LARS Contract Report 082981

Quarterly Progress Report

Evaluation of SLAR and Thematic Mapper MSS Data for Forest Cover Mapping Using Computer-Aided Analysis Techniques

by

R.M. Hoffer, D.J. Knowlton, and M.E. Dean

Contract No. NAS 9-15889

Reporting Period: June 1, 1981 - August 31, 1981

Submitted to: Exploratory Investigations Branch
NASA Lyndon B. Johnson Space Center

Prepared by: Laboratory for Applications of Remote Sensing
Purdue University
West Lafayette, Indiana 47906

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Principal Investigator: Dr. Roger M. Hoffer
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I. Activities of the Past Quarter

A. Analysis of the Thematic Mapper Simulator MSS Data

1. Analysis of the 1979 Data Set

a. Supervised Training Statistics

Evaluation of the classification results reported in the last Quarterly Progress Report indicated a need to refine some of the training areas, particularly for the tupelo, hardwood, and pine cover types, so that the training statistics would be more representative of the various cover types. This was completed and a feature selection analysis was conducted using the separability processor. Various combinations of one through seven channels were evaluated and several classifications have been run. Table 1 shows the comparison for the overall classification by cover type of the training data using the supervised training statistics with all seven and two combinations of four bands. The feature select processor had indicated that the combinations of channels 2, 4, 5, & 7 should provide the best overall classification result. However, the average divergence value was very little higher for 2, 4, 5, & 7 than the combination of channels 2, 4, 6, & 7, and secondly the 2, 4, 5, 7 combination utilized two near infrared channels but no middle infrared whereas 2, 4, 6, 7 utilized one channel from each of the major regions of the spectrum (i.e., visible, near IR, middle IR, and thermal IR). Therefore, we decided to compare the sensitivity of the separability processor for both the training and the test data sets using both combinations of four bands. The results shown in Table 3 indicate that the 2, 4, 5, 7 combination

Table 1. Classification Results Summary.

Supervised Training Stats, GML Classifier, Training Area Results, 1979 Data.

Cover Type	# Training Pixels	All 7 Bands	2,4,6,7[1/]	2,4,5,7
Pine	962	99.5	98.6	99.0
Hardwood	5052	98.9	97.6	98.2
Tupelo	228	97.8	96.9	96.5
Clearcut	335	100.0	95.2	97.3
Soil	344	99.7	97.7	98.8
Pasture	325	98.2	96.9	93.5
Crop	432	100.0	99.1	99.5
Water	460	99.8	98.7	97.8
Total	8138			
Overall		99.1	97.7	98.1
Average		99.2	97.6	97.6

[1/] Waveband Designation	Wavelength (μm)	Spectral Region
1	0.45 - 0.52	Visible
2	0.52 - 0.60	Visible
3	0.63 - 0.69	Visible
4	0.76 - 0.90	Near IR
5	1.00 - 1.30	Near IR
6	2.08 - 2.35	Middle IR
7	10.4 - 12.5	Thermal IR

did produce somewhat higher overall results but not significantly different from the 2, 4, 6, 7 classification results. The next step was to evaluate these different waveband combinations using the test data set.

Table 2 presents the classification results summary using the sample block test data set and the supervised training statistics, again with the Gaussian Maximum Likelihood classifier. As described in the previous Quarterly report, the sample block test data was derived using a statistical procedure to locate 25 x 25 pixel blocks spaced at 50-pixel intervals throughout the data set. Within each 25 x 25 sample block, one area of each cover type present was identified and located by the analyst, the area defined being the largest possible for that cover type within the block. This approach allowed a relatively large, statistically valid, test data set to be defined. In the case of this 1979 data set, this procedure resulted in a total of 11,838 test pixels being defined.

In evaluating the results shown in Table 2, it appears that the overall classification results (88.9%) were very good. Pine and hardwood seemed to be differentiated with a high degree of accuracy, although some of the other cover types were not classified as accurately as one might have anticipated. Water, for example, only had an 81.7% classification performance because of confusion with clearcut, which was caused by the very wet soil and standing water present in some of the clearcut areas. Likewise, clearcut had only 64.9% classification performance because of confusion between the

Table 2. Classification Results Summary

Supervised Training Stats, GML Classifier, Sample Block Test Data, 1979 Data.

Cover Type	# Test Samples	All 7 Bands	2,4,6,7 1/	2,4,6	2,3,4,5
Pine	775	95.0	92.3	88.5	92.6
Hardwood	8553	90.4	87.7	88.4	89.1
Tupelo	120	68.3	43.3	32.5	78.3
Clearcut	370	64.9	58.6	43.5	51.4
Soil	1006	90.6	81.0	77.8	90.3
Pasture	350	83.4	82.3	67.4	71.1
Crop	364	78.6	68.1	55.8	76.4
Water	300	81.7	81.0	91.0	86.3
Total	11,838				
Overall		88.9	85.1	84.0	87.1
Average		81.6	74.3	68.1	79.4

1/ Waveband Designation	Wavelength (μm)	Spectral Region
1	0.45 - 0.52	Visible
2	0.52 - 0.60	Visible
3	0.63 - 0.69	Visible
4	0.76 - 0.90	Near IR
5	1.00 - 1.30	Near IR
6	2.08 - 2.35	Middle IR
7	10.4 - 12.5	Thermal IR

standing water in some of the clearcut areas and river. Tupelo continued to become confused with the hardwood cover type. The detailed classification matrix for ths and the subsequent classification results discussed will be shown as part of the final report on this project.

