Reprinted from

Eleventh International Symposium

Machine Processing of

Remotely Sensed Data

with special emphasis on

Quantifying Global Process: Models, Sensor Systems, and Analytical Methods

June 25 - 27, 1985

Proceedings

Purdue University
The Laboratory for Applications of Remote Sensing
West Lafayette, Indiana 47907 USA

ANALYSIS OF DATA ACQUIRED BY SHUTTLE IMAGING RADAR SIR-A AND LANDSAT THEMATIC MAPPER OVER BALDWIN COUNTY, ALABAMA

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I. ABSTRACT

SIR-A and Landsat 4 TM data acquired over a forest scene located in Baldwin County, Alabama were coregistered, processed and analyzed. The SIR-A images was acquired on November 14, 1981. The Landsat 4 TM data acquired on October 27, 1982 was selected as it was the earliest data set available and seasonally compatible to SIR-A data acquisition date. The SIR-A image was first digitized and then registered to TM data base to form a SIR-A/TM multichannel data set with 30m by 30m pixel size.

A variety of data processing and analysis techniques were employed. For observing data characteristics, spectral signature plots, and histogram analysis of the data were employed. For multisensor data classification and accuracy evaluation, a supervised signature development program and the maximum likelihood classifier were employed.

The results of data analysis are as follows: (1) Possibly the most significant finding, radar returns from pine forest classes highly correlated with tree ages with correlation coefficient of 0.93. This result suggests the potential utility of microwave remote sensing for forest biomass estimation. (2) the use of TM/SIR-A data set improved classification accuracy of the seven land cover types as compared with the TM-only data set. This finding suggests the usefulness of SIR-A data for improving forest-related cover type mapping and area estimation when combined with Landsat 4 TM data. (3) The TM/SIR-A classified data support the finding that microwave data appear to be correlated with differing bottomland hardwood forests as associated with varying water regime (i.e., wet vs dry).

II. INTRODUCTION

This study was conducted as part of the research tasks under the Radar Land Cover Analysis Program. The Radar Land Cover Analysis objective is, through utilization of multisensor data, to gain a basic understanding of the measurements and data characteristics in the visible-IR-microwave regions of the electromagnetic spectrum associated with specific surface features and cover types. Since the results of analysis of data acquired by Shuttle Imaging Radar (SIR-A) and Landsat Multispectral Scanner (MSS) over the study area were reported elsewhere this study focused on the analysis and evaluation of SIR-A and Landsat 4 Thematic Mapper (TM) data (Wu, S.T., 1984, pp. 550-557). The Landsat 4 TM launched in July 1982 is a sensing system with characteristics that are significantly more advanced than those of the MSS. It collects data in seven bands or channels which, in general, have a narrower spectral band width than do the four channels on the MSS. This increase in number of channels and spectral resolution of the TM over the MSS permits data from the sensor to be used for a wider assortment of applications than that collected from the MSS. Also, TM data have better spatial resolution than the MSS data. A recent investigation which used TM data for classification of forest stands in Baldwin County, Alabama, have shown better results in delineating specific forest cover types than those previously obtained from analysis of MSS data (Hill, C.L., 1983, pp. 110-121). In view of the above, this investigation includes: (1) the delineation of surface features, cover types, and conditions probably discernible through the use of SIR-A and TM data, with the emphasis placed on forest-related land cover parameters, and (2) a determination of some physical conditions under which the SIR-A/TM approach is and is not useful.

To address the program objectives, a multisensor data set consisting of one channel of SIR-A data and four channels of TM data (Channels 3, 4, 5, and 7) was constructed. Since Channels 1, 2, and 6 of TM data are relatively insensitive to forest-related land cover presented in the study area as determined by Hill these channels were not used (Hill, C.L., 1983, pp. 110-121). Data processing tasks included preprocessing of SIR-A data and resampling and registration of SIR-A data to the TM data base. Data analysis included both the direct visual comparison of SIR-A and TM data and supervised signature development and classification through spectral pattern recognition. The classified data and field verification plots were used to evaluate the accuracy of classification of forest-related land covers.

