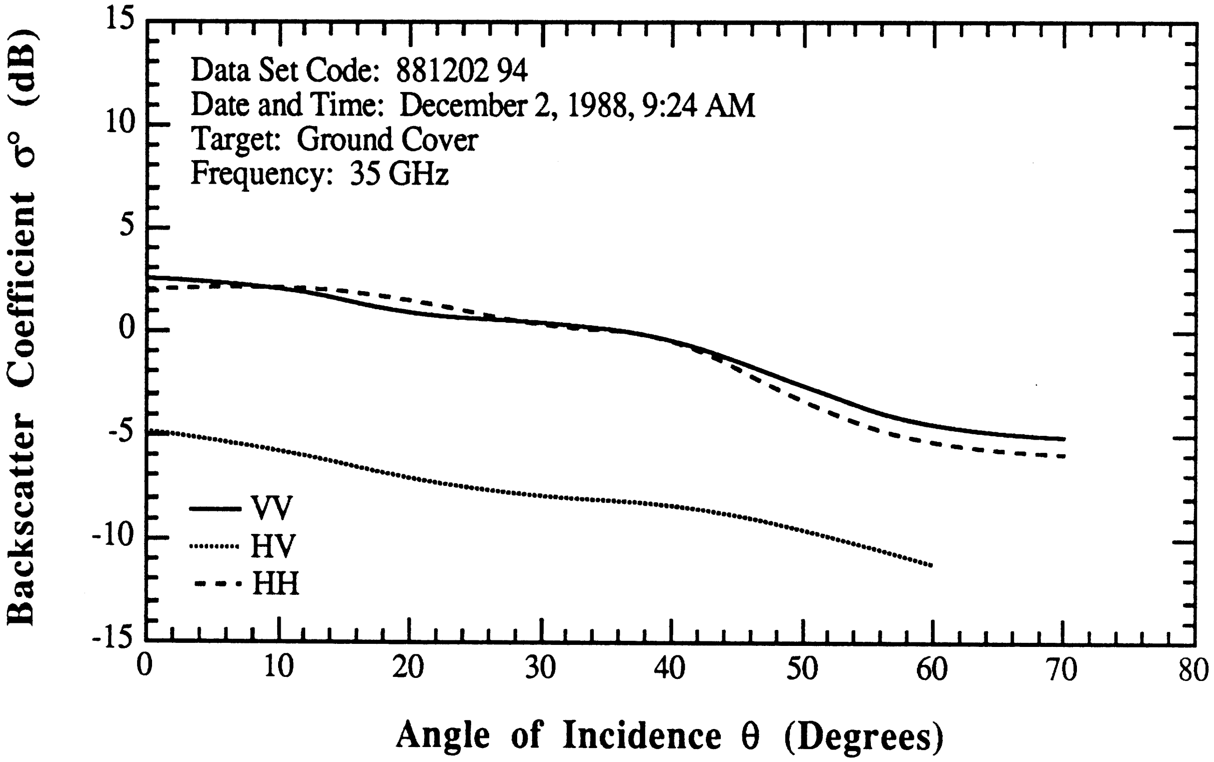
Amaranthus over chickweed

MMW DATA FOR GRASSES

881202



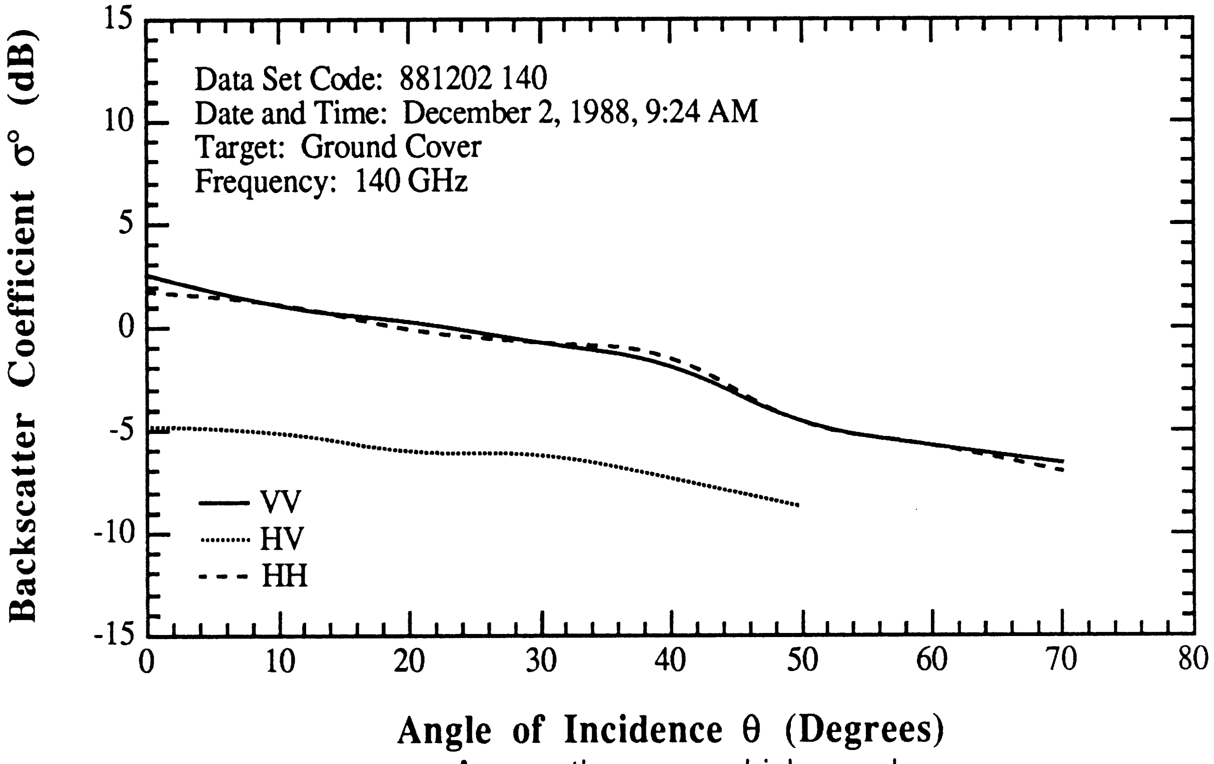
Amaranthus over chick weed



Amaranthus over chick weed

MMW WAVE DATA FOR GRASSES

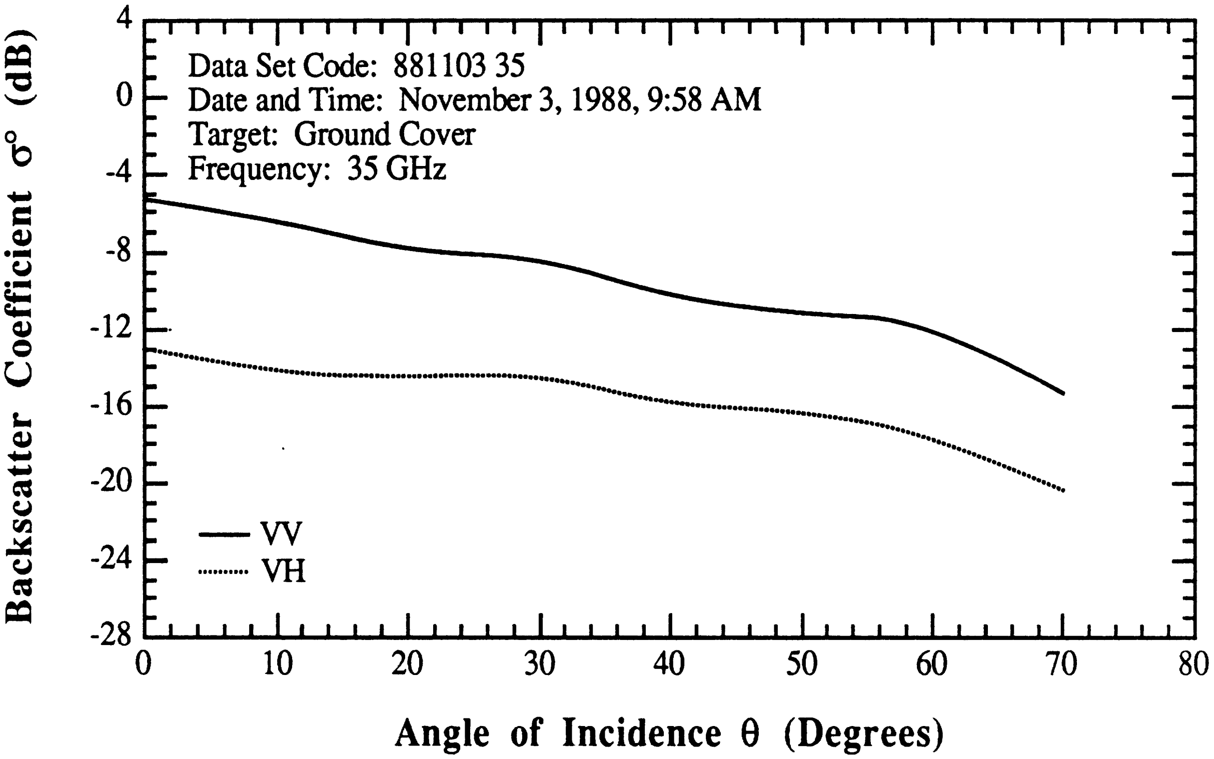
881202

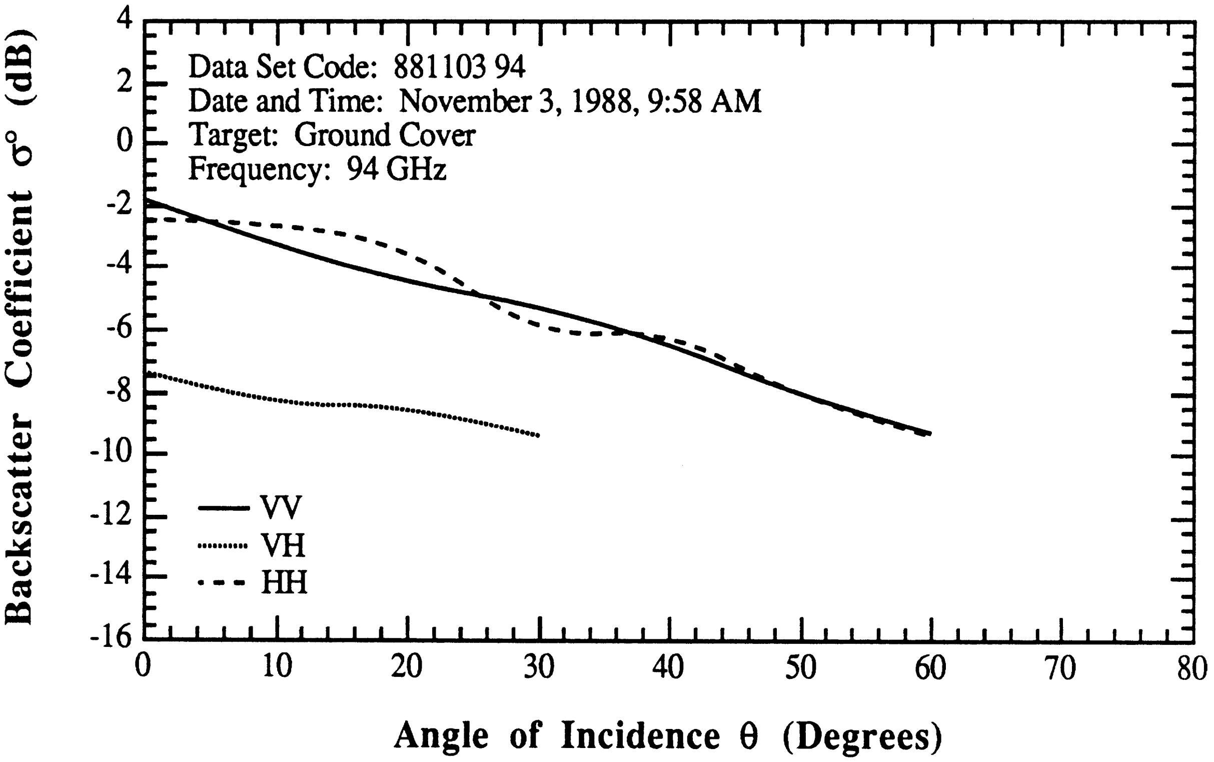


Amaranthus over chick weed

MMW WAVE DATA FOR GRASSES

881103





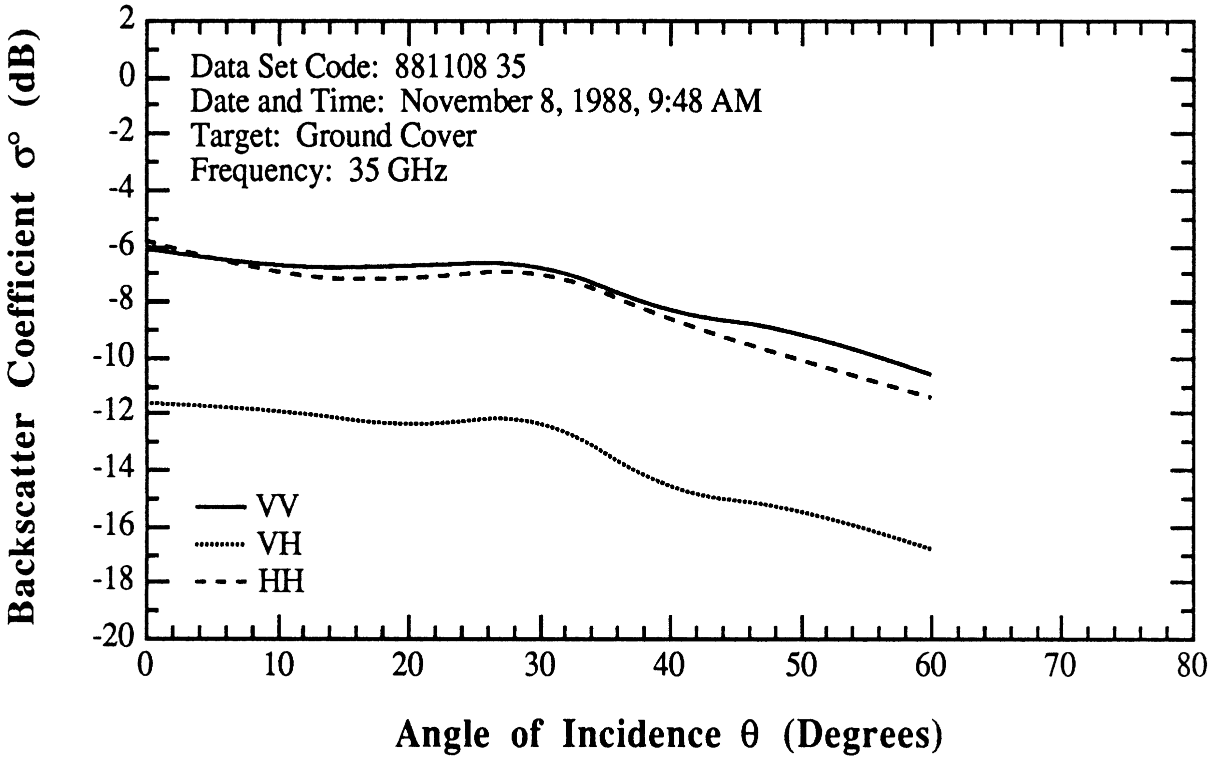
Tall Grass (Andropogon gerardi)

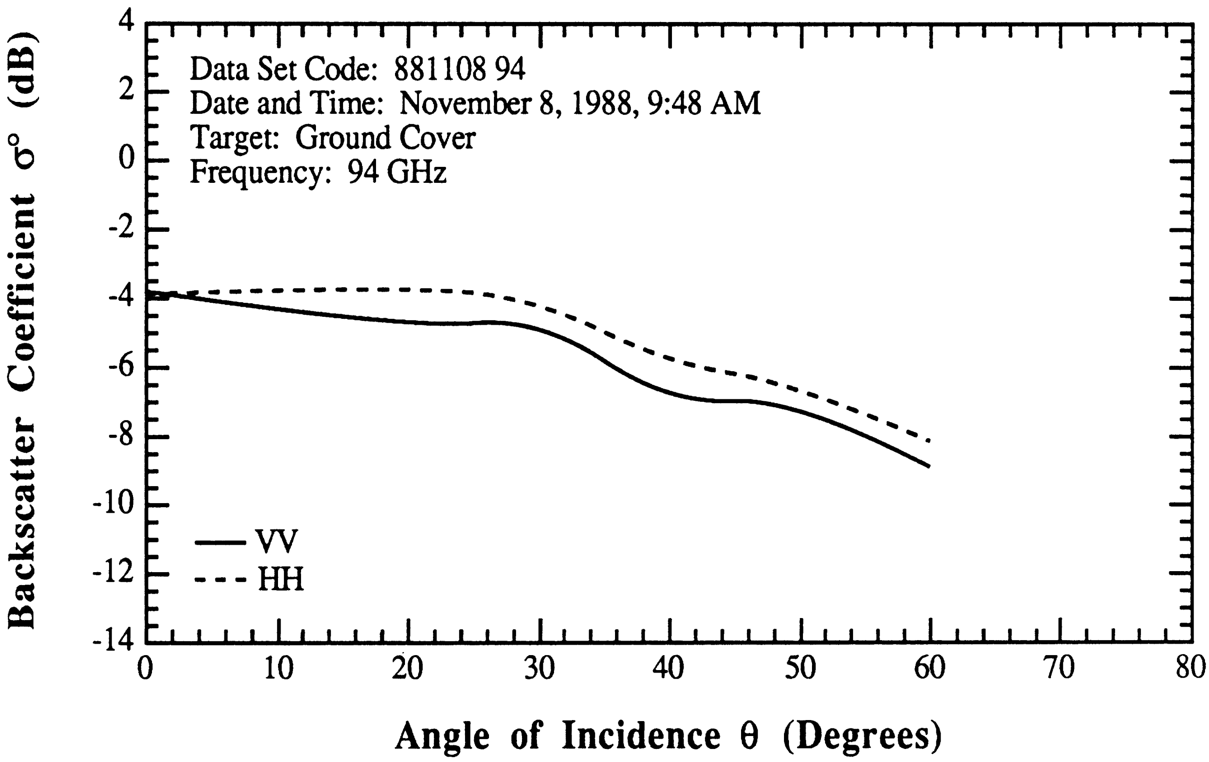
Leaf Moisture Content = 33%

Description: dry, uncut

MMW WAVE DATA FOR GRASSES

881108





Turkey Foot or Big Bluestem (Andropogon gerardi)

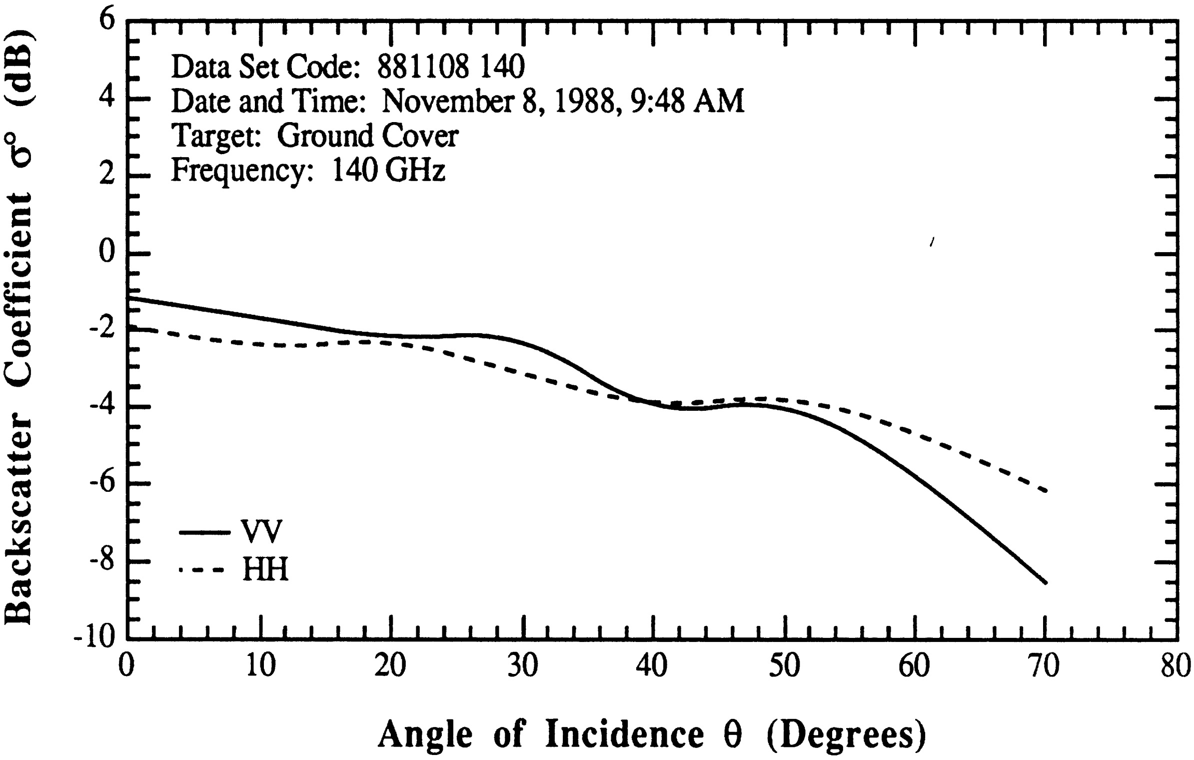
Grass (Andropogon gerardi)

Leaf Moisture Content = 44.5%

Description: moist, uncut

MMW WAVE DATA FOR GRASSES

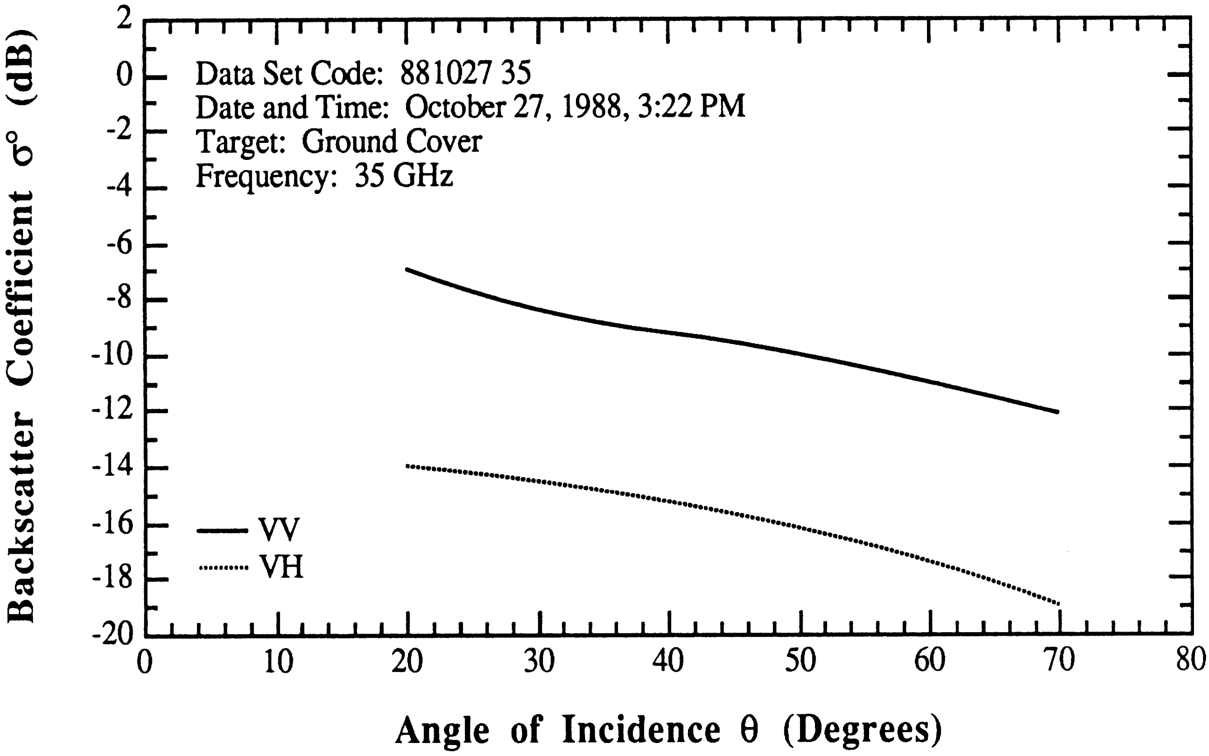
881108

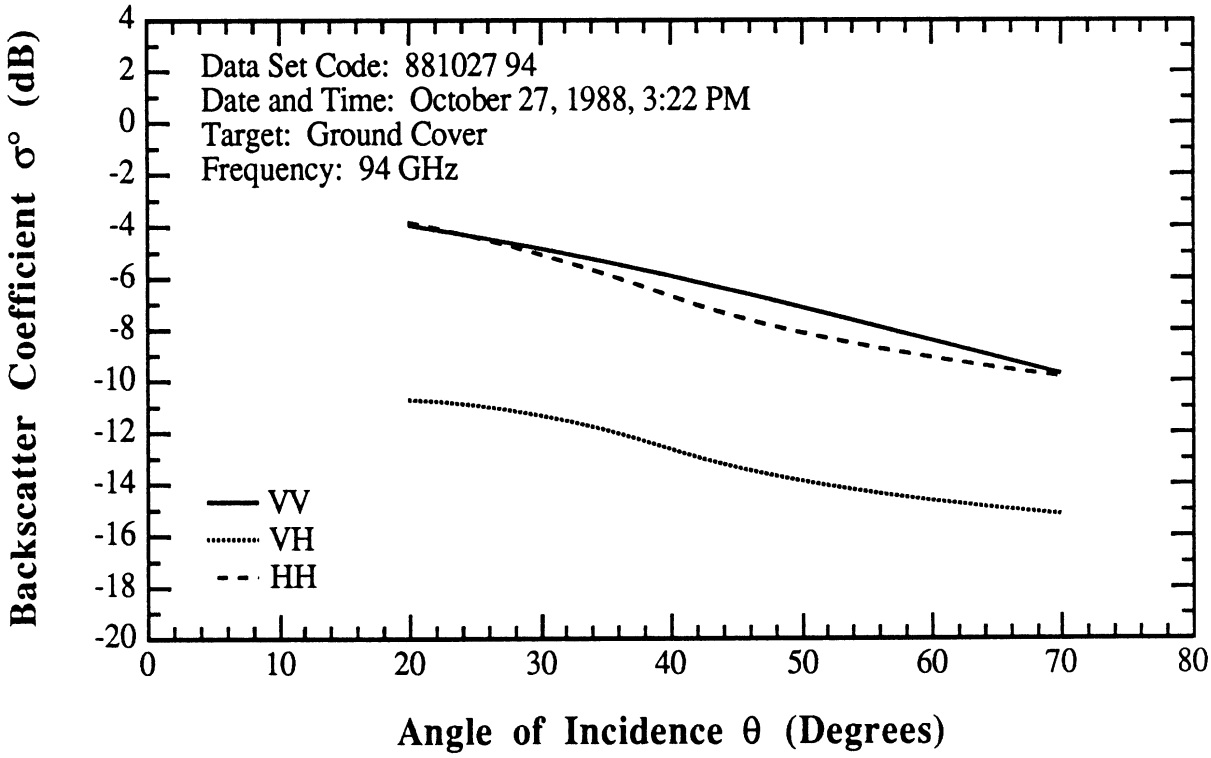


Turkey Foot or Big Bluestem (Andropogon gerardi)
Grass (Andropogon gerardi)

MMW WAVE DATA FOR GRASSES

881027





Tall Grass (Bromus inermis)
Leaf Moisture Content = 70% Height: 80 cm
Description: uncut

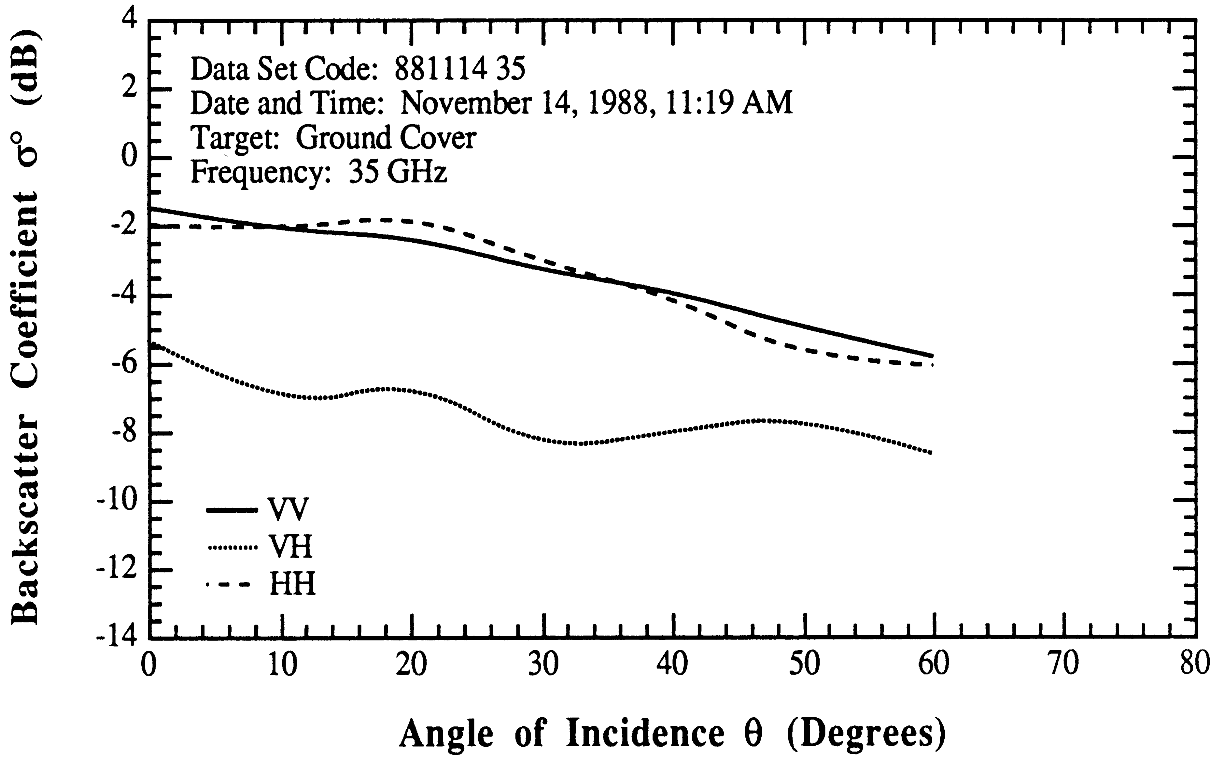
881114

Grass (Bromus inermis)
Data set code: 881114
Leaf Water Content = 43.1%
Height: 10 cm
Description: cut

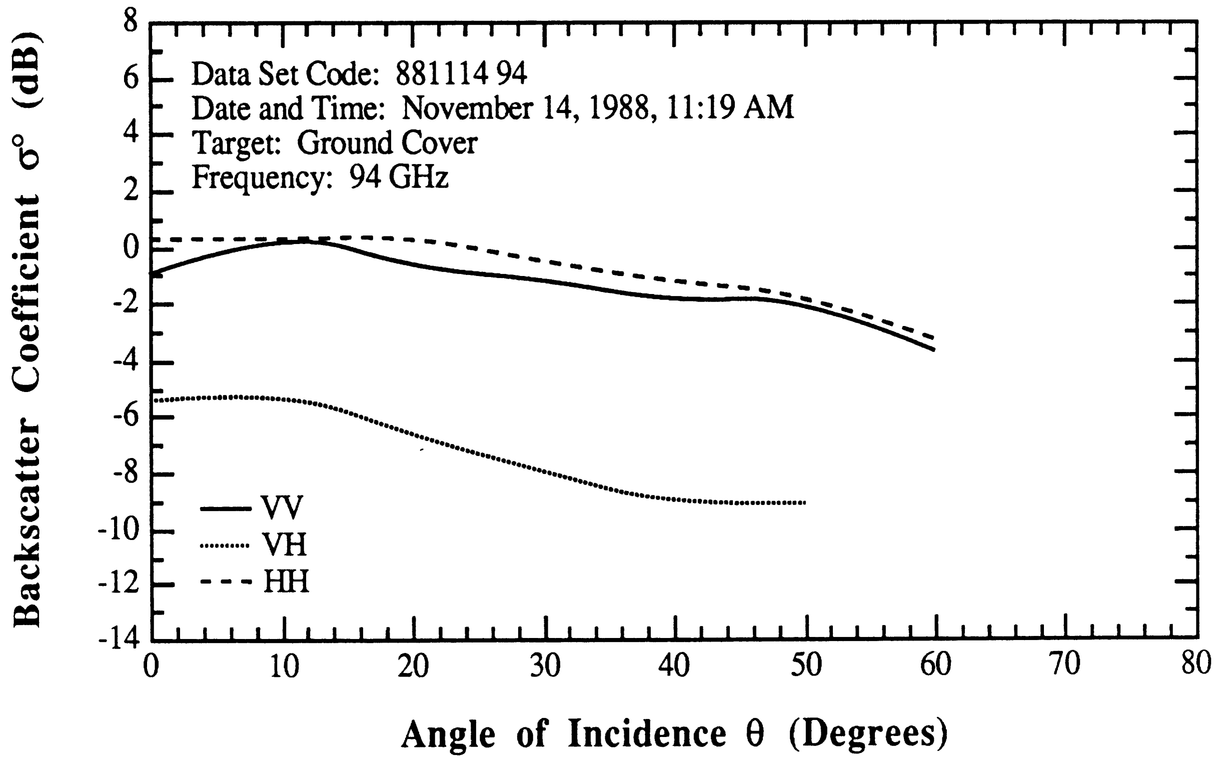
Broom grass (Bromus inermis)

MMW WAVE DATA FOR GRASSES

881114



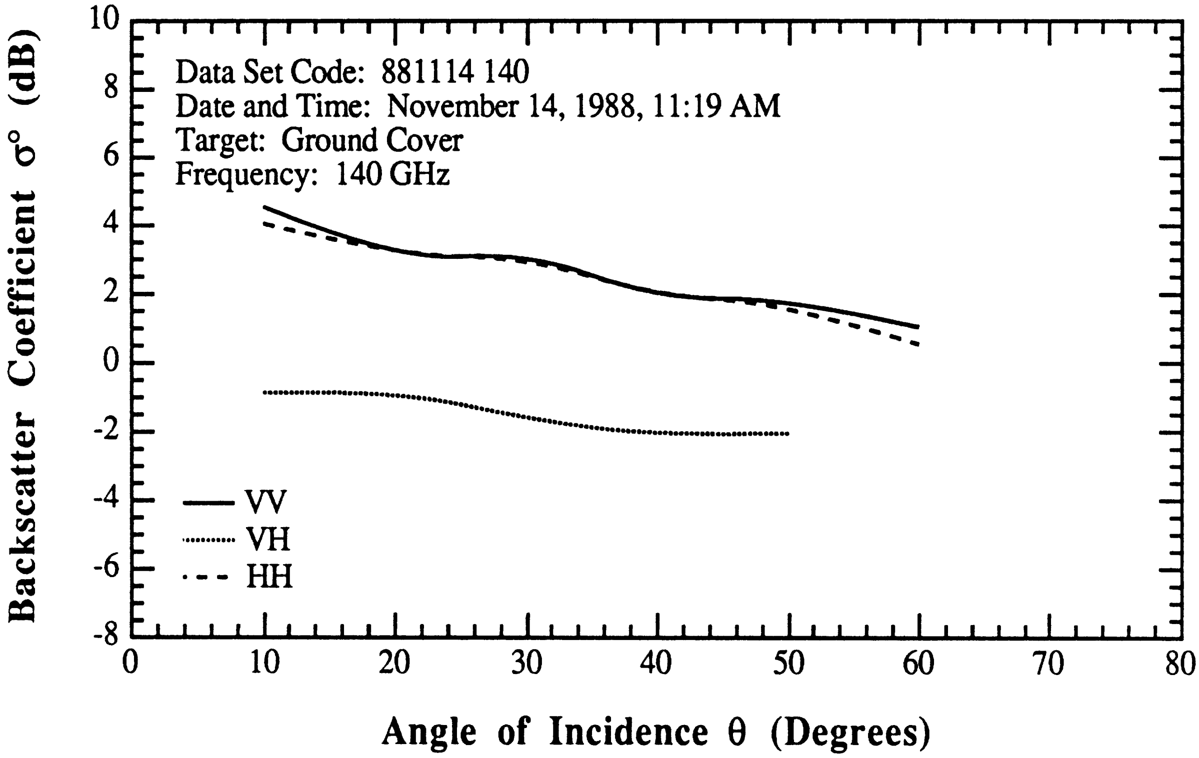
Broom Grass (Bromus inermis)



Broom Grass (Bromus inermis)

MMW WAVE DATA FOR GRASSES

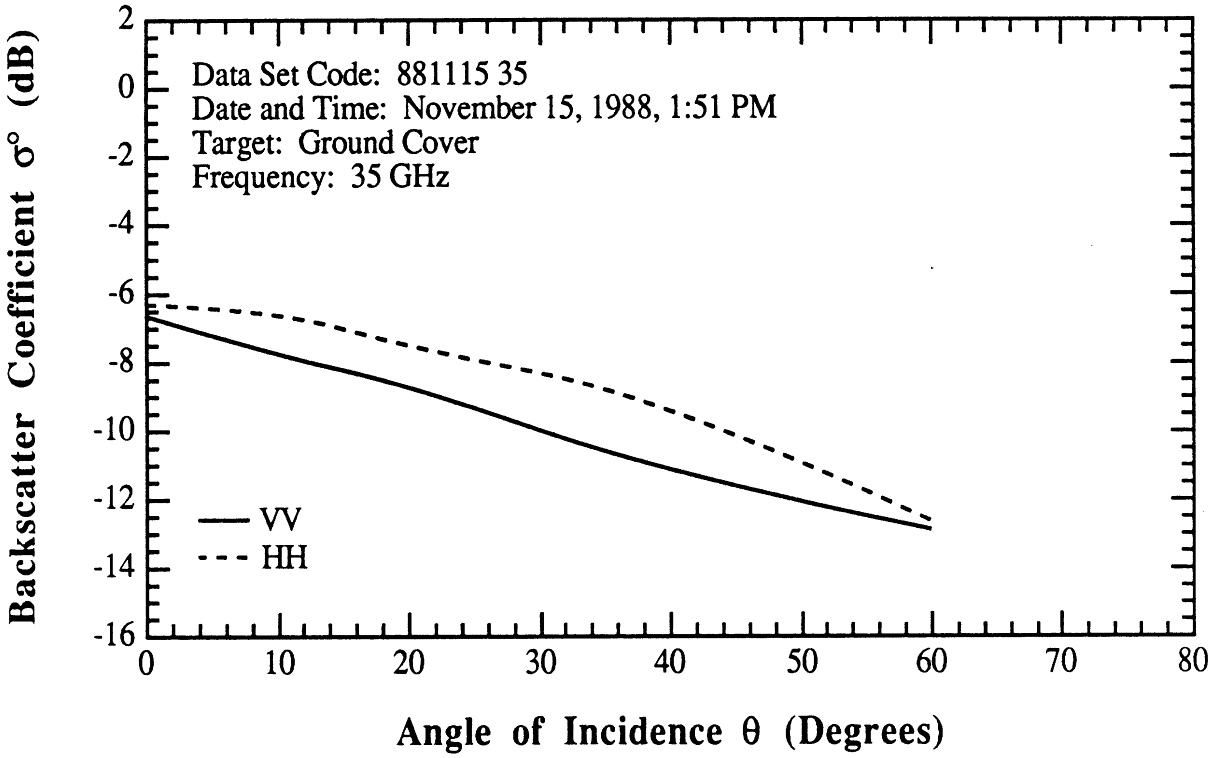
881114



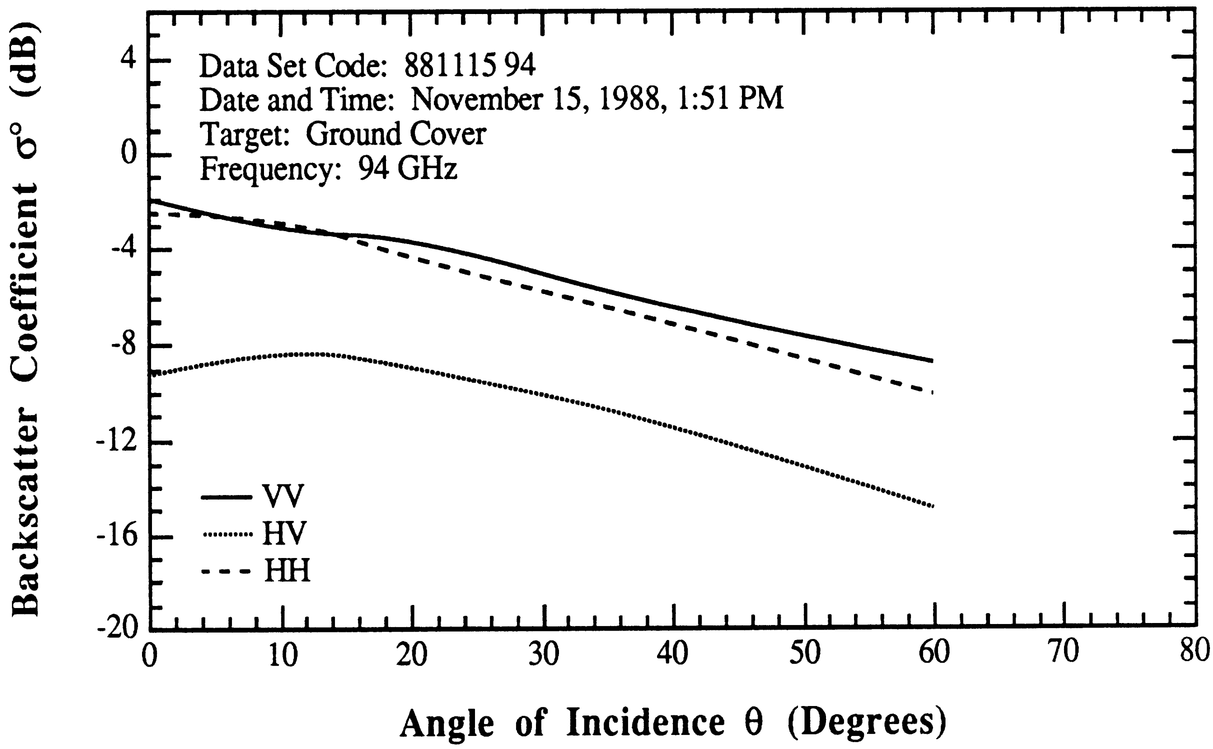
Broom Grass (Bromus inermis)

MMW WAVE DATA FOR GRASSES

881115



Broom Grass (Bromus inermis)



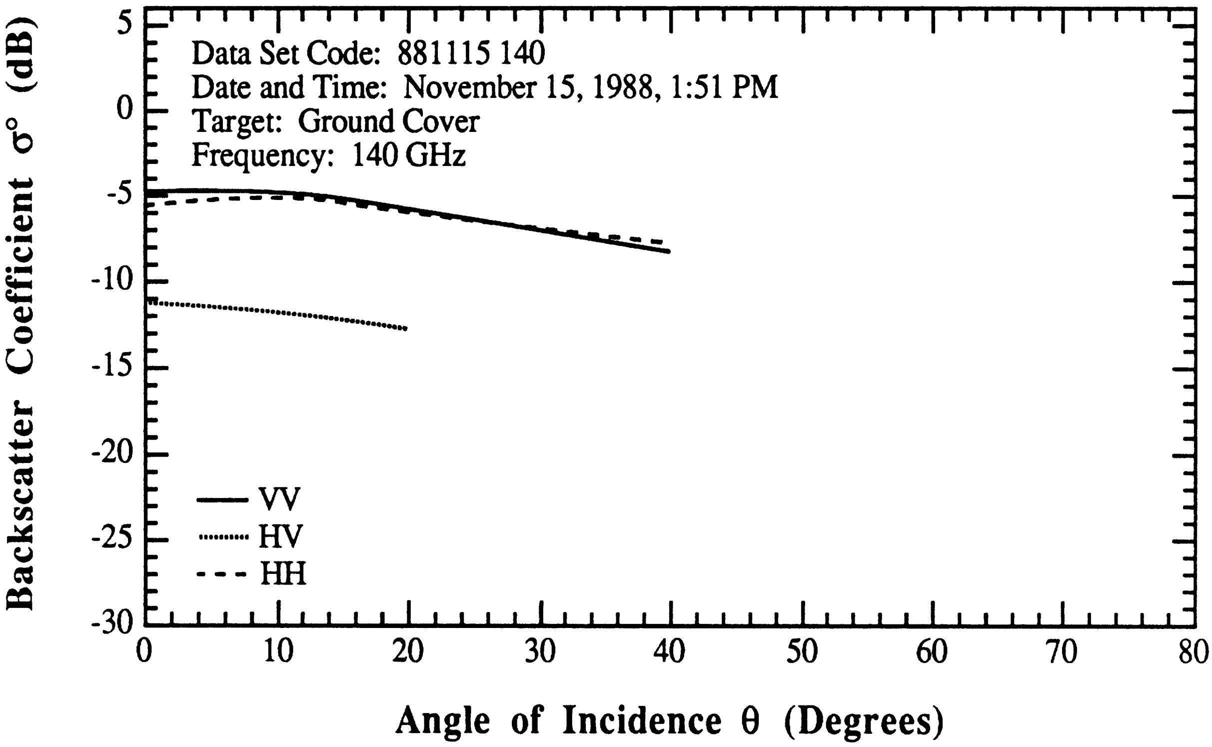
Broon Grass (Bromus Inermis)

Leaf Water Content = 50% Height: 25 cm

Description: uncut

MMW WAVE DATA FOR GRASSES

881115



Broom Grass (Bromus inermis)

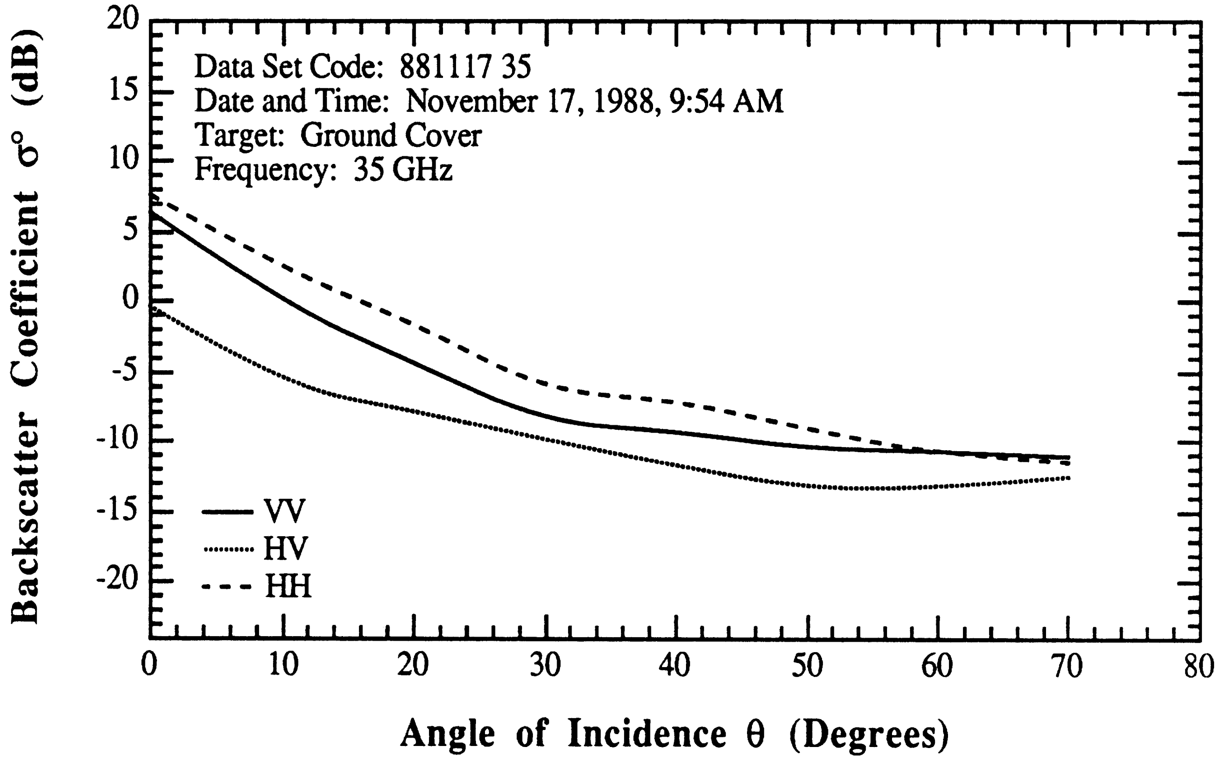
881117

Grass (Lythrum salicaria)
Data set code: 881117
Leaf Moisture Content = 24.8%
Height: 1 m
Description: uncut

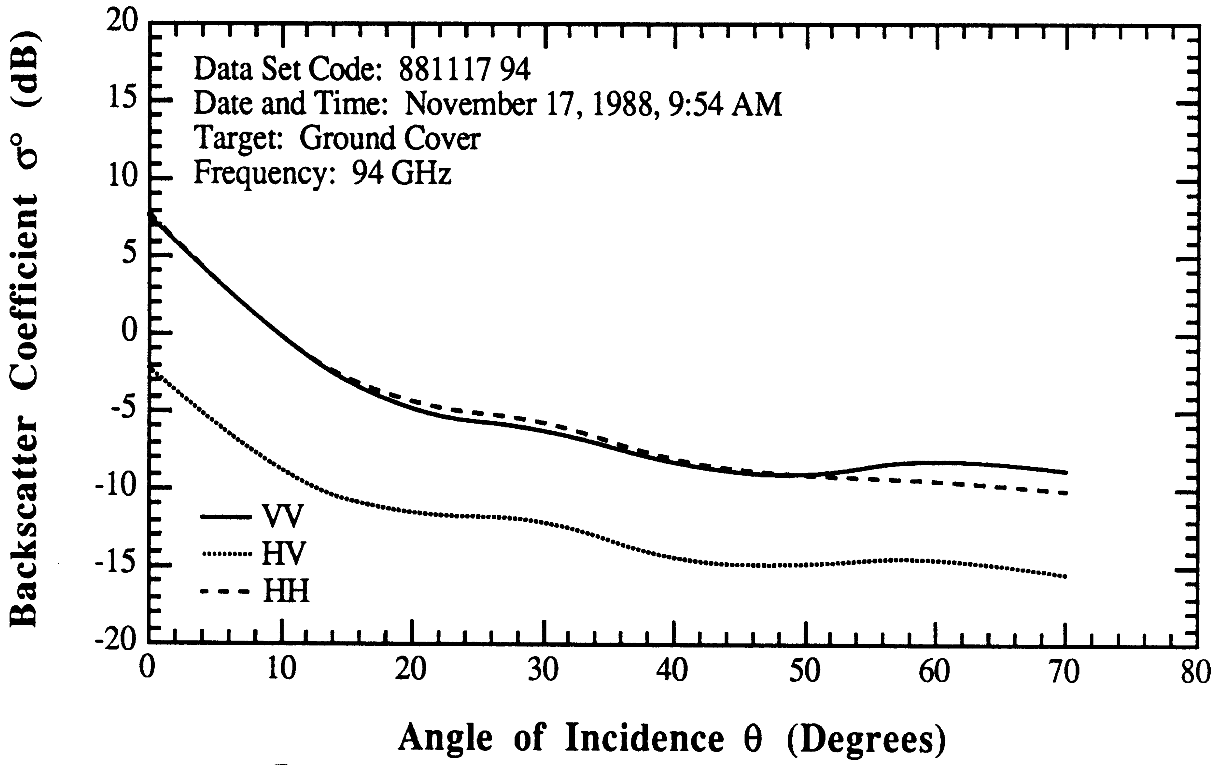
Purple loose strife (Lythrum salicaria)

MMW WAVE DATA FOR GRASSES

881117



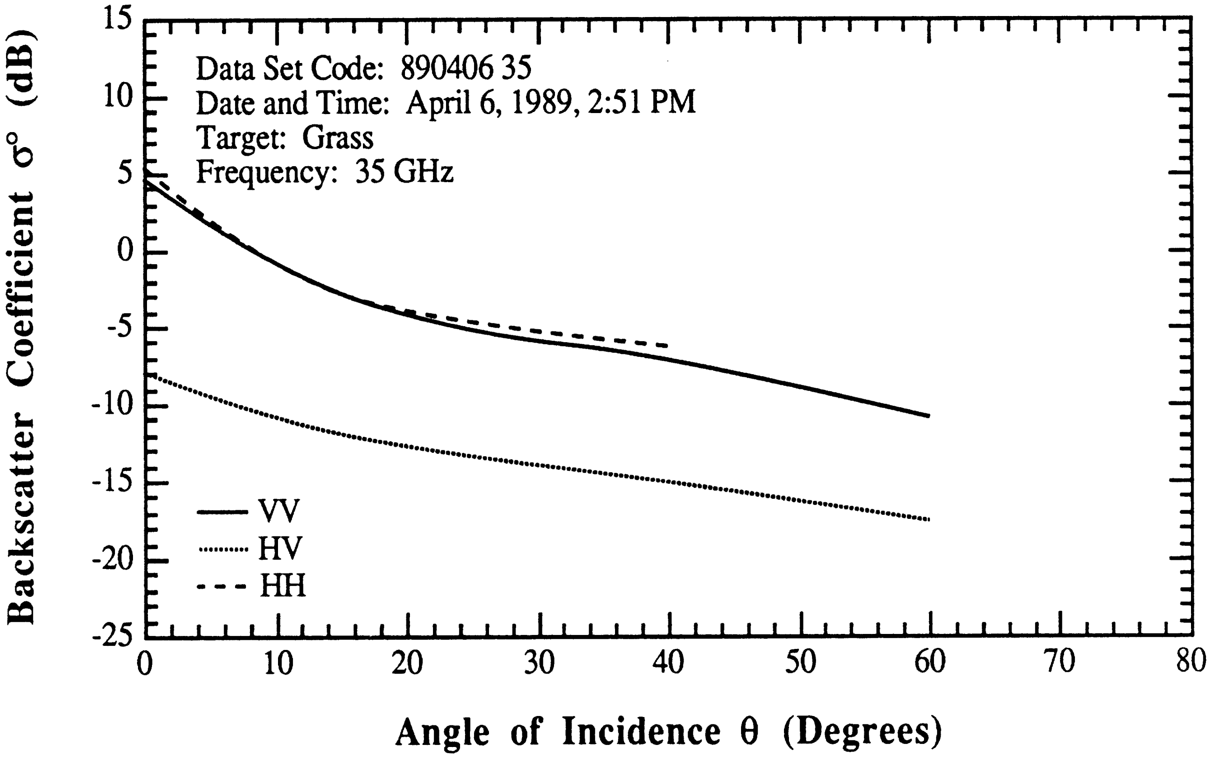
Purple Loose Strife over water (Lythrum salicaria)



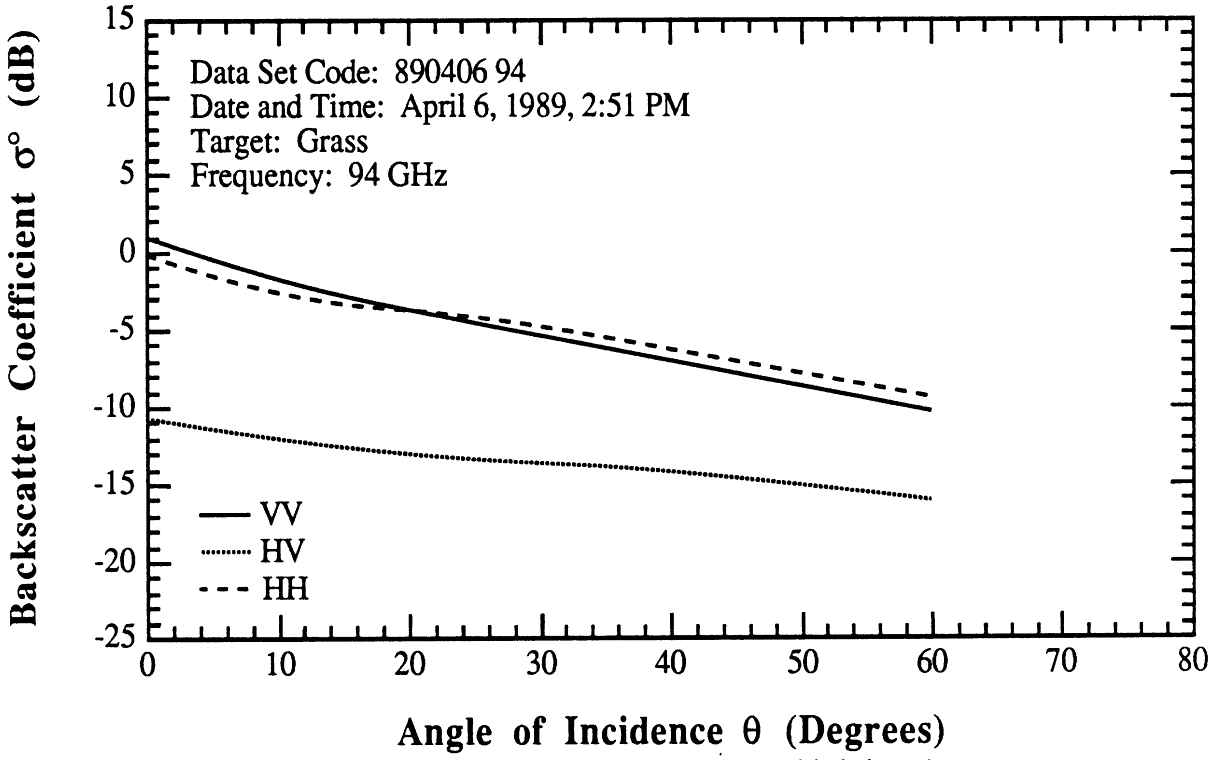
Purple Loose Strife over water (Lythrum salicaria)

MMW WAVE DATA FOR GRASSES

890406



Brighton grass substrate

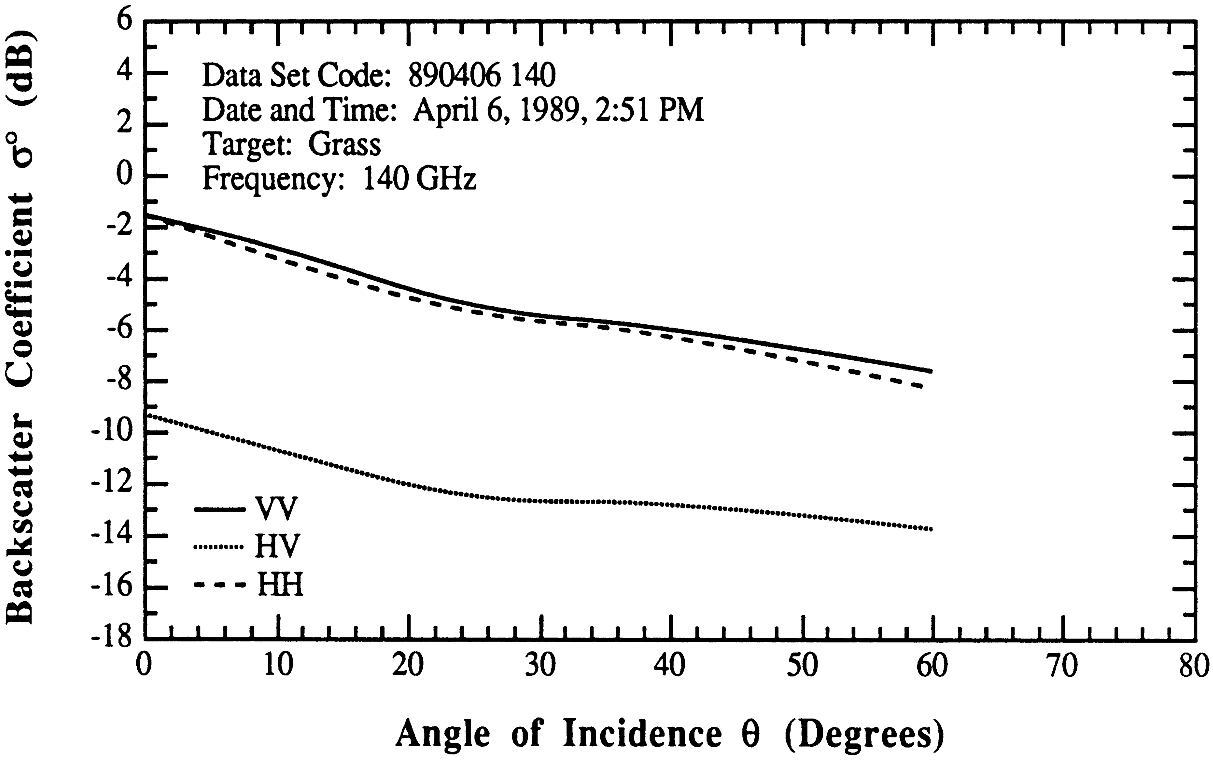


Leaf Moisture Content = 70% Height: 4 cm

Description: cut, packed down by winter's snow. This is the grass from under the Brighton snow for which data was taken in early 1989.

