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Technical Report

ANALYSIS OF DATA ACQUIRED BY SYNTHETIC APERTURE RADAR AND LANDSAT MULTISPECTRAL SCANNER OVER KERSHAW COUNTY, SOUTH CAROLINA, DURING THE SUMMER SEASON

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by S.T. Wu

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16. ABSTRACT

Data acquired by synthetic aperture radar (SAR) and Landsat Multispectral Scanner (MSS) over Kershaw County, South Carolina, during summer season were processed and analyzed to derive forest-related resources inventory information. The study area contains large stands of (Oak-tupelo) and coniferous (pine) forests, agricultural fields, pastures, shrubs, barren lands, urban areas, clearcuts and open water. The SAR data were acquired by using the NASA aircraft X-band SAR with linear (HH, VV) and cross (HV, VH) polarizations and the Seasat L-band SAR. After data processing and data quality examination, the three polarization (HH, HV, and VV) data from the aircraft X-band SAR were used in conjunction with Landsat MSS data for multisensor data classification. The results of accuracy evaluation for the SAR, MSS and SAR/MSS data using supervised classification show that the SAR-only data set contains low classification accuracy for several land cover classes. However, the SAR/MSS data show that significant improvement in classification accuracy is obtained for all eight land cover classes. These results suggest the usefulness of using combined SAR/MSS data for forest-related cover mapping. The SAR data also detect several small special surface features that are not detectable by MSS data.

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I. Introduction/Objective

This study was conducted as part of the research tasks under the AgRISTARS Domestic Crops and Land Cover (DCLC) Project. The objective of the Synthetic Aperture Radar (SAR) investigation of the DCLC Project is to evaluate the results obtained from combined data acquired by Multispectral Scanner (MSS) and SAR systems and to process such data on the Earth Resources Laboratory (ERL) digital computers. The focus of this research task is to determine if SAR data contain information which, when analyzed in conjunction with conventional MSS data, will permit a more detailed delineation of forest-related land cover parameters than is currently possible. The radar signatures of forest-related land cover parameters are also being investigated. The investigation includes; (1) the delineation of surface features, cover types, and conditions probably discernable through the use of X-band SAR data, and (2) a determination of some physical conditions under which the approach is and is not useful.

To achieve the program objectives, a multisensor data set consisting of five channels of SAR data and four channels of MSS data was constructed. The five channels of SAR data were acquired over the Kershaw County, South Carolina, study area using the aircraft X-band SAR with HH, HV, VV, and VH polarizations and the Seasat L-band SAR. Data processing tasks included preprocessing of SAR data and resampling and registration of MSS data to the SAR data base. Data analysis included both the direct visual comparison of SAR and MSS 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 land cover classes.

II. Description of Study Area and Data Sets.

The study area is located in Kershaw County, South Carolina, as shown in Figure 1. It consists of a rectangular strip with an east-west width of 18km (10 NM) and

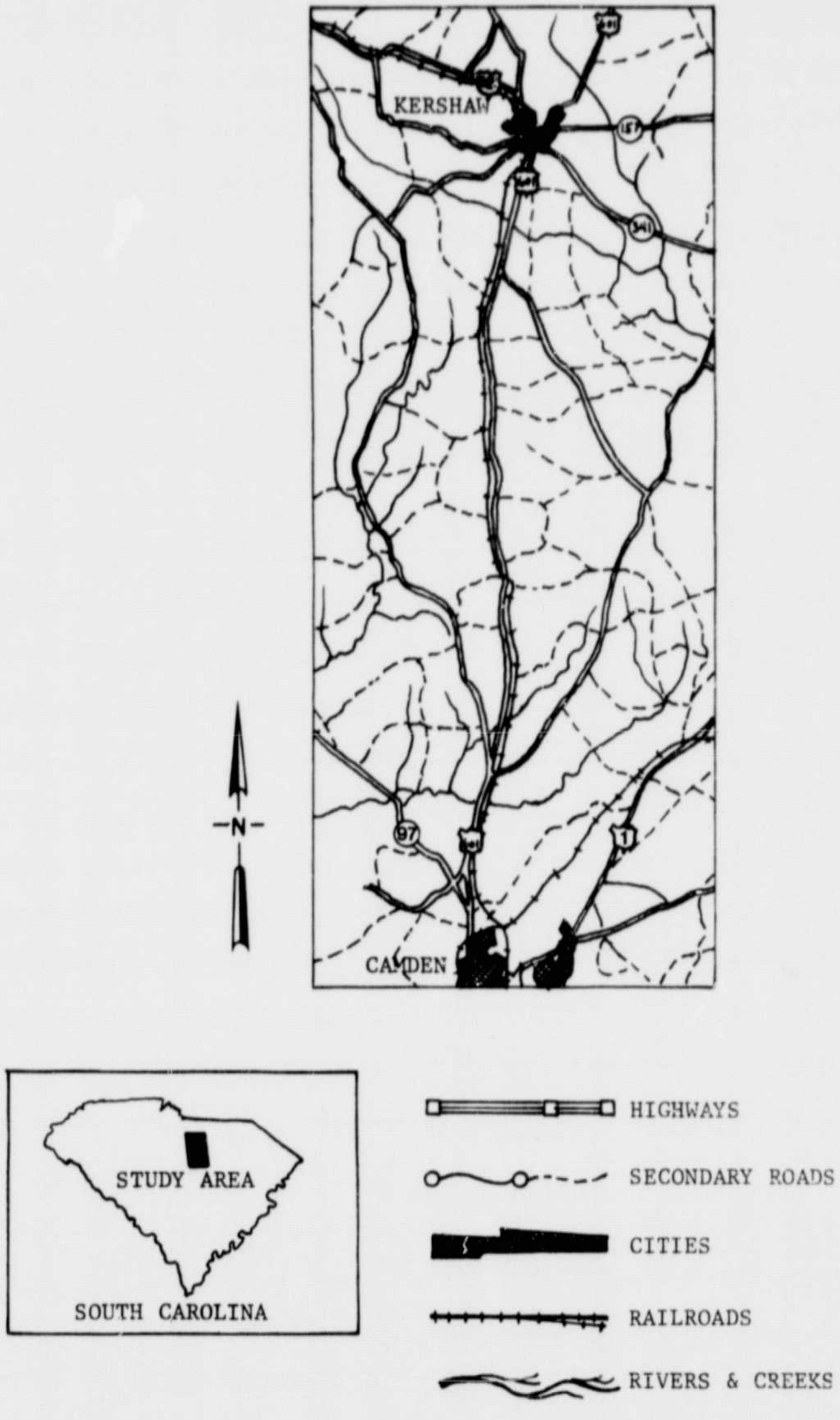

Figure 1. KERSHAW COUNTY, SOUTH CAROLINA STUDY AREA

a north-south length of 36km (20 NM) with the city of Camden located in the south end and the city of Kershaw in the north end. This area contains a wide variety of cover types, including large stands of deciduous (oak-tupelo) and coniferous (pine) forests, forest clear-cuts, cropland, pasture, brush, barren land, urban areas, and water. Some transitional mixed forest, areas of partial tree cover, and pine forest with emergent to mature stage are also present, providing many typical vegetation cover conditions.

The aircraft SAR data were acquired with an AN/APQ-102A (X-band 9.6 GHz, 3.12 cm wavelength) SAR system, flown in a NASA Lyndon B. Johnson Space Center (JSC) WB-57 aircraft, on June 29, 1981. Eight channels of image data were obtained by using mode I and mode II configuration and two radar transmitting polarizations. Details of the aircraft SAR operating configuration have been reported in NASA/NSTL Earth Resources Laboratory Report No. 207 (Ref 1.).

To facilitate ground truth verification, color infrared (CIR) aerial photography was acquired concurrently with the SAR data acquisition over the study area.

The Landsat MSS data set acquired on September 22, 1981, was selected because it contained cloud-free MSS data closest to the aircraft SAR acquisition date. Seasat SAR data were acquired on August 19, 1978, with a descending pass orbit of 759.

III. Data Processing

A. SAR Data Preprocessing

Since the aircraft SAR data were optically correlated, the image product obtained from JSC was a roll of positive transparent film. It can be used to validate data quality and visually discriminate surface features using tone and texture. Before digital analysis, the film was digitized and converted into discrete count value data (digital data). The digitization of SAR film image was performed by NASA Wallops Flight Center using its digital microdensitometer resulting in a data set with approximately 18.5m by 18.5m resolution. After digitization, the SAR data were further processed to reduce the striping or banding effect (Ref 1) and the radiometrically-corrected data were used to form a nine-channel data set.

For Seasat data, spatial filtering using a 5 by 5 window was applied to reduce the speckle noise. An investigation concerning the need, approach, and results of using this technique has been reported elsewhere (Ref 2). No across-track radiometric correction was applied.

B. Registration of SAR and MSS Data

The digitized aircraft SAR data contain a ground range resolution of 18.5m by 18.5m. The Seasat L-band SAR data contain a ground range resolution of 25m by 25m while the Landsat MSS data contain a resolution of 57m by 79m. To construct a multisensor data set, the aircraft SAR data with 18.5m by 18.5m resolution were selected as the base with Landsat MSS and Seasat SAR data overlaid to the base data set resulting in an 18.5 meter cell for all data. This overlaying or registering procedure is called scene-to-scene registration (Ref. 3). Only one aircraft SAR data set with mode II configuration was selected to form the multisensor data set; the mode I configuration data set was used for direct visual comparison only.

IV. Direct Comparison of Multidata Set

A. SAR Image Interpretation

The aircraft X-band SAR images of HH, HV, and VV polarizations with mode-II configuration are shown in Figures 2, 3, and 4, respectively. Since the same study area had been investigated by Knowlton and Hoffer (Ref. 4) for forest cover mapping using radar imagery, it is pertinent to review their findings prior to analyzing or interpretating Figures 2, 3, and 4. The data set they used was acquired on June 30, 1980. In their study, only the aircraft X-band HH