In evaluating the impact of fewer numbers of wavebands, a classification with the test data was first run with channels 2, 4, 6, & 7. This combination of channels had provided a 97.7% overall classification result using the <u>training</u> data, and since these four channels represented each of the major portions of the spectrum it seemed that this would be a key combination of wavebands to eavluate. The overall classification of the test data was 85.1% as shown in Table 2. In general, each of the classes were somewhat lower in classification performance then when seven channels were used, as one might have anticipated. However, the tupelo class was reduced by 25% (from 68.3 to 43.3), thereby indicating some problems with effectively identifying tupelo using these four combinations of channels. Due to some questions in relation to the impact of the thermal channel on the classification, another analysis was conducted using only channels 2, 4, and 6. The overall classification performance was not reduced significantly and classification performance for hardwood was actually increased somewhat over the 2, 4, 6, & 7 combination. However, tupelo was reduced to 32% and the clearcut and pasture and crop categories were also significantly reduced. The water class acutally increased by 10%.

To provide a comparison of four-channel results using all four portions of the spectrum and four channels approximating those of the Landsat scanner system, a classification was run using channels 2, 3, 4, & 5. The comparison between this result and the 2, 4, 6, & 7 result would tend to indicate that the inclusion of the middle and thermal IR channel was indeed hampering the classification of tupelo and to a lesser extent soil and crop cover classes.

b. Cluster Blocks Training Statistics

After the supervised set of training statistics had been defined, the multi-cluster blocks (MCB) procedure was utilized to define a second set of training statistics. Because this procedure involves clustering of blocks of data into the various spectral classes, it is not possible to quantitatively assess the accuracy of the training statistics. Therefore, these results are assessed only with the sample block test data. Table 3 shows the results of the classification using the cluster blocks training statistics for the same waveband combinations that were previously shown on Table 2. Therefore, these two tables both involve sample block test data but use two different sets of training statistics derived through two totally different methods.

The overall classification results using all seven channels are very similar for the two sets of training statistics but there are some notable exceptions among the individual classes. For instance, the cluster blocks training statistics provided a much higher classification for tupelo and crop but a considerably lower

Table 3. Classification Results Summary

Cluster Blocks Training Stats, GML Classifier, Sample Block Test Data, 1979 Data

Cover Type	# Test Samples	All 7 Bands	2,4,6,7[1/]	2,4,6	2,3,4,5
Pine	775	93.3	92.3	91.7	94.1
Hardwood	8553	88.4	85.1	85.7	87.6
Tupelo	120	84.2	80.0	57.5	82.5
Clearcut	370	45.7	40.3	39.2	37.8
Soil	1006	90.8	90.0	94.1	95.0
Pasture	350	61.4	69.1	57.1	51.1
Crop	364	98.6	97.8	98.1	98.9
Water	300	86.7	85.3	86.7	86.3
Total	11,838				
Overall		87.0	84.5	84.6	86.3
Average		81.1	80.0	76.3	79.2

[1/] Waveband Designation	Wavelength (μm)	Spectral Region
1	0.45 - 0.52	Visible
2	0.52 - 0.60	Visible
3	0.63 - 0.69	Visible
4	0.76 - 0.90	Near IR
5	1.00 - 1.30	Near IR
6	2.08 - 2.35	Middle IR
7	10.4 - 12.5	Thermal IR

classifiction for clearcut and pasture. Since all seven bands were used in both classifications, and these are test data results, this may indicate that neither set of training statistics was completely representative in describing the spectral characteristics of these different cover types.

Comparison of the seven-band versus the 2, 4, 6, & 7 four-band results shows a predictable decrease in overall classification performance and a slight decrease in each of the individual classes except pasture, which for some reason had an 8% increase in classification performance. The band 2, 4, 6 & 7 classification was very similar to the band 2, 3, 4, & 5 classification except for pasture which was much lower for the simulated Landsat channels. Comparison of the classification results using wavebands 2, 4, 6, & 7 and 2, 4, & 6 would seem to indicate the importance of the thermal channel for effectively identifying tupelo. However, the simulated Landsat channels gave an 82% classification of tupelo! Perhaps it is a case of <u>either</u> channel 3 or channel 7 being critical for tupelo. This is being investigated further.

At present, a total of 19 separate classifications have been run using various combinations of channels and data sets and training statistics. The overall classification accuracy along with the type and file locations of these classifications are summarized in Table 4. A complete summary of these classifications and their significance will be included in the final report upon completion of the entire analysis sequence.

Table 4. Classification Results Synopsis.

[Overall Performance, GML Classifier, and also the Results Location, (Tape/File)]

		Test Data	
Wavebands[1/] Used	Training Data	Supervised Training Stats	MCB Training Stats
All 7	99.1 5910/2	88.9 5910/7	87.0 5910/12
2,4,6,7	97.7 5910/1	85.1 5910/8	84.5 5910/13
2,4,5,7	98.1 5243/14		
2,4,6		84.0 5910/9	84.6 5910/14
2,3,4,5		87.1 5910/19	

[1/] Waveband Designation	Wavelength (μm)	Spectral Region
1	0.45 - 0.52	Visible
2	0.52 - 0.60	Visible
3	0.63 - 0.69	Visible
4	0.76 - 0.90	Near IR
5	1.00 - 1.30	Near IR
6	2.08 - 2.35	Middle IR
7	10.4 - 12.5	Thermal IR

Additional classifictions using this 1979 data and various combinations of channels will be run to develop a better understanding of the interrelationship between the various cover types and their spectral response in the various wavelength regions.