MMW WAVE DATA FOR GRASSES

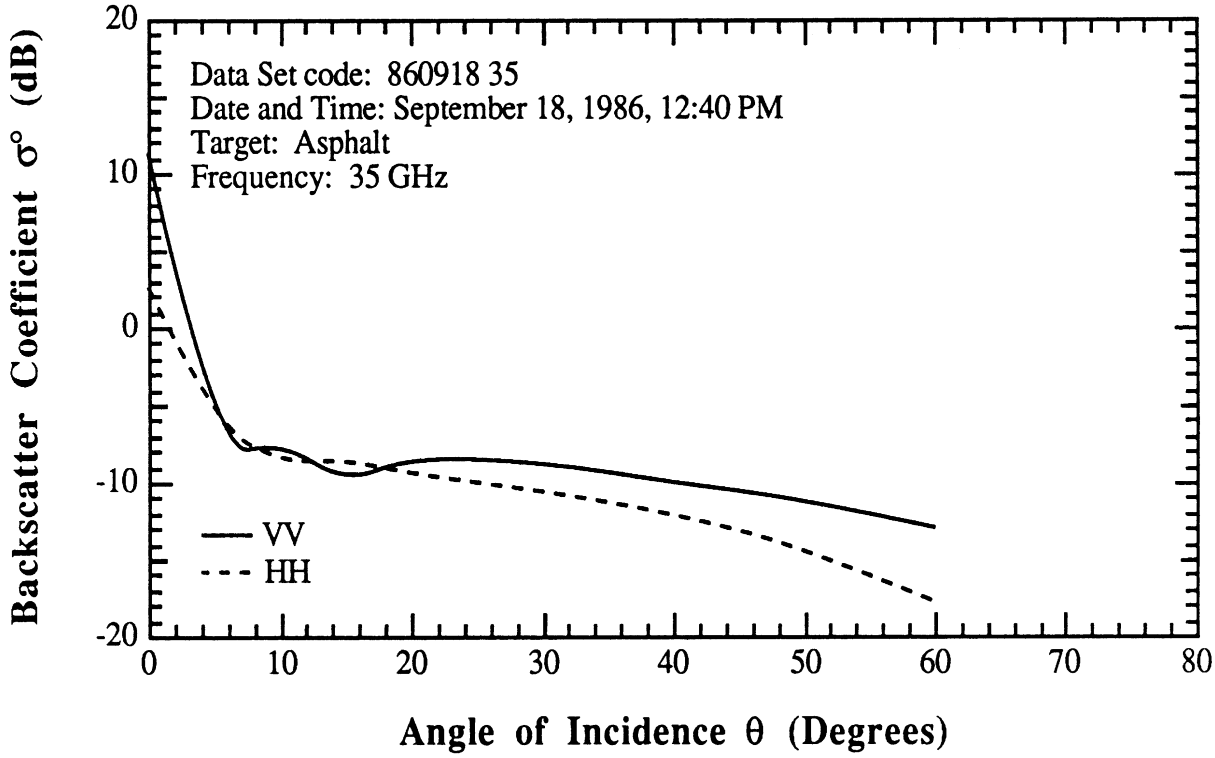
890406



Brighton grass substrate

MMW WAVE DATA FOR ROAD SURFACES

860918



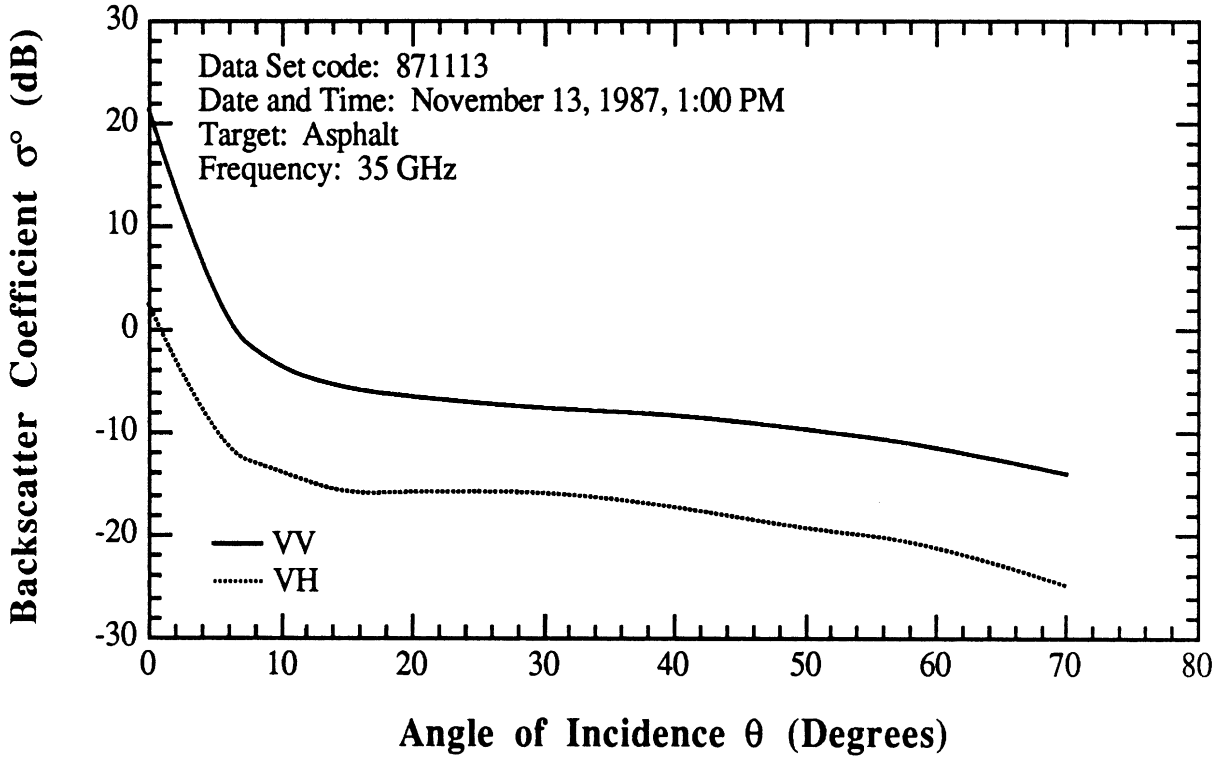
Dry Asphalt at Willow Run

Surface RMS height: 0.7 mm

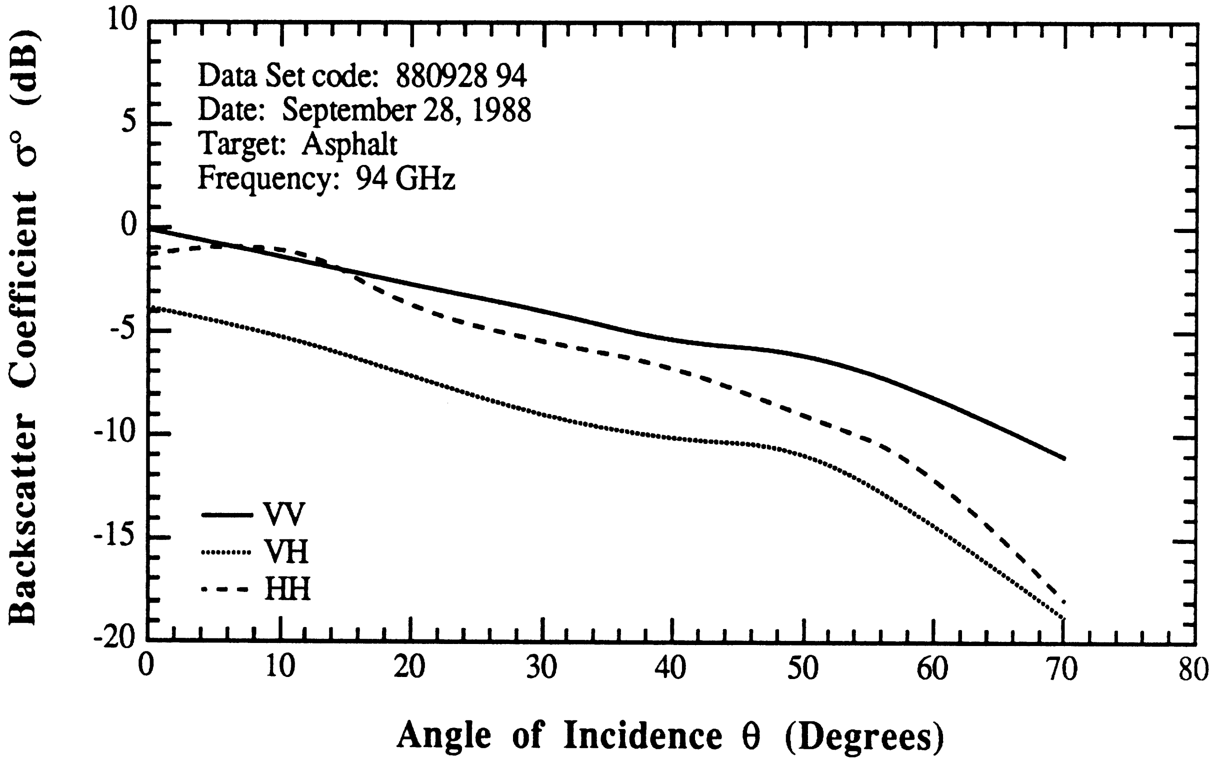
Description: smooth, dry asphalt

MMW WAVE DATA FOR ROAD SURFACES

871113



880928

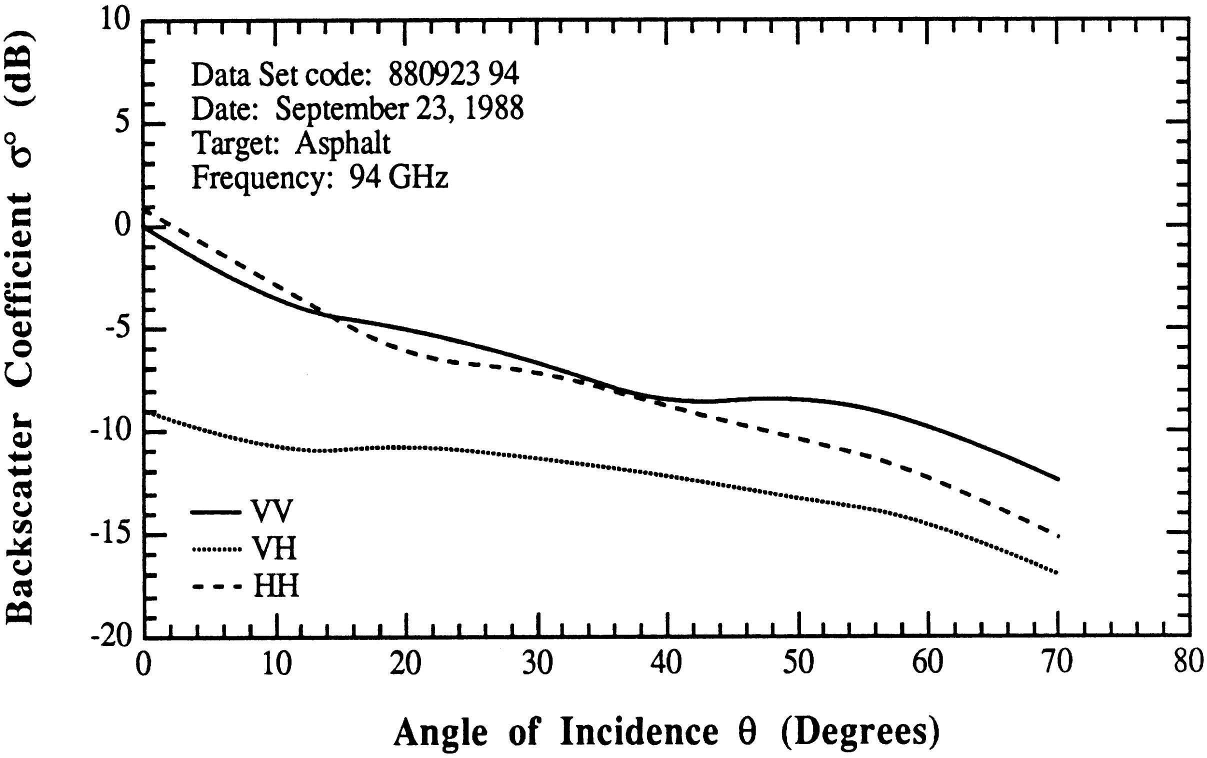


Asphalt Surface RMS height: 0.42 mm

Condition: Dry, smooth asphalt

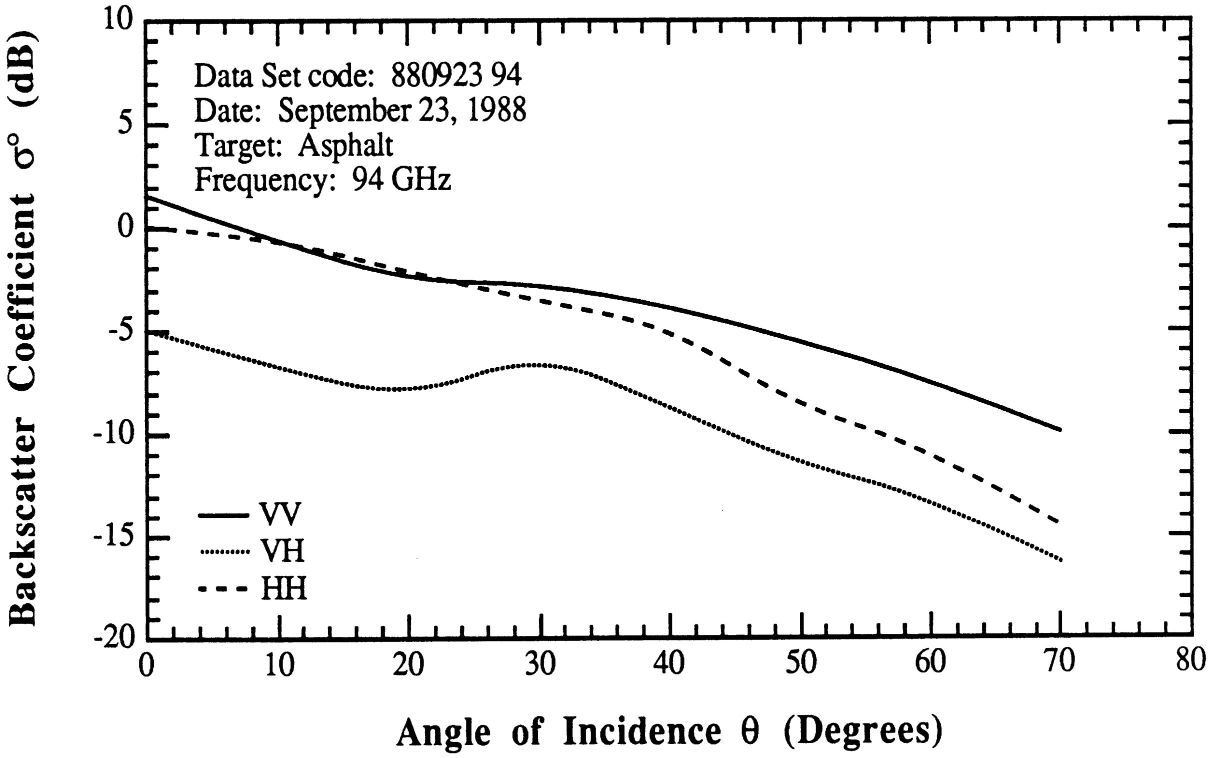
MMW WAVE DATA FOR ROAD SURFACES

880923 (1)



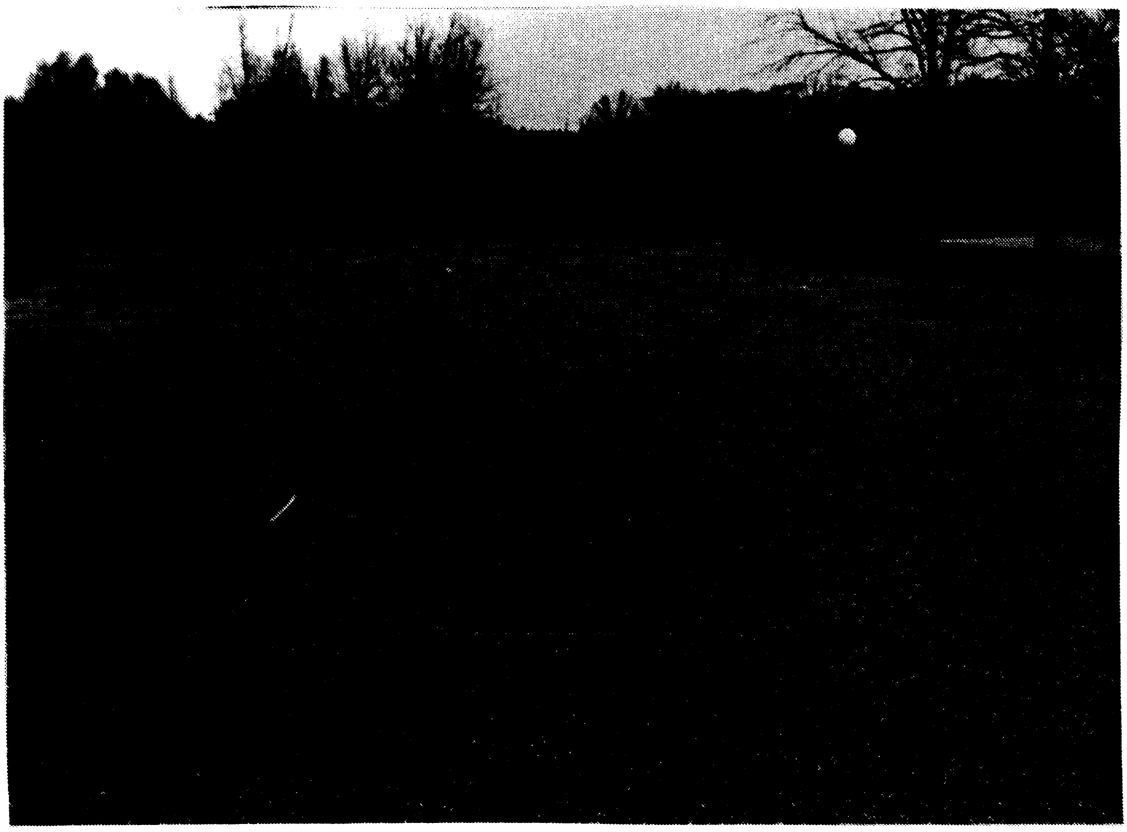
Damp Asphalt at Dow Parking Lot

880923 (2)



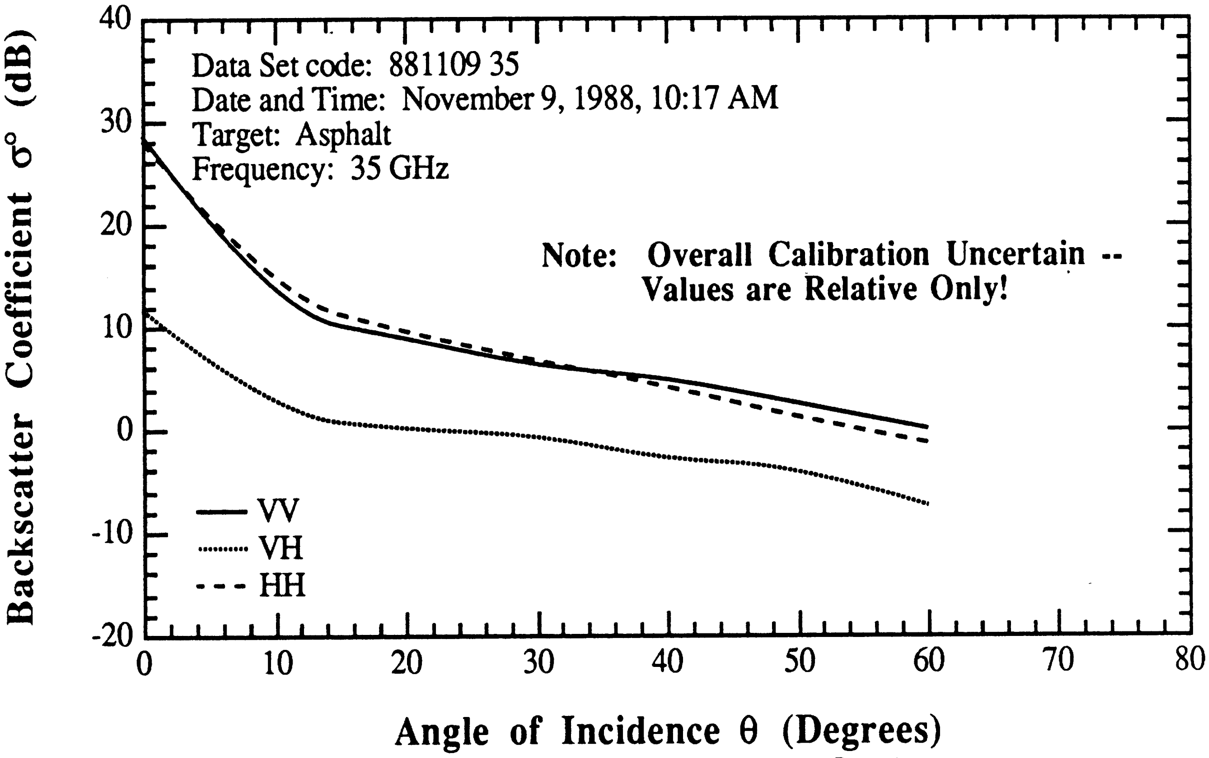
Dry Asphalt at Dow Parking Lot

Rough Asphalt
Data set code: 881109
Surface RMS height: ~ 2 mm
Condition: rough, dry asphalt



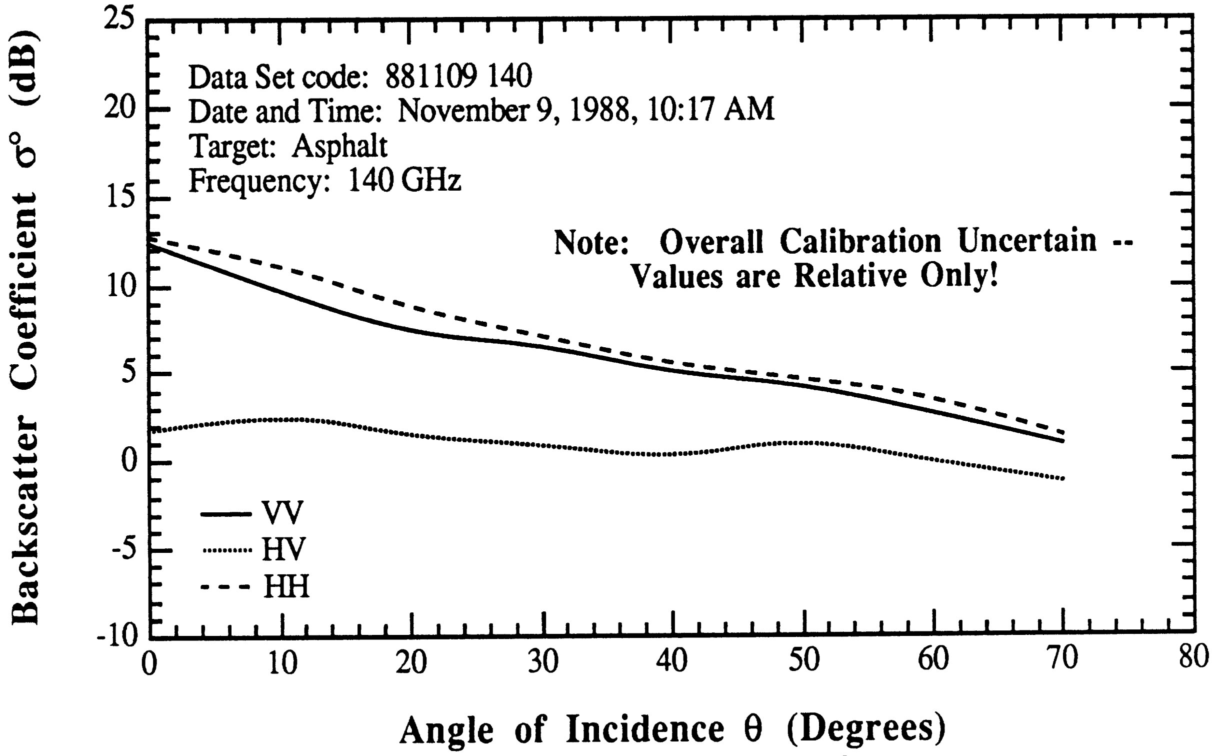
Asphalt at Botanical Gardens

881109



Rough Asphalt at Botanical Gardens

881109

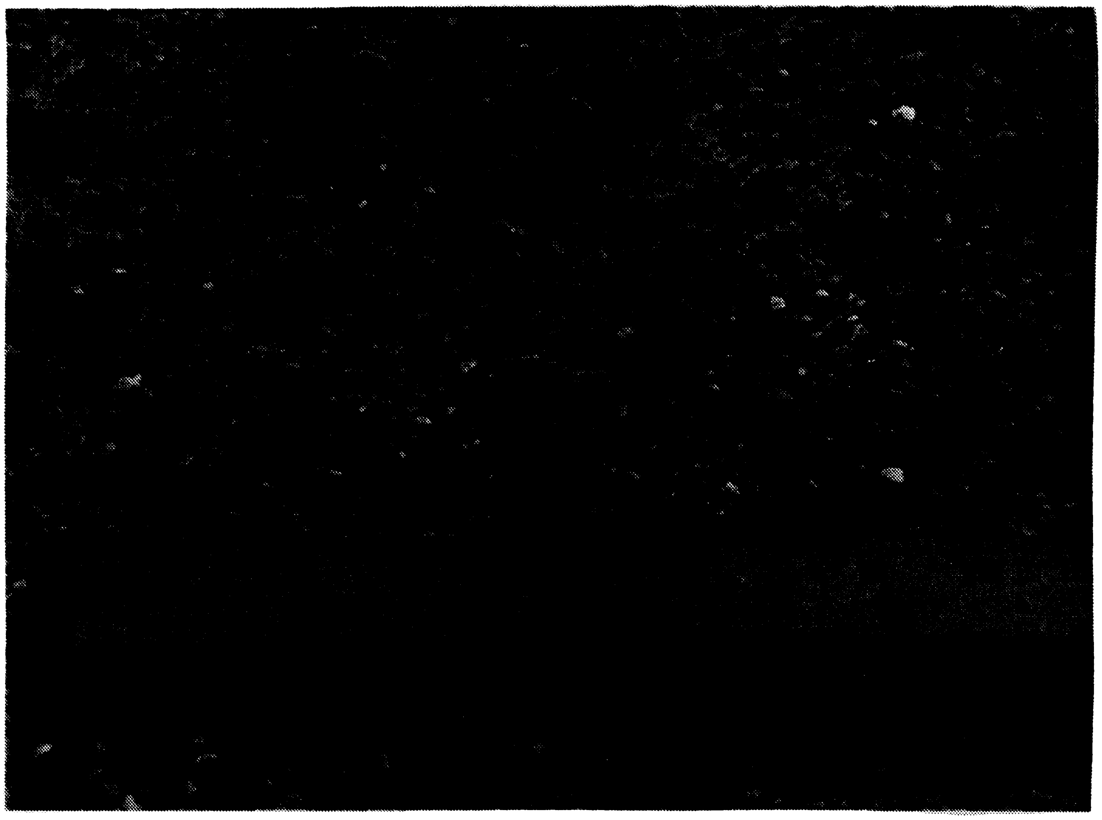


Rough Asphalt at Botanical Gardens

871113/880815

B. Gravel

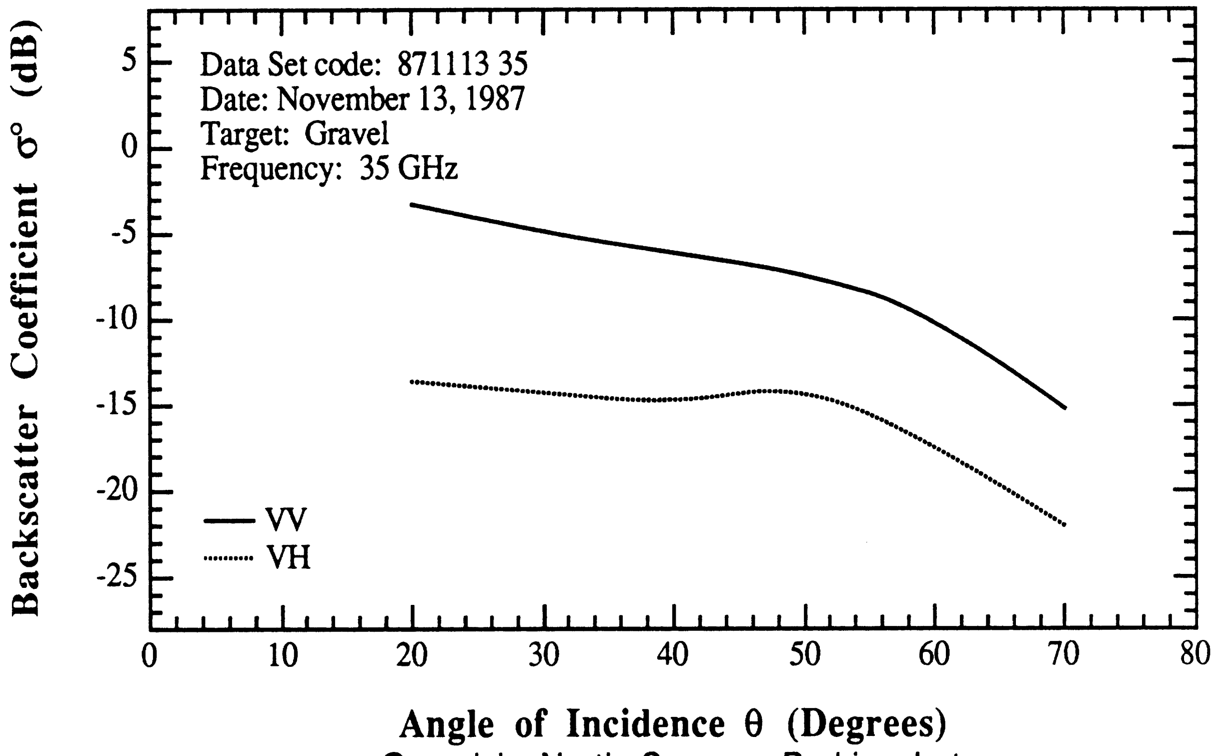
Gravel
Data set code: 871113 and 880815
Surface RMS height: ~ 2 mm
Typical stone size: ~ 6 mm
Description: dry gravel



Gravel in North Campus parking lot

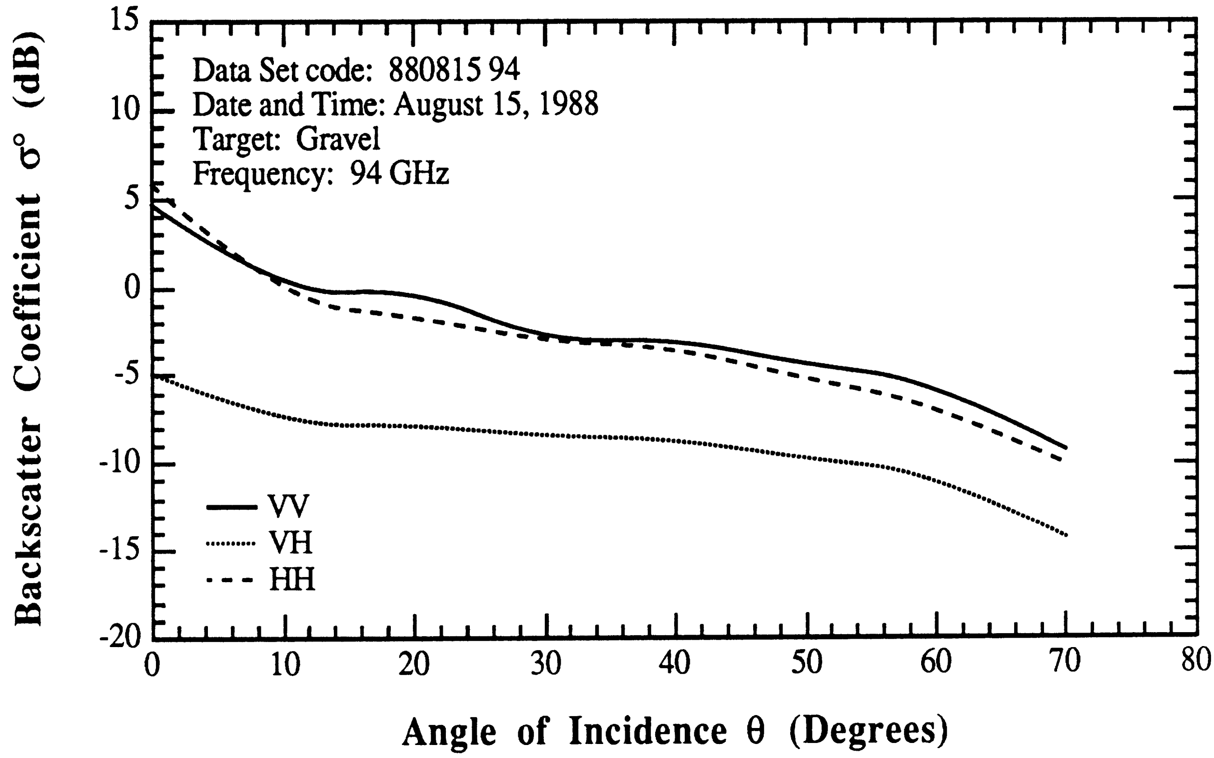
MMW WAVE DATA FOR ROAD SURFACES

871113



Gravel in North Campus Parking Lot

880815 (2)



Gravel in North Campus Parking Lot

PART II. UNIVERSITY OF MASSACHUSETTS DATA

Using a 215-GHz radar system, multipolarization backscatter measurements were made by the University of Massachusetts [15, 16] for various types of trees and for snow covered terrain in 1987 and 1988. The measurements were made from a 80-m high tower at the University of Massachusetts. The radar system used an extended interaction oscillator (EIO) capable of producing 100-ns pulses with 60 W of peak power. The transmit antenna consisted of a 15-cm lens fed by a corrugated scalar horn, with a beam width of 0.64°, and the receiver antenna was a horn with a wide beam width of 23°.

9. 215-GHZ DATA FOR TREES

Table II-1 provides a summary of the parameters of the trees for which the backscattering coefficient σ^o was measured. The radar observations were made as a function of time over an approximately six-month period, and were augmented with ground-truth measurements including:

GLWC: gravimetric liquid water content of leaves

Cover: percentage of the sky covered by leaves and branches as seen looking up from the base of the tree

Normalized Leaf Area: Average leaf area of between 10 and 50 leaf samples, normalized to the maximum value during the season.

TABLE II-1

CHARACTERISTICS OF TREES SELECTED FOR STUDY

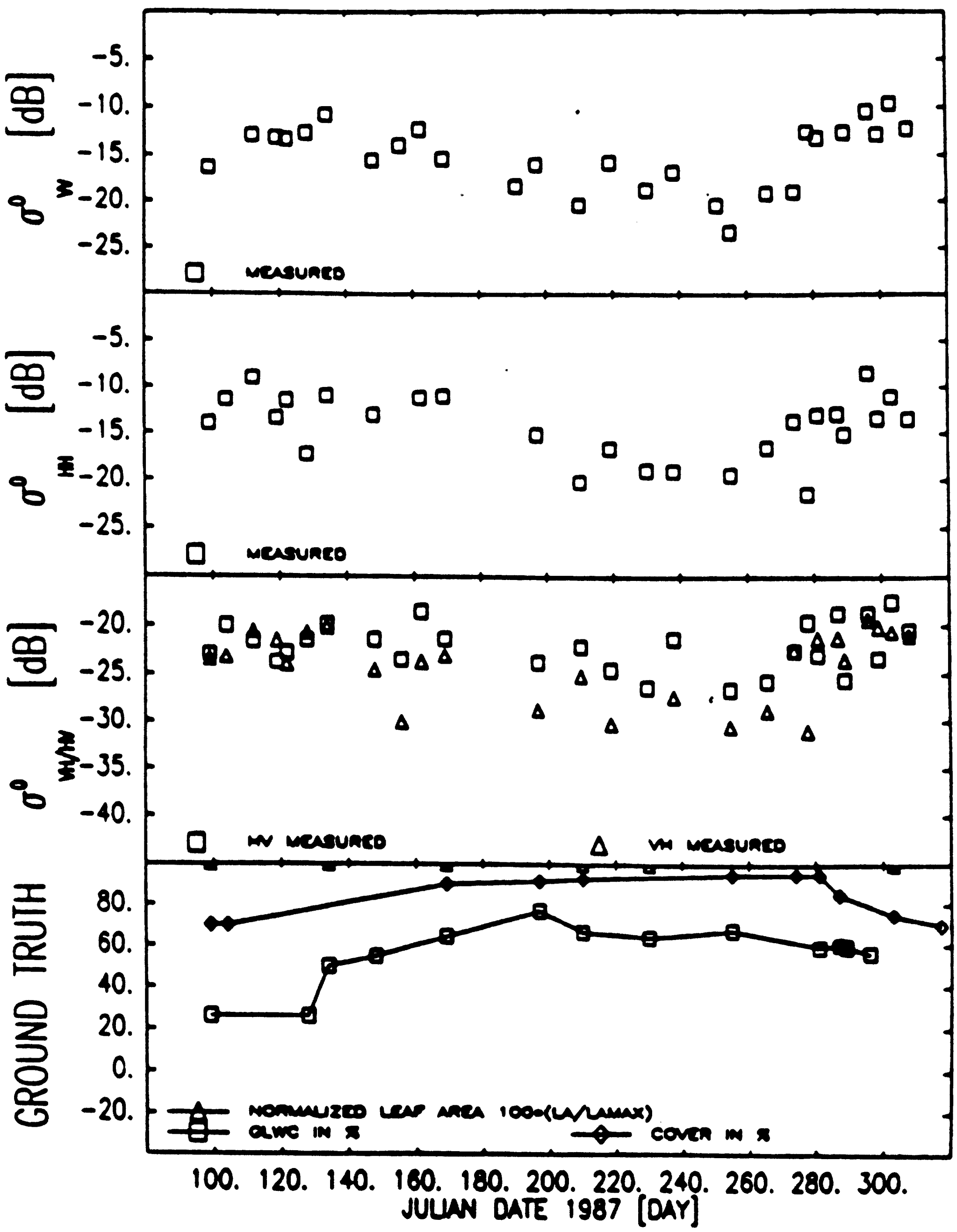
Tree Code	Tree Name (*Latin Name*)	Basal Diameter [m]	Canopy Height [m]	Crown Diameter [m]	Canopy Cover Day 99 [%]	Canopy Cover 210 [%]	Tree Type	Position Depression [deg]	Position Azimuth [deg]
A	Northern White Cedar (*Thuja occidentalis*)	0.15-0.3	13.	5.	90	90	C	28.8	56.5
B	White Pine (*Pinus strobus*)	0.73	30.	16.	85	90	E	20.8	41.
C	Fir (*Abies spp.*)	0.48	21.	8.	80	85	D	21.9	38.5
D	Sugar Maple (*Acer saccharum*)	0.32	19.	14.	40	95	A	19.2	31.5
E	Eastern Cottonwood (*Populus deltoides*)	0.43	25.	3.	35	65	B	24.3	30.5
F	Pin Oak (*Quercus palustris*)	1.05	38.	24.	45	90	E	14.2	37.
G	Black Oak (*Quercus velutina*)	1.02	20.	24.	30	90	A	11.6	43.
H	Silver Maple (*Acer saccharinum*)	0.78	21.	20.	30	75	A	11.8	46.
I	Weeping Willow (*Salix babylonica*)	0.82	22.	15.	50	90	B	10.4	49.5
J	White Pine (*Pinus strobus*)	1.05	27.	13.	85	95	E	10.4	51.
L	White Pine (*Pinus strobus*)	0.6	27.	14.	85	90	E	8.3	56.5
M	Pin Oak (*Quercus Palustris*)	0.92	20.	14.	35	90	B	9.1	58.
N	Red Maple (*Acer rubrum*)	1.01	14.	15.	35	80	A	9.7	59.
O	Group of White Pines	0.5-0.8	20.-30.	5.-10.	85	90	E	9.4	63.5
X	Mixed Forest*	0.2-0.6	15.-25.	3.-8.	35	85	AB	8.3	53.
Y	Mixed Forest**	0.2-0.6	15.-25.	3.-8.	35	85	AB	6.6	53.
Z	Mixed Forest***	0.2-0.6	15.-25.	3.-8.	35	85	ABE	7.0	60.5

* Eastern Cottonwood (*Poplus deltoides*), Grapes (*Vitis sspp.*), Glossy Buckthorn (*Rhamnus frangula*) and Red Maple (*Acer rubrum*)

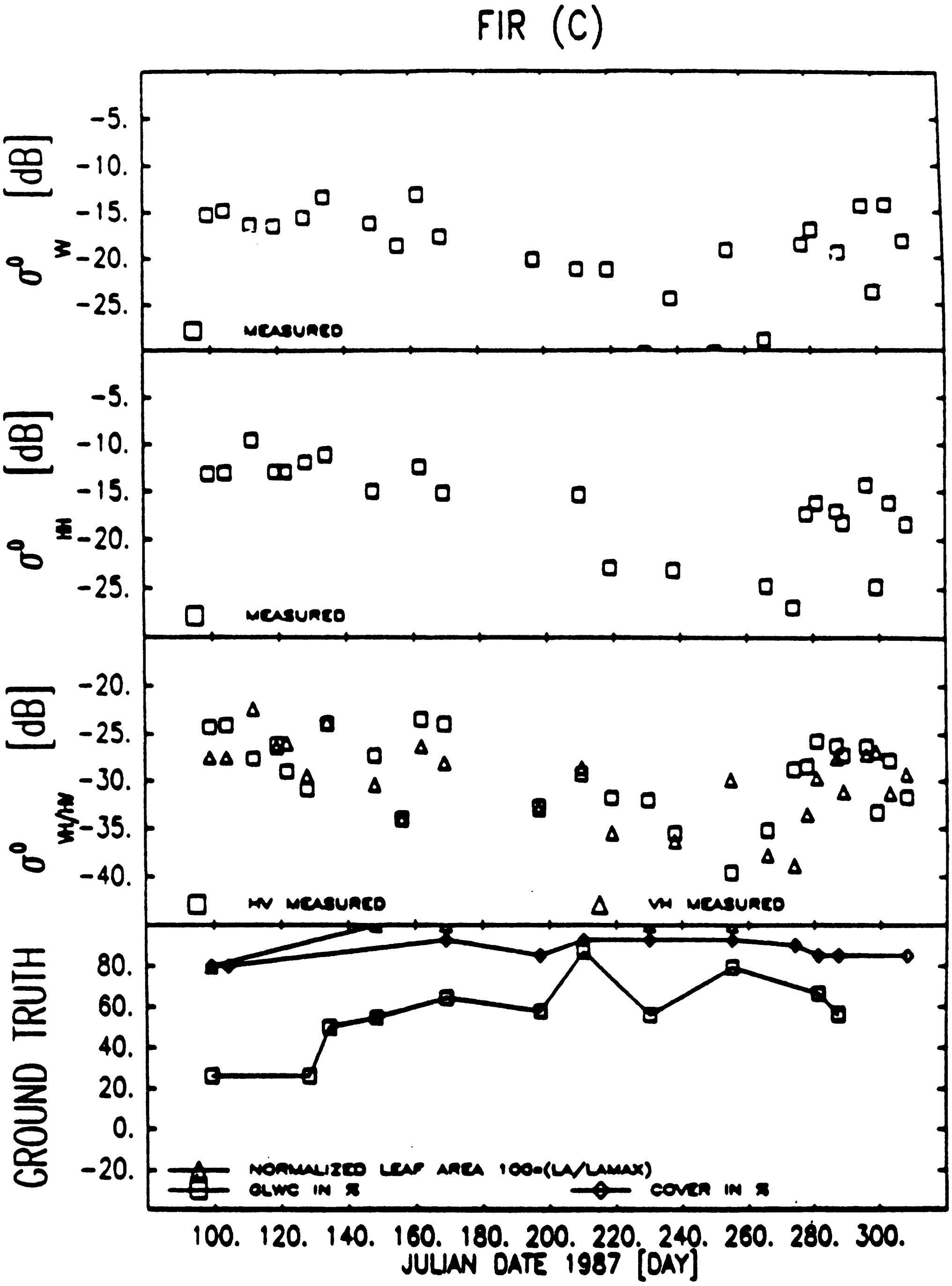
** Eastern Cottonwood (*Poplus deltoides*) and Red Maple (*Acer rubrum*)

*** Red Maple (*Acer rubrum*), Pin Oak (*Quercus Palustris*) and White Pine (*Pinus strobus*)

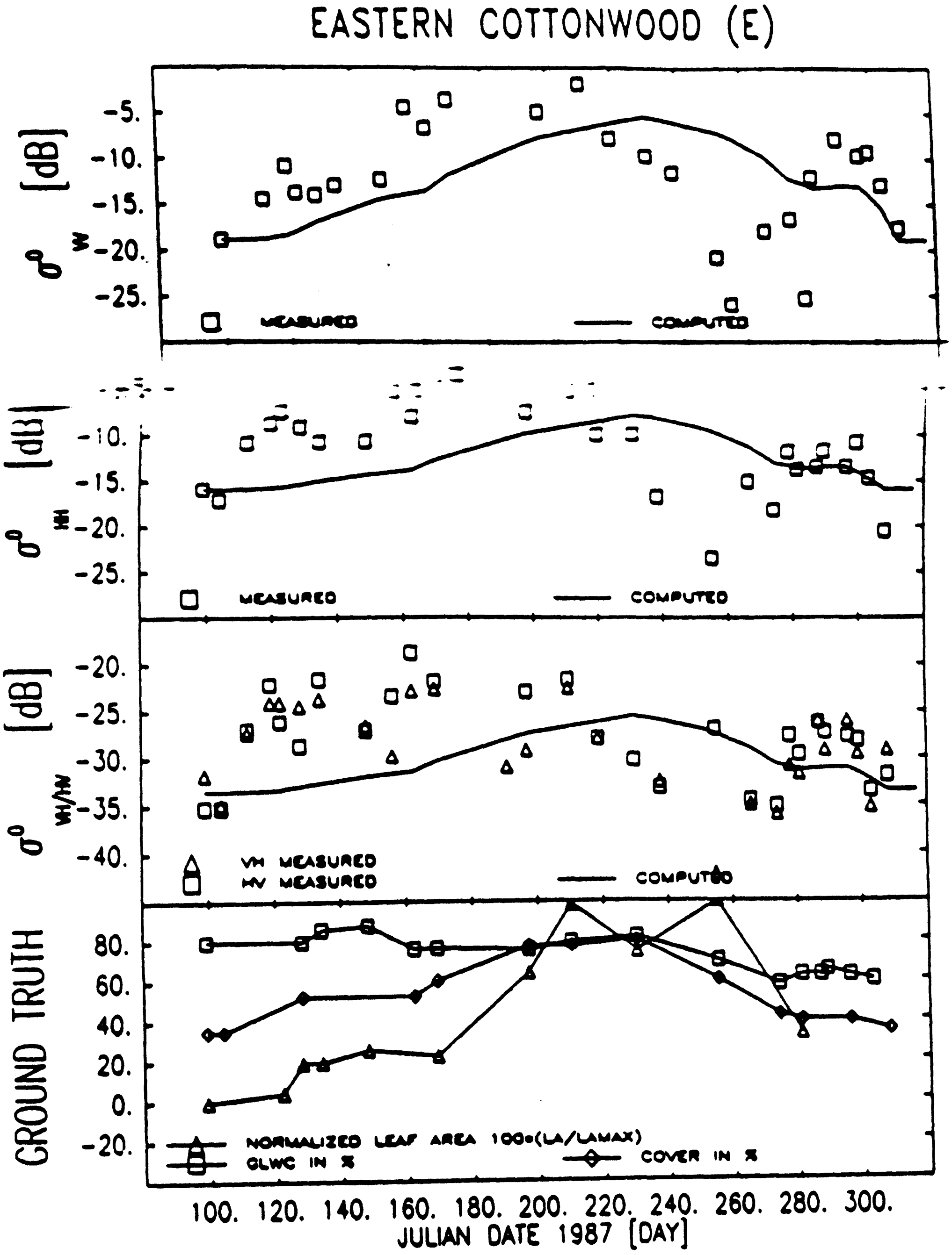
WHITE PINE (B)



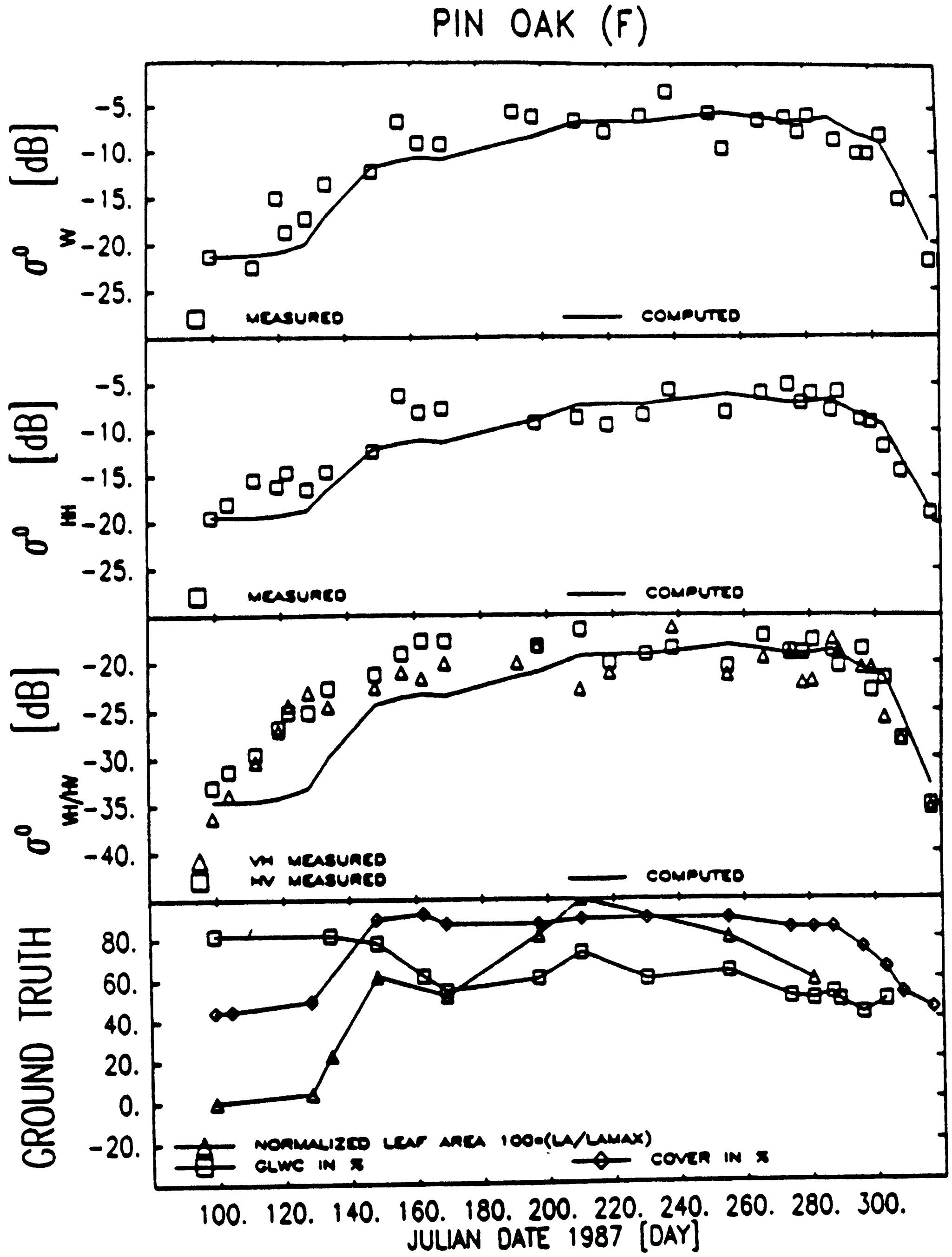
Curves showing measured σ^0 versus Julian date for VV, HH, and VH/HV polarizations for White Pine (B). Also shown is the corresponding measured ground truth data.



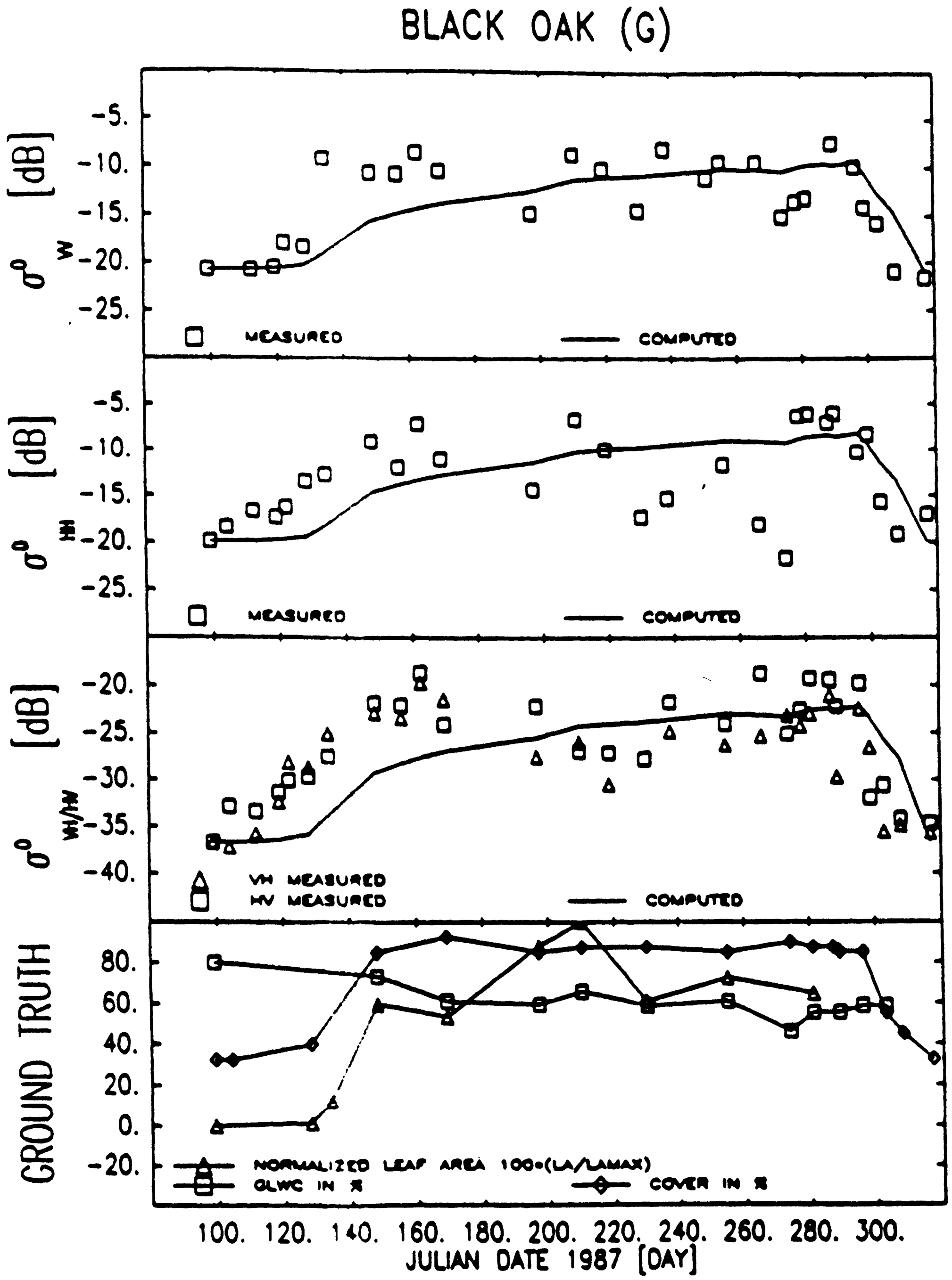
Curves showing measured σ^{o} versus Julian date for VV, HH, and VH/HV polarizations for Fir (C). Also shown is the corresponding measured ground truth data.



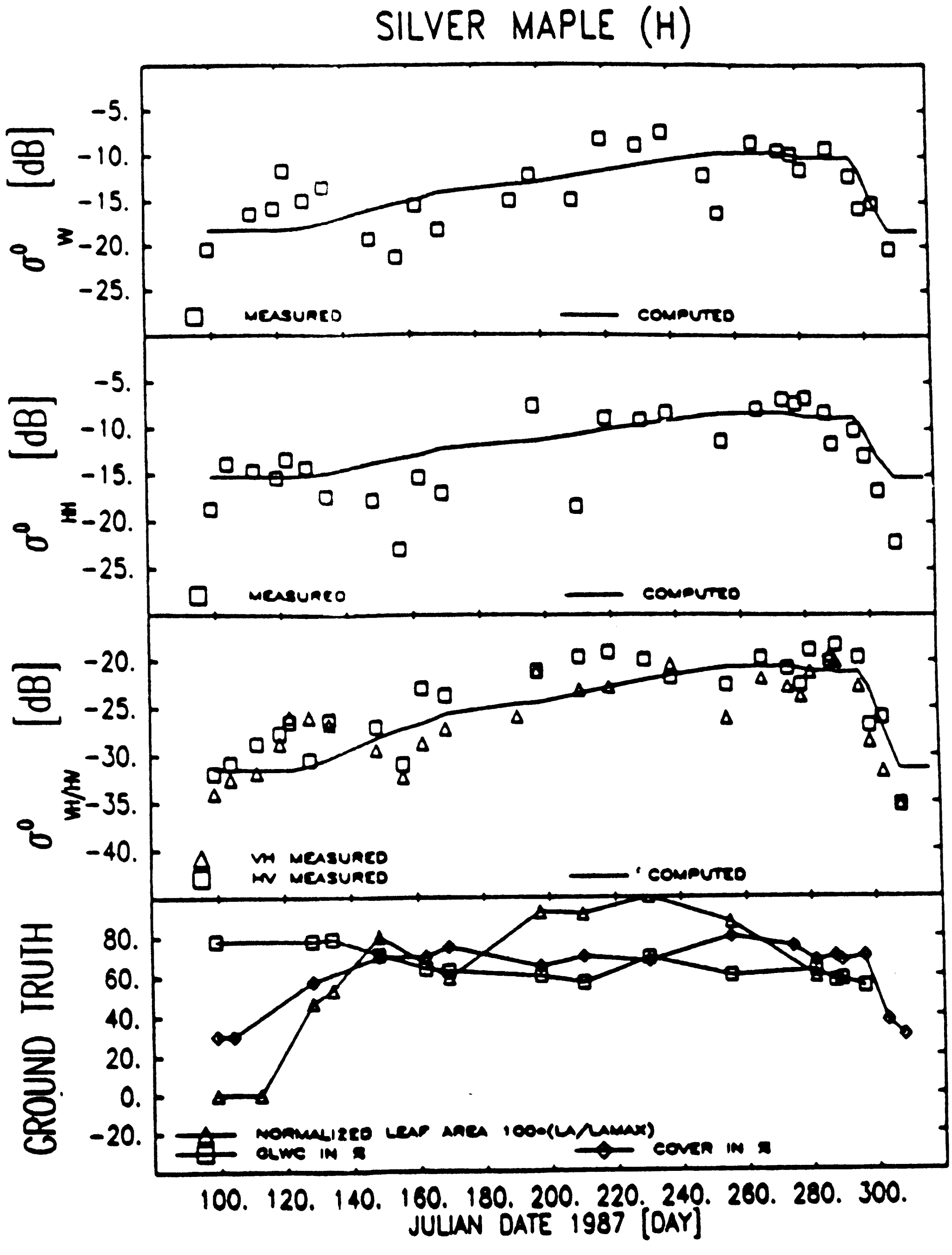
Curves showing measured and computed σ^o versus Julian date for VV, HH, and VH/HV polarizations for Eastern Cottonwood (E). Also shown is the corresponding measured ground truth data.