III. STUDY AREA AND DATA SOURCES

A forested study area in Baldwin County, Alabama was selected to evaluate SIR-A and TM data characteristics (Figure 1). The study area, located in southwest Alabama, is part of the Gulf Coastal Plain physiographic region referred to as the Lower Coastal Plain. This particular area is representative of the longleaf-slash pine and oak-gum-cypress forest ecosystem found throughout the extreme southeastern United States. The longleaf-slash pine biome is typified by the presence of longleaf pine (Pinus palustris Mill) and slash pine (P. elliottii Engelm). Other southern yellow pine found throughout the area include loblolly pine (P. taeda L.), shortleaf pine (P. echinata Mill), and spruce pine (P. glabra Walt). The understory components of the longleaf-slash pine forest include various deciduous and evergreen broadleaf plants. Species commonly found in the oak-gum-cypress type include various oaks (Quercus spp.), American holly (Ilex opaca Ait), sweetbay magnolia (Magnolia virginicus L.), and sweetgum (Liquidambar styraciflua L.) on the drier sites. The wetter areas include water tupelo (Nyssa aquatica Marsh), red maple (Acer rubrum L.), bald cypress (Taxodium distichum Rich), Atlantic white cedar (Chamaecyparis thoides L.), and various species of ash (Fraxinus spp.).

The topography of the study area is flat to gently rolling, with elevations ranging from sea level to over 200 feet. The lower elevations encompass the major drainage basins of the Mobile/Middle/ Tensaw River complex, the Styx River water system, and the Perdido River system. The majority of the upland portion of the study area is occupied by pine forest. Very little of the area supports agriculture, with most of the pine forest managed by forest industries.

The composition of pine stands may range from uneven-aged mixed pine-hardwood to even-aged pine plantations. The upland drains contain various species of broadleaf evergreen shrubs, deciduous hardwood, and from 25% to 75% "turpentine" (old growth) pine. Fire is an important management tool in southern pine production; controlled burning is used to maintain the pine composition in the managed pine stands. A marked difference in understory presence can be noted when comparing burned versus unburned stands. In general, the study area contains a diversity of timber types, each maintained with various selections of forest management treatments. As a result, the study area is ideal for testing and evaluating SIR-A and TM data characteristics in a forest regime.

The SIR-A images were acquired over the study area on November 14, 1981, on shuttle orbits No. 17 (ascending pass) and No. 21 (descending pass). Since the ascending pass image did not cover the bottomland hardwood forest, which is one of the cover types of interest, and since it contained data characteristics similar to those of the descending pass image, only the descending pass image (Figure 2) was selected for data analysis and classification. In Figure 2, several distinguishable surface features are designated with coded letters as follows:

B - bridge
C - City of Mobile
F - agricultural field
H - Interstate 10 highway
N - natural pine
P - pine plantation
R - river
T - small town
V - very densed mixed pine hardwood
W - forested wetland

The optically correlated image covered a swath of 50 km with image resolution of 40m by 40m. The image area given in Figure 2 was approximately 20 km cross track by 50 km along track. The near range part of approximately 30 km cross track was not used. Since Baldwin County is located in coastal flat land with very slight elevation variation, the incidence angle, after earth curvature correction, is 50 degrees.

The Landsat-4 TM data acquired on October 27, 1982 (Scene ID #4010315533), was selected because it was the earliest data set available and seasonally compatible with the SIR-A data acquisition date (i.e., approximately one year between the dates of data acquisition). Because of this, it was assumed that very similar or compatible forest vegetation conditions existed on the dates of SIR-A and TM data acquisition.

IV. DATA PROCESSING

The SIR-A image selected was of relatively good quality. It was necessary to digitize the image film, because the relative tonal variations of various surface features in the film could be expressed quantitatively and the SIR-A digital data set could then be directly combined with TM data.

In the digitization process, appropriate brightness density scales were selected to preserve the dynamic range of the image and a compatible aperture size was used to prevent degradation of the SIR-A acquisition resolution of 40m. The grey scale that represented tonal variation of image film was converted to digital levels of 0 to 255, where 0 and 255 signified the darkest and the lightest image tone, respectively. After digitization, the L-band SIR-A data contained a pixel size of 20m by 20m. The digitized SIR-A data were filtered with a 3 by 3 averaging window to reduce the speckled noise effect (Wu, S.T., 1980, pp. 293-309). A scene-to-scene registration was performed to form a SIR-A/TM multichannel data set (Junkin, B.G., et al., 1981). The coregistered data set was composed of 30m by 30m pixels. For observing data characteristics, spectral signature plots and histogram analysis of the data were emloyed. For multisensor data classification and accuracy evaluation, a supervised signature development and the maximum likelihood classifier were employed for the TM singularly and for the combined SIR-A and TM data sets.