2. Analysis of the 1980 Data set

Supervised training statistics have been generated for the 1980 data set, and the Sample Bock test areas have been defined. Classifications of both the training and test data have begun using all eight channels of data obtained in this 1980 data set. Results obtained with the 1979 data analysis will be verified using similar waveband combinations on the 1980 data set during the next month.

B. Analysis of the Radar Data

1. Digital Overlay of SAR Data

The digital overlay of the HH and HV polarized SAR data has been successfully completed. However, before the data was overlayed several obstacles were encountered during the procedures.

An initial attempt to overlay the two data sets using an AFFINE program was not successful. The AFFINE program is a two-dimensional linear least squares fit program. It fits two 3 term polynomials to two-dimensional control points. The 19 control points used in the AFFINE program were identified throughout the flightline using an IRA program. The IRA program is an image correlation program which implements several methods. The overall results from the least squares fit were given in terms of RMS (Residual Mean Square) errors.* The overall line RMS error was greater than 0.5 and the overall column

RMS error was greater than 6.0 (RMS errors less than .5 are considered to be a good estimators). Therefore, it was determined that a linear least squares fit was not suitable for overlaying the SAR data sets.

Using the same control points, a biquadratic least squares polynomial fit (BIQUAD) program was applied. This program fits a 6 term polynomial for each of two dimensions to the control points, and point and RMS were computed. The overall line and column RMS errors were greater than 0.5 and 3.0 respectively, which was still not acceptable.

From these two attempts, it was determined that the two SAR data sets contained a curvelinear orientation with more than one inflection point between the data sets. This type of orientation may have developed through a combination of variables, possibly involving the movement of the aircraft during flight or the optical-digital recording procedures of the final data set. To compensate for the orientation differences, the data along the flight line was divided into separate blocks.

The data was initially broken up into two blocks with the data being separated just below the city of Camden. Over 30 control points were located in each block using the IRA program. The BIQUAD program was applied to each block and RMS errors were calculated. Table 5 gives the RMS errors for each block. These RMS errors were still not deemed to be suitable for overlaying the data sets.

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*Residual mean square (RMS) is an unbiased estimator of σ^2 for the least squares model.[1/]

Table 5. RMS errors for blocks A and B.

Block	Overall RMS Error Line	Column
A*	0.492	0.769
B**	0.695	1.629

*A - represents area above the separation line

**B - represents area below the separation line

Each block was then divided in half forming a total of four blocks, each representing approximately a quarter of the data set. Over 30 control points were located in each of the blocks using the IRA program. The BIQUAD was then applied to each block with RMS errors being calculated (see Table 6).

Table 6. Results of biquadratic least squares fit.

Block	Maximun Acceptable Linear Error	Overall RMS Error Line	Column	Number of Accepted Checkpoints
A1	1.5	0.484	0.487	20
A2	1.5	0.425	0.491	20
B1	1.5	0.486	0.488	21
B2	1.9	0.639	0.864	15

These results indicate that blocks A1, A2, and B1 can be overlayed using their independent biquadratic functions. Although block B2 did not have an RMS error of less than 0.5, rather than divide the block into smaller units or delete it from further analysis, it was decided that the data in the block would be overlayed using the biquadratic function generated. Special attention will be given to this southern-most block during the analysis, since it will have a significantly larger RMS error than the northern three blocks.

To facilitate the development of the statistics for the SAR data, the four blocks have been combined into a single data set (i.e., simulated flight line). The recombining of the blocks is done by visually locating overlapping points and reassigning the starting line and column locations.

2. Qualitative Interpretation of Radar Imagery

a. Poster Paper Presentation

The poster paper entitled "Radar Imagery for Mapping Forest Cover Types" by Douglas J. Knowlton and Roger M. Hoffer was presented at the 7th International Symposium on Machine Processing of Remotely Sensed Data, Purdue University. A copy of the written paper submitted for inclusion in the Proceedings of this symposium is attached to this report as Appendix A. The poster paper will also be presented during the student session of the 1981 ASP-ACSM Fall Technical Meeting (September 9-11) in San Francisco.

b. Identification of Cover Types

The identification of cover types on the SAR imagery has been successfully completed. The cover informational classes that were identified are: hardwood, pine, mixed pine-hardwood, clearcut, pasture, crops, emergent crops, bare soil, urban, and water.

In a previous quarterly report (Reporting Period: December 1, 1980 - February 28, 1981), it was reported that an attempt would be made to determine which species could be identified on the imagery by age and stand density.

After a detailed interpretation of the aerial photos, followed by the field trip to the test site, it was determined that loblolly pine, slash pine, and tupelo stands were the only homogeneous stands of individual species large enough to be identified on the color IR photography. Various combinations of species of the other hardwoods were defined on the photos as identifiable heterogeneous stands during the field trip, but the radar data for these areas could not be evaluated in relation to individual species. After identifying a number of loblolly and slash pine stands on the SAR imagery, it was concluded that there was no apparent tonal difference between the stands on either the HH or the HV polarization. This was not too suprising, since these species are rather similar in their morphological characteristics. However, it was also determined that the tupelo stands and the heterogeneous hardwood stands could not be effectively differentiated on either polarization of the SAR data. Therefore, for purposes of interpreting the SAR data in relation to forest cover types, we concluded that we would have to group the two pine species into one informational class, and the tupelo and other hardwood species would need to be grouped into a single hardwood informational class.

