8.0-10073
CR-162644

CONTINUATION OF MEASUREMENT OF HYDROLOGIC SOIL-COVER COMPLEX WITH AIRBORNE SCATTEROMETERS

By

Bruce J. Blanchard
John L. Nieber
Andrew J. Blanchard

Remote Sensing Center
Texas A&M University
College Station, Texas 77843

Final Report

Prepared for
Goddard Space Flight Center
Greenbelt, Maryland 20771
Contract No. NSG-5156

TEXAS A&M UNIVERSITY
REMOTE SENSING CENTER
COLLEGE STATION, TEXAS

Final Report 3496

CONTINUATION OF MEASUREMENT OF HYDROLOGIC SOIL-COVER COMPLEX WITH AIRBORNE SCATTEROMETERS

By

Bruce J. Blanchard
John L. Nieber
Andrew J. Blanchard

Remote Sensing Center
Texas A&M University
College Station, Texas 77843

Final Report

Prepared for

Goddard Space Flight Center
Greenbelt, Maryland 20771

Contract No. NSG-5156

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

1.0 INTRODUCTION

The application of remote sensing techniques to hydrologic analysis is becoming more important today due to the increasing demand for data related to water resources problems. Several areas of hydrologic analysis which are being tackled with remote sensing techniques are:

1) soil moisture monitoring,
2) land-use assessment,
3) snowpack assessment,
4) flood-plain delineation,
5) detection of pollution sources,
6) sediment transport,
7) reservoir storage,
8) delineation of runoff producing areas, and
9) assessment of runoff potential.

Traditional approaches to hydrologic analysis in these areas are generally based upon point measurements; the point measurements being used to deduce generalities about the specific water problem. The limitation of the traditional approach is that point measurements may not be sufficient to yield reliable conclusions. In addition, the collection of data for the point measurements is expensive. Remote sensing techniques do not depend upon point measurements but instead provide a broader perspective of a situation even though the techniques may miss some of the details that point measurements provide. The remote sensing approach also provides a more convenient system for continuous or periodic monitoring of a specific hydrologic phenomenon.

The research presented in this final report was concerned with the use of active microwave sensors for the measurement of the runoff generation potential. The runoff generation potential of a watershed can be gauged in terms of parameters such as soil characteristics, geomorphic characteristics, and vegetation and land-use characteristics. The Soil Conservation Service has developed an index which relates these characteristics to runoff generation potential. This index is called the curve number. The SCS approach is used extensively by government agencies, planning organizations, and by consulting engineers. The hypothesis set forth within the framework of this research project was that differences in the curve number can be detected using active microwave sensors mounted on an airborne platform.

2.0 PREVIOUS WORK

Remote detection of differences in curve number has been accomplished in studies by Blanchard et al. (1975), Blanchard and Bausch (1978), and Walker (1978). Blanchard and Bausch (1978) investigated the use of LANDSAT images to discriminate between areas having different curve number. They used linear combinations of means for different spectral bands and related these combinations to measured curve numbers on designated watersheds. The resulting graphical correlations were quite promising. The limitation of the approach was that it could only be used effectively when the soil was relatively dry and where little vegetative cover exists. Also, the approach cannot be used at night or when there is cloud cover.

The microwave band of the electromagnetic spectrum is sensitive to soil moisture, soil texture, vegetative cover, and roughness of the soil surface (Walker, 1978). These very factors are important in the determination of the runoff potential of an area. Therefore, the curve number should be related to the microwave emission (for passive systems) or microwave backscatter (for active systems) of an area. Both Blanchard et al. (1975) and Walker (1978) demonstrated this to be true for passive microwave systems.

Blanchard et al. (1975) applied passive microwave technology to the sensing of differences in the runoff curve number of eight watersheds. It was found that the horizontally polarized passive microwave emission from the watershed surface were quite sensitive to the measured runoff curve number when the vegetation was dormant. Under full vegetation on the same watersheds the sensitivity dropped off significantly. Therefore, although the passive microwave system was not limited to dry soil moisture conditions, nor to cloud-free days, it was limited to conditions of light vegetative cover. With microwave sensors using microwaves of larger wavelengths (up to 21 cm) it is possible that this vegetative limitation will be removed. The potential of these longer wavelengths is illustrated by Newton et al (1974).

Blanchard (1977) analyzed the relationship between microwave emission and curve number for 27 watersheds located in Texas and Oklahoma. A method for computing runoff curve number as suggested by Hawkins (1973) was used in this study rather than using the conventional approach. The method suggested by Hawkins had an advantage over the conventional approach since it provides a normalizing effect on the curve number estimate between watersheds having adequate and inadequate measured storm events. Blanchard concluded that to calibrate a microwave system to measure runoff curve number it is necessary to have several major measured runoff events to assist in computing runoff curve numbers.

Walker (1978) analyzed the sensitivity of measured microwave emissions to measured curve number. He used two instrumented watersheds located in Texas and attempted to determine the optimum time of year at which flights should be made for determining runoff curve number. Walker was not able to identify the optimal time based upon the data used.

The obvious extension of the work reported in these several studies is to apply active microwave technology to the discrimination of curve number differences on the earth's surface. Active microwave systems have an advantage over passive microwave systems in that the resolution of the ground scene can be controlled with active microwave systems. This advantage is especially valuable for satellite mounted systems.

The purpose of this project was to investigate the feasibility of using active microwave systems in the discrimination of areas with different runoff potential.

3.0 OBJECTIVE

The NASA-C130 aircraft carries a fan beam active microwave system with which it is possible to obtain backscatter for different look angles, frequencies and polarizations.

The objective of this research project was to investigate the capabilities of active microwave systems to discriminate between land areas having different runoff curve numbers. It was hypothesized that there should be a certain combination of look angles and frequencies which will provide the quantitative basis for making this discrimination. If land areas with different curve numbers could be discriminated, the research in this project was to identify the optimal combination of look-angles and frequencies to perform the discrimination.

The results of the research program indicated that it was not possible to discriminate between land areas of different curve number, at least for the data set used for the analysis. The major difficulty associated with this failure was the lack of detailed ground-truth information. In the previous studies reviewed earlier the curve number for the watershed areas sensed was measured from runoff records. This type of information was not available for this study.

Two accomplishments were made on the project. This first was that a scheme was developed for discriminating between land-use conditions. The discrimination was made among three different land-use categories: forested, cultivated and pastured. The second accomplishment of the project was that it was demonstrated that active microwave systems can delineate flooded areas located under dense timber. This capability should also extend to sensing flooded areas through dense cloud cover.

4.0 PROCEDURE

The frequency-polarization combinations acquired for this project by the NASA-C130 aircraft were 13.3 GHz Vertical-Vertical, 1.6 GHz Horizontal-Vertical and 1.6 GHz Horizontal-Horizontal. The look-angles for each of these frequency-polarization combinations were 5, 10, 15, 20, 25, 35, 40, 45 degrees from nadir.

Flight missions with the C130 were made on two dates and over five flight-lines on each date. The first flight was made on April 20, 1977, and the second flight was made on May 4, 1978. The purpose for making the flights on two different dates was to attempt to achieve ground conditions which were hydrologically different. The flight lines used for this study were all made within the State of Texas and are illustrated on a small scale maps in Figures 1a to 1e.

The scatterometer data collected from the missions were relayed to the Texas A&M Remote Sensing Center in digital form on tape disks. The data contained reference time and the power return (in decibels) for the different frequency-polarization and look-angle combinations. To assist in locating ground position for the scatterometer data an infra-red photograph strip was supplied for each flight-line. These photographs had the reference times marked on them.

For the study of the soil-vegetation complex, the scatterometer data were analyzed by two procedures. Both of these procedures were also used to ascertain the ability of active microwave systems to delineate flooded areas beneath dense timber cover. The first procedure was to

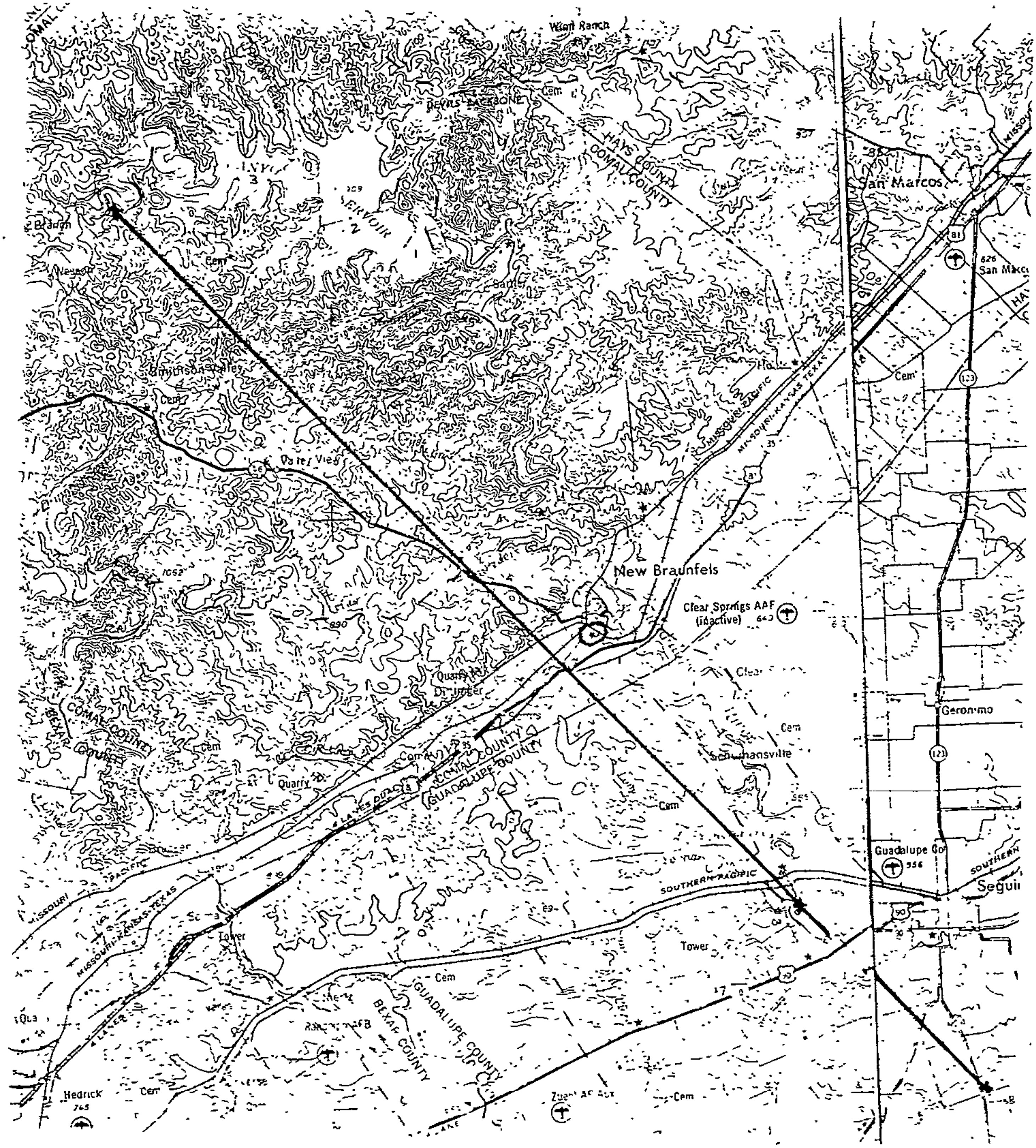

Figure 1a. Illustration of the Seguin-New Braunfels Flight Line.

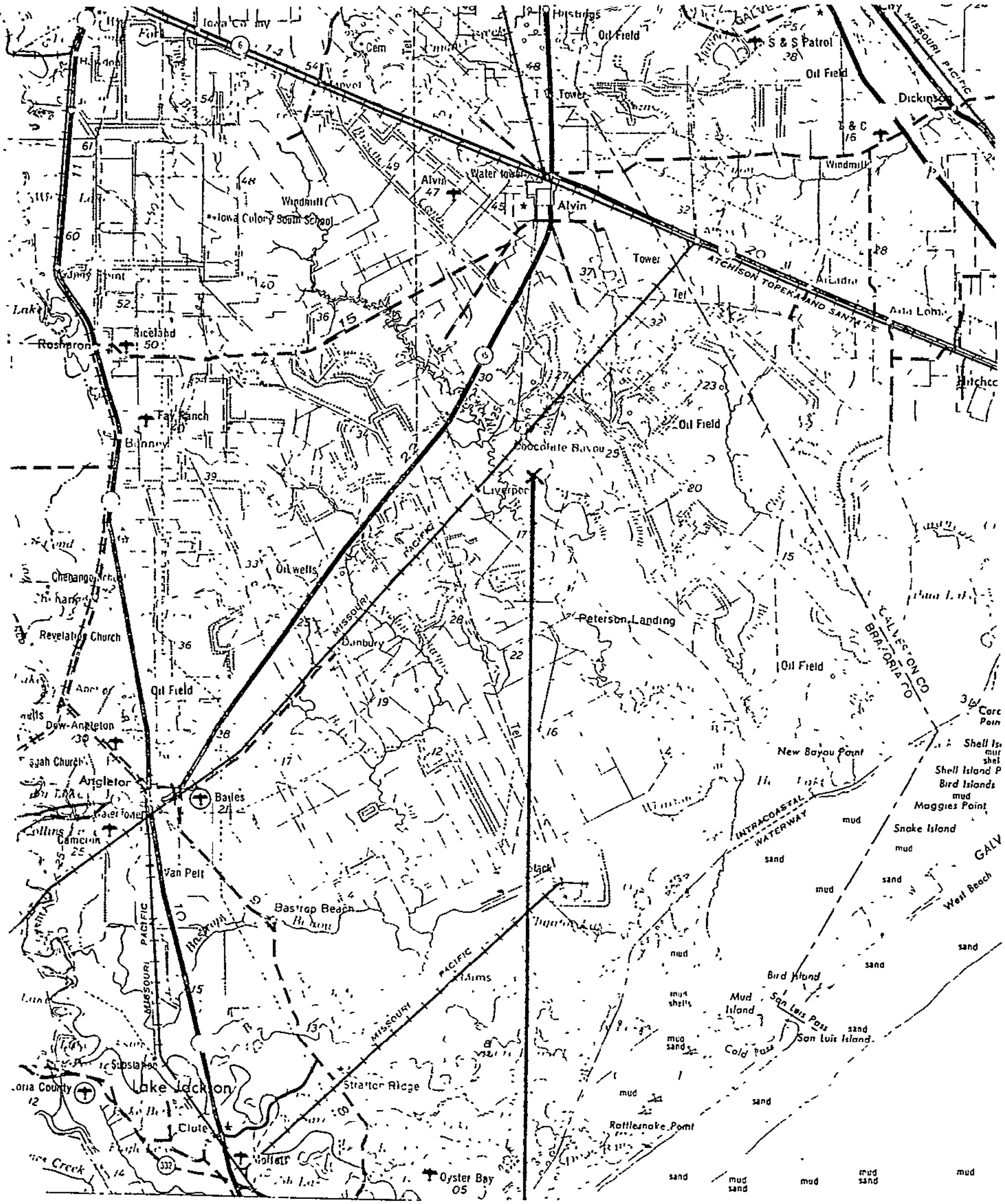

Figure 1b. Illustration of the Freeport Flight Line.