V. SCOPE OF INVESTIGATION AND FOREST TYPE

Since the results of analysis of data acquired by SIR-A and Landsat MSS over the study area were reported elsewhere, this study focused on the analysis of SIR-A and Landsat-4 TM data and the scope of investigation was restricted as follows: (1) A linear regression analysis was applied to the data of 27 pine plantation plots with different years of planting ranging from 1980 to 1971. This was to determine whether SIR-A data can be used to correlate with forest biomass. (2) MSS data significantly improved the classification accuracy of urban/inert, cropland/pasture, and water classes; therefore, there was no need to reexamine these land cover classes in the SIR-A/TM data analysis. (3) MSS- only data resulted in relatively lower classification accuracy for the three pine forest classes. They are the forest cover types of interest for SIR-A/TM data analysis; thus, the pine forest and the bottomland hardwood forest cover types were to be the focus of the SIR-A/TM data analysis. (4) Only four TM channels (3, 4, 5, and 7) were utilized, since these channels indicated spectral separation of several forest cover types of the study area (Figure 3).

Since SIR-A/TM data analysis focused on forest-related land cover, the seven categories of cover type selected for data analysis are described as follows: (1) Young pine plantation, which coincides with pine regenerated areas less than 8 years old; (2) slash pine plantation, comprised of medium-aged slash pine and thus related primarily to dense, even-aged pine plantations 10-20 years old; (3) natural pine, predominantly uneven-aged stands of longleaf, loblolly and partially thinned slash pine; (4) mixed pine/hardwood, consisting predominantly of hardwood stands with scattered pine (the low land drainage or riverine preference of these hardwood stands provides useful spatial information for delineation against other forest types); (5) dry bottomland hardwood, consisting of oak, sweetgum, and red maple type deciduous forest situated on slightly elevated dry ground; (6) wet bottomland hardwood, consisting of oak, sweetgum, and red maple type deciduous forest situated in relatively lower wet ground (the ground may be inundated with backed-up water by the tide or flooded when the level of river water is very high), and (7) non-forest, consisting of marsh, shrub, or clear-cut with regrowth.

VI. RESULTS OF DATA ANALYSIS

A. DATA CHARACTERISTICS

Prior to a specific analysis of the data characteristics of forested land cover classes previously described, an analysis of data characteristics over the study area was made; the results are shown in Figure 4. In Figure 4, the range of variation, expressed in digital number (DN), is defined as the range in which more than 99.5% of the data reside. For example, the SIR-A data contained less than 0.5% of data with a DN larger than 186 and smaller than 54; the data within these bounds had a mean DN of 119.18. In the case of TM data, there was some similarity between the distribution of Channel 4 and 5 data, but Channel 5 data contained a larger range of variation than that of Channel 4. There was also some similarity between the distribution of Channel 3 and 7 data, with Channel 7 data exhibiting a lower DN and wider range of variation than that of Channel 3. This kind of data distribution indicates that there is some correlation between Channels 4 and 5, and between Channels 3 and 7. Correlation between SIR-A and TM data is not observed. The blips of Channels 4, 5, and 7 distribution at the very low end (DN from 0 to 20) reflect the water class signature contained in the data set.

B. REGRESSIONAL ANALYSIS OF PINE PLANTATION DATA

To test the hypothesis that SAR data can be used to estimate forest biomass per unit area, the pine plantation plots were grouped according to the year of planting, as listed in Table 1. Forest vegetation maps, compiled by the International Paper Company, which manages the pine plantation sites, were used as a base to obtain the information regarding the year of planting, pine species, and area coverage. Twenty-seven plots were selected from the maps for plantings ranging from 1971 to 1980. These plots were input as a polygon data file from which SIR-A data were extracted, including the number of pixels and the mean DN, and the results were tabulated. From Table 1, it appears that the mean DN, which is proportional to radar return signal strength, seems to correlate with the age of pine plantation. It appears that the older the pine plantation, the higher its DN. Alabama plantations contain similar silviculture practices and biophysical parameters (localities, slopes, elevation, climate, soil types, etc.), but due to annual growth, an older pine plantation, in general, will contain higher above-ground-biomass than that of a younger one. Based on this assumption, a "relative" index of green biomass (GBM) was assigned to each plot according to the year of planting; the index is listed in column two of Table 1.

A simple linear regression using the DN as an independent variable and GBM as a dependent variable resulted in the following equations:

$$GBM = -0.637 + 0.135\ DN,\ R^2 = 0.93$$

With a correlation coefficient (R^2) of 0.93, it appears that SAR DN's correlate very well with GBM. In future studies, actual green biomass instead of the index of GBM should be used to obtain a better biomass estimation algorithm.