Only a few stands of a single cover type with stand densities of 30-70 percent could be identified on both the IR photography and SAR imagery, the large majority of forest stands having a 70-100 percent stand density. Those stands that did have different stand densities could be separated on the SAR imagery. However, due to a lack of sufficient numbers of stands having low to intermediate levels of stand densities, it was determined that a reliable evaluation of the value of the SAR data to delineate a cover type according to stand density could not be performed. Such an evaluation should be pursued in future studies.

3. Quantitative Analysis of SAR Data

To initiate the quantitative analysis of the HH and HV polarized SAR data, a number of training fields representing the various cover types were selected on each data set. Statistics were computed for each field and their respective information class.

The results from the preliminary analysis indicate that there is a high variance associated with each class except for water and bare soil. There was a distinct difference between the spectral means of the hardwood and pine information classes on the HH data - a result which was anticipated from the qualitative analysis. However, there was also a significant difference between the means of the two spectral classes on the HV data, which had not been indicated by the qualitative analysis.

The large variances for most spectral classes suggests that while the means might be statistically separable, a significant overlap may exist between the classes which could introduce a significant amount of classification error.

The overall range of values between the spectral classes is relatively small when compared to the possible range of values, particularly for the HH polarized data. Additionally, the quantitative values of many cover types, especially hardwood, are much larger on the HV polarization than the HH, thereby indicating the relative nature of the digitized data values.

Another important characteristic of the data is the quantitative effect of look angle in certain areas. The mean values of the spectral classes in the areas with larger look angles are much greater than the means of the same cover type in other areas having steeper look angles. This characteristic of the data will require close attention during the quantitative classification of the data.

C. Field Trip

Ellen Dean, Doug Knowlton, and Roger Hoffer conducted an intensive field investigation of the test site during the period from July 19 to July 22. Upon arrival at the test site area, arrangements were made for a flight over the test site in a light aircraft during the second day of the field work. The research team then proceeded to travel by car throughout the 1-S portion of the test site during the first day of the field work and the afternoon of the second day. The third day was spent in the 1-N area. Pre-selected locations throughout the test site (based upon analysis of the aerial photography, scanner data and radar data) were visited. In addition, frequent stops were made to identify species mixtures of the forest cover types, stand characteristics and other features of significance within the test site area. Stands of slash pine and loblolly pine were located and identified throughout the flightline area.

The aircraft flight during the morning of the second day proved invaluable, in that many of the areas along the Wateree River were not accessible because they were on private land holdings and in many cases there were no roads near the particular areas of interest. A number of 35 mm color and color infrared photos were obtained during the flight for later use and study. All key points which had been pre-selected for visitation during the field trip were also checked from the air.

The results of the field trip provided a meaningful input to the data analysis sequence and have enabled the investigators to proceed with confidence concerning the identification of various cover types and cover type mixtures on the aerial photography, radar, and TMS data.

II. Problems Encountered

No unusual problems were encountered during this past quarter, other than the geometric distortions in the two polarizations of SAR data. As described in the report above, this difficulty in accurately overlaying the dual polarizations of the SAR data has been satisfactorily resolved.

III. Personnel Status

The following personnel committed the respective percentages of time to the project during the past quarter:

Name	Position	Ave. Monthly Effort(%)
Dean, Ellen	Research Associate	92
Hoffer, Roger	Principal Investigator	63
Knowlton, Doug	Research Associate	92
Prather, Brenda	Secretary	35

IV. Anticipated Accomplishments

The following are the anticipated accomplishments for the forthcoming quarter (Sept. 1 - Nov. 30, 1981):

1) Complete the classification of the 1980 TMS data using both the GML per point classifier and the ECHO classifier.
2) Use a principle components transformation on the TMS data, and classify the data using the transformed data set using the same cover types and test data set as were used with the original TMS data (i.e., non-transformed).
3) Evaluate the effectiveness of data transformations for classifying forest and other cover types using TMS data containing several different wave bands. Make recommendations concerning effective preprocessing and analysis techniques when working with Thematic Mapper type data.

4) Complete the computer classification of dual-polarized SAR data using both the per point and ECHO classification algorithms.

5) Evaluate the effectiveness of SAR data as compared to TMS data for identifying forest and other cover types.

6) Prepare the final report summarizing the results of this research.

References

1. Neter, J. and W. Wasserman. 1974. Applied Linear Statistical Models. Richard D. Irwin, Inc. Homewood, Illinois. pp. 842.

Appendix A

RADAR IMAGERY FOR FOREST COVER MAPPING

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I. ABSTRACT

Dual-polarized, X-band Synthetic Aperture Radar (SAR) imagery was obtained from an altitude of 60,000 feet over a test area near Camden, South Carolina on June 30, 1980. The objective of this study was to determine, qualitatively, the value of the SAR imagery for identifying various forest cover types. In analyzing the HH and HV polarization images, particular attention was given to the tonal and textural characteristics of the cover types involved.

The analysis of the dual-polarized SAR imagery has shown that certain forest cover features are more easily identified in one polarization than the other, while some features look very similar in both polarizations. In general, the results for this data set have shown that the overall tonal contrast between features was greater on the HH image. Neither polarization was consistently better for identifying the various forest cover types examined. These results suggest the usefulness of a dual-polarized SAR system for mapping forest cover.

