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SKYLAB - 4 RADAR SCATTEROMETER MEASUREMENTS OVER LAND

RSL Technical Report 243-13
Remote Sensing Laboratory

Richard K. Moore

February, 1976

Supported by:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Johnson Spacecraft Center
Houston, Texas 77058

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(E76-10307) SKYLAB-4 RADAR SCATTEROMETER MEASUREMENTS OVER LAND Final Report, 26 Mar. 1973 - 31 Dec. 1975 (Kansas Univ. Center for Research, Inc.) 38 p HC $4.00 CSCL 17E G3/43
N76-23641
Unclas
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THE UNIVERSITY OF KANSAS CENTER FOR RESEARCH, INC.
2291 Irving Hill Drive—Campus West Lawrence, Kansas 66045

THE UNIVERSITY OF KANSAS SPACE TECHNOLOGY CENTER
Raymond Nichols Hall

2291 Irving Hill Drive—Campus West Lawrence, Kansas 66045

Telephone:

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REMOTE SENSING LABORATORY

Organization Full Name:	The University of Kansas Center for Research, Inc. 2291 Irving Hill Drive - Campus West Lawrence, Kansas 66045
Title of Investigation:	Design Data Collection with SKYLAB/EREP Microwave Instrument S-193
Title of Report:	Skylab - 4 Radar Scatterometer Measurements Over Land
Period Covered:	3-26-73 through 12-31-75
EREP Investigation:	549 M
Principal Investigator:	Professor Richard K. Moore
Date Written:	February 1, 1976
Monitor and Address:	Mr. Larry York Earth Observations Division Science and Applications Directorate NASA Johnson Spacecraft Center Code TF 3 Houston, Texas 77058
Type of Report:	Final Report

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

LIST OF FIGURES AND TABLES
(continued)

ABSTRACT

The Skylab winter mission SL-4 was used to collect a modest amount of overland and a large amount of oversea radar backscatter information. The overland data were studied in terms of snow-covered and snow-free terrain in different land-use categories, but no consistent differences were noted. Most of the snow-covered areas observed probably only had a few inches of snow, for the instrument was not operated over the northern areas where deep snow is prevalent; so this inconsistent result probably is not representative of return from snow-covered areas.

The general character of the returns measured over land during SL-4 was similar to that measured during SL2/SL3, but the fall-off with angle was somewhat steeper during the winter. This probably is due to the lack of active vegetation in most of the areas observed during SL-4, since vegetated terrain observed during SL2/SL3, and in aircraft and ground measurements by others, usually has a flatter angular characteristic than non-vegetated terrain. The SL-4 results, like those from SL2/SL3, were found to fit well with an exponential relation between scattering coefficient and angle of incidence. Because of antenna problems most of the SL4 observations were made near vertical incidence, so an adequate comparison with the large body of 30° incidence SL2/SL3 observations was not possible.

Over the oceans the SL4 returns did not fall off as rapidly with angle as those during the earlier missions. This was caused by the more frequent observation of stormy seas during SL4, so the vertical incidence returns were somewhat smaller and the returns between 30° and 50° were larger. Since the wind response of the ocean is the subject of another Skylab investigation, only the composite results are given in this report.

SKYLAB - 4 RADAR SCATTEROMETER MEASUREMENTS
OVER LAND

1.0 INTRODUCTION

Skylab spacecraft was occupied during three periods between May 1973 and February 1974. The winter-occupancy mission SL-4 provided the first opportunity to measure significant amounts of snow-covered or cold ground with the 13.9 GHz S-193 scatterometer. Unfortunately, a malfunction in the scan mechanism of the S-193 during September 1973 resulted in degraded winter observations. During the partial repair of the scanning mechanism, the antenna feed structure was damaged and the result was a large reduction in antenna gain and a great increase in level of the antenna sidelobes. The width of the main beam was not changed a great deal, but it's shape was altered. This problem made the radiometer data useless, since more energy was in the large main sidelobe than in the central beam, but the scatterometer data could be used because of the smaller sidelobe response that results from the product of the receiving and transmitting gains. The damage to the scanning mechanism was partially repaired by the astronauts during an EVA, but scanning was possible after the repair only in the cross-track modes, and the in-track modes as well as the cross-track modes in which the antenna is tilted ahead were not useable. On January 9, 1974, a further failure in the scanning mechanism occured so that it would only scan to the right, but not the left, of the Skylab. Furthermore, the entire scanning operation during SL-4 was somewhat erratic although the angles to which the antenna pointed were known.

Another problem reduced the validity of the over-land data. Most of the measurements during Skylab - 4 over land were made with the system operating in the cross-track contiguous (CTC) pitch-zero, roll-zero mode. This meant that angles were observed only out to about 12°. Two passes were made in the mode centered about 30° to the side, but comparability with the summer data would have required many more passes in which this mode was used. Furthermore, it is our belief that the measurements at the larger angles would have been more interesting for comparison between snow and no snow conditions than the near-vertical measurements that predominated.

Detailed results for two passes over snow-covered areas were reported in

the results of EREP experiment 540-A2 under contract NAS 9-13273.* In this report, we concentrate on a more general discussion and no effort was made to obtain detailed snow-cover information other than the presence or absence of snow for reporting here.

A multi-institution team spent a great deal of time and effort modifying the processing techniques used for the data so that SL-4 data could be processed in a manner to be as nearly comparable with SL-2 and SL-3 data as possible. This analysis has been described elsewhere in more detail.** During our analysis of the data observed during SL-4 we prepared a set of corrections to the "corrected" data based on measurements over the ocean where 18 knot winds were present. These are described in Appendix E to the main final report for this project.*** The corrections applied here on the basis of that procedure are summarized in Figure 1, a reproduction of Figure E-1 of the referenced report.

The passes over the United States during SL-4 are summarized in Figure 2. Unfortunately for measurements of snow-covered conditions, the passes were not over the northern part of the United States, although snow cover was observed in Nebraska, Kansas, Missouri, Iowa, and in pass 2 that went across a part of the Allegheny Mountains. Of course, data from mountainous regions are somewhat more complicated than those from the flat regions. High elevation data from Nevada and Utah also contain snow. The only observations made at the angles around 30° from nadir were on the passes through Nevada and Arizona, so these data are highly unrepresentative.

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* Eagleman, J. R., E. C. Pogge, R. K. Moore et al., "Detection of Soil Moisture and Snow Characteristics From Skylab," Final Report 239-23, EREP No. 540-A2, Contract NAS 9-13273, Atmospheric Science Laboratory, Center for Research, Inc., Lawrence, Kansas, October 1975.

** Kaupp, V. and J.C. Holtzman, "Skylab Program Earth Resources Experiment Package," S-193 Final Report, RSL TR-236-4, Remote Sensing Laboratory, Center for Research, Inc., Lawrence, Kansas, July 1975, 477p.; and "Earth Resources Production Processing Requirements for EREP Electronic Sensors," Revision B, Doc. No. PHO-TR524, NASA/Lyndon B. Johnson Space Center, Houston, Texas, March 1975.

*** Moore, R. K., et al., "Design Data Collection with Skylab Microwave Radiometer-Scatterometer S-193 - Final Report," RSL Technical Report 243-12, Remote Sensing Laboratory, University of Kansas Center for Research, Inc., Lawrence, Kansas, under Contract NAS 9-13331, September 1975.

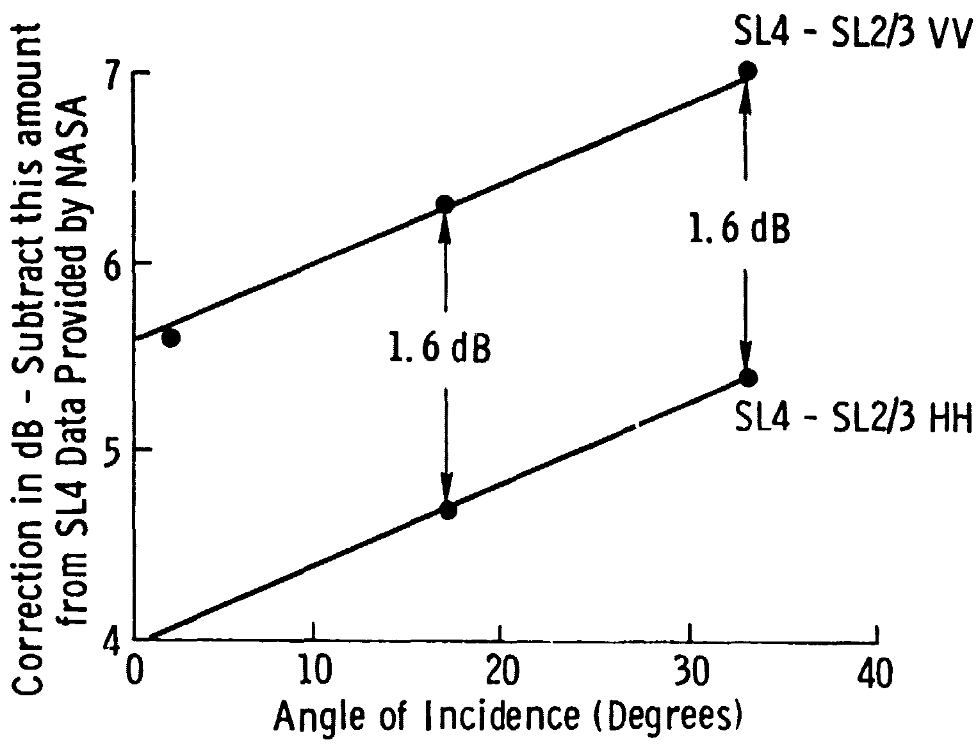

Figure 1. Corrections to be made to SL4 Scatterometer data. Points at 17° and 33° based on 17-knot winds. Point at 2.3° based on Texas Panhandle rangeland.

