Interpretation of Satellite and Aircraft L-Band Synthetic Aperture Radar Imagery

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ABSTRACT

A collection of SAR imagery acquired by three different L-band radar sensors for a predominantly forested area of northeastern Florida was utilized to study the characteristics of various forest cover types as expressed on the SAR imagery. The imagery had been obtained by the Seasat (1978), Shuttle Imaging Radar-B (1984), and NASA/JPL Synthetic Aperture Radar (1984) sensors. The latter was an aircraft system and operated at a wavelength of 24.6 cm, while the other two sensors were both operated from a space platform at a wavelength of 23.5 cm. The two satellite sensors obtained HH polarized data from different look angles and look directions, while the airborne SAR acquired data having four different polarizations -- HH, HV, VH, and VV. The objective of this study was to qualitatively investigate the similarities and differences in radar return for identifying and discriminating between various forest cover types when interpreting synthetic aperture radar acquired by three different L-band sensors. The results indicate that distinct differences in forest cover

and polarization are both significant factors influencing the radar return.

INTRODUCTION

Multispectral optical data, particularly that of the Landsat series satellites, has been used extensively for identification and mapping of forest and other vegetation types. Remote sensing systems operating in the microwave region of the electromagnetic spectrum offer some unique advantages over the traditionally utilized optical systems. Because synthetic aperture radar (SAR) systems are active sensors -- both transmitting and receiving the microwave signal -- they are not dependent on solar illumination. Additionally, the radar signal can penetrate cloud cover which often hinders the acquisition of optical data for forest cover mapping in tropical regions.

The interpretation of radar imagery is similar to aerial photo interpretation using tone, texture, shape, pattern, size, shadow, and association as interpretive clues (Henderson 1985). Tone and texture are the major factors to consider when developing interpretive keys for forest typing (Knowlton and Hoffer 1981; Morain 1980). As with optically acquired images, tone on radar imagery refers to the brightness of the gray scale representation of the radar return. The brightness is directly related to the intensity of the return. Texture refers to the degree of homogeneity in tone over an area and degree of speckling.

The signal transmitted by a radar is scattered by the target and only a portion will be returned to the radar antenna. The strength of the radar return is influenced by the properties of both the target and the sensor system. Target parameters affecting radar backscatter are surface slope and roughness, complex dielectric constant, and target orientation and geometry, while system parameters include operating wavelength, antenna depression angle, polarization, and antenna look direction (Avery and Berlin 1985).

OBJECTIVE

As plans are being made for future earth observing SAR systems, a thorough knowledge of the effects of various system parameters on radar backscatter is essential. Such information is necessary to determine the relative advantages and disadvantages of various SAR configurations, and will be useful when designing future SAR sensors. The objective of this study was to qualitatively investigate the similarities and differences in radar return for identifying and discriminating between various forest cover types when interpreting SAR data for the same land area acquired by three different L-band radar systems--Seasat SAR, Shuttle Imaging Radar-B, and NASA/JPL airborne SAR.

The study site is located in Baker County, Florida, which is in the northeastern section of the State (Figure 1). The dominant cultural feature in the study site is the highway intersection of Interstate 10 and U.S. 90 which is located approximately 12 km south of the Okefenokee Swamp and 12 km east of Lake City, Florida. This highway intersection is evident in Figures 2 and 3. Soils of the area are predominantly sandy and the topography is relatively flat with the elevation ranging from approximately 27 to 53 meters above mean sea level.

The study site is predominantly forested, and ownership of the forested land is principally divided between Champion International Corporation, Owens-Illinois Corporation, Southern Resin and Chemical Company, and the U.S. Department of Agriculture Forest Service (Osceola National Forest). The major forest cover types present in the study site are pine flatwoods, cypress swamps, and cypress-tupelo swamps. The pine flatwoods are composed of slash pine (Pinus elliottii) and/or longleaf pine (P. palustris), the former often in plantations. Pine is managed for sawtimber with a rotation age of 50 years on the Osceola National Forest, while it is managed for pulpwood with a rotation age of 25 to 30 years on land owned by the three forest product companies. The cypress and cypress-tupelo swamps largely consist of such deciduous species as pondcypress (Taxodium distichum var. nutans), baldcypress (T. distichum), swamp tupelo (Nyssa sylvatica), water tupelo (N. aquatica), black tupelo (N. sylvatica), sweetbay (Magnolia virginiana), red maple (Acer rubrum), and sweetgum (Liquidambar styraciflua), often with some scattered slash pine and/or pond pine (P. serotina). The cypress swamps are distinguished from the cypress-tupelo swamps in that the former are predominantly pondcypress and baldcypress.