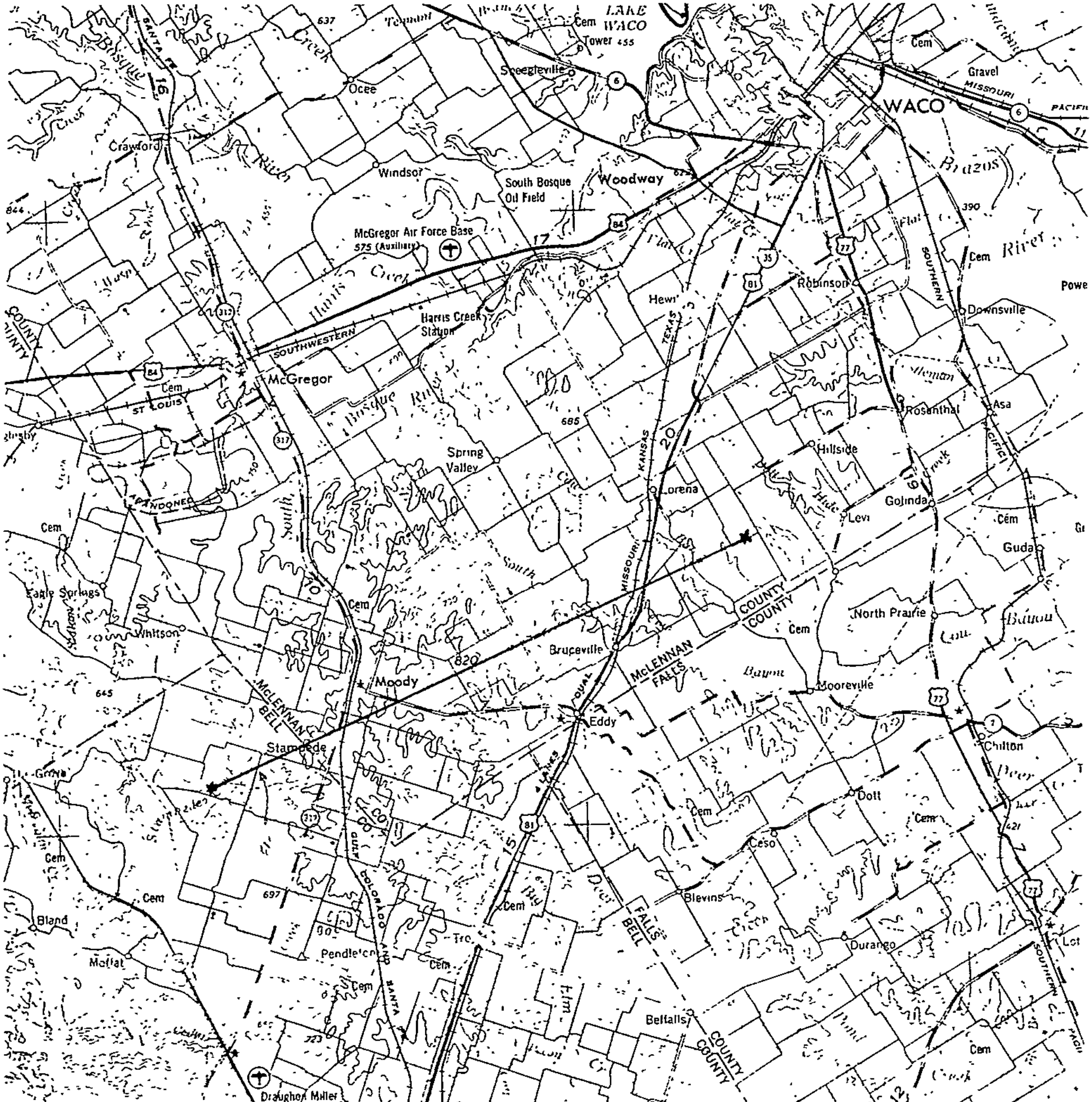

Figure 1c. Illustration of the Cow Bayou Flight Line

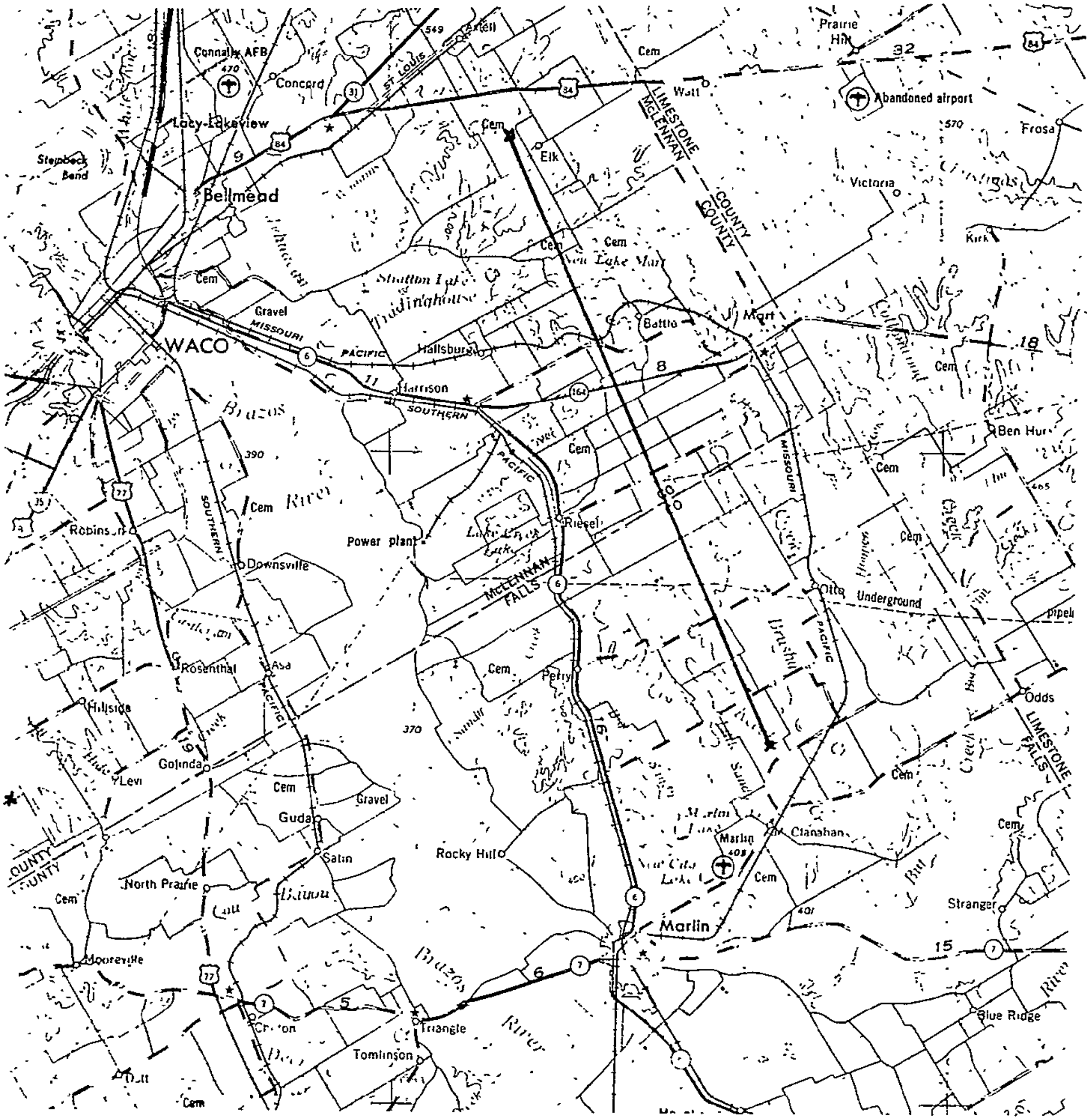

Figure 1d. Illustration of the Riesel Flight Line.

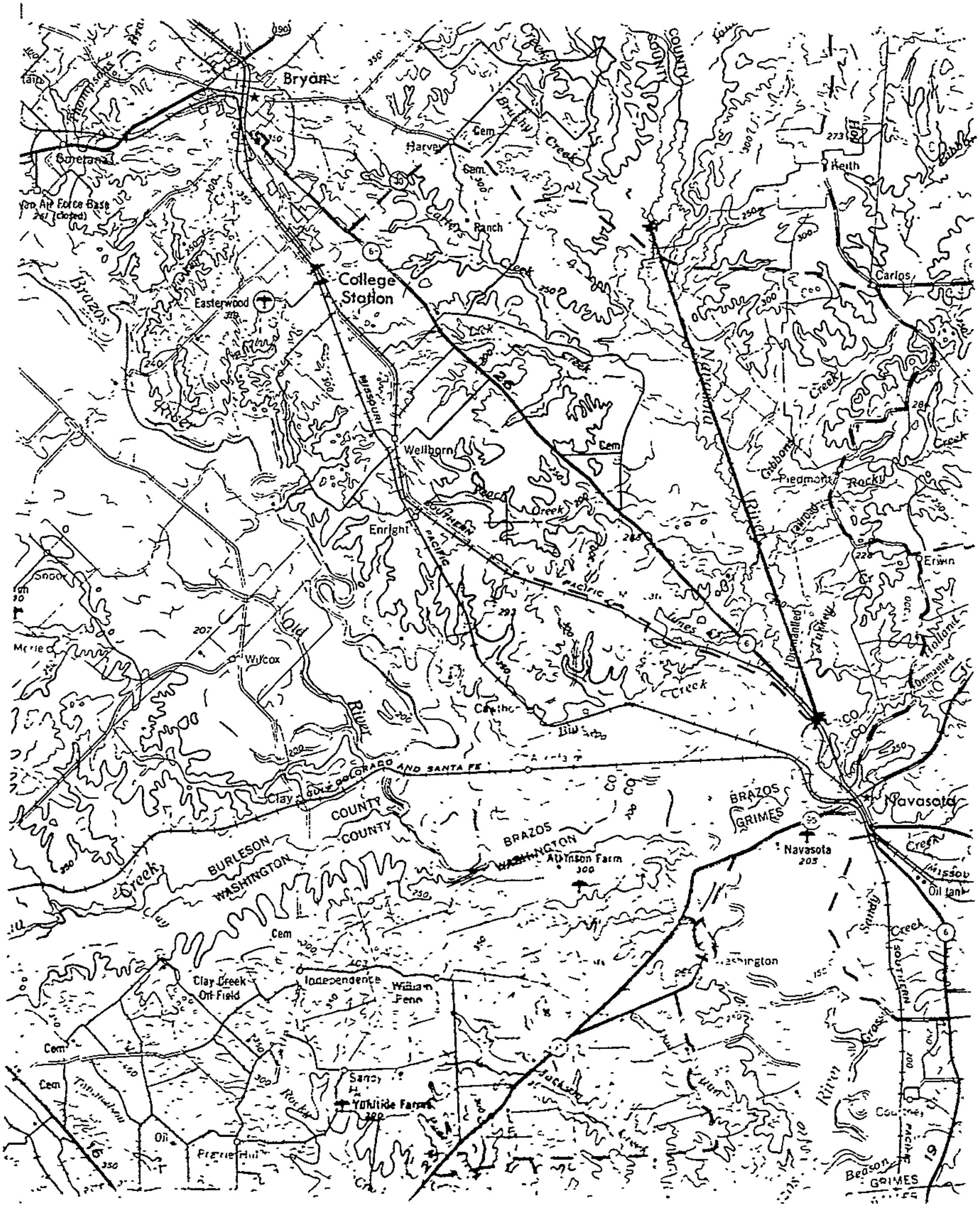

Figure 1e. Illustration of the Navasota River Flight Line.

chose specific areas from the infra-red photographs for analysis. Different categories of land surface areas were chosen. These categories included forested land, pastured land, and cultivated land. Numerous areas fitting into each of these categories were chosen for the analysis.

The size of each area chosen was large enough to obtain a good representation of the scatterometer over the area. Generally, at least a one second sample was used for each area. A one second sample represented approximately 40 meters on the ground surface.

The scatterometer return for each area chosen was averaged over each area for the different frequency-polarization and look-angle combinations. It was hoped that the averaging process would eliminate the effects of roughness variation surface over the test area. This averaging procedure does not eliminate the effects of large-scale topographic variations, In plotting the data the average scattering coefficient for a particular sample was rounded to the nearest integer value.

The second procedure used in the analysis was to filter the scatterometer return along each light line. Filtering was performed to eliminate small-scale target effects. These effects tended to mask the variations in scatterometer return which was due to changes in the vegetative-soil complex.

The filtering was accomplished by taking three second intervals of the scatterometer data and averaging the values in the interval. The computed average was then assigned to the time corresponding to the center of the three-second interval.

Three sets of data were then produced from the filtered scatterometer data. The first set was just that of the filtered data. The second set was produced by computing the difference between the filtered 1.6 GHz HH and 1.6 GHz HV data for the 20 degree look-angle. The third set was produced by computing the difference between the filtered data for the 10 degree and 35 degree look-angle for the 1.6 GHz HH frequency-polarization combination.

The three sets of data obtained in this way were then illustrated in line-plots and these plots were used to interpret changes in vegetative-soil complex. It was found that the filtering process smoothed the scatterometer data and made it possible to identify subtle differences in scatterometer return.

5.0 RESULTS

Eighty-seven ground locations were chosen to test the possibility of distinguishing between areas having different hydrologic characteristics using active microwaves. These eighty-seven areas were categorized according to the land-use conditions apparent from the photographic image provided along the flight line. The categories used were:

1) cultivated land (bare and vegetated), A;

2) pastured land, B;

3) forested land (0-40% cover, C; 41-80% cover, D; 81-100% cover, E),

4) wetlands, F.

The averaged scatterometer return for each area was plotted for each look angle and each frequency - polarization combination. The plots are shown in Figures 2-13. In each figure the category is plotted along the abscissa and the scattering coefficient class plotted on the ordinate.

As illustrated in each of the figures given, the average scatterometer return in each category has a broad range. The reason for this scatter of return values for a given category is not known but it may be due to factors such as soil moisture and topography.