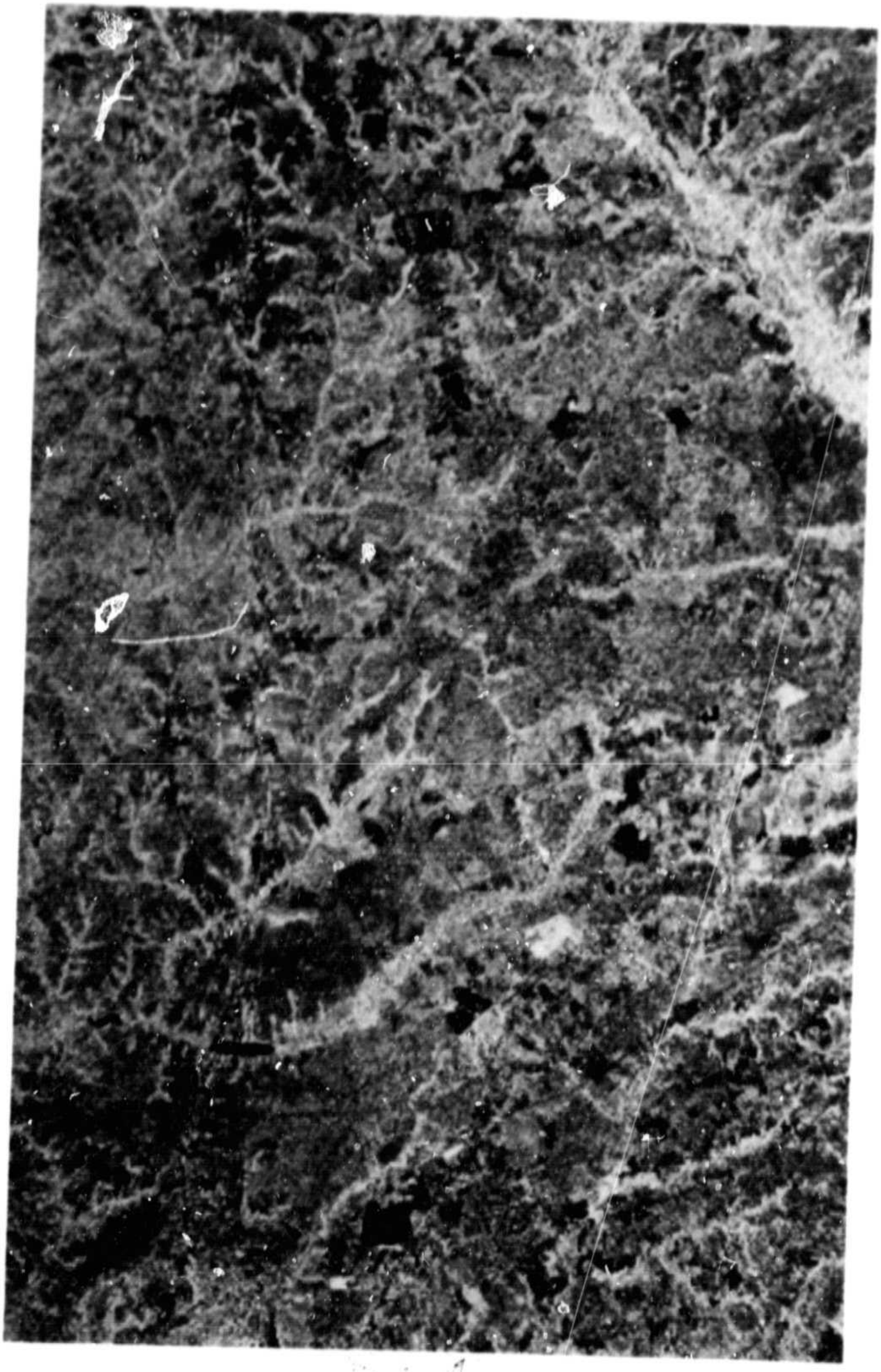

Figure 2. Aircraft SAR X Band HH Pol. Data of Kershaw Co., S.C.

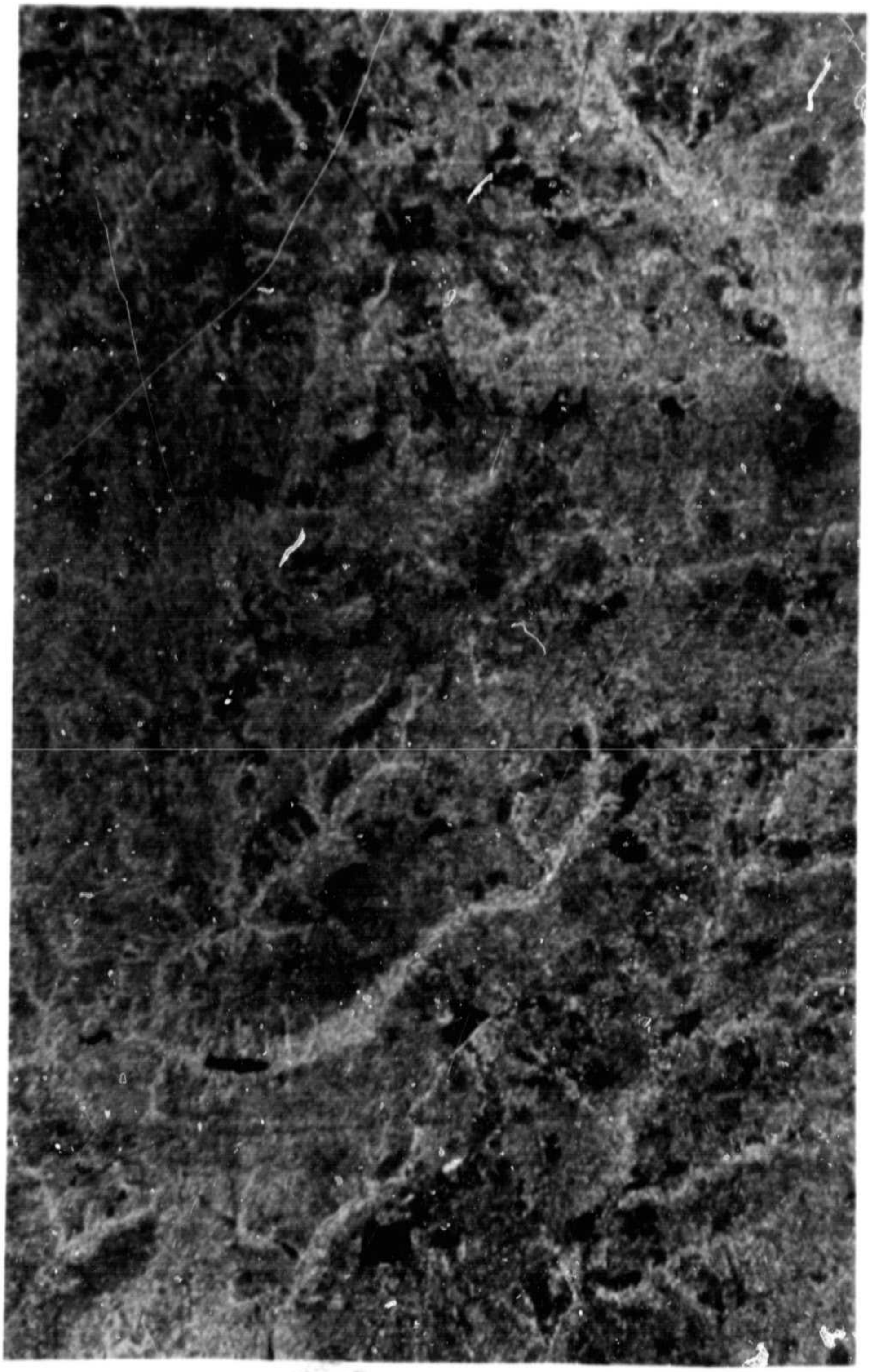

Figure 3. Aircraft SAR X Band HV Pol. Data of Kershaw Co., S.C.

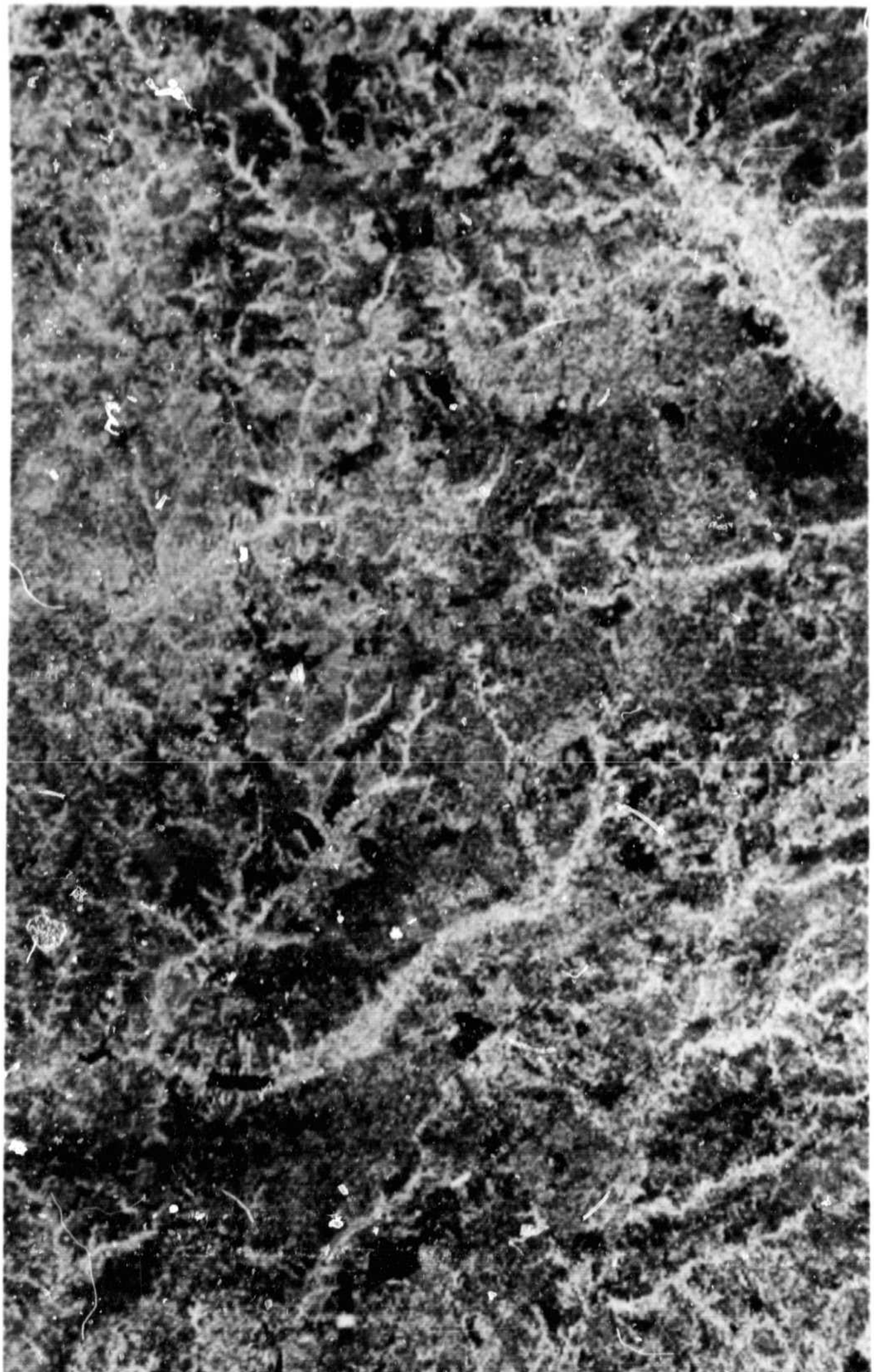

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Figure 4. Aircraft SAR X Band VV Pol. Data of Kershaw Co., S.C.

and HV polarization data were used, and the results of tone and texture interpretation of the radar imagery are summarized in Table 1.

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

COVER TYPE	TONE HH	TONE HV	TEXTURE HH	TEXTURE HV
Hardwood	white	light gray	grainy	grainy
Pine	dark gray	gray	speckled	speckled
Mixed Pine-Hardwood	dark gray	gray	grainy	speckled
Clearcut	dark gray	dary gray	grainy	grainy
Bottomland Scrub	dary 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

Results similar to those tabulated in Table 1 can be obtained from figures 2 and 3 using image interpretation techniques; however, in this study, emphasis was placed on digital data analysis.