MATERIALS AND METHODS

L-band SAR imagery utilized in this study was collected by the Seasat SAR, the Shuttle Imaging Radar-B (SIR-B), and the NASA/JPL airborne SAR. A summary of the characteristics of the radar data is shown in Table 1. The three data sets were acquired on three different dates, but the forest cover, for the most part, has remained the same. The two spaceborne SAR's, Seasat and SIR-B, both operated at a wavelength of 23.5 cm with an HH polarization. The incidence angle of these two data sets is similar, but the look direction is quite different. The operating wavelength of the airborne data is only slightly different than that of the two spaceborne sensors. The major difference is that the airborne SAR data were obtained at four polarizations--HH, HV, VH, and VV. This variety of system parameters provides opportunities for investigating the affects of SAR system parameters on the radar backscatter from forest cover.

A multiple incidence angle SIR-B data set exists for this

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

TABLE 1. L-band synthetic aperture radar imagery of the Florida forestry test site.

	SENSOR		
Parameter	Seasat SAR	SIR-B	NASA/JPL SAR
Platform	Seasat satellite	Space Shuttle orbiter	CV-990 aircraft
Acquisition Date	8 Aug. 1978	11 Oct. 1984	14 Sept. 1984
Acquisition Time (EDT)	8:25	5:00	14:00-14:31
Nominal resolution	25 m	25 m	9 m
Polarization	HH	HH	HH,HV,VH,VV
Wavelength	23.5 cm	23.5 cm	24.6 cm
Platform track	339°	46°	0°, 180°
Look direction (from North)	69°	316°	90°, 270°
Angle of incidence	23°-25°	25°-32°	15°-63°
Approximate Altitude	800 km	226 km	8 km

test site, consisting of data obtained at incidence angles of 28°, 45°, and 58°. For manual image interpretation, Hoffer et al. (1985) have shown that the 28° image provides maximum discrimination between forest cover types. Therefore, of the three SIR-B images available for this site, only the 28° incidence angle image was used in this study.

Photographic prints of the digital imagery were utilized in the analyses. Prints for the Seasat SAR and NASA/JPL airborne SAR along with a SIR-B negative and print were provided by the NASA Jet Propulsion Laboratory (JPL).

Reference data for the interpretation of the SAR images included aerial and ground photography, field notes, and forest stand inventory information. The aerial photography included both oblique and vertical photographs. Complete vertical color infrared photographic (1:100,000) coverage of the study site was obtained at the time of the NASA/JPL radar acquisition. Additionally, 1:58,000 color infrared vertical photography was 1983 and 1984 as part of the National High Altitude Photography program. In October 1984, when the SIR-B sensor was operating aboard the orbiter Challenger during Space Shuttle Flight 41-G, 35 mm format color and color infrared photographs of the study site were taken from light aircraft and on the ground as additional reference data. Field trips were made to the study site in August and October 1984, and notes on stand conditions were taken. Detailed stand maps and inventory data were provided by the timberland owners.

Imagery from the three sensors are shown in Figures 2 and 3. These images are a sampling of the entire set of data analyzed in this study. A qualitative interpretation and comparison of the SAR imagery from the three different sensors was conducted. The two spaceborne sensor images were compared and the airborne SAR data was analyzed to determine the usefulness of the different polarizations. Forest cover classes were identified on the SAR images using photo interpretive techniques. Extensive use of the reference data aided the interpretation of the SAR data. The causes for differences between the SAR images were hypothesized.