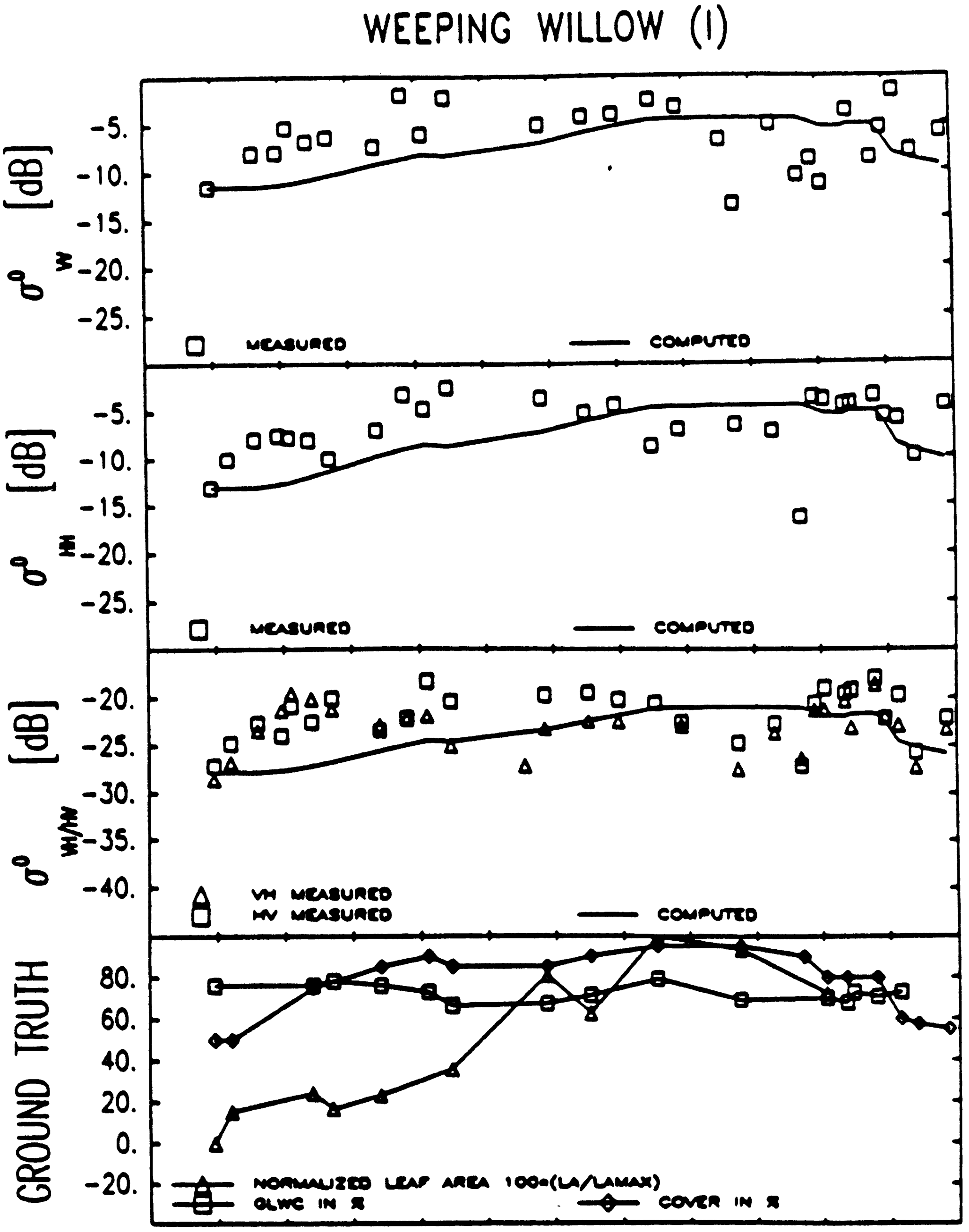
Curves showing measured and computed σ^o versus Julian date for VV, HH, and VH/HV polarizations for Pine Oak (F). Also shown is the corresponding measured ground truth data.



Curves showing measured and computed σ^0 versus Julian date for VV, HH, and VH/HV polarizations for Black Oak (G). Also shown is the corresponding measured ground truth data.

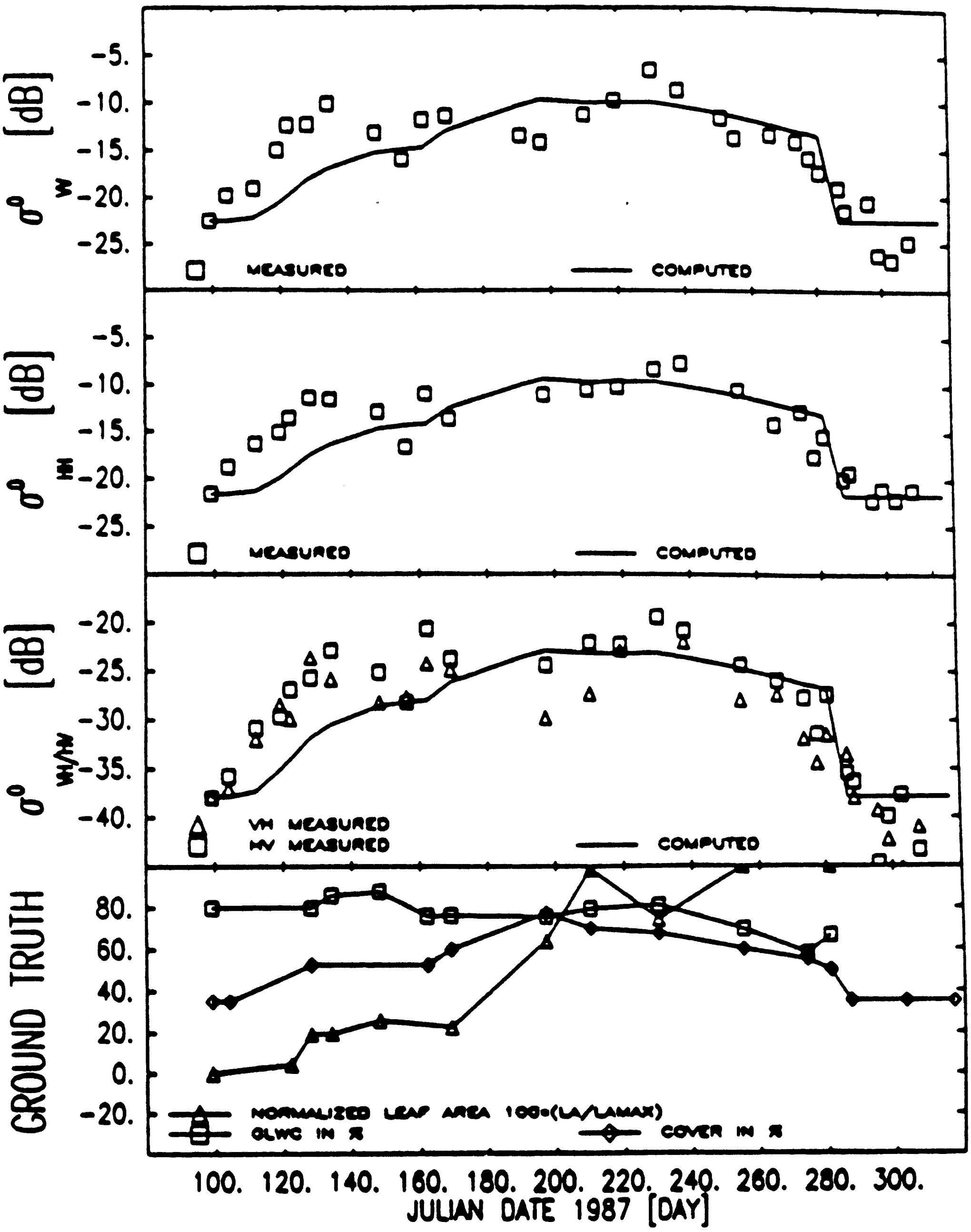


Curves showing measured and computed σ^o versus Julian date for VV, HH, and VH/HV polarizations for Silver Maple (H). Also shown is the corresponding measured ground truth data.



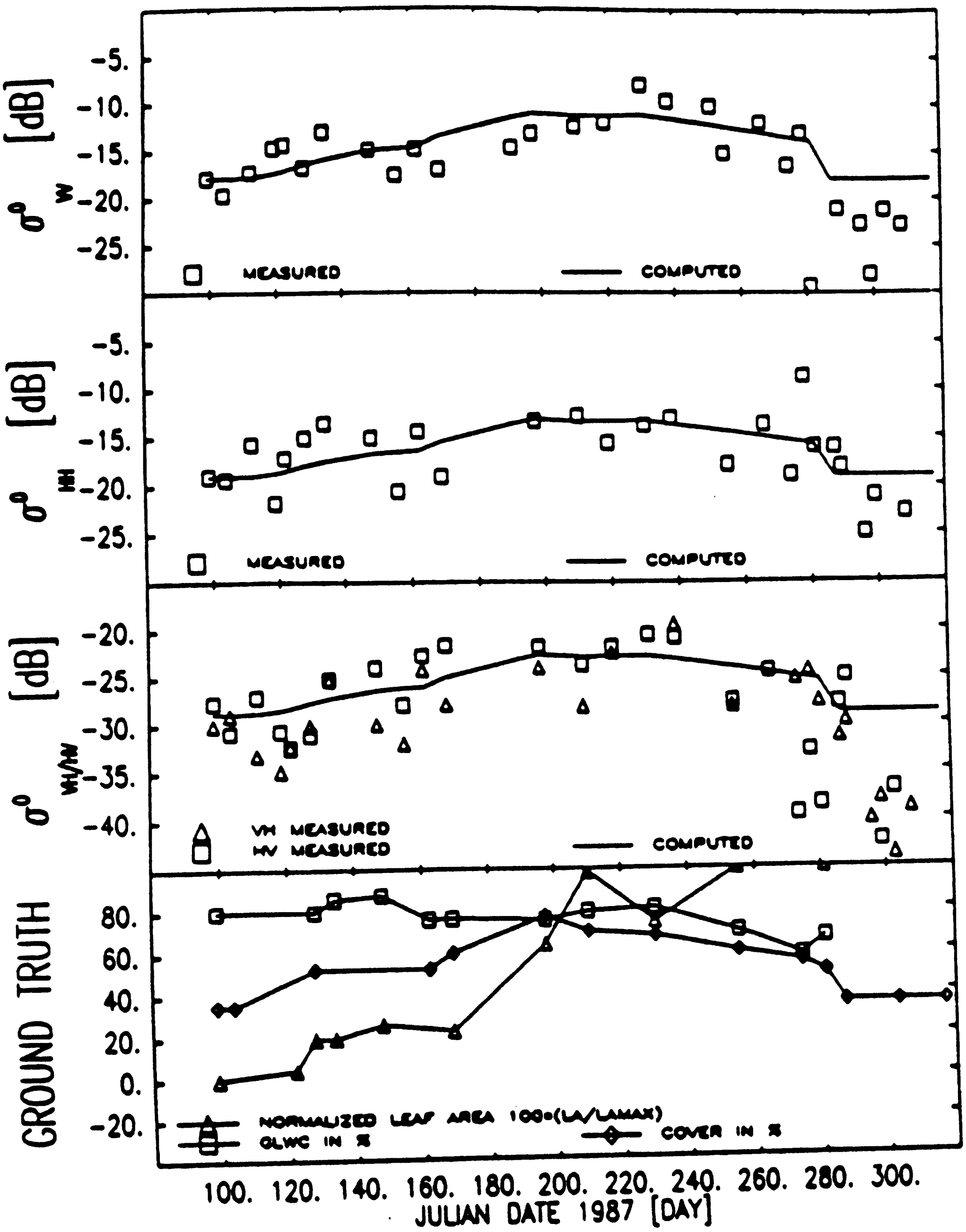
Curves showing measured and computed σ^0 versus Julian date for VV, HH, and VH/HV polarizations for Weeping Willow (I). Also shown is the corresponding measured ground truth data.

MIXED FOREST (X)

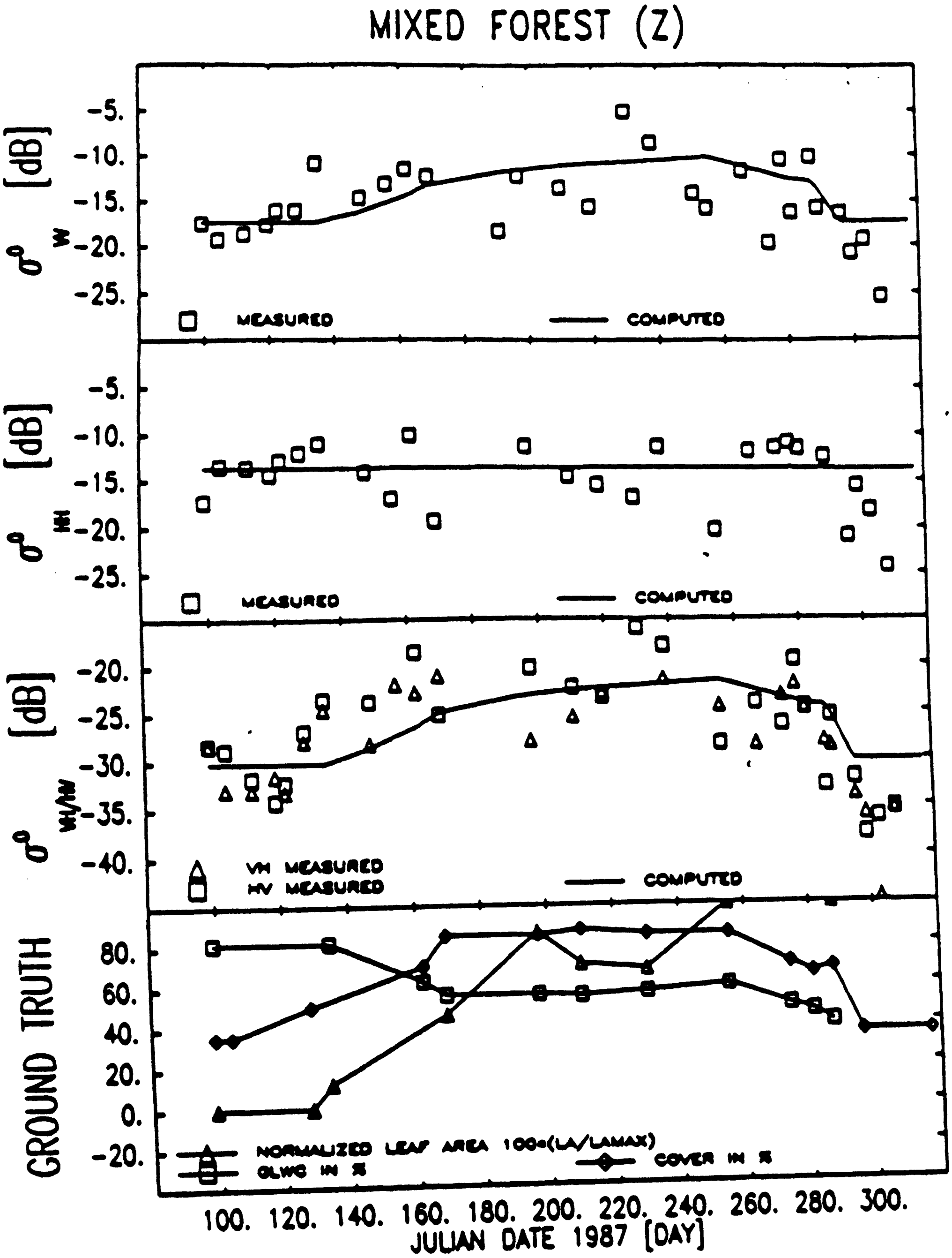


Curves showing measured and computed σ^o versus Julian date for VV, HH, and VH/HV polarizations for Mixed Forest (X). Also shown is the corresponding measured ground truth data.

MIXED FOREST (Y)



Curves showing measured and computed σ^o versus Julian date for VV, HH, and VH/HV polarizations for Mixed Forest (Y). Also shown is the corresponding measured ground truth data.



Curves showing measured and computed σ^o versus Julian date for VV, HH, and VH/HV polarizations for Mixed Forest (Z). Also shown is the corresponding measured ground truth data.

10. 215-GHZ DATA FOR SNOW

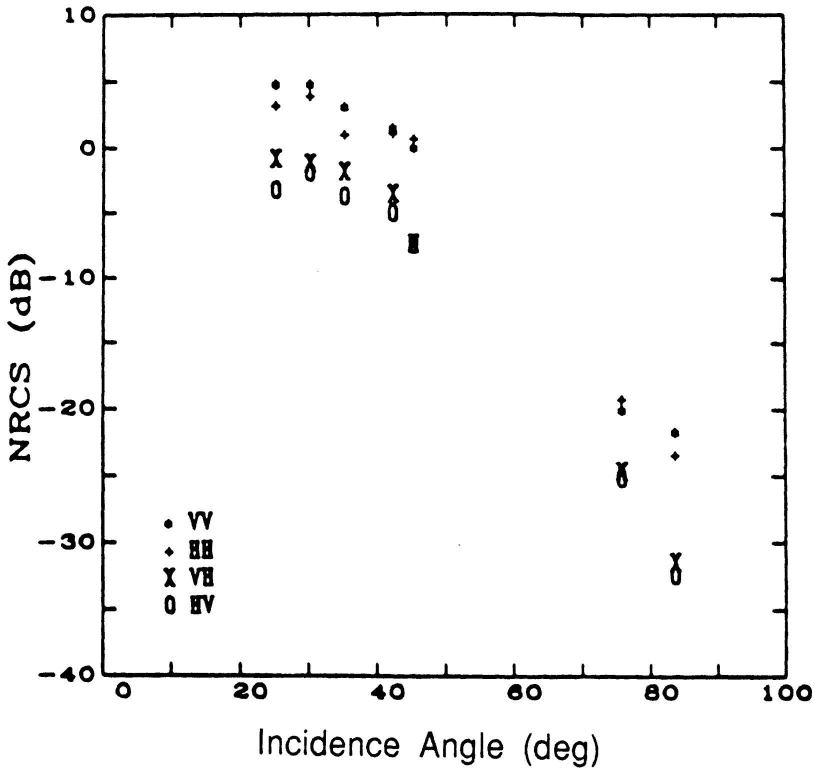
The snow observations, which were made from the same tower platform, included measurements at various incidence angles extending from 25° to 83.2°, corresponding to ground areas for which the radar had an unobstructed view. Table II-2 provides a summary of the ground truth observations that were recorded in support of the radar measurements.

TABLE II-2

GROUND TRUTH FOR SNOW DATA SHOWN IN FIG. 3

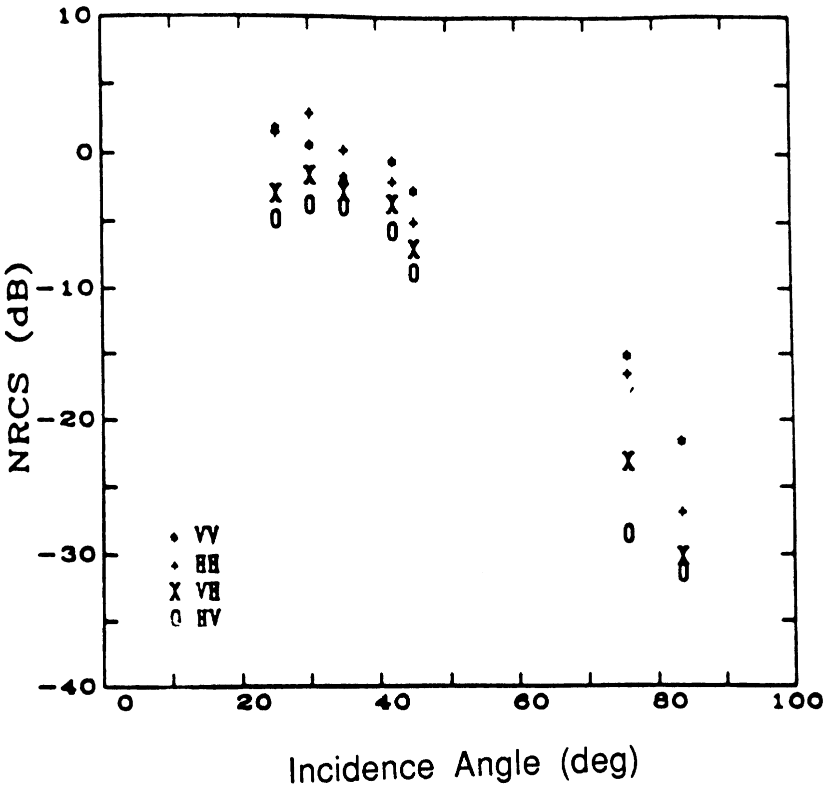
Day # (Fig. Ref.)	RMS Surface Roughness (mm)	No. of Layers	Layer #	Particle Size (mm) Minimum	Maximum	Temperature (°C)	Density (gm/cc)	Volumetric Moisture (%)	Layer Thickness (mm)
7 (no figure)	0.96	2	1 (Bottom)	3	6	-3.0	0.190	0.00	30.0
			2 (Top)	3	8	-8.5	0.260	0.00	42.5
8 (Fig. 5a)	1.32	3	1 (Bottom)	3	10	0.0	0.200	0.00	15.0
			2 (Middle)	2	10	1.0	0.210	1.08	60.0
			3 (Top)	2	5	-1.0	0.090	0.68	45.0
9 (Fig. 3e)	1.03	2	1 (Bottom)	3	16	-1.0	0.245	0.40	40.0
			2 (Top)	3	10	-4.5	0.225	0.00	55.0
10 (Fig. 3c)	1.35	2	1 (Bottom)	3	15	0.0	0.255	0.93	42.5
			2 (Top)	3	9	-3.5	0.190	0.00	47.5
11 (Figs. 3a & 5b)	1.16	2	1 (Bottom)	1	10	0.0	0.240	1.77	42.5
			2 (Top)	1	10	0.0	0.205	0.15	65.0
12 (Fig. 3b)	1.17	1	1	2	6	1.5	0.200	1.30	67.5
13 (Fig. 5c)	1.32	1	1	1	4	-1.5	0.120	0.85	50.0
14 (Fig. 3d)	1.58	2	1 (Bottom)	1	3	-1.0	0.180	1.90	60.0
			2 (Top)	1	3	-2.0	0.160	0.00	50.0

SNOW AT 215 GHz: DAY 09

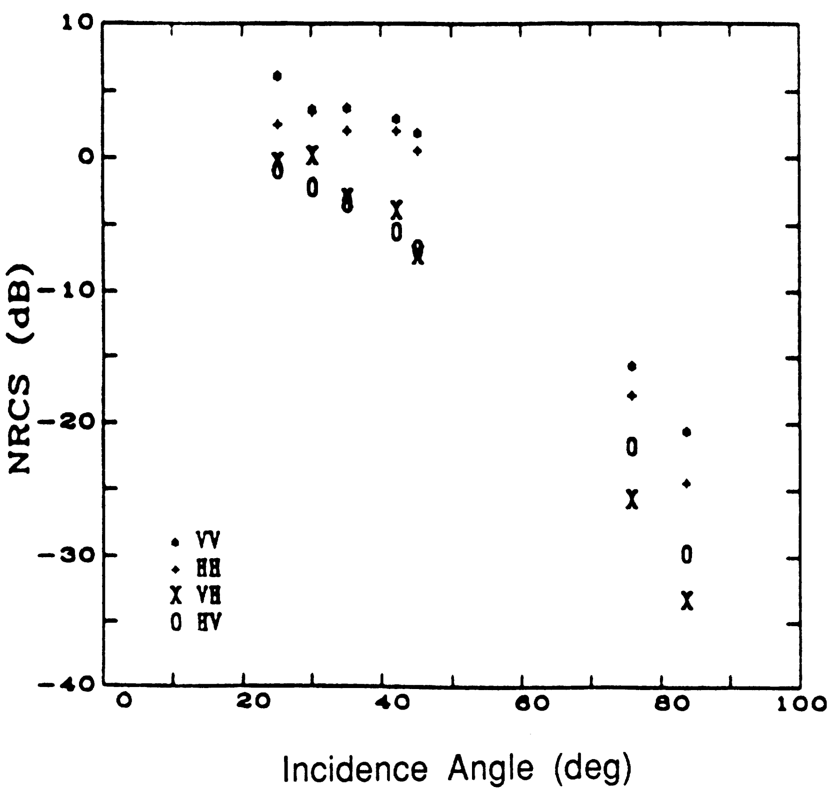


Measured value of σ^o_{VV} (*), σ^o_{HH} (+), σ^o_{VH}(X), and σ^o_{HV} (0) of snow at 215 GHz

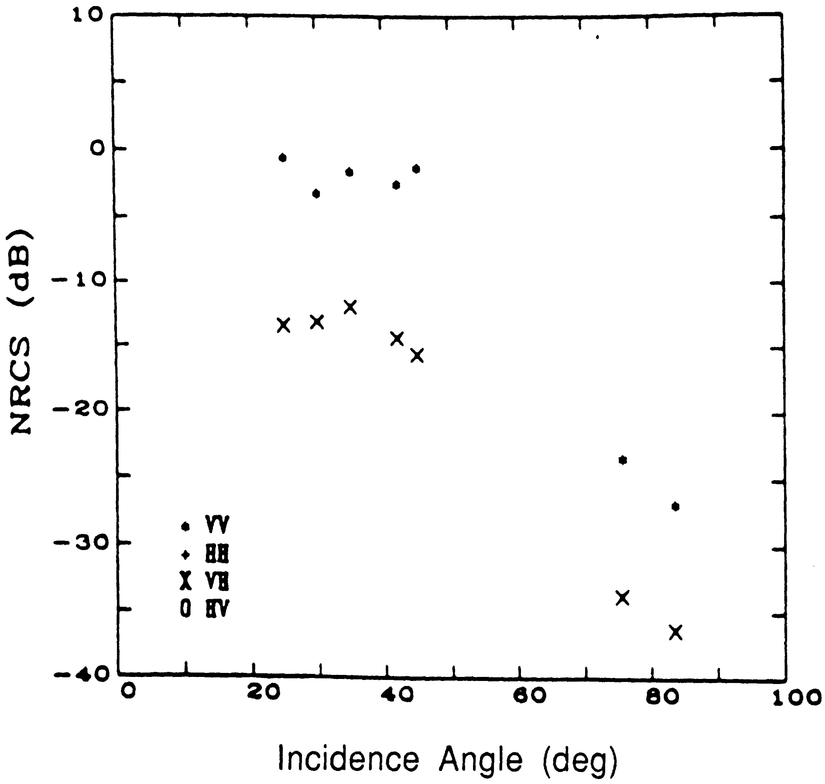
SNOW AT 215 GHz: DAY 11



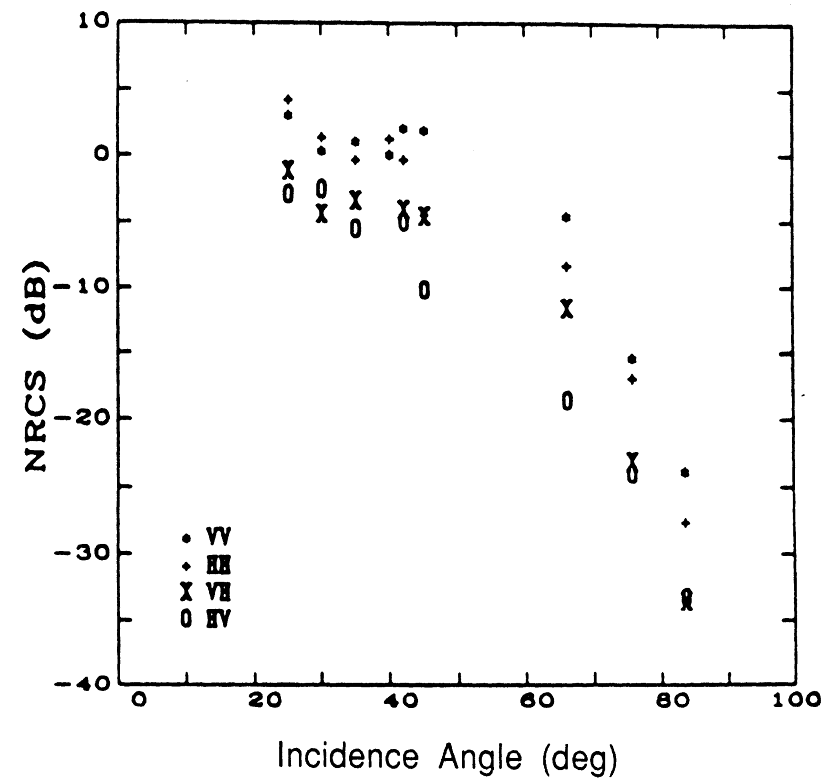
SNOW AT 215 GHz: DAY 10

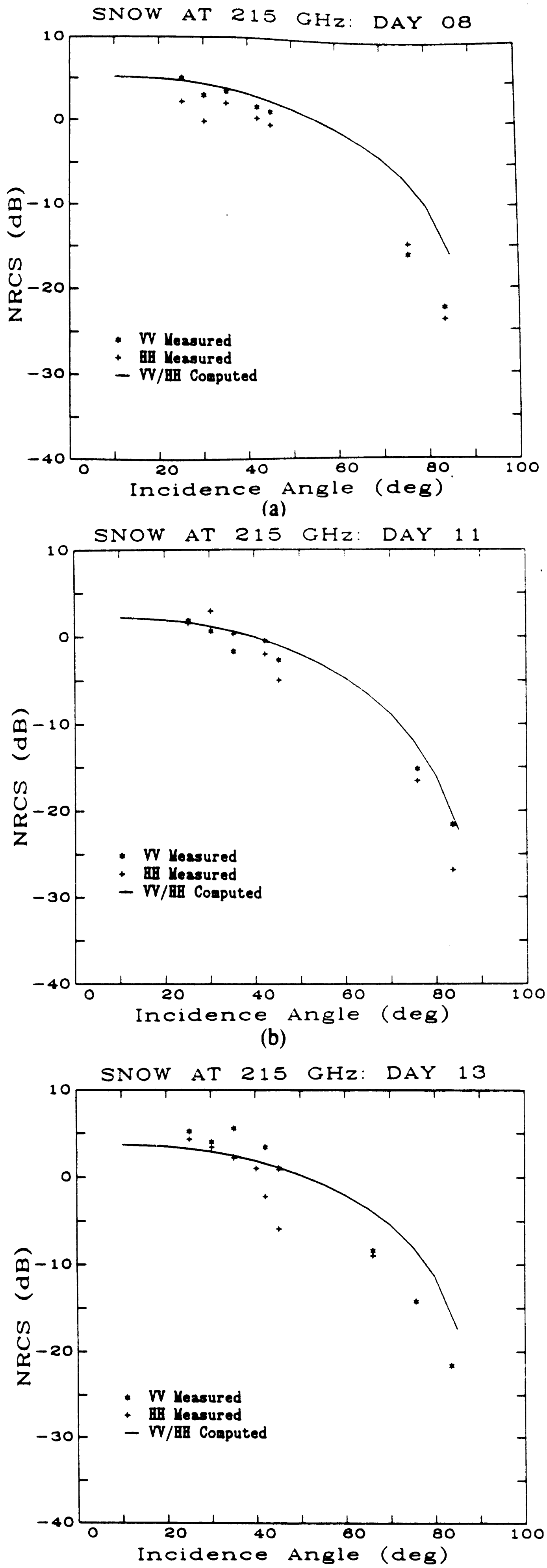


SNOW AT 215 GHz: DAY 12



SNOW AT 215 GHz: DAY 14





(c)

Measured (*: σ°_{VV}, +: σ°_{HH}) and computed (–) values of co-polarized backscatter for (a) Day 8, (b) Day 11, (c) Day 13.

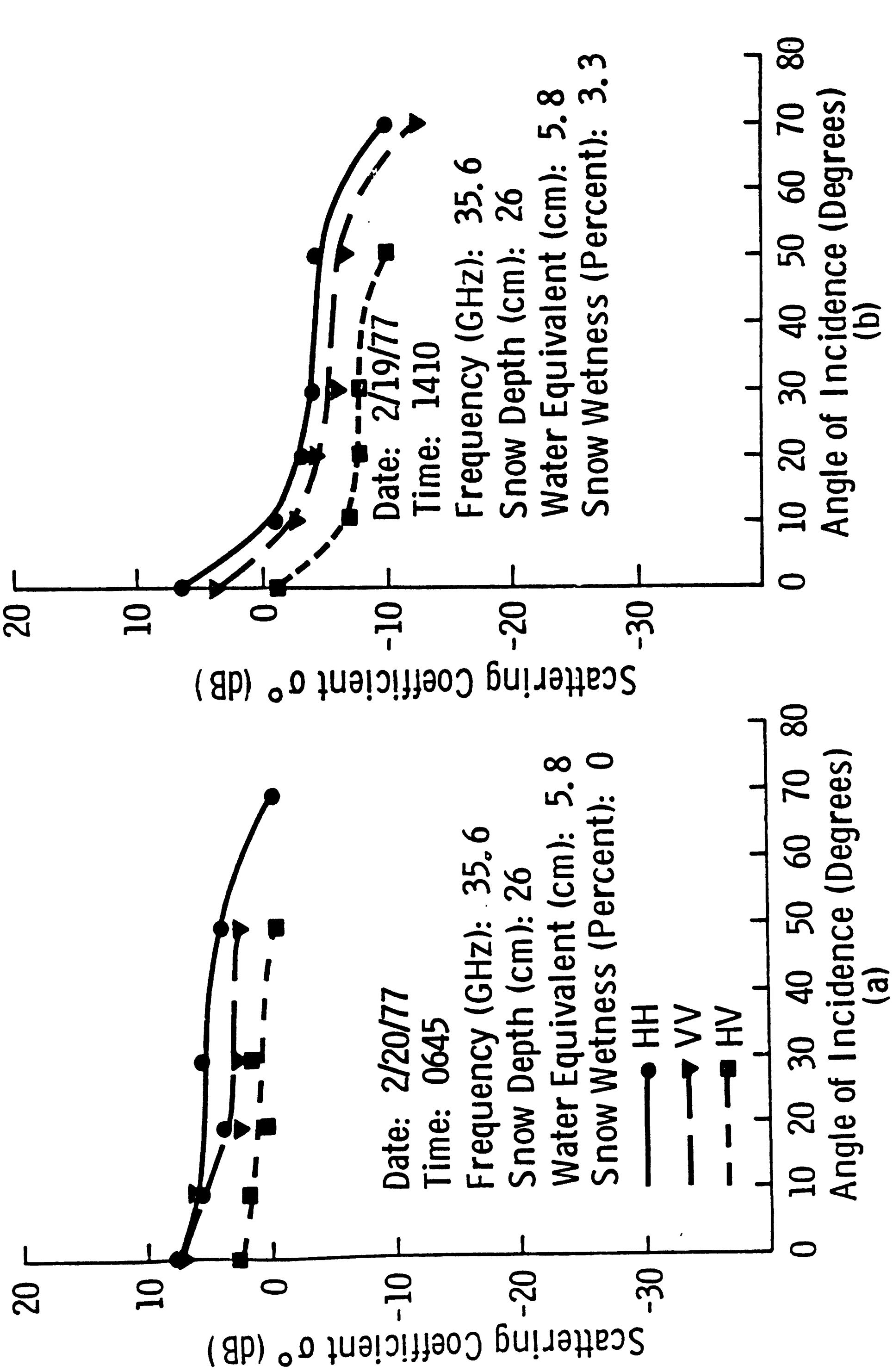
PART III. UNIVERSITY OF KANSAS DATA

The University of Kansas program used a 20-m high truck-mounted platform, similar to that used by the University of Michigan, to make multipolarization radar backscatter measurements at 35 GHz for various types of terrain surfaces. The majority of the data were recorded for HH, HV, VH, and VV linear polarization combinations, although a few were made for circular polarization configurations (RL, LL, LR, RR) also.

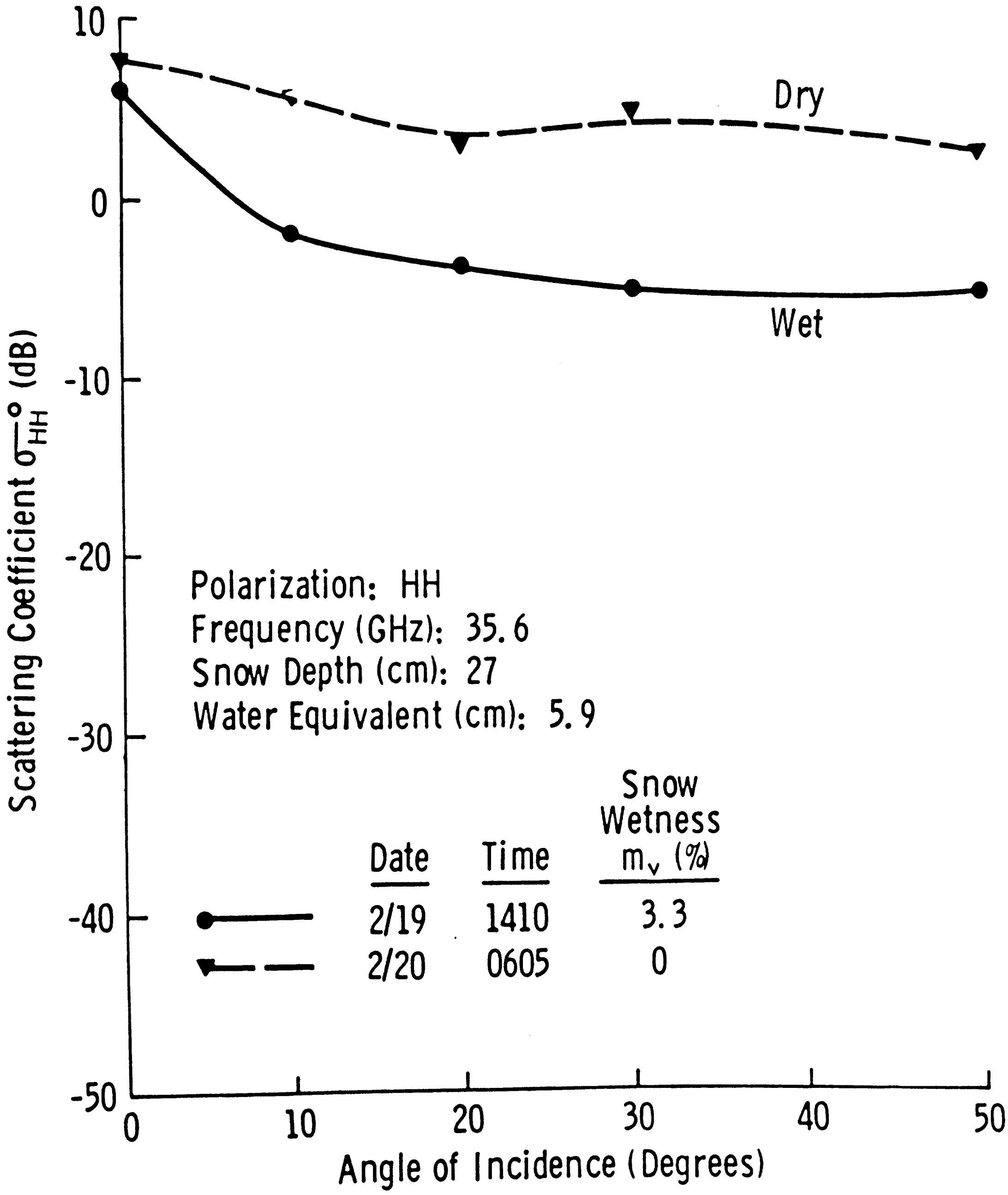
The radar used was an FM-CW system with separate transmit and receiver antennas. The antennas were equipped with polarizers and had a beam width of 3^{o} each, resulting in a product beam width of about 2^{o}.

The data reported in this part of the Handbook, which was extracted from reference [17]-[20], is divided into three categories: (1) angular plots of σ^{o} for snow-covered ground under both dry and wet conditions, (2) diurnal plots of σ^{o} as a function of time for snow, and (3) angular plots for various types of road surfaces with and without snow cover.

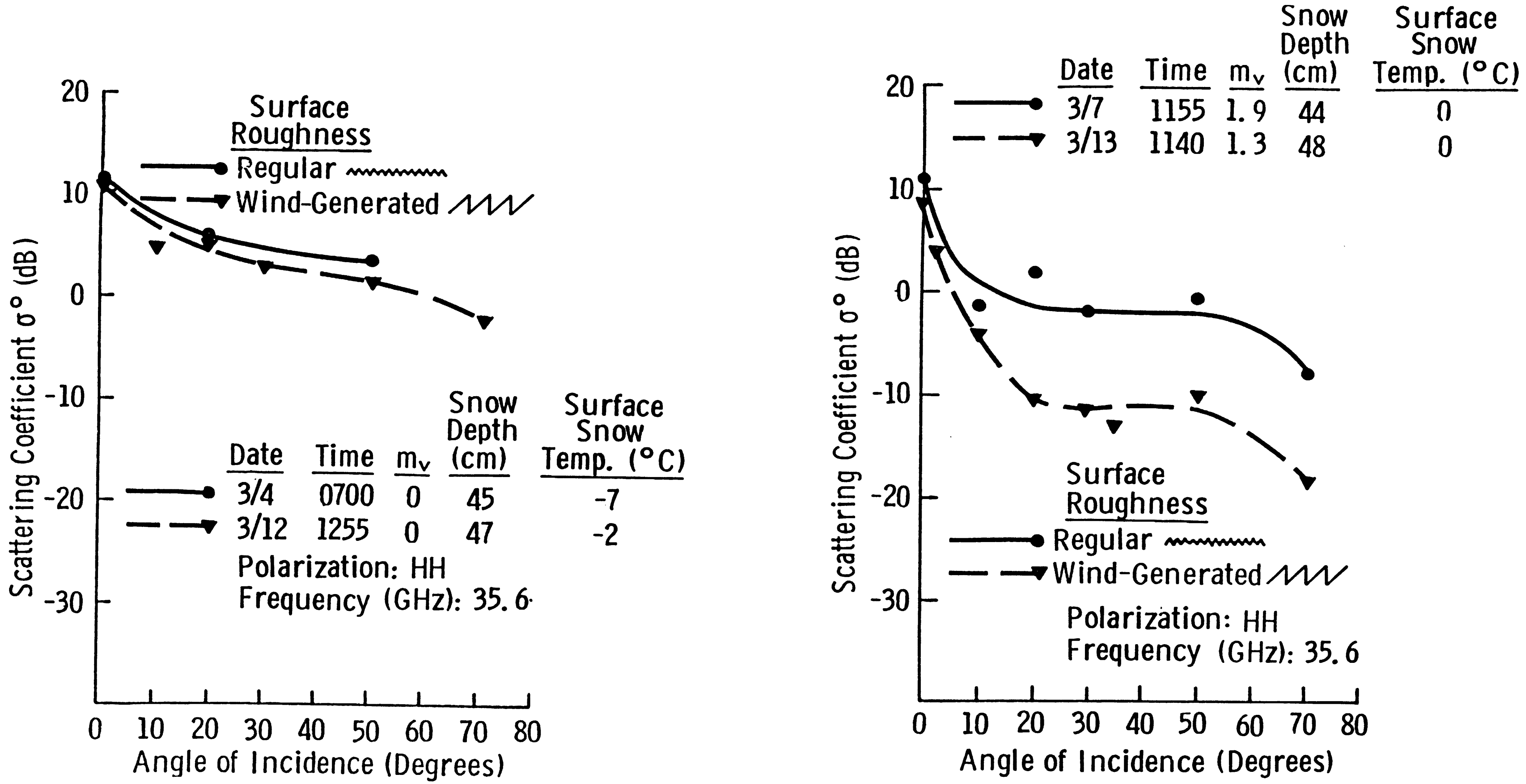
11. 35 GHz DATA FOR SNOW



Polarization and angular response of σ^o for (a) dry snow condition and (b) wet snow condition.

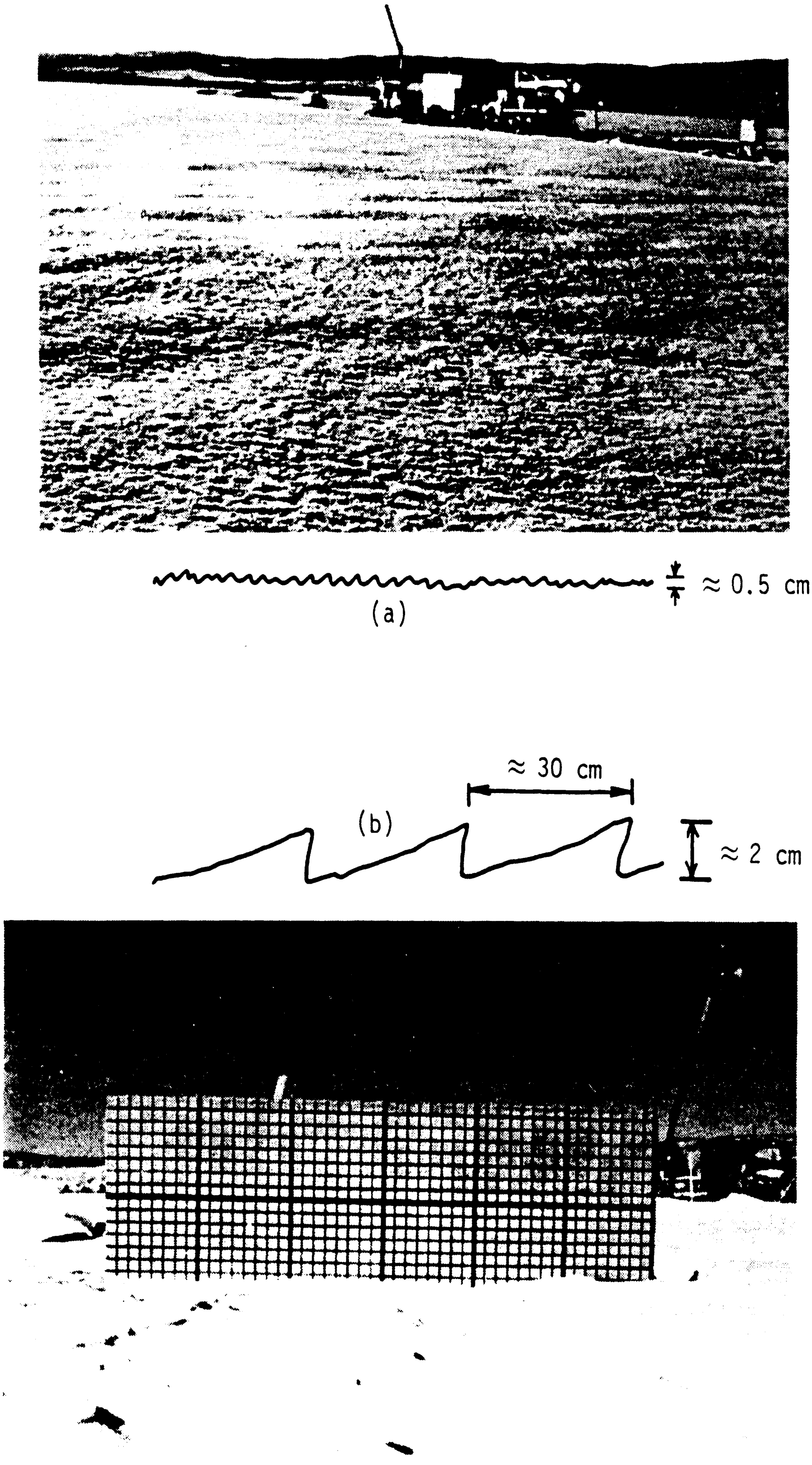


Angular Response of σ^o at 35.6 GHz to Wet and Dry Snow



(a) Dry Snow (b) Wet Snow

Effect of surface roughness for (a) dry snow and (b) wet snow. (m_v is volumetric liquid water content of 5-cm surface layer). Photographs of surfaces are shown on the following page.

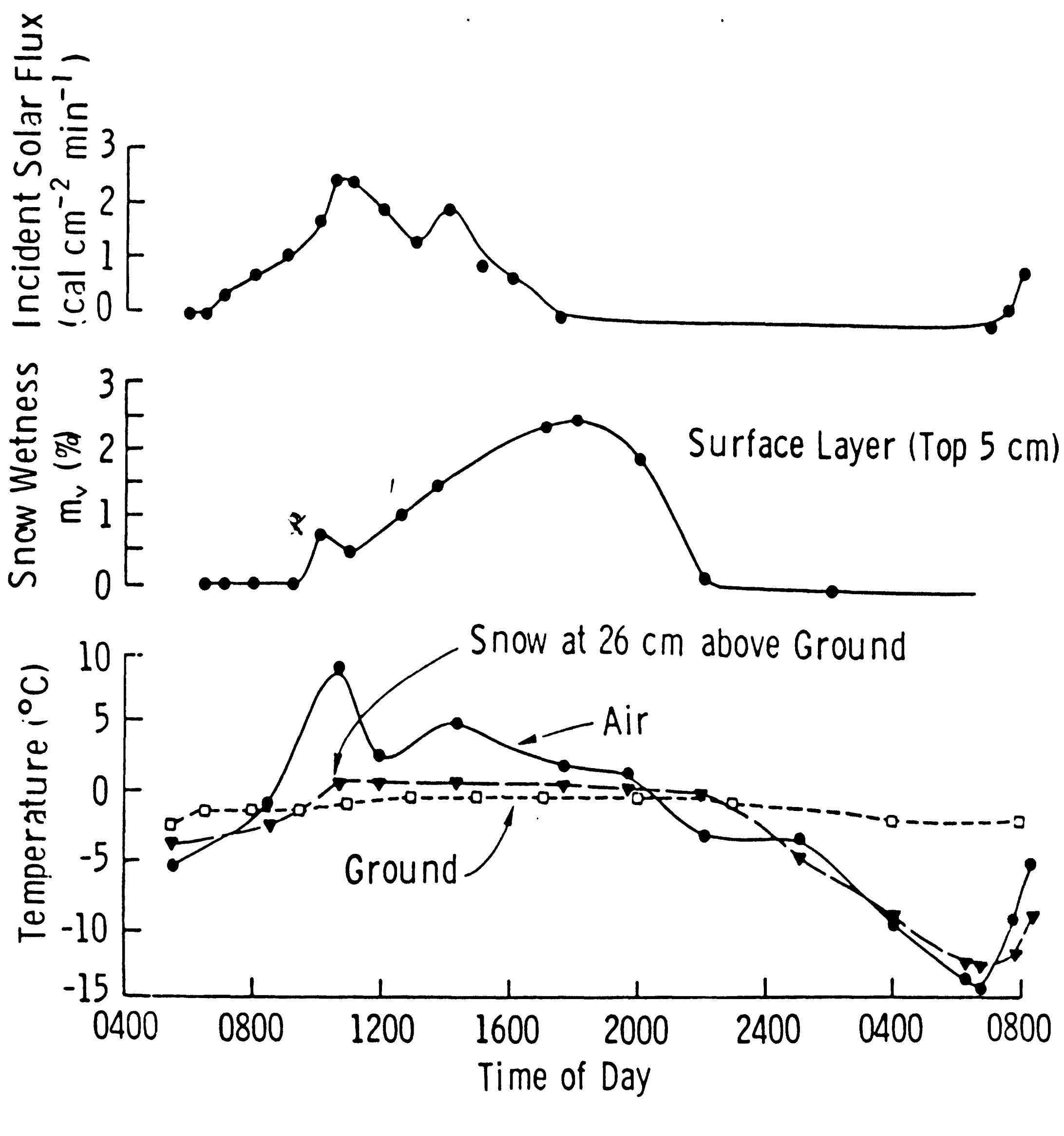


Snow surface structure: (a) regular snow surface, (b) wind-generated snow surface

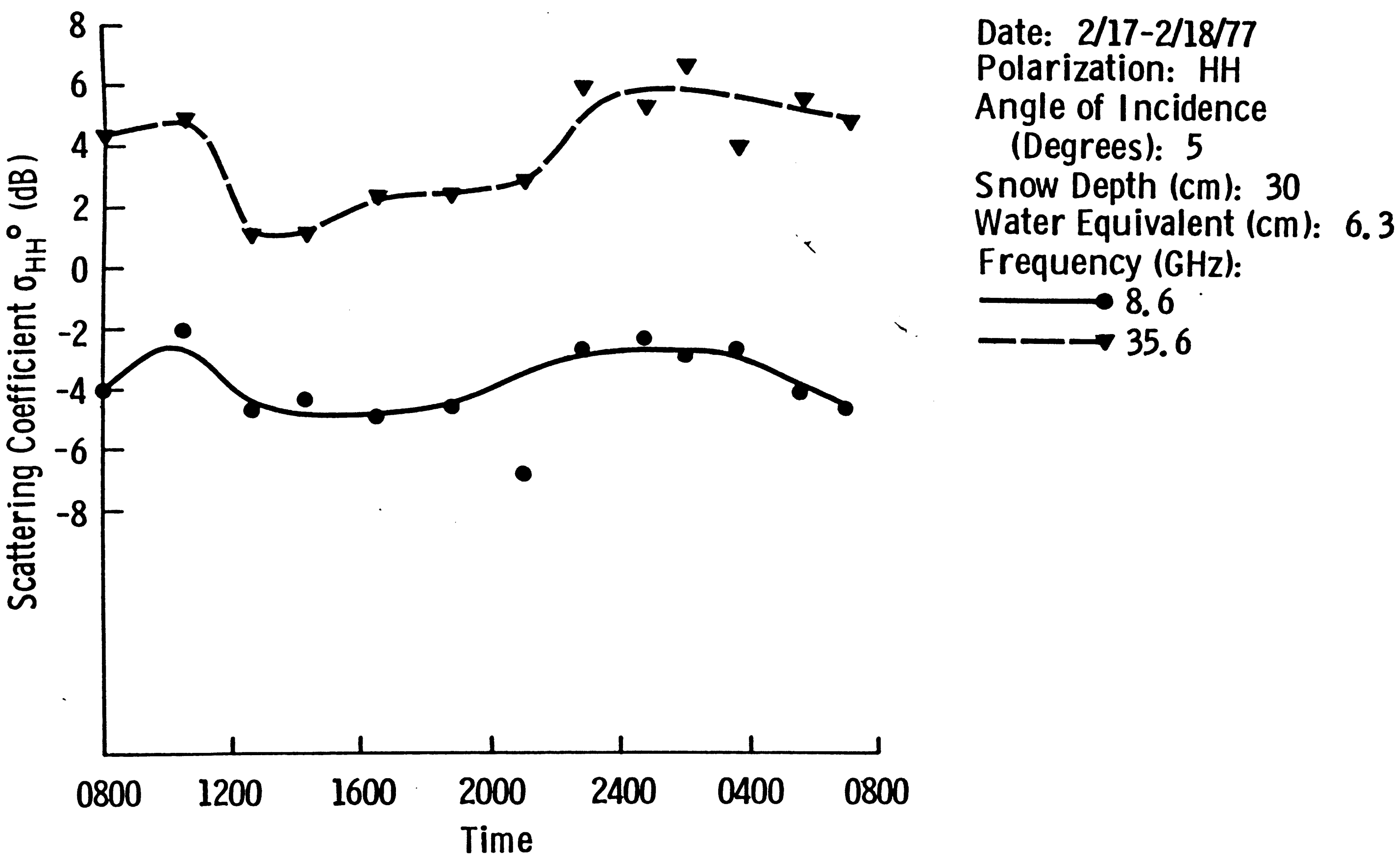
12. 35 GHz DIURNAL DATA FOR SNOW

A. February 17-18, 1977 Diurnal

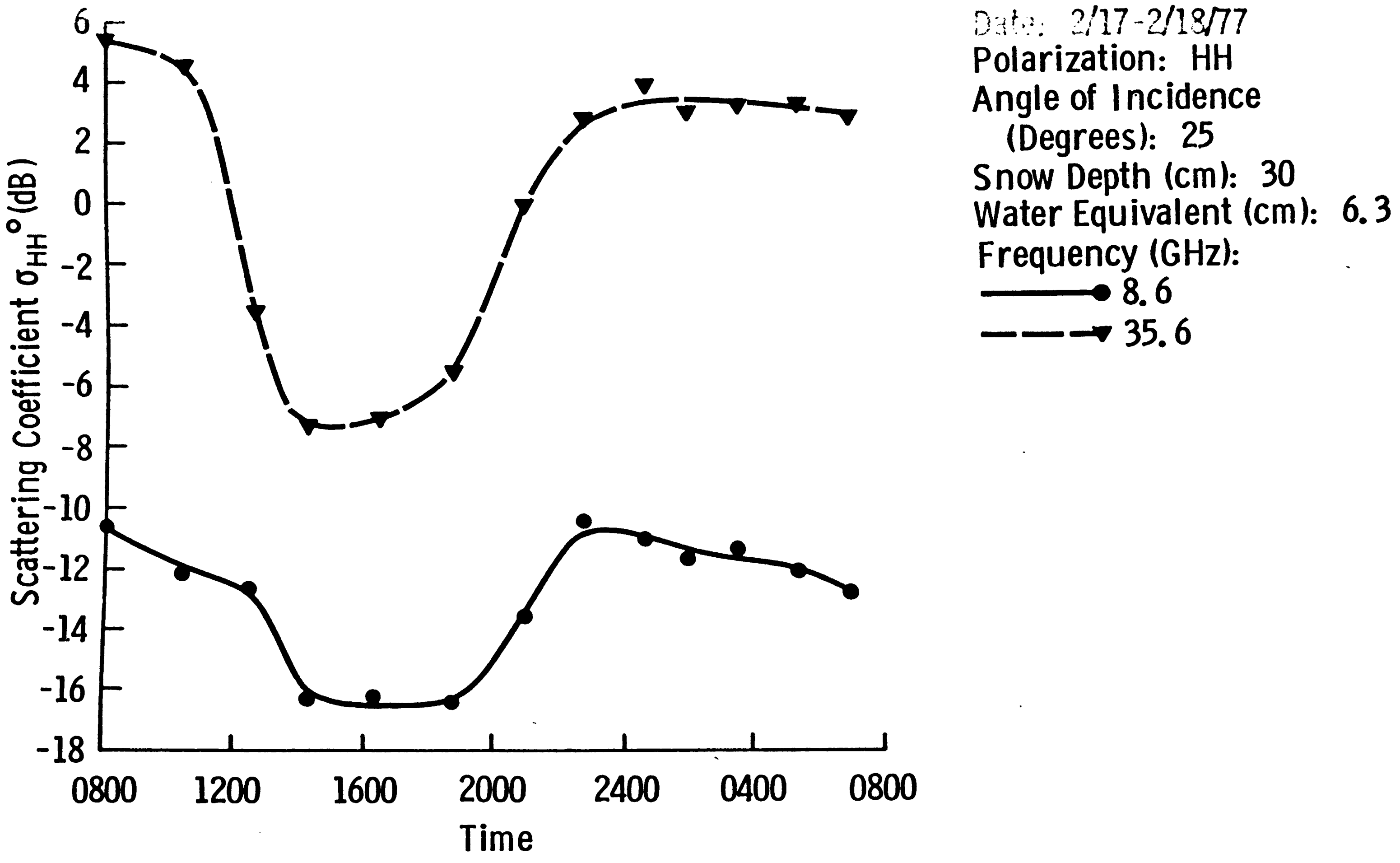
Date: 2/17 - 2/18/77
Snow Depth (cm): 30
Water Equivalent (cm): 6.3



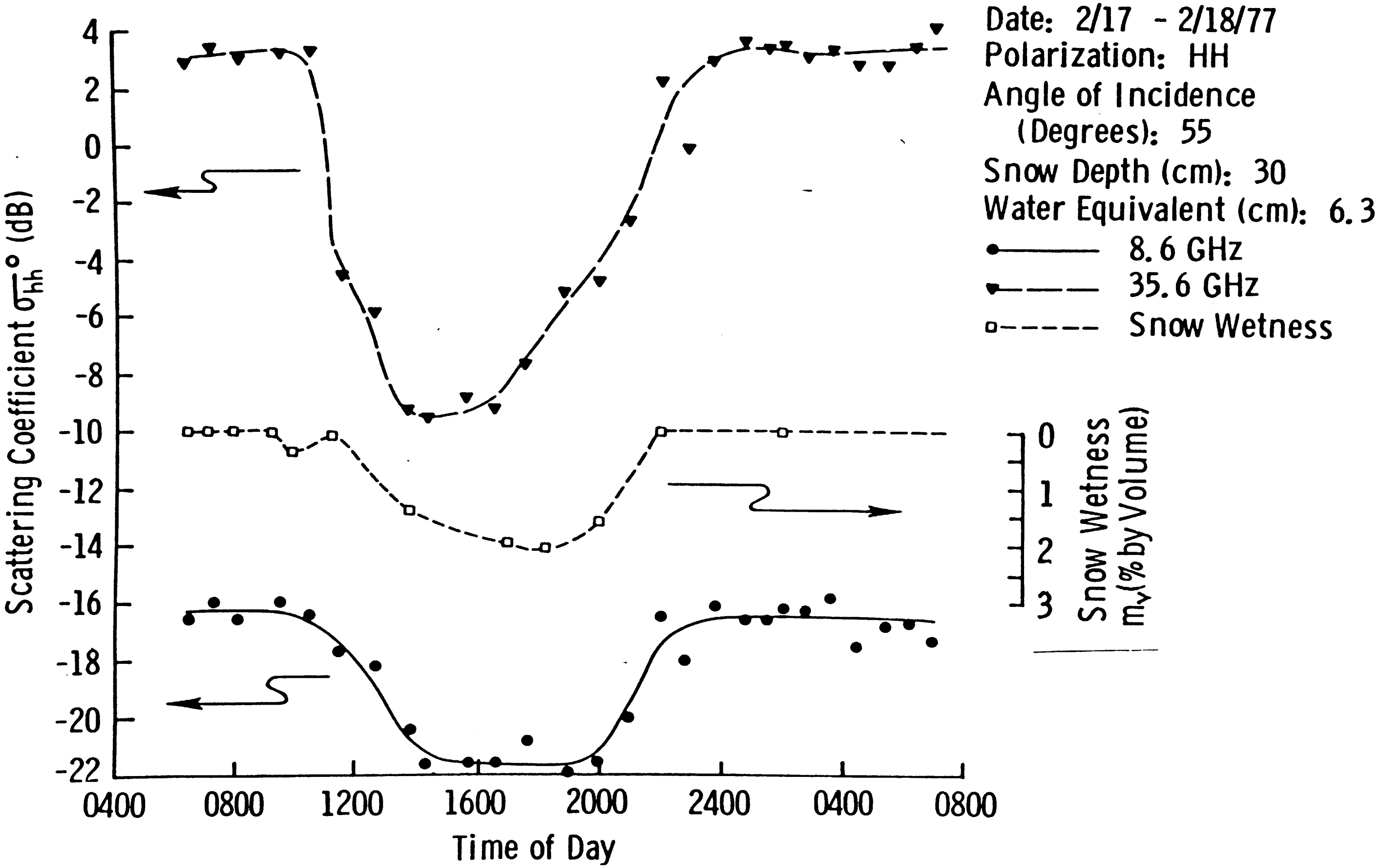
Diurnal variation of the supportive ground truth data on 2/17 - 2/18/77. m_v is the volumetric snow wetness of the top 5-cm layer.