The aircraft SAR data consist of HH, HV, VV and VH polarization data. The VH polarization image was not included in this study for data analysis because VH and HV polarizations contain the same radar signatures based on the reciprocity principle of electromagnetic wave scattering. The preprocessed and registered Seasat L-band SAR image is shown in Figure 5. Part of the image in Figure 5 contains double images due to a processing defect which occurred during the image formation stage. Furthermore, Seasat SAR data were acquired on August 19, 1978, while aircraft SAR and Landsat MSS data were acquired in June and August 1981, respectively.

Because of the three-year time difference between the Seasat SAR and the Landsat MSS data acquisition dates, the Seasat L-band SAR image was only analyzed independently through visual interpretation. The tone and texture

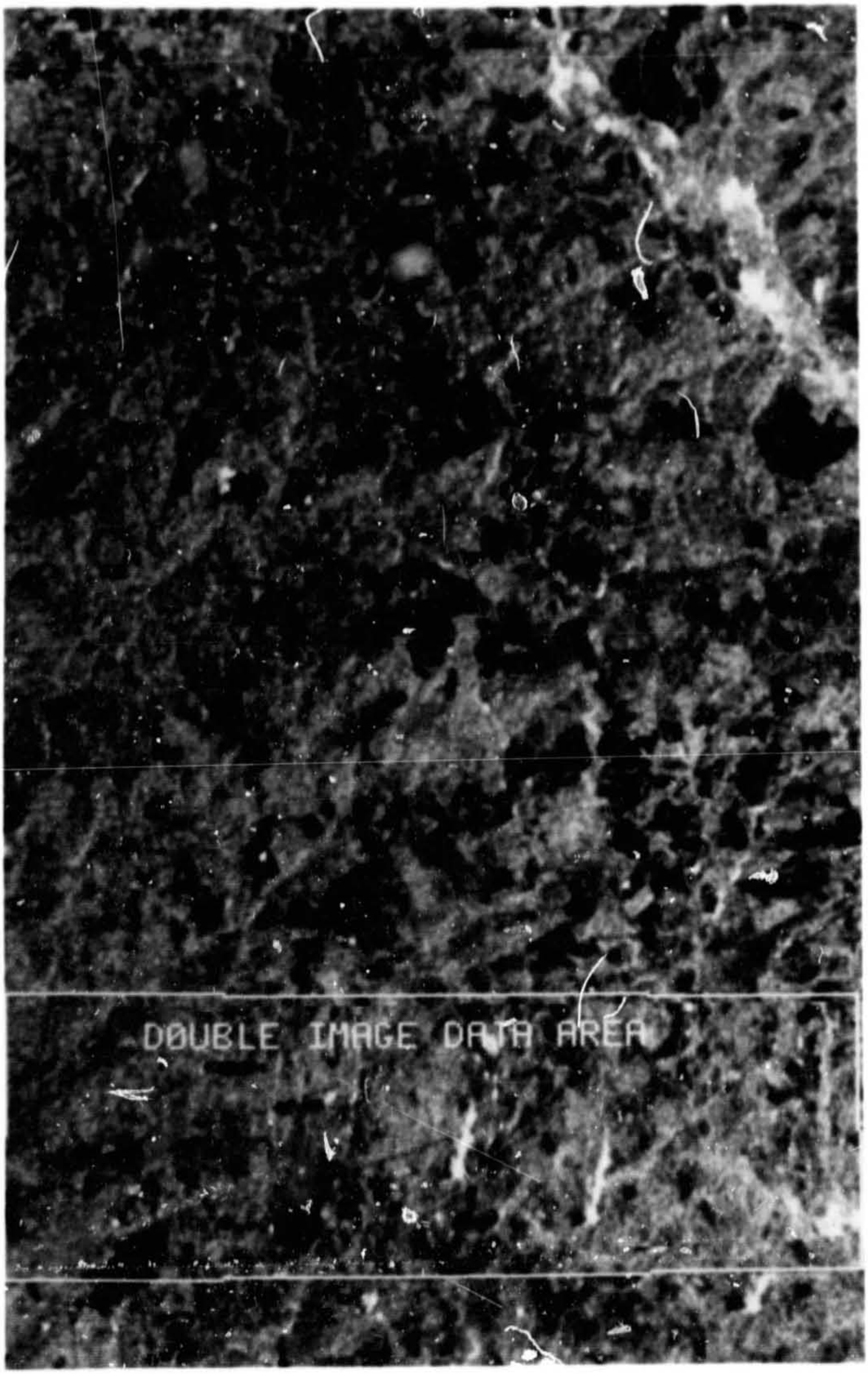

Figure 5. Seasat SAR L Band HH Pol. Data of Kershaw Co., S.C.

characteristics of the Seasat L-band SAR image of HH polarization are summarized as follows:

1) Bright tone (high return) with smooth texture signifies bottomland hardwood forest or swamp forest with standing water.

2) No distinctive delineation of hardwood, pine and mixed forest can be made. These cover types are characterized by a gray tone with grainy to smooth texture.

3) Clearcuts, pasture, cropland with bare soil, and water bodies are all characterized by a dark to black tone with smooth texture.

Overall this data set contains less tonal and texture variations to provide meaningful delineations of vegetative cover types than that of the aircraft X-band SAR data shown in Figures 2, 3, and 4.

To better visualize the count value range distribution of the SAR images, the histogram of SAR images from Figures 2 through 5 and the aircraft X-band VH polarization data are plotted in Figure 6. The characteristics of the five-channel SAR data over the study area, using the histogram curves, can be summarized as follows: (1) The Seasat L-band SAR data contain the least variation while the aircraft X-band SAR VV polarization data contain the most variation. The hypothesis that a wider range of values provides a better delineation of land cover types suggests that VV polarization data will be best for general land cover delineation when a single-channel data set is used, (2) The aircraft X-band SAR HV and VH polarization data contain the same type of count value distribution with about a 15-count offset between the two curves. This result is as expected because the two data sets provide the same spectral signatures. Therefore, only one type of polarization (either HV or VH) data is sufficient in image interpretation and data analysis, (3) The highest frequency of occurrence exists at count values 156, 136, 108, 93, and 34 for X-band HH,

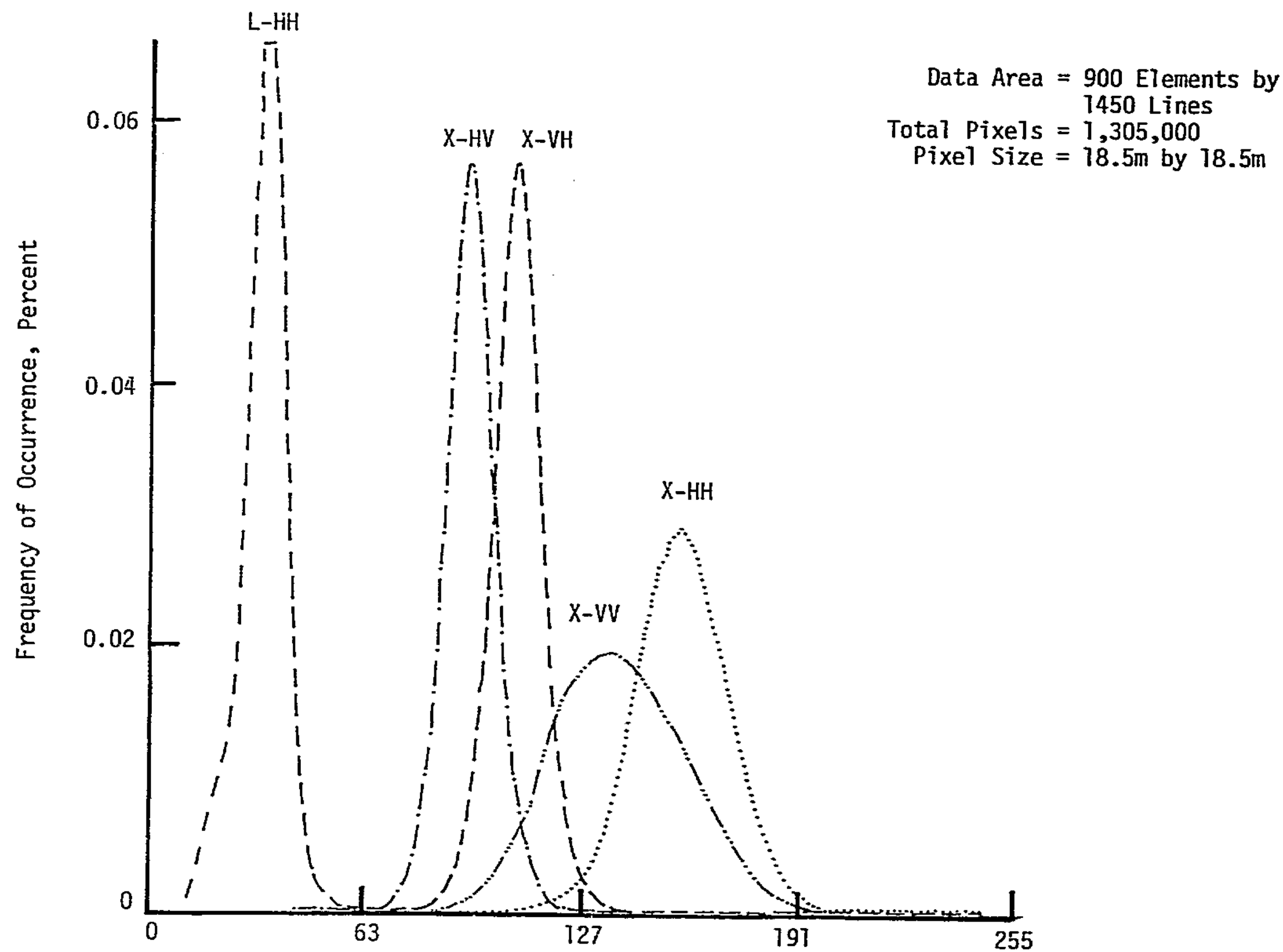

Figure 6. Histogram of SAR Data from Kershaw Co., S.C., Study Area

VV, VH, HV and L-band HH pol data, respectively. Since HV pol data are displaced further off from VV and HH pol data than that of the VH pol data, the HV pol data were selected for SAR/MSS data classification.

To obtain a better understanding of the SAR data count value variation and what the count values represent, several bright return and dark return areas which are not typical forest and cropland cover types were analyzed, and the results were summarized in Table 2.

Table 2. Mean Count Value and Standard Deviation of Some Special Feature Land Cover Types

Land Cover Description	No. of Pixels Used	Aircraft X-Band SAR					
		HH Pol		HV Pol		VV Pol	
		μ	σ	μ	σ	μ	σ
Block Bldg (Warehouse)	102	224.42	12.50	112.09	9.74	209.35	14.49
Auto Junk Yard	80	201.22	15.09	145.35	15.14	193.42	13.97
Cypress Forest with Standing Water	229	184.96	9.80	91.90	7.42	147.64	15.46
Deciduous Forest	257	166.82	15.31	106.22	7.87	152.03	17.93
Air Force Base (Flat Surface)	147	108.28	6.07	77.88	3.42	99.66	7.83
Water	67	99.69	5.73	71.00	2.43	77.06	6.73

In Table 2, deciduous forest and water classes have been used for land cover classification to be discussed in a later section. These two cover types were included for comparison purposes. A large block building oriented along a north-south street direction provided the highest return because the radar flight line was also oriented in North-South direction with zero azimuth angle. The auto junk yard with its large volume of randomly piled cars also showed a very high return in both HH and VV polarization data. It also contained the highest return from the cross (HV) polarization data.