C. SEVEN LAND COVER CLASSES SIGNATURES

The analysis proceeded further with the use of the seven land cover classes described previously. To facilitate the presentation of surface features the seven classes are designated with specific coded letters as follows:

- YP - young pine plantation
- PP - slash pine plantation
- NP - natural pine
- PH - mixed pine hardwood
- DBH - dry bottomland hardwood
- WBH - wet bottomland hardwood
- NF - non-forest

Fifty-five training sample plots were selected from the study area; the number of plots from the specific surface classes are YP = 10, PP = 14, NP = 15, PH = 3, DBH = 6, WBH = 3, and NF = 4. To help visualize the digital numbers of the seven surface features, the means and standard deviations are tabulated and plotted for the combined SIR-A/TM data as shown in Table 2 and Figure 5. The statistics shown are the merged results of the respective number of training sample plots. For example, the YP statistics used 10 training sample plots of seemingly similar surface features designated as young pine in the study area. This kind of merged statistics makes the results a better representation of such a land cover type. A close examination of these statistics helps one to better understand the discriminating power of the four TM and one SIR-A channel of the combined SIR-A/TM data set. Accordingly, the following attributes of data can be concluded from Figure 5 and Table 2:

1. The similarity between Channels 4 and 5, and between Channels 3 and 7, described previously for a general study area, also is present in the specific land cover classes. In the case of Channels 3 and 7, both curves of the means look relatively flat, with the means expressed in DN's of 20 to 28. The curves of the means of Channels 4 and 5 also look relatively flat, with the means expressed in DN's of 45 to 71.

2. A more meaningful indication of separation is the DN difference between the two land cover classes. In the case of DBH and WBH classes, the TM DN difference of 3 in Channel 5 data provided some discriminating power to separate them from each other; DN differences of less than 1 in the other three channels made these channels useless. To a greater extent, a SAR DN difference of 29 will better discriminate DBH from WBH and significantly improved the classification accuracy of DBH and WBH when SIR-A data are combined with TM data. Similar results could be expected between YP and PP, NP and PH, and PH and DBH, because they all exhibited significant DN differences between the land cover classes to be discriminated from each other. It is pertinent to point out that the wide spread of data, expressed in DN standard deviation, will decrease the discriminating power, because it produces significant overlapping data points even though the means are separated. For example, there is a DN difference of 18 between DBH and NF classes, but the high standard deviation (DN of 20 for both classes) produces a significant amount of overlapped data points and thereby renders the classes more difficult to separate. This is the reason, then, that the classification accuracy of the NF class was not significantly improved when SIR-A data were combined with TM data.

D. CLASSIFICATION RESULTS

The analysis proceeded further with the use of the coregistered SIR-A and TM data for forest-related land cover classification. Using the seven cover types described previously, a supervised training sample selection was followed by a maximum likelihood classification technique applied to the TM and the combined SIR-A/TM data (Junkin, B.G., et al., 1981). An accuracy verification of the land cover classes was conducted for the two classifications.

The test sample plots for accuracy evaluation were first randomly selected from color infrared photography and then field checked by field personnel for a detailed description of surface cover types and conditions. The test sample plots were used exclusively for accuracy evaluation; they were completely separated from the training sample plots which were used to develop spectral signatures. The classification accuracy, expressed in percent correct, for the TM and the combined SIR-A/TM data are shown in Tables 3 and 4, respectively.

The following can be concluded from the results of the accuracy evaluation:

1. The inclusion of SIR-A data in the combined SIR-A/TM data classification increased classification accuracy of all seven land cover classes and the overall data set. The increase in classification accuracy is simply due to the fact that the information available from microwaves is different from that available in the visible and infrared regions. The SIR-A dielectric properties and surface roughness characteristics add to the discrimination ability of reflected sunlight sensors (such as the TM). The largest increase is the mixed pine/hardwood class which attains classification accuracy of 52.37% correct from that of 36.87%. An increase of more than 10% in classification accuracy is attained in the dry bottomland hardwood, wet bottomland hardwood, and natural pine classes. The smallest increase is the nonforest and slash pine plantation classes, with less than a 2% increase in classification accuracy.