To attempt to visualize trends in scatterometer return from one category to another the values for each category were averaged and the calculated averages was plotted on Figures 2 to 13. Using these average values it is possible to see some distinction between areas of different land use. This distinction is seen by proceeding through a look-angle series for a given frequency polarization angle. The 1.6 GHz HH frequency

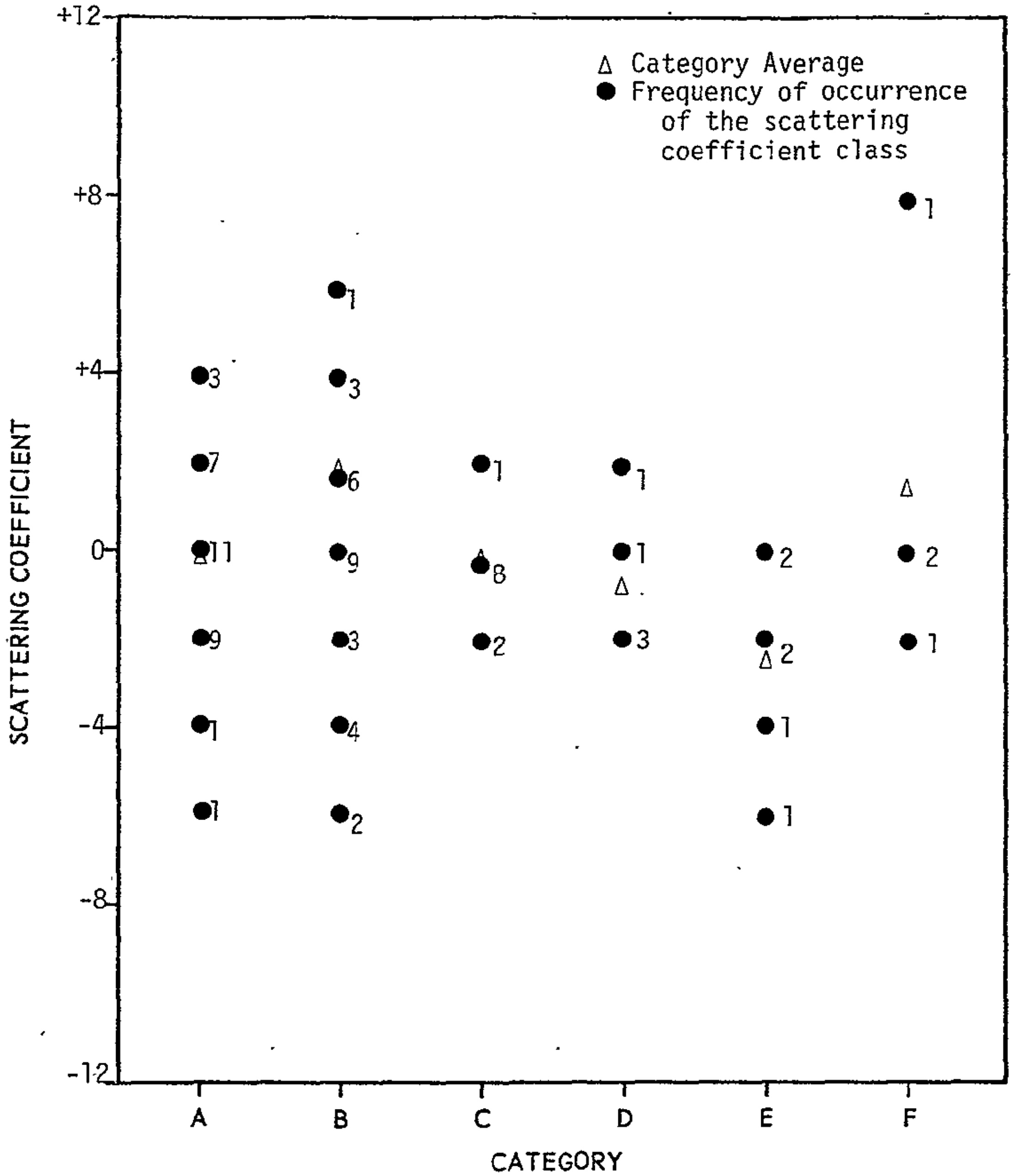

Figure 2. Scattering Coefficient Versus Land Cover Category for 10 Degree Look Angle and 13.3 GHz VV.

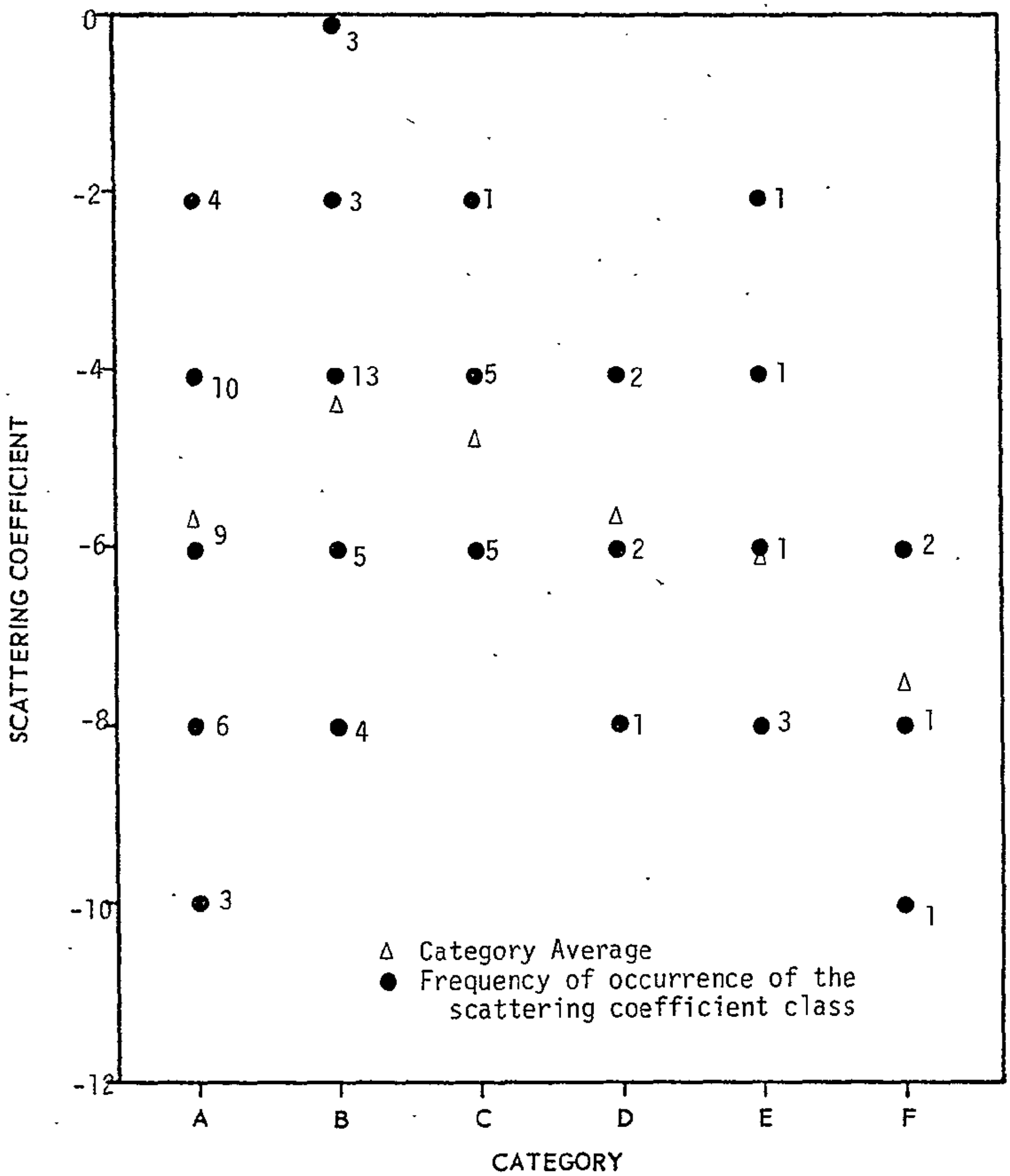

Figure 3. Scattering Coefficient Versus Land Cover Category for 20 Degree Look Angle and 13.3 GHz VV.

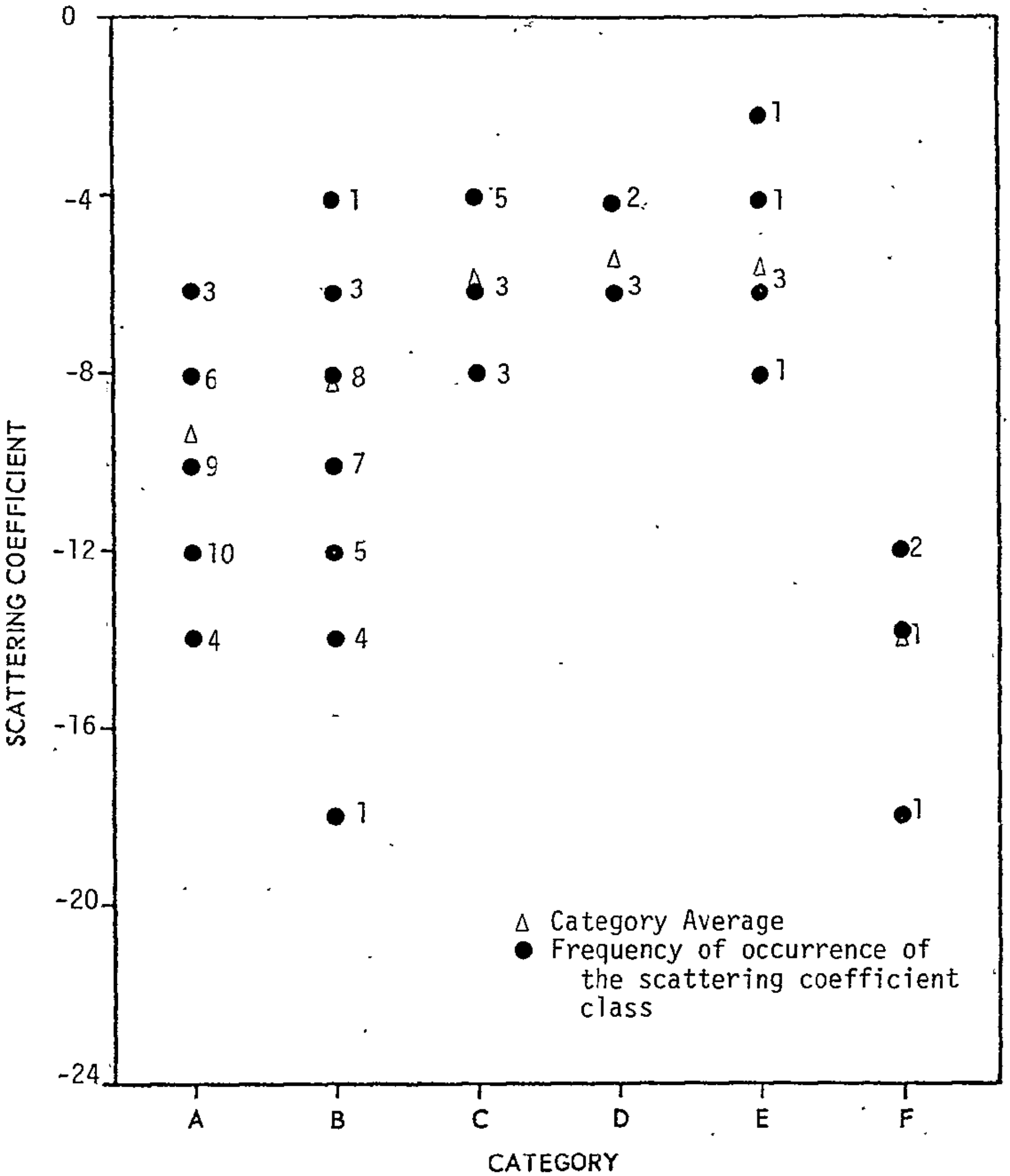

Figure 4. Scattering Coefficient Class Versus Land Cover Category for 35 Degree Look Angle and 13.3 GHz VV.

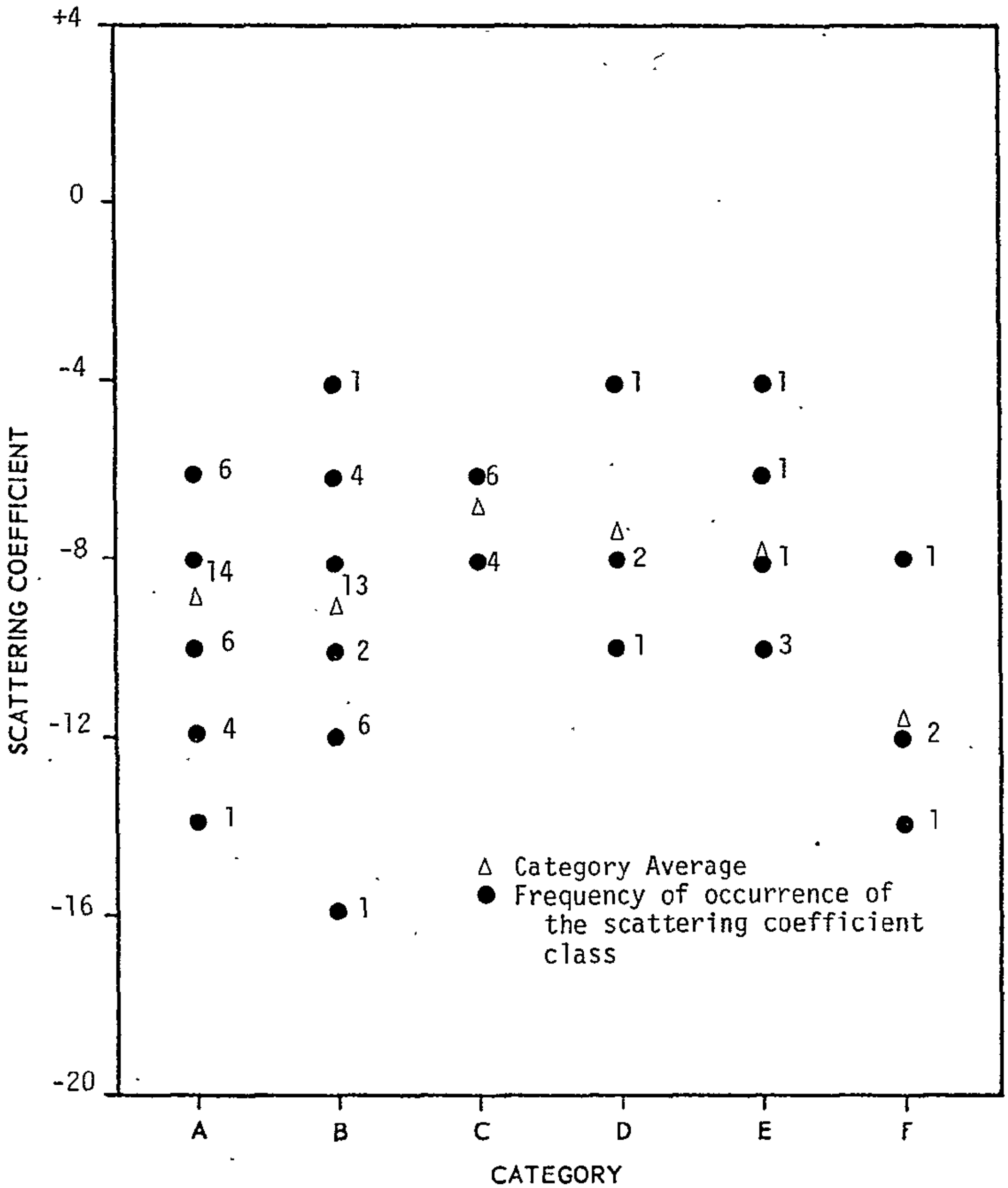

Figure 5. Scattering Coefficient Versus Land Cover Category for 45 Degree Look Angle and 13.3 GHz VV.