The results suggest that the cross-polarization data are highly correlated to the roughness of surface cover. Cypress forest with standing water shows a high return for the HH polarization data but moderate return for VV polarization data. This implies that HH polarization data can be used for detecting standing water as demonstrated in a previous investigation (Ref. 2).

B. SAR and MSS Data Comparison

1. Visual Comparison Using False Color Images

Visual comparison of SAR and MSS data was conducted using false color images in which surface features containing different spectral band regions are shown as the three prime colors: blue, green and red. Hence each false color image is capable of presenting three spectral bands simultaneously. If one prime color shows up in a particular area, it means that the content of the spectral band represented by that prime color predominates over that particular area. If all three bands predominate over an area, the false color image will be white over the particular area. A false color image, therefore, is an effective tool in presenting multiband signatures of various land cover types.

To visually examine the difference between mode I and mode II SAR data, these SAR data false color images of the study area are shown in Figures 7 and 8 for mode I and mode II configurations, respectively. In both figures, the blue, green and red colors represent the X-band HH, HV and VV polarization data, respectively. Visual comparison of the false color images of Figures 7 and 8 depicts very similar color tones over various land cover types. Therefore, it may be assumed that spectral signatures of the surface cover types of interest for this study such as "deciduous forest", "pine forest without slash", "pine forest with slash", "forest clear-cuts", "pasture/fallow field", "cropland", and "wet fields" are insensitive to incidence angle change from 55 to 35 degrees.

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Figure 7. Three Band Color Composite of Aircraft SAR Data Mode I Configuration

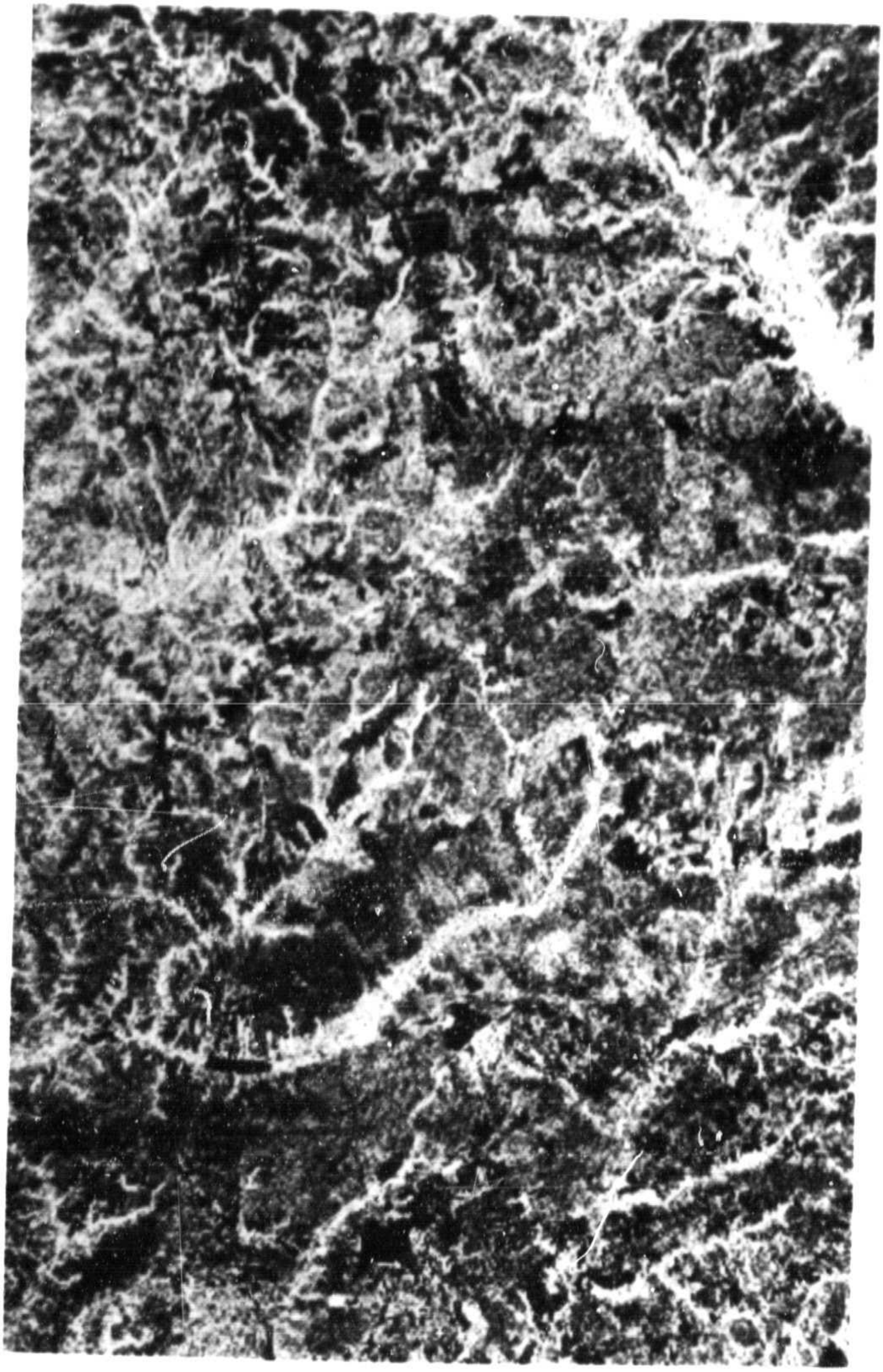

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Figure 8. Three Band Color Composite of Aircraft SAR Data Mode II Configuration

There are no significant color tonal differences between the two false color images; however, the mode II image has less geometric distortion than that of the mode I image along the left side area. Because of this, the mode II configuration data were used in the SAR image interpretation and the construction of a multisensor data set.

The September 22, 1981 Landsat MSS data false color image over the study area is shown in Figure 9 with blue, green and red colors representing bands 4, 7 and 5, respectively. Past investigations (Refs. 1 and 2) indicate that Landsat MSS bands 4 and 5 and 6 and 7 are highly correlated; therefore, the three-band color presentation of MSS data is pertinent to compare with the SAR false color image for a basic understanding of the difference of spectral characteristics in each spectral region.

In addition to utilizing the Color Infrared (CIR) photography, field trips were made to visit more than 200 test plots about a year after the SAR data acquisition. The ground data are used to facilitate the comparison of SAR and MSS false color images and to evaluate the multidata supervised classification results given in a later section.

In microwave regions shown in Figure 8, the "deciduous forest" class can be easily delineated from the "pine forest with slash" or the "pine forest without slash" class and other non-forest cover types in the study area because all three polarizations of the X-band SAR data contain relatively high return from the foliated deciduous forest class. The small special feature classes such as the auto junk yard and large block building mentioned in the previous section cannot be visually separated from the deciduous forest class because they also contain high return. This microwave attribute has been observed previously (Ref. 1, 2). Some cropland with exposed soil, pasture and air strips with a flat surface may be confused with open water due to their similar dark gray to black color tones, but count value analysis, as given in the next section, indicates that significant difference does exist to allow for separation of the water class from other classes. Pine forest can be delineated from the deciduous forest class; however, separation of pine forest into "with slash" and "without slash" classes is a difficult task because these classes are spectrally overlapping. The "pine forest with slash" class is also difficult to separate from clearcuts, especially old clearcuts with new growth or emerging pine trees, and some pasture fallow fields.

In Landsat MSS spectral band regions shown in Figure 9, the deciduous forest classes are clearly separable from the small special feature classes and cropland with exposed soil due to the difference in reflectance values for green leaves and the concrete roof top or exposed soil. No distinct delineation can be made between the deciduous forest and pine forest class as seen from the SAR false color image. The "pine forest with slash" class is spectrally overlapping with some pasture fallow fields.

The results of visual comparison using false color images of the two data sets are presented in Table 3 with the eight land cover classes which are well represented in the study area.

2. Count Value Comparison

The SAR and MSS data comparison is based on the combined SAR/MSS nine-channel multidata set with the deletion of X-band SAR VH polarization data and Seasat L-band HH polarization data. The reasons for deletion has been described previously. Prior to classifying the seven-channel data set through the supervised classification programs, it was necessary to generate the multidata spectral signatures for various land cover types in the study area. To obtain valid statistics for each spectral signature class, the field-verified land cover plot from which the signatures were generated was selected as

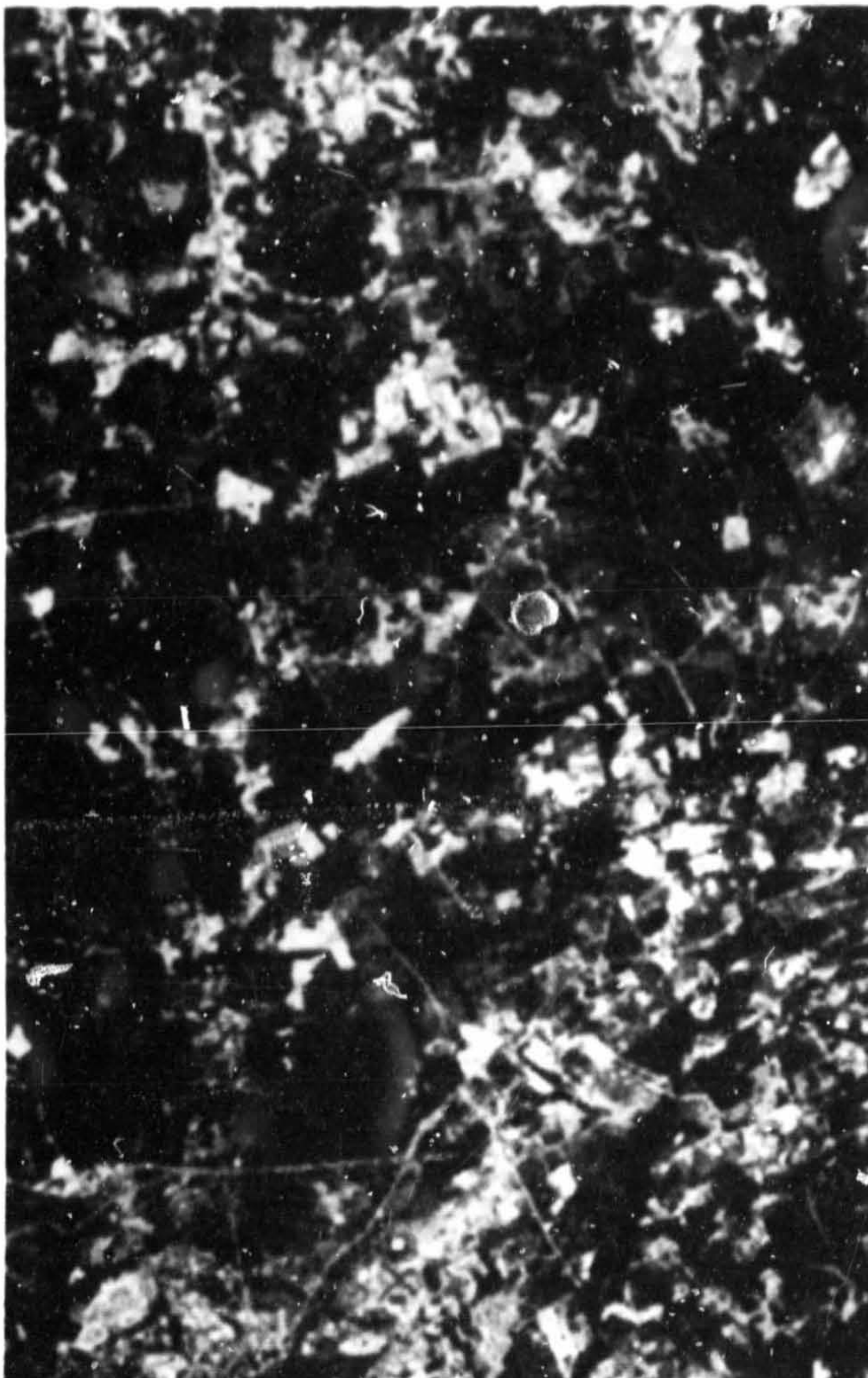

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Figure 9. Three Band Color Composite of MSS Data