II. INTRODUCTION

Tremendous progress has been made over the past decade in demonstrating the potentials and limitations for utilizing data in the optical portion of the electromagnetic spectrum for identifying and mapping various earth surface features, including major forest cover groups (deciduous and coniferous) and individual forest cover types. With the continual improvement and interest of sensors that obtain data at wavelengths beyond the optical portion of the spectrum, (i.e., Synthetic Aperture Radar (SAR) systems), additional data sources are becoming available.

Radar systems have several unique advantages over optical systems. These advantages include the capability to penetrate clouds, to be operated day or night, and to obtain imagery in which the tone and texture characteristics are related to the dielectric constant and physionomic properties of the cover types present. The side-look angle of radar systems also provides some characteristics to the data which are not found in other remote sensor systems. Because of the different and perhaps unique characteristics of radar data, a key question is raised: can radar systems provide more effective data for differentiation of forest cover types and density of forest stands than is obtained in the optical portion of the spectrum? Earlier work in the mid-1960's with K-band imagery showed that some vegetative cover types could be differentiated, and that differences were sometimes apparent in cross-polarized data (Morain and Simonett, 1966, 1967). However, these early studies had not involved X-band data, and did not indicate which polarization provided the best capability for discriminating among forest cover types.

III. OBJECTIVE

The objective of this investigation was to determine, qualitatively, the value of dual-polarized, X-band SAR imagery for identifying various forest cover types.

IV. MATERIALS AND METHODS

A. INFRARED AERIAL PHOTOGRAPHY

The photo-interpretation was conducted using 1:40,000 scale color infrared photography obtained on August 29, 1980. Although some changes had occurred in the agricultural cover types between June 30 when the SAR data had been obtained, the forest cover types obviously would not change, so the difference in collection dates between the SAR imagery and IR photography were not considered to be significant for the purposes of this study.

It should be noted that color IR photography was obtained when the radar data had been collected (June 30) and again on July 2; however, both of these sets of color IR photography contained such a large portion of cloud cover that they could not be effectively utilized for photo-interpretation purposes.

B. SAR IMAGERY

The SAR imagery utilized for the study was obtained by NASA's APQ-102 side-looking radar mounted on the RB-57 aircraft. The aircraft was flown at an altitude of 18,000 meters (60,000 feet). Since the radar antenna was mounted on the left side of the aircraft flying to the north so that the look direction was to the west. This created radar shadow effects similar to the sun-shadow effects observed on the photography obtained in mid-morning.

The radar system is a fully focused SAR imaging system. A horizontally polarized pulse of energy of 9600 MHz +/- 5 MHz (commonly known as X-band) is transmitted by the system, with the returning energy being recorded on separate holograms as horizontally (HH) and vertically (HV) polarized responses. These holograms were processed through an optical correlator by Goodyear Aerospace Corporation, under contract to NASA, and the resulting images were recorded on positive film. For these conditions of data collection and processing, the range and azimuth resolutions depicted by the imagery are just under 15 meters. For interpretation purposes, the original transparencies were enlarged to produce positive prints having a scale of both 1:80,000 and 1:50,000, which were then used for the interpretation and analysis.

C. IDENTIFICATION OF FOREST COVER TYPES

Various forest cover types were identified on color infrared photography using standard photo-interpretation techniques supplimented by field observation data. The forest cover types identified on the aerial photography included old growth hardwood, second growth hardwood, water tupelo, pine (primarily slash pine although some areas of long leaf and loblolly pine also occurred). In addition, there were areas where the forest had been clearcut, as well as pasture areas, crop land, areas of exposed agricultural soil, and water features that were identified on the photography.

D. IDENTIFY AND COMPARE FOREST COVER TYPES ON SAR IMAGERY

Based upon the photo interpretation results, stands of the various forest and other cover types were located on both polarizations of SAR imagery. The two polarized images then were analyzed to determine if tonal and/or textural differences existed between the cover types. The tonal characteristics were determined by evaluating the discrete or representative gray tone for each cover type. The textural characteristics were determined by evaluating the relative speckle for each cover type. The tonal and/or textural differences between the HH and HV polarized images then were compared and evaluated for each cover type. An attempt was made to determine why particular differences did occur.

V. RESULTS

The initial analysis of the SAR imagery depicted a banding effect which was particularly noticable on the HH image. A much more subtle tonal variation that seemed to be related to the range angle could be observed, particularly on the HV image. Both of these effects can be observed in Figure 1, which shows the data for both polarizations of the entire flight line. Both effects had a significant impact on the ability of the interpreter to determine various cover types using the radar imagery alone. Both the banding and tonal variation effects were not due to any characteristics of the ground terrain, but were due strictly to variables inherent in this particular data collection and processing system. Both effects were also quite evident on several other data sets obtained at the same time over other flight lines. It should be pointed out that although the HH polarization had greater tonal contrast, the overall lack of contrast of the HV imagery may have been due to the parameters involved in obtaining and processing this particular data set and not necessarily an inherent characteristic of HV polarized imagery.