Diurnal variation of σ^o at 8.6 and 35.6 GHz at 5^o angle of incidence.

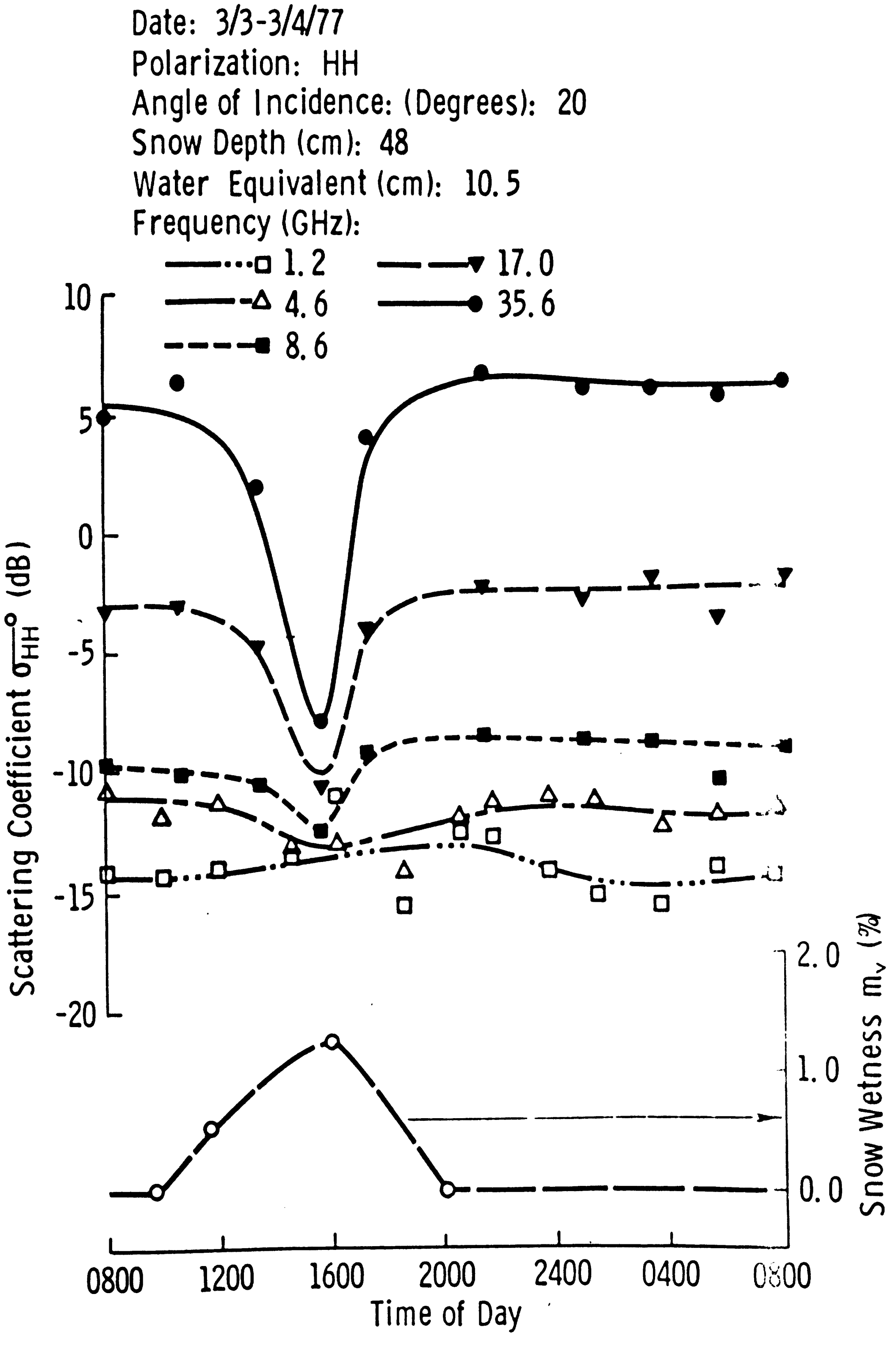


Diurnal variation of σ^o at 8.6 and 35.6 GHz at 25° angle of incidence.

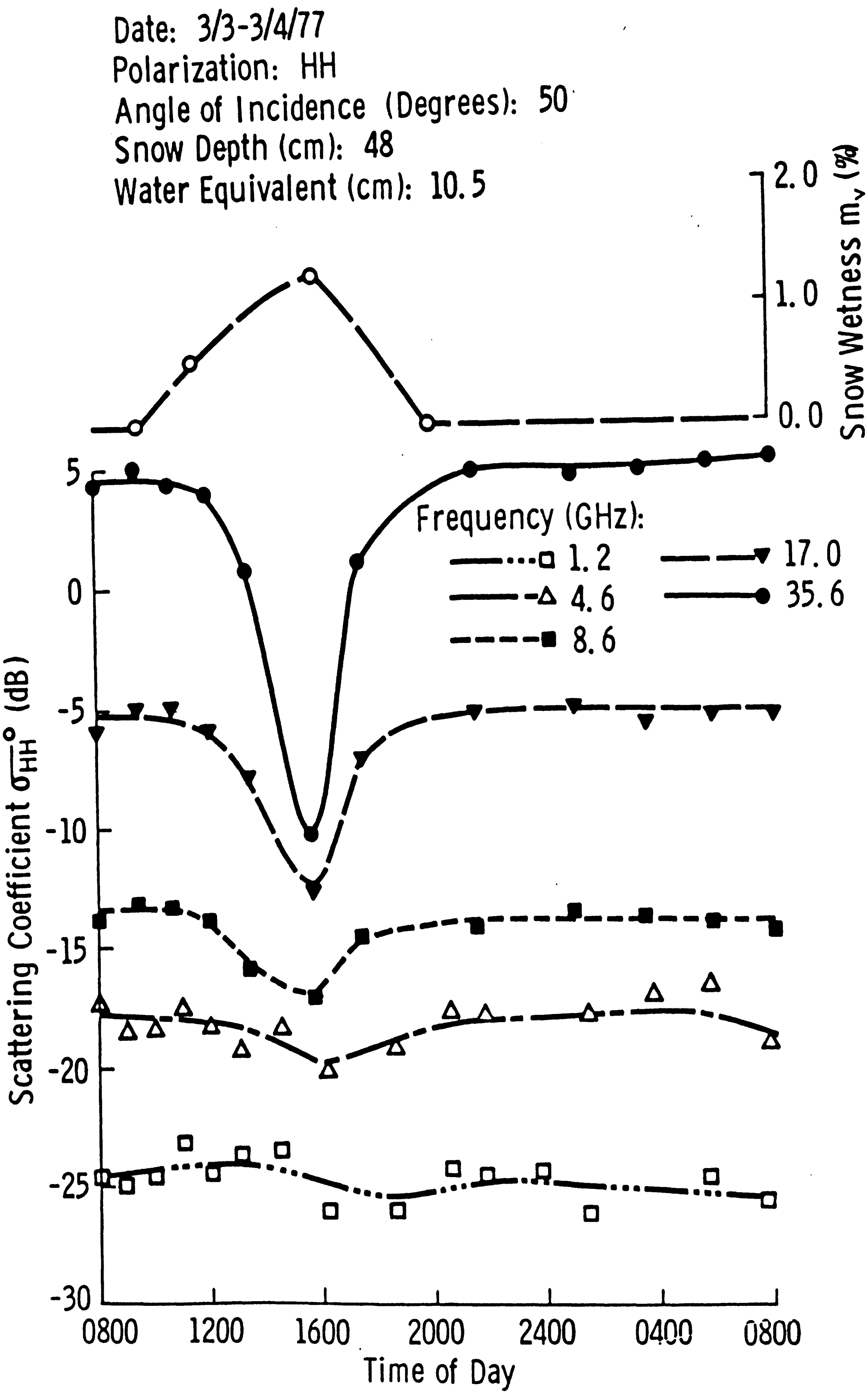


Diurnal variation snow wetness and σ^o at 8.6 and 35.6 GHz. (Note that snow wetness scale has been reversed for ease of comparison with σ^o.

B. March 3-4, 1977 Diurnal

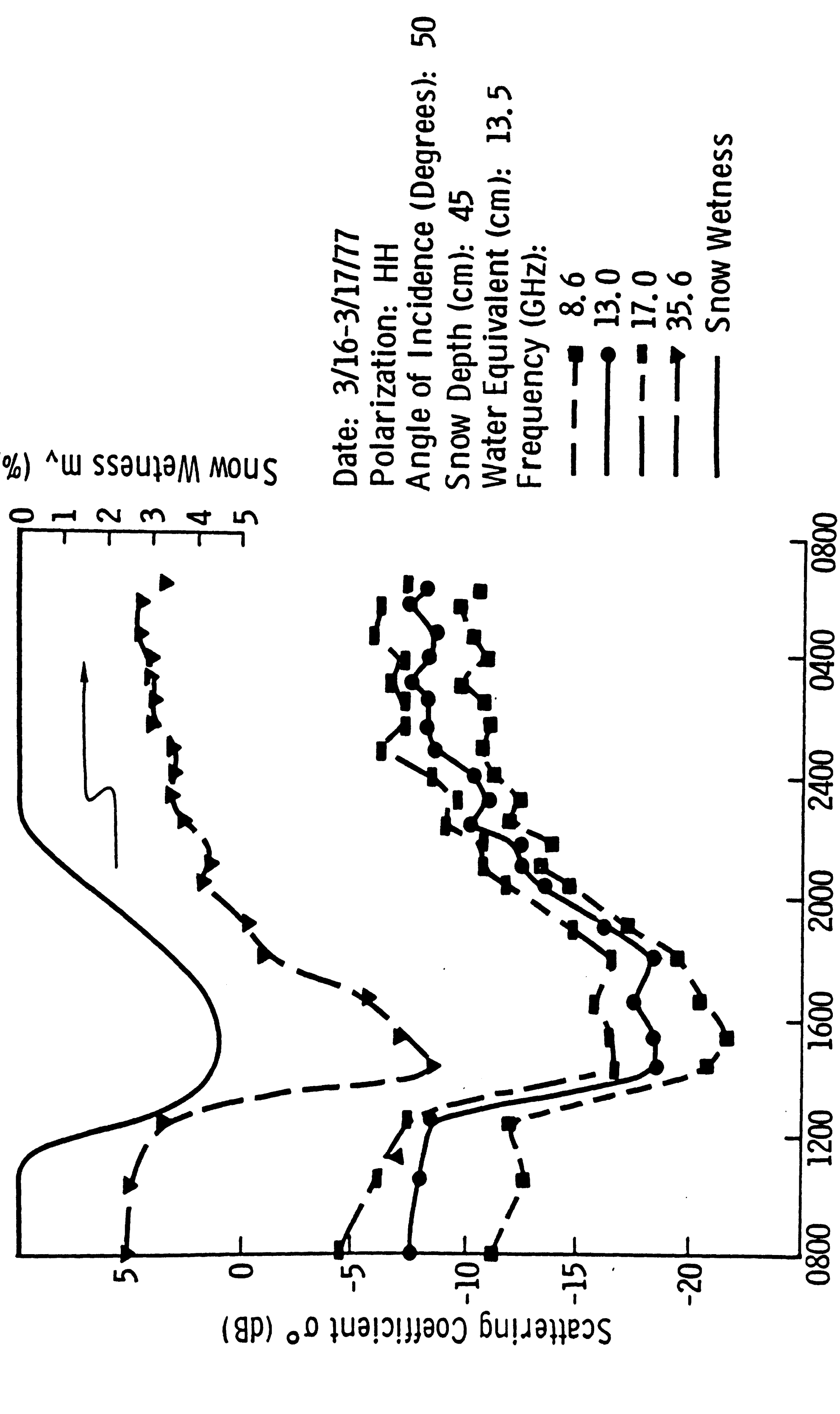


Diurnal Variation of Snow Wetness and σ^o Between 1 and 35 GHz at 20^o Angle of Incidence.

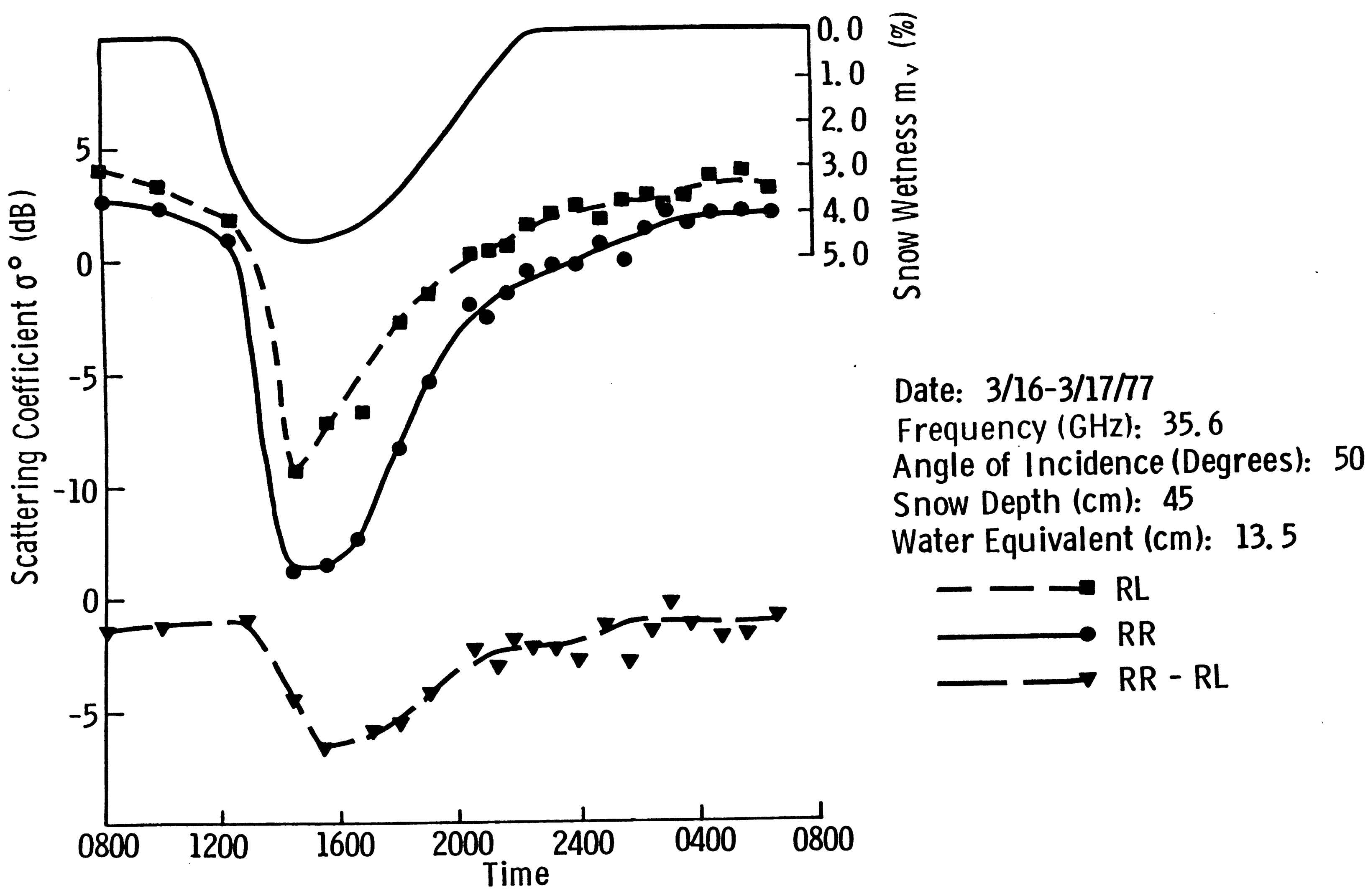


Diurnal Variation of Snow Wetness and σ° Between 1 and 35 GHz at 20° Angle of Incidence.

C. March 16-17, 1977 Diurnal

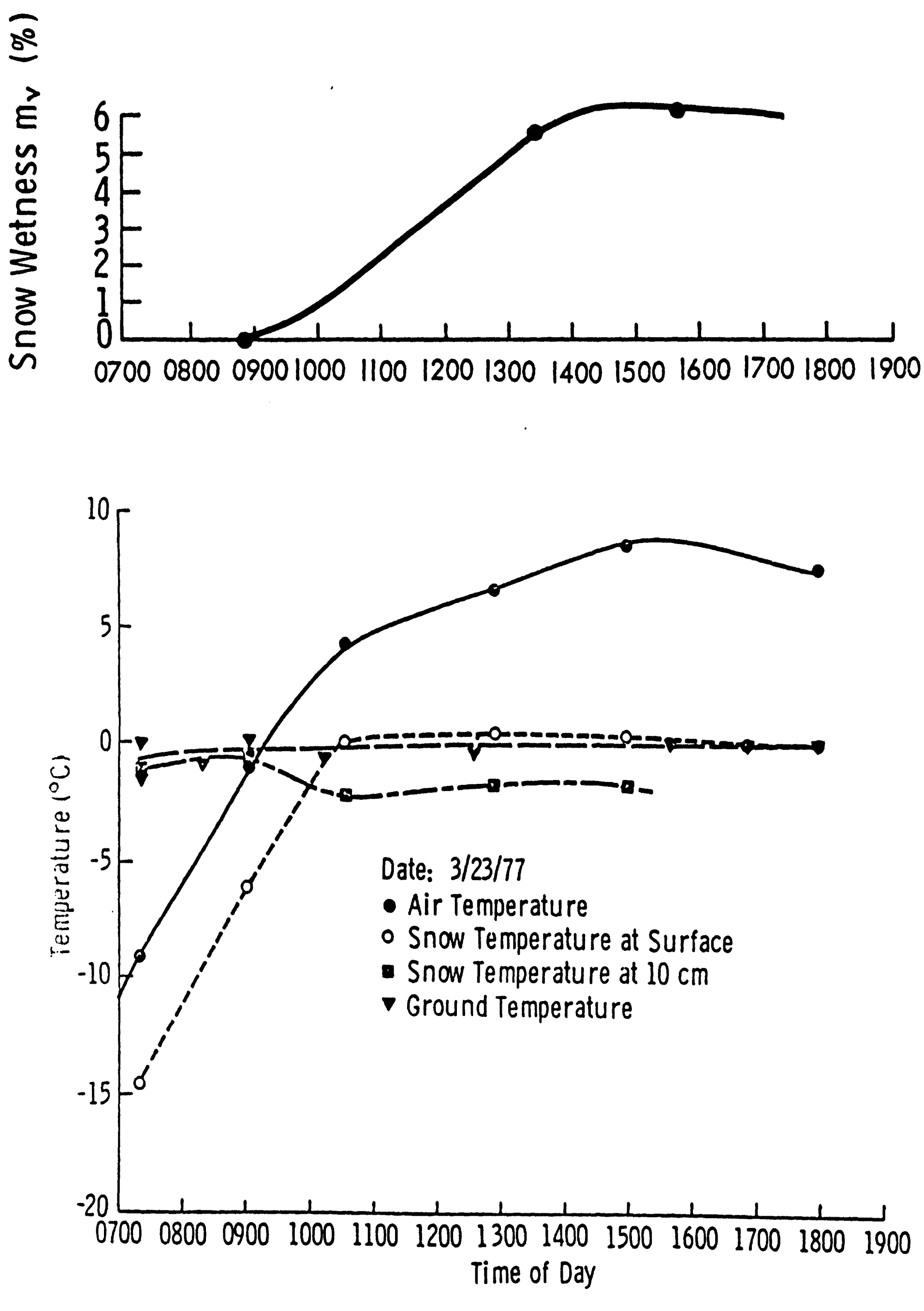


Diurnal variation of snow wetness and σ^o at 8.6, 13.0, 17.0 and 35.6 GHz at 50° angle of incidence.

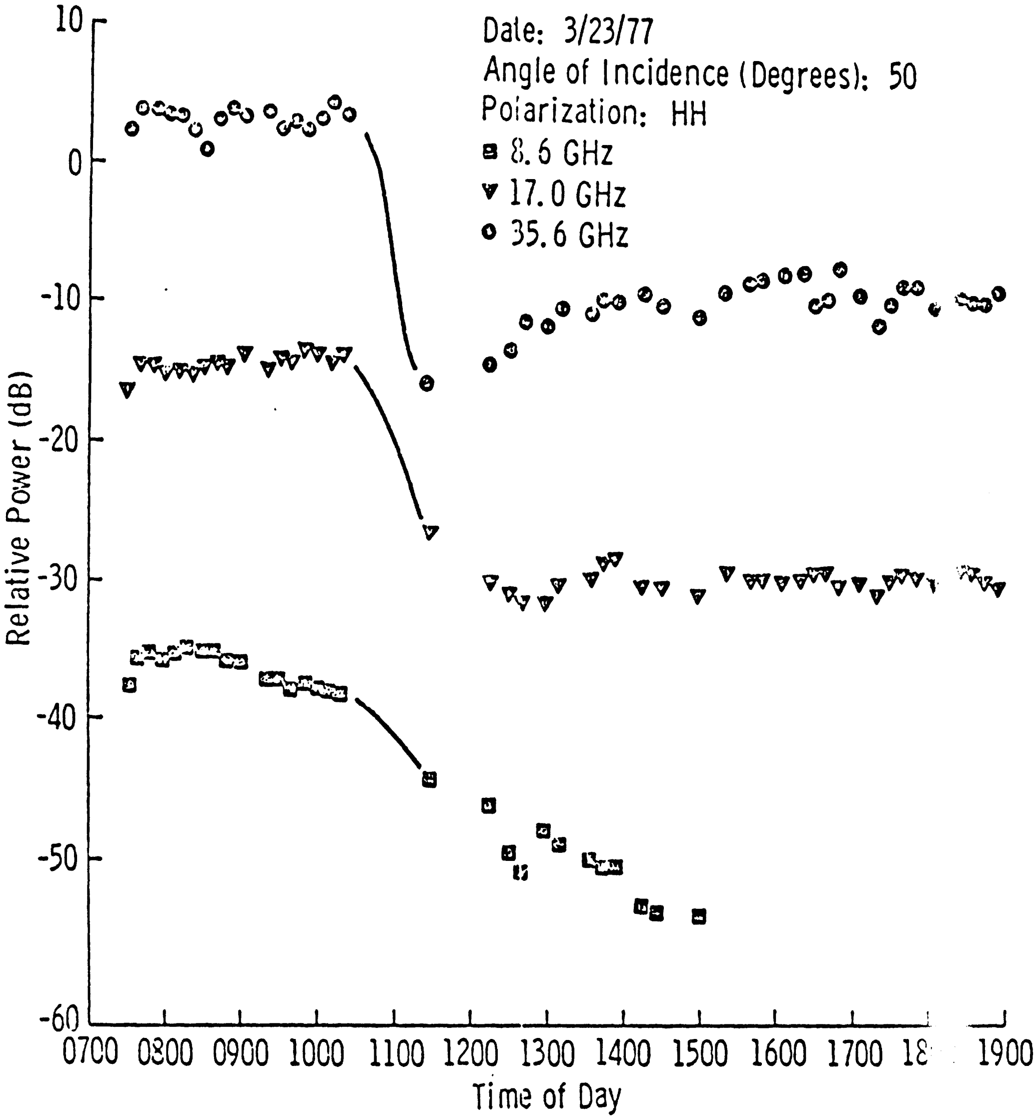


Diurnal variation of snow wetness and the circular polarized σ^o values at 35.6 and the depolarization ratio (σ_{RR}/σ_{RL}) at 50° angle of incidence.

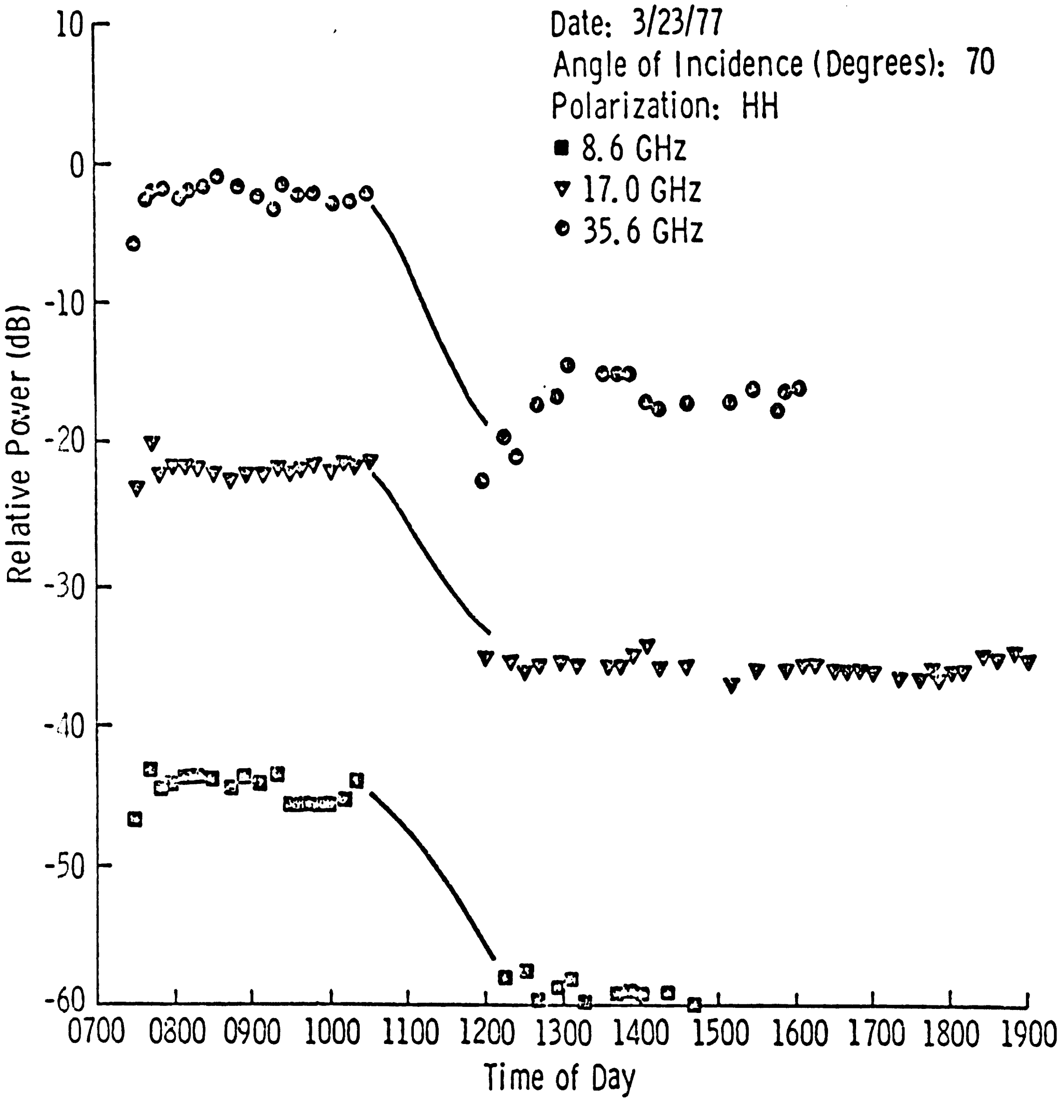
D. March 23, 1977 Diurnal



Snow wetness and temperature variation over the measurement period of the diurnal experiment on 3/23/77.

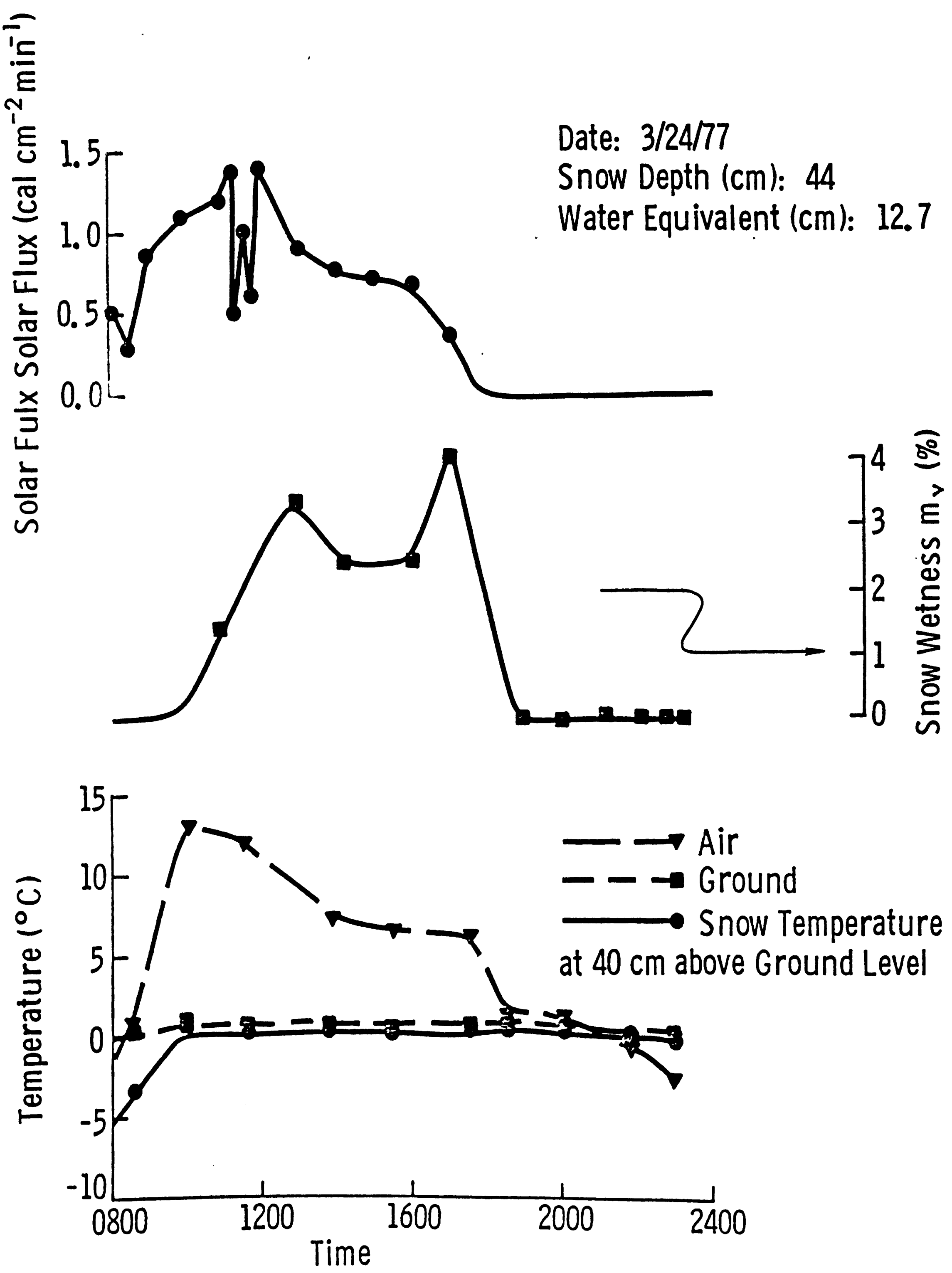


Time variation of 50° backscatter power at 8.6, 17.0, and 35.6 GHz.

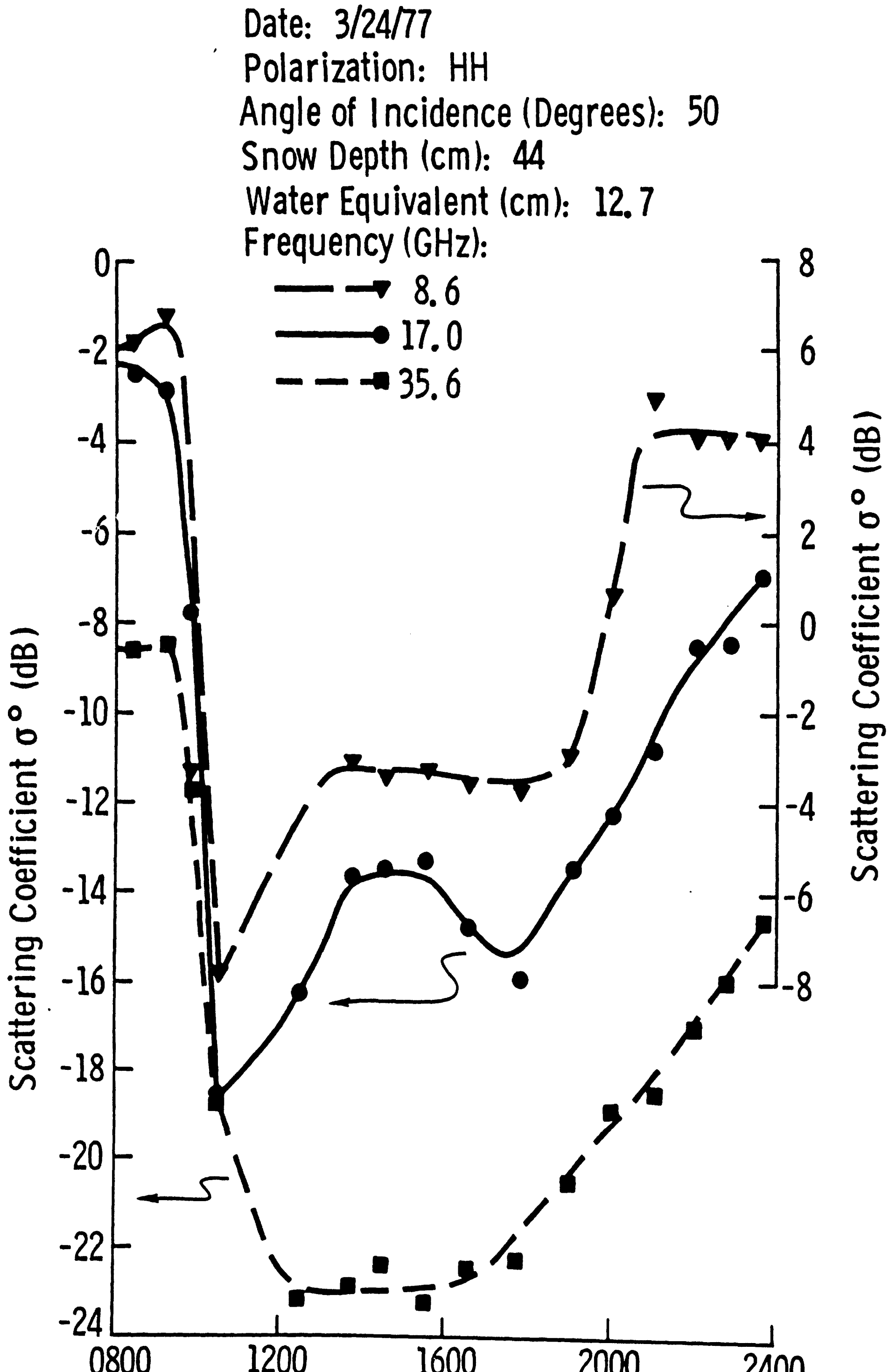


Time variation of 70° backscatter power at 8.6, 17.0, and 35.6 GHz.

E. March 24, 1977 Diurnal



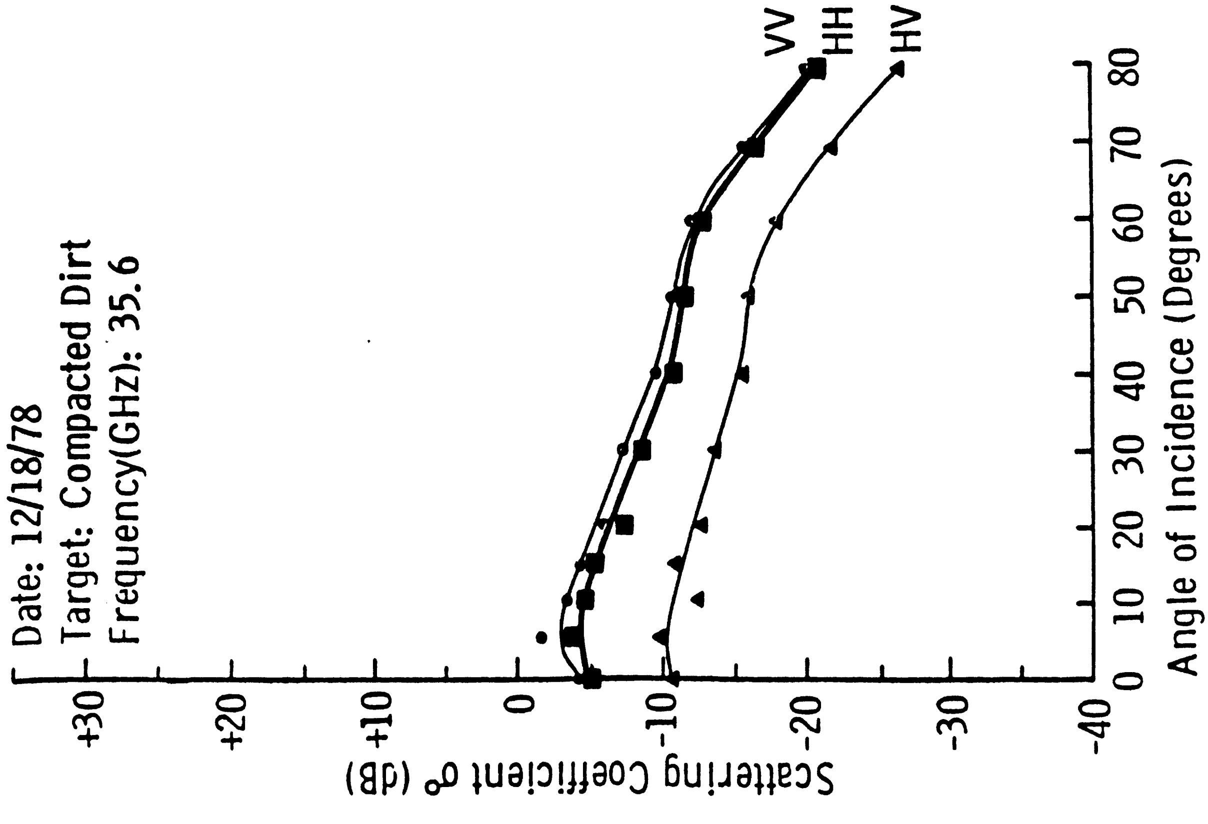
Diurnal variation of ground truth data on 3/24/77.



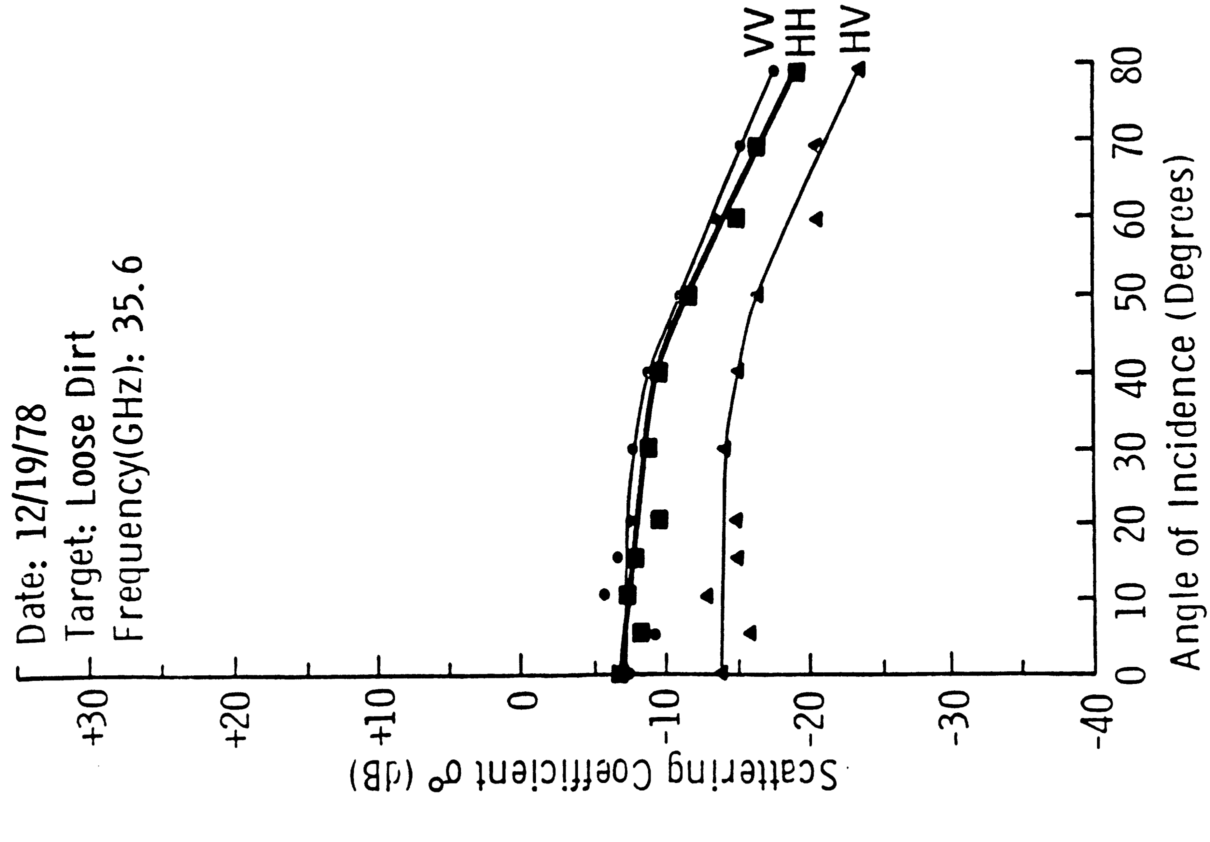
Diurnal variation of σ^0 at 8.6, 17.0 and 35.6 GHz at 50^0 angle of incidence.