Table 3. Visual Comparison of Surface Feature Extraction Capabilities Between Microwave and Visible-Near Infrared Regions Using Three Band False Color. (Color description is based on the ISCC-NBS Centroid Color System)

SURFACE FEATURE CLASSES	MICROWAVE REGION SAR X BAND HH, HV & VV POL.	VISIBLE - NEAR INFRARED REGION LANDSAT MSS BAND 4, 5, 6 & 7
Deciduous Forest	GREENISH WHITE WITH MOTTLED PINK Separable from other forest classes.	STRONG GREENISH BLUE TO BLUISH GREEN Separable from other forest classes.
Pine Forest Without Slash	STRONG PURPLISH BLUE WITH MOTTLED PINK Confused with "pine forest with slash" class and pasture fallow field.	DARK YELLOWISH GREEN Confused with "pine forest with slash" class.
Pine Forest With Slash	DARK GRAYISH GREEN Confused with clearcut, pasture fallow field, cropland and "Pine forest without slash" classes.	VERY DARK PURPLISH RED Confused with pasture fallow field.
Clearcut	DARK GREEN WITH MOTTLED YELLOW Confused with cropland, and pine forest with slash classes.	GRAYISH PURPLISH PINK Slightly confused with cropland classes.
Pasture/Fallow Field	BLACKISH GREEN Confused with cropland and clearcut classes.	GRAYISH GREEN Slightly confused with clearcut class.
Cropland	BLACK TO DARK BLUISH GREEN Confused with pasture fallow field and clearcut classes.	PINK WHITE Separable from other surface class.
Wet Field	DEEP PURPLISH PINK Separable from other surface classes due to its distinct color tone.	DARK GRAY TO PINK WHITE Confused with cropland and pasture fallow field classes.
Water	BLACK Inseparable from flat cropland and air force base.	DARK GRAY Separable from other surface classes.

homogeneous and of an adequate size. In other words, the land cover classes to be used for supervised classification need to be well represented in the study area. This requirement precluded the use of the small special feature classes such as the auto junk yard and one large block building.

Based on aerial color infrared (CIR) photography taken concurrently with SAR data acquisition, and extensive field verification, 47 plots were selected to generate the seven-channel spectral signatures for the eight land cover classes as shown in Table 4. The first column of the table describes the land cover classes and the second column gives the statistical class number. Columns 3 through 6 give the Landsat MSS four-band data mean count values while columns 7 through 9 give the aircraft X-band SAR three polarization data mean count values ranging from 0 to 255. To help visualize the mean count values of the eight land cover classes in the microwave and Landsat MSS spectral band regions, the 47 statistical signature classes were merged into the eight land cover classes according to the class number given in column two of Table 4. The results of the merged statistics with the mean and standard deviation were plotted against the eight land cover classes in Figures 10 and 11 for SAR and MSS data, respectively.

In microwave regions shown in Figure 10, the mean and standard deviations of the merged deciduous forest (DCF) class are separable from other land cover classes. However, the mean and standard deviations of the two pine forest classes are similar and thereby make them difficult to be separated from each other. Spectral overlapping also occurs between the pasture fallow field (PSF) and cropland (CL) classes. The open water (WTR) class contains the lowest mean values and standard deviations for all three polarizations. The wet-field (WFD) class contains a very high mean value for the HH polarization data and moderate

Table 4. MSS AND SAR SIGNATURE OF 47 SELECTED CLASSES - MEAN VALUE

LAND COVER CLASS	CLASS NO.	LANDSAT MSS				AIRCRAFT X BAND SAR		
		BAND 4	BAND 5	BAND 6	BAND 7	HH POL	HV POL	VV POL
DECIDUOUS FOREST A	1	18.92	15.76	39.79	42.62	177.55	98.40	154.34
	3	19.83	18.05	40.82	41.48	169.09	98.92	157.80
	4	19.61	17.95	39.07	40.45	167.02	96.99	152.17
	10	18.67	16.26	36.43	37.64	179.78	106.68	167.24
	23	22.39	22.14	49.09	50.32	151.26	87.02	129.92
	33	19.45	17.04	40.81	42.29	167.77	102.10	158.19
	36	18.75	15.97	39.44	42.11	174.42	102.29	157.51
PINE FOREST WITHOUT SLASH B	5	22.29	21.71	37.67	34.85	154.24	91.64	135.58
	18	19.87	17.17	37.24	35.42	150.49	95.78	132.16
	19	19.37	17.86	37.29	34.55	156.15	95.72	135.62
	26	19.61	17.37	35.88	35.04	149.55	92.74	138.50
	37	19.71	18.21	37.66	37.70	155.29	98.35	142.12
PINE FOREST WITH SLASH C	12	19.43	17.88	37.62	36.78	159.95	96.52	145.04
	16	19.63	18.97	33.70	29.71	151.62	92.62	126.93
	42	19.65	17.71	33.71	33.03	140.68	93.12	113.68
	43	19.15	17.51	36.11	33.66	157.83	95.89	123.23
	45	19.99	17.39	33.74	30.16	140.07	88.19	120.96
FOREST CLEARCUTS D	2	34.65	44.21	50.86	43.32	151.17	80.02	133.18
	9	20.74	21.93	43.56	42.45	142.57	87.69	133.27
	15	25.61	29.68	45.74	41.08	146.88	88.95	125.45
PASTURE, FALLOW FIELD E	6	22.50	24.02	37.60	33.97	140.40	85.18	116.15
	7	25.64	31.57	49.49	44.92	128.51	79.34	99.92
	8	24.19	28.95	43.41	39.29	136.10	80.99	109.11
	20	22.90	26.34	41.76	39.55	135.67	79.19	118.27
	25	19.52	18.36	35.65	33.26	153.14	91.88	122.36
	32	22.04	24.29	37.17	34.84	143.12	84.66	131.50
	40	23.39	23.71	47.51	46.49	124.53	84.22	110.28
	46	22.82	24.15	37.04	34.49	141.08	85.07	114.02
CROPLAND, BARE SOIL, TILLED FIELDS F	11	21.41	19.94	58.55	63.29	125.24	86.23	103.39
	13	24.55	26.31	54.38	54.23	117.37	74.85	99.43
	21	34.61	46.94	55.09	45.70	147.34	86.53	119.34
	22	32.23	40.76	61.47	57.31	129.84	77.40	116.41
	24	31.70	42.18	50.68	43.80	139.74	85.35	106.54
	27	22.36	21.80	57.81	61.52	136.28	82.04	117.21
	29	22.09	21.20	54.09	59.80	145.17	82.83	129.89
	30	21.03	20.32	57.01	61.63	134.81	87.89	126.20
	31	21.88	21.03	52.84	57.65	144.33	86.05	130.35
	34	29.63	34.69	56.99	54.29	113.97	74.65	94.82
	35	28.86	33.11	56.00	54.35	132.52	76.00	113.18
	39	27.72	31.99	41.25	35.12	116.93	75.72	100.50
	41	23.38	23.19	46.82	44.94	174.01	99.92	158.40
	44	26.49	32.49	47.28	43.90	151.56	83.26	106.45
WET FIELD G	14	30.25	44.58	53.60	45.30	163.78	84.75	134.21
	17	23.53	23.73	44.64	43.13	186.81	96.63	141.05
	28	22.73	23.15	41.91	38.89	179.61	95.21	146.56
	38	18.76	16.97	29.30	26.77	181.91	91.74	148.38
WATER H	47	18.78	16.69	18.33	11.99	104.81	78.93	76.26