2. Comparison of the commission errors tabulated in both tables illustrates how the inclusion of SIR-A data improved classification accuracy. In the case of young pine, 11.25% is misclassified as natural pine, using TM data, while only 3.72% is misclassified as natural pine using the combined TM/SIR-A data. The 7.5% improvement is due to the fact that SIR-A data can differentiate different amounts of green biomass contained in the two pine classes. In the case of the two bottomland hardwood classes, the discriminating power of SIR-A data significantly decreases the commission errors of both classes and thereby simultaneously improves the respective classification accuracy. The results reveal that, when SIR-A data are highly distinguishable but TM data are heavily overlapped between two land cover classes (such as dry and wet bottomland hardwood classes), the combined SIR-A/TM data are most useful to improve classification. This result is in agreement with the finding that microwave data appear to be correlated with differing bottomland hardwood forest vegetation as associated with varying water regimes (i.e., wet vs. dry) (Wu, S.T., 1980, pp. 293-309). The reason that SIR-A data can delineate forest vegetation with wet or dry underlying surface is because the long wavelength penetration capability of a microwave sensor enables it to see through vegetation canopy, while the TM sensor only measures the reflected sunlight from the top layer of vegetation canopy.

VII. CONCLUDING REMARKS

Analysis of Landsat 4 TM and SIR-A data acquired over the Baldwin County study area resulted in the following:

1. Possibly the most important finding is that the results of regressional analysis of SIR-A data indicated that radar returns from pine plantation, as given in Table 1, may be related to forest biomass. More extensive study, in the future, is needed to explore the potential of using SAR data for forest biomass estimation.

2. The combined SIR-A/TM data set resulted in an improved classification accuracy of the seven land cover classes as compared with the TM-only data set because two sensors complement each other, as described previously. The results suggested the usefulness of SIR-A data for improving forest-related cover type mapping and area estimation when combined with Landsat 4 TM data.

3. The classification of the SIR-A/TM data set revealed that, in the case of dry and wet bottomland hardwood classes, the results support previous findings that microwave data appear to be correlated with differing bottomland hardwood forest vegetation as associated with varying water regimes (i.e., wet vs. dry) because of the long wavelength penetration (Engheta 1982, pp. 212-216).

VII. REFERENCES

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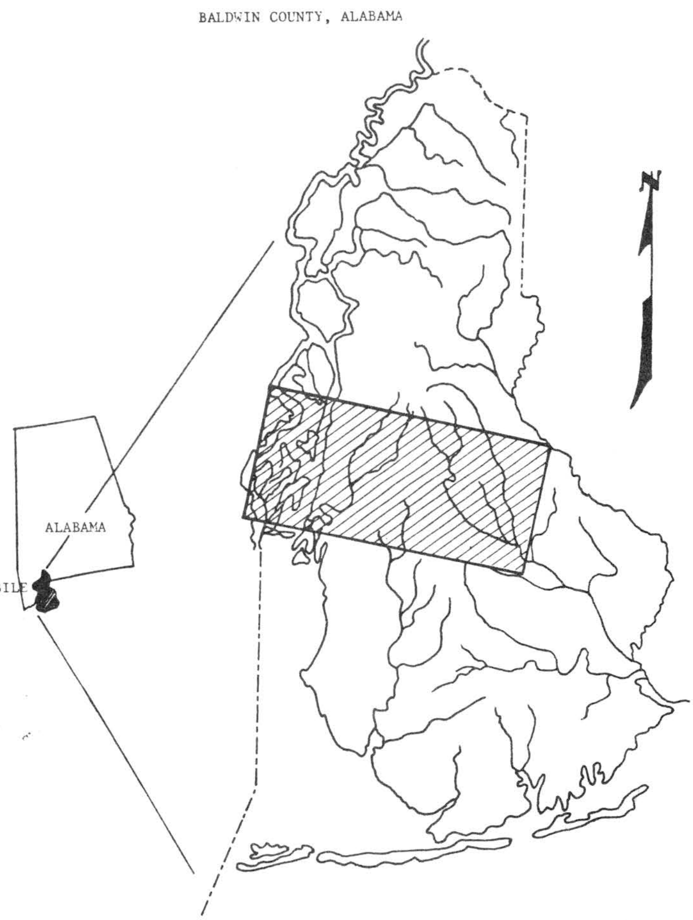


Figure 1. Location Map of Baldwin County Forest Study Area.