13. 35 GHz DATA FOR ROAD SURFACES

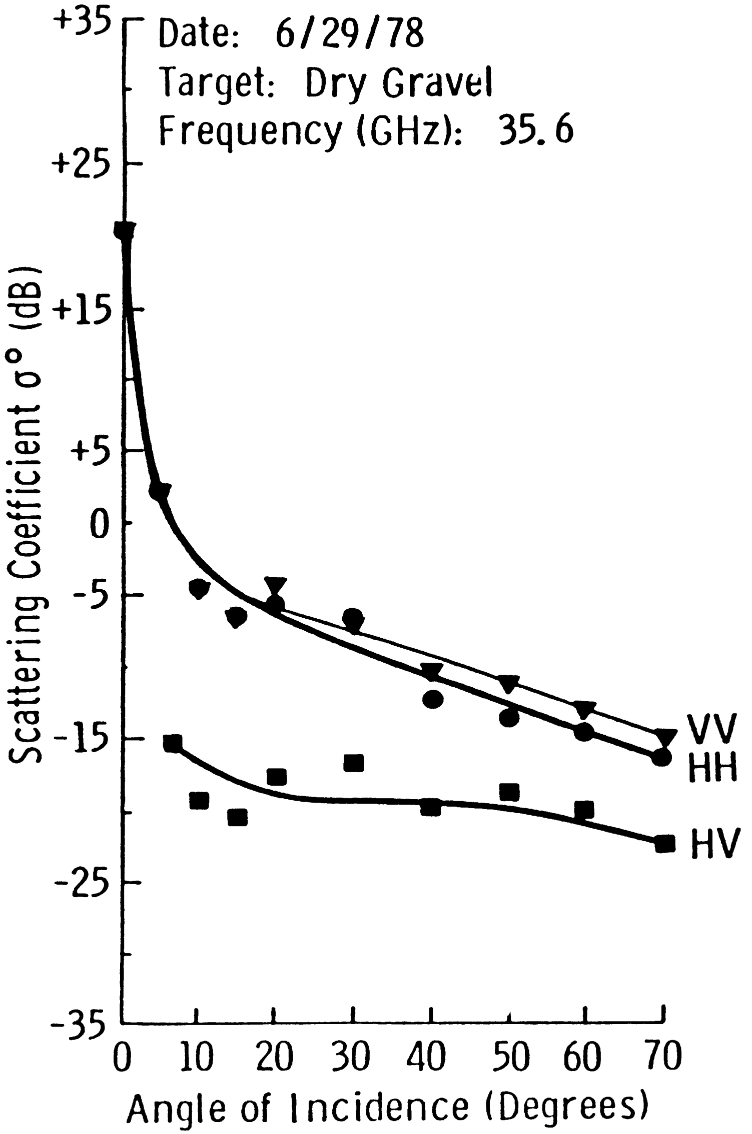
A. Various Surfaces



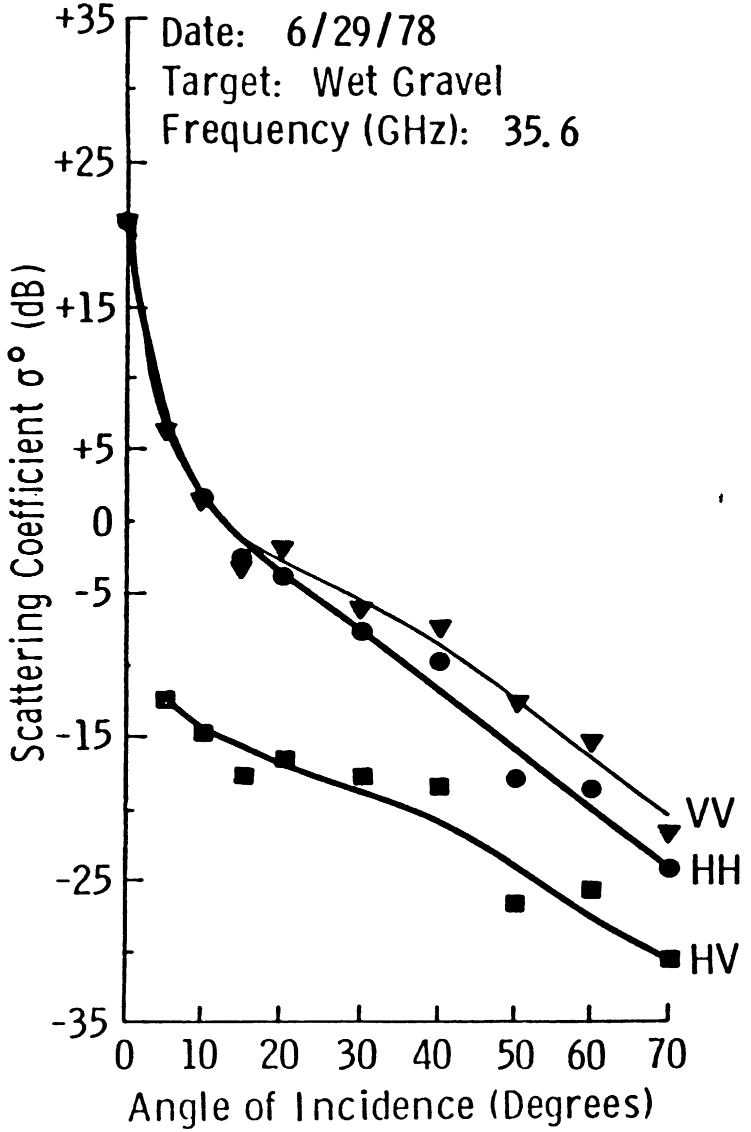
Compacted Dirt Surface



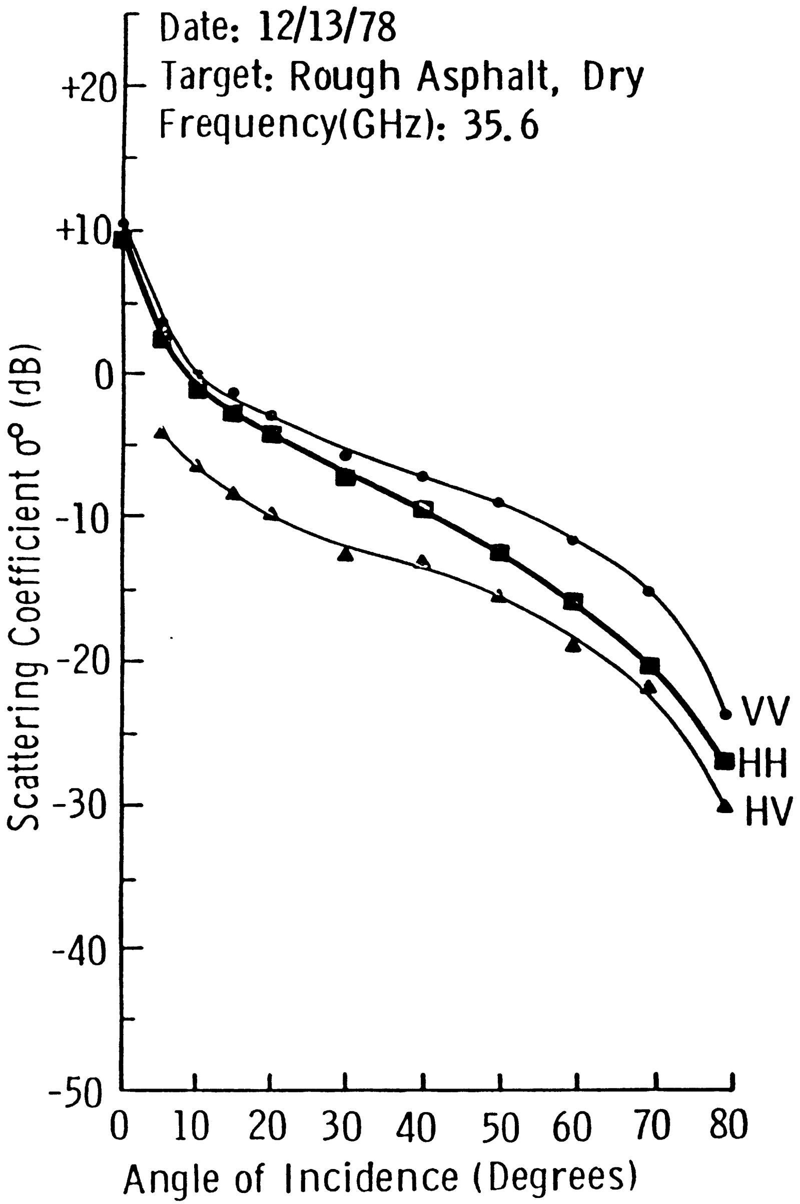
Loose Dirt Surface



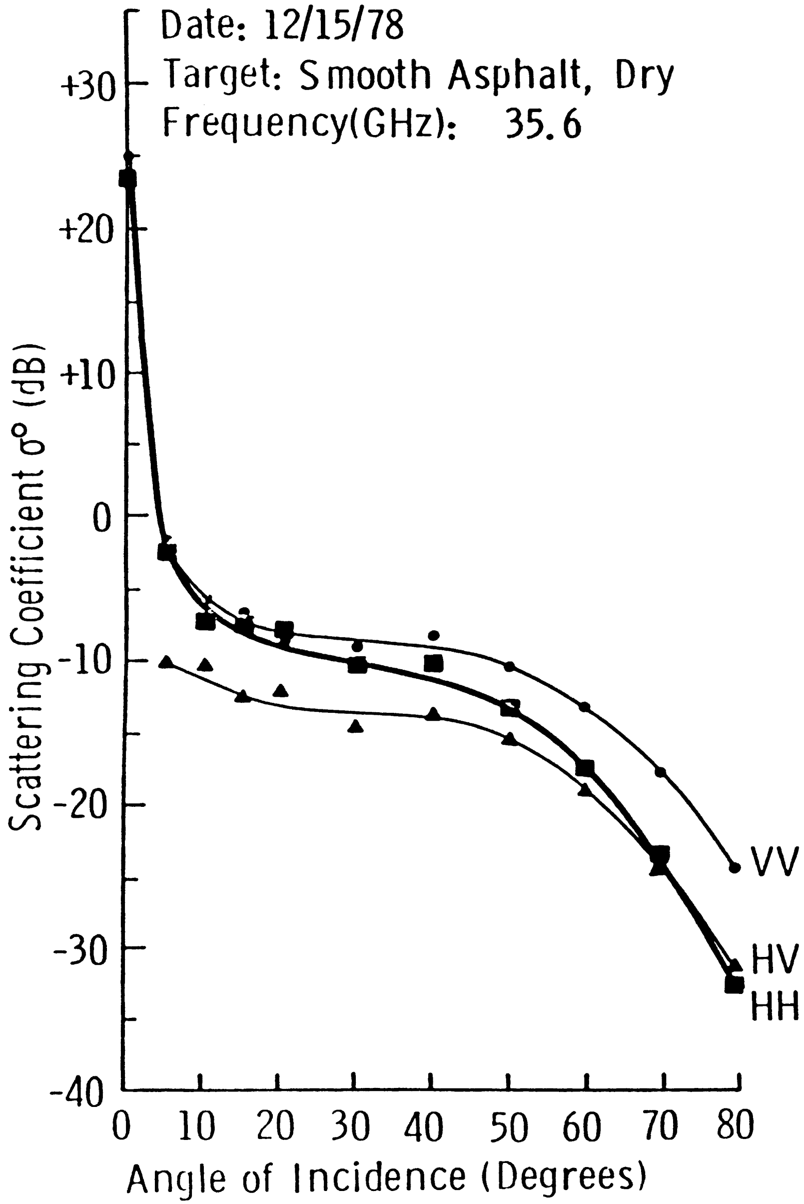
Dry Gravel Surface



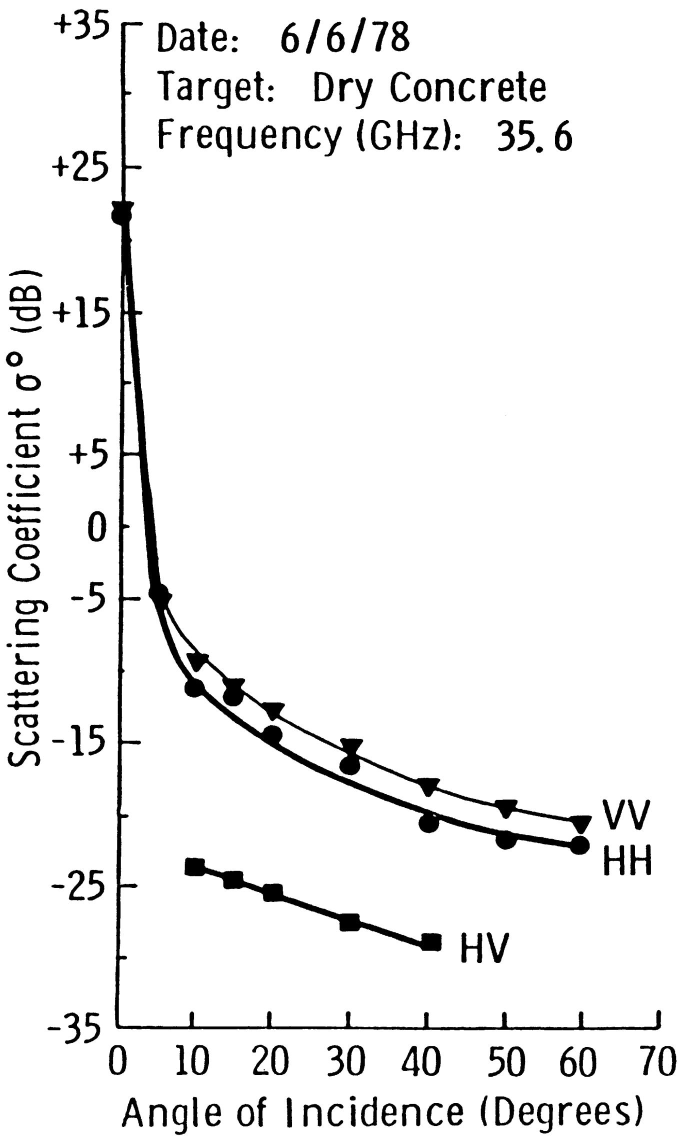
Wet Gravel Surface



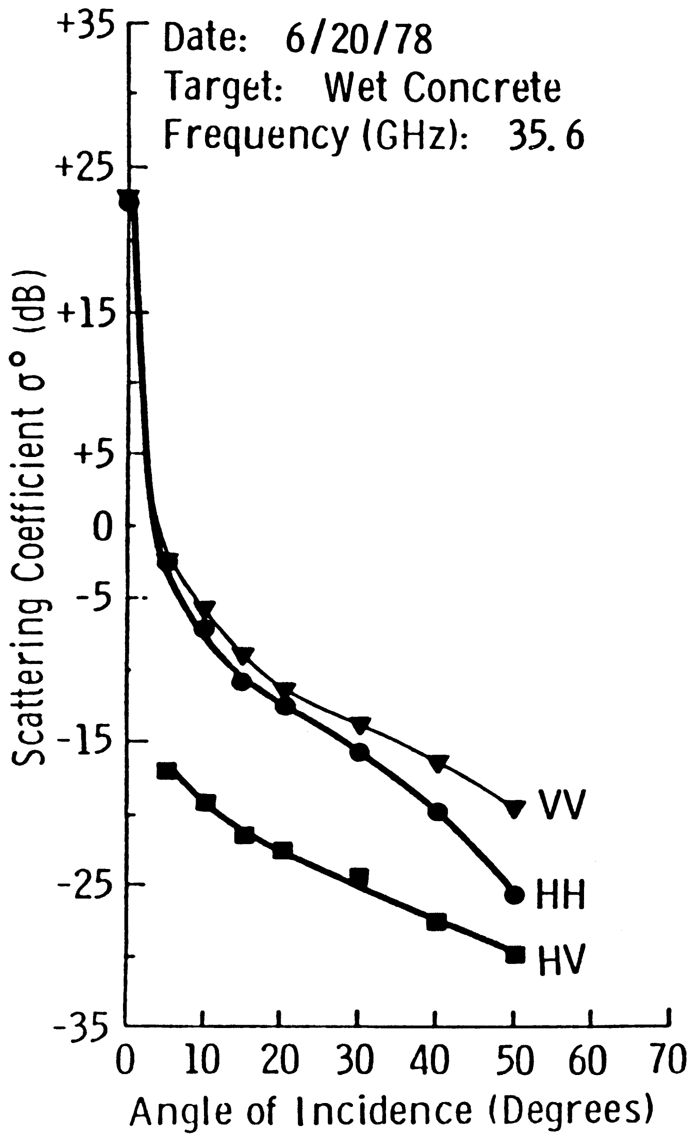
Rough Asphalt Surface



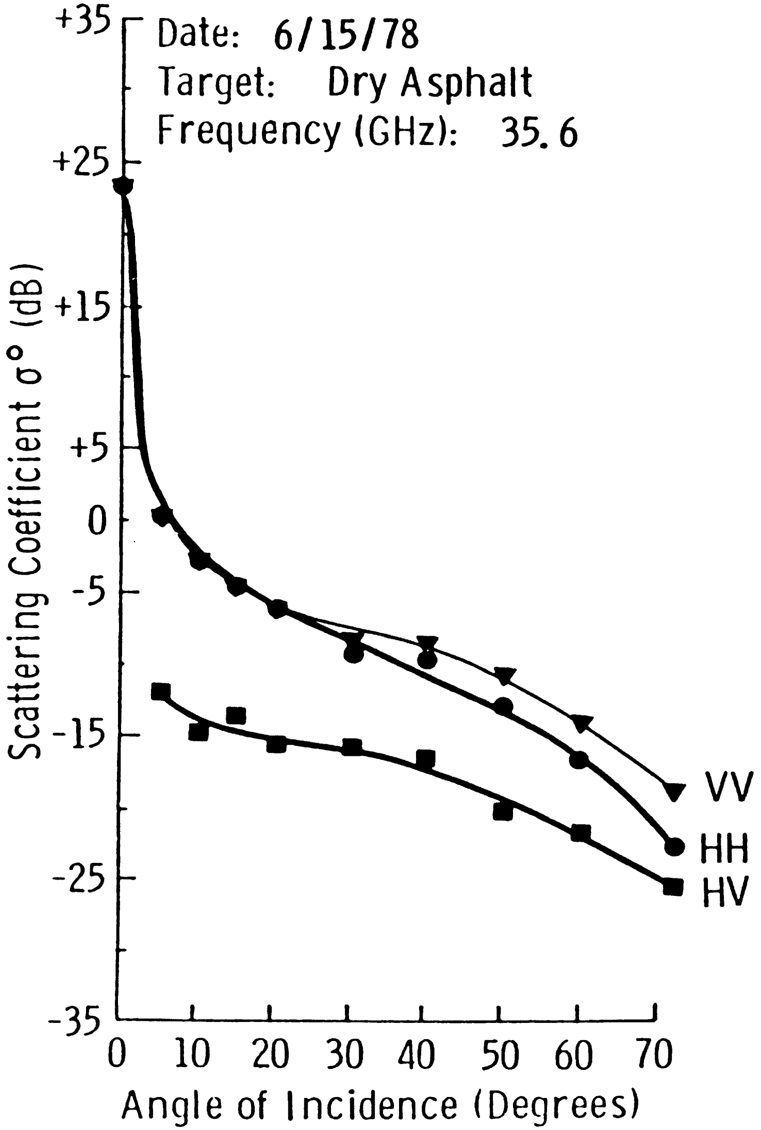
Smooth Asphalt Surface



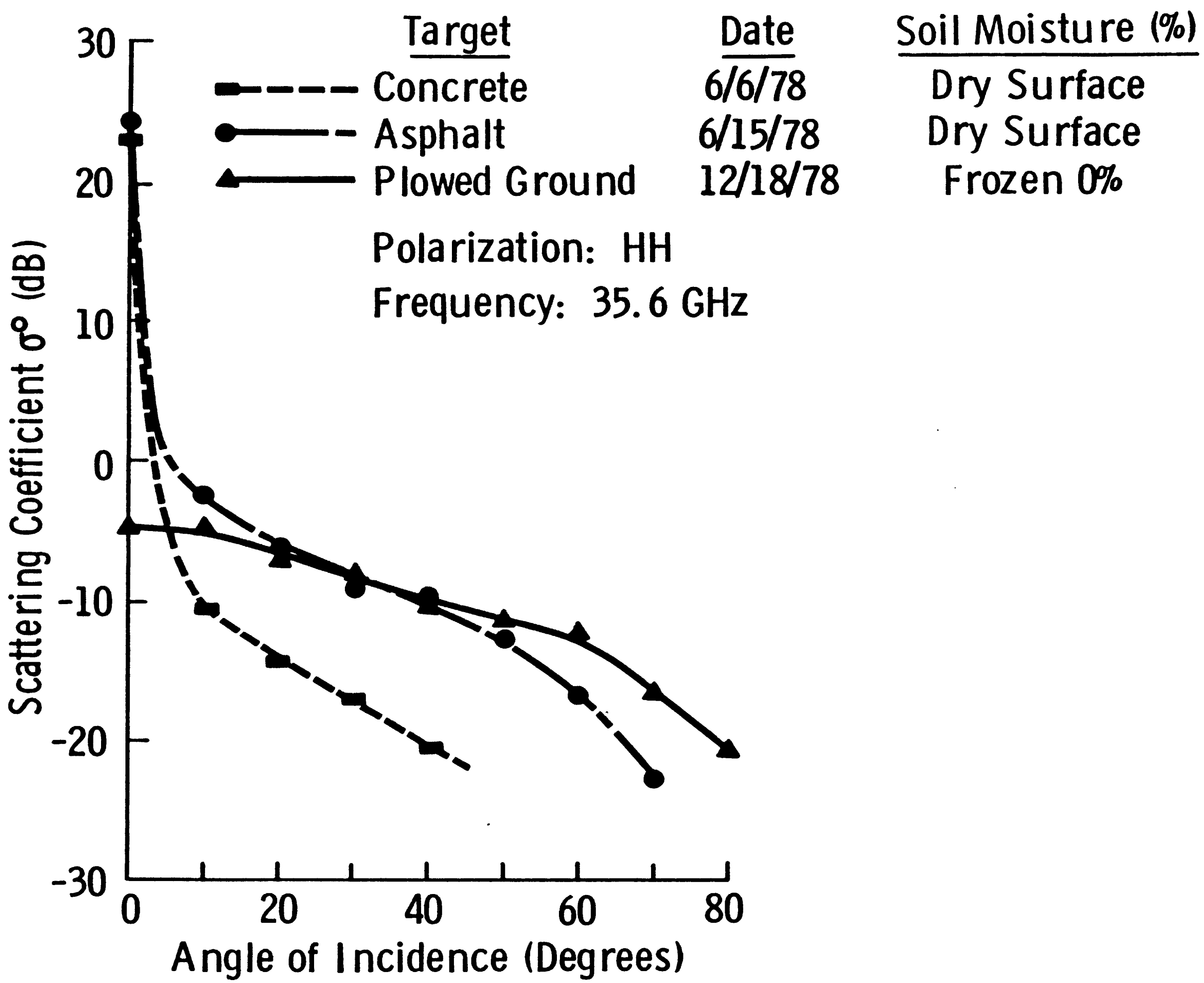
Dry Concrete



Wet Concrete



Dry Asphalt



Various Surfaces

B. Road Surfaces With Snow Cover

Ground Truth Data

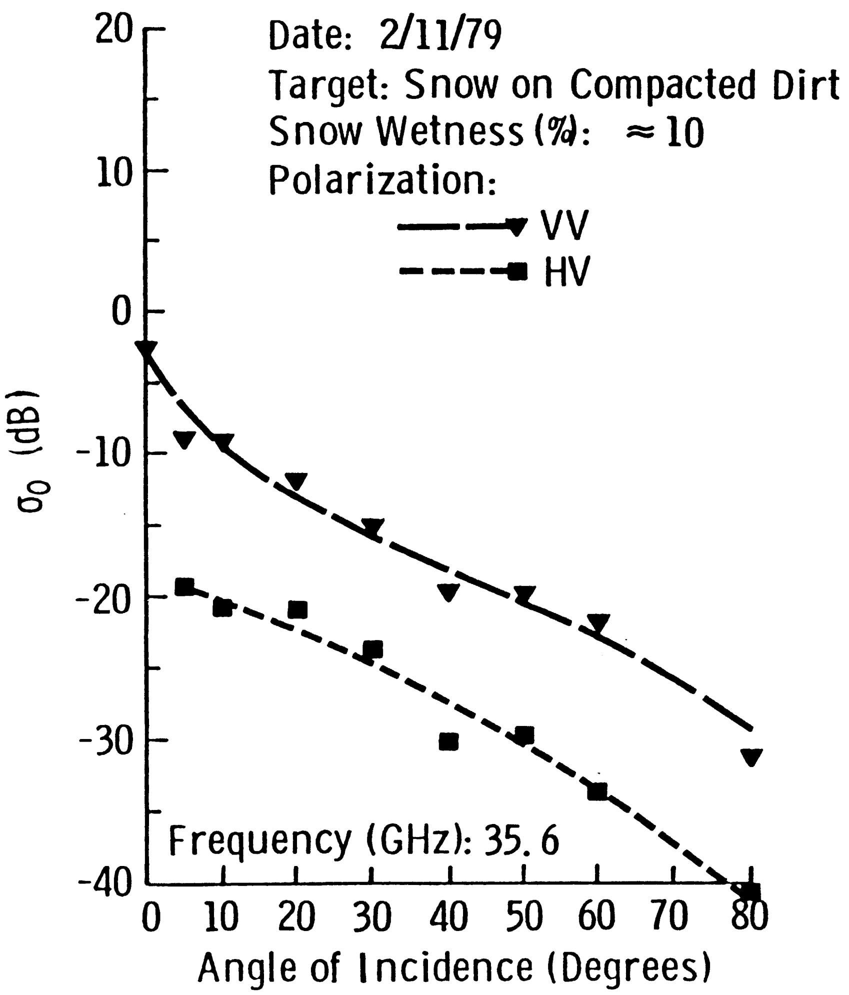
Date	Time	Target (Snow)	Soil State	Soil Moisture (% vol.)	Snow Depth (cm)	# of Layers	Water Equiv. (cm)	Snow Wetness (% vol.)	Air Temp. (°C)	Snow Temp.[1] (°C)	Snow/Ground Temp. (°C)
2/10	1315	Dirt	Frozen	---	6-14	1-3	3.0	0	-1.3	-.3	-1.9
2/11	1030	Dirt	Frozen	---	6-14	1-3	2.8	≈10	2.8	-.4	-2.0
2/13	1037	Grass	Partially Frozen	N.M.[4]	14-20	2-3	5.2	0	-3.0	-.5	-.5
2/13	1350	Asphalt[2]	---	---	5-13	2	2.0	7.7	-.2	-.5	-.8
2/14	1050	Concrete[3]	---	---	3-4	1	3.0	≈10	.5	---	-.4
2/16	1400	Asphalt	---	---	2-6	2-3	1.5	0	-14.6	-5.5	-5.1
2/18	1420	Concrete	---	---	6-13	2-3	3.1	0	-5.2	-2.8	-3.1
2/19	1100	Grass	Partially Frozen	N.M.	9-14	2	2.8	10.9	4.5	.8	-.9
2/19	1430	Concrete	---	---	0-3	1	1.5	3.9	2.5	.0	-.1
2/20	1015	Asphalt	---	---	0-9	0-2	1.1	13.4	2.0	.0	-.7
2/20	1352	Grass	Partially Frozen	N.M.	0-14	0-2	≈2	12.1	1.9	.0	-.4

(1) At 2 cm below the surface.

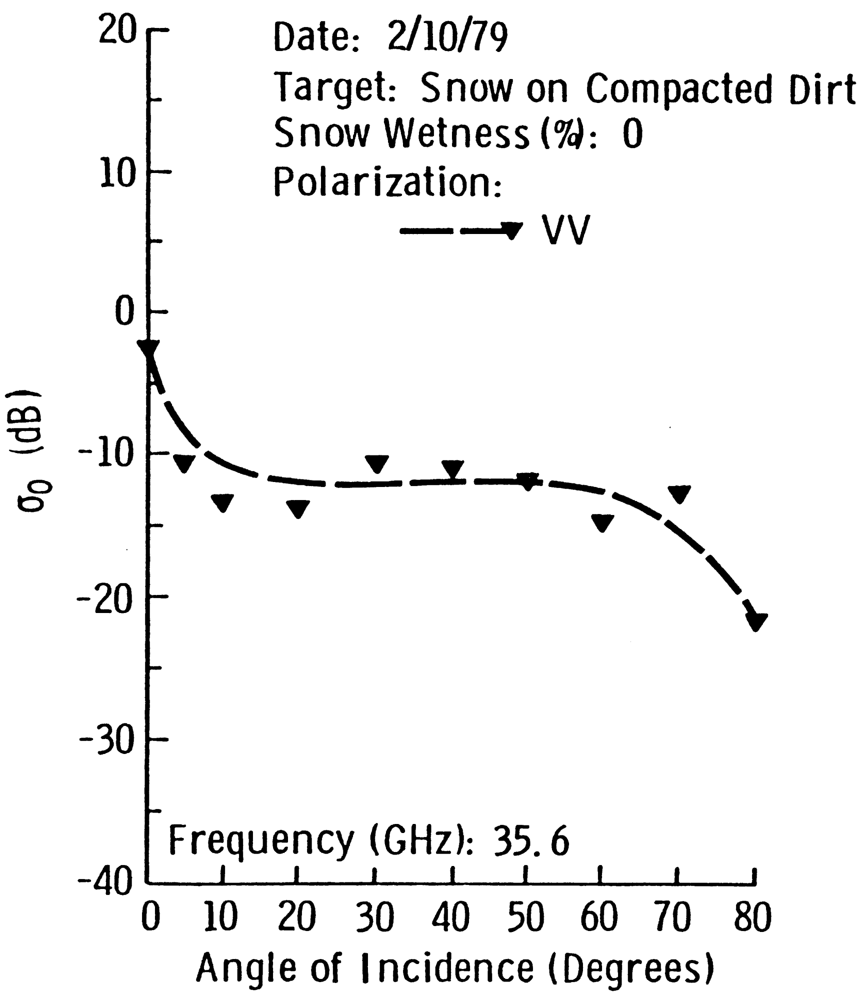
(2) Ice layer underneath snow 5 cm thick.

(3) Layer consisted of packed snow, slush, water and ice. Wetness was not measured; however, the snow was wet.

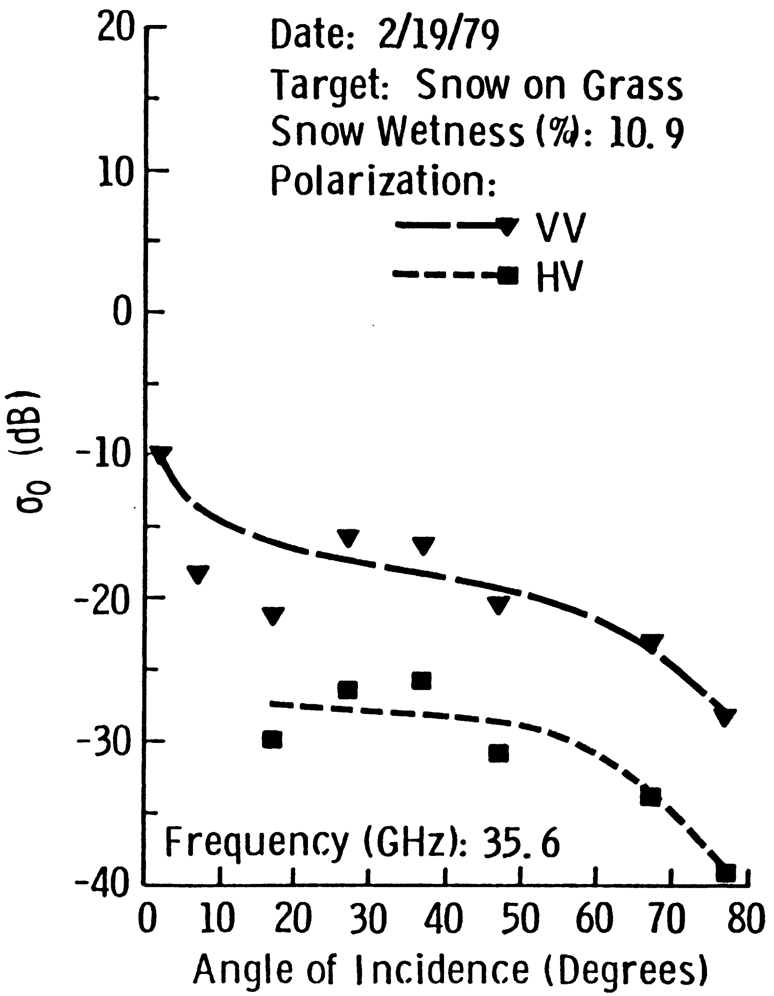
(4) N.M.--not measurable with present technique.



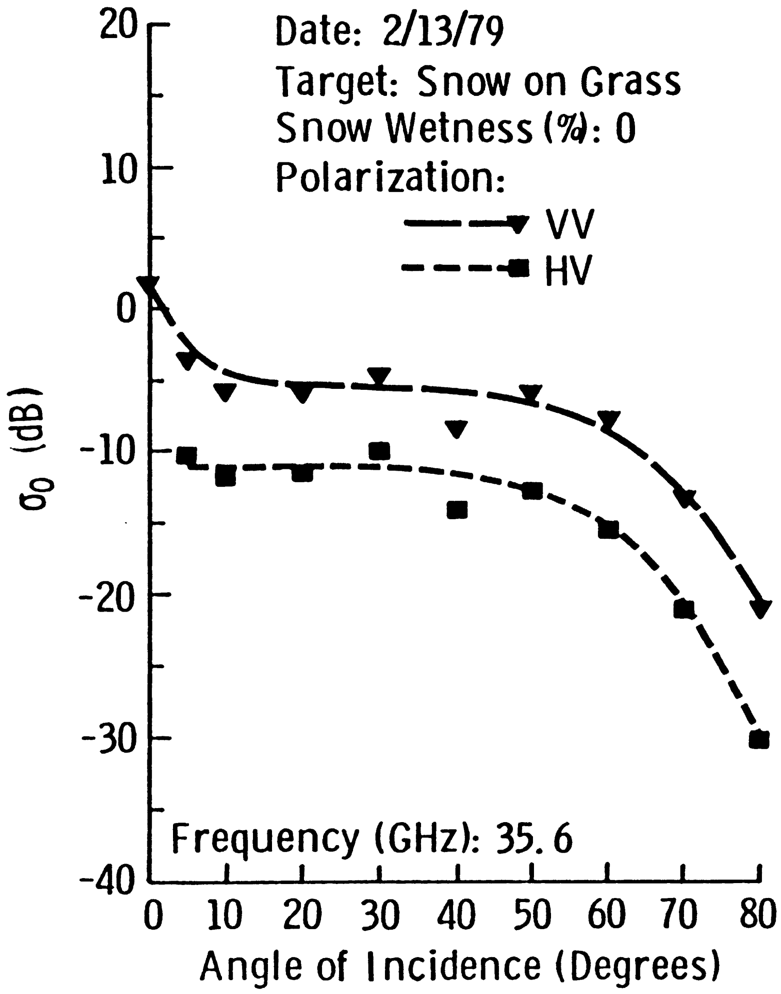
Wet Snow on Compacted Dirt Surface



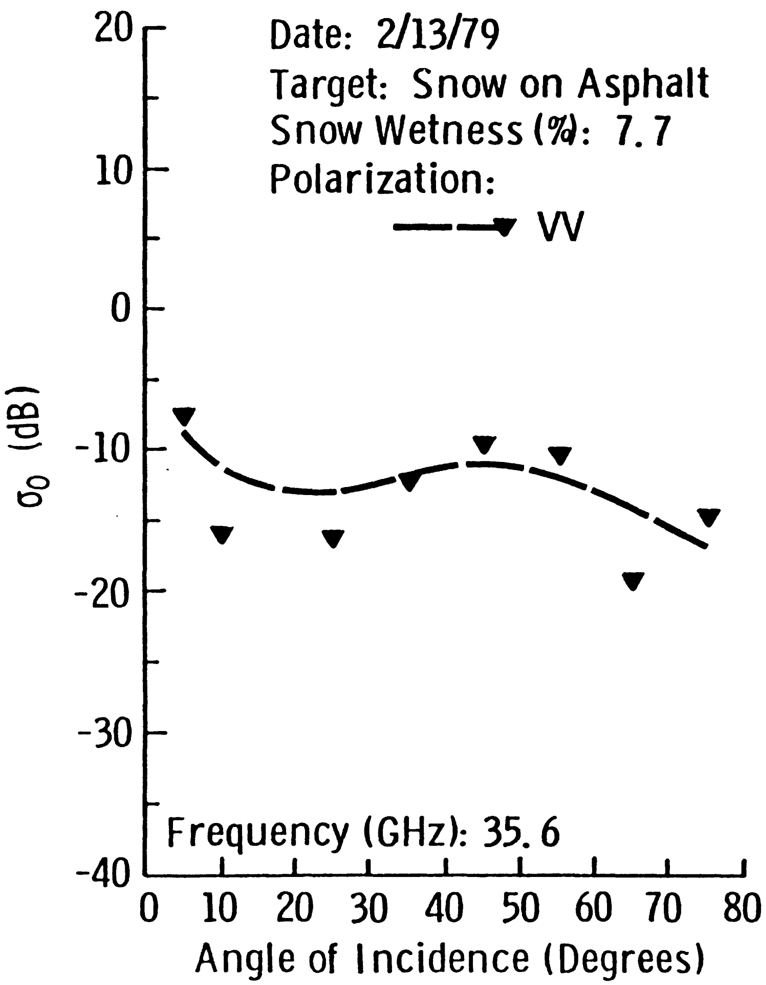
Dry Snow on Compacted Dirt Surface



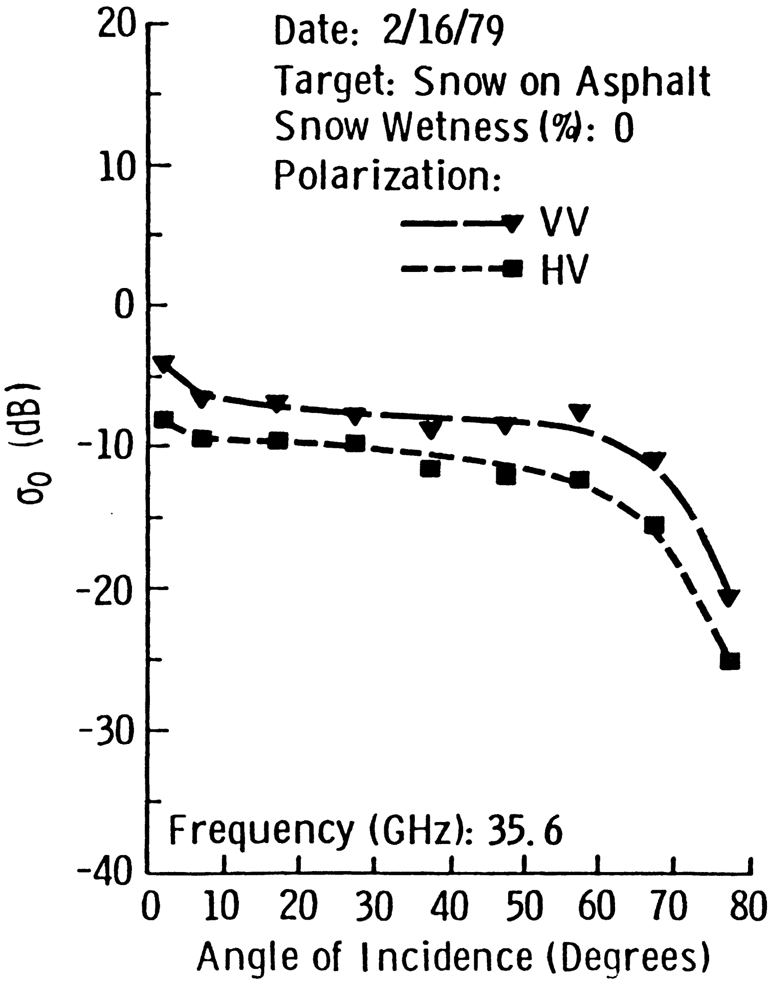
Wet Snow on Grass



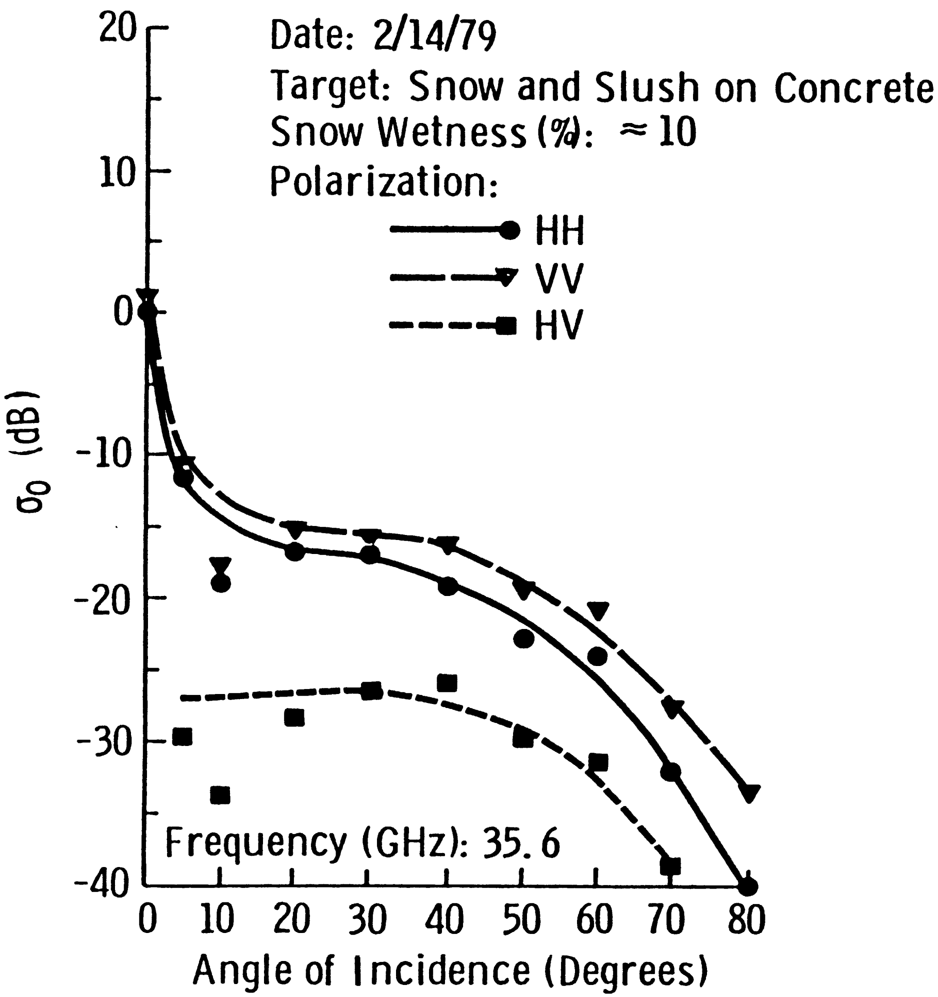
Dry Snow on Grass



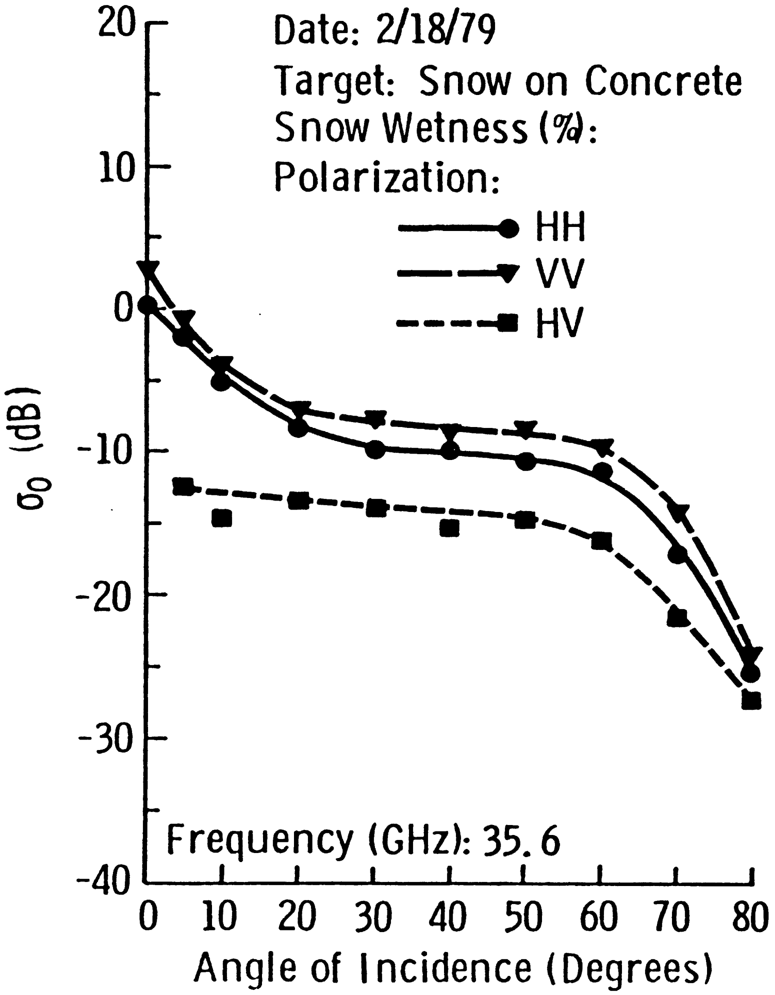
Wet Snow on Asphalt



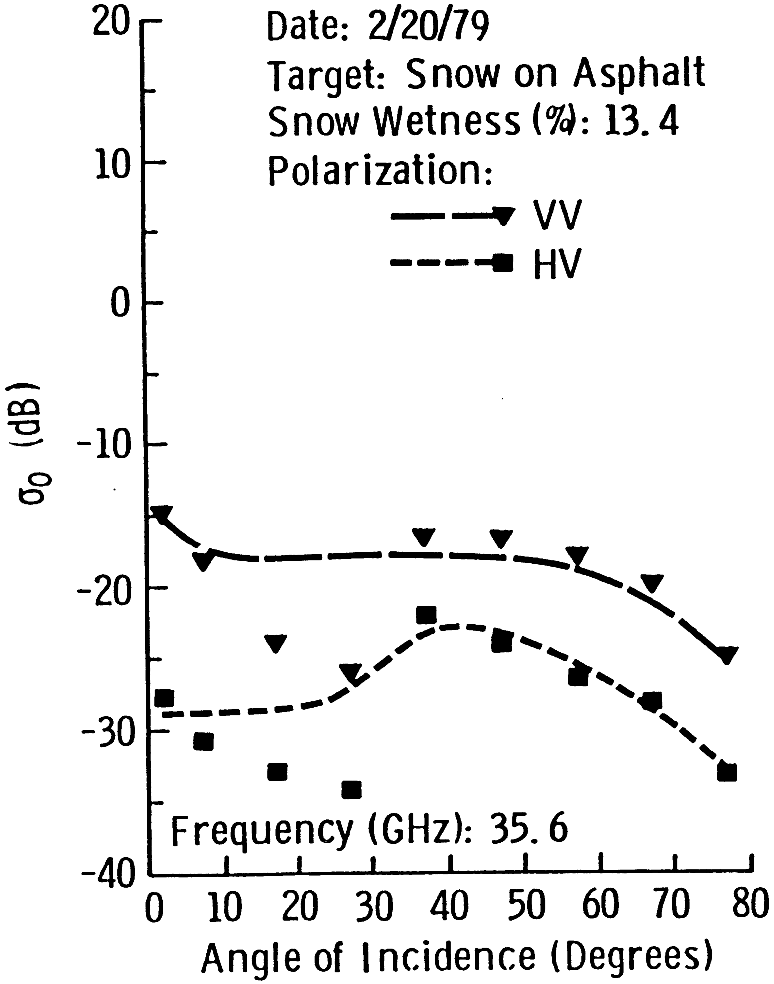
Dry Snow on Asphalt



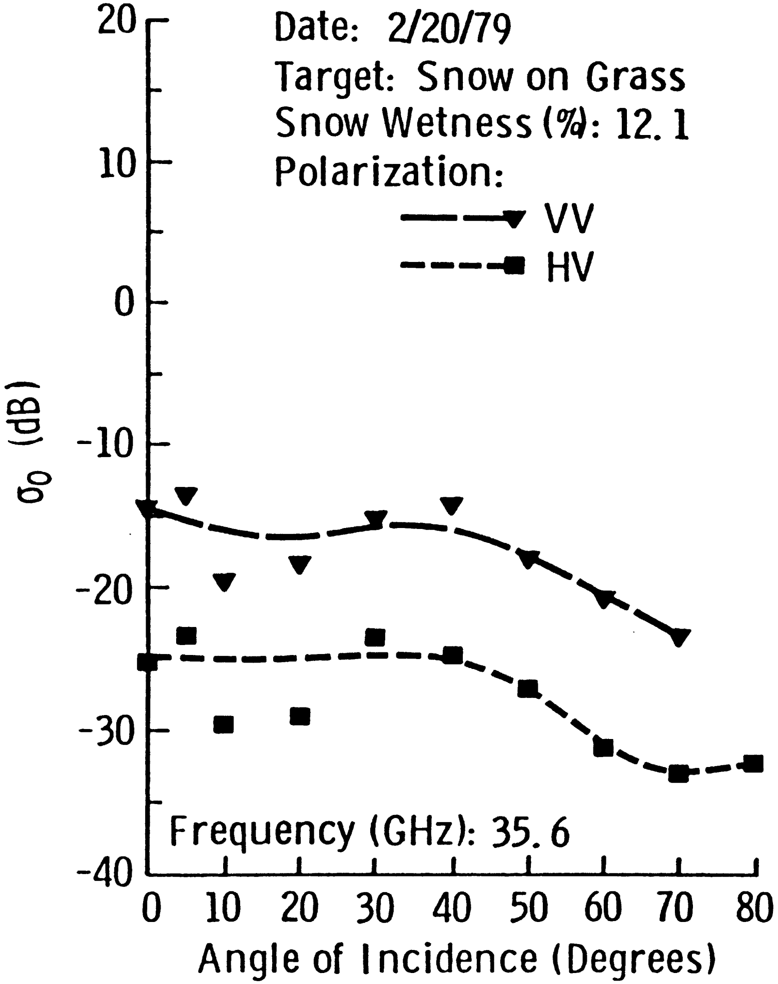
Wet Snow on Concrete



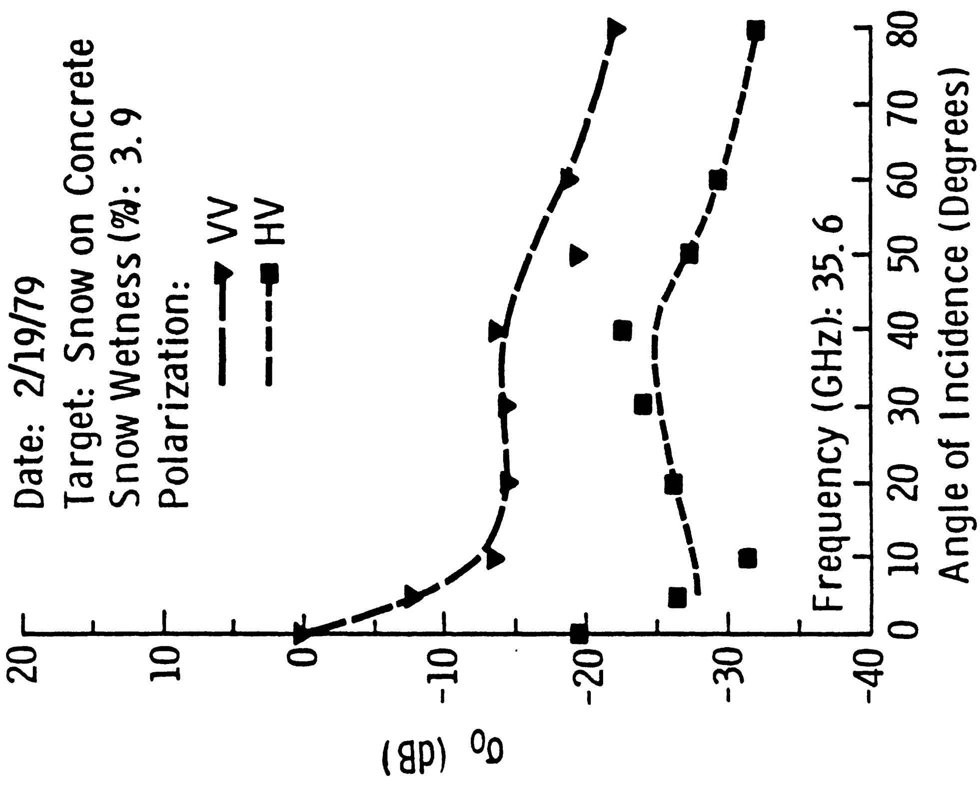
Dry Snow on Concrete



Wet Snow on Asphalt



Wet Snow on Grass



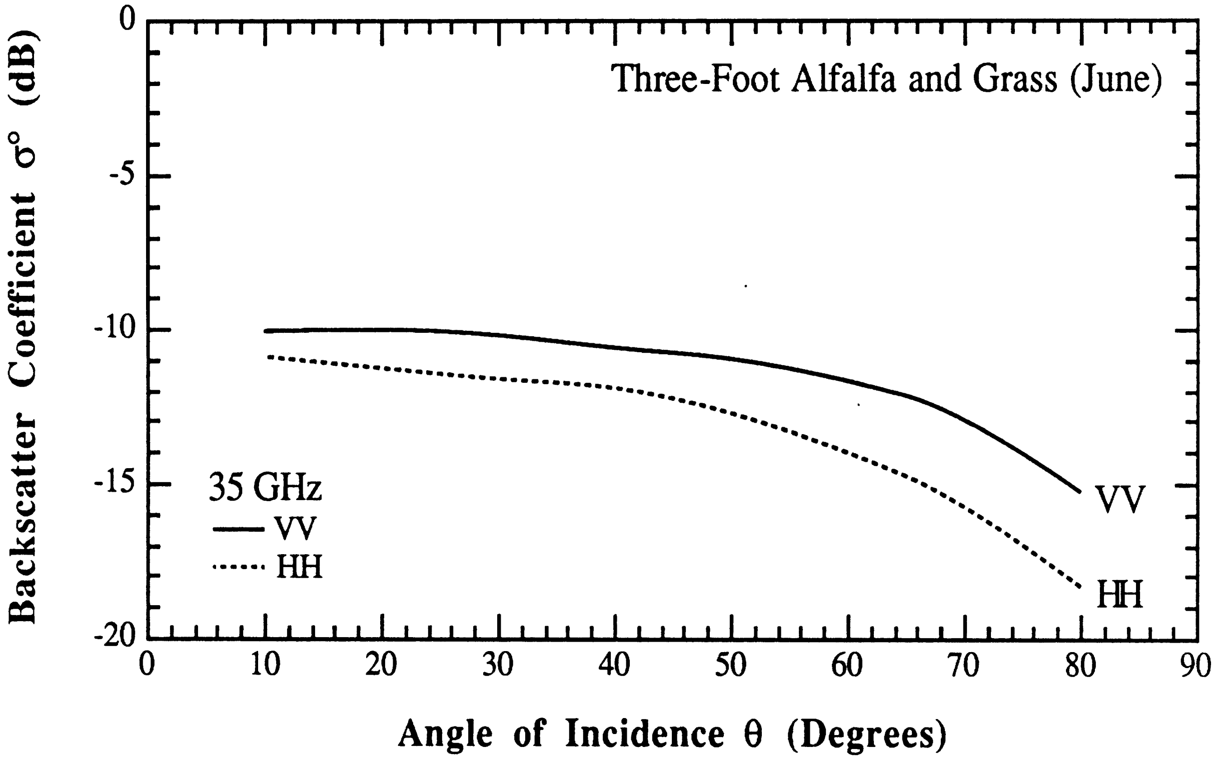
Wet Snow on Concrete

PART IV. OHIO STATE UNIVERSITY DATA

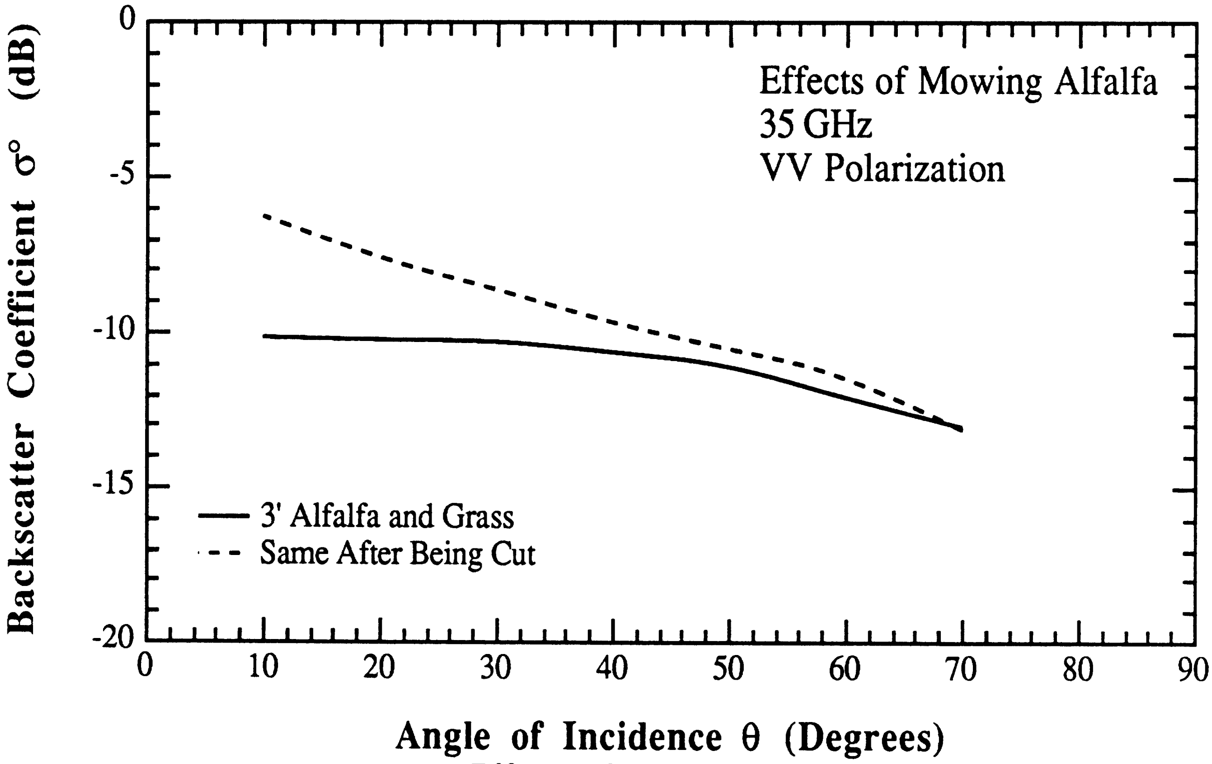
The Ohio State University data presented in this part of the Handbook were extracted from references [21] and [22]. In its original form, the data were presented in the form of plots of $\gamma = \sigma^o/\cos\theta$ versus the depression angle $\theta' = 90^o - \theta$. All data were converted to σ^o versus the incidence angle θ. Moreover, for data measured prior to 1960, which includes all the data reported in the Terrain Handbook II [21] issued by OSU in May, 1960, the level of the data was off by about 6 dB due to a recorder calibration error. As noted in the article by Bush and Ulaby [27] and confirmed by Peake (one of the principal authors of the OSU reports) in the same article, the level of σ^o should be increased by 5-7 dB. Hence, all OSU data measured prior to 1960 has been increased in level by 6 dB in this Handbook.

The OSU measurement program used a truck-mounted CW-Doppler radar to measure the backscatter as a function of incidence angle at 10, 15, and 35 GHz. Only the 35 GHz data is presented in this Handbook.

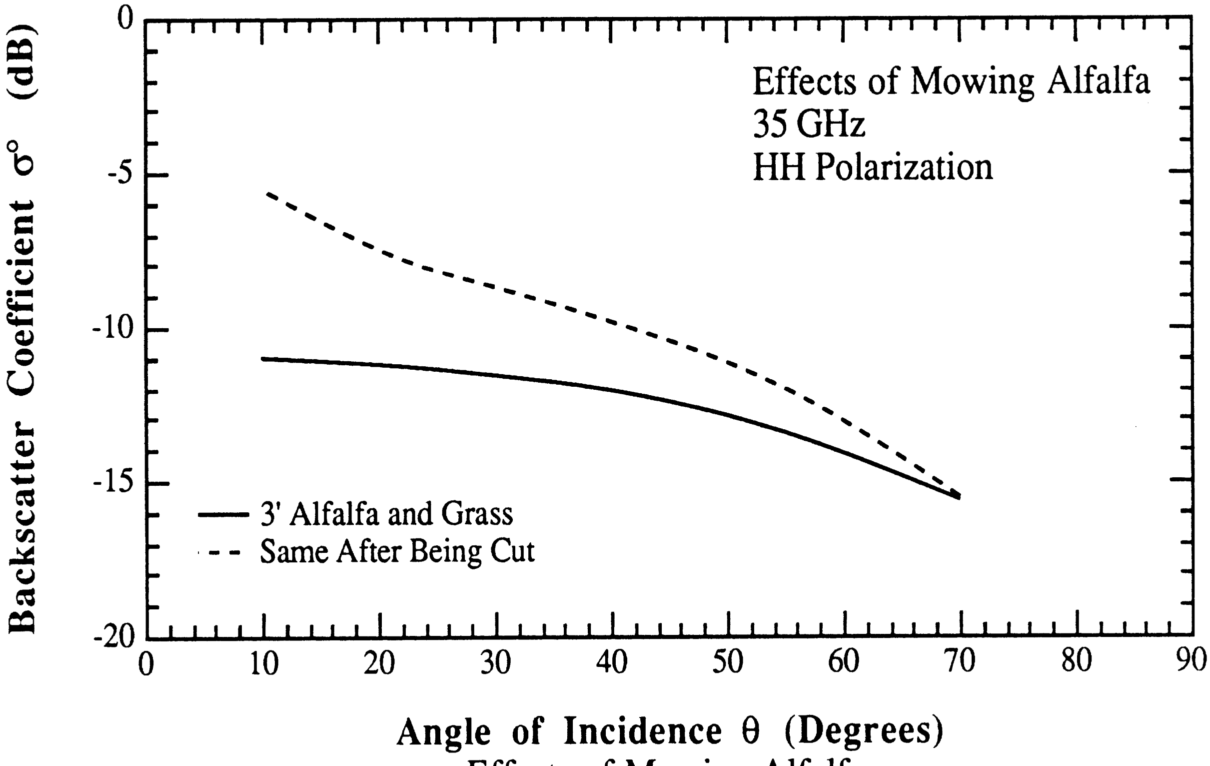
14. 35 GHz DATA FOR VEGETATION



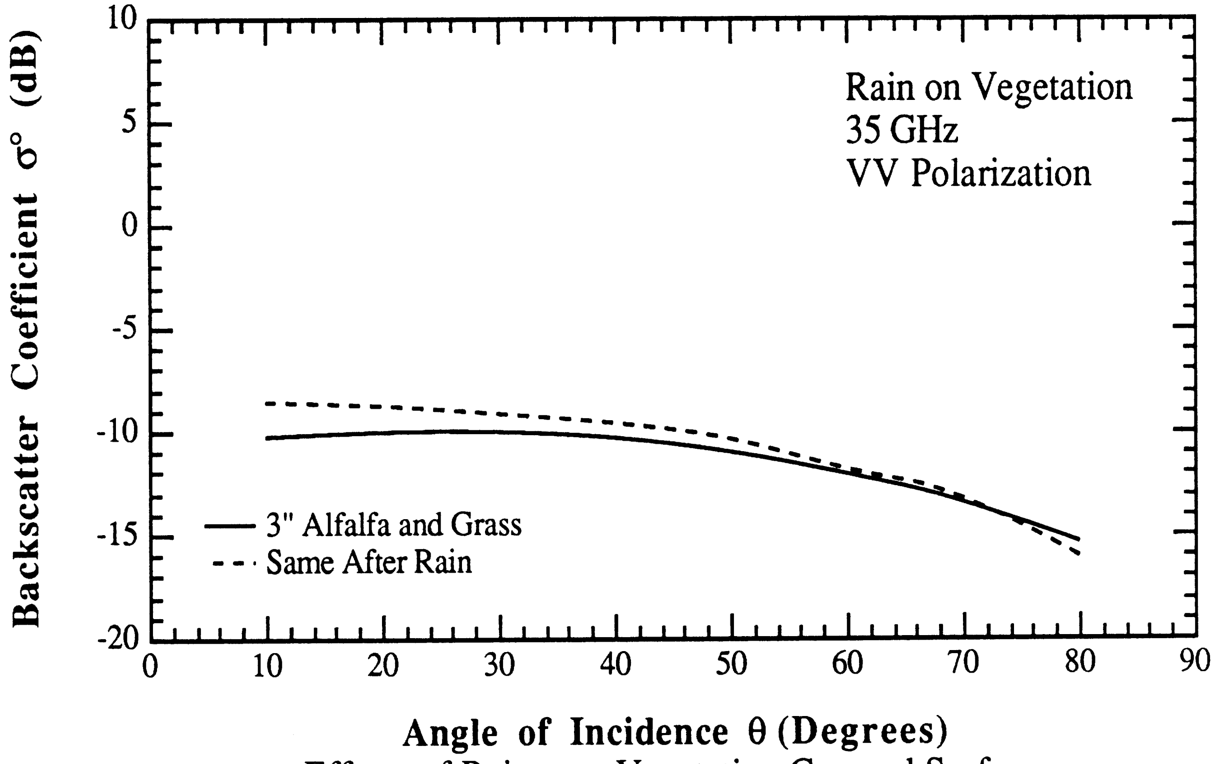
Three-Foot Alfalfa and Grass (June)



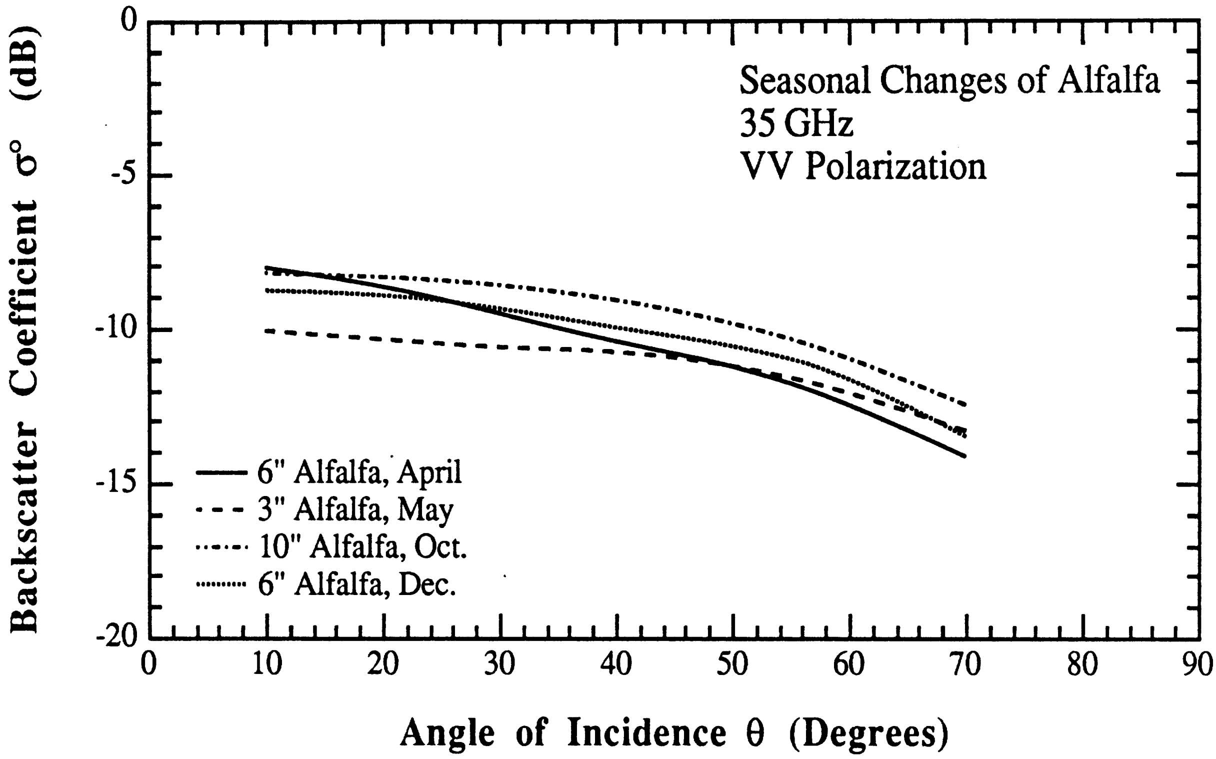
Effects of Mowing Alfalfa



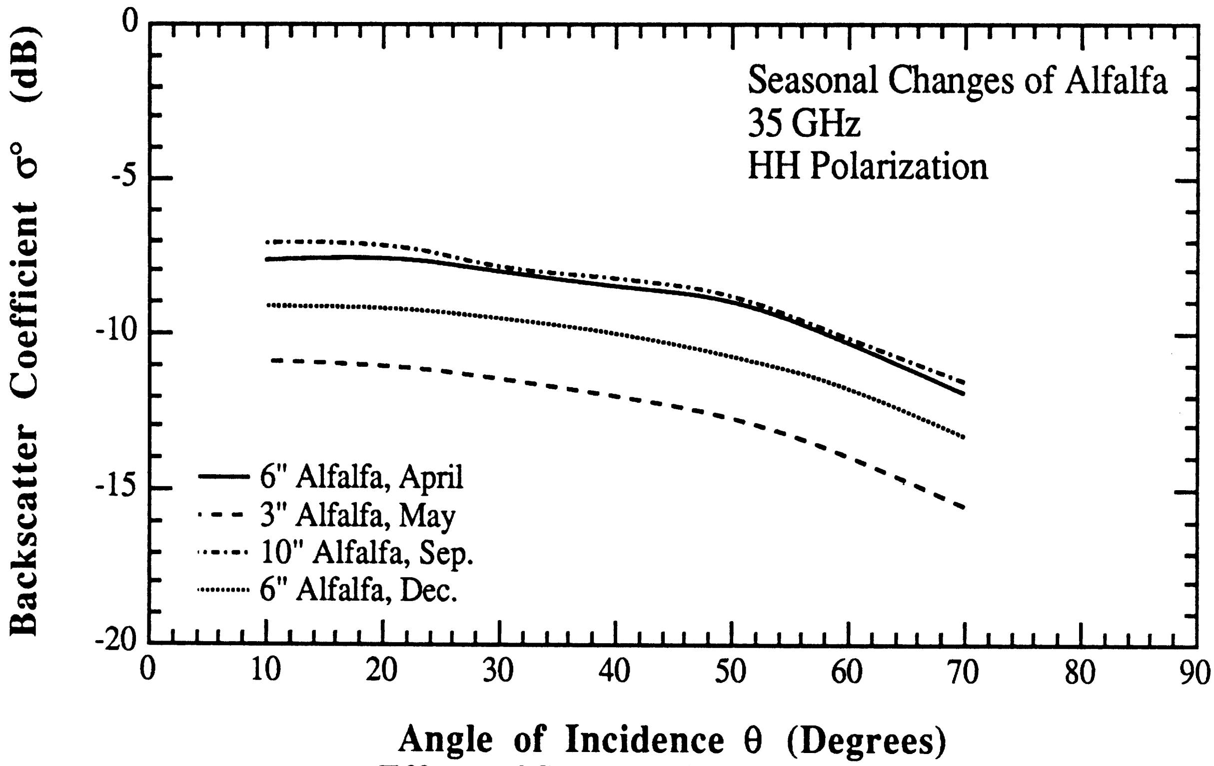
Effects of Mowing Alfalfa



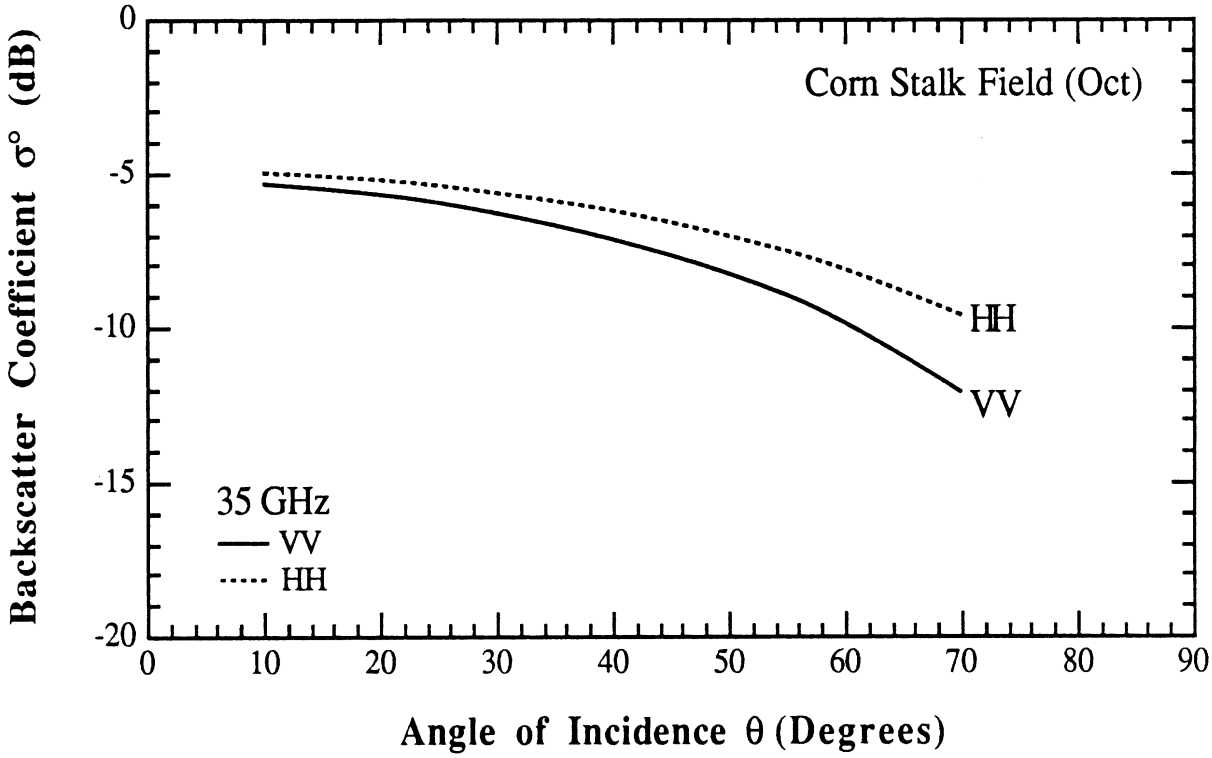
Effects of Rain on a Vegetation Covered Surface