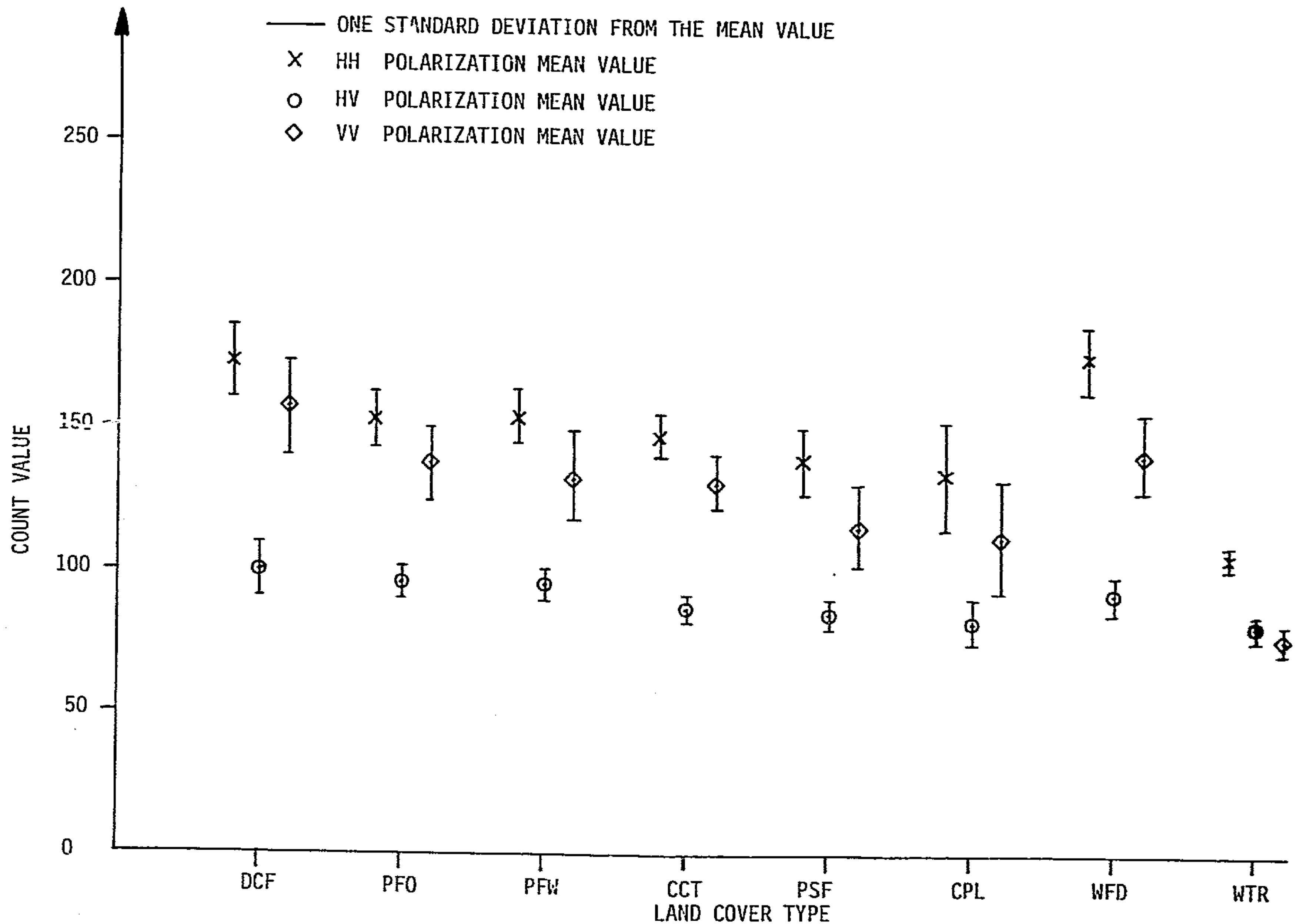

Figure 10. SAR SIGNATURE OF EIGHT LAND COVER CLASSES

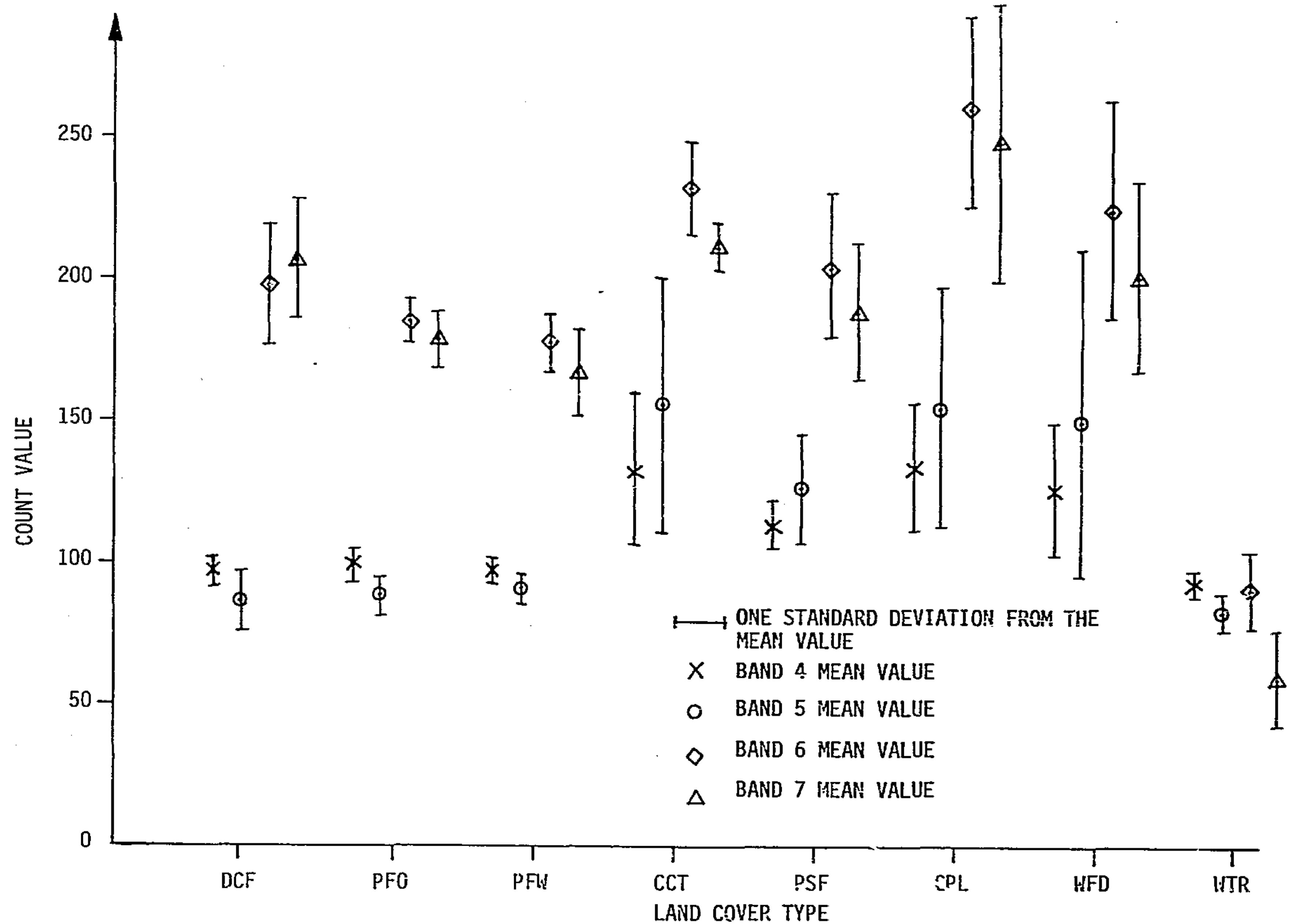

Figure 11. MSS SIGNATURE OF EIGHT LAND COVER CLASSES

mean values for the HV and VV polarization data. This information implies that the HH polarization data are sensitive to surface wetness or water content in the surface. The cropland class contains the largest standard deviation. This fact implies that signature classes selected to represent the cropland class are not uniform. This may actually reflect the real ground condition because cropland encompasses a variety of surface cover and ground conditions depending on the percent of exposed soil, stage of crop growth, and crop type.

In the Landsat MSS spectral band regions shown in Figure 11, the largest variation of standard deviation also occurs for the cropland and wet field classes which is consistent with the finding described in the microwave region. Separation of deciduous forest from pine forest is attributed to the mean value differences in bands 6 and 7 data. On the other hand, separation of forest classes from non-forest is attributed to the mean value differences in bands 4 and 5 data. Last, the open water class contains the lowest mean count values and standard deviations for all four bands of data.

As shown in Figures 10 and 11, there exists a distinctive difference between SAR and MSS data in cover type spectral overlap, and this finding suggests the use of the combined SAR/MSS data for improving land cover classification.

V. Evaluation of Classification Results

A. Supervised Classification

Since comparative analysis concerning the use of a multidata set for improving land cover classification should not be dependent upon classification approach, and since extensive ground truth data were available through field observation prior to data processing, the supervised classification approach was employed for this data set.

The mean count values shown in Table 4 were part of the statistics developed from the 47 selected training sample plots which represent the eight land cover classes in the study area. The 47 developed statistics or spectral signatures, which include mean, standard deviation, covariance, etc., together with 99.9 percent threshold were input into the maximum likelihood Bayesian classifier, MAXL, MXAP, or M234 (Ref. 3), to classify the 3 pol SAR data, the 4 band MSS data, and the combined 3 pol SAR and MSS bands 5 and 7 data sets. Since not all surface features can be related to the eight land cover classes named, and since the larger the percent threshold used, the less data cells are left unclassified, a 99.9 percent threshold was used to minimize the data cells left unclassified. Because of this, the classified data sets shown in Figures 12, 13 and 14 contain a very small number of unclassified data cells.

B. Results of Accuracy Evaluation

Since the emphasis of this study was to determine if SAR data contains information which, when analyzed in conjunction with conventional MSS data, will permit a more detailed delineation of forest-related land cover paramenters than is currently possible, three forest classes and five other land cover classes were included in the training sample plots and test sample plots. The residential area, highway, and other inert classes, although present in a small percentage of the study area, were not included for evaluation. The test sample plots for accuracy evaluation were first selected from color infrared photography and then verified in the field with detailed descriptions of surface cover type and condition. The test sample plots were used exclusively for accuracy evaluation only, and they were completely separated from the training sample plots which were used to developed spectral signatures.

The locations and land cover class designations of the test sample plots used in accuracy evaluation are shown in Figure 15. The number of test sample plots selected for the eight land cover types and the total pixels contained in

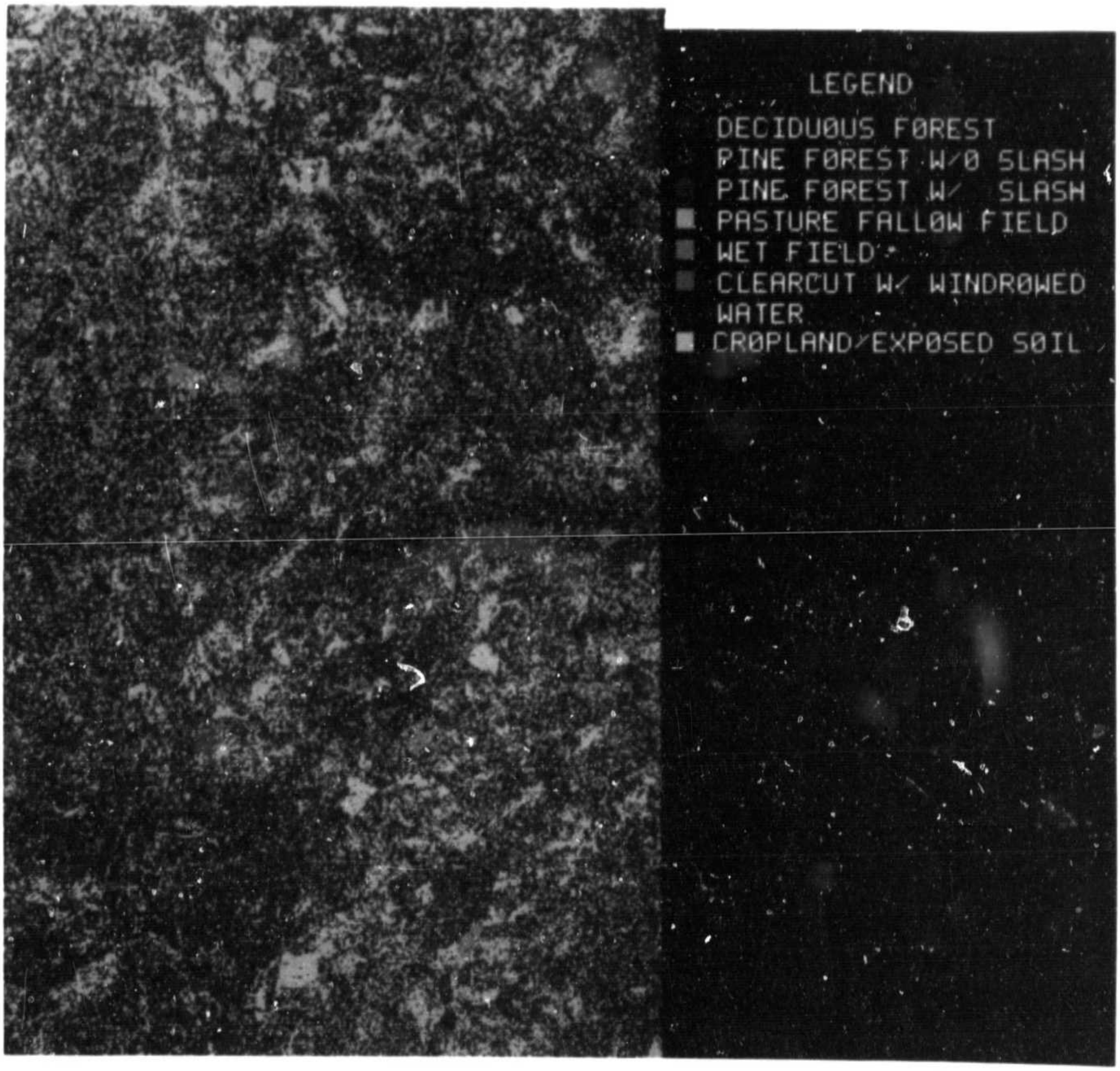

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Figure 12. Color Coded Land Cover Classification of X Band SAR HH, HV and VV Pol. Data