Deciduous forest cover appears to have a characteristic light tone on the HH image, whereas on the HV image these deciduous areas have a darker tone. This was most evident in the area of the alluvial plain where dense deciduous forest cover was located (see Figure 2). The dense deciduous forest stands located in small ravines were identified on both polarizations due to their distinctive spatial patterns (see Figure 3). These patterns were highlighted because of the high response given by the deciduous forest cover growing within the ravines and perhaps

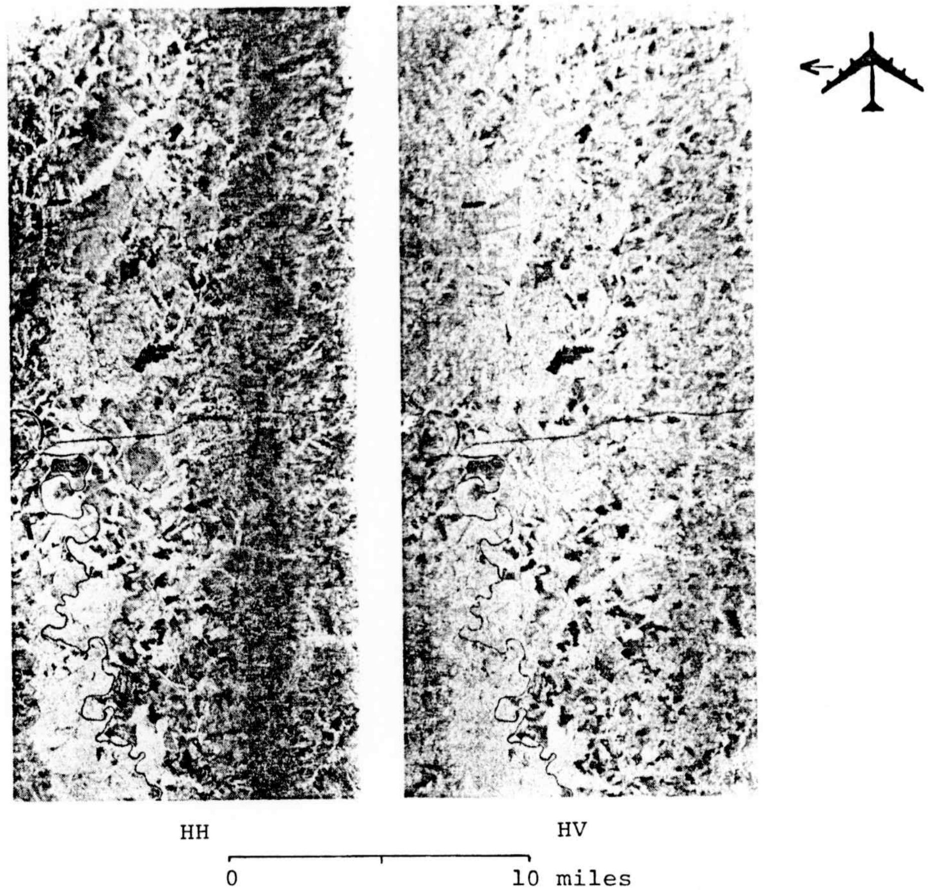

Figure 1. Dual-polarized X-band SAR imagery of the test site near Camden, S.C.

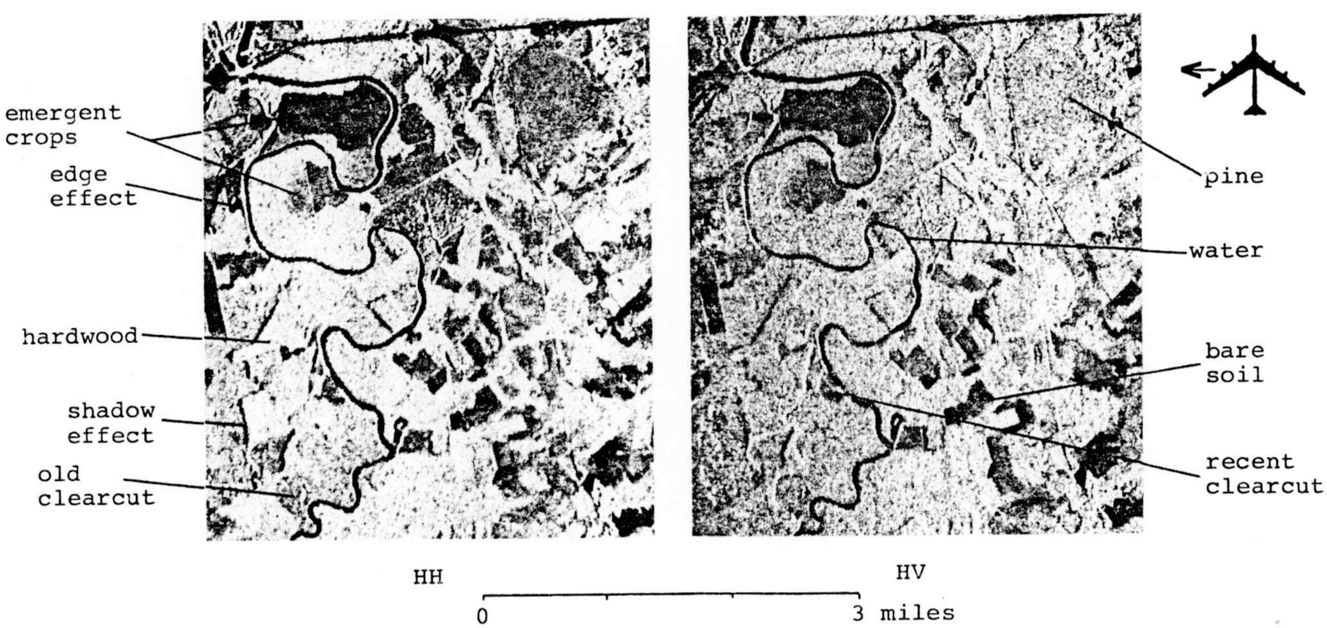

Figure 2. Enlargement of dual-polarized imagery showing tonal differences between deciduous and coniferous forest cover.

also highlighted in part by the slopes of the ravines per se acting as angular reflectors. Due to the contrast difference between the two polarizations these patterns were more distinctive on the HH image than on the HV image.