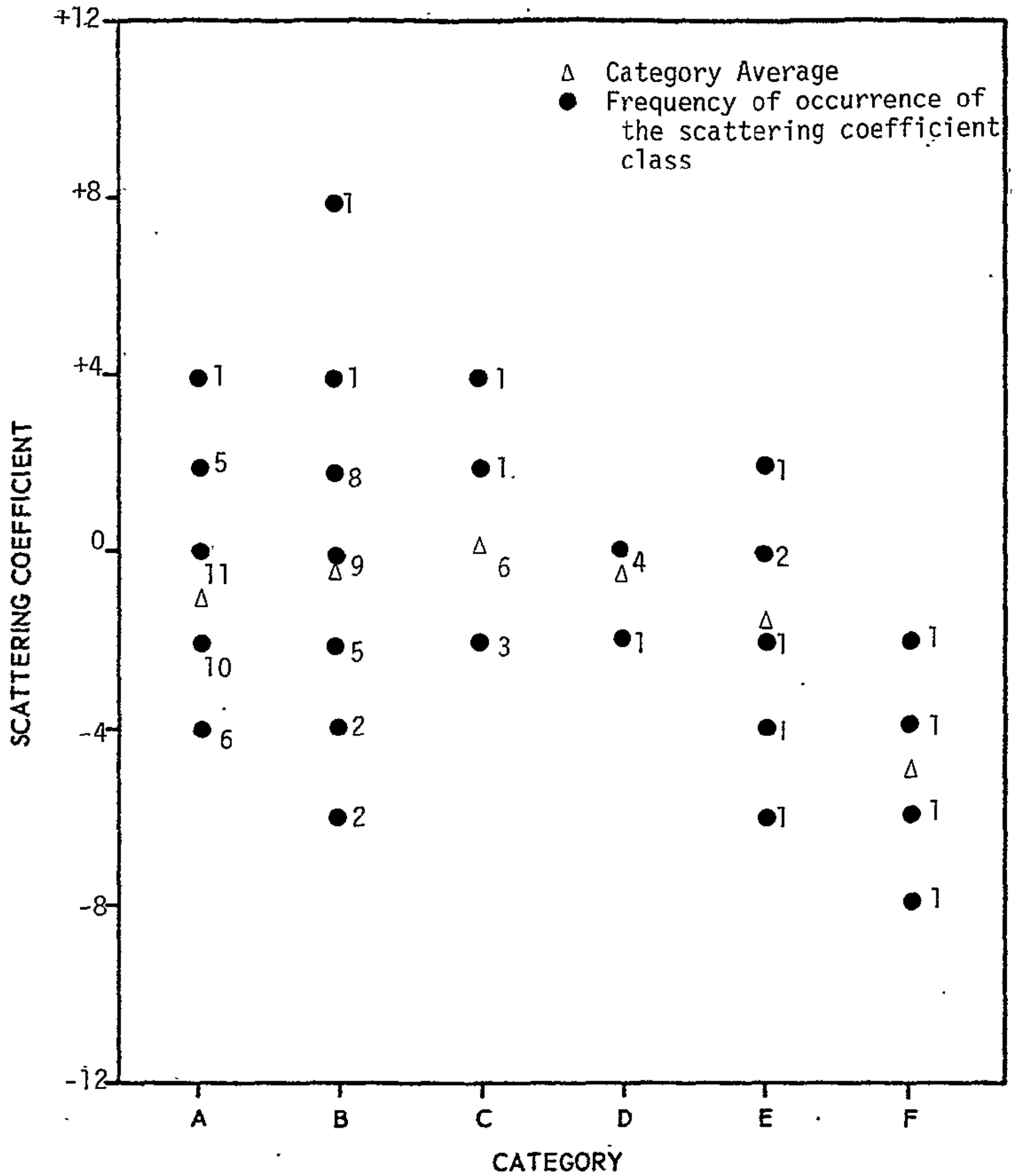

Figure 6. Scattering Coefficient Versus Land Cover Category for 10 Degree Look Angle and 1.6 GHz HH.

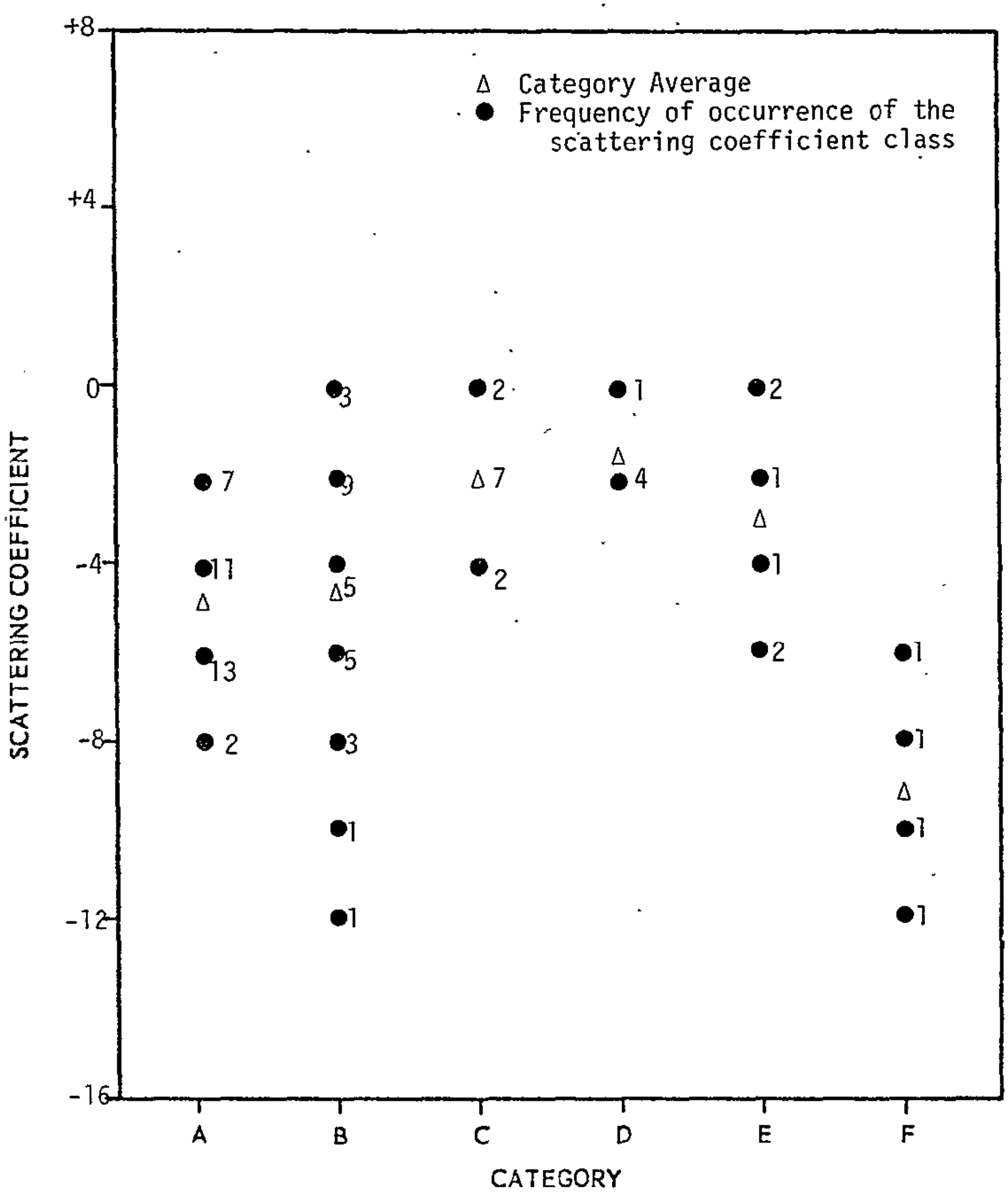

Figure 7. Scattering Coefficient Versus Land Cover Category for 20 Degree Look Angle and 1.6 GHz HH.

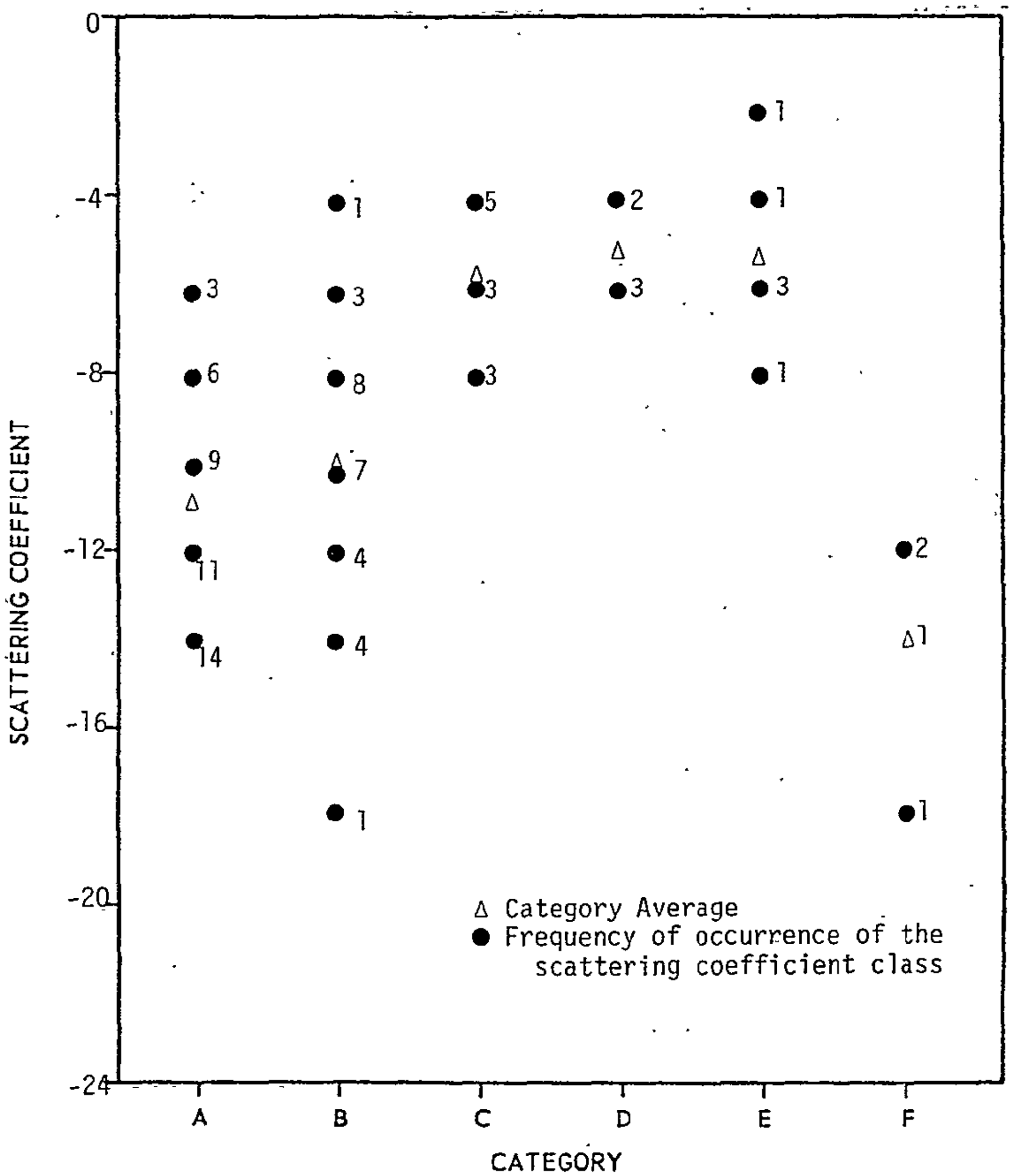

Figure 8. Scattering Coefficient Versus Land Cover Category for 35 Degree Look Angle and 1.6 GHz HH.