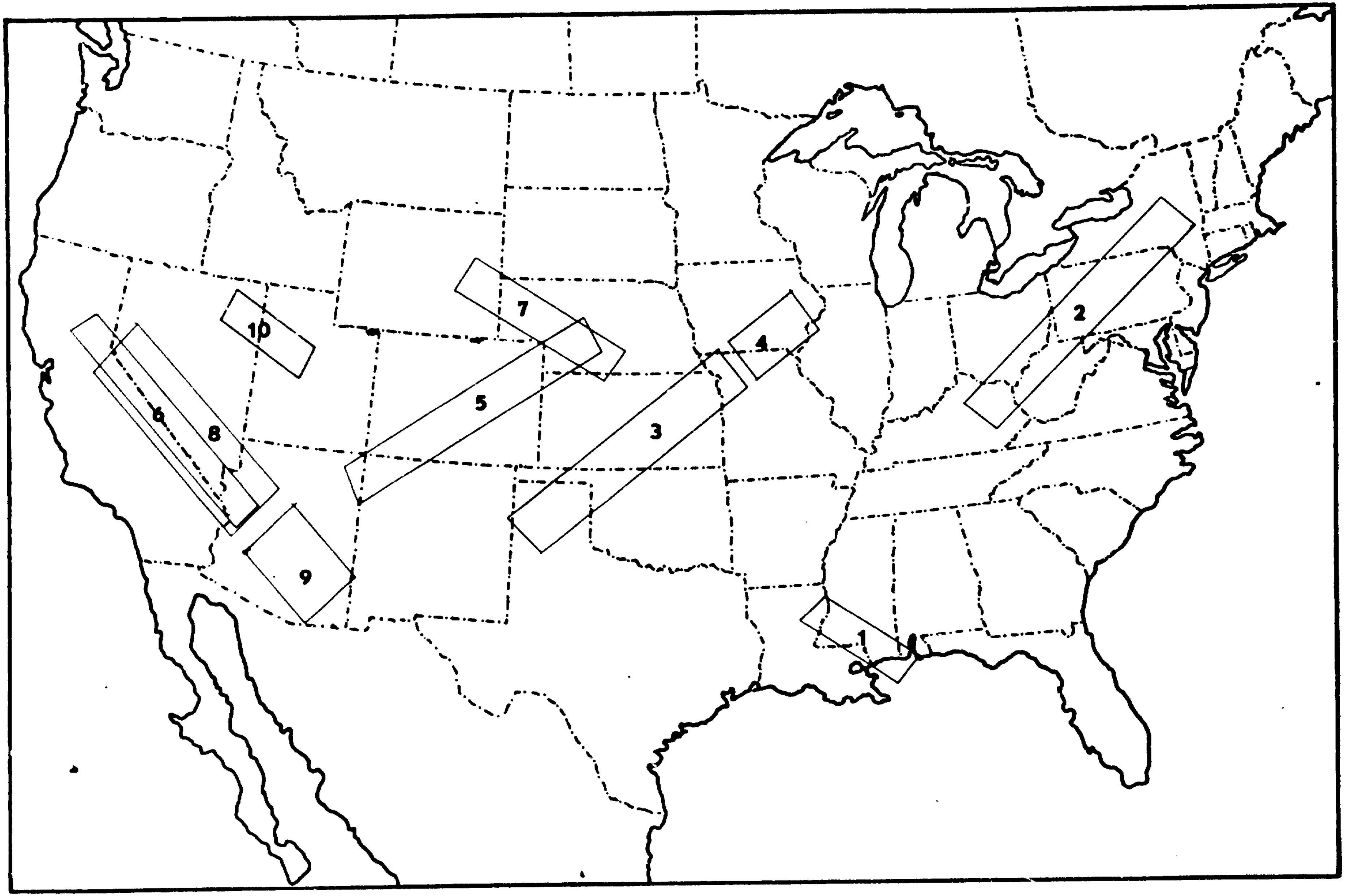

Figure 2. Cross-Track Contiguous Data Takes over U.S.A. During SL4 Mission Considered in Designing Data Catalogue. (See Table 1).

TABLE 1

CTC PASSES OF S-193 SCATTEROMETER OVER NORTH AMERICA DURING SL4

Label on Figure 2	Pass	Day of year (1974)	Center of scan (Pitch, roll)	Polarization	
1	87	21	0,0	VV	
2	73	4	0,0	HH	
3	81	11	0,0	VV	
4	81	11	0,0	HH	
5	83	14	0,0	HH	
6	98	32	0,0	VH	(Not Used)
7	88	22	0,0	VV	
8	94	28	0,30 Right	VV	
9	94	28	0,30 Right	HH	
10	95	29	0,0	HH	

1.1 Description of Experiment

Figure 3 illustrates the performance of the cross-track contiguous scan during SL-4. The performance was extremely variable, but this figure is a representative one for pass 81 on January 11. The "wander" of the scan is quite apparent from the illustration. The footprints on the illustration are for the 2 dB contour for the 1-way pattern and exhibit considerable overlap. The contour, of course, is questionable because of the difficulty in specifying exactly the performance of the broken antenna. The locations of the centers of the footprints, however, are believed to be accurate.

2.0 INDIVIDUAL PASS RESULTS

The scattering coefficient-versus-angle curves are presented here for observations made during three passes. Pass 81, which started in the Texas Panhandle on 11 January and entered an area of snow cover near the southern boundary of Kansas remaining in snow-covered area through Kansas and a part of Missouri and Iowa, pass 94 in the California and Nevada desert extending into Arizona, and Pass 95 that extended a relatively short distance from Nevada across into Utah toward the northern part of the states involved. Similar plots could be presented for the other passes but these are sufficiently representative to indicate the kinds of trends observed. The data from the applicable passes have been separated into regions with and without snow for each of the various categories of land use present on the pass. Of course, during the winter the difference to be expected between agricultural land, range land, and even desert is not very great since there is essentially no vegetation present on any of them during the winter. Some of the forests are probably deciduous, but many of the western forests are coniferous so that the results for forests certainly should be somewhat different from those for the other categories. On the other hand, the forest results are likely to be more similar to those for the other categories for the near-vertical angles of incidence used on most of these passes than they would be at large angles of incidence since the angle of observation allows looking at the ground between the trees where the cover is not too dense. At larger angles of incidence, even the deciduous trees would very likely provide some screening and contribute a major part of the backscatter in winter, and the coniferous trees certainly would be expected to give a greater backscatter than the ground. However, only the one pass was observed

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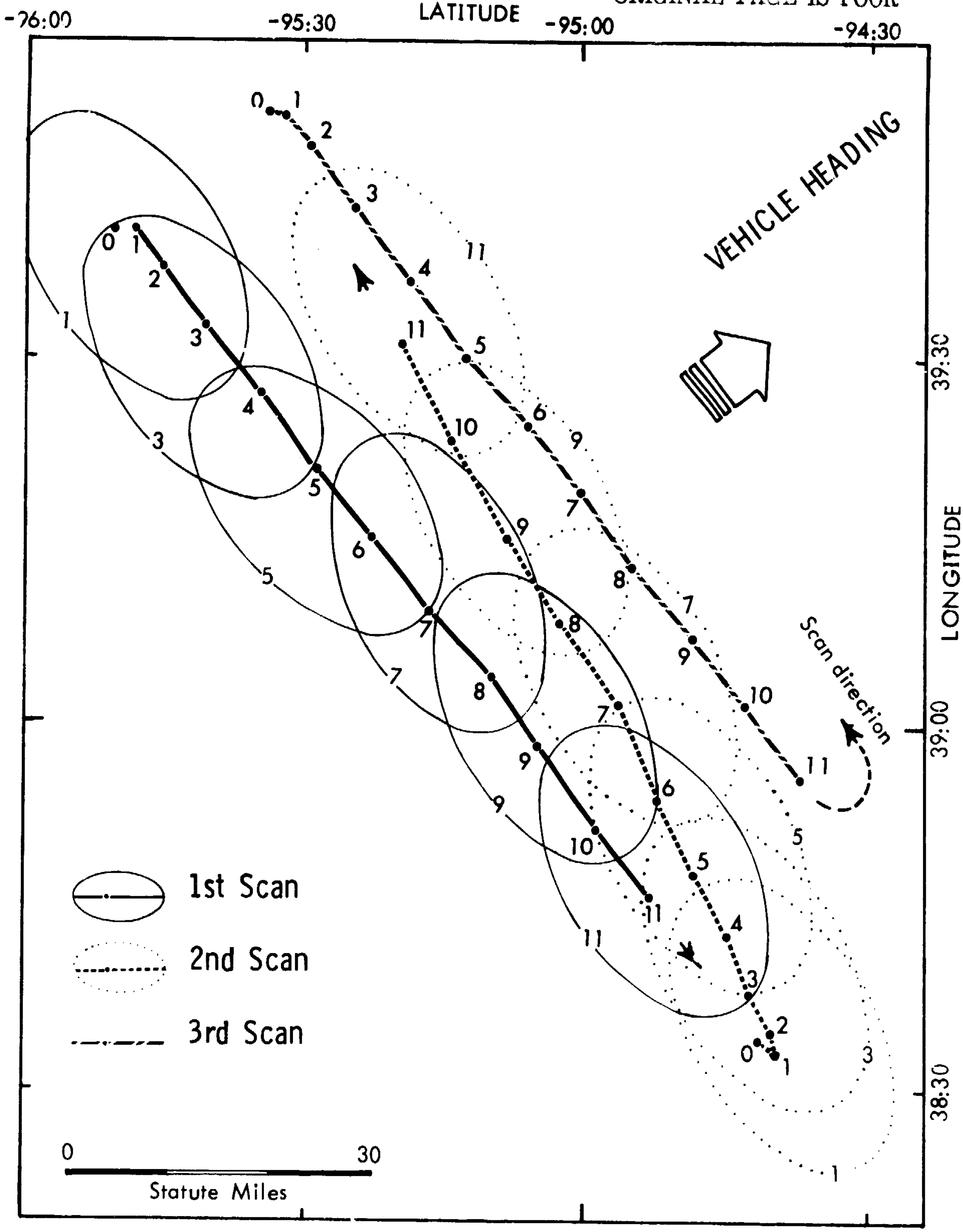

Spatial distribution of illuminated targets for the CTC pitch 0°, roll 0° mode during SL4 operation (January 11/Pass 81). 2 dB isogain contour of every alternate scatterometer footprint is shown for two scans.

Figure 3.

with the larger angles of incidence. These were only in the vicinity of 30° where it is still possible to see between the trees when they are not too densely spaced.

Figure 4 shows the agricultural category during Pass 81. Part of this is in Texas and Oklahoma and much of it in Kansas. No distinction of significance was observed between the snow-covered and non-snow-covered agricultural category in this case. However, as indicated in Eagleman et al., [1975]* there should be a distinction when the snow depth is taken into account. Figure 5 shows a similar result for the category of range land and agriculture. This same pass and Figure 6 shows a combined range - grassland category. In this case the snow-covered terrain gives a significantly larger return than the non-snow-covered terrain. Perhaps this is because much of the grassland is in the area of deep snow, at least that was the indication in the other study.

Figure 7 shows a category "range-forest" on Pass 95 across the boundary of Nevada and Utah. No distinction appears here between snow-covered and non-snow-covered terrain. Figure 8 shows a similar result for desert in the same pass. The apparent difference at 5° between snow-covered and non-snow-covered terrain is quite likely a result of the small sample size for the snow-covered condition and should not be viewed as representative of distinction between snow-covered and non-snow-covered desert.

Figure 9 shows the only pass where the larger angles of incidence were present,with angles extending from about 20° to 43°. As can be seen, the variation with angle is extremely small over this range and there is no distinction observed between snow-covered and non-snow-covered terrain. The amount of snow present in this high desert may not have been very great and its moisture content may have been quite low.

From these curves it is not possible to draw any conclusions about the effect of snow except that the mere presence of snow does not significantly affect the scattering characteristics of the ground near vertical incidence. In no part of the observation area shown is the snow likely to be very deep. The deepest snow was about 10 inches in a small part of the pass across Kansas and northern Missouri.