One of the most distinct differences observed in the imagery was a difference between deciduous and coniferous forest cover that could be observed as a function of polarization. As shown in Figure 2, there is very little difference between deciduous and coniferous forest on the HV image. On the HH image however, the deciduous forest cover has a distinct light tone whereas the coniferous forest cover has a relatively dark tone. Thus, deciduous and coniferous forest cover can be easily separated on the HH image due to the distinctive tonal differences that are very difficult to separate on HV image.

Other features such as older clearcuts and fields having emergent vegetation tend to look very similar in both tone and texture on both polarizations. Although recent clearcuts are very dark in tone in both polarizations as compared to the surrounding forest cover, they are easier to separate from coniferous and mixed cover types on the HV imagery. Water and smooth bare soil features have a distinctive black appearance on both polarizations due to the specular reflectance of the emitted radar signal away from the antenna. However, by using the shapes and speckling characteristics of some agricultural fields, water and fields with bare soil usually can be separated.

It should be noted that of the features identified on the color IR photography, several could not be identified on the SAR imagery. Old growth and second growth hardwood stands could not be separated. Water tupelo was very easy to identify on the color IR photography because of its distinctive color, but could not be identified at all on the SAR imagery. Table 1 summarizes the tonal and textural characteristics of the various forest and other cover types examined in this study. Examples of the tonal and textural characteristics are illustrated in Figure 4.

Table 1. Tone and Texture Characteristics of Various Cover Types in Relation to Polarization of the Radar Imagery.

Cover Type	Tone[1/]		Texture[2/]	
	HH	HV	HH	HV
Hardwood	white	light gray	grainy	grainy
Pine	dark gray	gray	speckled	speckled
Mixed Pine-Hardwood	dark gray	gray	grainy	speckled
Clearcut	dark gray	dark gray	grainy	grainy
Bottomland scrub	dark gray	dark gray	speckled	speckled
Pasture	dark gray	dark gray	grainy	grainy
Emergent Crops	dark gray	dark gray	grainy	grainy
Bare Soil	black	black	smooth	smooth
Water	black	black	smooth	smooth

[1/] Tone: (A) black; (B) dark gray; (C) light gray; (D) white

[2/] Texture: (1) smooth; (2) grainy; (3) speckled

(These letters or numbers indicate the examples of these descriptions shown in Figure 4)

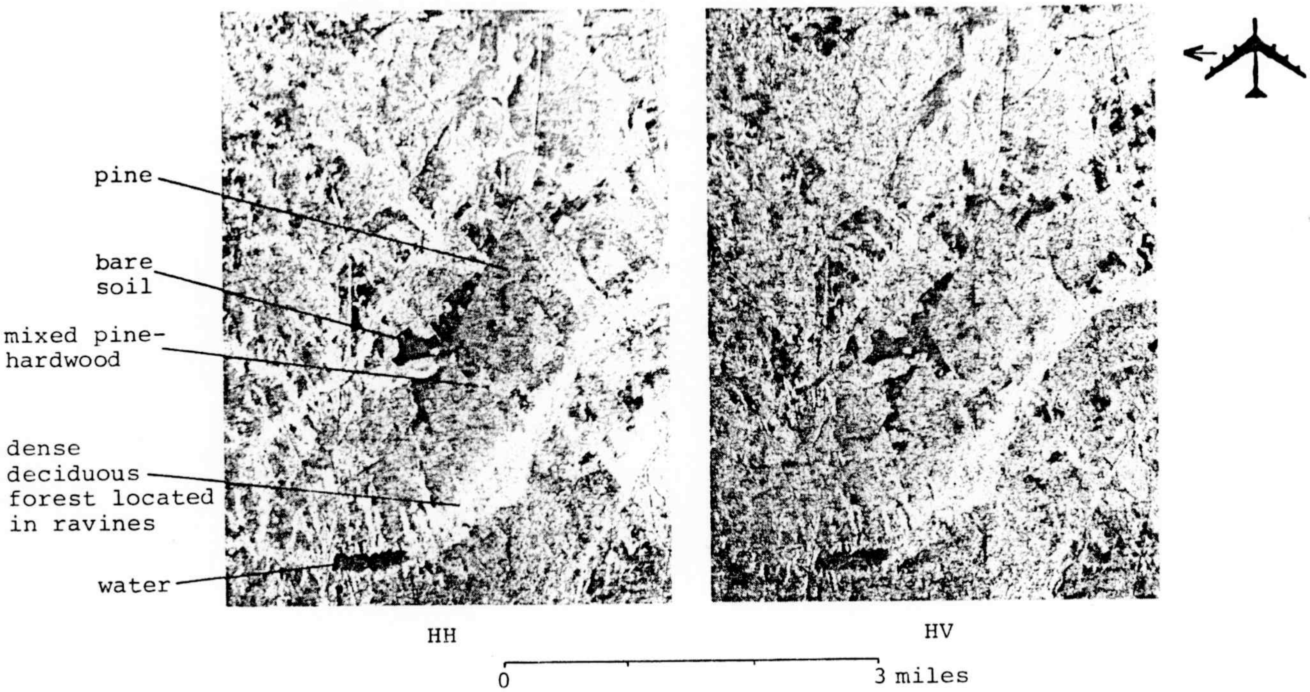

Figure 3. Example of radar imagery indicating distinct apperance of vegetated ravines on HH polarization.