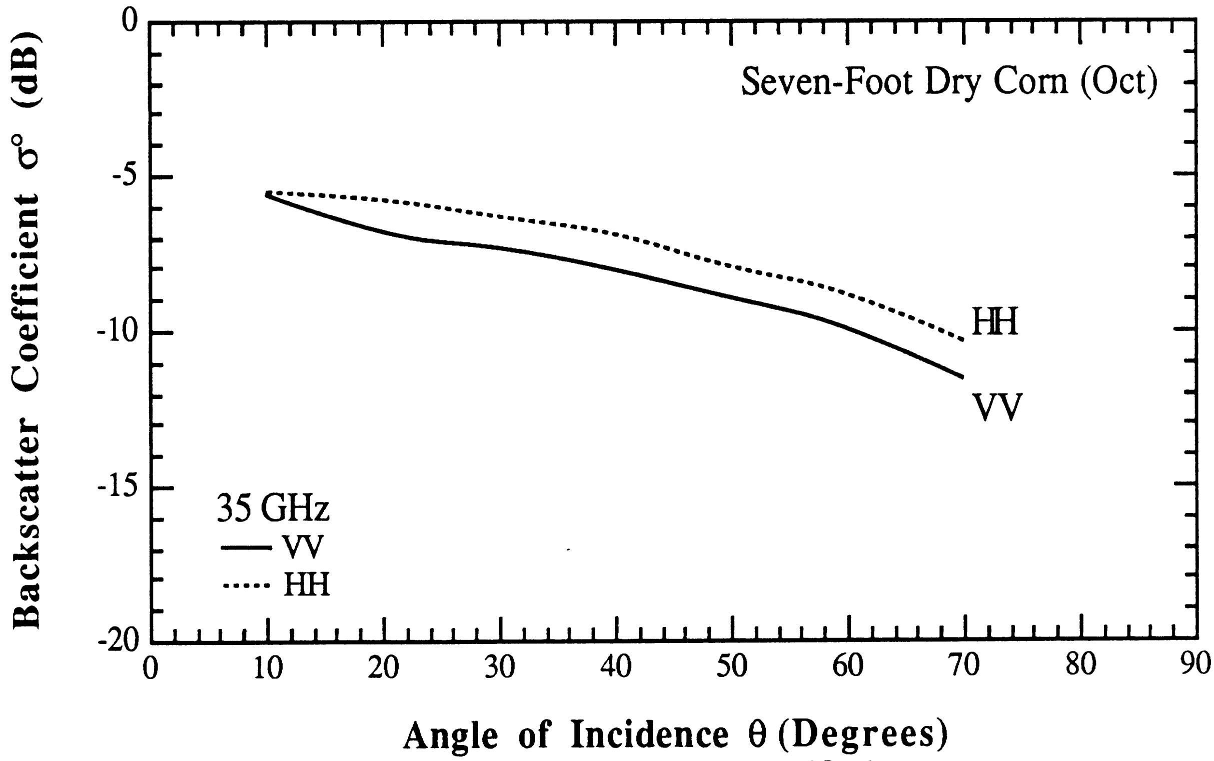
Effects of Seasonal Changes of Alfalfa



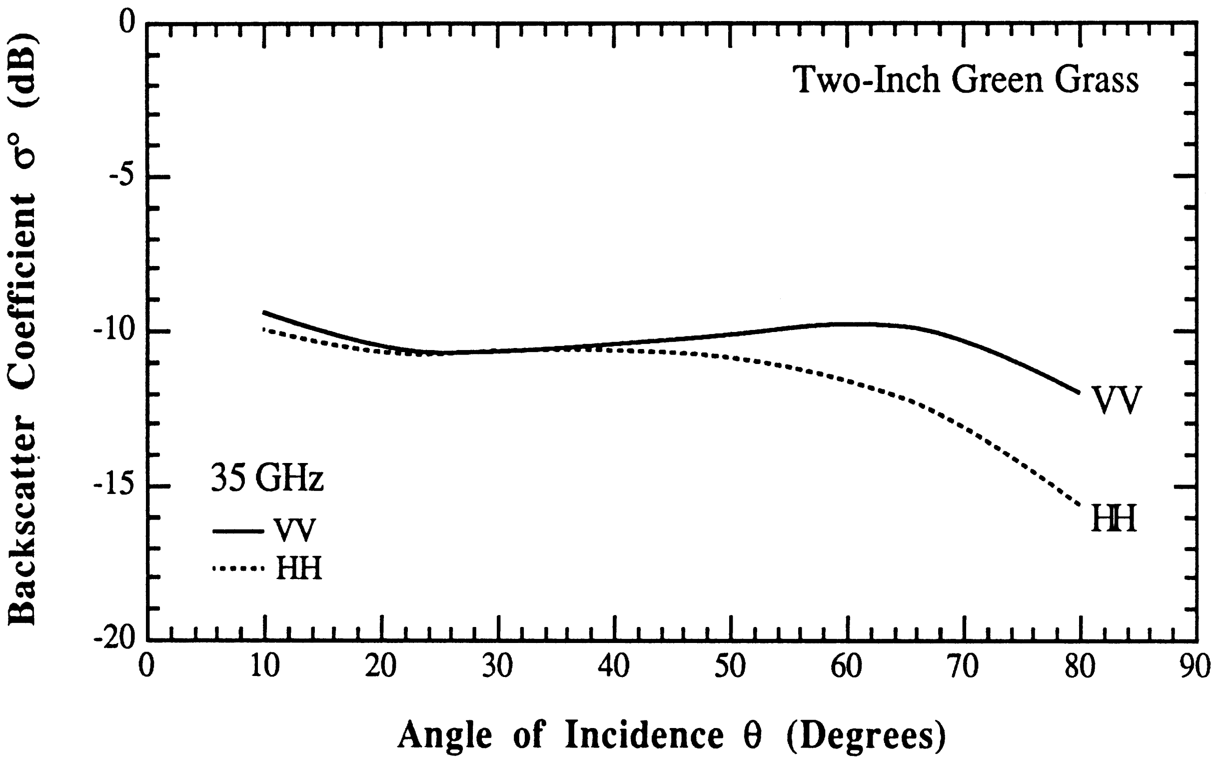
Effects of Seasonal Changes of Alfalfa



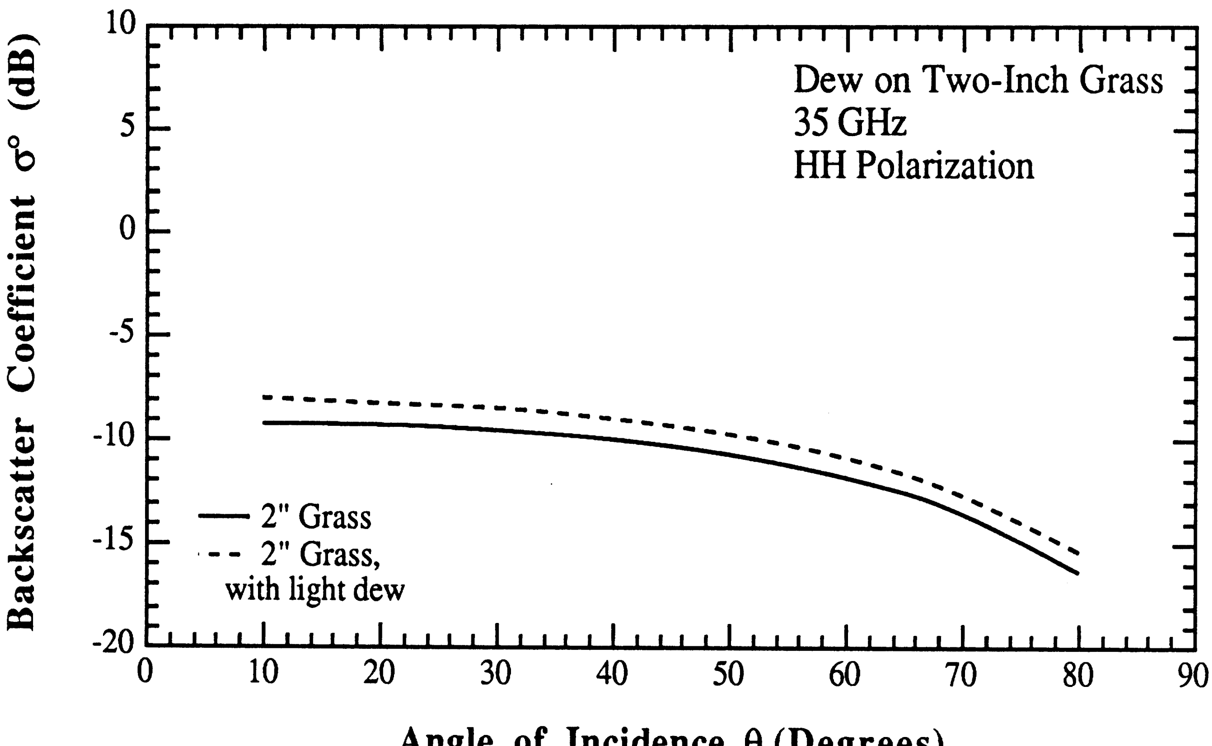
Corn Stalk Field (Oct)



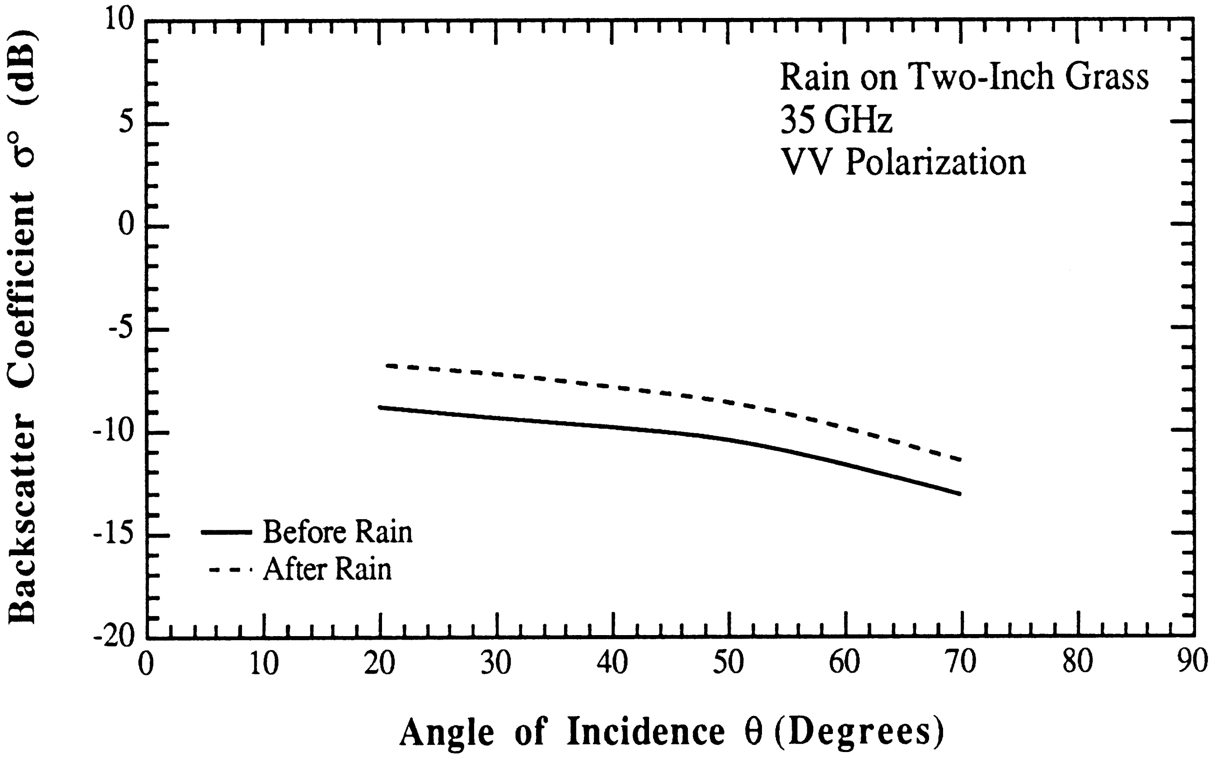
Seven-Foot Dry Corn (Oct)



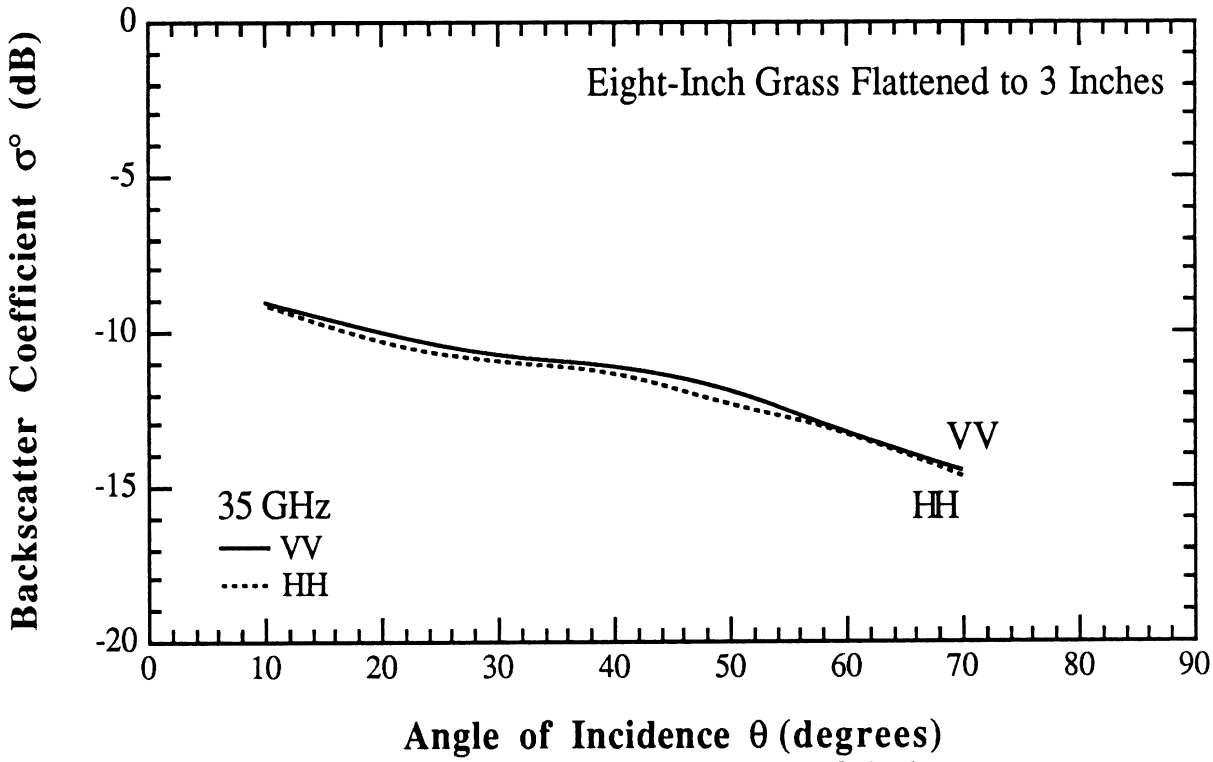
Two-Inch Green Grass



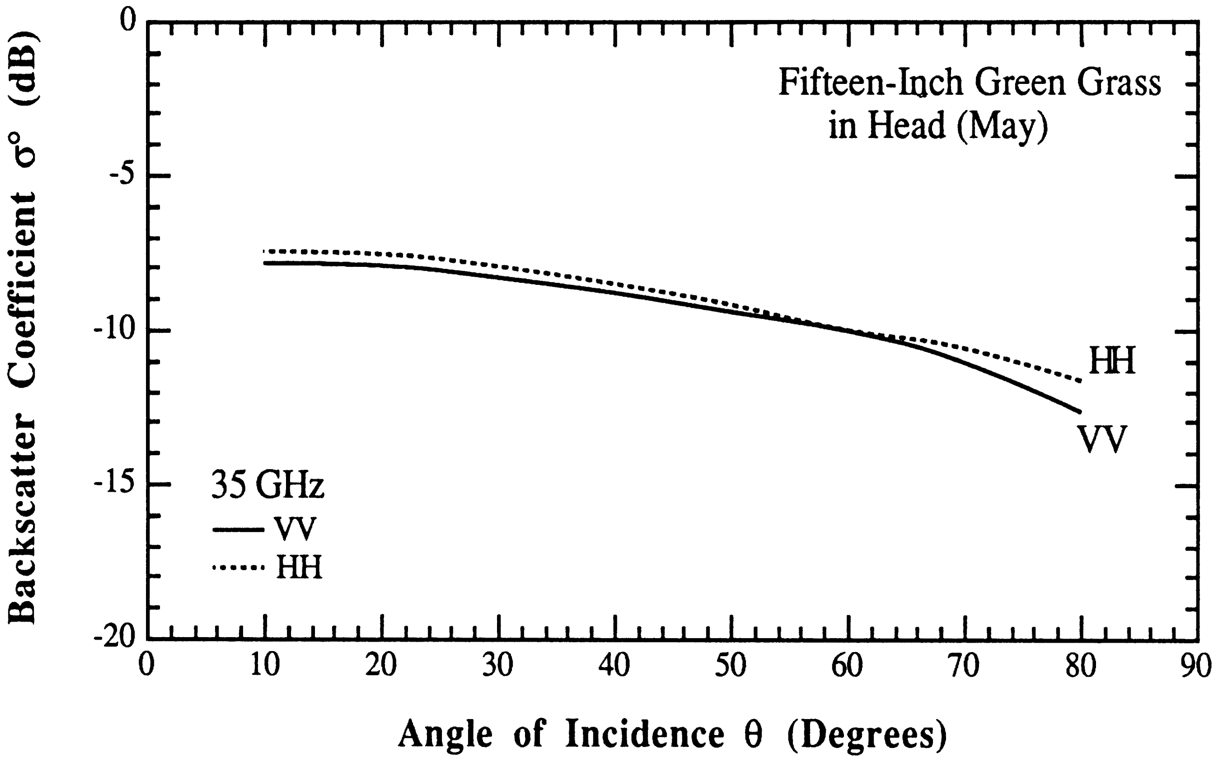
Effects of Dew on Two-Inch Grass



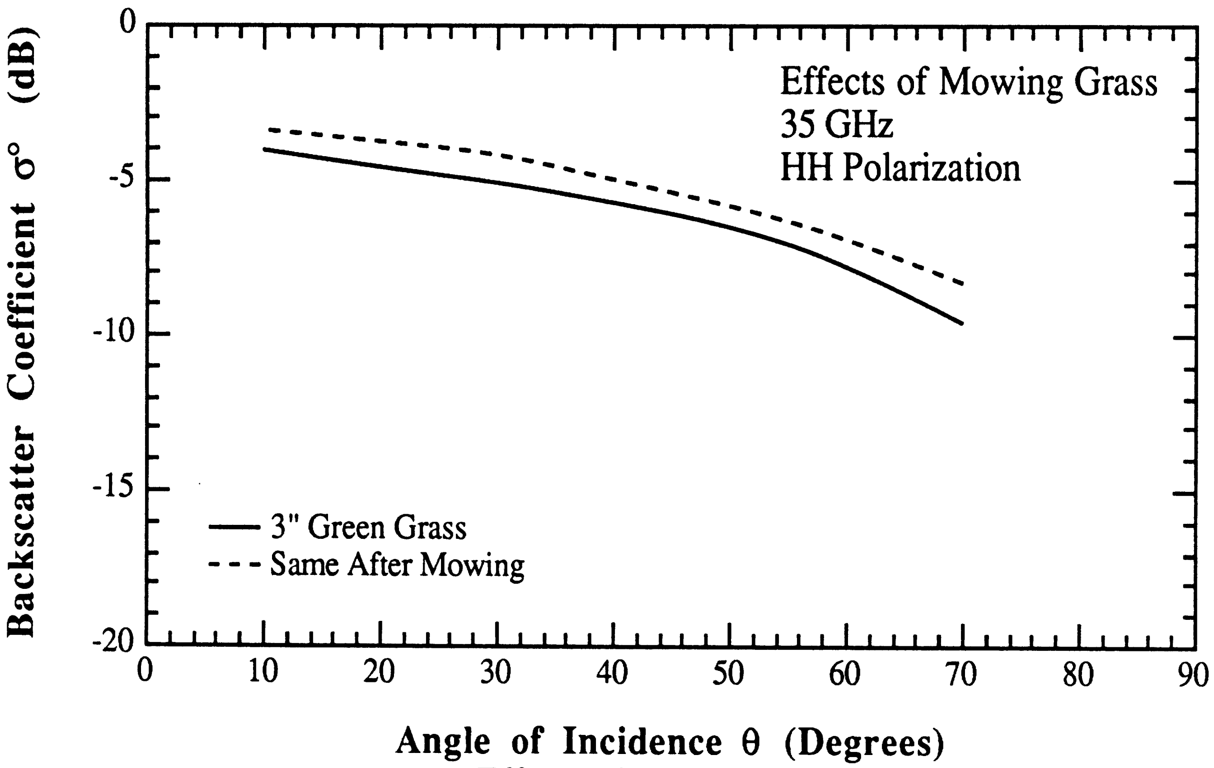
Effects of Rain on Two-Inch Grass



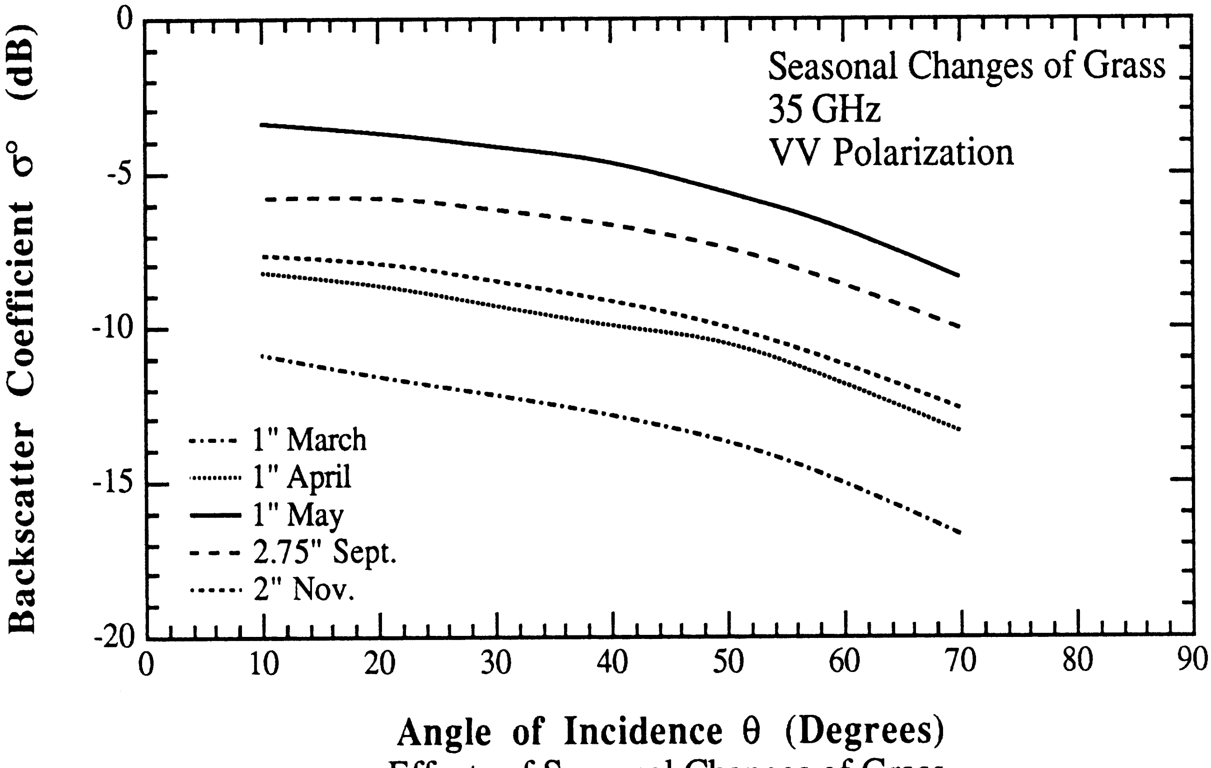
Eight-Inch Grass Flattened to 3 Inches



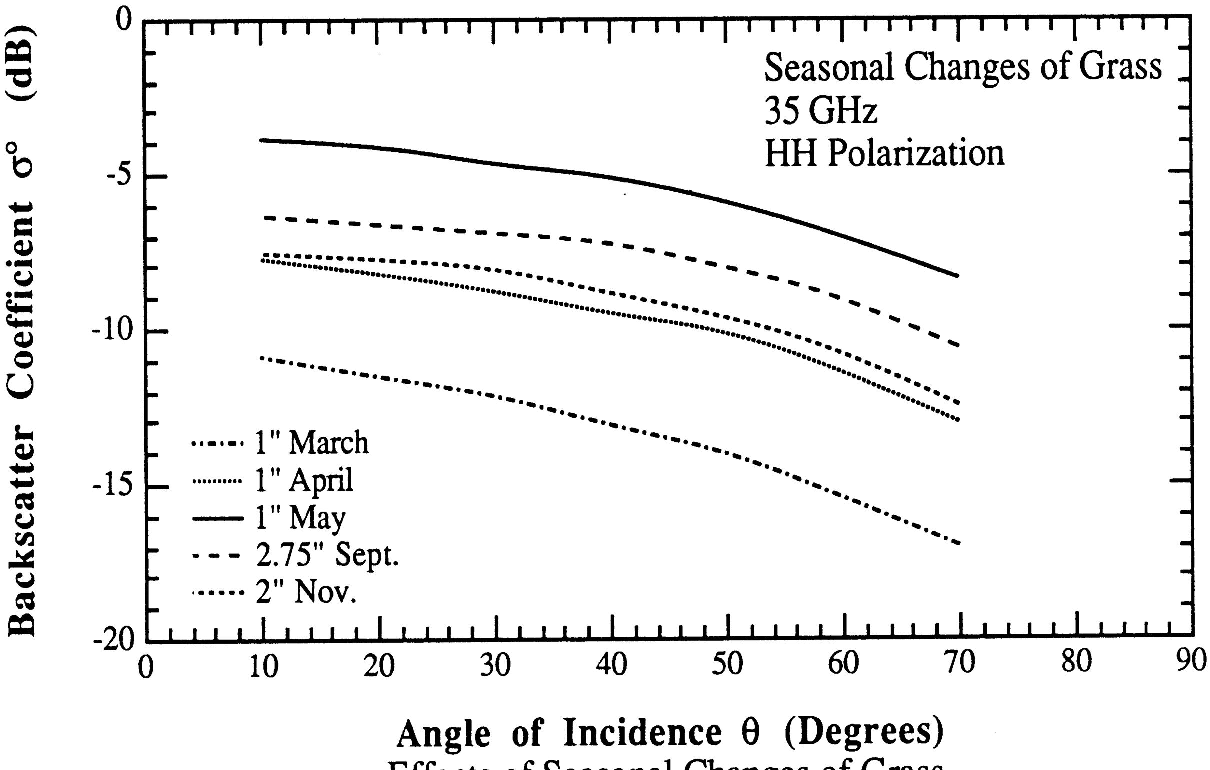
Fifteen-Inch Green Grass in Head (May)



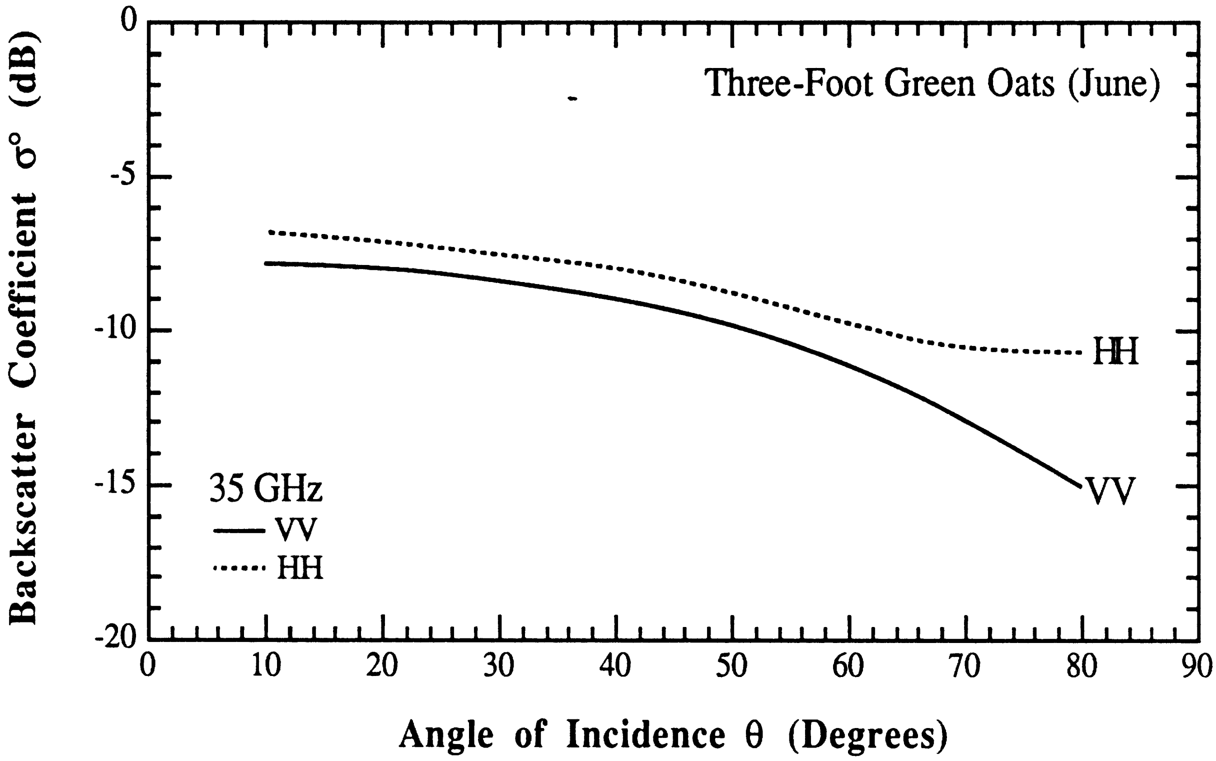
Effects of Mowing Grass



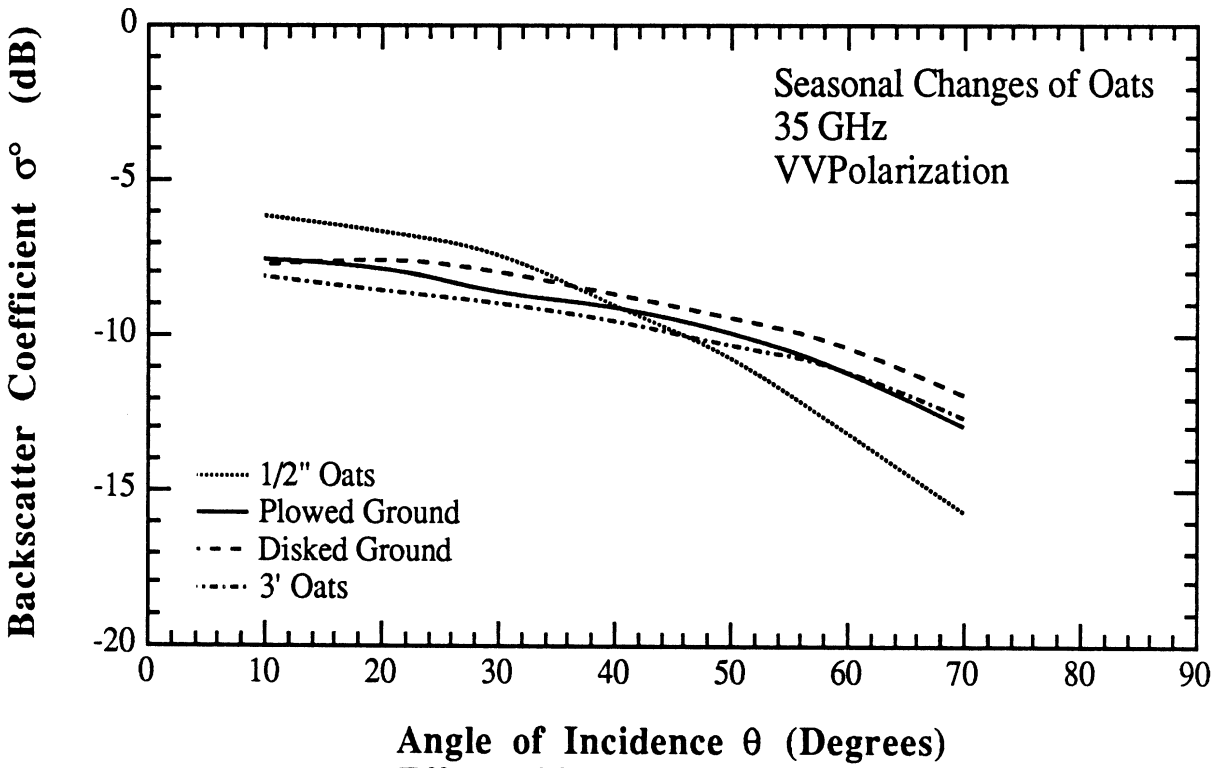
Effects of Seasonal Changes of Grass



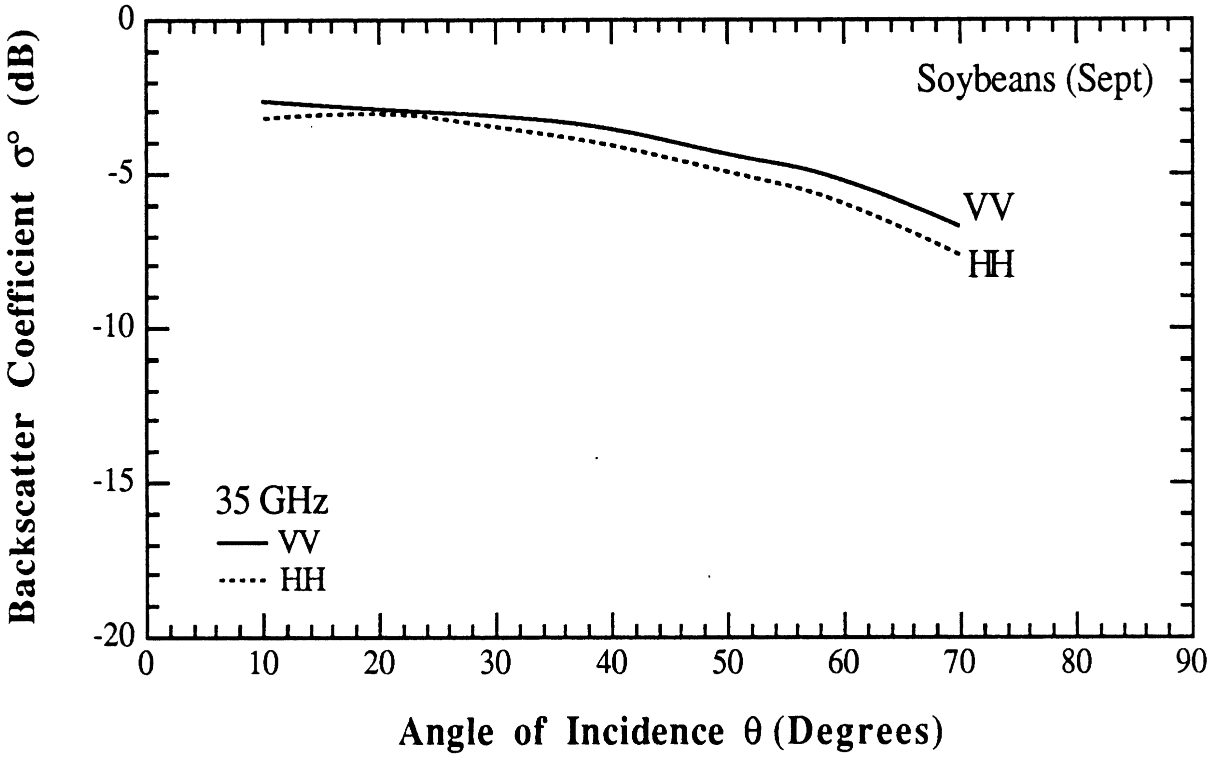
Effects of Seasonal Changes of Grass



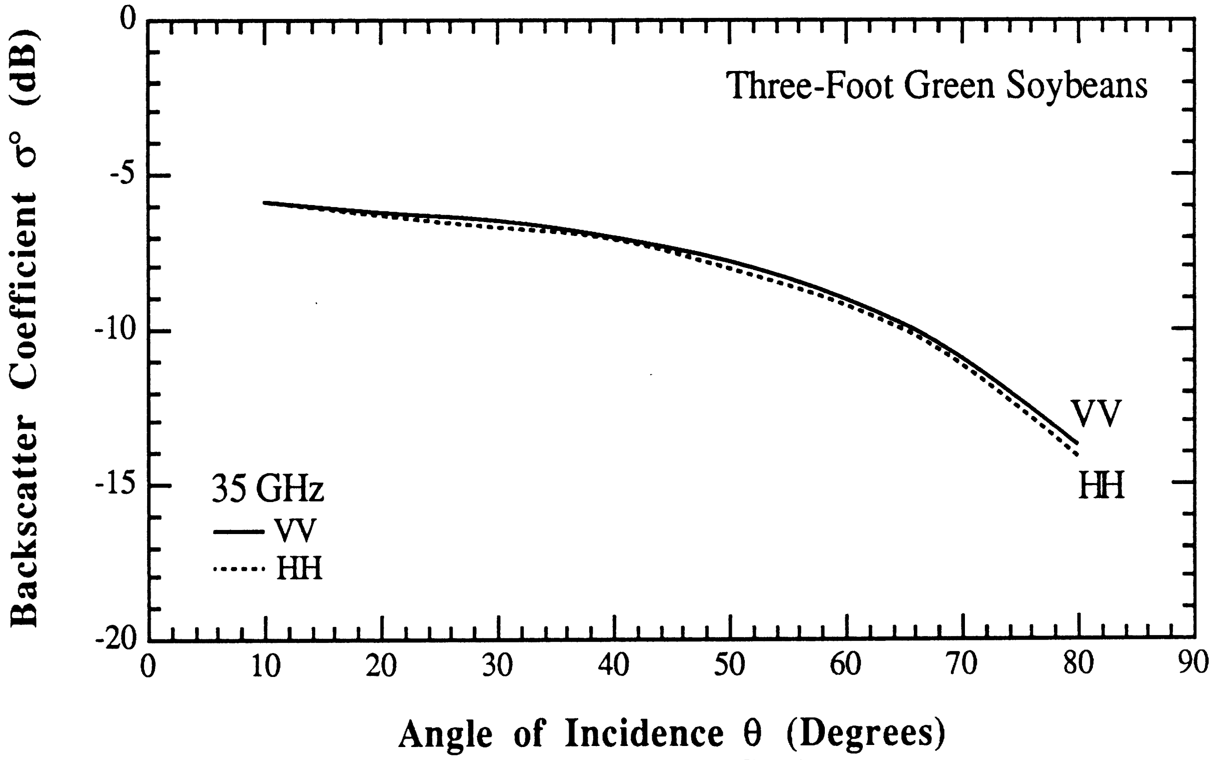
Three-Foot Green Oats (June)



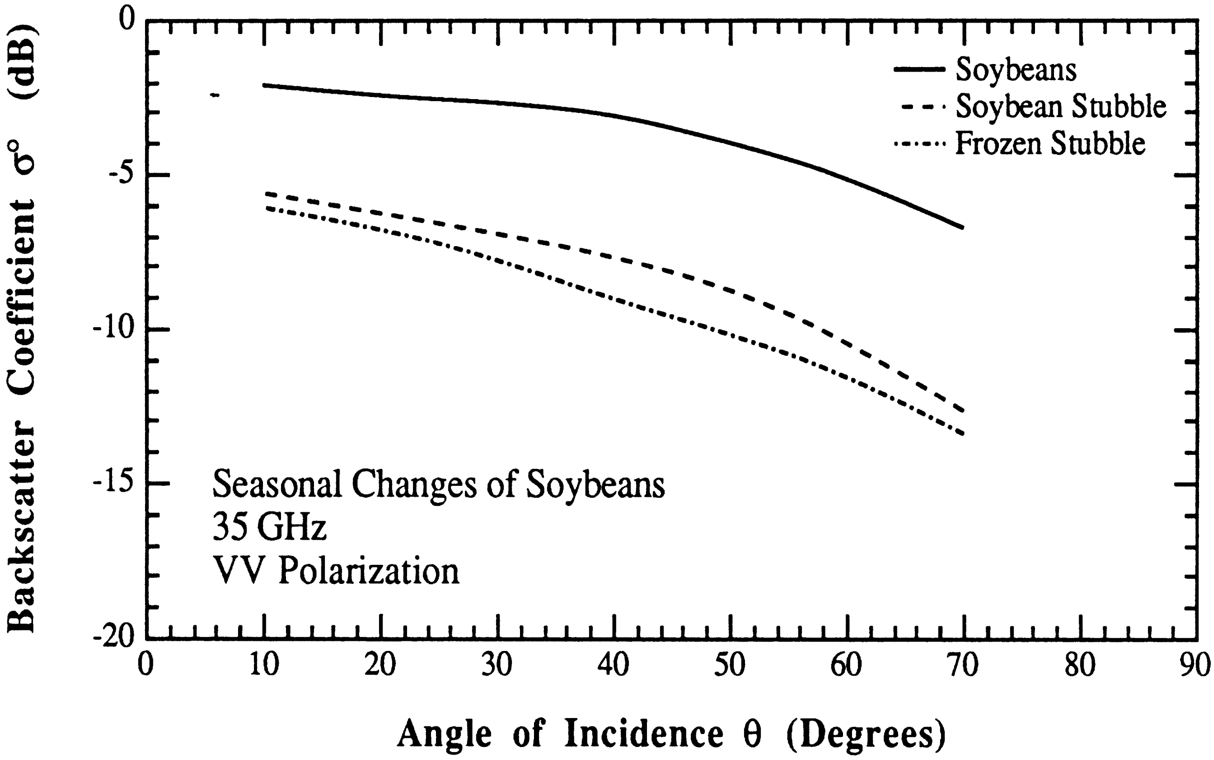
Effects of Seasonal Changes of Oats



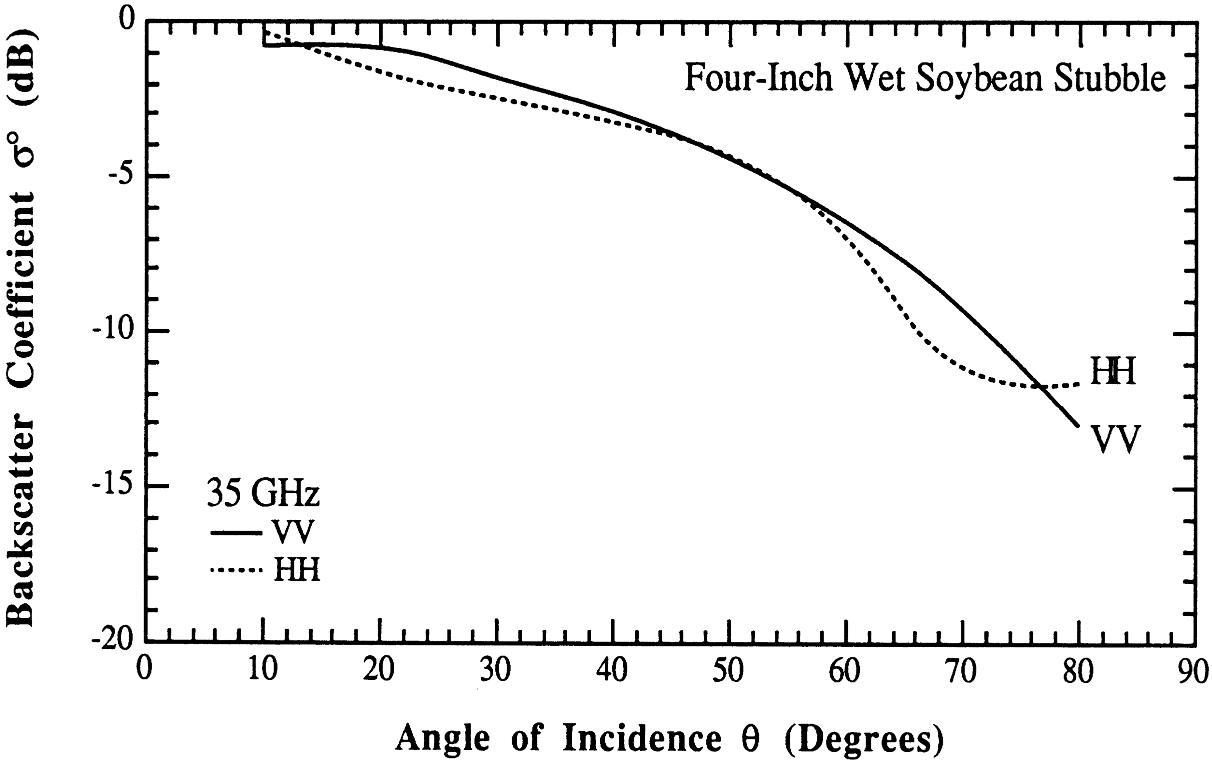
Soybeans (Sept)



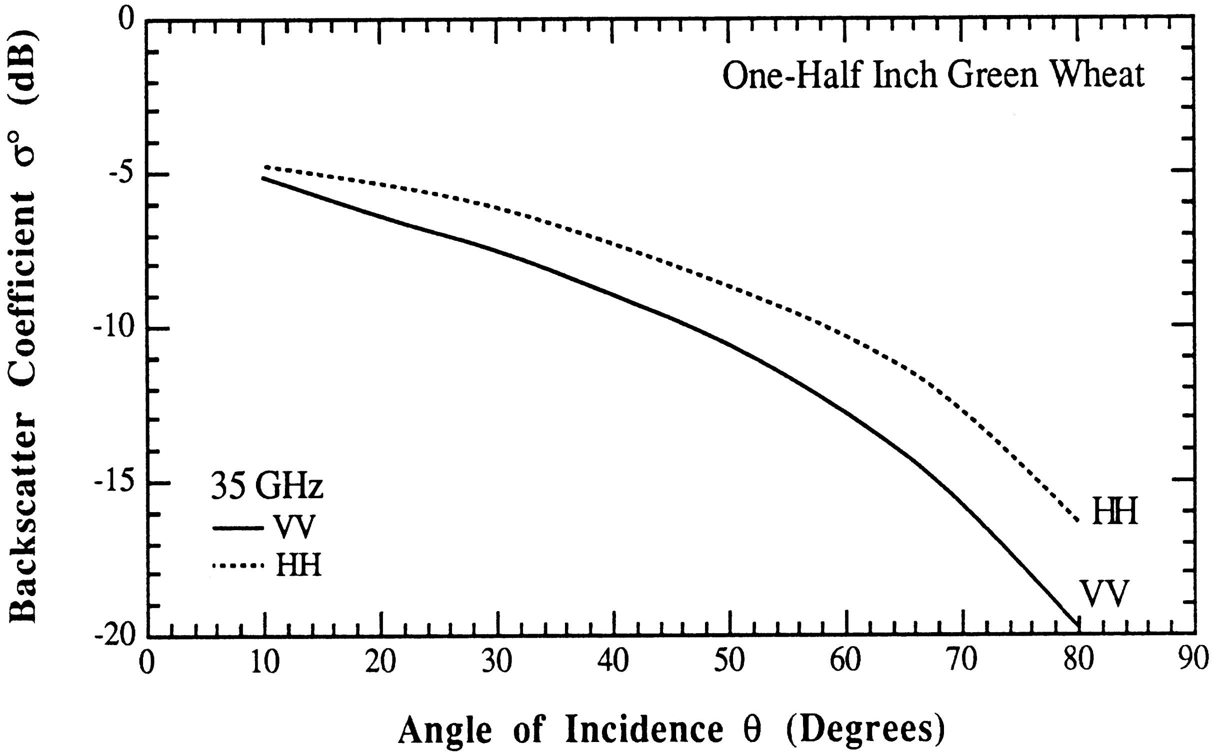
Three-Foot Green Soybeans



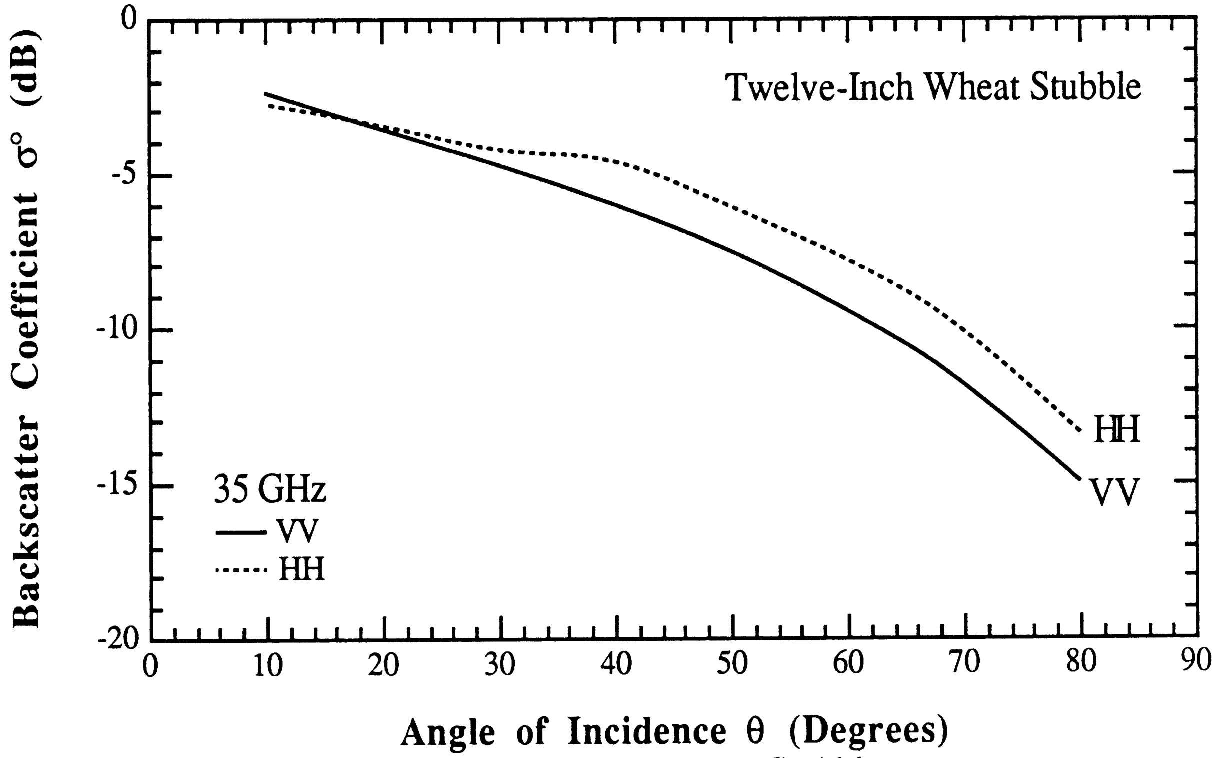
Effects of Seasonal Changes of Soybeans



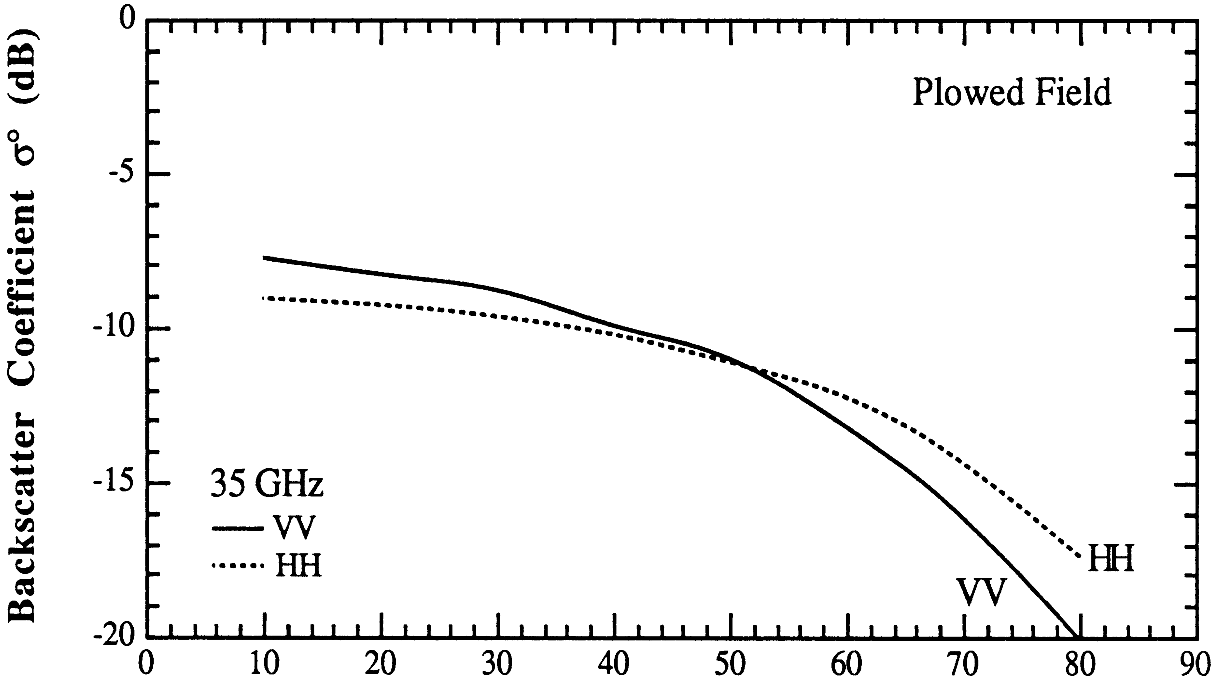
Four-Inch Wet Soybean Stubble



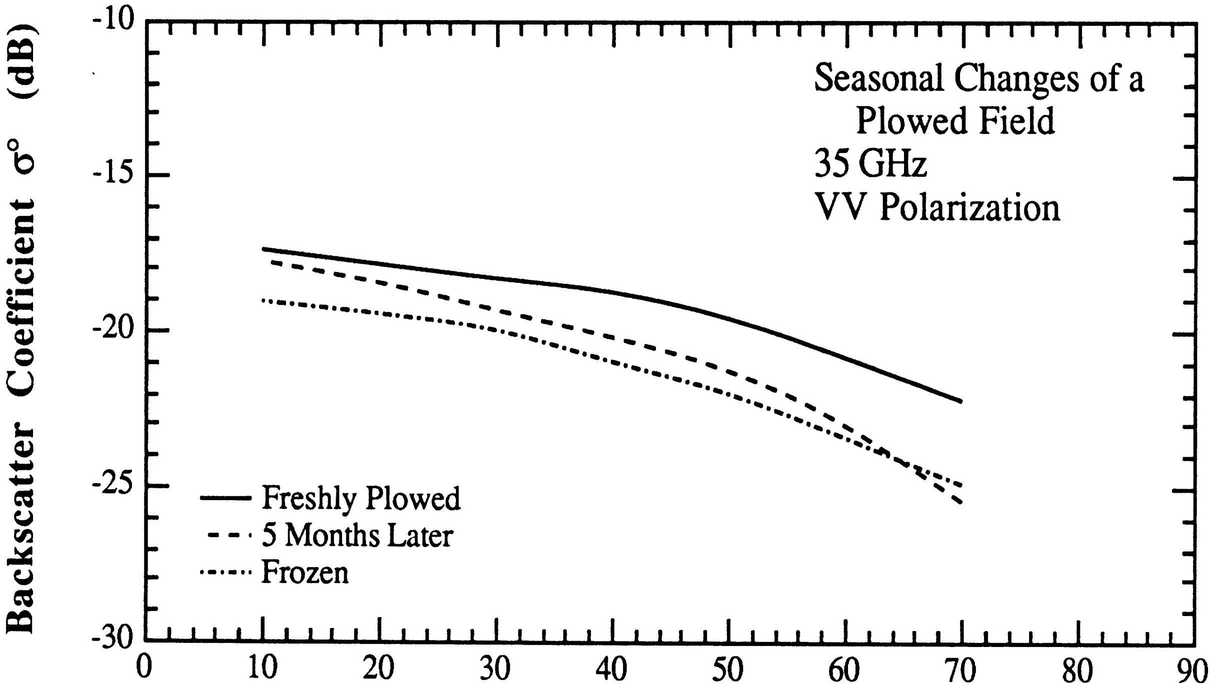
One-Half Inch Green Wheat



Twelve-Inch Wheat Stubble



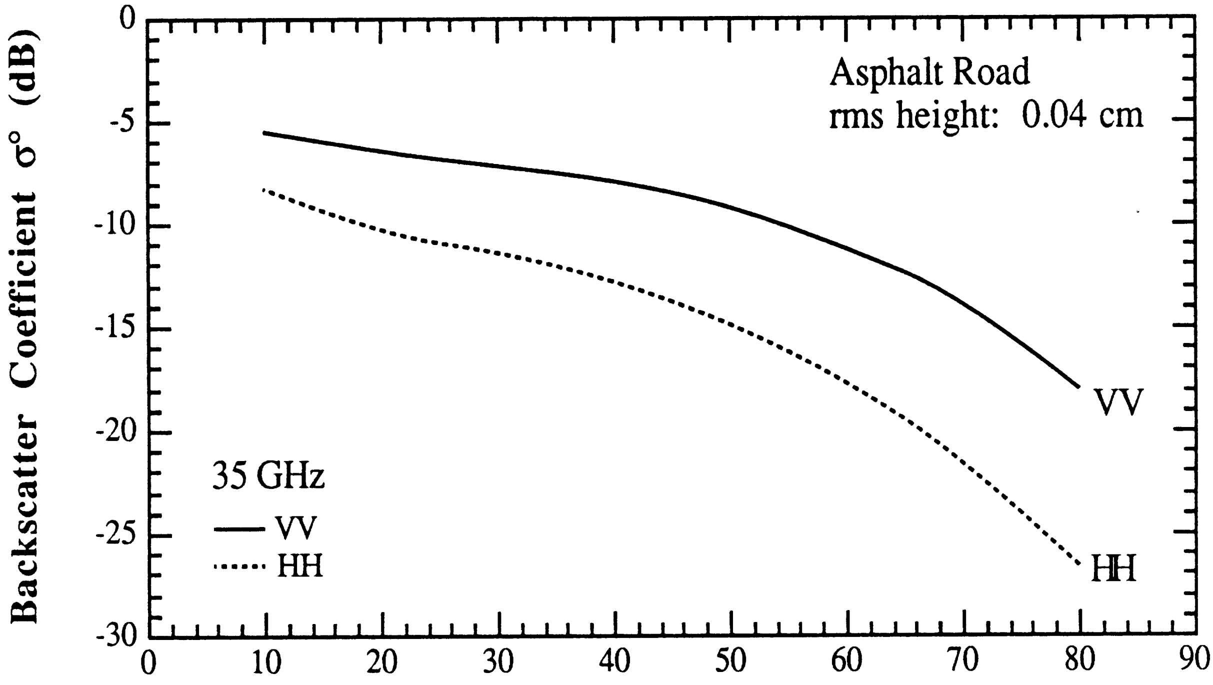
Angle of Incidence θ (Degrees)
Plowed Field



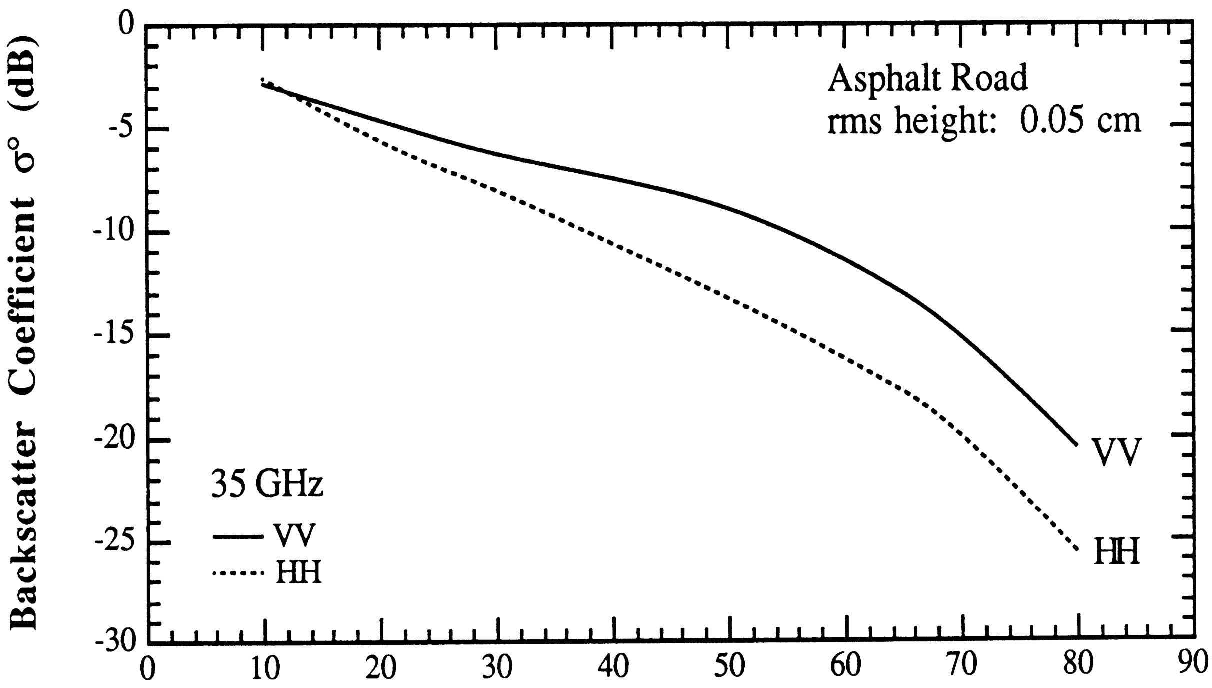
Angle of Incidence θ (Degrees)
Effects of Seasonal Changes of a Plowed Field