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* Op. cit. (Eagleman, et al., 1975)

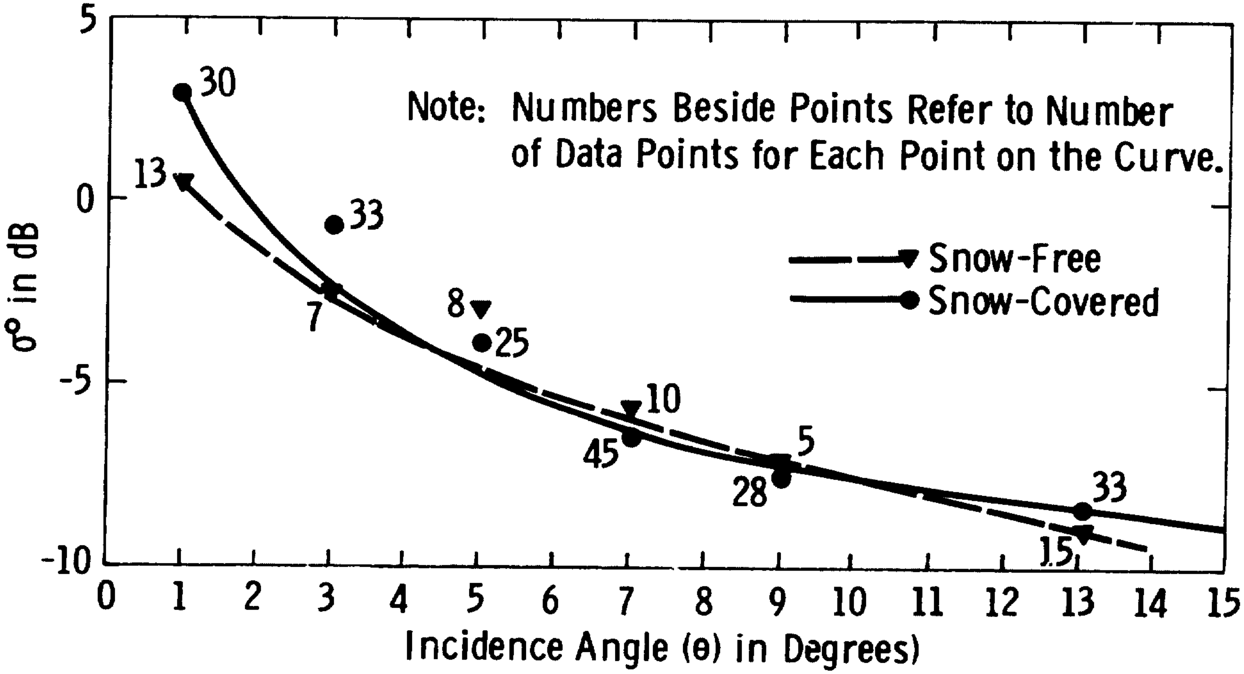

Figure 4. Scattering Coefficient for Radar Return from Agricultural Terrain. Pass 81, 11 January 1974 - Texas to Missouri. VV Polarization.

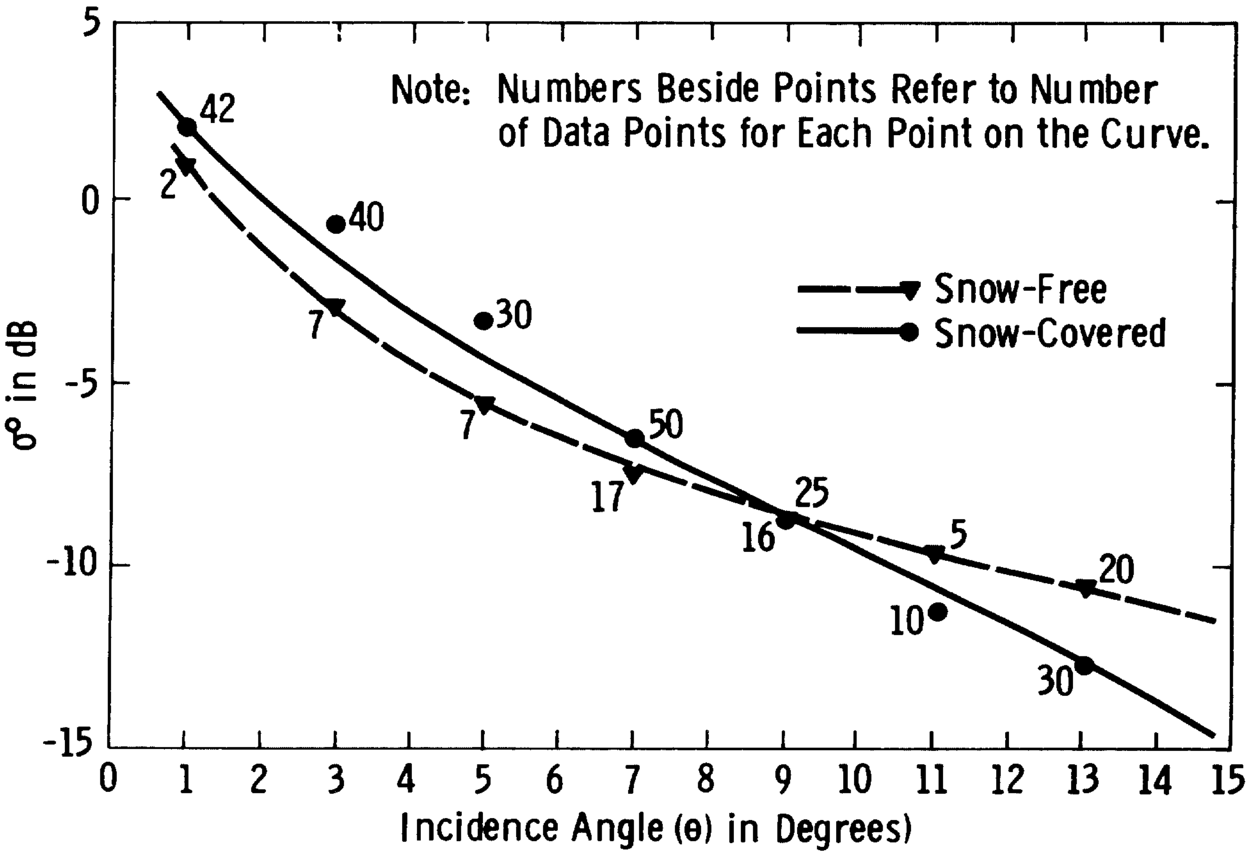

Figure 5. Scattering Coefficient for Radar Return from Terrain Combining Rangeland and Agricultural Areas. Pass 81, 11 January 1974 - Texas to Missouri. VV Polarization.

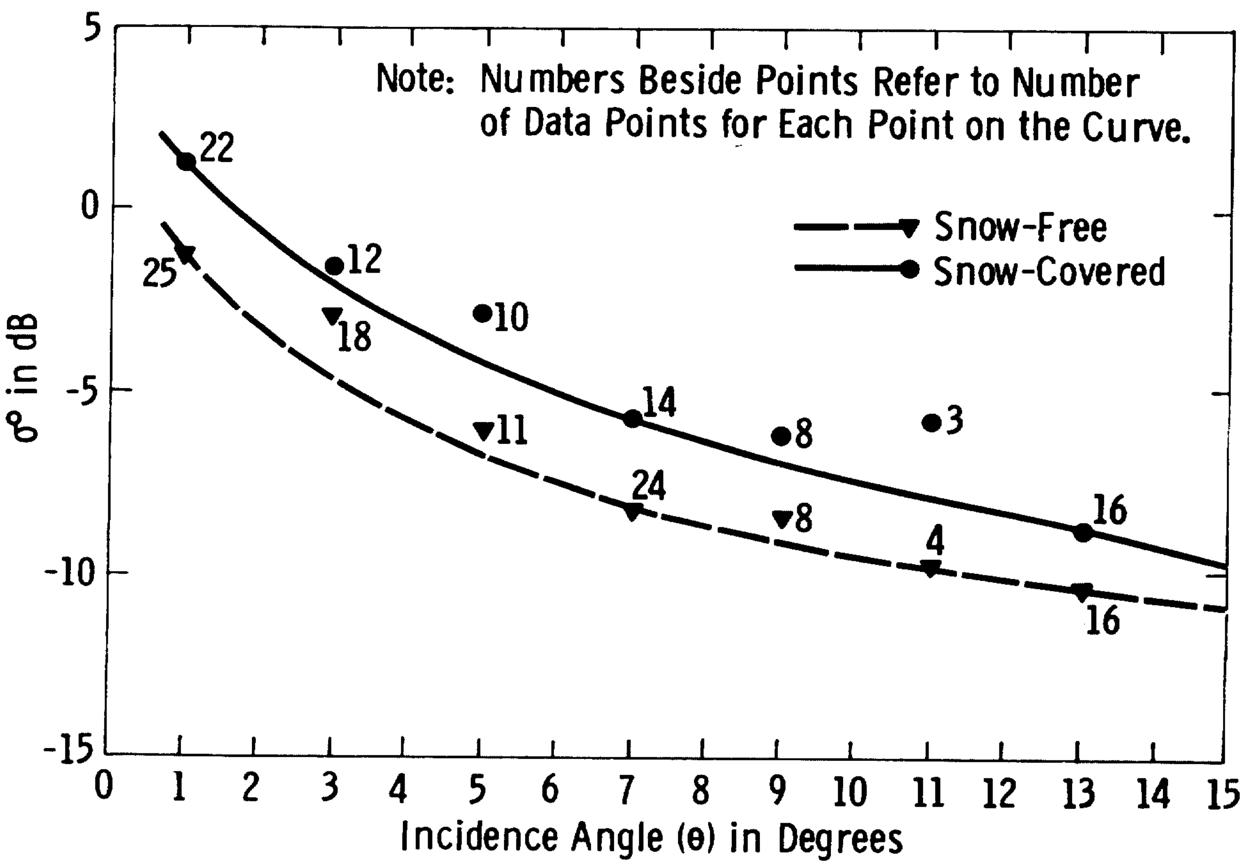

Figure 6. Scattering Coefficient for Radar Return from Terrain Conbining Rangeland and Grassland Categories. Pass 81, 11 January 1973 - Texas to Missouri. VV Polarization.

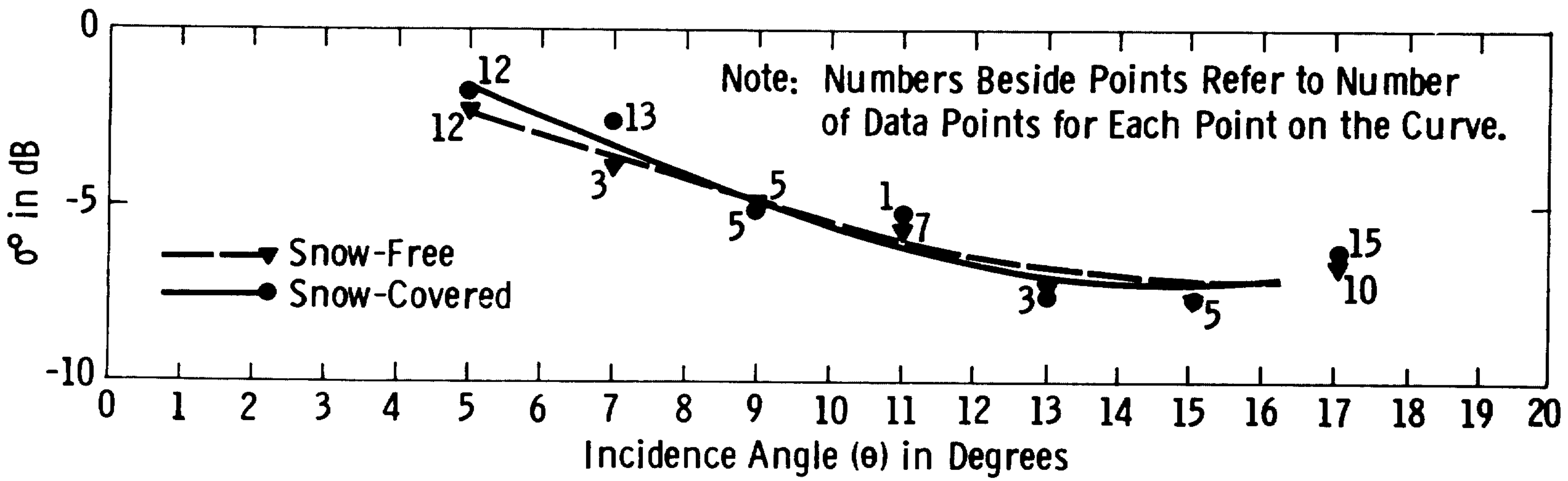

Figure 7. Scattering Coefficient for Radar Return from Rangeland and Forest. Pass 95, 29 January 1974 - Nevada and Utah. HH Polarization.