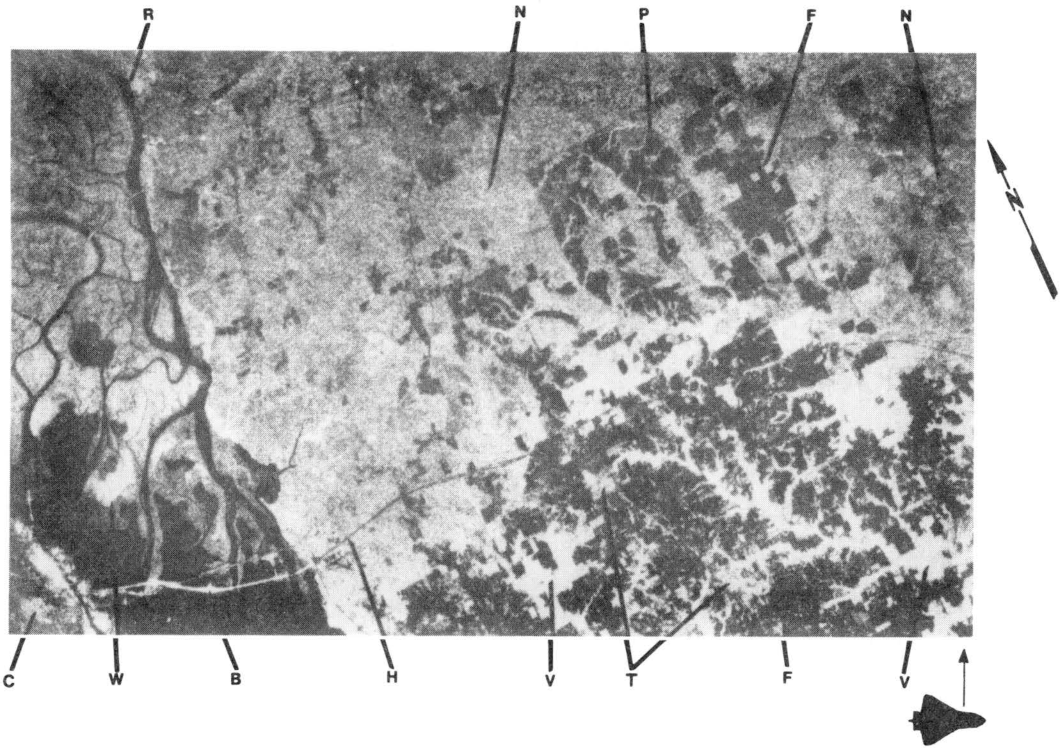


Figure 2. SIR-A L-Band HH-Polarization Image of Baldwin County, Alabama.

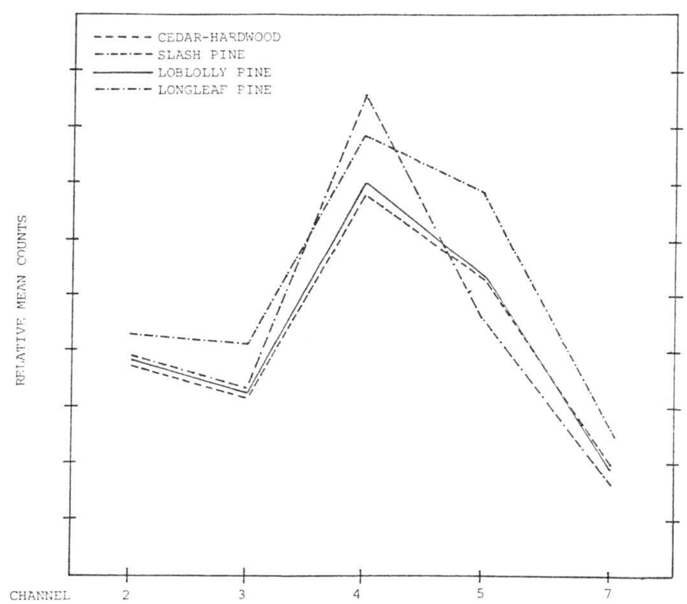
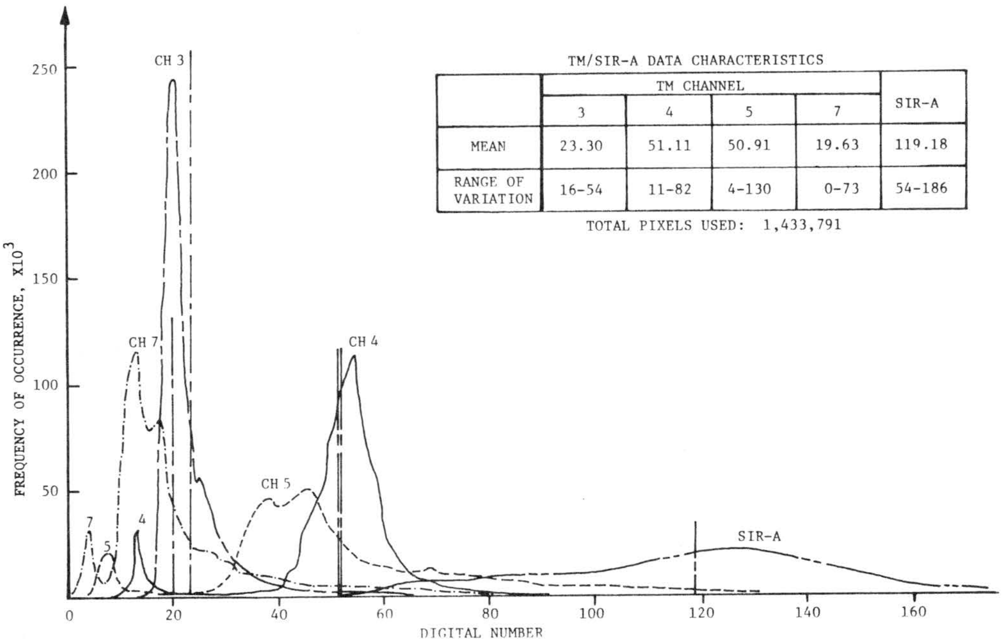