RESULTS

<u>SIR-B</u>

Three major tonal groupings were evident in the SIR-B image and when subgroups were considered, a total of six forest classes and four other classes could be discriminated. The first major tonal group were the lightest tones on the SIR-B image and were characteristic of deciduous swamp forest species underlain by water. For those stands that had a smooth textured canopy on the color infrared photographs with little or no pine present (such as cypress swamps), the SAR image texture was smooth and yielded an almost pure white tone (Figure 2, top). As the presence of pine increased in the cypress-tupelo swamp forest stands, the texture on the SIR-B image became somewhat rougher

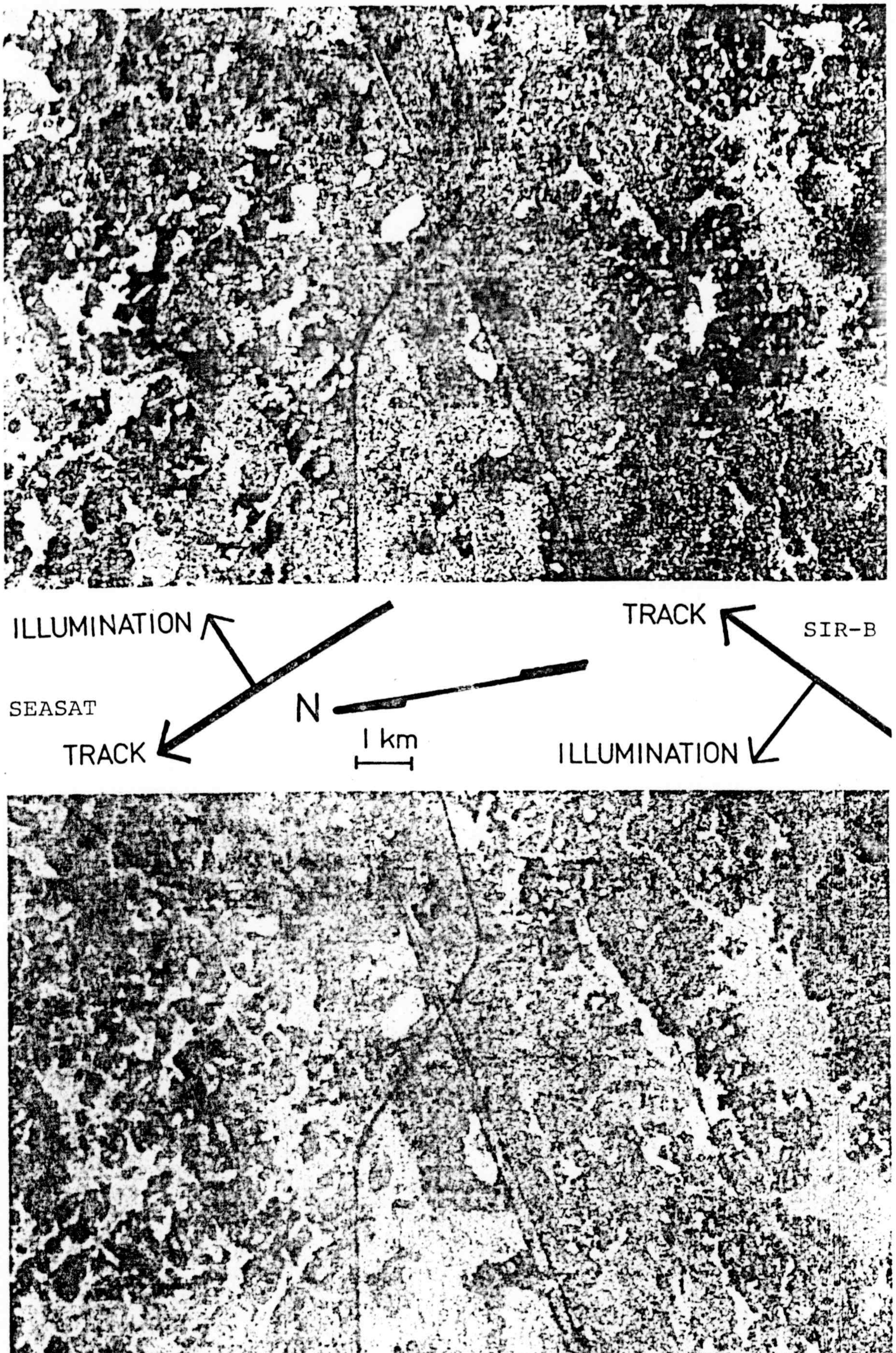

Figure 2. Example of SIR-B 28^{o} incidence angle imagery (top) and Seasat SAR imagery (bottom), Baker County, FL.