15. 35 GHz DATA FOR ROAD SURFACES

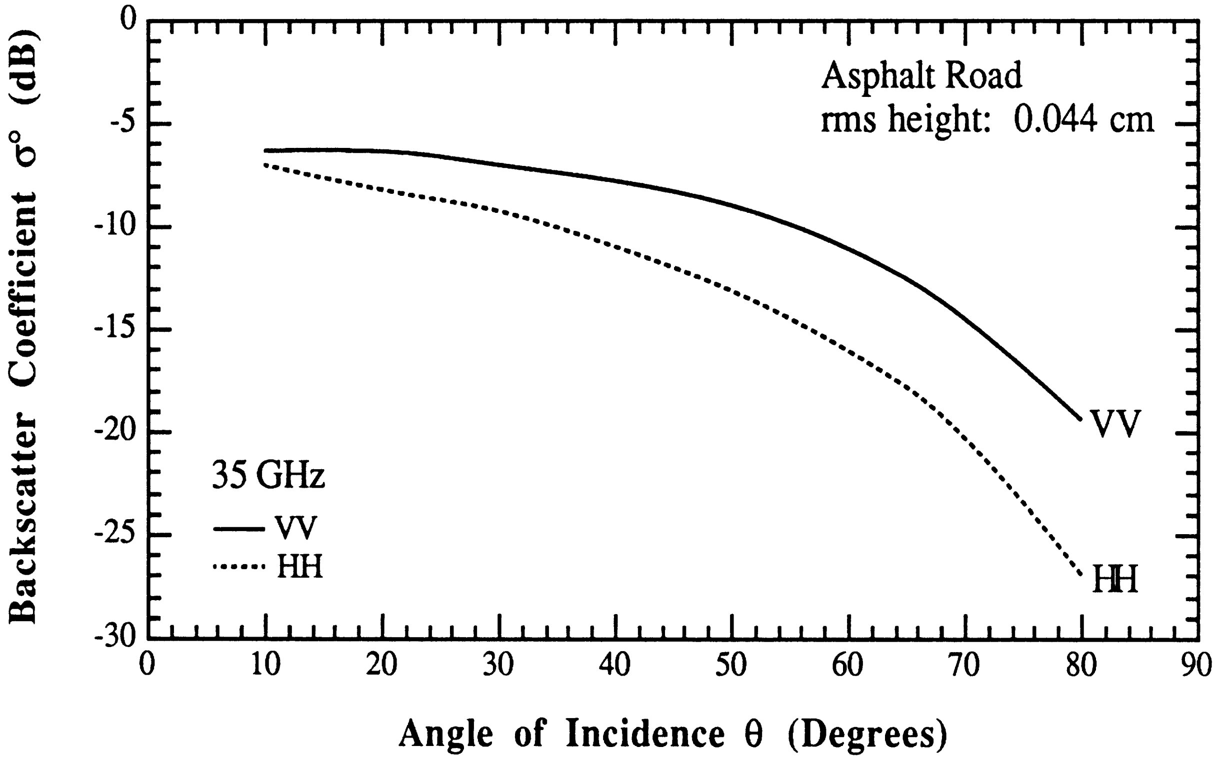
A. Various Surfaces



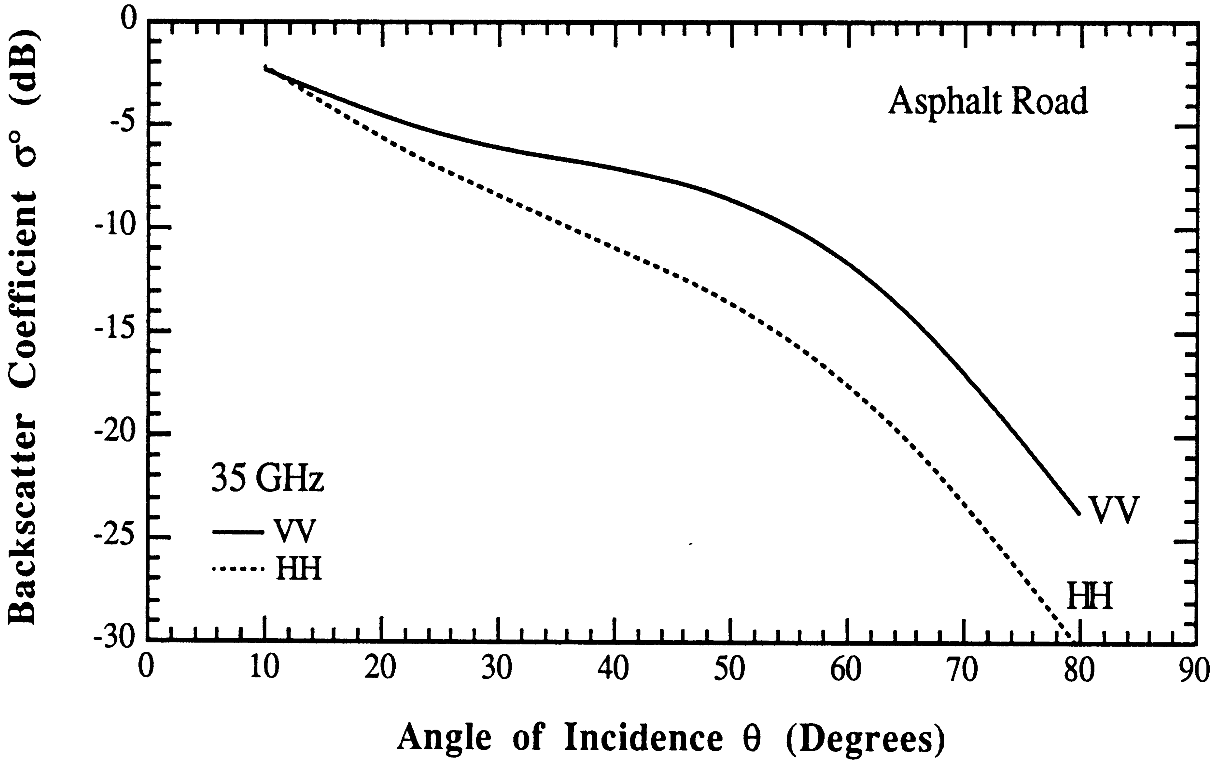
Angle of Incidence θ (Degrees)
Asphalt Road



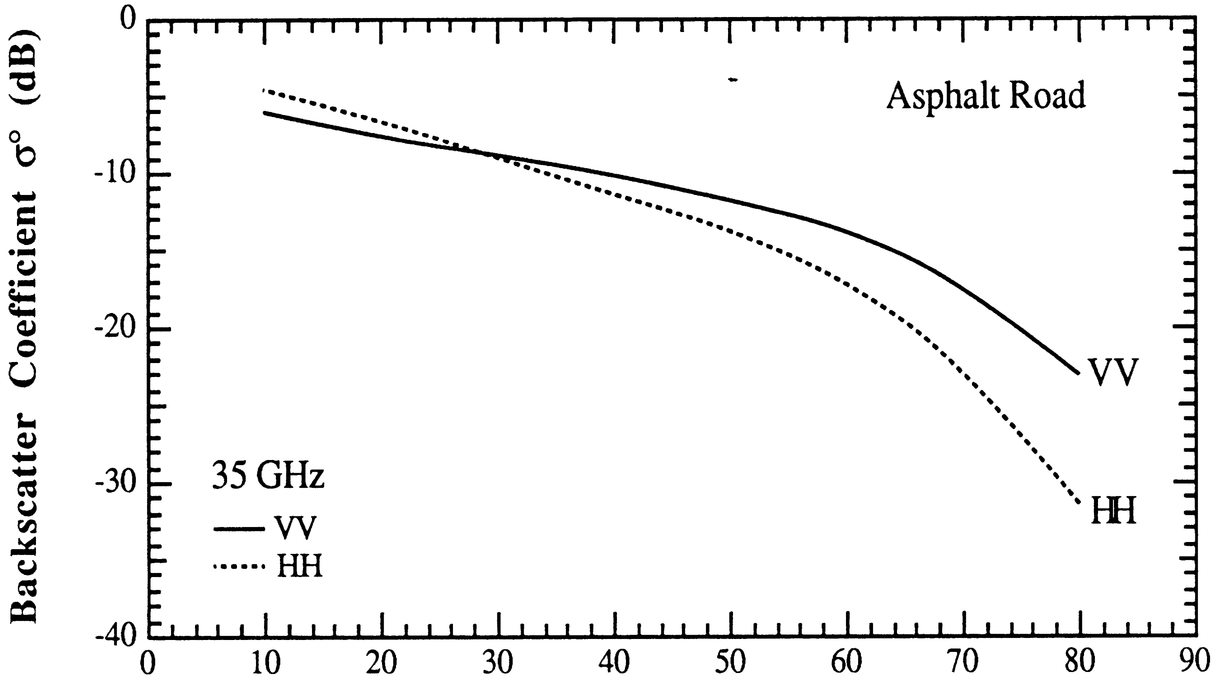
Angle of Incidence θ (Degrees)
Asphalt Road



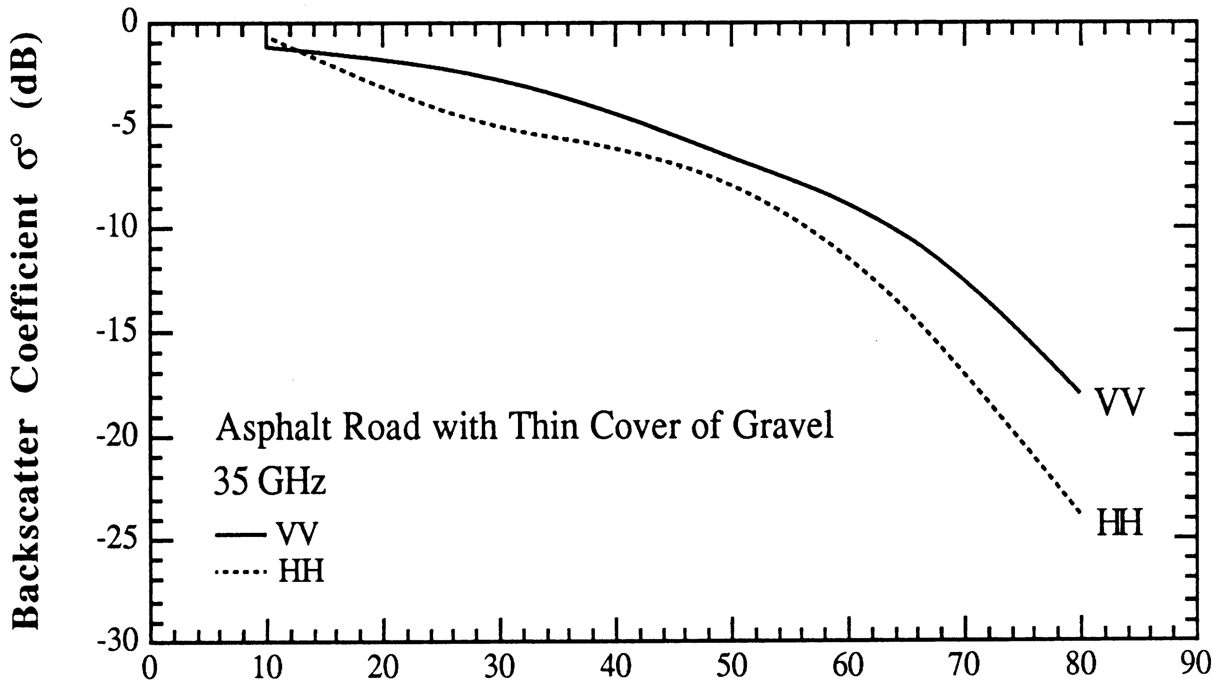
Asphalt Road



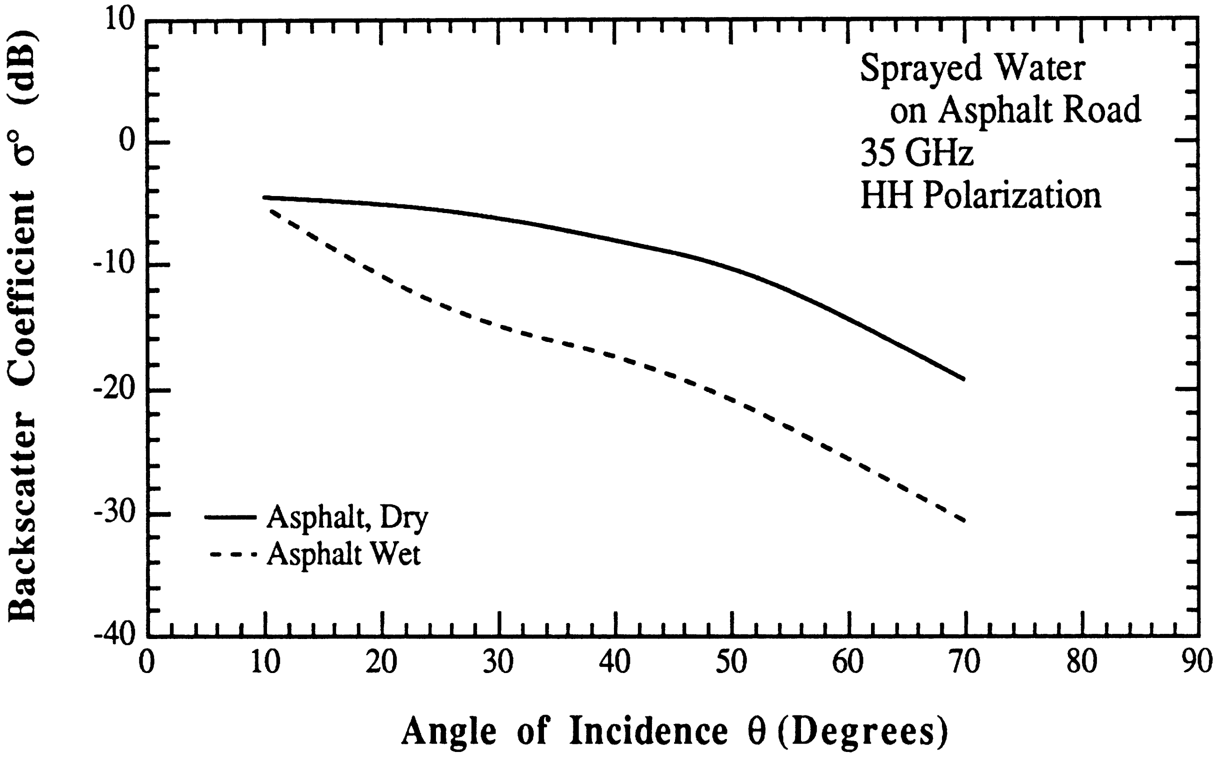
Asphalt Road



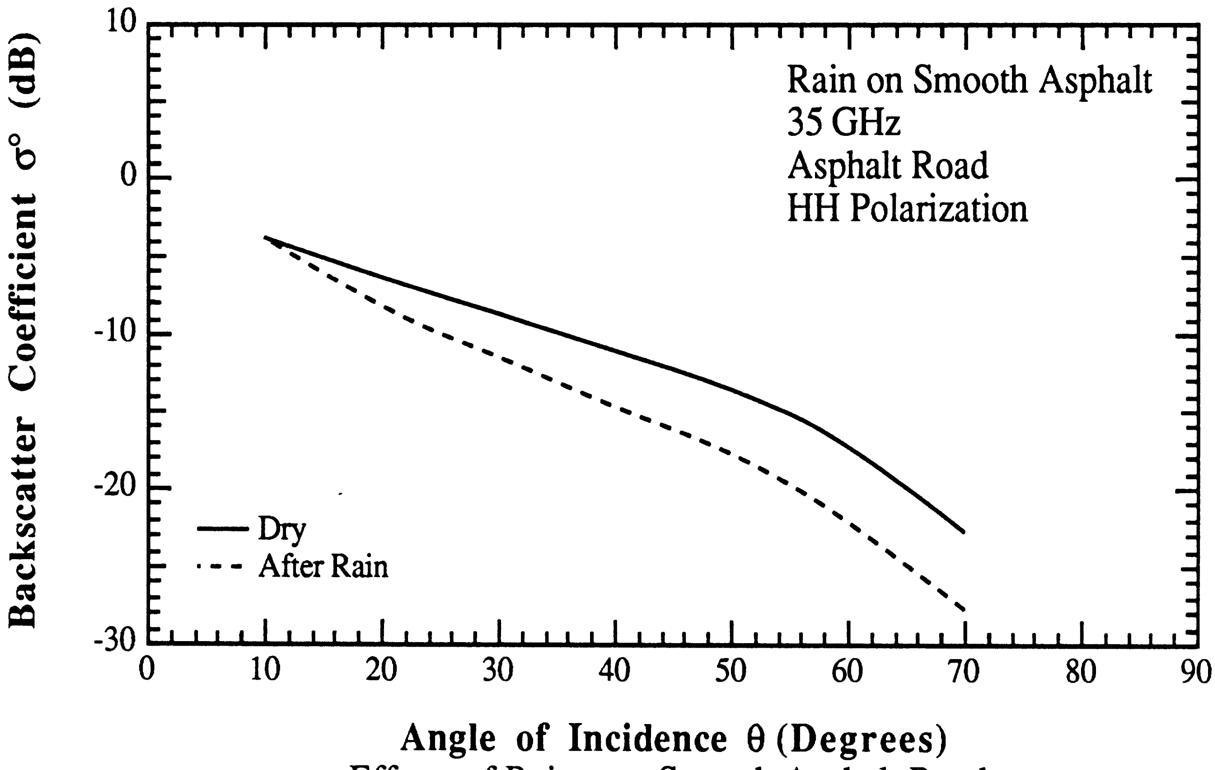
Angle of Incidence θ (Degrees)
Asphalt Road



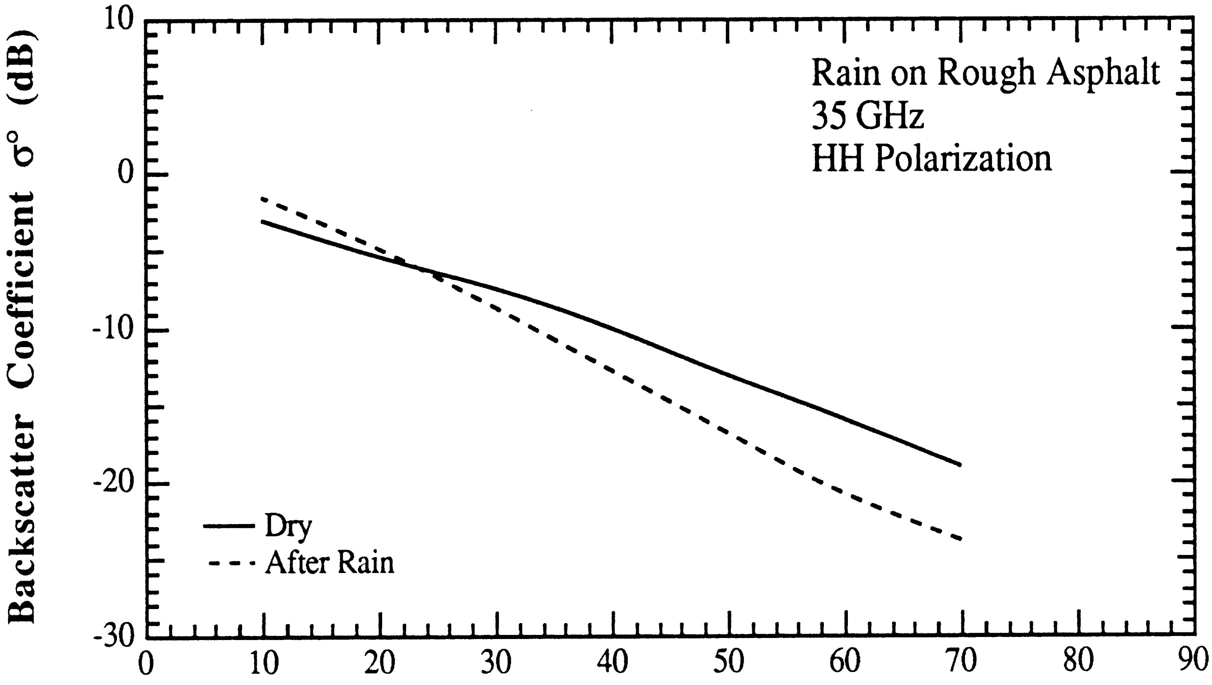
Angle of Incidence θ (Degrees)
Asphalt Road with Thin Cover of Gravel



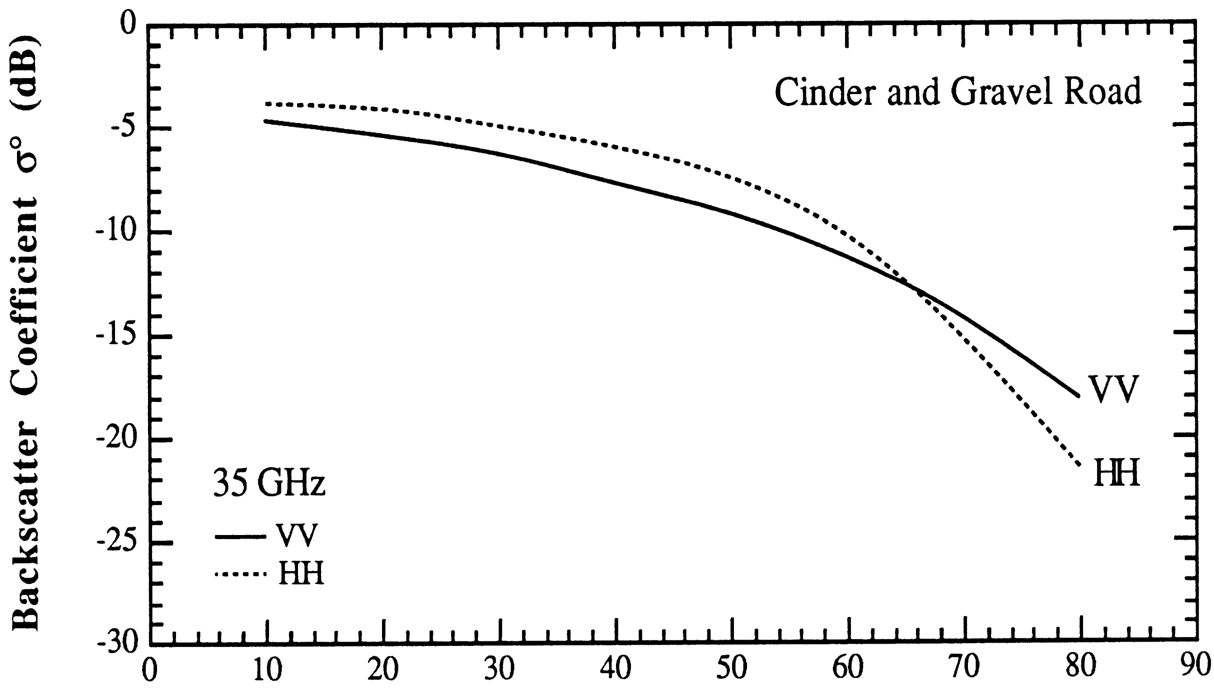
Effects of Sprayed Water on an Asphalt Road



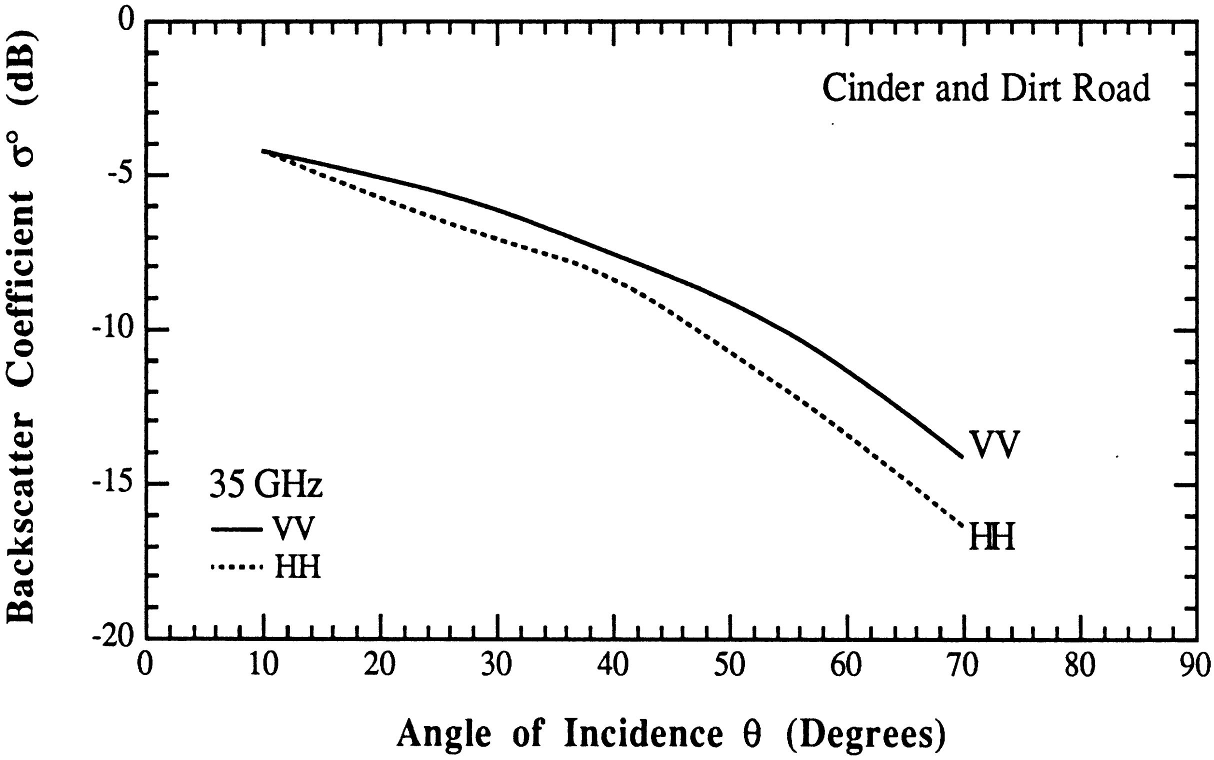
Effects of Rain on a Smooth Asphalt Road



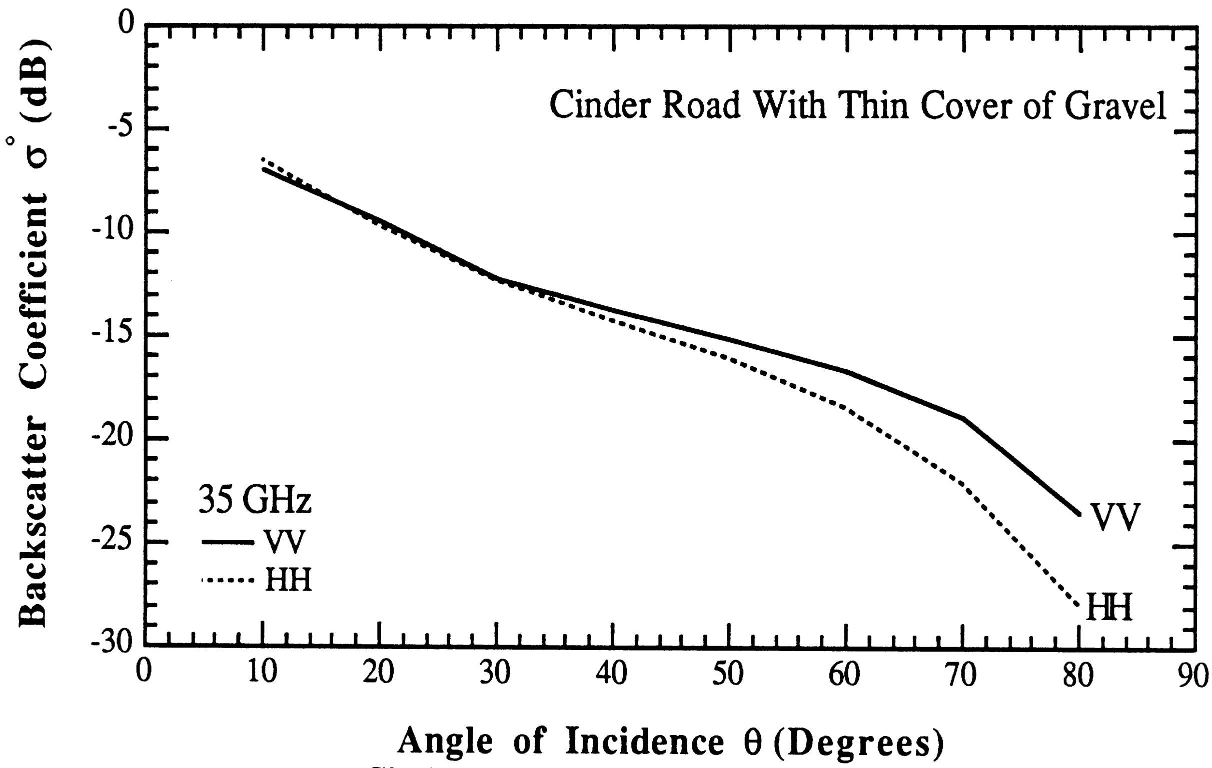
Angle of Incidence θ (Degrees)
Effects of Rain on a Rough Asphalt Road



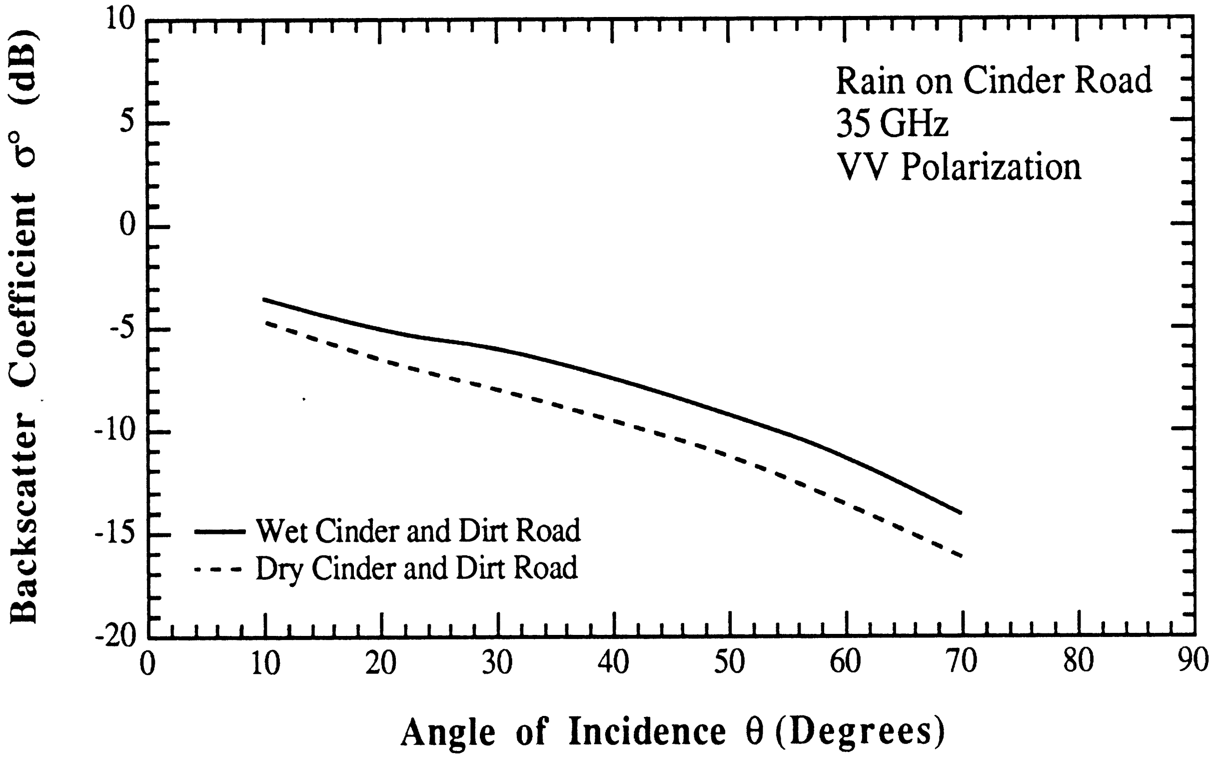
Angle of Incidence θ (Degrees)
Cinder and Gravel Road