Figure 3. Channel Means Plotted for Forested Types Using Thematic Mapper Data Imaged January 15, 1983.



TM/SIR-A DATA CHARACTERISTICS

	TM CHANNEL				SIR-A
	3	4	5	7	
MEAN	23.30	51.11	50.91	19.63	119.18
RANGE OF VARIATION	16-54	11-82	4-130	0-73	54-186

TOTAL PIXELS USED: 1,433,791

Figure 4. Histogram of Combined SIR-A/TM Data from Baldwin County Alabama Study Area.

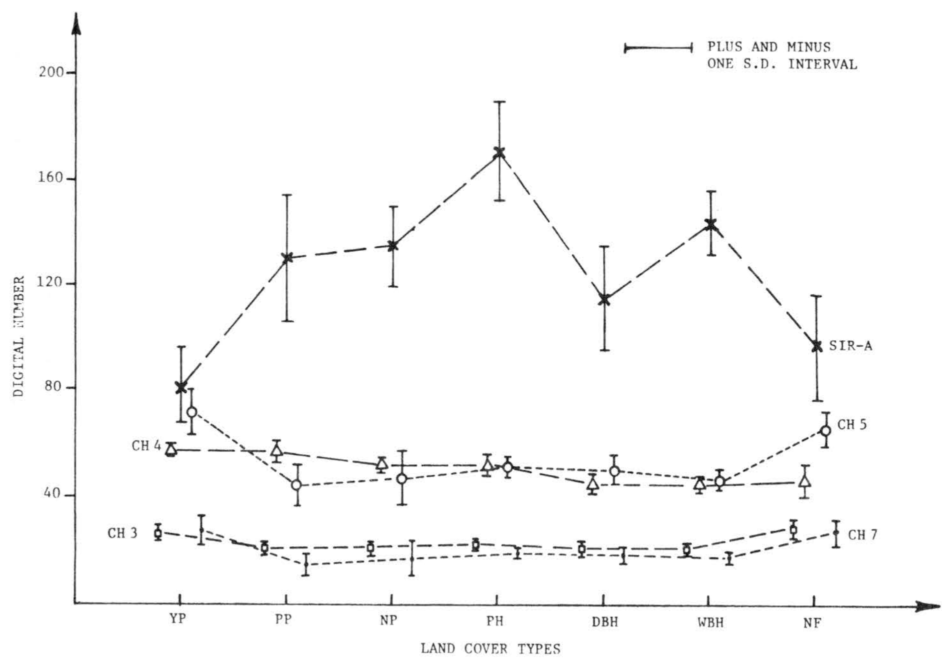


Figure 5. Means and Standard Deviations of Seven Land Cover Classes.

Table 1. Mean Digital Numbers of 27 Pine Plantation Plots Listed According to Year of Planting.