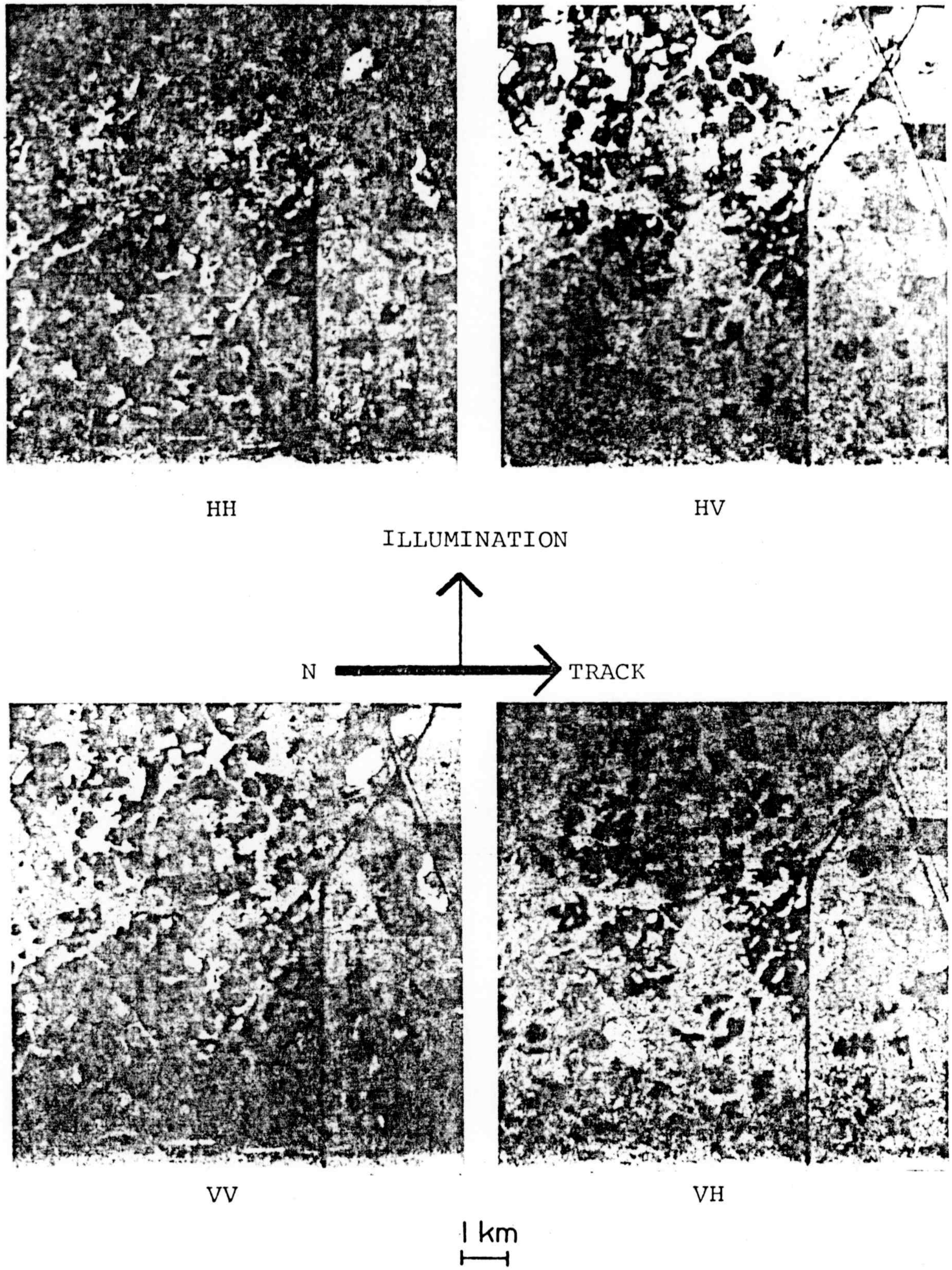

Figure 3. Example of quad-polarized NASA/JPL airborne synthetic aperture radar data, Baker County, Florida.

... in a light tone with slight gray mottling.

The second tonal group had a medium to dark gray mottled tone with a rough texture and generally was associated with pine forest. Three pine classes could be distinguished, depending on the amount of black and white in the mottled pattern. Young plantations, three to seven years of age, had the darkest mottled tone. Pine stands aged between ten and twenty years generally had a mottled pattern with a dark to medium tone. The mottled pattern of older pine stands generally had equal shares of black and white or more white than black in its tonal makeup, thus allowing for two groups to be discriminated. Recent clearcuts (not yet replanted) were confused with young to medium age pine which must have been due to the rough texture of the residual logging slash. It should be noted, however, that the tone and texture of pine stands was not always related to age. This aspect of the interpretation is being investigated further.