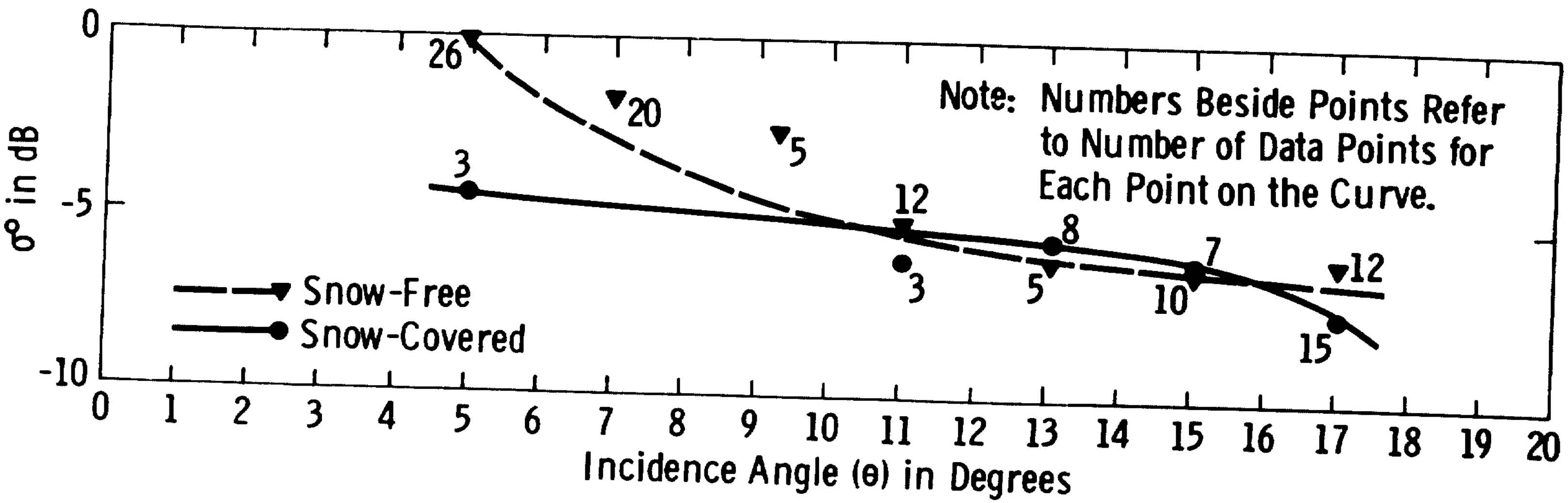

Figure 8. Scattering Coefficient for Radar Return from Desert. Pass 95, 29 January 1974 - Nevada and Utah. HH Polarization.

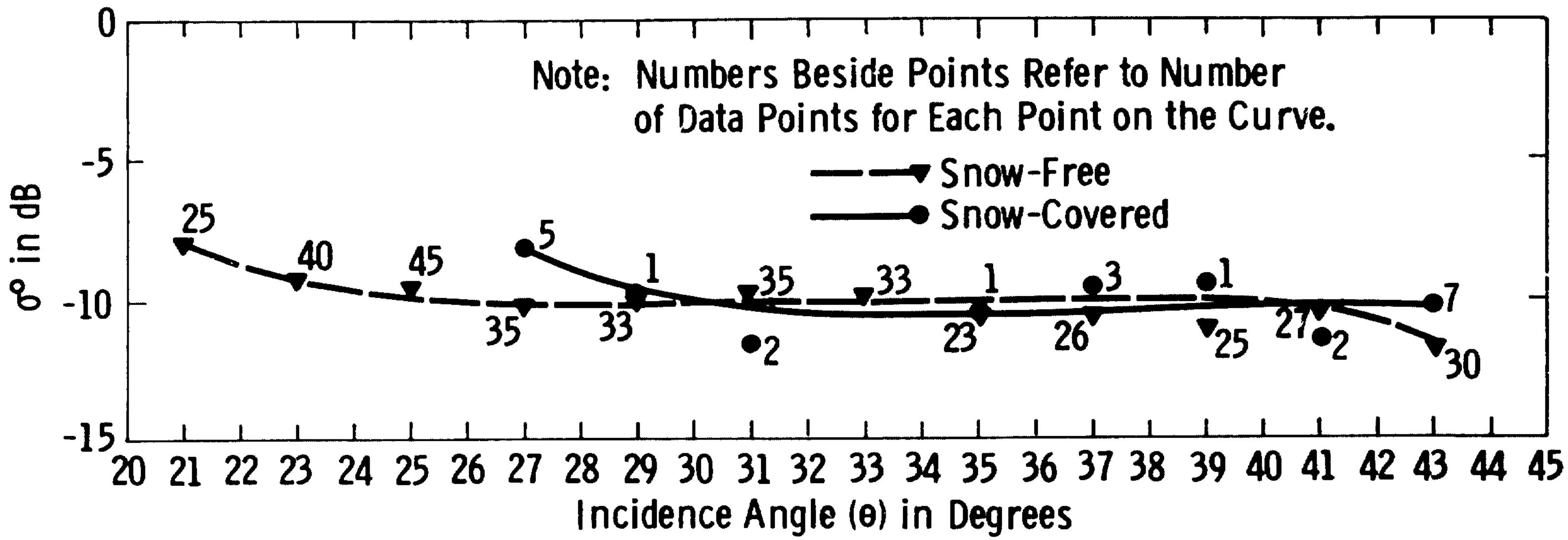

Figure 9. Scattering Coefficient for Radar Return from Desert. Pass 94, 28 January 1974 - Nevada and Utah. VV Polarization.

Observations over the deep snows in Minnesota would have been desirable, but were not obtained.

3.0 SCATTERING COEFFICIENT RANGES FOR THE DIFFERENT CATEGORIES

In discussion of the results of the summer missions, the scattering coefficients for different categories of land use were shown along with their standard deviations both in comparison with each other and in comparison with previous measurements by other investigators. In this case we shall not compare with other investigators, but similar plots are presented for the different land use categories observed during the winter mission, both with and without snow and in some cases they are compared with the results obtained during the Skylab 2 and 3 missions in the summer.

Figure 10 illustrates the results at 3^{o} angle of incidence for agricultural terrain, forest, and range land. The agricultural results in the winter mission, SL-4, and the summer mission, SL-2 and 3, are almost the same with the snow-covered winter ground and the vegetated summer ground. Although separate bars are shown for vertical and horizontal polarization, at this angle of incidence the two are essentially the same except for the azimuth angle; that is, vertical polarization simply represents an electric vector that makes an angle of 90^{o} with respect to the electric vector for horizontal polarization. In the case of forest, the winter-time snow-free measurement shows a higher return than either the winter-time snow-covered or the summer-time forest measurements. Since the forests concerned were quite different, however, it is not likely that these results are significant for a forest in general, but rather it is more probable that they simply reflect the differences in the kinds of forests observed.

The returns from snow-covered and non-snow-covered range land in the winter at vertical polarization are about the same but about 4.5 dB less than the summer-time range-land measurements. On the other hand, the small sample of horizontally polarized winter measurements, also with snow, are more nearly comparable with the summer time measurements. Again, these distinctions probably are more due to the small sample and the sampling variability than to any intrinsic difference in the return from range land.

Some caution should be used in drawing conclusions from data at angles of incidence close to the vertical under any circumstance and particularly so during

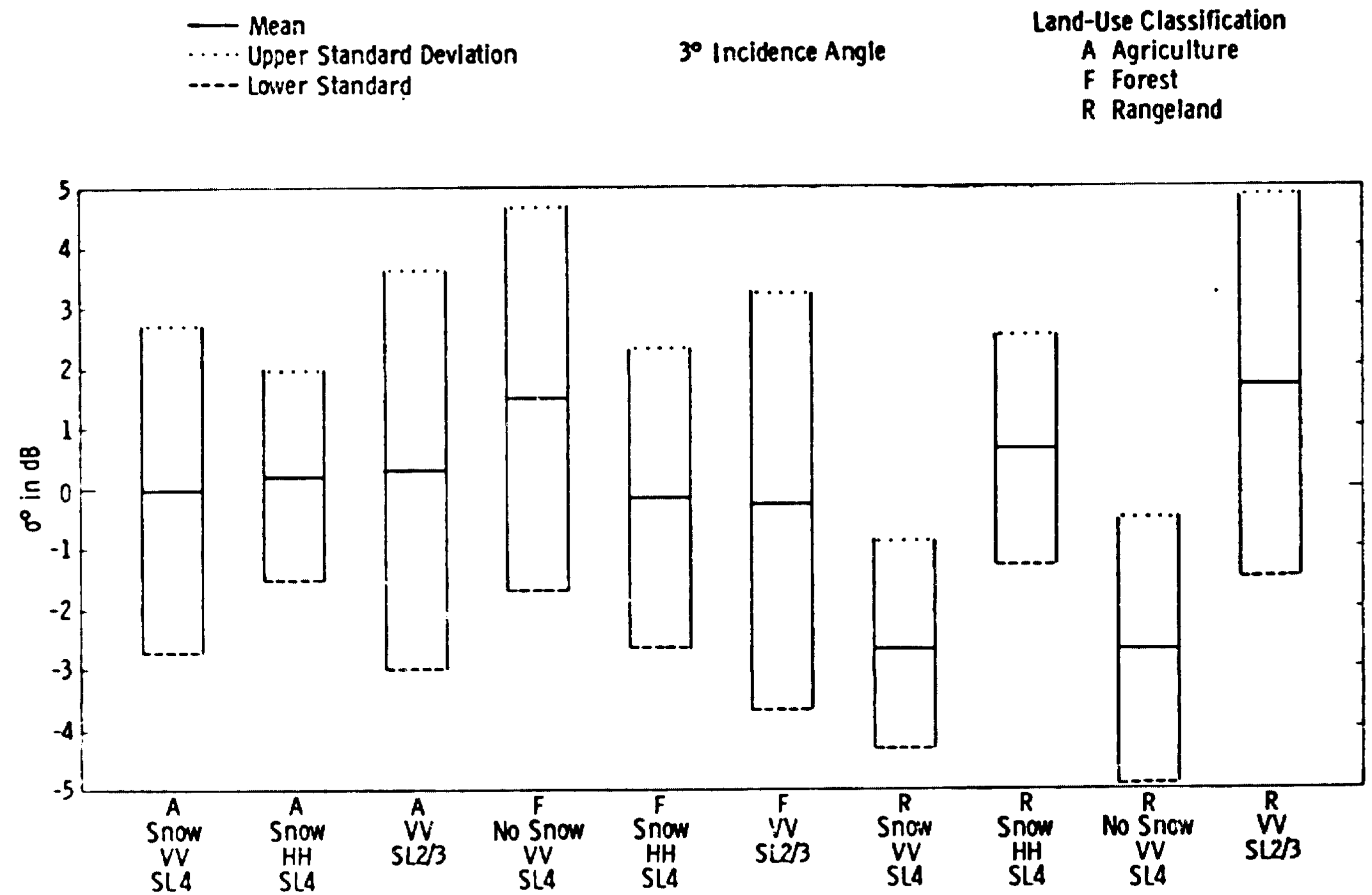

Figure 10. Comparison of Backscattering Coefficient at 3° for Various Terrain Categories from SL4 and SL2/3 Missions of S-193 Scatterometer.

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SL-4 where the broader antenna pattern and the greater uncertainities associated with the pointing angle are significant factors.

Figure 11 shows a comparable plot for 7° angle of incidence, but with only the winter measurements indicated. The snow-covered agricultural terrain has a return somewhat more than 2 dB higher at horizontal polarization than at vertical polarization. This must be a problem in sampling variability, since the horizontally polarized measurements were made in the far West and many of the vertically polarized measurements were made in the Midwest and East. Only one measurement is shown for desert and it is the strongest return of all the target categories, having a mean value in the neighborhood of -2 dB, whereas the forest and range horizontally polarized signals with snow on the surfaces are about 1 dB lower. The vertically polarized range measurement is much lower, almost down to -6 dB, but the range-land without snow is even lower at almost -8 dB. Probably the most significant conclusion to be drawn from these is not that these values are representative of the classifications, but rather that the variability of return is fairly great. Note that no single classification has more than 58 measurements (snow-covered forest) and most of the others only have about 20 measurements. Consequently, the results are really specific only to the particular areas observed.

Figure 12 shows a comparable plot for 13° angle of incidence. Here we have agricultural measurements with both horizontal and vertical polarization, which may be slightly different at this angle, and range-land measurements with both polarizations. Vertically polarized agricultural terrain measurements with and without snow show no significant difference. Here as elsewhere, it should be pointed out that the definition of snow-covered terrain does not take into account the amount of moisture present or the depth of the snow.

The results of the previously reported study * indicate that there may well be some effect for radar return from snow at this angle of incidence. In the case of range-land, the snow-covered terrain gives a higher return than the non-snow-covered terrain. Perhaps this is because range-land was a significant category where the snow was deep in Kansas and Nebraska, but strong conclusions cannot be drawn because of the lack of enough data. The much stronger return for range-land was with horizontal polarization over snow-covered terrain. In this case, with

* Op. cit. (Eagleman, et al., 1975)

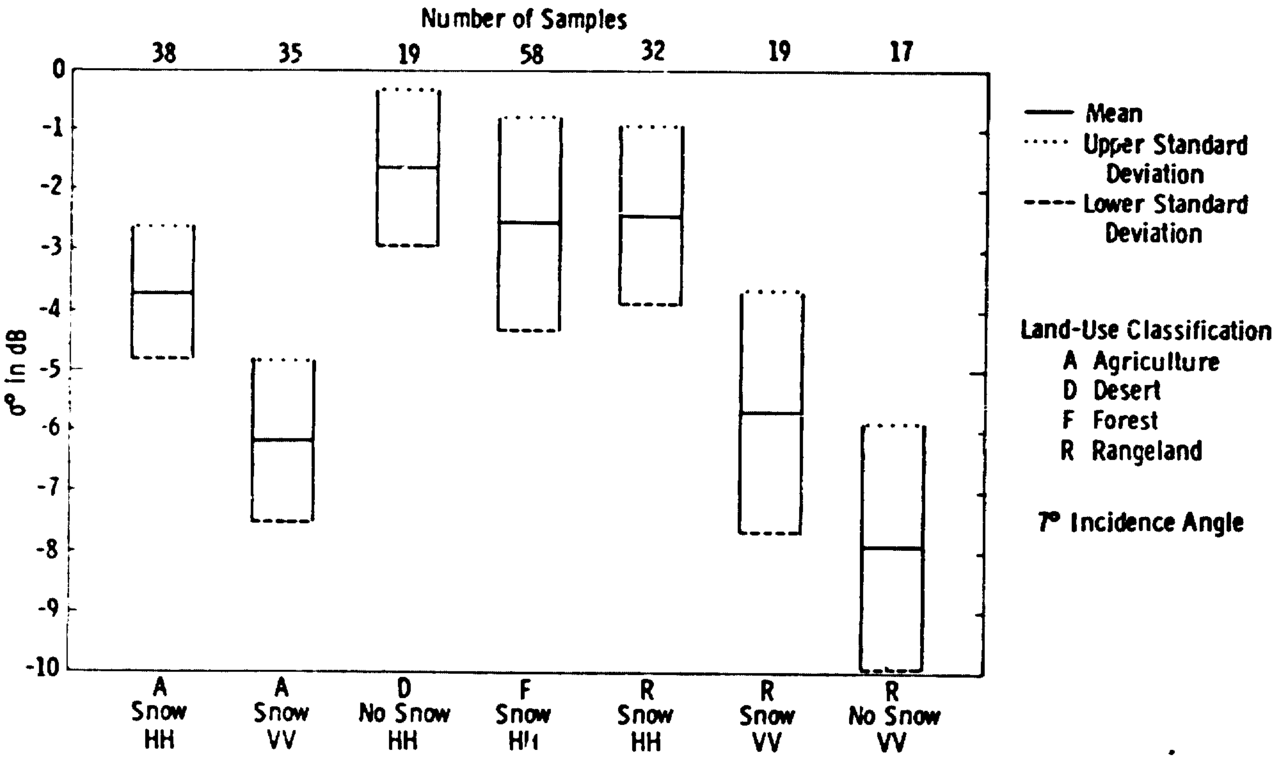

Figure 11. Comparison of Backscattering Coefficient at 7° for Various Terrain Categories from SL4 Mission of S-193 Scatterometer.

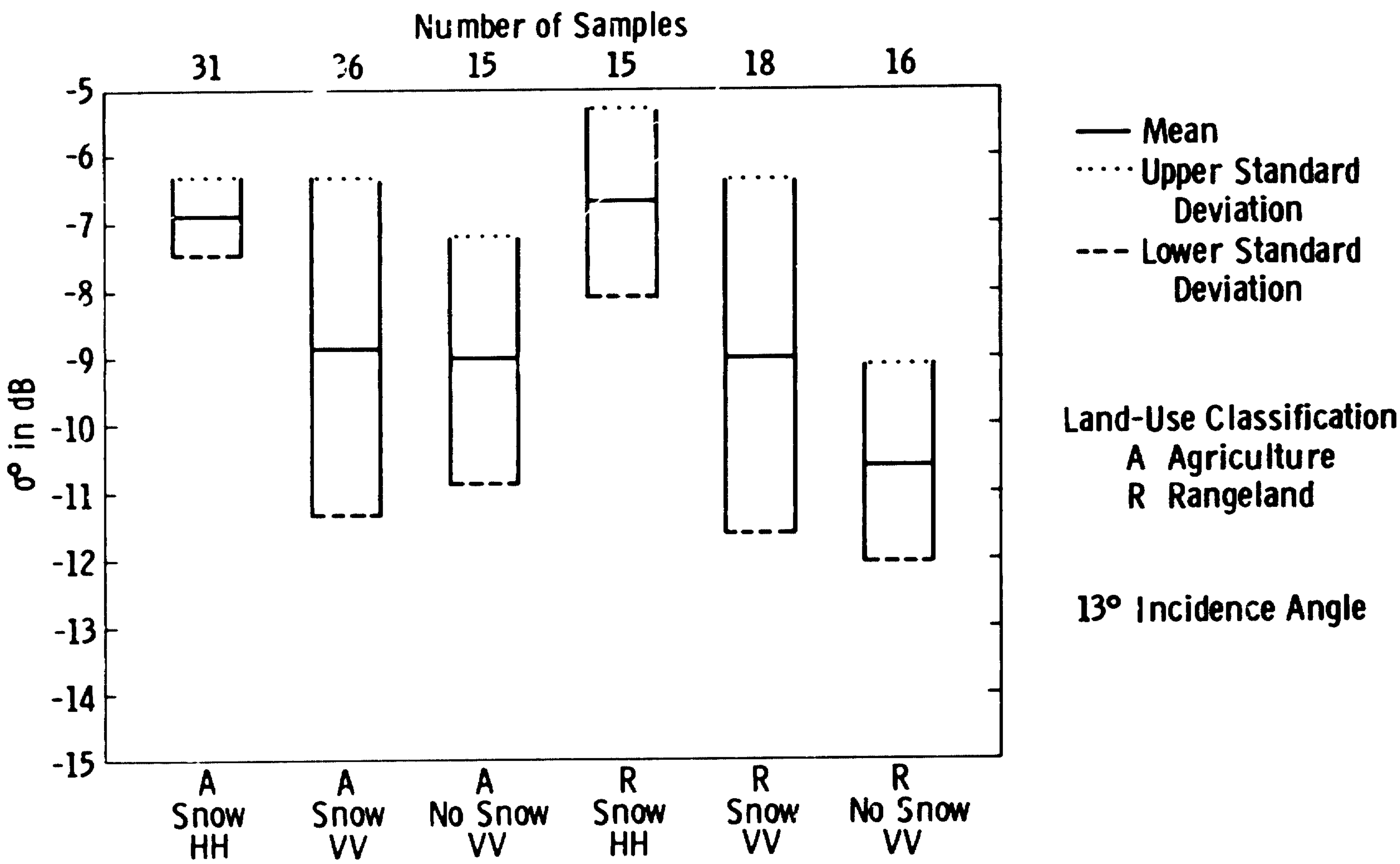

Figure 12. Comparison of Backscattering Coefficient at 13° for Various Terrain Categories from SL4 Mission of S-193 Scatterometer.

the exception of the snow-covered agricultural terrain, less than 20 samples were observed so the variability can easily be attributed to differences in the general character of targets categorized as range land.

Figure 13 shows a comparable result for 15° angle of incidence, in this case with a comparison with the data from the summer missions. Unfortunately, the CTC 0° pitch and roll was nearly the only mode used in the winter and it was almost never used in the summer, so comparisons between summer and winter data are only possible at the very small angles where the in-track contiguous (ITC) mode in the summer would produce returns and at angles of around 15° and 30° where the ITC mode produced returns. In this figure, we observe that agricultural terrain with snow cover in the winter as in other cases is quite different between vertical and horizontal polarization, primarily because of differences in the location, and the summer-time value lies somewhat between them. In the case of the forest with vertical polarization there is no significant difference between the snow-free winter-time forest and the summer forest. For range land, the vertically polarized return is quite weak compared to both the horizontally polarized winter return and the vertically polarized summer return, which are about the same. Because of the very small distance travelled in the mode where the scan went out to the 30° to 40° region, only two bars are shown on the graph for this angular area (nominally labeled 33°) and shown in Figure 14. The problem is that essentially all of the winter-time data in this angular regime were obtained over the desert so the comparison can only be made between summer and winter desert. The return for the winter-time is 2.5 dB lower than for summer and this may, in fact, be significant. The winter-time desert returns are the lowest of any category for the 33° angular incidence range and the sample size is large enough to be useful: 87 points.

As can be seen from Figures 10 through 14, the range of variation from one target classification to another is several dB and the signals are, of course, as expected: weaker at the larger angles. Because of the small samples during the winter mission, much of the variability must be attributed to differences in area, for one would expect that two areas in different parts of the country having the same land use might have sufficiently different topography so that the radar return would be different.

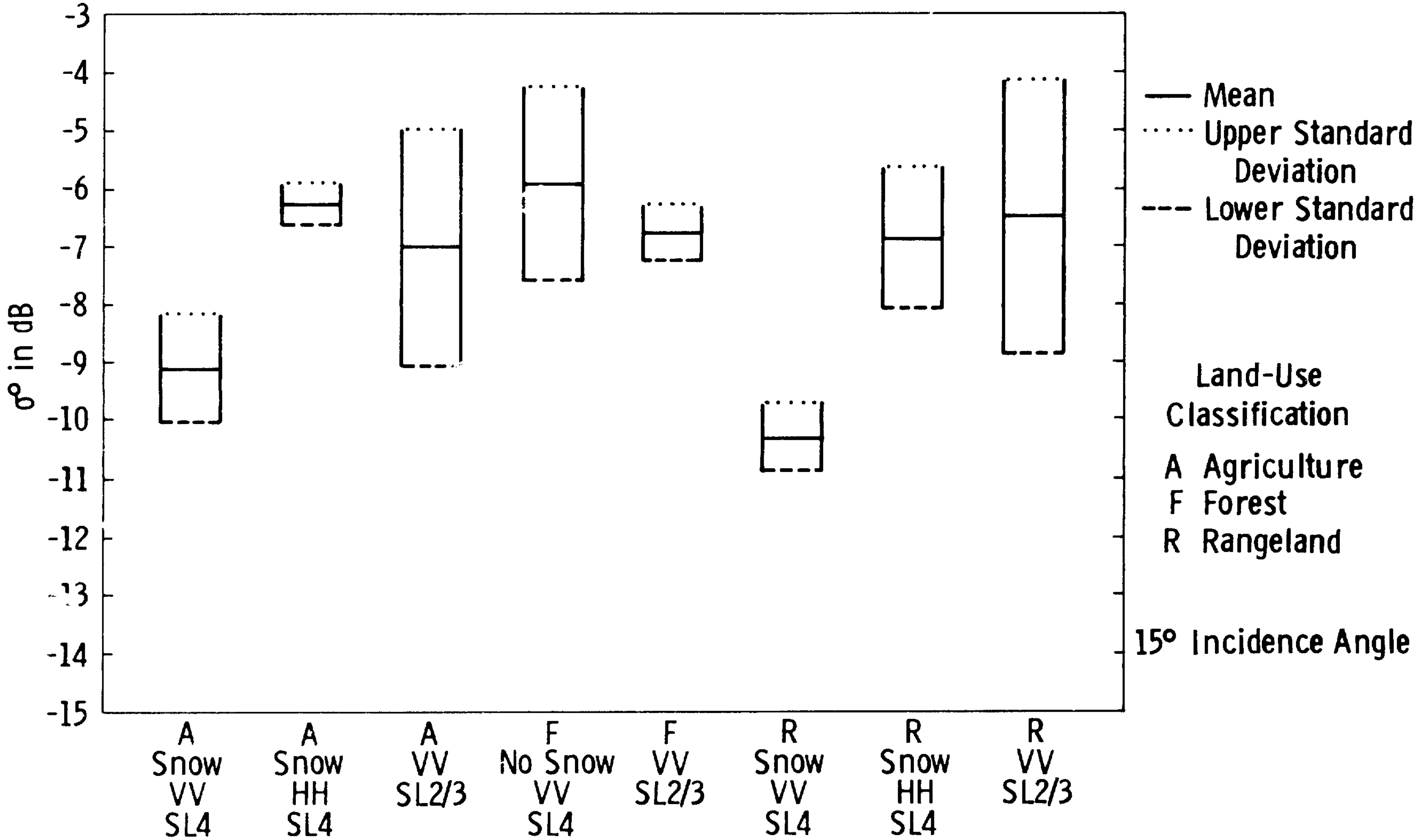

Figure 13. Comparison of Backscattering Coefficient at 15° for Various Terrain Categories from SL4 and SL2/3 Missions of S-193 Scatterometer.

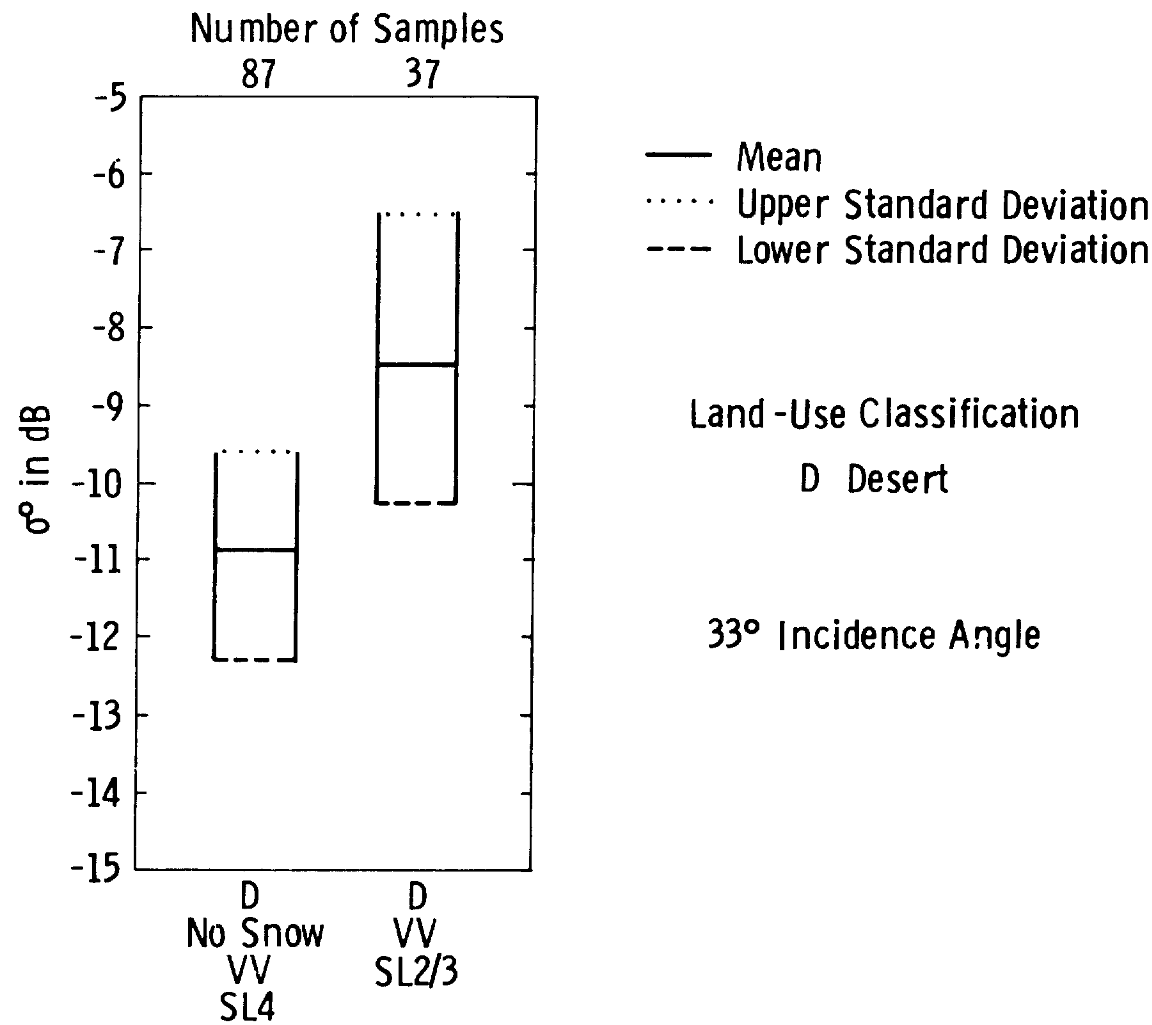

Figure 14. Comparison of Backscattering Coefficient at 33° for Desert from SL4 and SL2/3 Missions of S-193 Scatterometer.

4.0 COMPOSITE SCATTERING COEFFICIENT DATA FOR WINTER

As with the data for the summer SL2/SL3 passes reported in Sections 8.1 and 8.2 of Appendix A of the SL2/SL3 final report *, the results of the SL4 passes have been combined to produce summary data useful in radar design. The conclusions reached here are not significantly different from those of the earlier report, but differ somewhat in detail. Because the overland data during SL2/SL3 were much more plentiful than those during SL4, some variation is to be expected. During SL4 nearly all the data are from angles within 13° of the vertical over land, so the data for the larger angles are particularly unrepresentative. Over the ocean, however, more data were obtained during SL4 than during SL2/SL3. Furthermore these data contained a much larger fraction from relatively high-wind conditions, and the results presented here are different in the way that would be expected; i.e., the ocean backscatter curves are not as steep as during the calmer conditions of the summer.

Figure 15 illustrates the composite VV returns over land and Figure 16 illustrates the composite HH returns over land. These data have been corrected using the method described in Appendix E of the reference.** The data for the first 13° are from a variety of land-use categories, whereas most of those for the larger angles are from desert. Snow-covered and snow-free areas have been combined. The VV and HH returns should be about the same for the smaller angles, as discussed above; but they differ because the HH returns represent a small sample of terrain categories whereas the VV returns were more plentiful and covered a wider range of terrains.

Figures 17 and 18 show the comparable results for ocean. Data are also shown in Figure 19 for the VH polarization over the ocean, although the absolute levels are in error because of the difficulty in obtaining a suitable correction factor to the data reported by the JSC team. These difficulties in correcting the absolute level are not of significance in determining angular response or in determining wind response, so these data have been used in analysis of ocean backscatter.***

---

* Op. cit. (Moore, et al., 1975)

** Ibid.

*** Young, J. D., "Active Microwave Measurements of Sea-Surface Winds from Space," (Ph.D. Thesis), RSL Technical Report 254-5, Remote Sensing Laboratory, University of Kansas Center for Research, Inc., Lawrence, Kansas, February 1976.

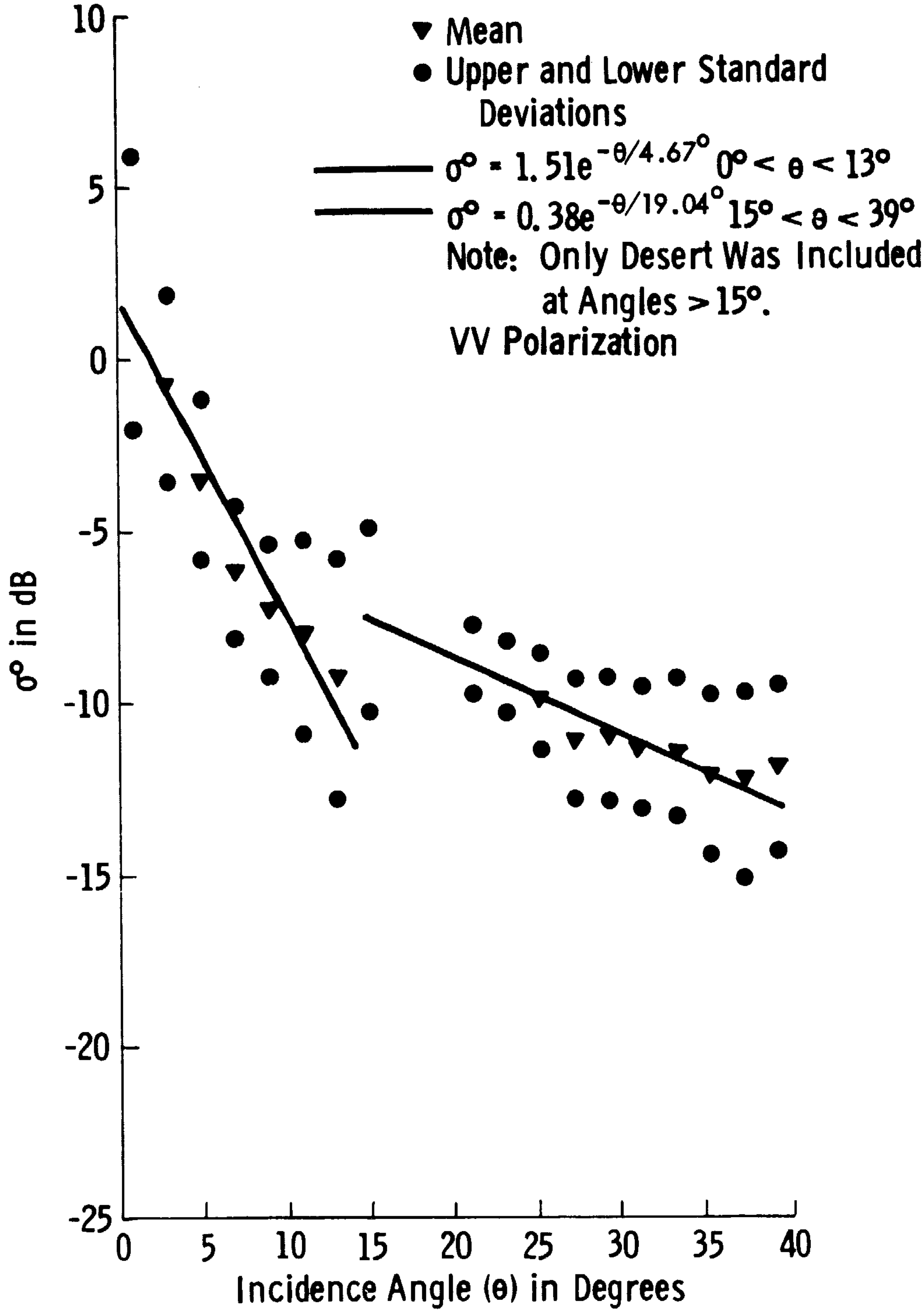

Figure 15. Composite Scattering Coefficient of Land from SL4 S-193 Scatterometer - VV Polarization.

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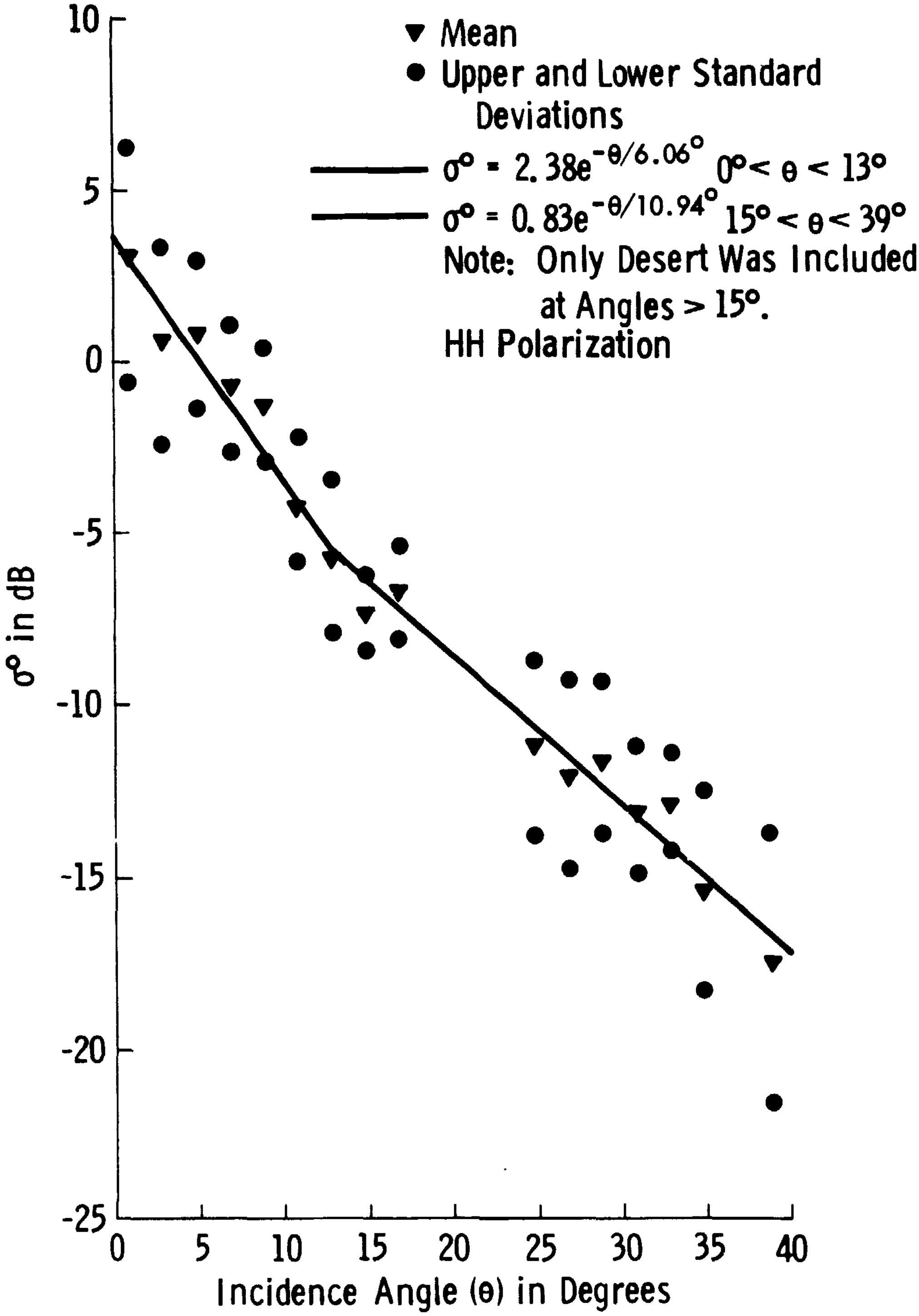

Figure 16. Composite Scattering Coefficient of Land from SL4 S-193 Scatterometer - HH Polarization.

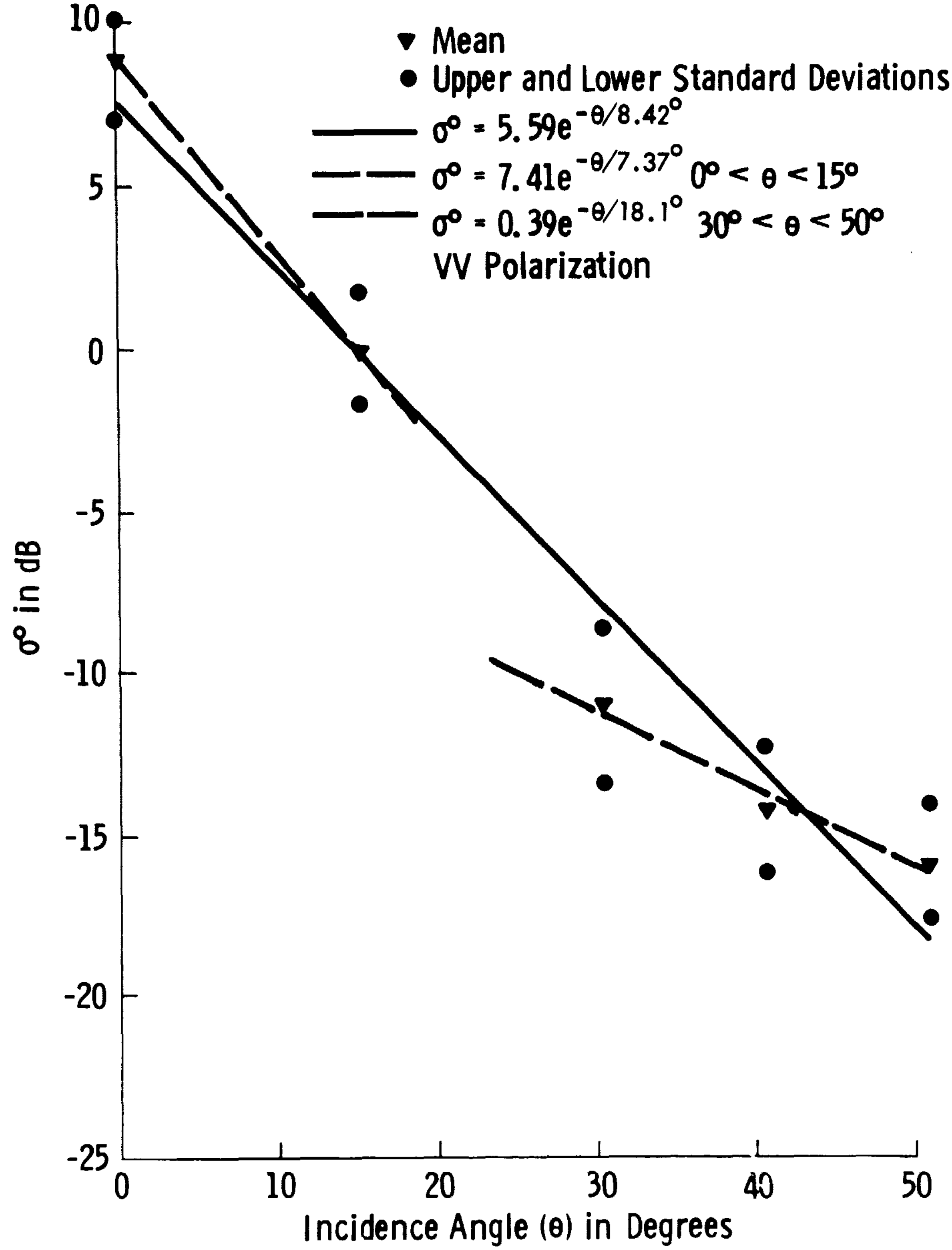

Figure 17. Composite Scattering Coefficient of Ocean from SL4 S-193 Scatterometer - Vertical Polarization.

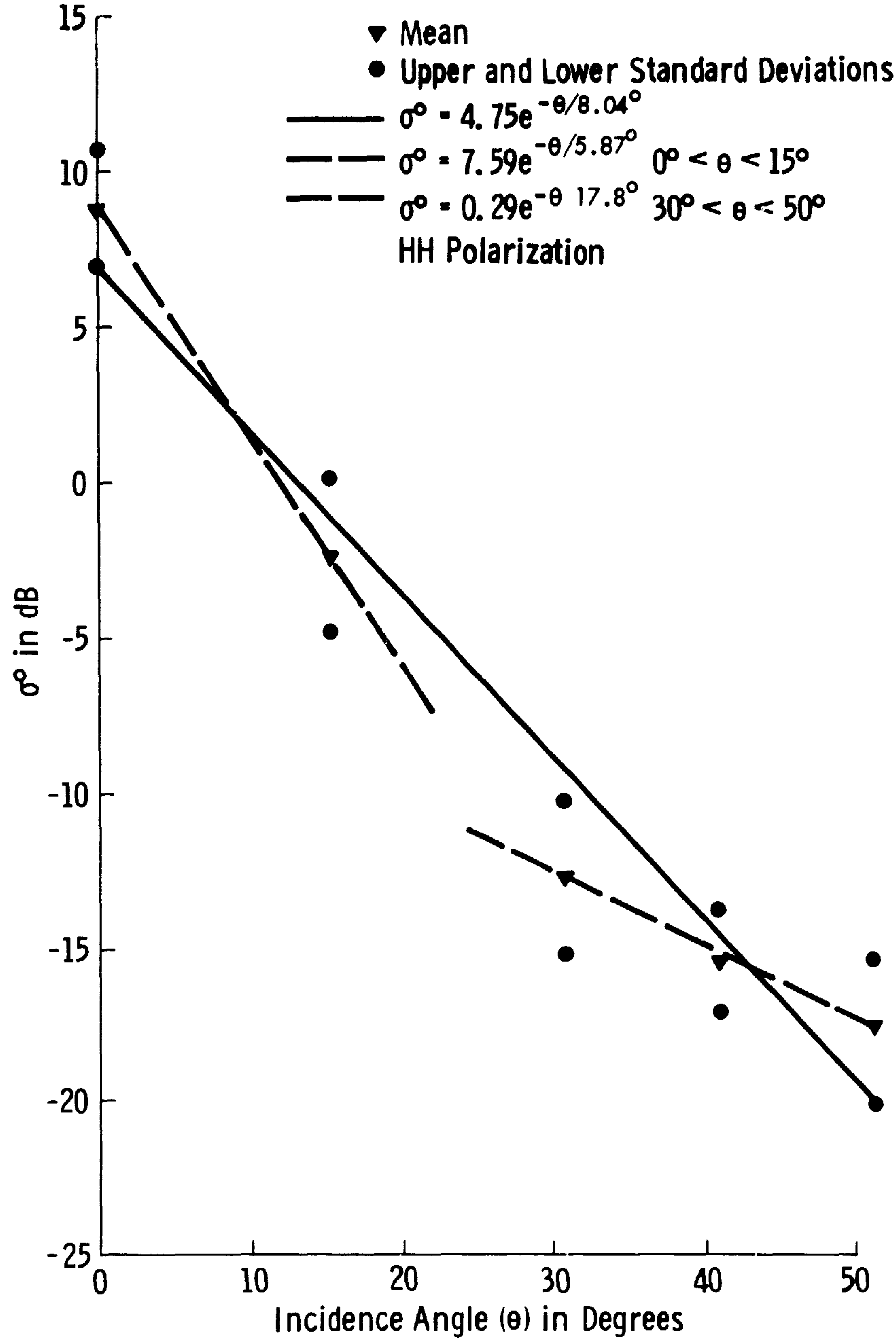

Figure 18. Composite Scattering Coefficient of Ocean from SL4 S-193 Scatterometer - Horizontal Polarization.

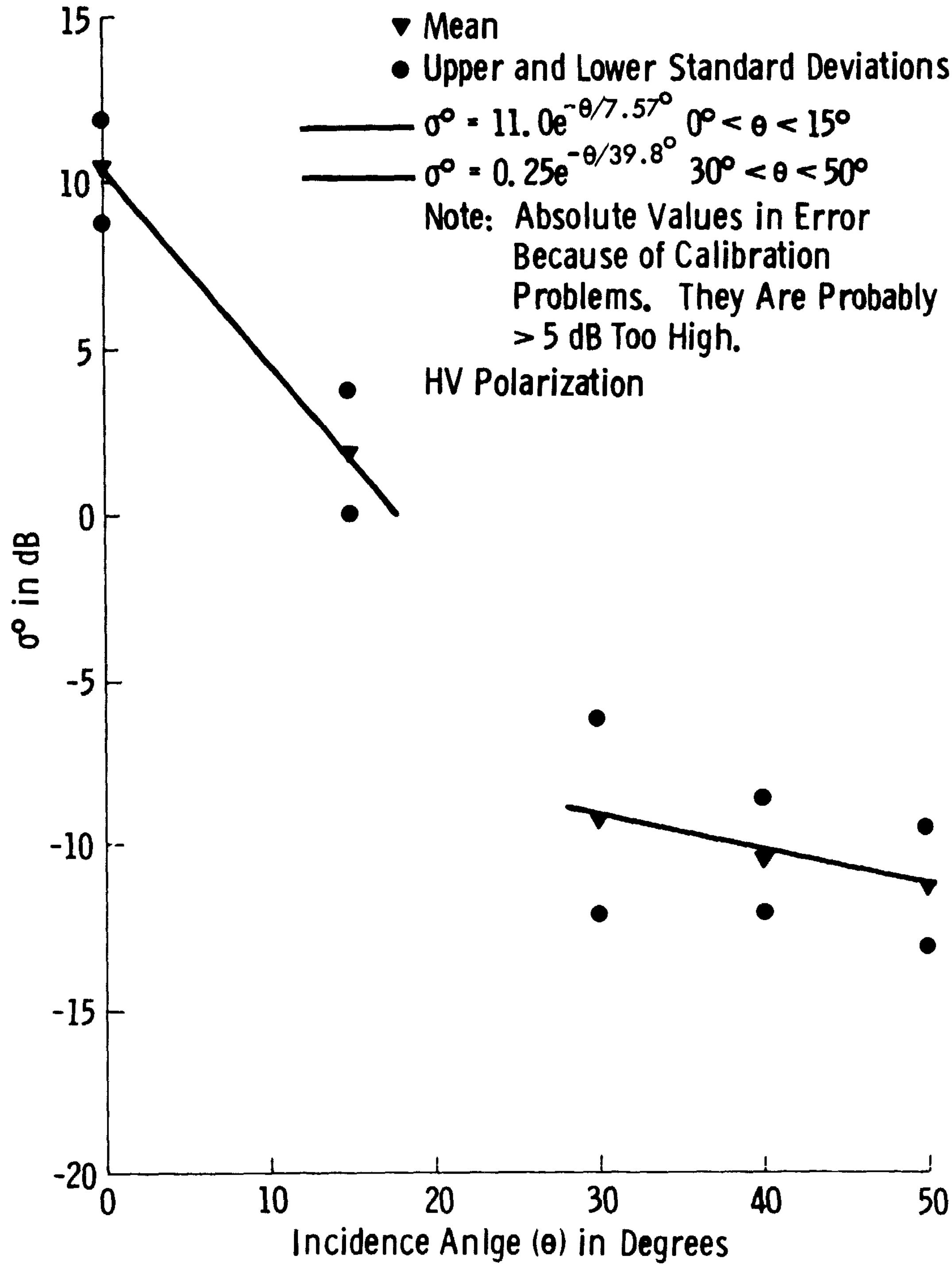

Figure 19. Composite Scattering Coefficient of Ocean from SL4 S-193 Scatterometer - VH Polarization.

As mentioned above, these ocean curves are not as steep as those for the calmer conditions that prevailed during SL2/SL3. The maxima are lower (at 0°) and the minima (at 50°) are higher, as can be seen by reference to these figures and figures 8.57 and 8.58 of Appendix A of the previous report.*

As with the SL2/SL3 observations, both land and sea data can be well described by exponentials in θ, with different coefficients used over land for the near-vertical and off-vertical angles. The results of these regression analyses are shown in Table 2, with comparable expressions from Table 8.1 of the previous report. The land data were so sparse with horizontal polarization during the summer missions that no regression fit was calculated for them, so none is shown in the table. The winter curves over land are a bit steeper, as indicated by the smaller e-folding angles: 4.67° instead of 5.60° near vertical and 19.0° instead of 29.6° off-vertical. Conceivably this is because the relatively flat returns from trees in leaf and active crop and range vegetation are missing from the winter data. As seen in Section 3, the effect of snow is probably not very important in establishing this steeper trend because so few of the passes were over snow-covered terrain with a deep snow blanket.

Over the ocean this trend is reversed; the SL4 scattering coefficients do not fall off as rapidly as the SL2/SL3 scattering coefficients. Furthermore, the 0° intercepts of the regression lines are lower. Since most of the SL4 data were over stormy seas, this is not surprising. For SL2/SL3, a single exponential fit the data over the entire range of angles, but for SL4, a dual exponential fit like that for land is more appropriate. Because of the great variability of ocean returns due to changes in wind and waves, the composite curves summarizing all of the ocean data are less useful than those for land where the variability is less. The coincidence of the 15° values for summer and winter indicates that the correction for absolute level is probably right, since these values are least affected by the sea conditions.

5.0 CONCLUSIONS

Analysis of the SL4 S-193 scatterometer observations shows that the winter measurements were reasonably consistent with the summer measurements. The

* Op.cit. (Moore, et al., 1975)

TABLE 2
REGRESSION ANALYSIS OF SL-4 COMPOSITE S-193 DATA COMPARED WITH SL2/3 DATA

Area	Polarization	Angular Range of Fit	SL4 Function of Theta	SL2/3 Function of Theta
Land	VV	$1^\circ - 13^\circ$	$1.51\ e^{-\theta^\circ/4.67^\circ}$	$1.67\ e^{-\theta/5.60^\circ}$
Land	HH	$1^\circ - 13^\circ$	$2.38\ e^{-\theta/6.49^\circ}$	Not calculated
Land	VV + HH	$1^\circ - 13^\circ$	$1.84\ e^{-\theta/5.28^\circ}$	Not calculated
Land	VV	$15^\circ - 39^\circ$	$0.38\ e^{-\theta/19.04^\circ}$	$0.36\ e^{-\theta/29.6^\circ}$
Land	HH	$15^\circ - 39^\circ$	$0.83\ e^{-\theta/10.94^\circ}$	Not calculated
Ocean	VV	$0^\circ - 50^\circ$	$5.59\ e^{-\theta/8.42^\circ}$	$15.6\ e^{-\theta/6.13^\circ}$
Ocean	HH	$0^\circ - 50^\circ$	$4.75\ e^{-\theta/8.04^\circ}$	$21.9\ e^{-\theta/5.35^\circ}$
Ocean	VV	$0^\circ - 50^\circ$	$7.41\ e^{-\theta/7.37^\circ}$	$15.6\ e^{-\theta/6.13^\circ}$
Ocean	VV	$30^\circ - 50^\circ$	$0.39\ e^{-\theta/18.1^\circ}$	$15.6\ e^{-\theta/6.13^\circ}$
Ocean	HH	$0^\circ - 15^\circ$	$4.75\ e^{-\theta/8.04^\circ}$	$21.9\ e^{-\theta/5.35^\circ}$
Ocean	HH	$30^\circ - 50^\circ$	$0.29\ e^{-\theta/17.8^\circ}$	$21.9\ e^{-\theta/5.35^\circ}$
Ocean	VH	$0^\circ - 15^\circ$	$11.0 *\ e^{-\theta/7.57^\circ}$	$0.32\ e^{-\theta/5.35^\circ}$
Ocean	VH	$30^\circ - 50^\circ$	$0.25 *\ e^{-\theta/39.8^\circ}$	$0.32\ e^{-\theta/5.35^\circ}$

* Absolute values of VH σ° for SL4 are uncorrected and therefore too large.

signals over land fall off more rapidly in winter than in summer, probably because of the lack of vegetation return in winter; but the winter and summer results over land do not differ enough to cause changes in the general conclusions for the design of radars to be constructed for future space use.

No consistent difference was found between snow-covered and snow-free terrain radar returns. However, the depth and water content of the snow were not correlated with the returns in this study, and no doubt this is essential for determining any significance for snow return. Probably most of the snow-covered areas in the SL-4 passes were covered only to small depths, for the S-193 was not, unfortunately, operated duringSL-4 over the northern part of the United States or over Canada. Future missions should use radars in these areas during the winter, but even more crucial would be ground-based measurements of snow return so that space missions and their equipment may be designed to obtain maximum information from the signals affected by snow cover.

The oceanic returns in the winter were significantly different from those in summer, with a much less rapid fall-off with angle and a lower return at vertical. This is a true seasonal bias, for the winter seas tend to be much stormier than those in summer. The only high-wind-speed data obtained in summer were from hurricanes or tropical storms, but the winter North Atlantic observations were almost always made in stormy conditions, as climatology indicates they should be.