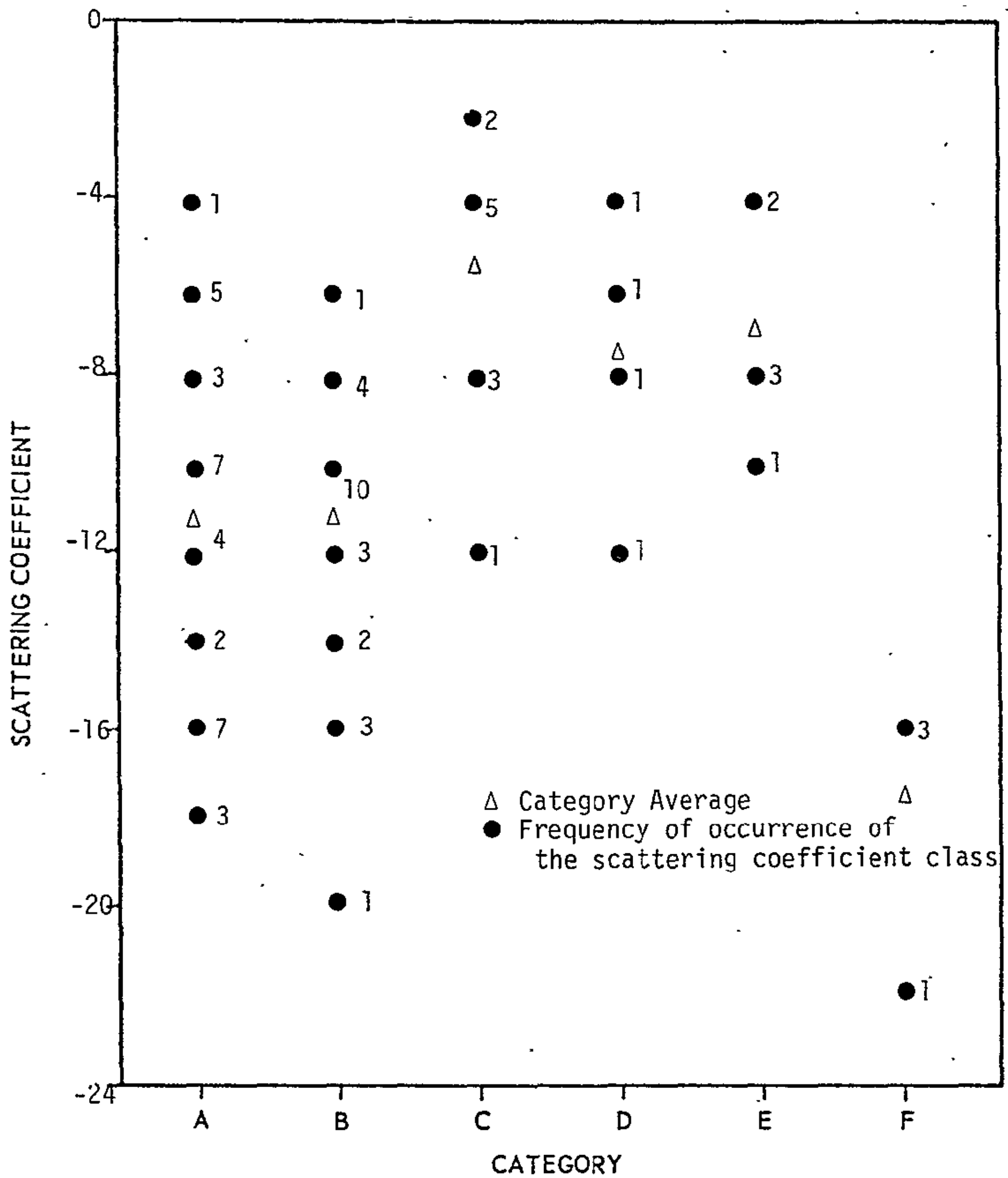

Figure 9. Scattering Coefficient Versus Land Cover Category for 45 Degree Look Angle and 1.6 GHz HH.

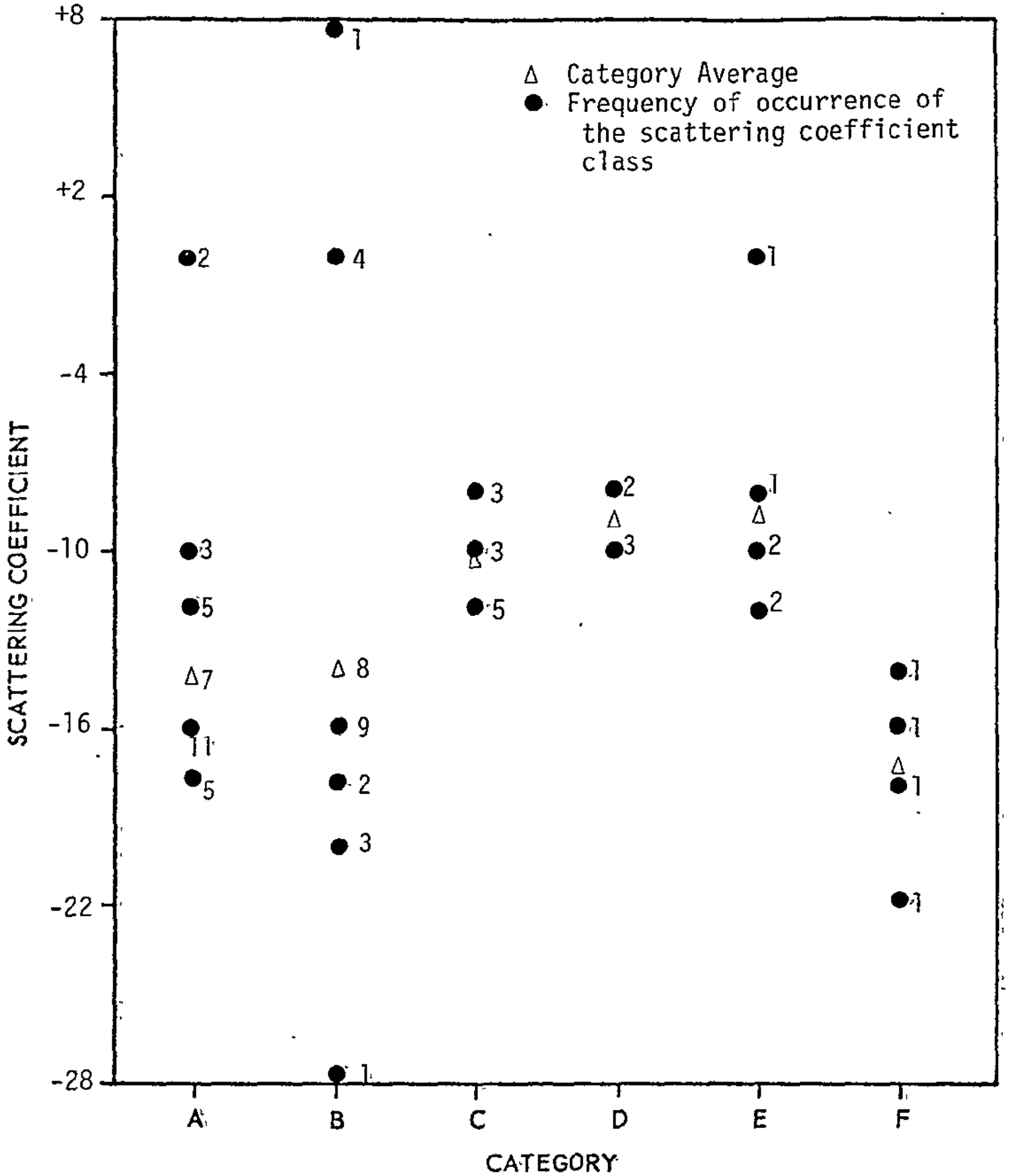

Figure 10. Scattering Coefficient Versus Land Cover Category for 10 Degree Look Angle and 1.6 GHz HV.

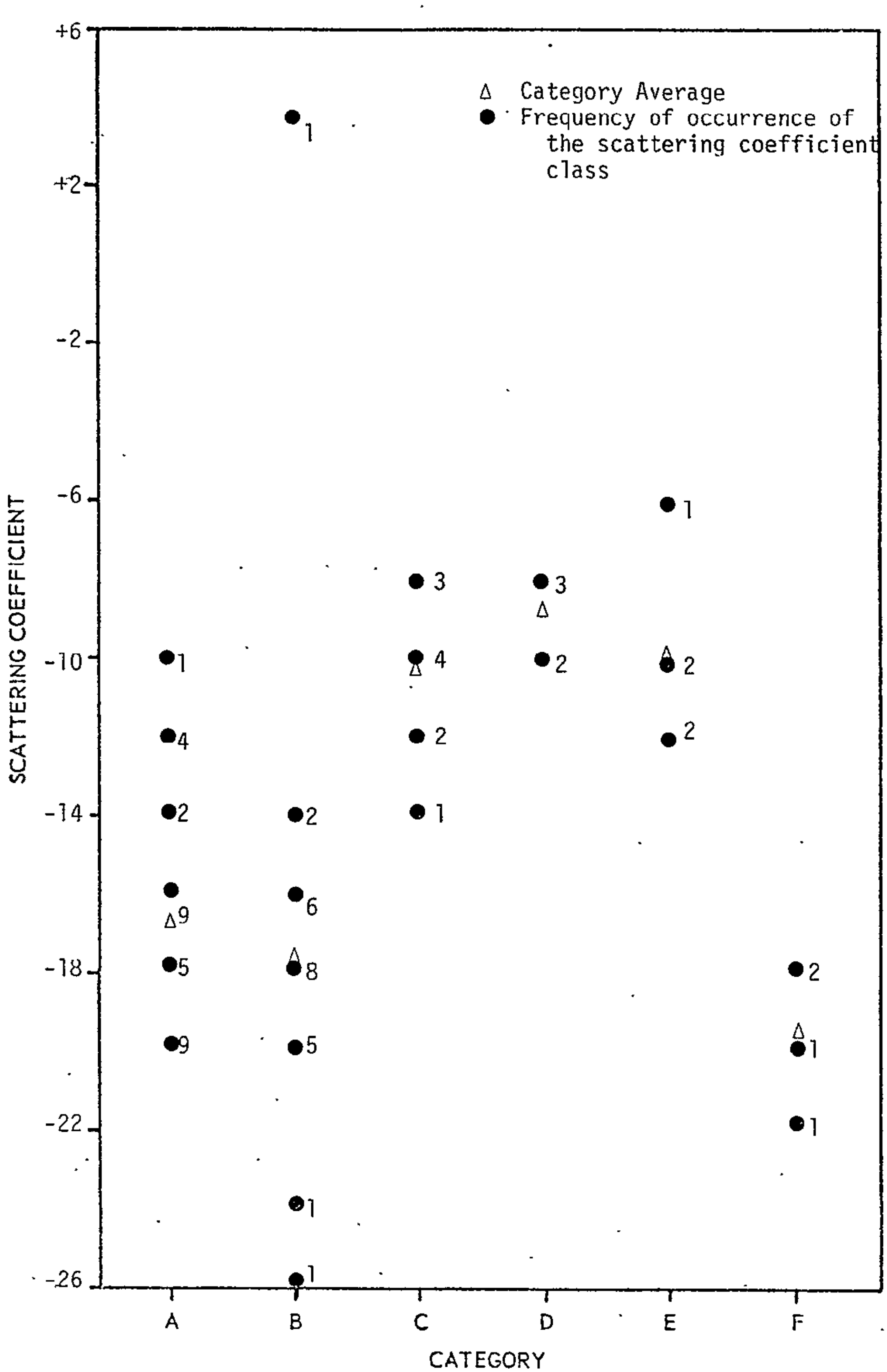

Figure 11. Scattering Coefficient Versus Land Cover Category for 20 Degree Look Angle and 1.6 GHz HV.

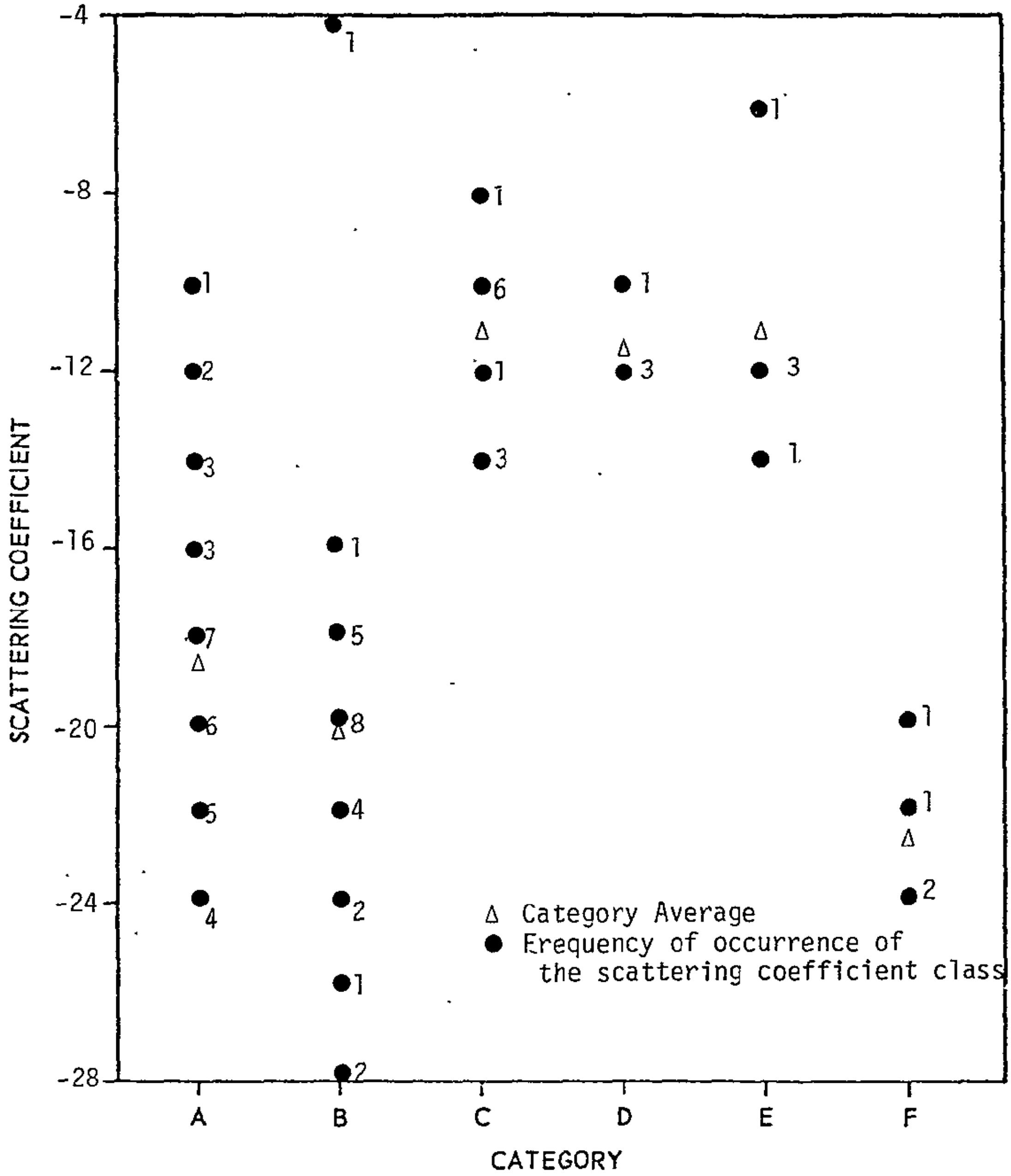

Figure 12. Scattering Coefficient Versus Land Cover Category for 35 Degree Look Angle and 1.6 GHz HV.

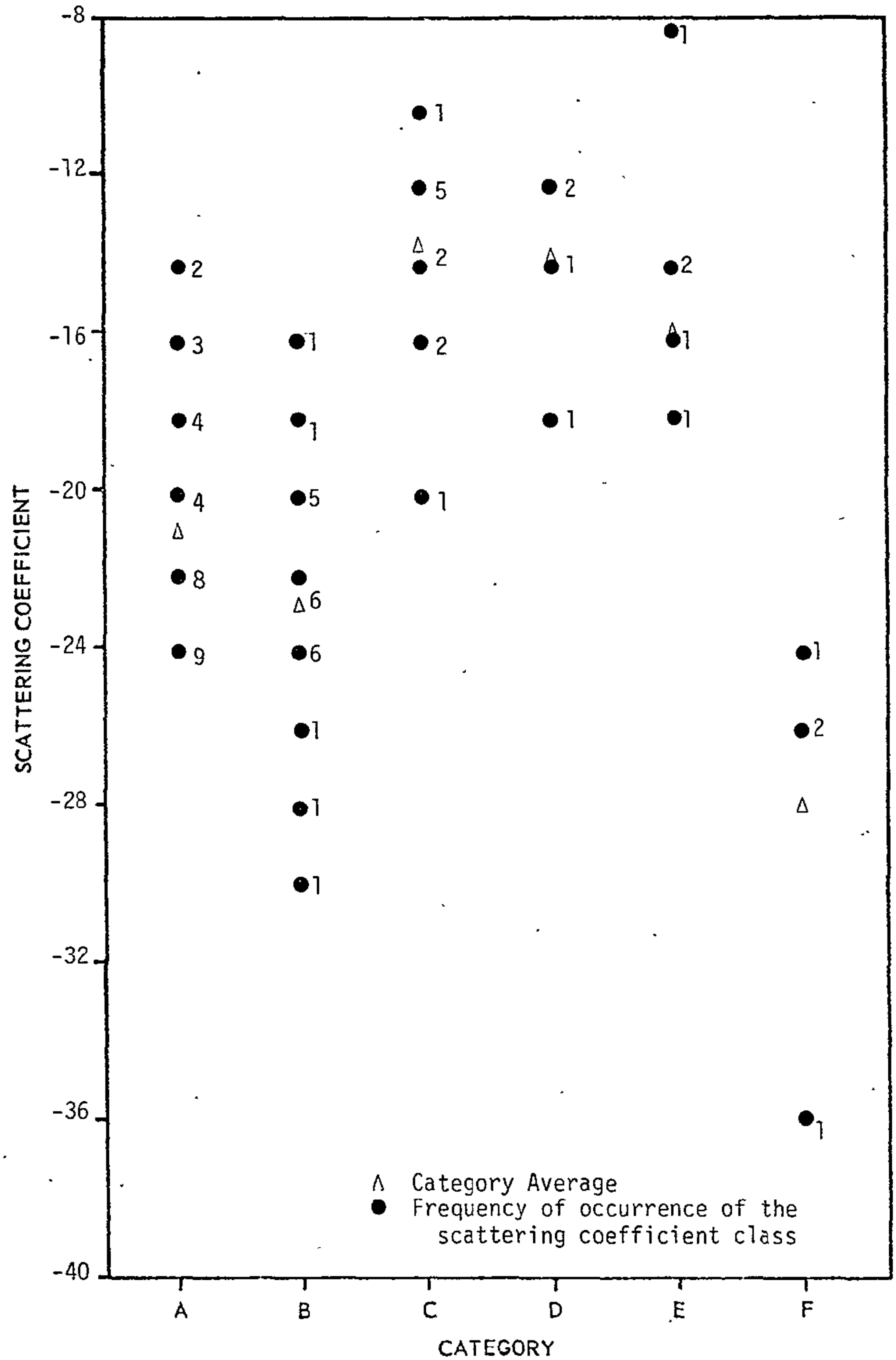

Figure 13. Scattering Coefficient Versus Land Cover Category for 45 Degree Look Angle and 1.6 GHz HV.

polarization continuation will be used to demonstrate this procedure and the results.

Beginning with the 10 degree look-angle the average response from all categories is essentially the same except for the wetland area, which has a noticeably lower response value. Proceeding to the 20 degree look-angle the response from the forested area is larger than from the cultivated, pastured and marsh area. There is essentially no distinction between cultivated and pastured areas, but the marsh area is significantly different from all other categories. The maximum distinction between the forested and non-forested areas is seen at the 35 degree look-angle. Again the cultivated and pastured areas are not distinct from each other and the marsh area is distinct from all other categories.

To test the ability of active microwave sensors to detect the presence of flood water beneath heavy timber, the active microwave response data over three reaches of the Navasota River were analyzed The data for the two overflight dates, 4/29/77 and 5/4/78, were used in the analysis since on the first flight the river was flooded whereas on the second flight date the river was low. An average microwave response was obtained for each reach, each flight date, each look-angle and each frequency-polarization combination. The results are plotted in Figures 14 to 19. Here the look-angle is plotted on the abscissa and the average scatterometer return is plotted on the ordinate.

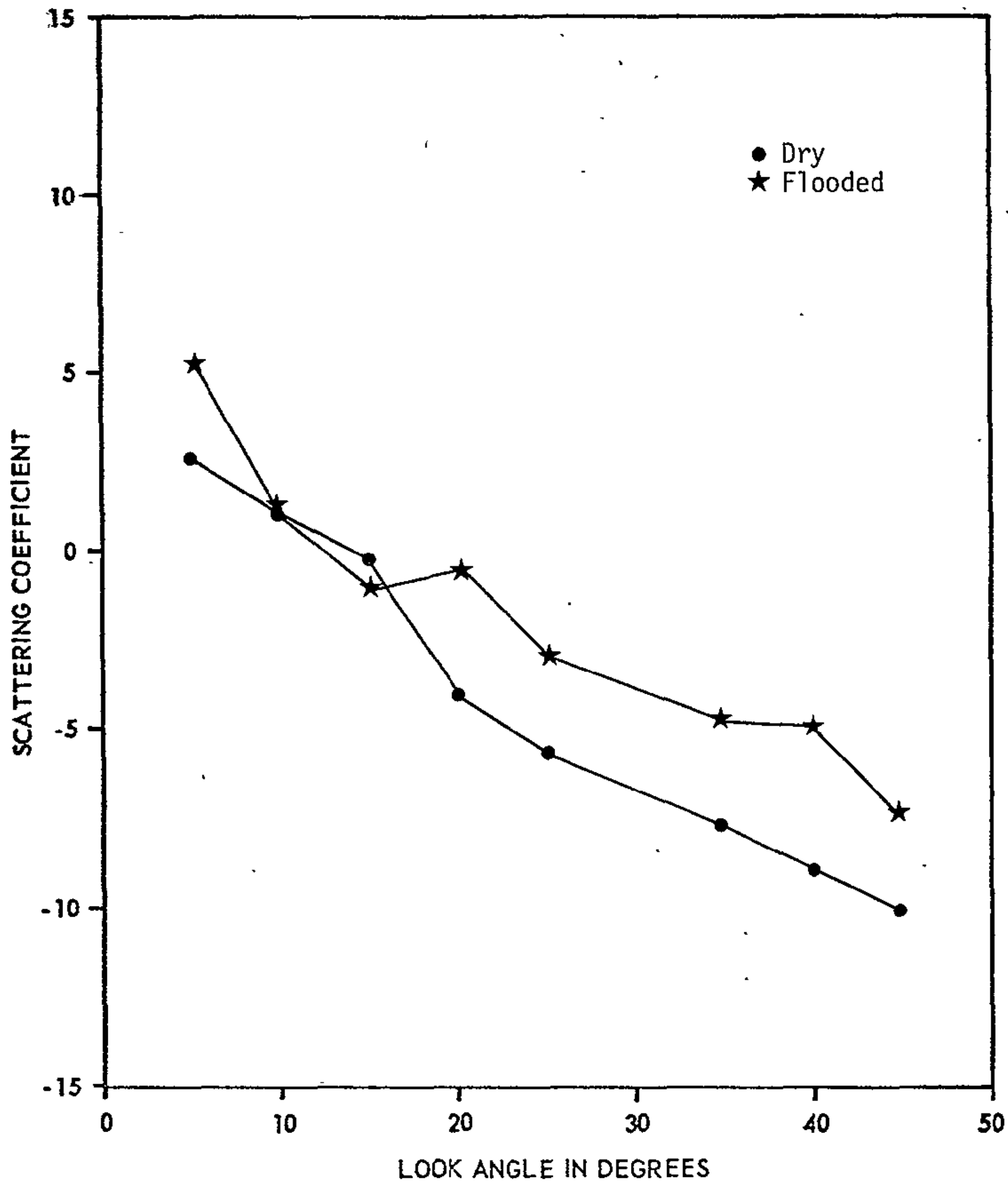

Figure 14. Scattering Coefficient Versus Look Angle for 1.6 GHz HH and Reach A of the Navasota River Under Flooded (4/29/77) and Dry (5/4/78) Conditions.

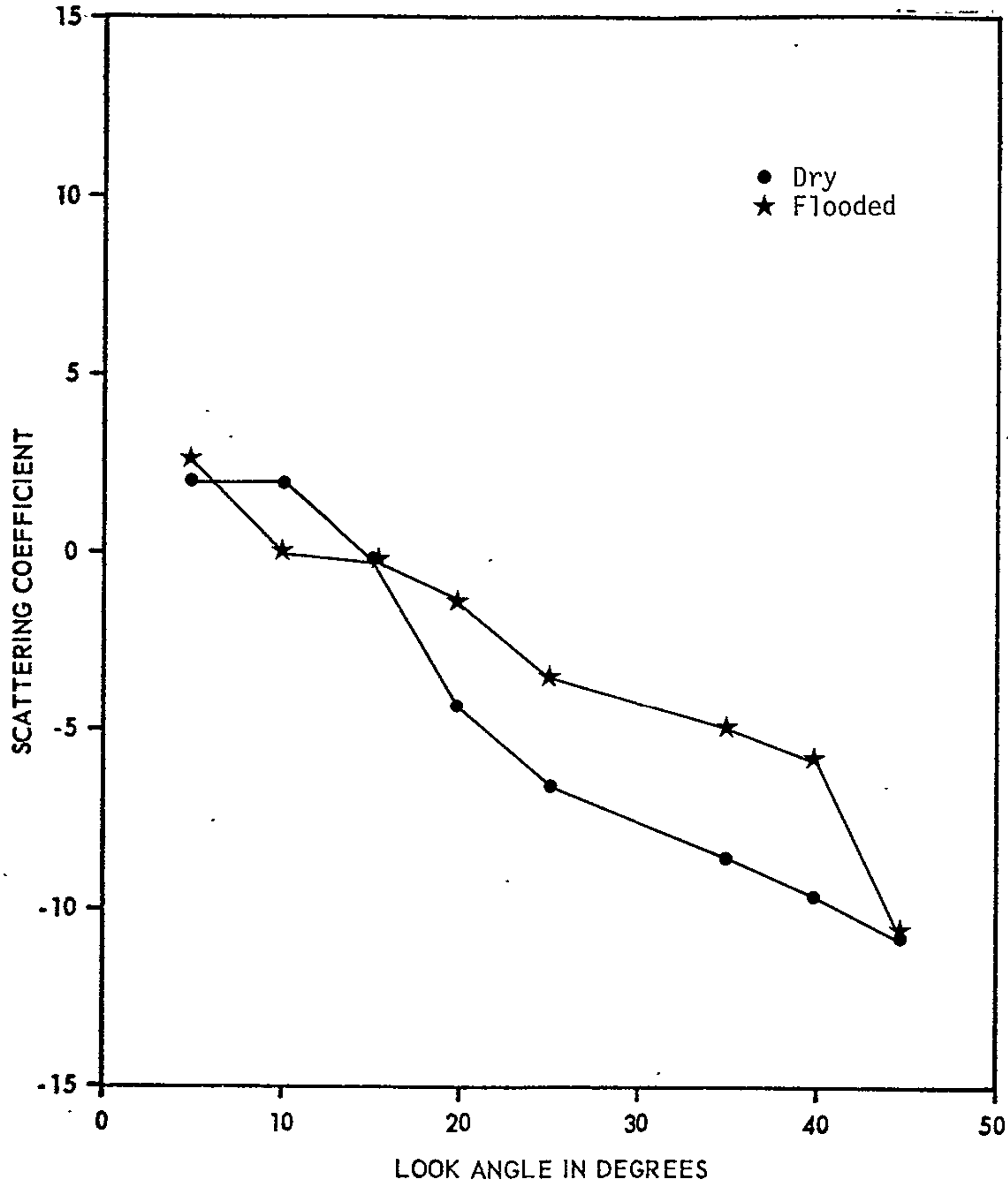

Figure 15. Scattering Coefficient Versus Look Angle for 1.6 GHz HH and Reach B of the Navasota River Under Flooded (4/29/77) and Dry (5/4/78) Conditions.

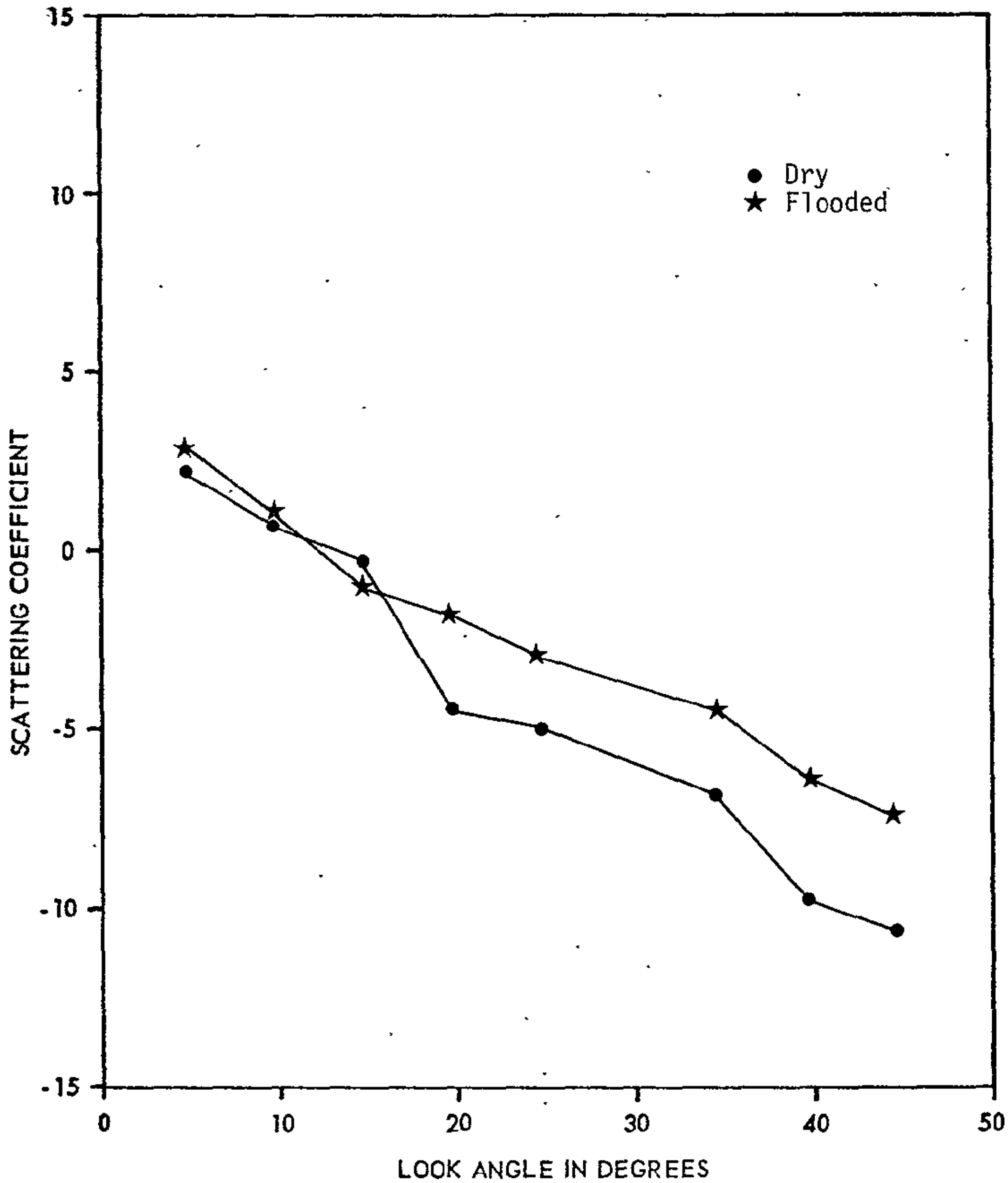

Figure 16. Scattering Coefficient Versus Look Angle for 1.6 GHz HH and Reach C of the Navasota River Under Flooded (4/29/77) and Dry (5/4/78) Conditions.

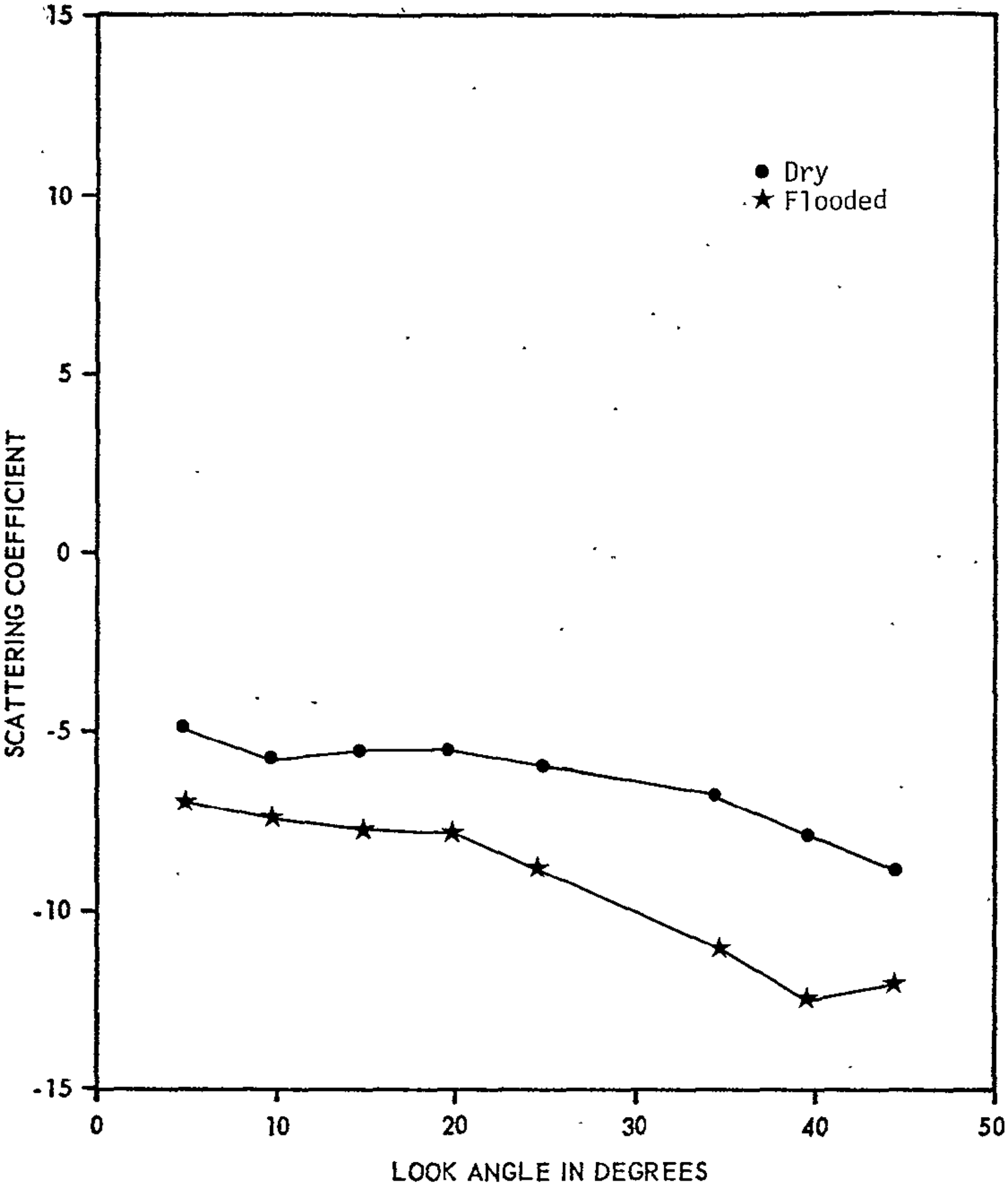

Figure 17. Scattering Coefficient Versus Look Angle for 1.6 GHz HV and Reach A of the Navasota River Under Flooded (4/29/77) and Dry (5/4/78) Conditions.

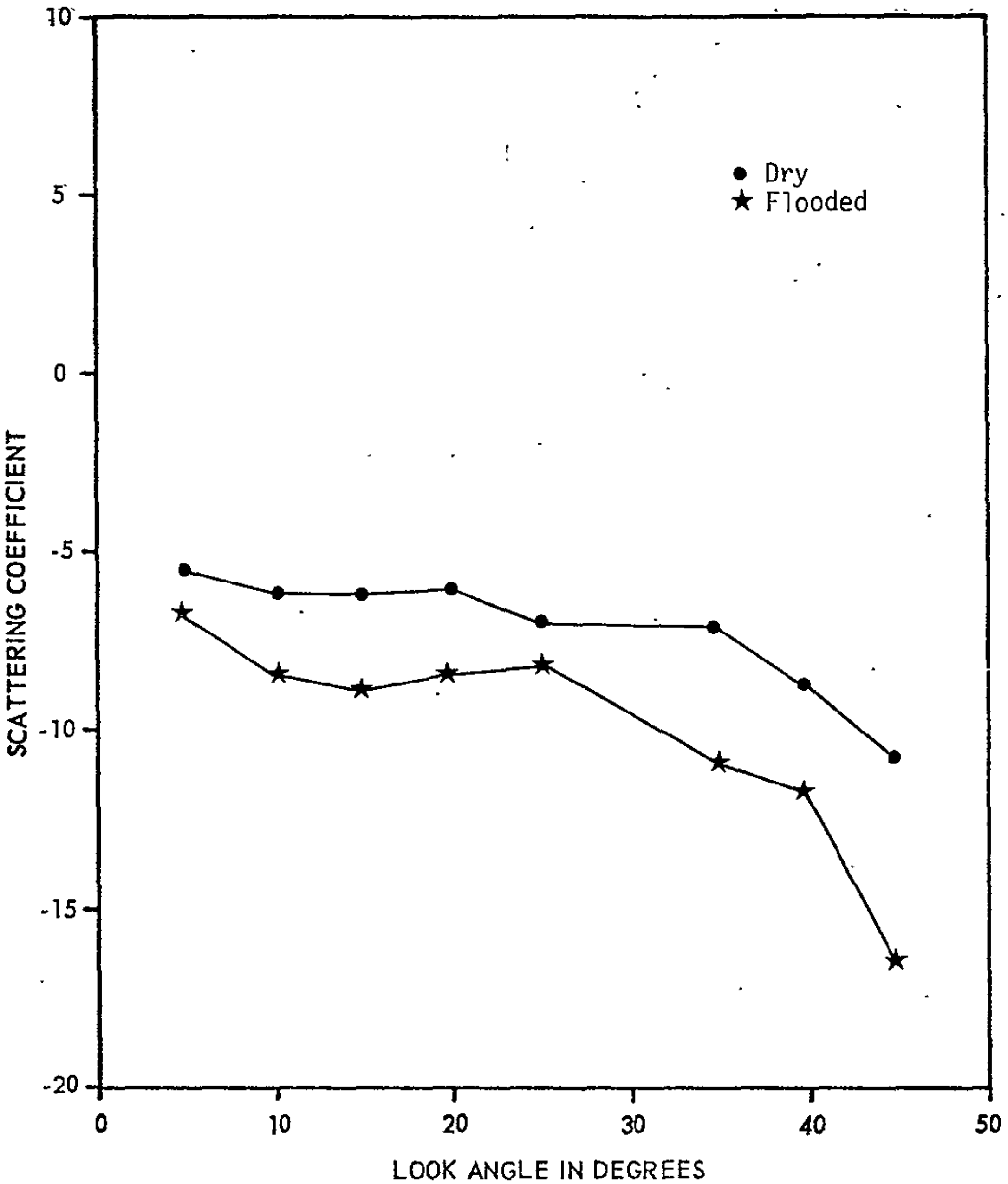

Figure 18. Scattering Coefficient Versus Look Angle for 1.6 GHz HV and Reach B of the Navasota River Under Flooded (4/29/77) and Dry (5/4/78) Conditions.

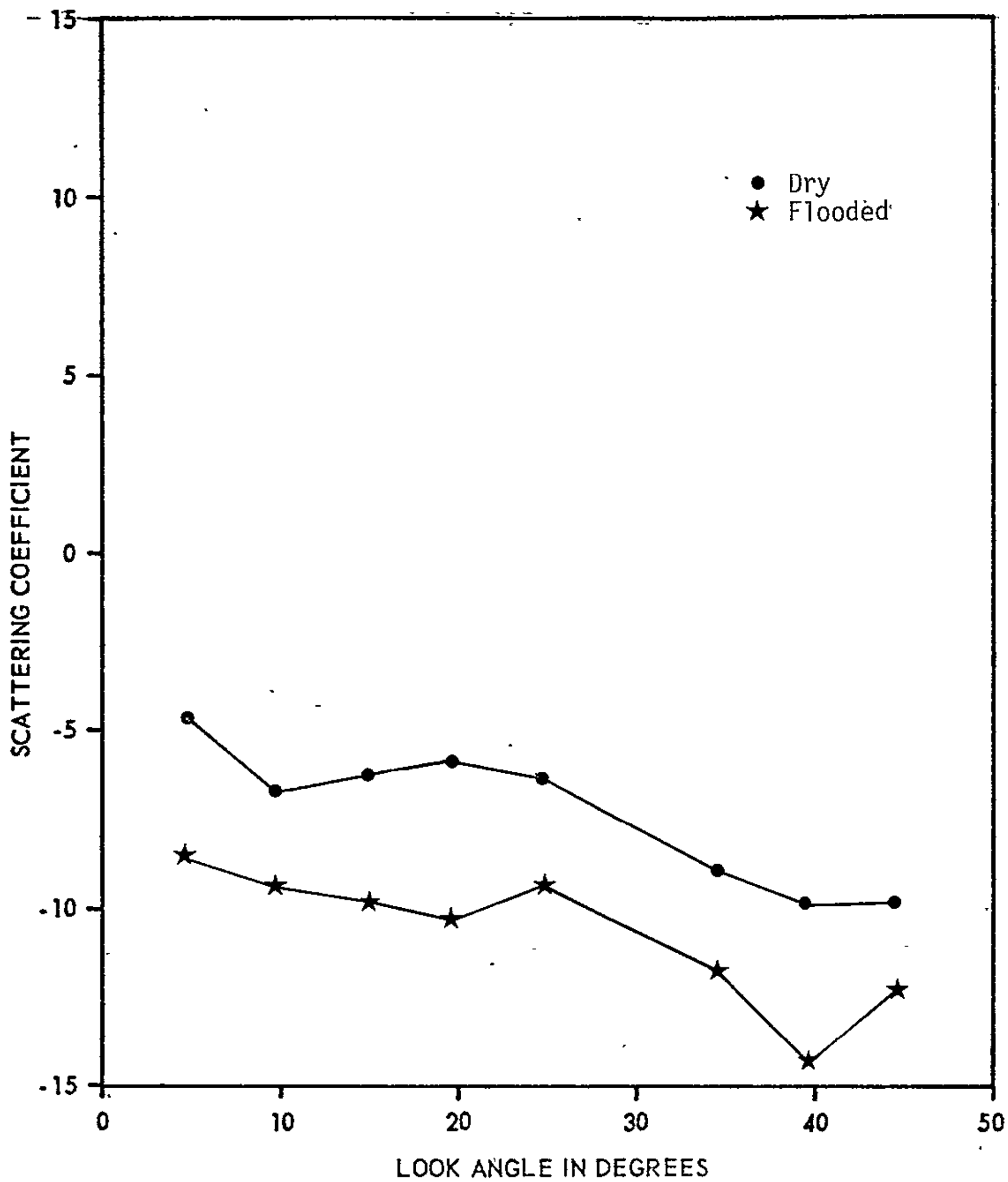

Figure 19. Scattering Coefficient Versus Look Angle for 1.6 GHz HV and Reach C of the Navasota River Under Flooded (4/29/77) and Dry (5/4/78) Conditions.

The results shown on all of the figures are interesting because of the apparent consistency. Also, the significant difference between the response for the flooded and dry condition demonstrates the potential that active microwave sensors possess for delineating flooded or wet areas through dense timber or dense cloud cover.

The difference in response of the active microwave sensor to flooded or dry condition depends on whether the sensor used like-polarization or cross-polarization. As noted from the figures the flooded condition yields a higher response for like-polarization, whereas just the opposite occurs for cross-polarization. This switching effect is an additional tool that can be used to distinguish flooded areas from dry areas.

In general the 1.6 Ghz radar data was used in the multivariant analysis. This radar system provides like and cross polarized cross section values for incident angles ranging from 0° to 45°. The 13.3 GHz provides only like polarized radar data and was not useful in predicting changes in land use. The 400 MHz radar system provided both like and cross polarized data but was not used for reasons of system reliability. By far this 1.6 GHz data provided the best discrimination of land use type and was used exclusively in our analysis.

Three basic channels of information was used. They included:

1. The difference in the 10° σ^0 value and the 35° σ^0 value for like polarized data.
2. The difference in the like polarized data and the cross polarized data at 10° incidence angle.

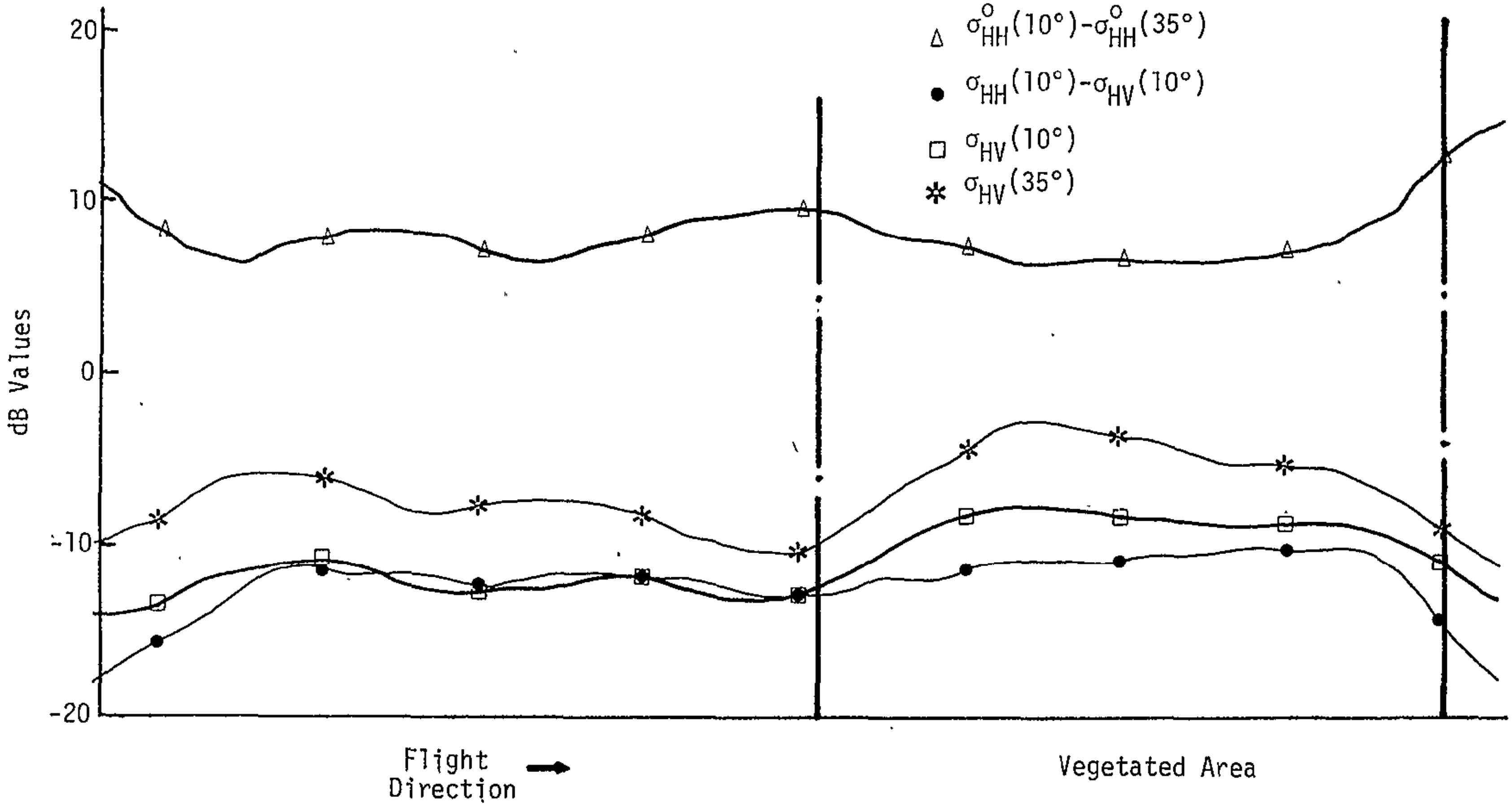

Figure 20. Scatterometer Response Over Vegetated ARBA (50% Brush Cover).

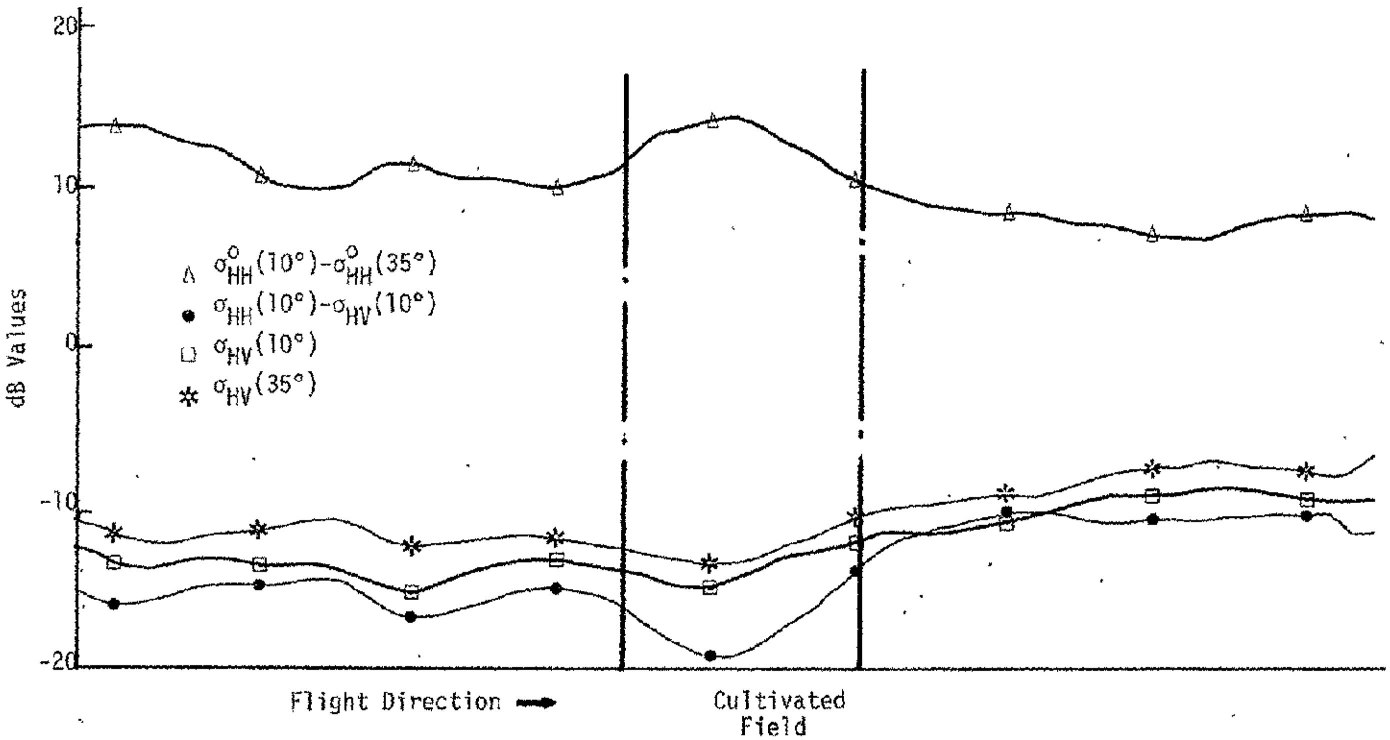

Figure 21. Scatterometer Response Over Cultivated Field (Bare Ground).

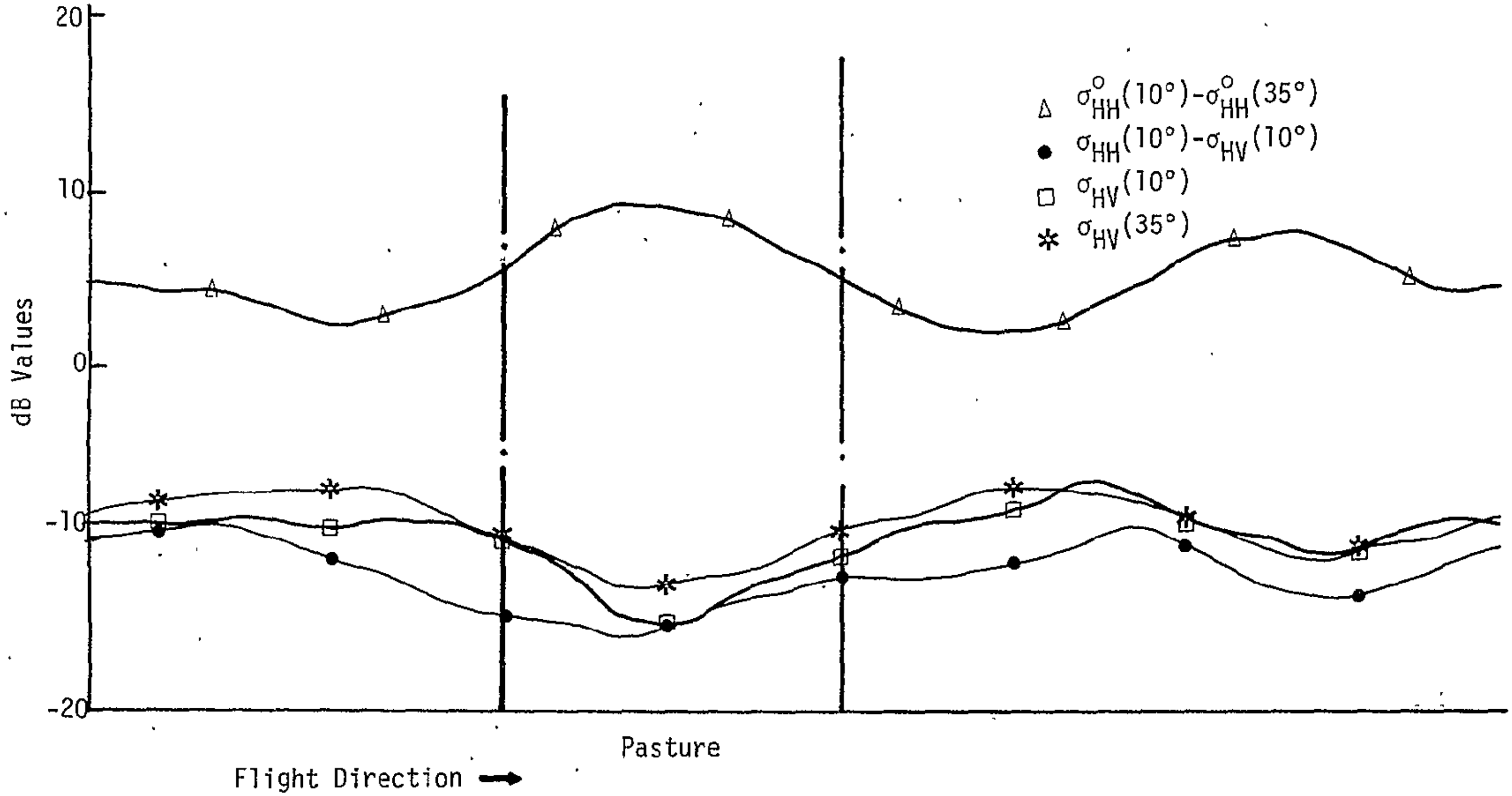

Figure 22. Scatterometer Response Over Pasture.

3. The cross polarized data at 10° incidence angle.

With these three independent data sets we were able to define, uniquely, three landcover, land use types: 1) vegetated land, 2) pasture, 3) cultivated land. The criteria for discrimination is outlined below:

Vegetated landcover - the difference in backscatter cross section at 10° and 35° incident angle tended to decrease. While the depolarized return increased and the difference in like and cross polarization also increased.

Pasture - the difference in backscatter cross-section at 10° and 35° incident angle tends to increase. The difference in the like and cross polarized data remains the same or decreases slightly. The cross polarized data decreases.

Cultivated fields - the difference in backscatter cross section at 10° and 35° incident angle increases whereas the cross polarized data remains the same with a decrease in the difference in like and cross polarization.

Representative flight line curves for each type of land cover investigated are illustrated in Figures 20 through 22. Each flight line was analyzed visually in this manner, first blocking land use types from the radar analysis and checking accuracy using concurrent aerial photography.

The results were very encouraging. In greater than 80% of the cases the interpretation of the radar data yielded a correct decision of the land use type. Flight lines in all parts of the State of Texas were used in this analysis. The same discriminating procedure could be used with success over a number of areas with varied cultural, vegetative, soil and geological situations.

6.0 CONCLUSION

This research on the ability to detect different hydrologic regions using microwave sensors has identified several important results:

1. It is possible to use multivariant radar data to distinguish difference in land use, and hence be an indicator of surface runoff characteristics.
2. Opens the possibility of using conventional automated multivariant classification techniques using radar data.
3. It has identified the capability of using microwave sensors to detect flood inundatation of timbered land.

These results are based on an analysis of radar scatterometry data. More research is needed in understanding the interaction of electromagnetic energy with natural land forms. The influence of surface and subsurface hydrologic conditions on the physical earth/land parameters which influence radar backscatter must be better understood. That understanding must be obtained from two approaches.

a) An understanding of the influence on earth/land parameters on radar backscatter measurements.

b) An understanding of how the hydrologic conditions influence the earth/land parameters measured by radar systems.

This approach requires a coordinated team effort between the radar specialist and the hydrologist. Both approaches cannot be attacked by either group alone.

REFERENCES

Blanchard, B. J. Demonstration to characterize watershed runoff potential by microwave techniques. Final Report RSC-3345, Texas A&M University, Remote Sensing Center, College Station, Texas, June 1977, NASA Contract NAS9-14898

Walker, J. D. Techniques for remotely sensing watershed runoff potential. Technical Report RSC-98, Texas A&M University, Remote Sensing Center, College Station, Texas, August 1978, NASA Contract NSG-5156.

Blanchard, B. J. and W. Bausch. Spectral measurement of watershed coefficients in the Southern Great Plains. Texas A&M University, Remote Sensing Center, Technical Report RSC-98, College Station, Texas, August 1978, NASA Contract NSG 5156.

Blanchard, B. J., J. W. Rouse, Jr. and T. J. Schmugge. Classifying storm runoff potential with passive microwave measurements. Water Resources Bulletin, Vol. 2(5), 892-907, 1975.

Hawkins, R. H. Improved prediction of storm runoff in mountain watersheds. Journal of Irrigation and Drainage Division, ASCE, Vol. 99 (IR4), 519-523, 1973.

Newton, R. W., S. L. Lee, J. W. Rouse, Jr. and J. F. Paris. On the feasibility of remote monitoring of soil moisture with microwave sensors. Proc. of the 9th Symposium on Remote Sensing of the Environment, Ann Arbor, Michigan, 1974.

The REMOTE SENSING CENTER was established by authority of the Board of Directors of the Texas A&M University System on February 27, 1968. The CENTER is a consortium of four colleges of the University; Agriculture, Engineering, Geosciences, and Science. This unique organization concentrates on the development and utilization of remote sensing techniques and technology for a broad range of applications to the betterment of mankind.