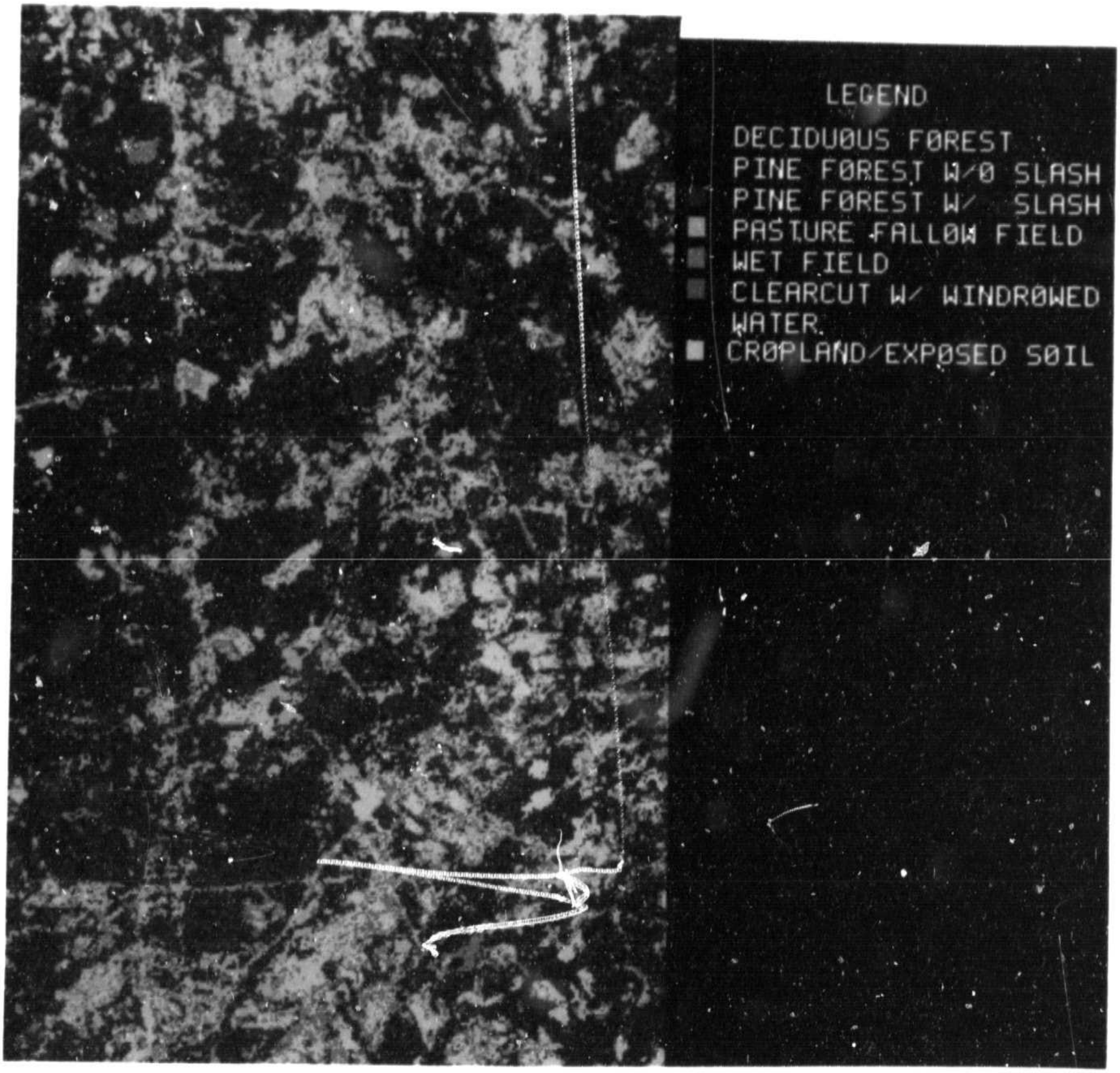

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Figure 13. Color Coded Land Cover Classification of Landsat MSS Bands 4,5,6, and 7 Data

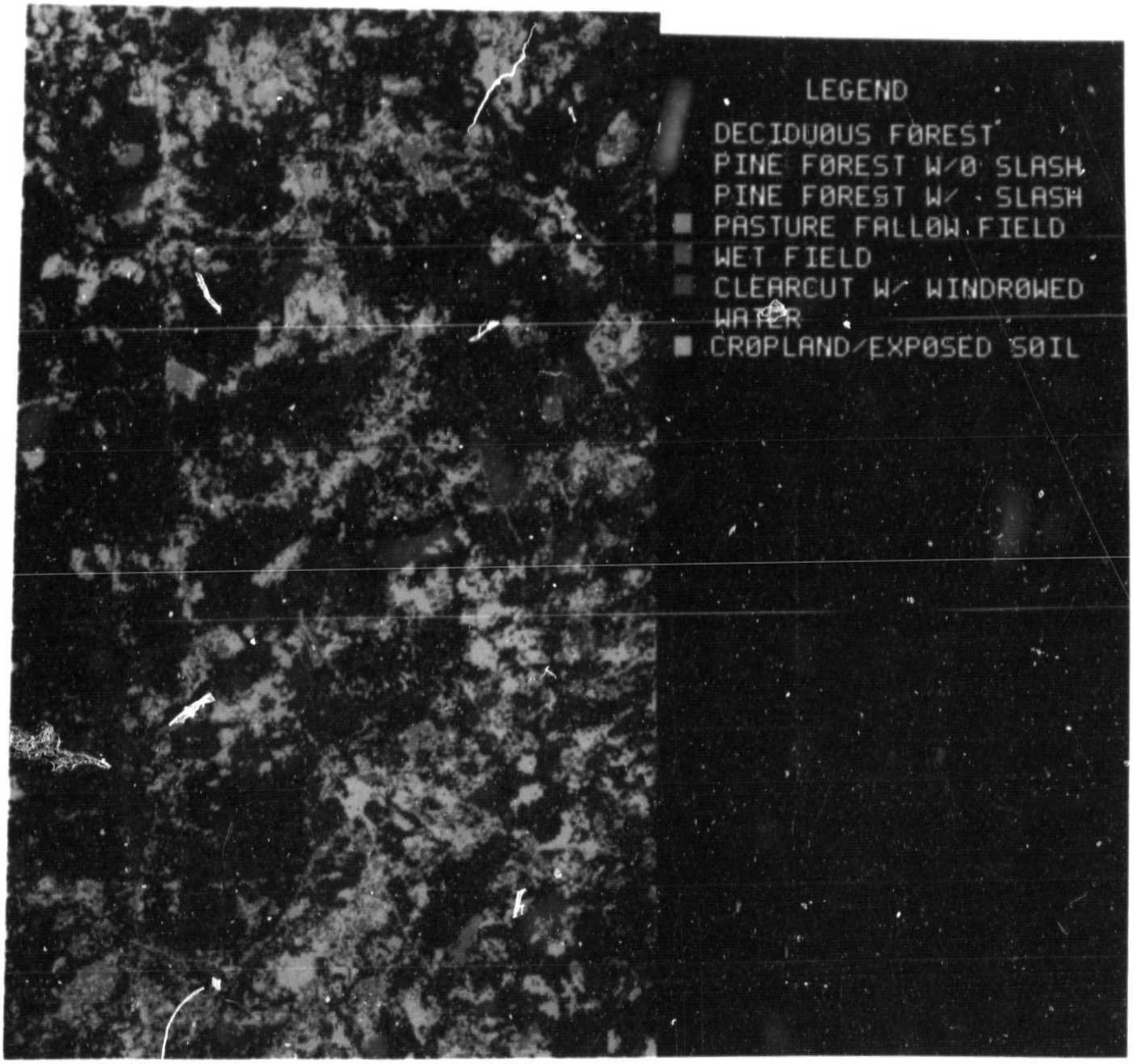

Figure 14. Color Coded Land Cover Classification of SAR 3 Pol. and MSS Bands 5, and 7 Data

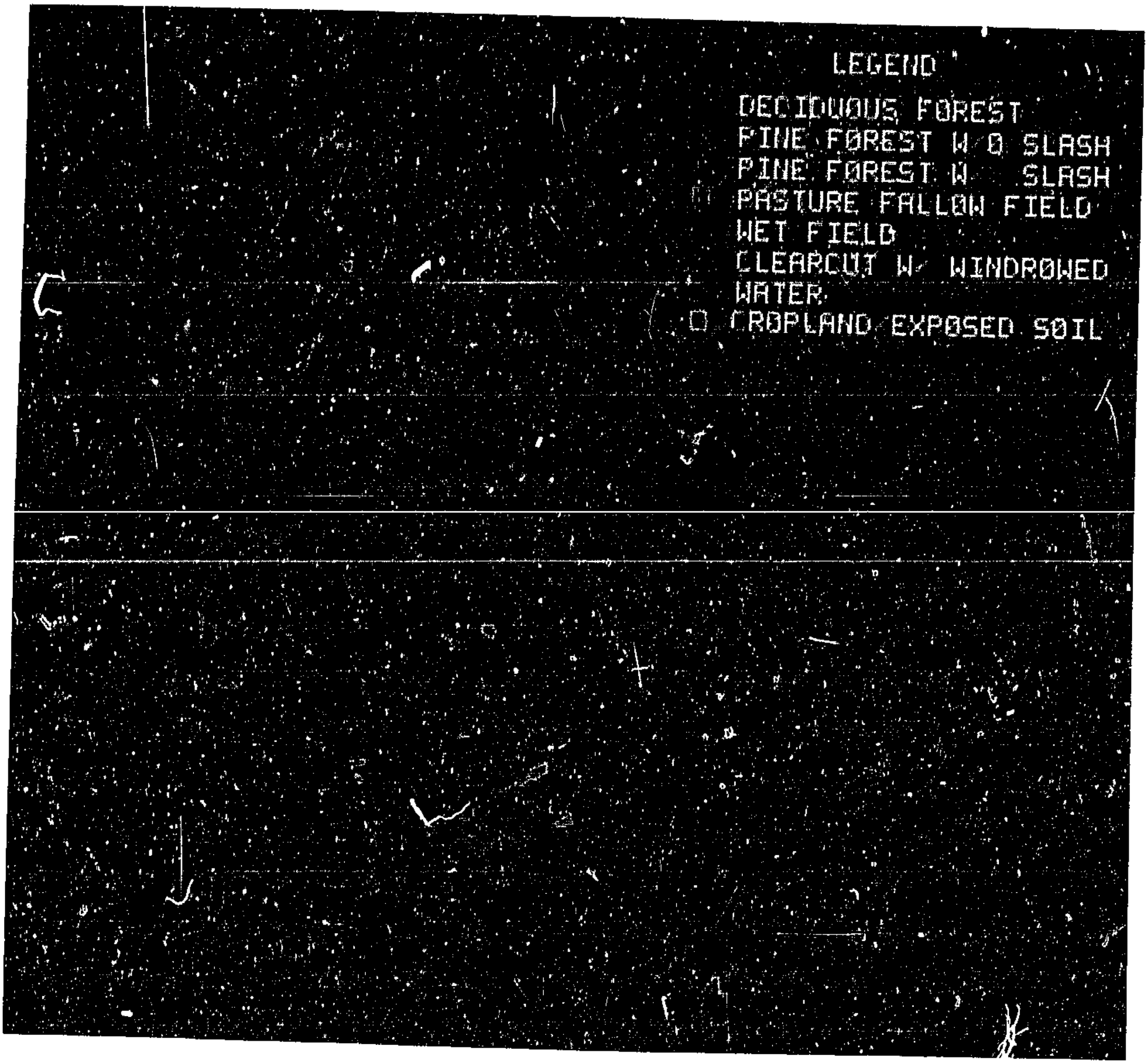

Figure 15. Color Coded Field Verification Plots

each cover types are as follows:

Land Cover Types	Number Plots Selected	Total Pixels Used
Deciduous Forest	8	16,107
Pine Forest Without Slash	6	6,872
Pine Forest With Slash	5	4,512
Clearcut	3	1,701
Pasture Fallow Field	11	2,444
Cropland	12	3,954
Wet Field	4	1,810
Water	1	514
TOTAL	50	37,914

A computer program called Accuracy of Classification Table (ACTB) documented in ELAS (Ref. 3) was used to compare the results of a classification with ground truth or test sample data. ACTB presented a table that shows class frequencies, percentages, percent correct, omission errors, and commission errors as a result of the comparison between the verification data and the classified data.

The results obtained from the ACTB program (expressed as percentage of pixels) for the three supervised classifications of the eight land cover classes are given in Tables 5, 6, and 7 for the X-band SAR 3 polarization data, the Landsat MSS 4-band data, and the SAR 3 polarization and MSS bands 5 and 7 data, respectively. The verification values (% classified correctly) of the eight land cover classes for the three classficiations are summarized in Table 8. The acreage estimation of the eight land cover classes for the three classifications, expressed in hectares, is given in Table 9.

The verification values of the X-band SAR three polarization data shown in Table 5 are relatively low for the pine forest without slash, pine forest with slash, clearcut, pasture fallow field, and cropland classes. The low classification accuracy was caused by spectral overlapping among these land cover classes and/or the intrinsic speckleness of the SAR data which makes it difficult for the conventional spectral pattern recognition classifier to

Table 5. Verification Values of the Classification of SAR X-Band HH, HV, VV Pol. Data

GROUND TRUTH CLASSES	DECIDUOUS FOREST	PINE FOREST WITHOUT SLASH	PINE FOREST WITH SLASH	CLEARCUT	PASTURE FALLOW FIELD	CROPLAND	WET FIELD	WATER
DECIDUOUS FOREST	79.33	3.00	6.46	0.12	0.16	4.87	6.07	0.00
PINE FOREST WITHOUT SLASH	3.61	44.05	28.75	4.74	12.62	2.90	3.33	0.00
PINE FOREST WITH SLASH	0.69	15.03	21.94	15.45	20.92	21.23	4.74	0.00
CLEARCUT	1.82	8.88	13.87	38.74	8.58	19.22	8.88	0.00
PASTURE FALLOW FIELD	0.78	2.21	7.12	9.25	35.43	41.49	3.72	0.00
CROPLAND	0.56	2.33	5.39	8.55	21.45	58.60	1.72	1.42
WET FIELD	20.94	0.88	3.92	1.82	0.66	4.64	67.13	0.00
WATER	0.00	0.00	0.00	0.00	0.19	8.17	0.00	91.63

Table 6. Verification Values of the Classification of Landsat MSS Bands 4, 5, 6, 7 Data

GROUND TRUTH CLASSES	DECIDUOUS FOREST	PINE FOREST WITHOUT SLASH	PINE FOREST WITH SLASH	CLEARCUT	PASTURE FALLOW FIELD	CROPLAND	WET FIELD	WATER
DECIDUOUS FOREST	78.88	13.20	6.39	0.11	0.20	0.73	0.48	0.00
PINE FOREST WITHOUT SLASH	5.97	59.65	26.78	0.03	6.88	0.00	0.70	0.00
PINE FOREST WITH SLASH	0.60	10.00	64.80	0.00	18.82	0.00	5.45	0.33
CLEARCUT	1.23	1.00	0.00	62.90	9.47	17.93	7.47	0.00
PASTURE FALLOW FIELD	0.00	5.61	0.08	10.88	64.36	5.97	13.09	0.00
CROPLAND	0.94	0.08	0.00	5.59	3.79	84.14	5.46	0.00
WET FIELD	1.65	6.80	1.10	4.36	8.45	6.30	70.44	0.88
WATER	0.00	0.00	0.39	0.00	0.00	0.58	1.36	97.67

Table 7. Verification Values of the Classification of SAR and MSS Bands 5, 7 Data

GROUND TRUTH CLASSES	DECIDUOUS FOREST	PINE FOREST WITHOUT SLASH	PINE FOREST WITH SLASH	CLEARCUT	PASTURE FALLOW FIELD	CROPLAND	WET FIELD	WATER
DECIDUOUS FOREST	88.82	4.75	4.73	0.00	0.04	0.74	0.93	0.00
PINE FOREST WITHOUT SLASH	0.63	67.17	25.99	0.03	5.89	0.00	0.29	0.00
PINE FOREST WITH SLASH	0.16	12.10	68.11	0.11	19.04	0.00	0.49	0.00
CLEARCUT	2.76	1.00	0.00	78.89	4.76	6.70	5.88	0.00
PASTURE FALLOW FIELD	0.25	3.85	0.00	13.79	77.17	2.50	2.45	0.00
CROPLAND	0.76	0.15	0.00	1.77	4.63	90.69	2.00	0.00
WET FIELD	1.77	4.75	0.50	1.93	0.61	3.98	86.46	0.00
WATER	0.00	0.00	0.00	0.00	0.00	0.58	0.39	99.03

Table 8. MULTISENSOR DATA CLASSIFICATION ACCURACY

LAND COVER TYPE	DATA SET USED		
	LANDSAT MSS BANDS 4, 5, 6, 7	SAR X-BAND HH, HV, VV POL	SAR AND MSS BANDS 5,7
DECIDUOUS FOREST	78.88	79.33	88.82
PINE FOREST WITHOUT SLASH	59.65	44.05	67.17
PINE FOREST WITH SLASH	64.80	21.94	68.11
CLEARCUT	62.90	38.74	78.89
PASTURE FALLOW FIELD	64.36	35.43	77.17
CROPLAND	84.14	58.60	90.69
WET FIELD	70.44	67.13	86.46
WATER	97.67	91.63	99.03
OVERALL ACCURACY	72.47	58.88	81.46

Table 9. LAND COVER CLASS AREA ESTIMATION OF THREE CLASSIFICATIONS (IN HECTARES)

LAND COVER CLASS	SAR 3 BAND DATA	MSS 4 BAND DATA	SAR/MSS 5 BAND DATA
DECIDUOUS FOREST	2,948	3,782	3,344
PINE FOREST WITHOUT SLASH	2,683	3,259	4,177
PINE FOREST WITH SLASH	2,747	1,707	1,739
CLEARCUT	851	486	701
PASTURE FALLOW FIELD	1,167	1,785	1,321
CROPLAND	1,319	869	885
WET FIELD	1,320	1,136	863
WATER	15	25	20

extract surface features properly. A special SAR data pattern recognition technique is needed to resolve the speckleness and other intrinsic characteristics of SAR data.

The verification values of the Landsat MSS 4-band data shown in Table 6 are relatively low for the pine forest without slash, pine forest with slash, clearcut, and pasture fallow field classes; however, the values of these low accuracy classes are still considerably higher than that of the corresponding classes of the SAR data set shown in columns two and three of Table 8. Also there is a confusion of class (high commission errors) for the specific classes in Tables 5 and 6. Using wet field class as an example, SAR data yields 67.13% correct classification with 20.94% misclassified as deciduous forest class, while MSS data show 70% correct classification with only 1.66% misclassified as deciduous forest class and 8.45% misclassified as pasture fallow field class.

This finding suggests that combined SAR/ MSS data will do significantly better when the confused classes are distinctively different between the SAR and MSS data. In the case of the wet field class, the percent correct classification increases significantly from 70.44 (MSS data) or 67.131 (SAR data) to 86.46. It is difficult to delineate pine forest class into "without slash" and "with slash" classes shown in Table 7, because the two classes are spectrally confused both in microwave and Landsat MSS spectral regions. Table 8 also shows that SAR/MSS data improved classification accuracy for all eight land cover classes.

Table 9 shows the area distribution of the eight land cover classes for three classifications. Assuming the result from the SAR/MSS data to be accurate. SAR data significantly under estimates the pine forest without slash class but significantly over estimates the pine forest with slash class. If the estimated areas of two pine forest classes are added together for the SAR data, they are very close to that of the combined SAR/MSS data. In the case of the deciduous forest class, Landsat MSS data overestimated the acreage while the SAR data underestimated the acreage. The same kind of comparison can easily be made for other land cover classes.

VI. Concluding Remarks:

The aircraft X-band and Seasat L-band SAR data have been combined with the Landsat MSS data to form a nine-channel multisensor data set for forest-related surface signature study and land cover classification in the Kershaw County, South Carolina, study area. Direct count value, visual comparison, and an evaluation of the supervised classification of the combined seven-channel aircraft SAR and Landsat MSS data set result in the following findings:

1. The combined SAR/MSS data set resulted in an improved classification accuracy of the eight land cover classes as compared with the SAR-only and MSS-only data sets. The results suggested the usefulness of SAR data for improving forest-related cover type mapping and area estimation when combined with Landsat MSS data.

2. In the case of the aircraft X-band three polarization data, VV polarization data contain the highest contrast while HV polarization data contain the least contrast. For the dense deciduous forest stands located in ravines, all three polarization data contain relatively high return. This kind of high return is also shown in the auto junk yard, with cross (HV) polarization data which contain the highest return. These observations suggest that VV polarization data are good for vegetation detection, HH polarization data are good for surface wetness detection, and HV polarization data are good for very rough surface detection.

3. Since Landsat MSS data are readily available over all of the United States, and since they can be resampled and registered to SAR data, it is advantageous to use Landsat MSS data to spectrally improve delineation of spectrally overlapping classes. These classes are forest clearcut, pasture/fallow field and cropland. Older clearcuts with regrowth, cropland with emergent vegetation, and pasture with tall grasses have very poor classification accuracy using SAR-only data, but were significantly improved when MSS data were combined with SAR data. Because wet fields contain different spectral overlapping characteristics in SAR data than those in MSS data, combining SAR and MSS data also significantly improved their discrimination.

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