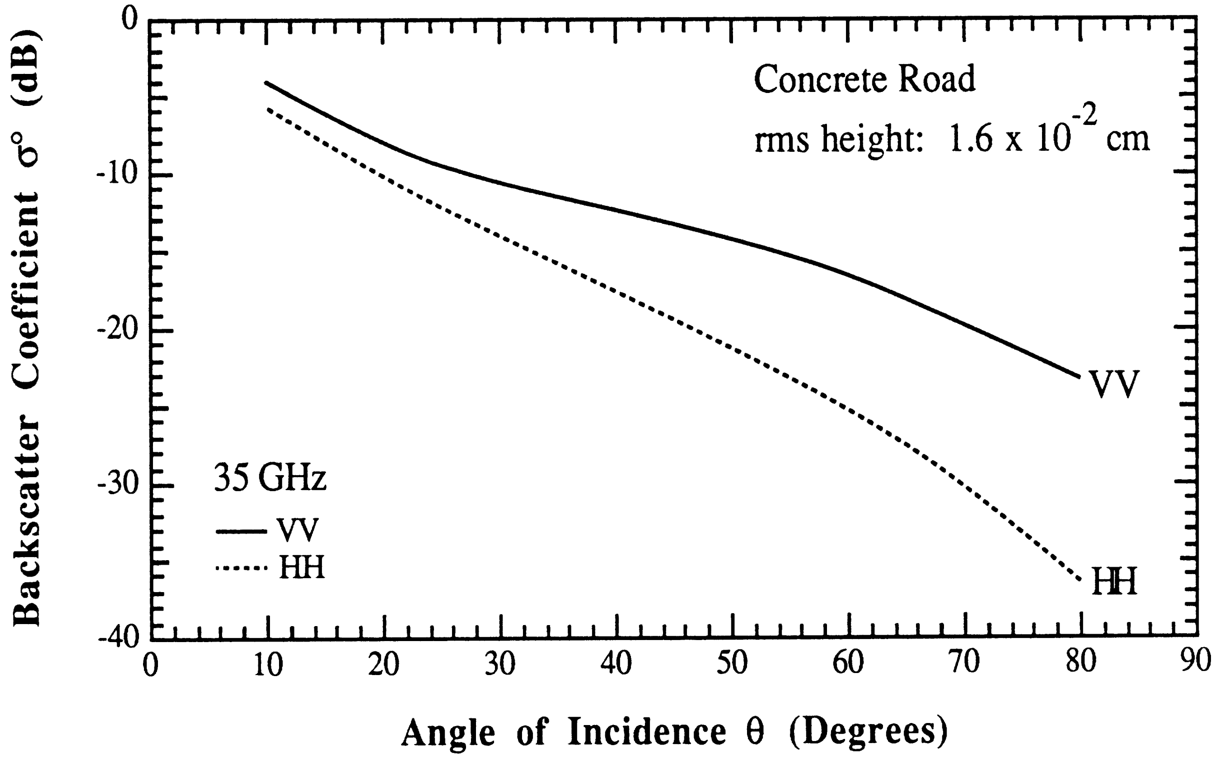
Cinder and Dirt Road



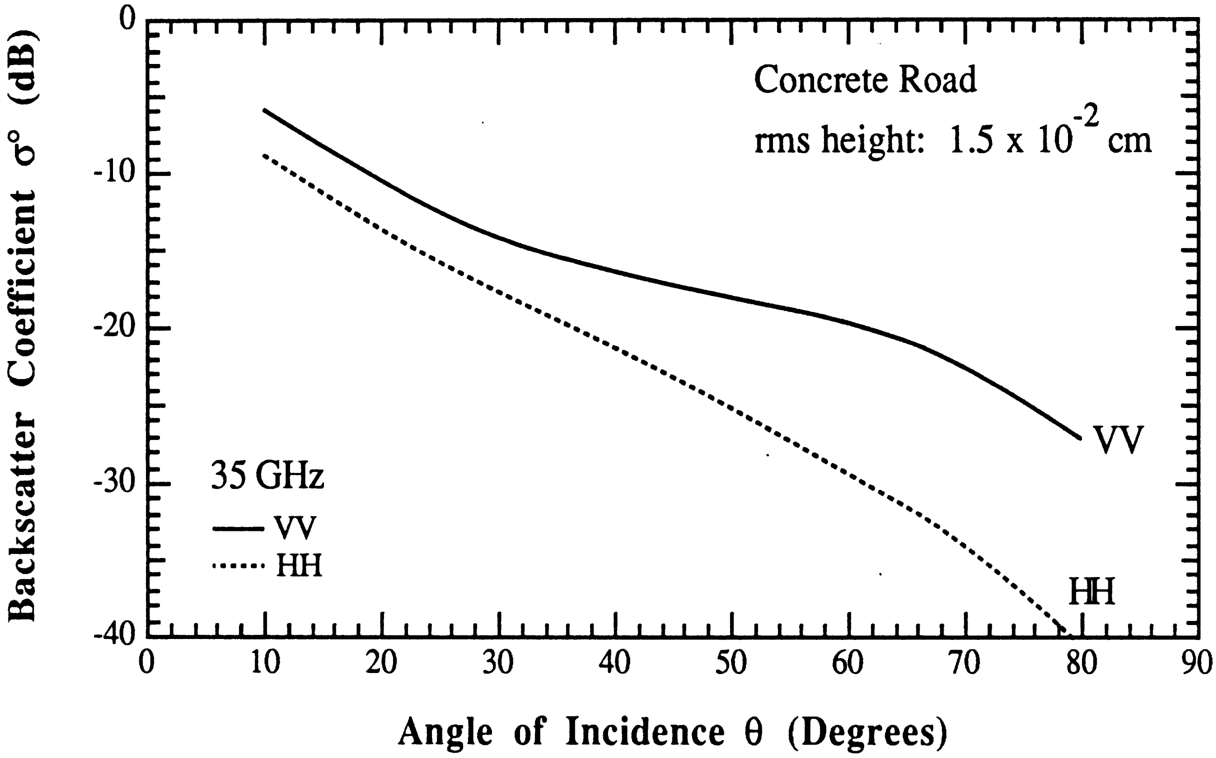
Cinder Road with Thin Cover of Gravel



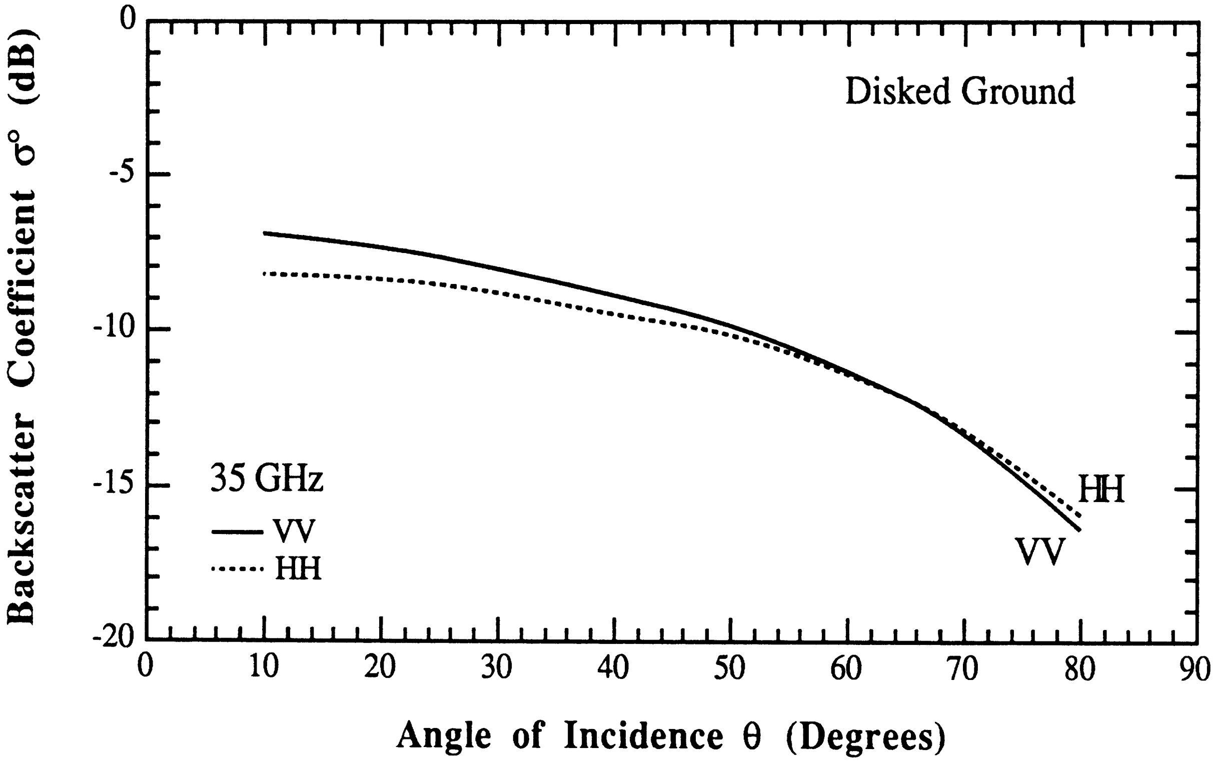
Effects of Rain on Cinder Road



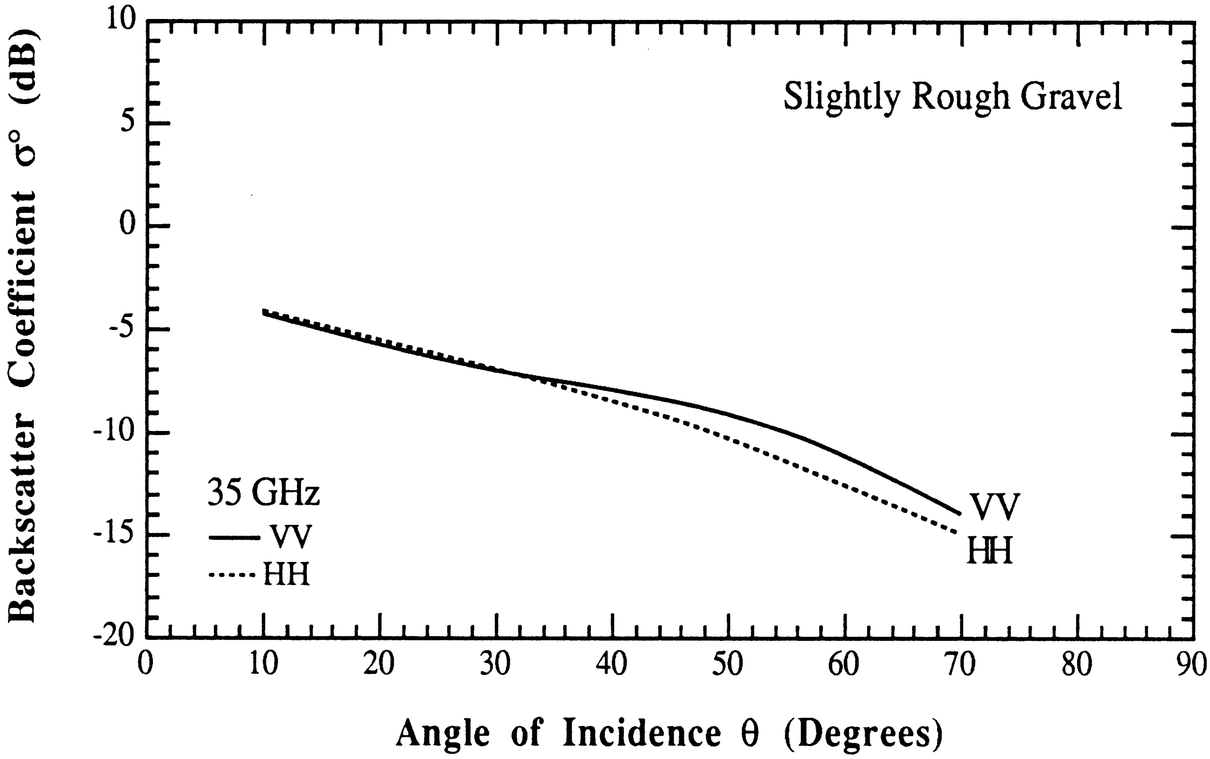
Concrete Road



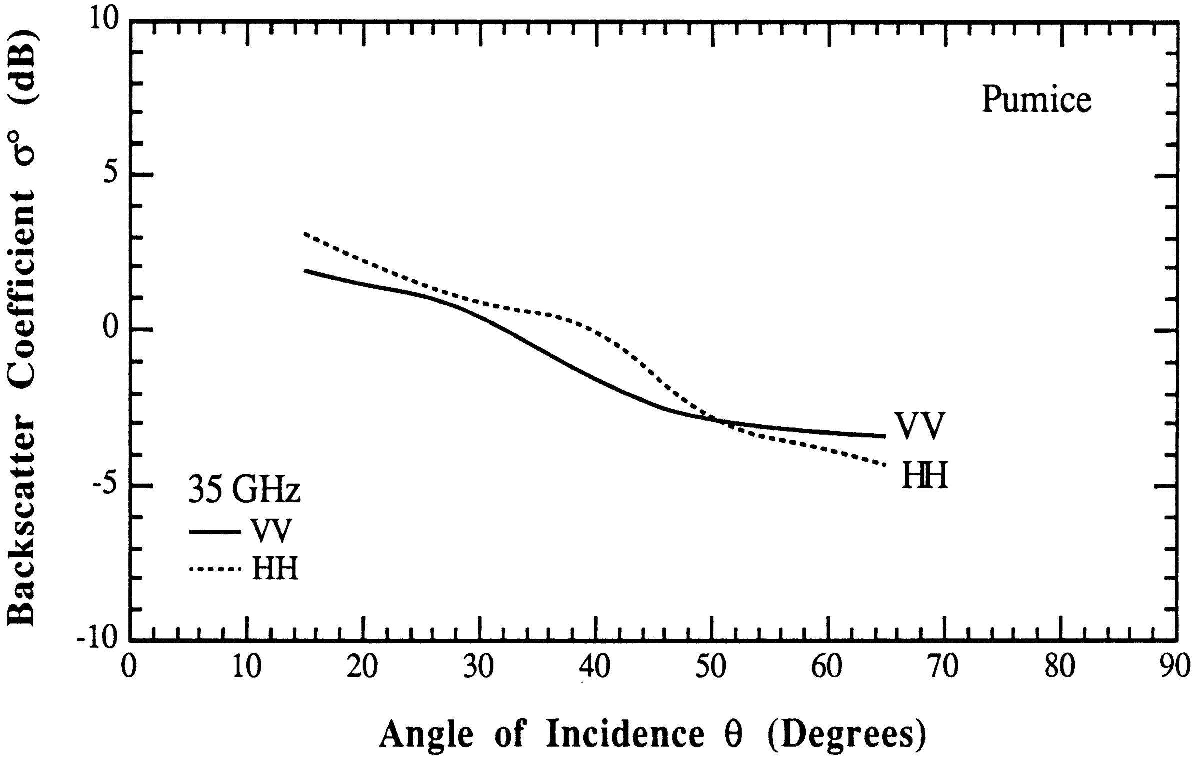
Concrete Road



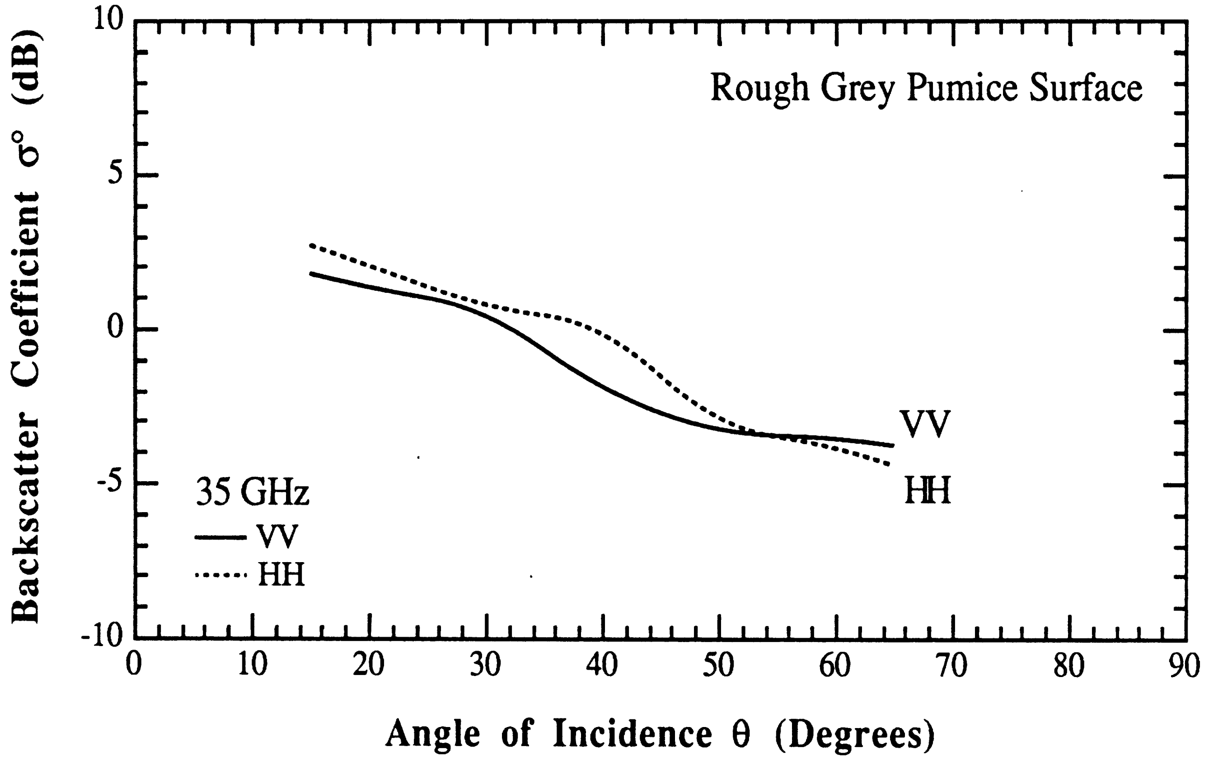
Disked Ground



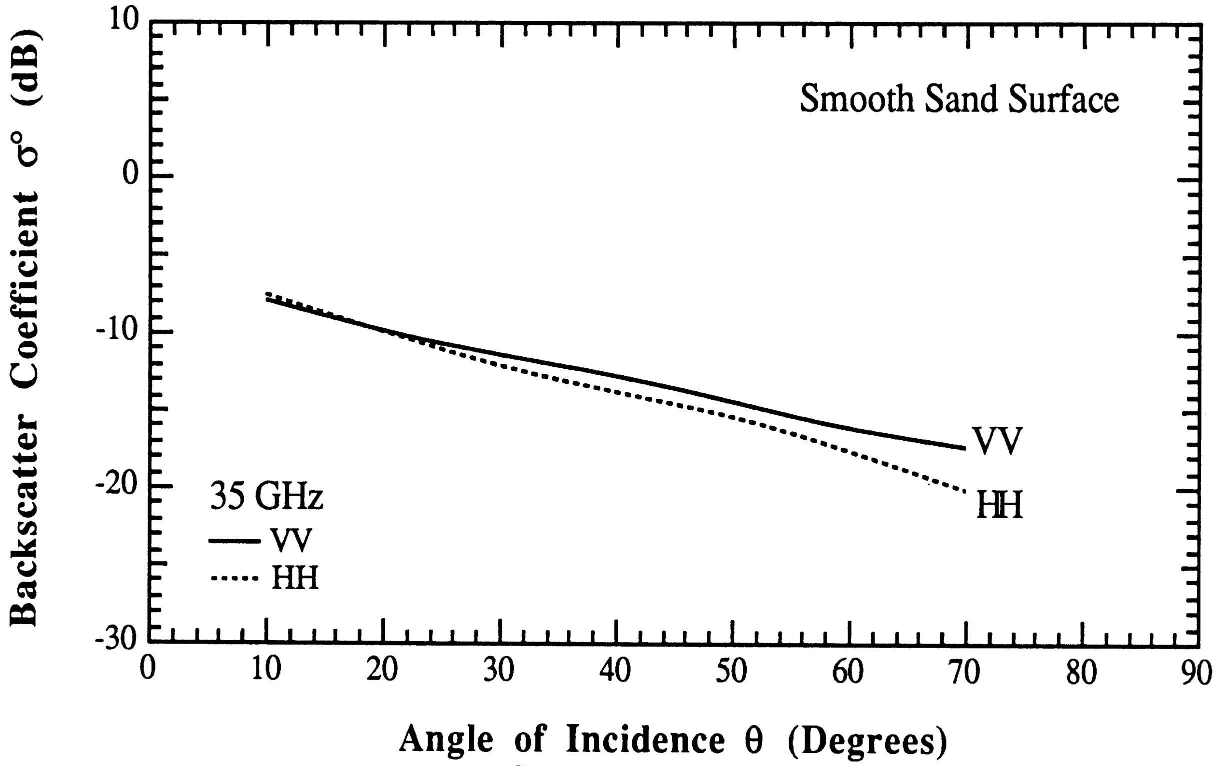
Sightly Rough Gravel



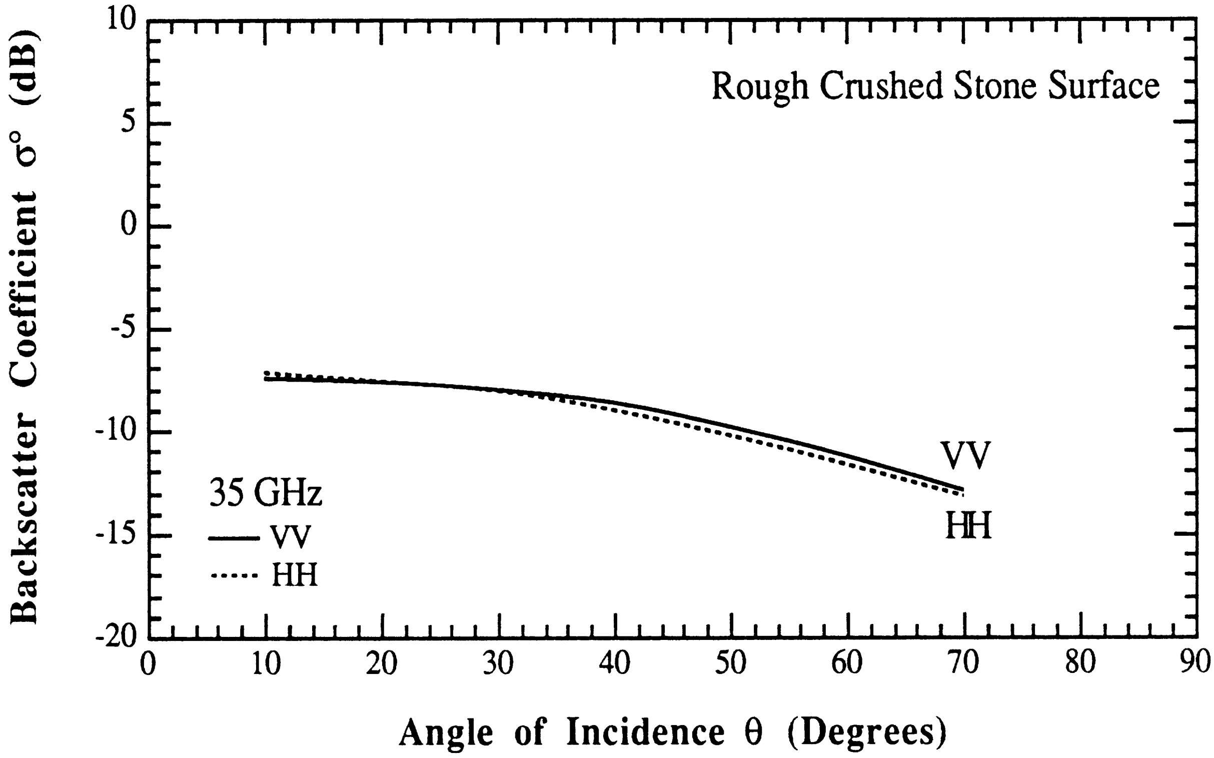
Pumice



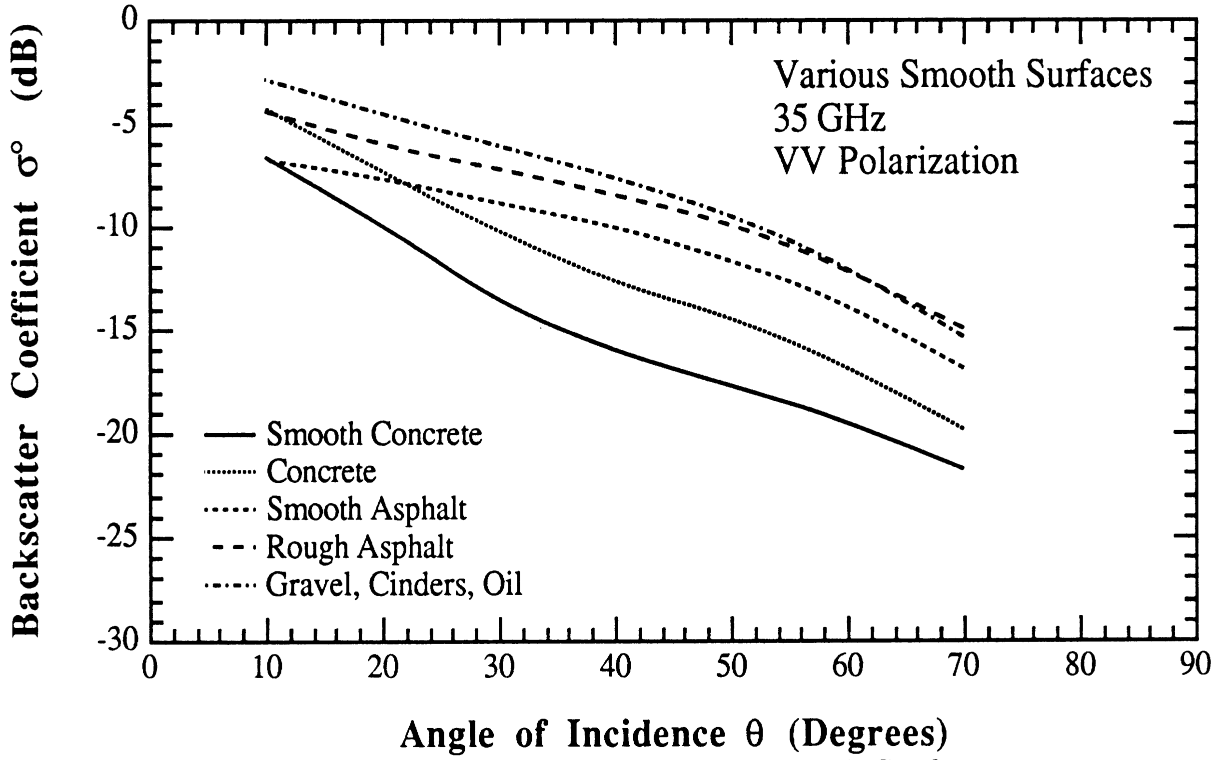
Rough Grey Pumice Surface



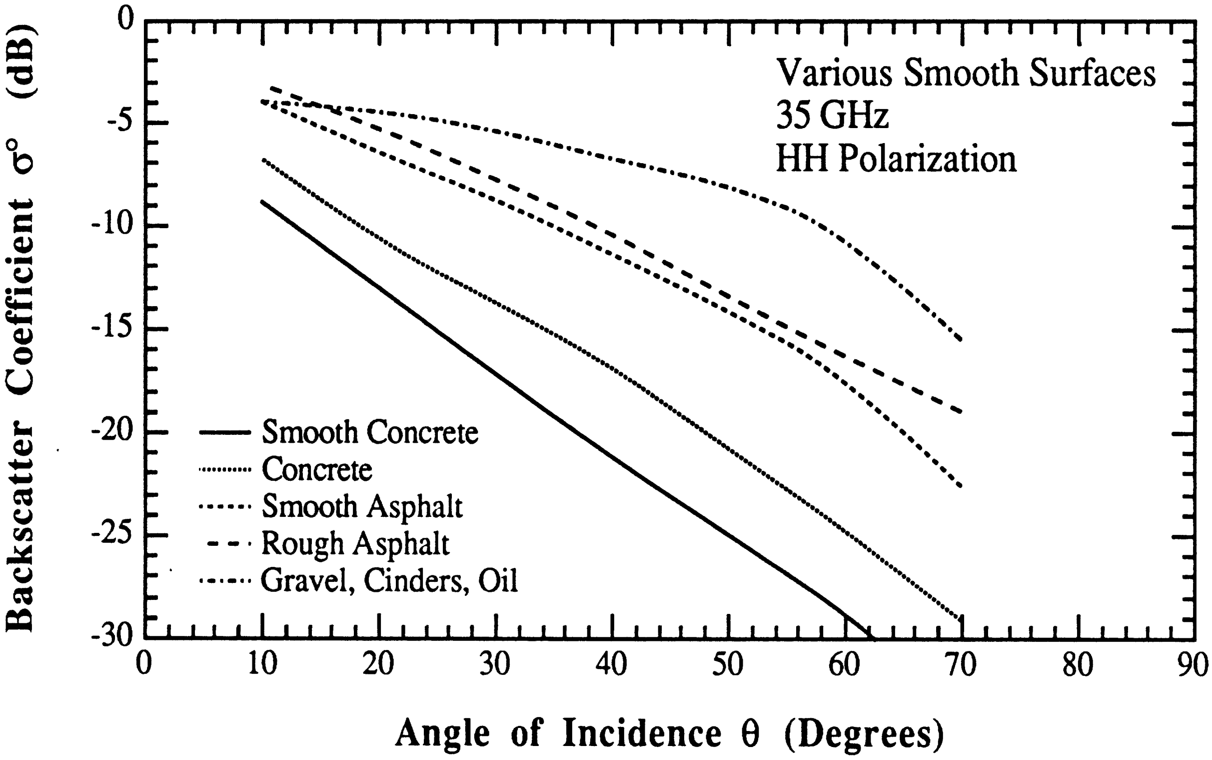
Smooth Sand Surface



Rough Crushed Stone Surface

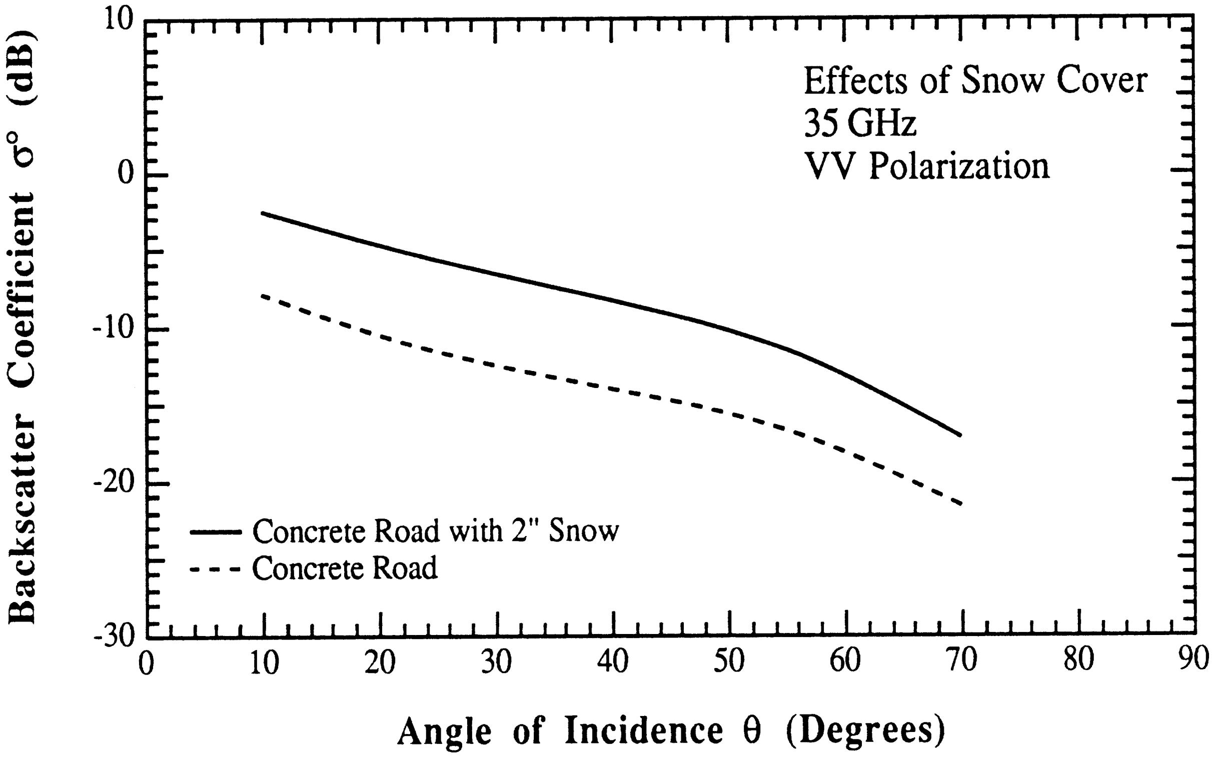


Contrast of $\sigma°$ for Various Smooth Surfaces

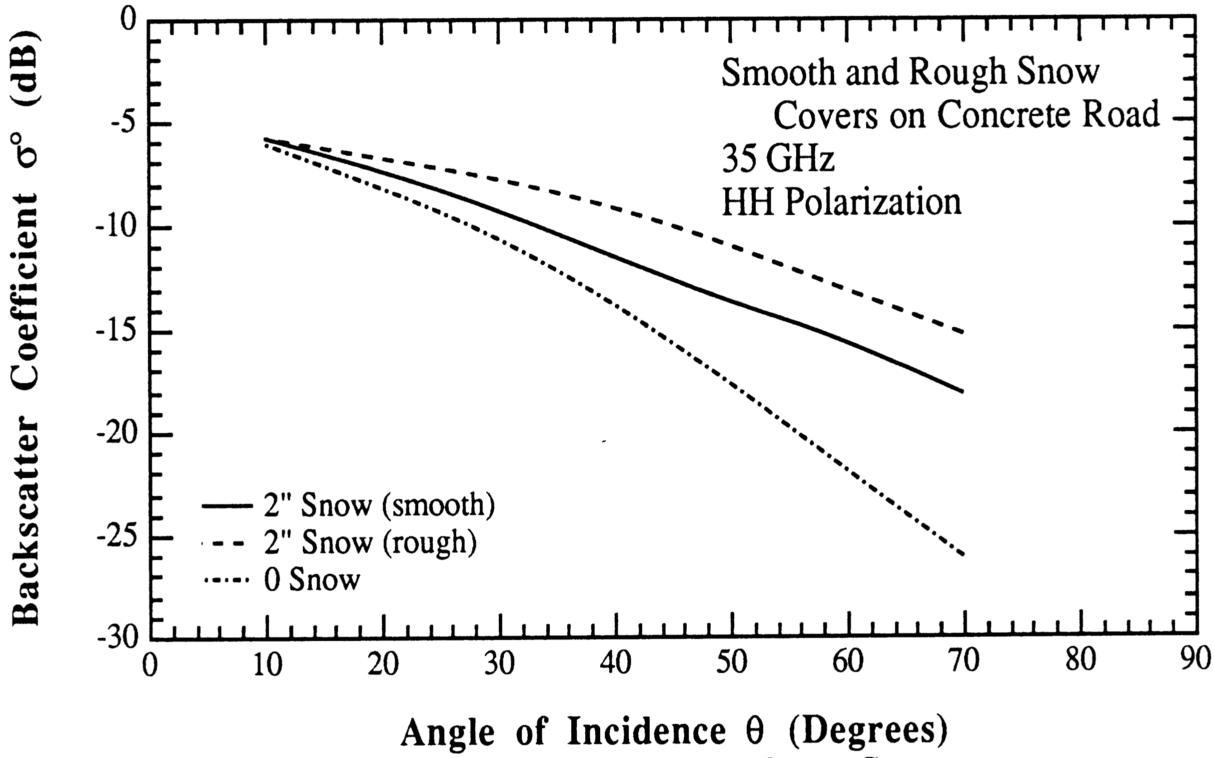


Contrast of σ° for Various Smooth Surfaces

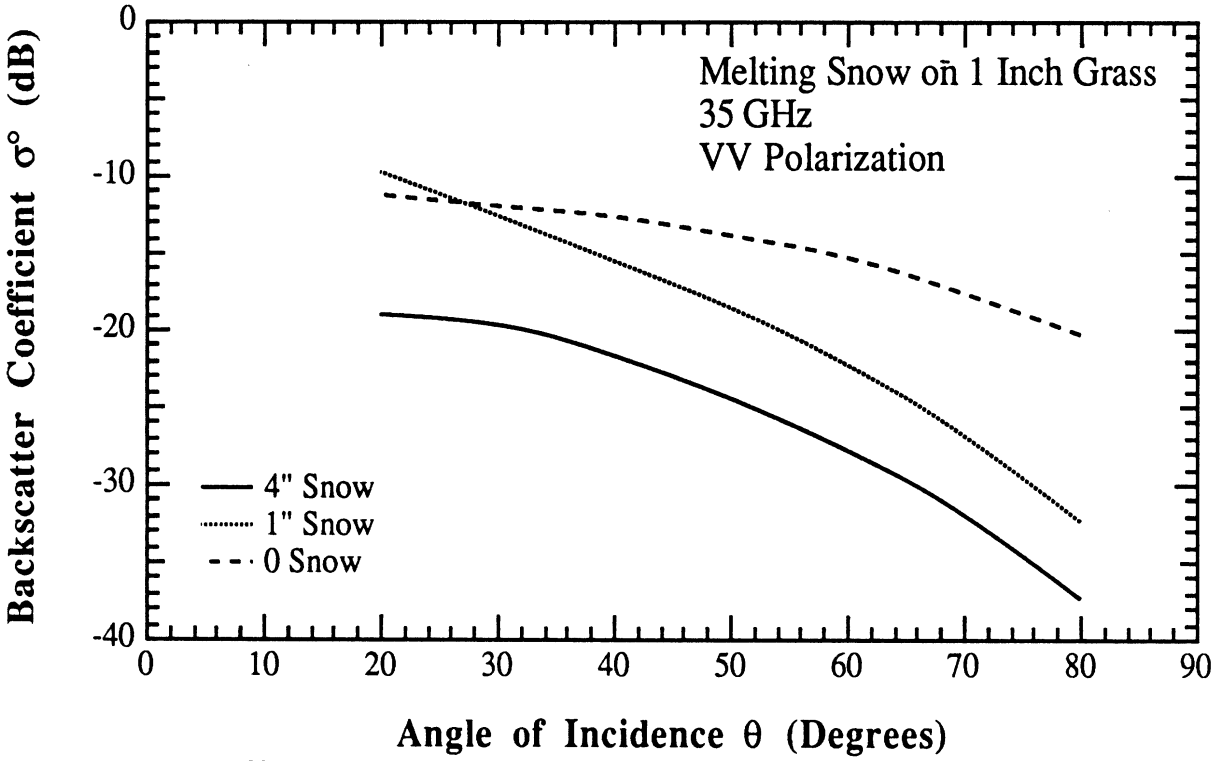
B. Various Surfaces With Snow Cover



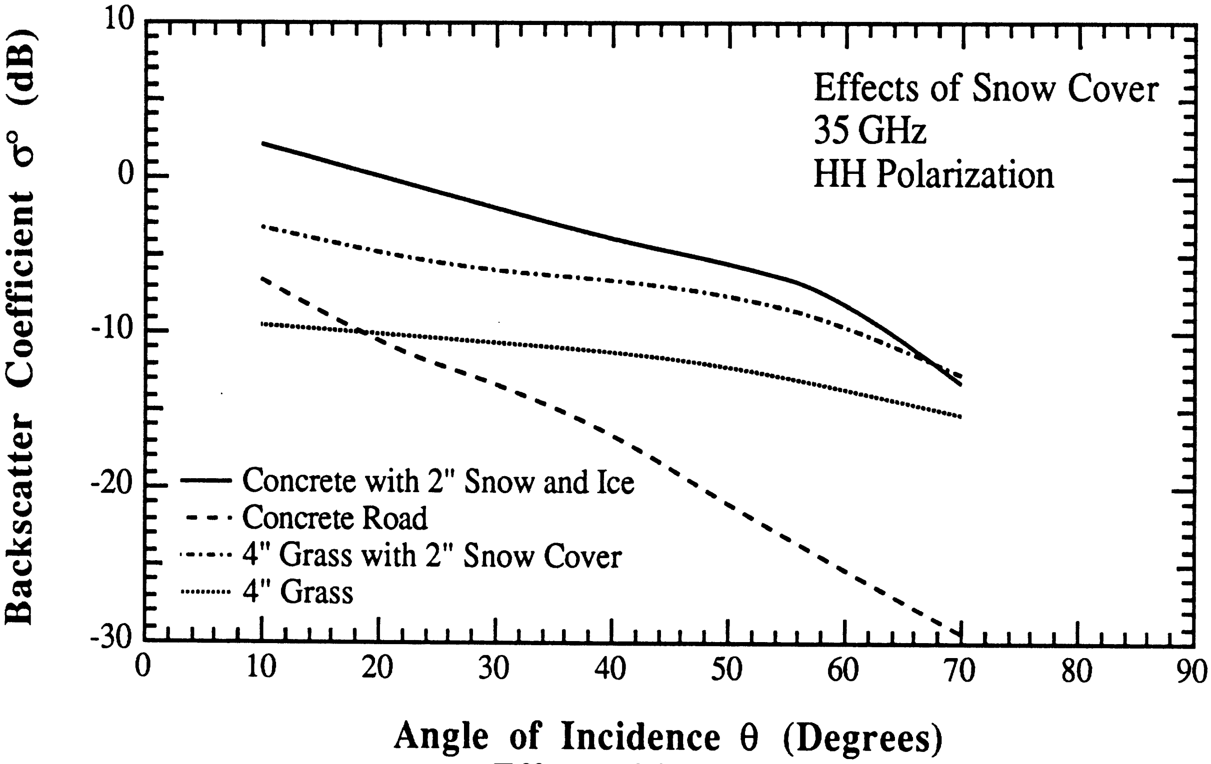
Effects of Snow Cover



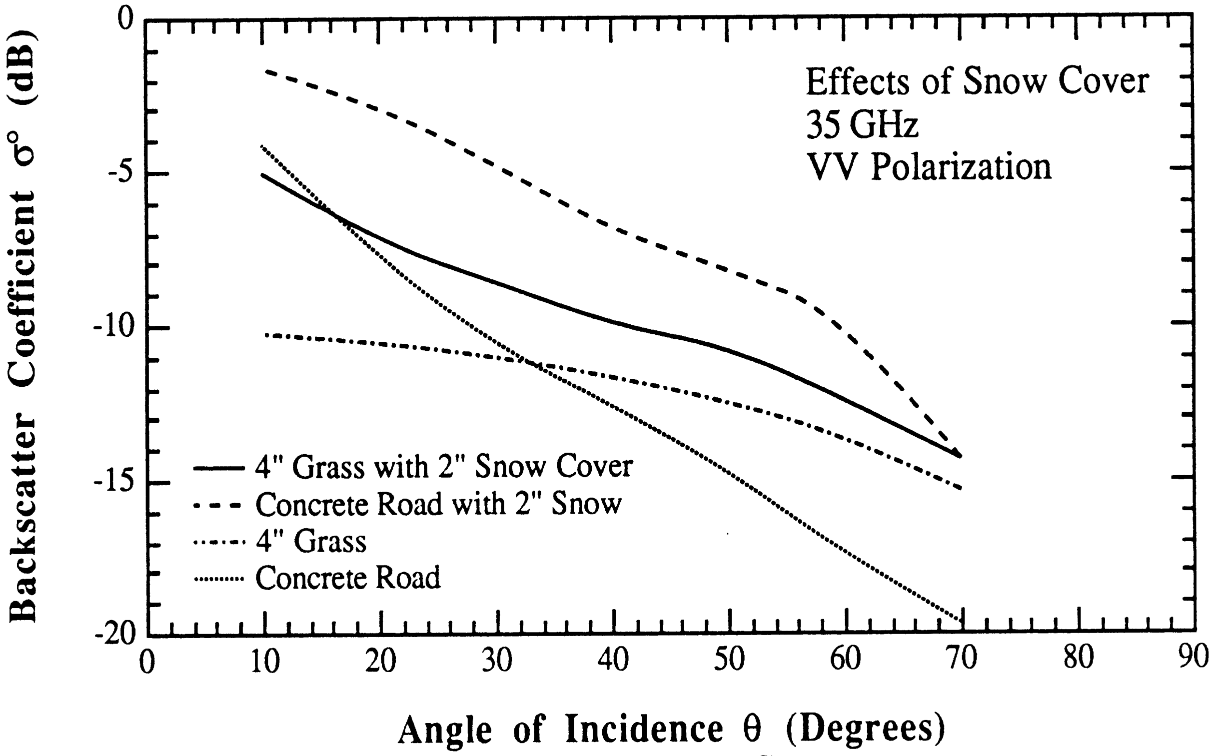
Effects of Smooth and Rough Snow Covers on a Concrete Road



Effects of Various Depth of Melting Snow for 1 Inch Grass



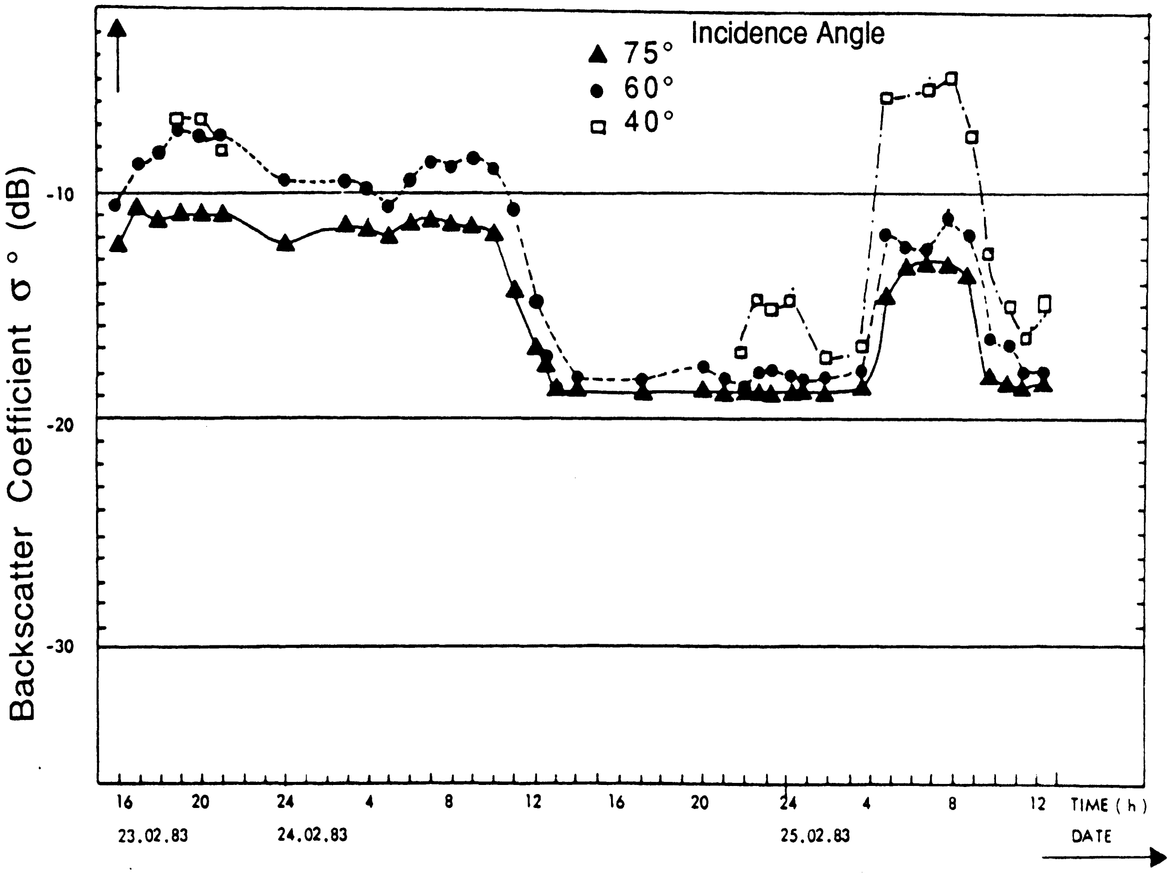
Effects of Snow Cover



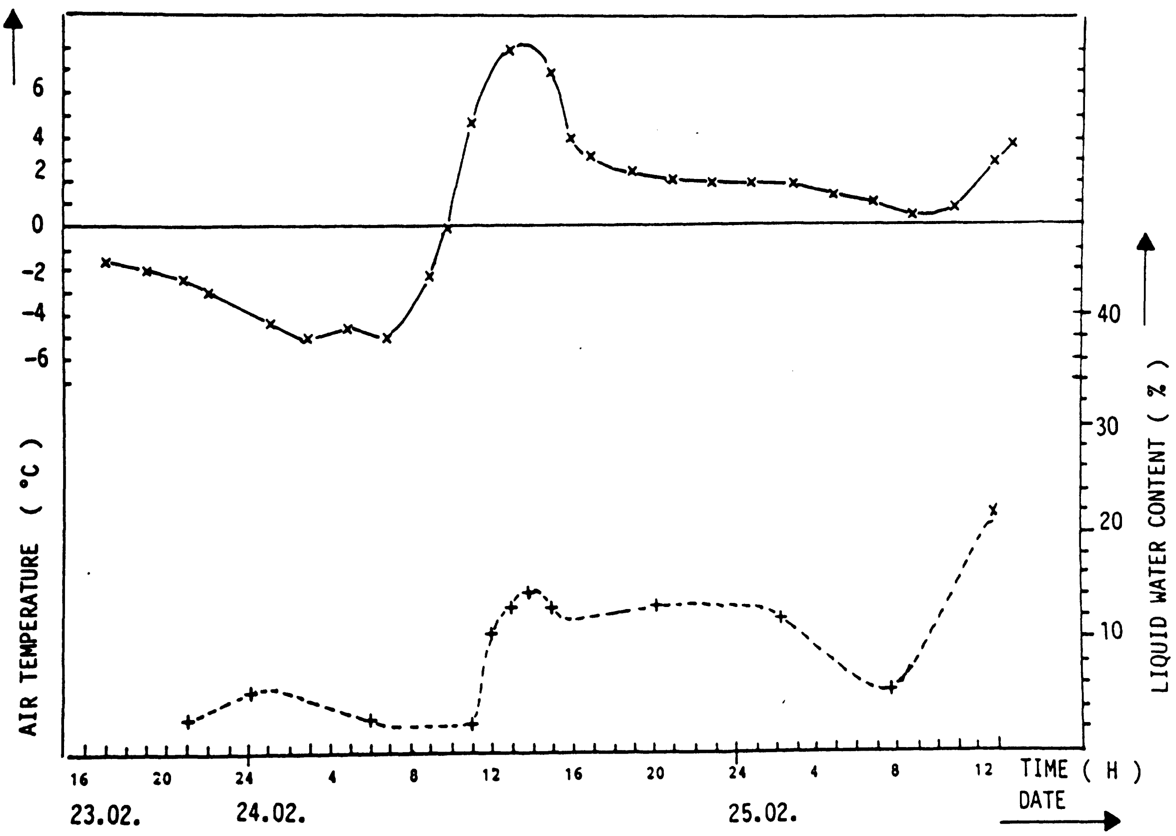
Effects of Snow Cover

PART V. OTHER MMW DATA

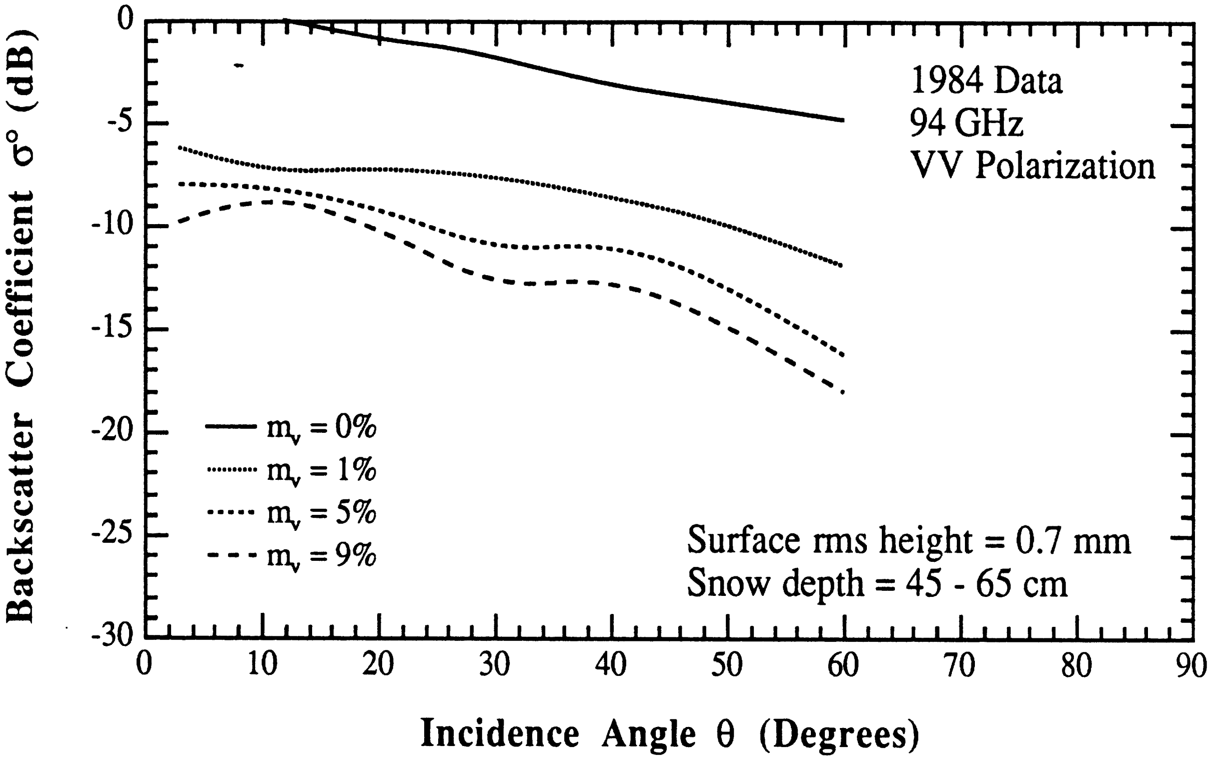
This part of the Handbook includes MMW data reported by organizations other than those covered in previous chapters of this Handbook. The data, the majority of which was extracted from plots published in scientific journals, do not include measurements that lack adequate ground-truth information or whose accuracy cannot be ascertained.

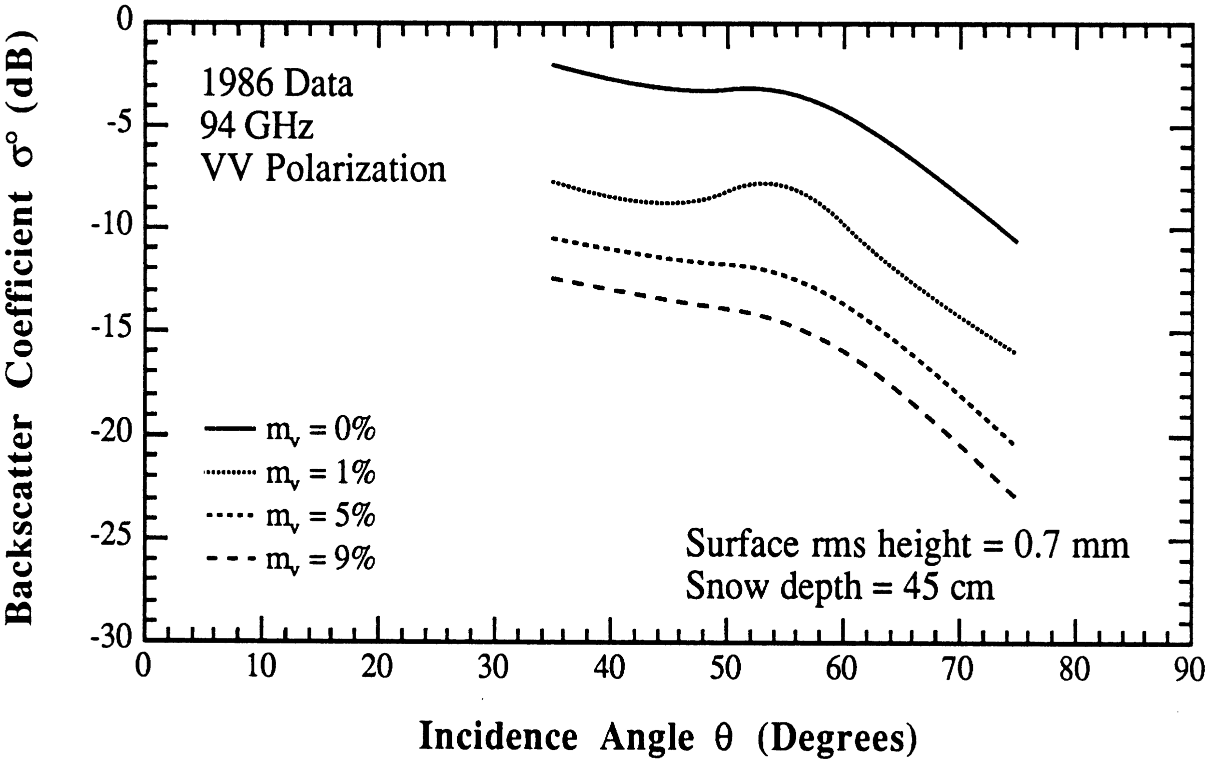


Diurnal variation of reflectivity for a metamorphic snow state at 94 GHz

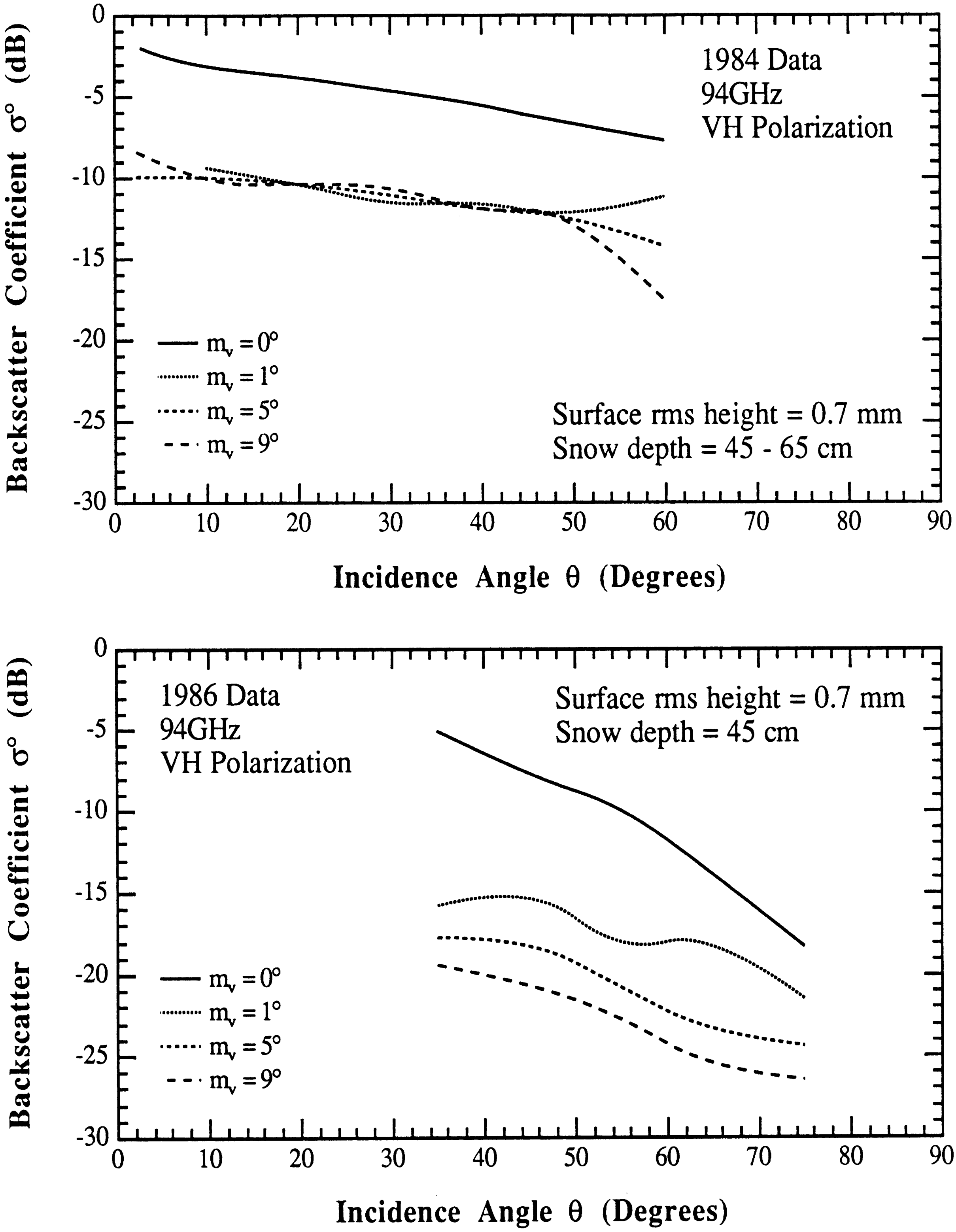


Diurnal variation of air temperature and liquid water content of snow from 23/2 to 25/2/82. From [23].

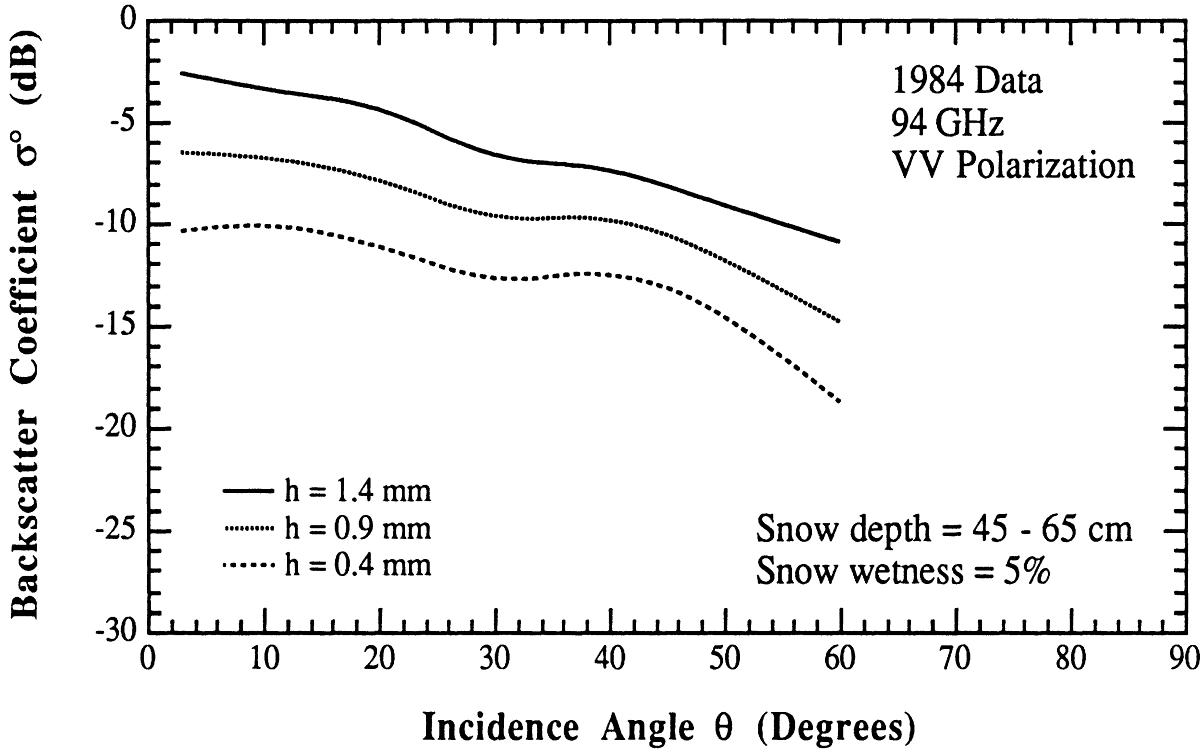


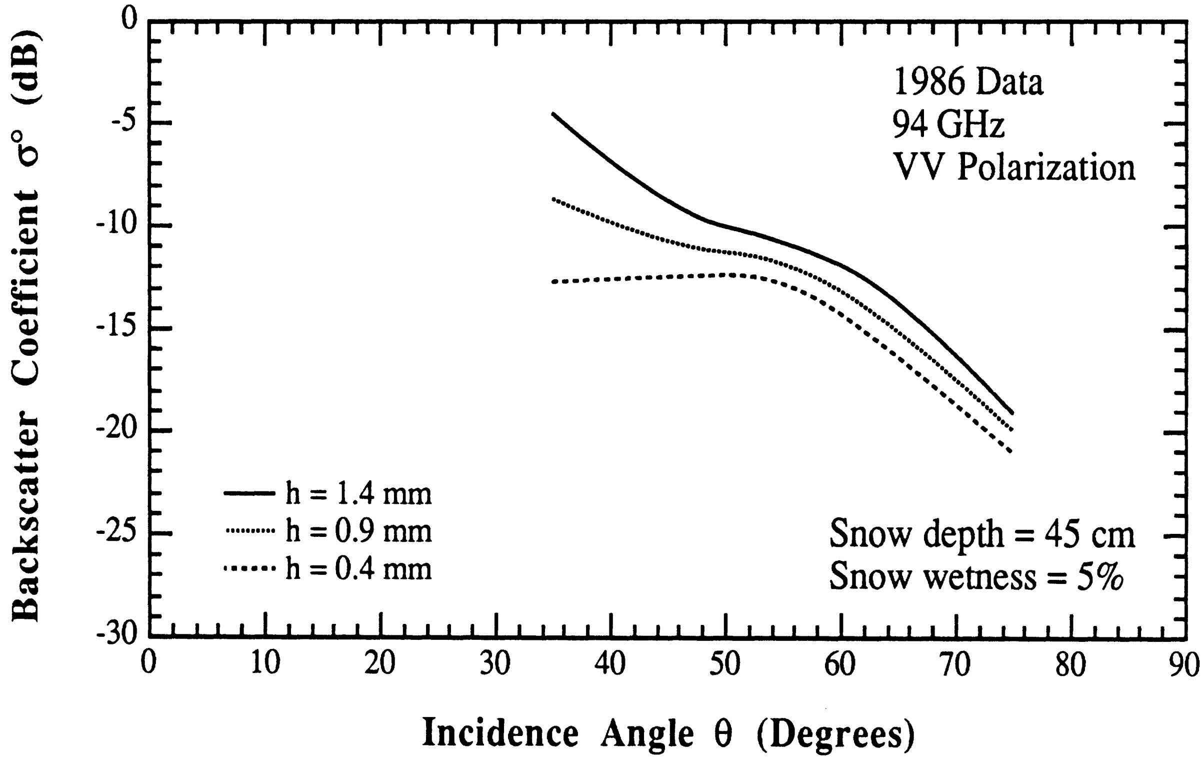


VV - Polarized Backscatter of Snow Measured in 1984 and 1986 for Various Liquid Water Contents m_v. From [24,25].

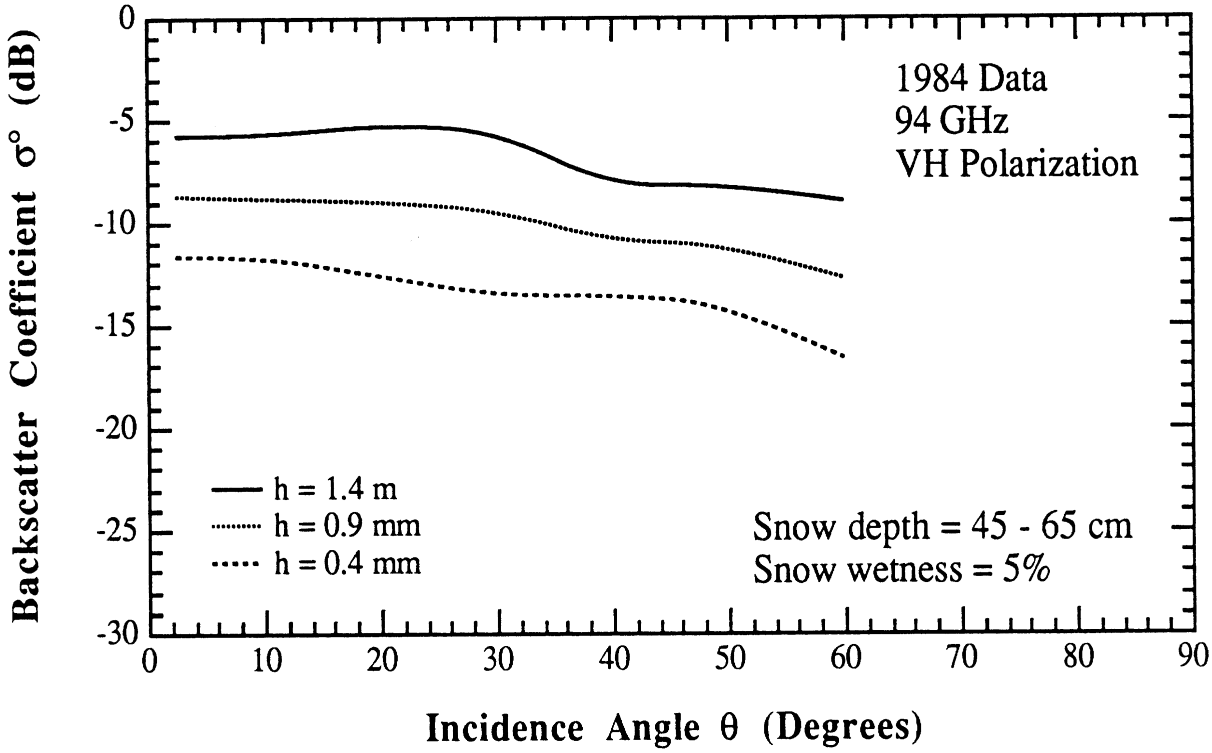


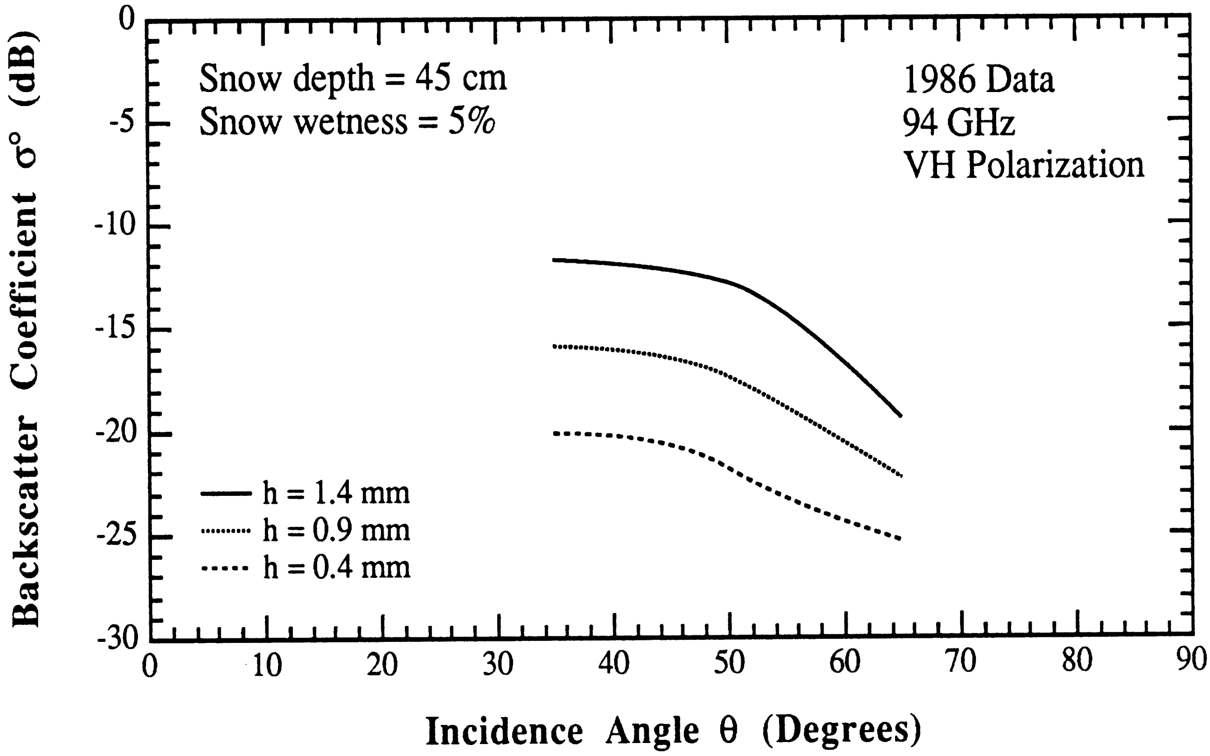
VH - Polarized Backscatter of Snow Measured in 1984 and 1986 for Various Liquid Water Contents $m_{v.}$ From [24,25].



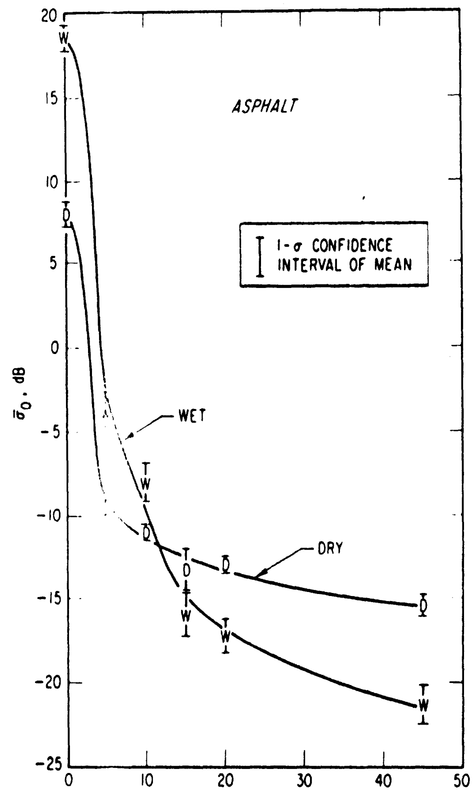


VV - Polarized Backscatter of Snow Measured in 1984 and 1986 Liquid Water Content of 5% and Various Surface Roughnesses (h = rms height). From [24,25].

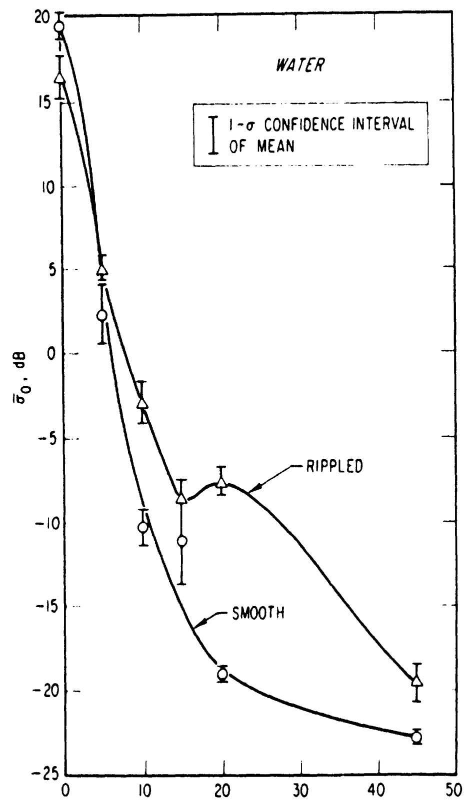




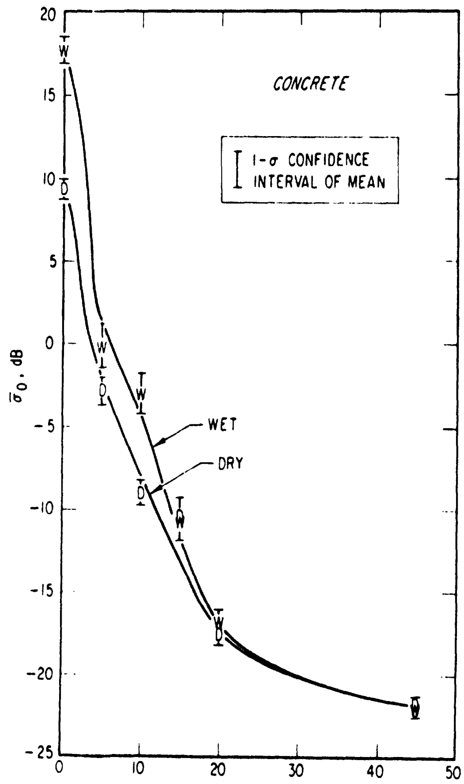
VH - Polarized Backscatter of Snow Measured in 1984 and 1986 Liquid Water Content of 5% and Various Surface Roughnesses (h = rms height). From [24,25].



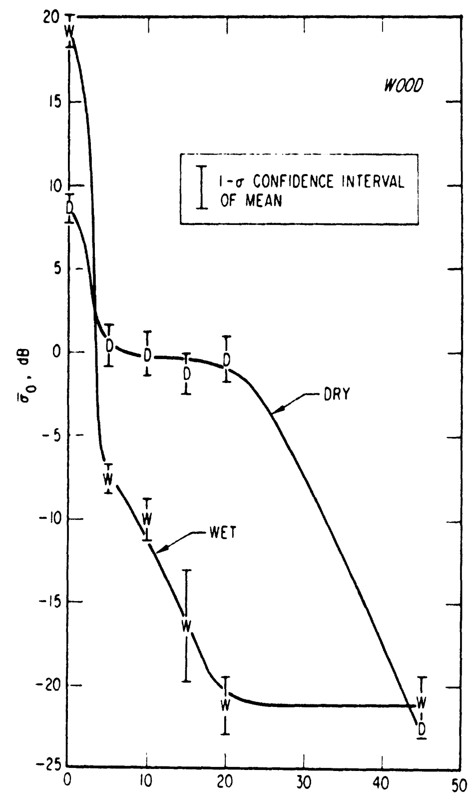
ANGLE OF INCIDENCE, deg
Mean σ_0 for wet and dry asphalt.



ANGLE OF INCIDENCE, deg
Mean σ_0 for smooth and rippled water.

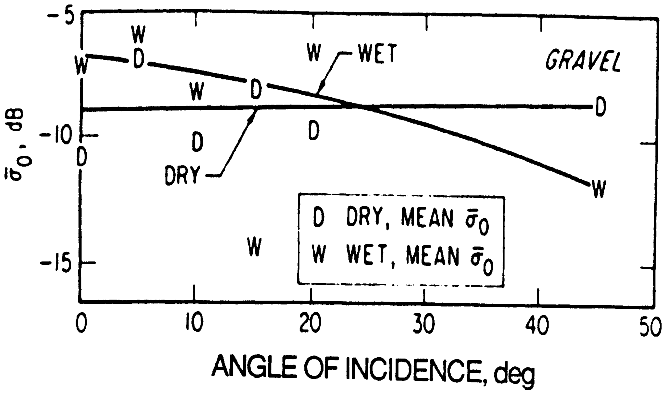


ANGLE OF INCIDENCE, deg
Mean σ_0 for wet and dry concrete.

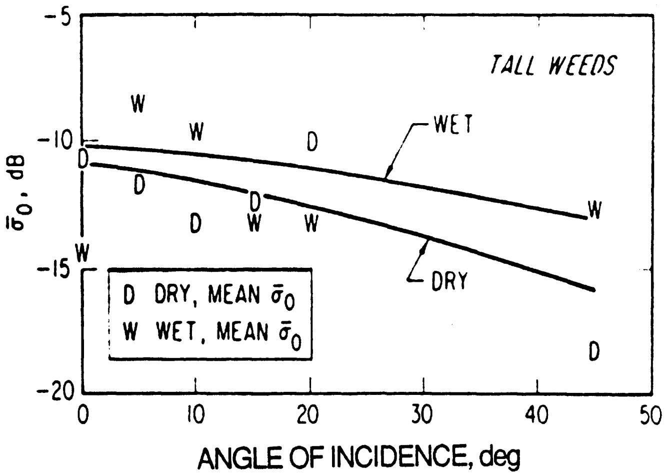


ANGLE OF INCIDENCE, deg
Mean σ_0 for wet and dry wood.

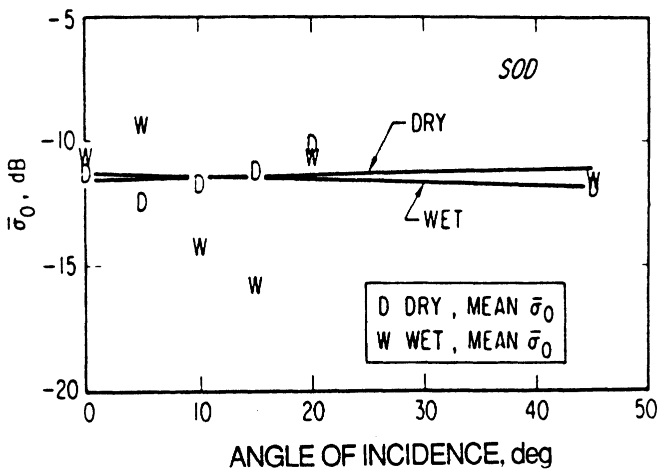
Backscattering Coefficient, Averaged over 40-90 GHz for various surfaces. From [26].



Mean σ_0 for wet and dry gravel.

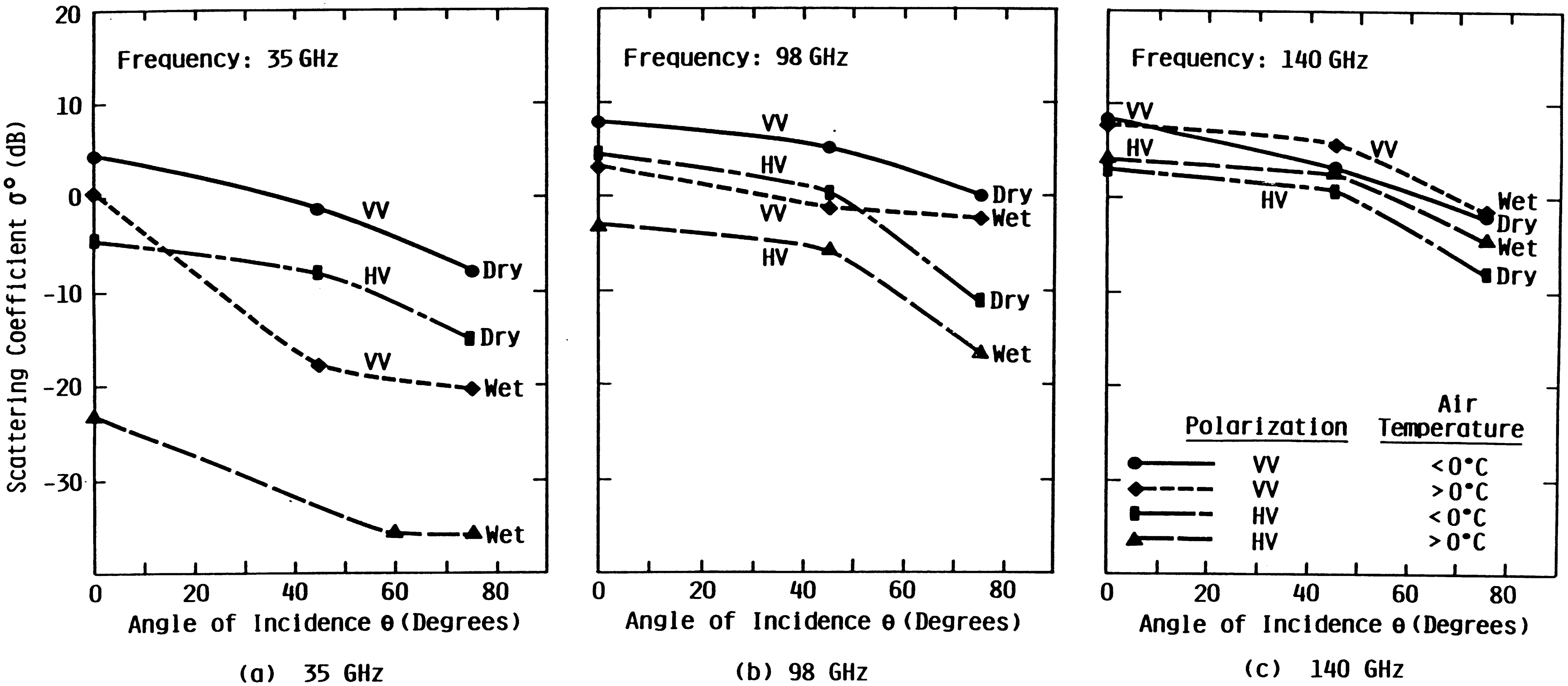


Mean σ_0 for wet and dry tall weeds.



Mean σ_0 for wet and dry sod.

Backscattering Coefficient, Averaged over 40-90 GHz for various surfaces. From [26].



Backscattering Coefficient at (a) 35 GHz, (b) 98 GHz, and (c) 140 GHz for Dry and Wet Snow. From [28].

REFERENCES

[1] Ulaby, F.T., T.F. Haddock, J.R. East and M.W. Whitt, "A Millimeterwave Network Analyzer based Scatterometer," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 26, pp. 75-81,1988.

[2] Whitt, M.W., and F.T. Ulaby, "Millimeter-Wave Polarimetric Measurements of Artificial and Natural Targets," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 26, pp. 562-573, 1988.

[3] Haddock, T.F., and F.T. Ulaby, "140-GHz Scatterometer System and Measurements of Terrain," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 28, pp. 492-499, 1990.

[4] Whitt, M.W., and F.T. Ulaby, "Millimeter-wave Polarimetric Measurements of Artificial and Natural Targets," *Proceedings of IGARSS '87 Symposium*, Ann Arbor, May 1987.

[5] Ulaby, F.T., T.F. Haddock, and R.T. Austin, "Fluctuation Statistics of Millimeter-Wave Scattering from Distributed Targets," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 26, pp. 268-281, 1988.

[6] Hallikainen, M.T., F.T. Ulaby, and T.E. Van Deventer, "Extinction Behavior of Dry Snow in the 18- to 90- GHz Range," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 25, pp. 737-745, 1987.

[7] Hallikainen, M.T., F.T. Ulaby, and T.E. Van Deventer, "Extinction Coefficient of Dry Snow at Microwave and Millimeterwave Frequencies," *Proceedings of IGARSS '87 Symposium,* Ann Arbor, pp. 859-864,1987.

[8] Van Deventer, T.E., J.R. East, and F.T. Ulaby, "Millimeter Transmission Properties of Foliage," *IEEE International Geoscience and Remote Sensing Symposium (IGARSS '87)*, Ann Arbor, Michigan, May 1987.

[9] Ulaby, F.T., T.E. Van Deventer, J.R. East, T.F. Haddock, and M.E. Coluzz "Millimeter-wave Bistatic Scattering From Ground and Vegetation Targets," *IEEE Transactions on Geoscience and Remote Sensing*, Vol 26, pp. 229-243, May 1988.

[10] Ulaby, F.T., T.F. Haddock, and M.E. Coluzzi,"Millimeter-wave Bistatic Radar Measurements of Sand and Gravel," *Proceedings of IGARSS '87 Symposium,* Ann Arbor, V. 1, pp. 281-286,1987.

[11] Sarabandi, K. , F.T. Ulaby, and T.B.A. Senior, "Millimeter Wave Scattering Model for a Leaf," *Accepted for publication in Radio Science.*

[12] Ulaby, F.T., T.H. Haddock, and Y. Kuga, "Measurement and Modeling of Millimeter-wave Scattering from Tree Foliage," *Radio Science,* Vol. 25, pp. 193-203, 1990.

[13] Kuga, Y., R.T. Austin, T.F. Haddock, and F.T. Ulaby, "Millimeter-wave Radar Scattering from Snow Part I--Radiative Transfer Model with Quasi-Crystalline Approximation," *Submitted for publication in Radio Science.*

[14] Ulaby, F.T., T. Haddock, R. Austin, and Y. Kuga, "Millimeter-Wave Radar Scattering From Snow: Part II-Comparison of Theory with Experimental Observations," submitted for publication in Radio Science.

[15] Narayanan, R.M., C.C. Borel, and R.E. McIntosh, "Radar Backscatter Characteristics of Tree at 215 GHz," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 26, pp. 217-228, 1988.

[16] Narayanan, R.M., and R.E. McIntosh, "Millimeter-Wave Backscatter Characteristics of Multi-Layered Snow Surface," *IEEE Transactions on Antennas and Propagation,* Vol 38, pp. 693-703, 1990.

[17] Ulaby, F.T., W. H. Stiles, and M. Abdelrazik, "Snowcover influence on Backscattering from Terrain," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 22, pp. 126-133,1984.

[18] Stiles, W.H., and F.T. Ulaby, "Backscatter Response of Roads and Roadside Surfaces," Remote Sensing Laboratory, University of Kansas Center for Research Inc., Lawrence, KS, Technical Report 377-1, 1979.

[19] Ulaby, F.T., and W.H. Stiles, "Backscatter Response of Snow Covered Roads and Roadside Surfaces," Remote Sensing Laboratory, University of Kansas Center for Research, Inc.,Lawrence, KS, Technical Report 377-2, 1979.

[20] Stiles, W.H., and F.T. Ulaby, "Microwave Remote Sensing of Snowpacks," Remote Sensing Laboratory, University of Kansas Center for Research, Inc., Lawrence, KS, Technical Report 340-3, June 1980 (or Stiles, W.H. and F.T. Ulaby, "Microwave Remote Sensing of Snowpacks," NASA Contractor Report 3263, 1980).

[21] Cosfriff, R.L., W.H. Peake, and R.C. Taylor, "Terrain Scattering Properties for Sensor System Design (Terrain Handbook II)," Engineering Experiment Station Bulletin 191, Ohio State University, 1960.

[22] Peake, W.H., and T.L. Oliver, "The Response of Terrestrial Surfaces at Microwave Frequencies," Air Force Systems Command, Air Force Avionics Laboratory, Technical Report AFAL-TR-70-301 (AADD 884 106), 1971.

[23] Baars, E.P., and H. Essen, "Millimeter-Wave Backscatter Measurements on Snow-Covered Terrain," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 26, pp. 282-299,1988.

[24] Williams, L.D., and J.G. Gallagher, "The Relation of Millimeter-Wavelength Backscatter to Surface Snow Properties," *IEEE Transactions on Geoscience and Remote Sensing,* Vol. 25, pp. 188-194, 1987.

[25] Williams, L.D., J.G. Gallagher, D.E. Sugden, and R.V. Birnie, "Surface Snow Properties Effects on Millimeter-Wave Backscatter," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 26, pp. 300-306, 1988.

[26] King, H.E., C.J. Zamites, Jr., D.E. Snow, and R.I. Colliton, "Terrain Backscatter Measuremens at 40 and 80 GHz," *IEEE Transactions on Antennas and Propagation,* Vol. 18, pp. 780-784, 1970.

[27] Bush, T.F., F.T. Ulaby, and W.H. Peake, "Variability in the Measurement of Radar Backscatter," *IEEE Transactions on Antennas and Propagation*, Vol. 24, pp. 896-899, 1976.

[28] Hayes, D.T., U.H.W. Lammoers, and R.A. Marr, "Scattering from Snow Backgrounds at 35, 98, and 140 GHz," Rome Air Development Center, Hanscom Air Force Base, Technical Report 84-69 MA, 1984.

UNCLASSIFIED MASTER COPY - FOR REPRODUCTION PURPOSES

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Radiation Laboratory, University of Michigan, Ann Arbor, Mi 48109 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION U. S. Army Research Office
6c. ADDRESS (City, State, and ZIP Code) Ann Arbor, Michigan 48109	7b. ADDRESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U. S. Army Research Office 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Millimeter-wave Radar Scattering From Terrain: Data Handbook, Version 2.0

12. PERSONAL AUTHOR(S)
Thomas F. Haddack and Fawwaz T. Ulaby

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Technical	FROM 1/90 TO 9/90	1990. September, 15	206

16. SUPPLEMENTARY NOTATION
The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report provides a summary of experimental observations of the radar backscatter from terrain, as reported in the literature. The data is at 35, 94, 140 and 225 GHz, primarily at HH, VV, and HV polarizations. The terrain types observed include dry and wet snow, in-covered ground, trees, grasses, asphalt, gravel, and others.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED