MULTIPLE INCIDENCE ANGLE SHUTTLE IMAGING RADAR DATA FOR DISCRIMINATING FOREST COVER TYPES

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BIOGRAPHICAL SKETCHES

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ABSTRACT

The Shuttle Imaging Radar-B (SIR-B) was flown in October 1984 on Space Shuttle Mission 41-G, and digital L-band HH-polarized synthetic aperture radar (SAR) data were obtained for designated test sites around the world, including a forested test site in northern Florida. The Shuttle Imaging Radar data obtained for this study is unique in that it is the first time that a set of multiple incidence angle (28^{o}, 45^{o}, and 58^{o}) radar data has ever been obtained from satellite altitude and then digitally registered. The objective of this study was to define the

potential for discriminating various forest cover types using L-band HH-polarized Shuttle Imaging Radar (SIR-B) data obtained at 28°, 45°, and 58° incidence angles. Qualitative and quantitative analysis of this unique set of satellite radar data has shown that many different forest cover types and land use features can be clearly discriminated as a function of look angle.

INTRODUCTION

The use of Landsat satellite data for mapping forest and other natural resources has received a great deal of attention for over a decade. Much has been learned concerning the very real advantages as well as the limitations of such satellite data for assessing and monitoring our natural resources. Forests cover a large portion of land surface of the earth, but on aerial photos and Landsat data, the forest areas are often obscured by clouds, particularly in the tropical regions. Since radar data can be obtained under any weather condition (as well as at any time of day or night), such systems provide an excellent opportunity to obtain valuable information about the forest resources of the earth.

In the 1960's, work with the relatively short wavelength (i.e., 0.86 cm) Ka-band radars flown from aircraft altitudes had shown some potential for discriminating forest from non-forest cover types, and some differences could be seen between forest and brushland areas (Morain and Simonett 1967). However, during the late 1960's and early 1970's, relatively little work was done with radar sensors. In the late 1970's, one of the most significant operational remote sensing resource surveys of all time was conducted using an airborne X-band (3 cm) radar sensor to survey and map the natural resources of the Amazon Basin in Brazil (van Roessel and deGodoy 1974). Research with cross-polarized X-band radar data indicated that deciduous and coniferous forest cover could be clearly differentiated on the HH polarized images, but not on the HV polarized data (Knowlton and Hoffer 1981).

In 1978, an earth resources radar system was flown for the first time from satellite altitudes when the Seasat satellite was used to obtain L-band (23.5 cm) SAR data. These data were obtained in a HH polarization using a 23° incidence angle. A similar L-band HH polarized sensor, Shuttle Imaging Radar-A (SIR-A), which also operated at a 23.5 cm wavelength but with an incidence angle of 50°, was flown aboard the Space Shuttle orbiter Columbia in 1981.

The SIR-B radar system, a modified SIR-A sensor flown aboard the Space Shuttle orbiter Challenger during Flight 41-G in October 1984, differs from all previous radar sensors in that the data can be processed entirely digitally without the need for optical correlation, thereby obtaining a larger dynamic range in the backscattered signal. Secondly, the SIR-B mission was designed to allow data to be obtained for a variety of look angles, ranging from 20° to 65°. This provided the opportunity to obtain

SAR radar data, for the first time, from satellite altitudes over the same area on the ground, but at different incidence angles. Because of the rather unique physiognomic structure of forest stands, i.e., trees of various heights and diameters (of both the crown and trunk of the tree), and with various spacing between trees, as well as the combination of vertical tree trunks, branches of various sizes and orientations, leaves or needles having various characteristics and orientations, etc., it is important to determine the effect, if any, of obtaining radar data from different incidence angles. Such information is necessary to specify the most effective configuration for obtaining SAR data of forest lands from the Space Station and other future Earth observing SAR systems.

One of the objectives of this research project, therefore, was to determine the effect of incidence angle on the ability to differentiate and identify forest and other cover types, using digitally processed L-band HH polarized data obtained from an altitude of approximately 230 km at incidence angles of 58^{o}, 45^{o}, and 28^{o}.

CHARACTERISTICS OF THE TEST SITE

The test site for this research is an area of nearly 1000 sq. km in Baker, Columbia, and Union counties in northern Florida, approximately 65 km west of Jacksonville (Figure 1). The area has relatively flat terrain, with a mean elevation of approximately 45 meters. Soils are predominantly sandy. Much of the land is owned by one of three forest products companies -- Champion International Corporation, Owens-Illinois Corporation, and Southern Resin and Chemical Company -- or the U.S. Department of Agriculture Forest Service (Osceola National Forest). Because of this land ownership, most of the area is forested, primarily with plantations of slash pine (Pinus elliottii). All three companies manage their forests for paper pulp production, using a 25 to 30 year rotation, while the USDA Forest Service manages for sawtimber on a 50 year rotation. In addition to the older stands of slash pine, the Osceola National Forest has many older stands of longleaf pine (Pinus palustris) and the two species combined. Most of the pine stands throughout the study area have a relatively dense understory consisting mostly of saw palmetto (Serenoa repens), common gallberry (Ilex glabra) and southern bayberry (Myrica cerifera). In addition to the pine stands, there are numerous cypress and cypress-tupelo swamps scattered throughout the area. The cypress and cypress-tupelo swamps largely consist of deciduous species such as pondcypress (Taxodium distichum var. nutans), baldcypress (Taxodium distichum), swamp tupelo (Nyssa sylvatica var. biflora), black tupelo (Nyssa sylvatica), water tupelo (Nyssa aquatica), sweet bay (Magnolia virginiana), and red maple (Acer rubrum), often with some interspersed slash pine and/or pond pine (Pinus serotina). The cypress swamps are distinguished from the cypress-tupelo swamps in that the former are predominantly cypress (Taxodium spp.).

Figure 1. Location of forestry test site in the State of Florida.

SIR-B AND REFERENCE DATA

During Space Shuttle Mission 41-G, L-band (23.5 cm), HH-polarized digital SAR data were obtained for the Florida forestry test site at 5:34 a.m., EDT, on Oct. 9 at an incidence angle of 58°; at 5:17 a.m., EDT, on Oct. 10 at an incidence angle of 45°; and at 5:00 a.m., EDT, on Oct. 11 at an incidence angle of 28°. This is graphically depicted in Figure 2. For each data take, the orbital track of the orbiter Challenger was between 45.0° and 45.6°, with a look direction to the left (northwest). The data were digitally processed and then registered at the Jet Propulsion Laboratory (J.P.L.), Pasadena, CA, thereby producing a computer compatible data tape containing three files, each corresponding to a different incidence angle. This SIR-B data set is unique in that it is the first set of multiple incidence angle radar data to be obtained from satellite altitude and then registered.

Various types of reference data were utilized in the analysis. Color infrared aerial photography from four different sources -- J.P.L., National High Altitude Photo-

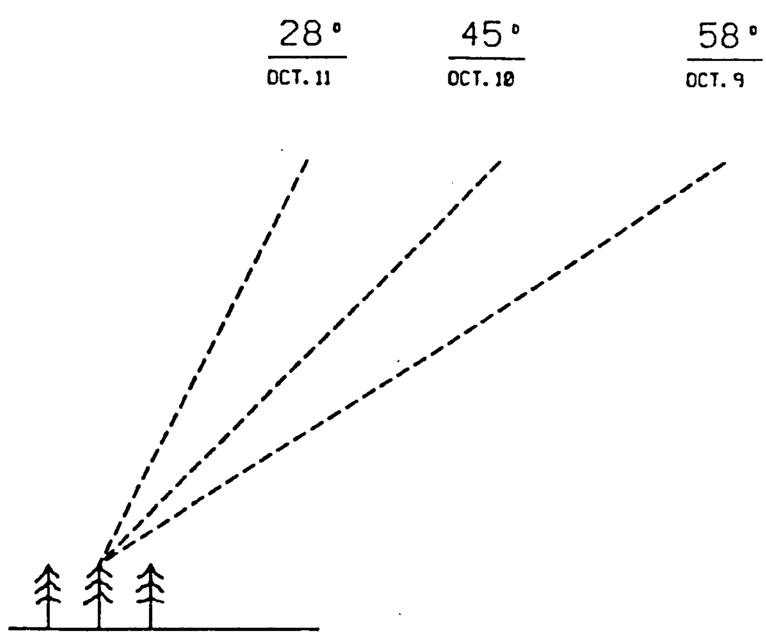


Figure 2. SIR-B multiple incidence angle data characteristics.

graphy program, St. Regis Corporation, and the authors -- along with ground photos taken at the time of Mission 41-G were utilized extensively. Cover type maps and detailed forest stand inventory data were provided by the U.S.D.A. Forest Service and the three forest product companies operating in the area. Additionally, various types of quantitative and qualitative data, such as vegetation samples, temperature and relative humidity, and stand descriptions, were obtained in the field at the time of the Space Shuttle mission.

RESULTS

A color composite image, obtained by using the red gun of the RGB (red/green/blue) color monitor to display the 58° data, the green gun to display the 45° data set, and the blue gun to display the 28° data, was utilized for qualitative interpretation of the multi-angle SIR-B data. Because of the limitations in printing color illustrations, only black and white images from which the color composite was made are shown here.

Figure 3 includes three SIR-B images corresponding to each of the individual incidence angle data sets for a portion of the test site. Because the color composite effectively combines the three individual incidence angle data sets, the results are reported in terms of the appearance of the features on the color composite. Thus, a feature that had a predominately blue color had a relatively high return in the 28° data; a green appearance would indicate a higher backscatter in the 45° data set than in the 28° or 58° data sets, etc. Black indicates a low return at all three incidence angles, and white indicates a very high return for all three incidence angles. Analysis of the color composite image has shown that seven classes of forest cover can be distinguished, in addition to five other classes of land cover or land use. Water bodies were evident as large, generally rounded black areas, such as pear-shaped Palestine Lake in each angle image of Figure 3. Roads and most agricultural fields (predominately fallow, recently planted, or short pasture at the time of the mission) also were black, but could be distinguished by their shape. Cypress or cypress-tupelo swamps, often with some slash and/or pond pine scattered throughout, were medium blue. Distinctive white and bright blue mottled areas were mostly stands of dense cypress without pine. Very dark blue/black were recently clearcut forest land (easily confused with agricultural land, but often had more speckle); purple was young pine forest (e.g., 3-12 years); green was medium-age pine forest (e.g., 15-25 year old plantations); a yellowish red corresponded to older (e.g., 45-55 year old) natural stands of slash pine and/or longleaf pine. A very high radar return in the 58° incidence angle data obtained on Oct. 9 created a distinct red square in the color composite image. It was determined that this was caused by an ornamental shrub nursery containing thousands of 25 cm high pots of plants.

To obtain a more quantitative analysis of the data, a relatively small area around Fisher Lake (see black

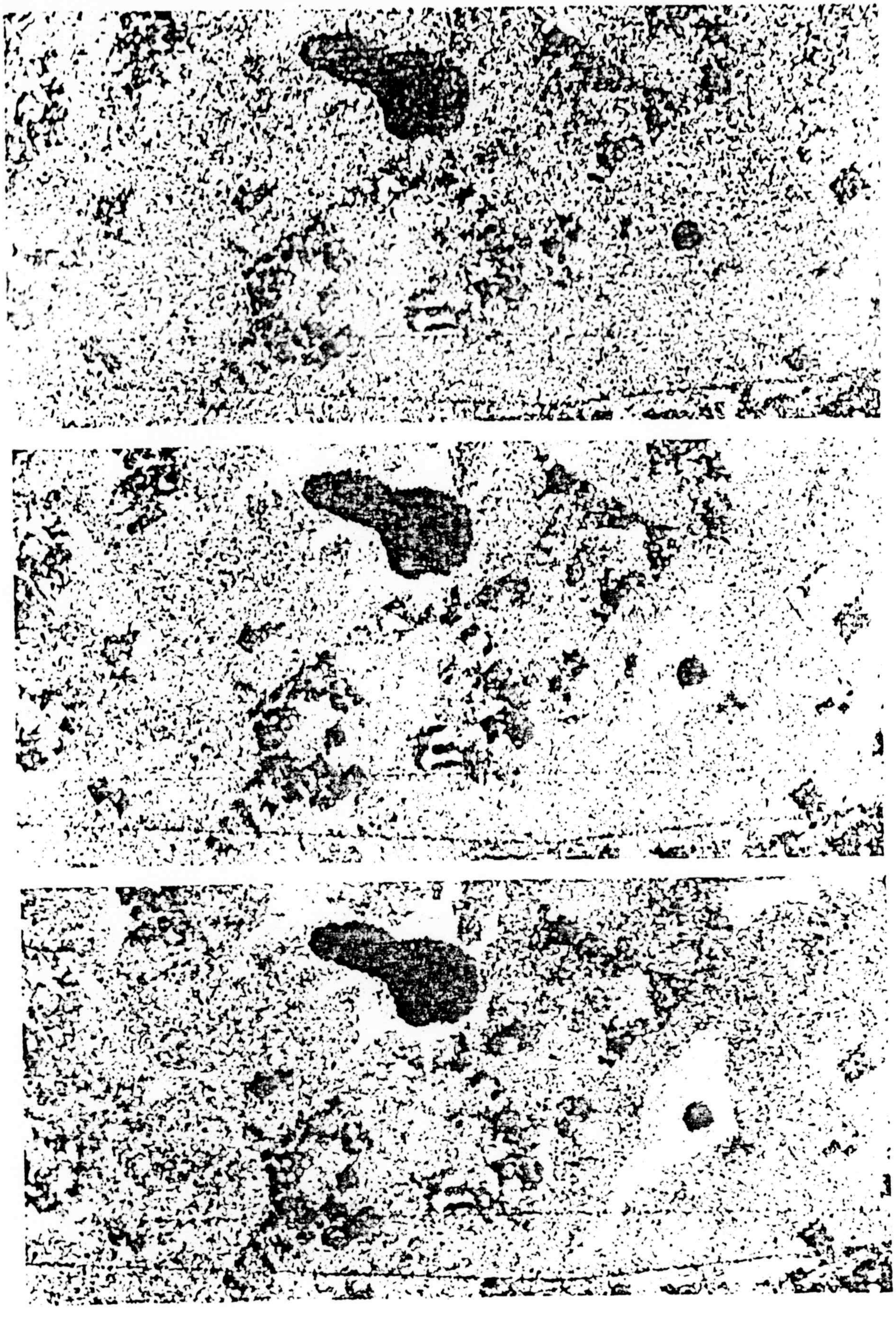


Figure 3. Individual incidence-angle SIR-B images.
(Top = 58°; Middle = 45°; Bottom = 28°)

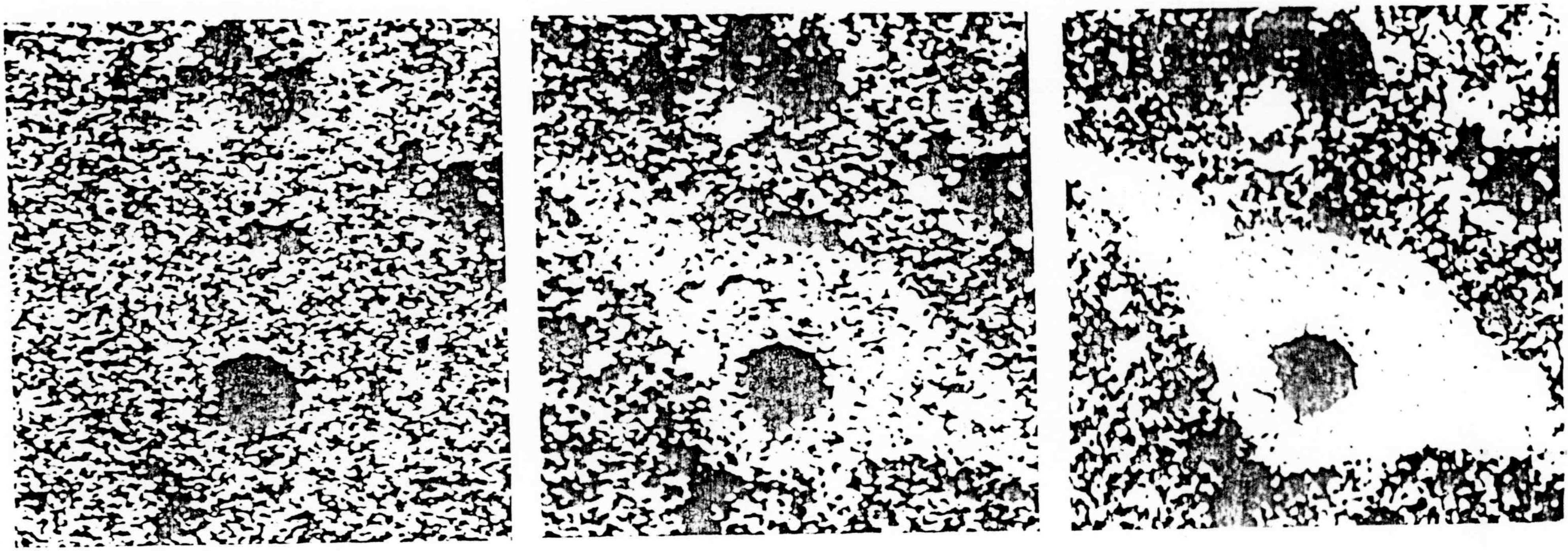
circular feature at right of Figure 3) was defined, and Figure 4 shows an enlargement of this area for each of the individual incidence angles. This figure dramatically depicts the impact of incidence angle on the radar backscatter from different forest cover types. On the 28° incidence angle data, the distinctive white area in the center of the figure is a cypress-tupelo swamp containing some slash and/or pond pine, with Fisher Lake being the black circular feature in the middle of this swamp. The darker areas above and below this swamp are slash pine plantations. A small, nearly square block of white near the top center is a dense stand of relatively pure cypress. The black areas adjacent to this stand are agricultural fields, while a black area near the right side of the image is a clearcut forest stand.

Blocks of data were defined for the six different cover types present in the Fisher Lake area, including slash pine, cypress-tupelo swamp (containing some scattered slash and/or pond pine), dense cypress swamp, pine regeneration (after clearcut harvest), agricultural land, and water. For each incidence angle, the mean and standard deviation were calculated for each cover type. Since these data have not been calibrated, digital number (DN) values rather than radar scattering coefficient (σ°) values were used. This also means that relative differences or similarities in DN values are meaningful within each incidence-angle data set, but have no significance between data sets. Figure 5 shows the quantitative differences and similarities among the various cover types for each of the three incidence angles. This figure clearly verifies, quantitatively, the qualitative differences and similarities seen in Figure 4. The 28° data allows good separation among all cover types, whereas at 58° the deciduous and pine forest are identical. Figure 5 also shows that the regenerating forest land can be separated from pine forest better on the 45° incidence angle data set than on the 28° data set.

The very high return observed for the dense cypress and the cypress-tupelo swampland areas is believed to be due to the specular reflectance of the radar signal from the standing water in the swamp in combination with the tree trunks which cause a complex corner-reflector effect. Therefore, because the radar signal penetrates down through the forest canopy much better at the steeper 28° angle than at the 58° angle, the radar signal reaches the water surface much more effectively, and a much higher return is generated. Anomalously high radar returns for forested areas underlain by water have also been found in Seasat L-band data, which had a fixed 23° angle of incidence, by MacDonald et al. (1980), Waite et al. (1981), and Krohn et al. (1983), as well as for SIR-A data, which had a fixed incidence angle of 50° (Ford et al., 1983).

CONCLUSIONS

Analysis of this 58°, 45°, and 28° multiple incidence angle data set has shown that the incidence angle significantly influences the capability to separate forest and other cover types, as well as age classes of pine plantations.



58° 45° 28°

Figure 4. Fisher Lake area on each of three incidence angles. Deciduous forest can be easily differentiated from pine on the 28° data set image, but they look identical on the 58° data set image.

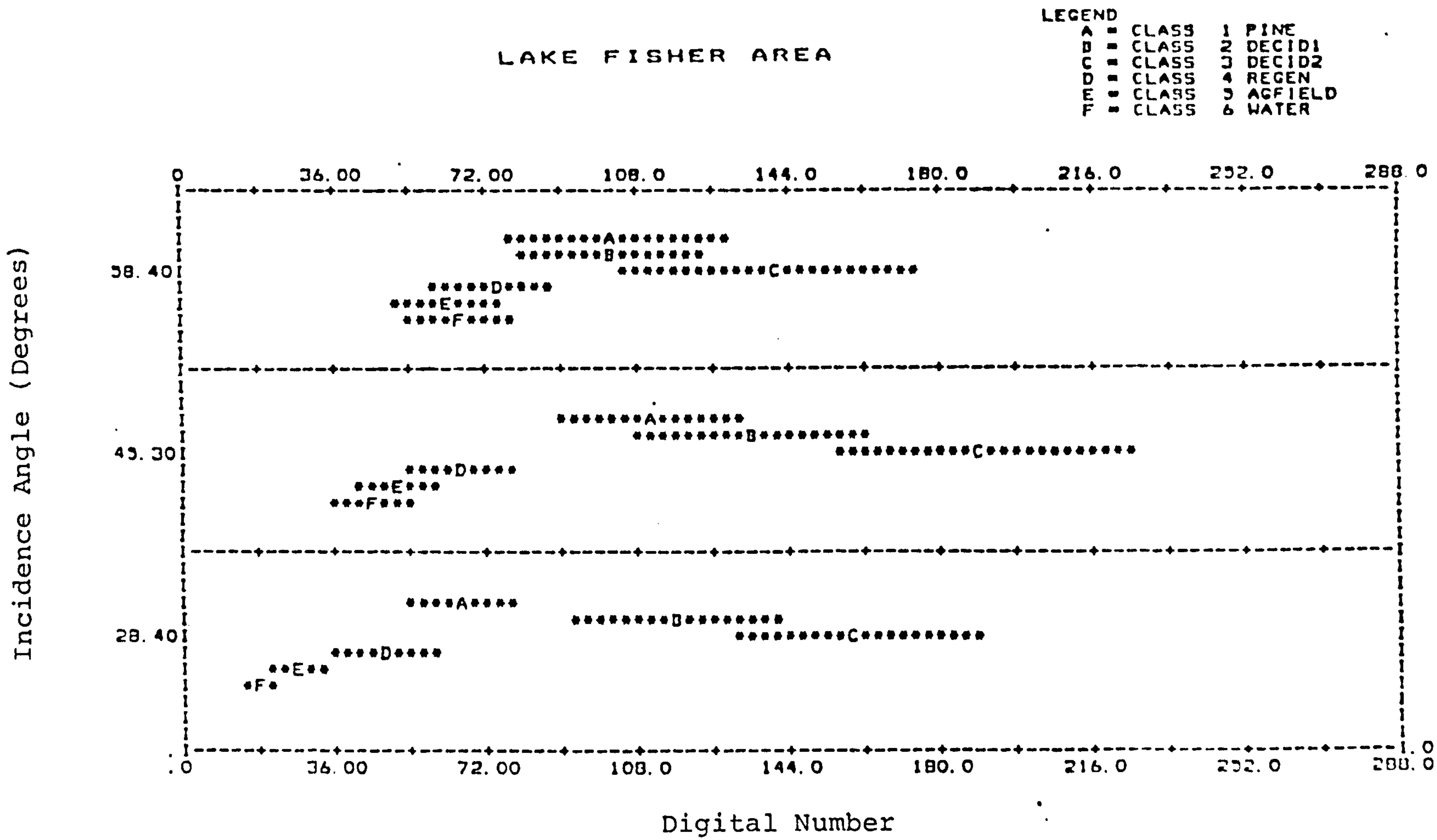


Figure 5. SIR-B multiple incidence angle backscatter plot for six cover types of the Lake Fisher area. The letter indicates the mean digital number (DN) of the radar backscatter for the various cover types defined in the key. The asterisks indicate ± 1 standard deviation.

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For the 28° incidence angle data, both qualitative and quantitative analyses showed that deciduous forest swamplands have relatively high radar backscatter while pine plantations have only a moderate backscatter, but on the 58° incidence angle data set there were no differences between these major forest cover types. Three age classes of pine forest, two groups of deciduous swampland forest, agricultural cropland, water, and some classes of cultural land use could also be differentiated as a function of incidence angle. Clearly, this SIR-B experiment has shown that incidence angle controls, to a very large extent, the amount and type of information that can be obtained from L-band, HH polarized satellite SAR data. Future experiments with other frequencies and polarizations of SAR data may prove equally beneficial in the quest to define efficient and effective techniques to obtain needed resource management information on a global scale.

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