A third major grouping included those cover types represented by an overall black tone. Water and some young pine stands were characterized by a very dark gray tone or black with a slight speckle of gray. A pure black tone was characteristic of bare soil, roads, and some water. These information classes within this third major tonal group could be identified using additional interpretive clues such as shape, size, and association.

Seasat SAR

The Seasat SAR image, in general, was darker in tone than the SIR-B 28° incidence angle image, but was otherwise very similar. In the Seasat image, there were very few pure white areas similar to those on the SIR-B image; none were in the area also imaged by SIR-B. As with the SIR-B data, two forested swamp classes could be discriminated. Uniform deciduous swamps without pine were mostly white in tone, but had some texture of gray mottling. Other forest swamps had a rough-textured salt and pepper appearance. A comparison of the two images in Figure 2 will demonstrate the differences in tone and texture.

For pine, the tone was generally gray with a rough speckled texture. The tonal classes were not as distinct as in the SIR-B image and the pine was found to be represented by a continuum of tones. In general though, the lighter the gray tone, the more mature the pine stand. In some locations, the predominantly deciduous swamps blend together with older pine stands. Perhaps the standing water level in these areas differed between the Seasat and SIR-B overpasses, or possibly the 5° difference in the incidence angle between these two sensors caused the confusion between older pine and deciduous swamps on the Seasat image.

In the Seasat image, black represented the same cover types as with the SIR-B image. The large water bodies such as Ocean Pond had a medium rough texture with much gray speckling. However, along the northeast shore of most of the water bodies, the tone was darker and the texture much

Therefore, the increased speckling may have been caused by a northeasterly wind during the Seasat data take.

NASA/JPL SAR

Due to the wide range of incidence angles for the NASA/JPL airborne SAR data, the overall tone for each image shifts from light to dark or vice versa with increased range (Figure 3). This meant that comparisons of images obtained by this sensor had to be made relative to the same incidence angle, and therefore, comparisons were only made in the azimuth direction. Due to this wide range of incidence angles and the resulting change in tone for a single cover type, a general interpretation in terms of tone could not be conducted for an entire image of a particular polarization. Rather, comparisons in tone and texture were made for specific features at a constant incidence angle within each set of quad-polarized images.

Like-polarized (HH and VV) images were found to be best for discriminating between pine and swamp forests. As with the SIR-B image, like-polarized aircraft images were also useful for differentiating between deciduous swamps having varying amounts of pine and those swamps not having any pine.

The total number of different pine classes present in the aircraft SAR data could not be determined due to the extreme tonal variations across the range. In some locations, though, adjacent young pine plantations differing in age by only one or two years could be differentiated. Imagery obtained by Seasat and SIR-B did not seem to be as sensitive to these differences. This effect may be due to the row directions in the individual plantations. In the area that this was observed, the tree planting rows were either perpendicular or parallel to the NASA/JPL SAR radar beam, causing maximum difference in target orientation for the two row directions. The look directions of Seasat and SIR-B would not allow for such drastic differences in the radar beam/tree row geometry since neither of the satellite orbital tracks was parallel to one of the perpendicularly oriented row directions.

In general, the two cross-polarized images (HV and VH) provided greater contrast between forest and non-forest than the like-polarized images (HH and VV). However, the two like-polarized images discriminated best between deciduous and non-deciduous. Other distinct differences between the polarizations have been noted, but their significance has not yet been determined. Further studies will be conducted to determine if these differences are linked to forest stand parameters such as stand density or stand volume.

DISCUSSION

L-band SAR at incidence angles of 23^{o} to 28^{o} apparently can detect, rather effectively, forest vegetation having standing water below the canopy. Forested areas underlain by water had a very bright return on both sets of satellite imagery -- a result similar to the findings of Krohn et al.

(1983), MacDonald et al. (1980), and Ormsby et al. (1985). From this study, it is not clear whether L-band SAR can be used to discriminate between pine and deciduous forest species when the underlying water is not present, since that situation did not occur to any great extent on this study site; this was not discussed by the authors of the other studies.