Year Planted	GBM Index	Plot No.	Individual Plot Pixels	Individual Plot Mean DN	Yearly Plot Pixels	Yearly Plot Mean DN
80	1	1	345	74.38		
80	1	2	691	74.15		
80	1	3	1231	70.33	4171	72.40
80	1	4	923	73.36		
80	1	5	981	72.17		
79	2	6	1004	78.87		
79	2	7	750	79.83		
79	2	8	377	84.21	3010	82.15
79	2	9	239	82.37		
79	2	10	640	88.70		
78	3	11	602	85.23		
78	3	12	489	81.34	1395	86.30
78	3	13	304	96.40		
77	4	14	214	93.14	906	100.62
77	4	15	692	102.93		
76	5	16	275	96.64	569	103.05
76	5	17	214	109.05		
74	7	18	845	100.85		
74	7	19	332	117.38		
74	7	20	126	104.21	2088	105.14
74	7	21	310	103.53		
74	7	22	475	105.53		
73	8	23	595	114.73		
73	8	24	395	118.74	1147	116.42
73	8	25	157	117.02		
71	10	26	266	136.79	790	143.88
71	10	27	524	147.48		

Linear Regression: GBM = -0.637 + 0.135 DN, R^2 = 0.93

Table 2. Means and Standard Deviations of Seven Land Cover Classes

Land Cover Classes	Landsat-4 TM CH 3 Mean	CH 3 S.D.	CH 4 Mean	CH 4 S.D.	CH 5 Mean	CH 5 S.D.	CH 7 Mean	CH 7 S.D.	SIR-A Des. Pass Mean	SIR-A Des. Pass S.D.
Young Pine	26.55	2.79	56.77	2.09	71.48	8.78	27.75	5.48	81.55	14.61
Slash Pine Plantation	20.78	1.78	56.13	3.60	44.79	7.79	15.17	3.65	130.57	24.02
Natural Pine	21.28	2.45	51.78	2.69	46.99	11.23	16.80	6.20	134.60	15.05
Mixed Pine/ Hardwood	22.41	1.31	51.84	2.09	51.50	3.87	18.57	1.91	170.99	18.02
Dry Bottom-land Hardwood	21.00	2.58	45.43	3.18	49.77	4.95	18.26	3.01	114.63	19.40
Wet Bottom-land Hardwood	20.90	2.85	45.03	2.84	46.86	3.51	17.30	1.52	143.49	12.29
Non-Forest	28.22	3.24	46.57	5.87	65.75	6.78	27.09	5.04	96.54	20.24

Table 3. Classification Accuracy of Landsat 4 TM Data

Ground Truth Classes	Young Pine	Slash Pine	Natural Pine	Mixed Pine Hardwood	Dry BTML Hardwood	Wet BTML Hardwood	Non-Forest
Young Pine	78.19	2.10	11.25	1.04	0.10	0.00	3.45
Slash Pine	3.14	72.47	13.43	8.47	0.45	0.04	1.55
Natural Pine	5.63	22.53	55.71	8.15	2.25	0.76	4.53
Mixed Pine Hardwood	3.30	21.81	23.23	36.87	7.46	3.44	3.73
Dry BTML Hardwood	0.00	0.95	4.55	1.75	81.43	11.03	0.31
Wet BTML Hardwood	0.14	5.70	7.30	3.82	37.46	45.38	0.14
Non-Forest	5.50	3.55	4.67	0.91	7.66	0.17	76.98

Overall Accuracy: 70.45

Table 4. Classification Accuracy of Combined SIR-A/TM Data

Ground Truth Classes	Young Pine	Slash Pine	Natural Pine	Mixed Pine/ Hardwood	Dry BTML Hardwood	Wet BTML Hardwood	Non-Forest
Young Pine	83.94	1.37	3.72	0.00	0.49	0.00	4.06
Slash Pine	3.72	74.04	16.81	1.41	0.76	0.04	2.56
Natural Pine	2.39	19.04	66.46	3.41	1.39	1.07	5.39
Mixed Pine Hardwood	0.14	14.06	23.67	52.37	0.72	5.74	2.15
Dry BTML Hardwood	0.31	0.86	2.32	0.01	91.87	4.21	0.34
Wet BTML Hardwood	0.00	3.41	13.48	3.68	21.33	57.26	0.49
Non-Forest	5.81	1.46	3.83	0.03	8.81	0.03	78.9

Overall Accuracy: 77.96

Shih-Tseng Wu. Dr. Wu received the M.S. and Ph.D. degrees in electrical engineering from the University of Kansas. Since 1978, he has been employed by NASA/National Space Technology Laboratories, Earth Resources Laboratory. As a microwave remote sensing specialist, his past research activities included the development of techniques for the analysis, application, and integration of radar image data with other remotely sensed data. He was involved in the AgRISTARS Domestic Crop and Land Cover Project and the NASA Radar Land Cover Analysis Project. His current research activities include the utility of the C-band scatterometer and optical radiometer for forest vegetation characterization in the southern temperate region and the microwave remote sensing of forest dynamics in tropical regions.