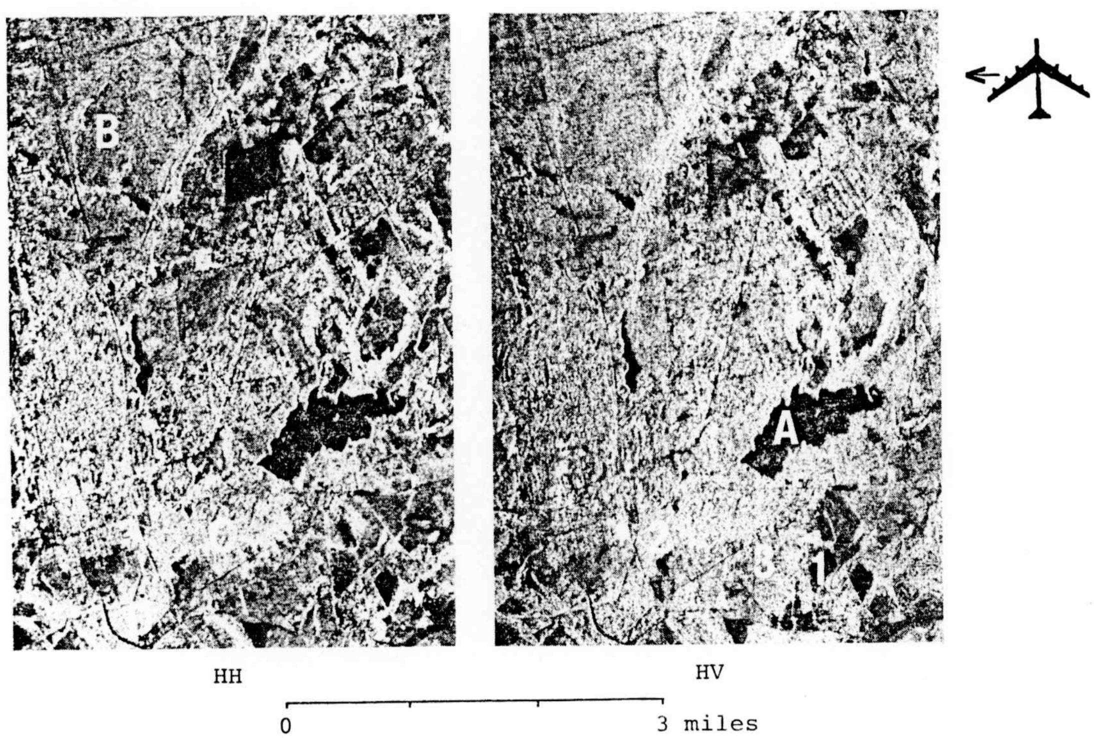

Figure 4. Example of tonal and textural characteristics of SAR data (see Table 1).

VI. SUMMARY AND CONCLUSIONS

The qualitative analysis of the dual-polarized SAR imagery has shown that certain forest cover features are more easily identified in one polarization than the other, while many non-forest features look very similar in both polarizations. Discriminating between coniferous stands and deciduous stands was easier on the HH image than on the HV image. However, this does not infer that the HH polarized image is better. The shadow and edge effect due to extreme differences in vegetation height help delineate the boundaries of clearcuts, and are much more prevalent on the HV image. Neither polarization is consistently better for identifying the various forest cover types examined.

The following points summarize the results obtained during the analysis:

- o Deciduous forest cover is easily identified on the HH image due to a distinctive light tone, whereas on the HV image these areas have a darker tone. (Figures 2 and 3)
- o Coniferous forest cover is dark in tone on the HH image and is somewhat lighter in tone on the HV image. (Figure 2)
- o Deciduous and coniferous forest cover are easily separated on the HH image due to their distinctive tonal differences, but are difficult to separate on the HV image. (Figure 2)
- o Dense deciduous forest stands located in ravines are easily identified on both polarizations because of the topographical pattern being highlighted by the response of the deciduous stands and partially highlighted by the slopes acting as angular reflectors. These patterns are more distinctive on the HH image than on the HV image. (Figure 3)
- o Older clearcuts and fields having emergent vegetation tend to look very similar in both tone and texture on both polarizations. (Figure 2)
- o Water and smooth bare soil features have a distinctive black appearance on both polarizations due to the specular reflectance of the emitted radar signal away from the antenna. (Figure 2)
- o There is a distinctive banding effect on the HH image and a tonal variation related to range angle on the HV image which impact the ability of the interpretor to determine various cover types. These effects were also evident on other data sets of different flight lines. (Figure 3)

These results suggest the usefulness of a dual-polarized SAR system for mapping forest cover. The next phase in the analysis of this data will involve digitization of the imagery using a scanning microdensitometer, followed by a quantitative evaluation of a spectral/spatial pattern recognition algorithm (ECHO) to classify forest and other cover types.

VII. REFERENCES

Morain, S. A. and D. S. Simonett. 1966. Vegetation Analysis With Radar Imagery. Univ. of Kansas, Lawrence, Kansas. CRES Report No. 61-9. 18 pp.

___ 1967. K-band Radar in Vegetation Mapping. Photogramm. Engr. 33: 730-740.

VIII. ACKNOWLEDGEMENT

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