Repetitive SAR coverage of a forested area has the potential for detecting where forest clearcutting is occurring. The change from forest to non-forest creates a drastic reduction in tone of subsequent images. When comparing the SIR-B (1984) and Seasat SAR (1978) images (Figure 2), on the SIR-B image one can see a large block west of the highway intersection where harvesting has occurred since the Seasat overpass. This particular clearcut has been replanted and the pine seedlings were two years old at the time of the SIR-B overpass. Interestingly, though, very recent clearcuts may not show up on the steep incidence angle L-band SAR imagery. An area that was being harvested in October 1984 was not apparent on the 28^{o} SIR-B data. However, this very recent clearcut was evident on the 45^{o} and 58^{o} incidence angle images of the SIR-B multiple angle data set mentioned earlier. Therefore, the potential for monitoring forest clearcutting is possible with repetitive SAR data, but a large incidence angle may be best.

The NASA/JPL airborne SAR data had a higher spatial resolution than the two spaceborne SAR data sets. This allowed for easier identification of individual forest stands. However, the major limitation of the airborne data was the extreme variation in tones across the range due to the change in incidence angle. At the higher altitude of the Seasat satellite and the Space Shuttle orbiter Challenger, the incidence angle did not vary as much across an image swath and the tonal variation across the image in the range direction was absent. This is a definite advantage for obtaining SAR data from a higher altitude.

Many differences in tone and texture were noted for forest cover. These variations are not yet fully understood due to the complex influences on radar backscatter. Quantitative investigations are now under way to determine the relationships between the SAR backscatter and various forest stand parameters such as tree age, tree height, tree spacing, stand timber volume, and stand basal area.

CONCLUSIONS

Based on this study of Seasat, SIR-B, and quad-polarized airborne L-band SAR data for a test site in northern Florida, the following conclusions can be drawn:

- L-band SAR data is an effective remote sensing tool for assessing forest resources. Forest and non-forest categories could be effectively discriminated, and also several type and age classes of forest could be discriminated.

- L-band SAR imagery, particularly if obtained at an incidence angle in the range of approximately 23° to 28° can be used to detect standing water beneath forest vegetation.

- Like-polarized (HH and VV) airborne L-band SAR images were found to be better than cross-polarized (HV and VH) images for discriminating between pine and swamp forest.

- Cross-polarized (HV and VH) airborne L-band SAR images showed more contrast between forest and non-forest than did the like-polarized images.

- The wide range of incidence angles across the NASA/JPL airborne SAR image caused drastic differences in tone, which was a severe hindrance to effective interpretation of the quad-polarized data.

REFERENCES

Avery, T.A., and G.L. Berlin. 1985 Nonphotographic Imaging Systems. Interpretation of Aerial Photographs. Fourth edition. Minneapolis, MN: Burgess Publishing Co. pp. 131-233.

Henderson, F.M. 1985. Active Microwave Imaging Systems. R.K. Holz, ed. The Surveillant Science: Remote Sensing of the Environment. Second edition. New York: John Wiley & Sons. pp. 234-247.

Hoffer, R.M., P.W. Mueller, and D.F. Lozano-Garcia. 1985. Use of Multiple Incidence Angle Shuttle Imaging Radar Data for Identifying Forest Cover. Science. (In press)

Knowlton, D.J., and R.M. Hoffer. 1981. Radar Imagery for Forest Cover Mapping. Proc. 7th Int. Symp. on Machine Processing of Remotely Sensed Data; June 23-26, 1981, Purdue University, West Lafayette, IN. pp. 626-632.

Krohn, M.D., N.M. Milton, and D.B. Segal. 1983. Seasat Synthetic Aperture Radar (SAR) Response to Lowland Vegetation Types in Eastern Maryland and Virginia. Journal of Geophysical Research 88(C36):1937-1952.

MacDonald, H.C., W.P. Waite, and J.S. Demarcke. 1980. Use of Seasat Satellite Radar Imagery for the Detection of Standing Water Beneath Forest Vegetation. Technical Papers of the American Society of Photogrammetry Fall Technical Meeting; October 7-10, 1980, Niagara Falls, NY. pp. RS-3-B-1 to RS-3-B-13.

Morain, S.A. 1980. Use of Radar for Vegetation Analysis. Proc. Seminar on Remote Sensing; October 1980, South Dakota State University, Brookings, SD. pp. 40-58.

Ormsby, J.P., B.J. Blanchard, and A.J. Blanchard. 1985. Detection of Lowland Flooding Using Active Microwave Systems. Photogrammetric Engineering and Remote Sensing 51(3):317- 328.