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ANALYSIS OF DATA ACQUIRED BY SYNTHETIC APERTURE RADAR OVER DADE COUNTY, FLORIDA, AND ACADIA PARISH, LOUISIANA

S. T. Wu

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16. ABSTRACT

This report presents results of digital processing of airborne X-band Synthetic Aperture Radar (SAR) data acquired over Dade County, Florida, and Acadia Parish, Louisiana. The goal of the research was to investigate the utility of SAR data for land cover mapping and area estimation under the AgRISTARS Domestic Crops and Land Cover Project. In the case of the Acadia Parish study area, Landsat Multispectral Scanner (MSS) data were also used to form a combined SAR and MSS data set. The results of accuracy evaluation for the SAR, MSS, and SAR/MSS data using supervised classification show that the combined SAR/MSS data set results in an improved classification accuracy of the five land cover classes as compared with SAR-only and MSS-only data sets. In the case of the Dade County study area, the results indicate that both HH and VV polarization data are highly responsive to the row orientation of the row crop but not to the specific vegetation which forms the row structure. On the other hand, the HV polarization data are relatively insensitive to the orientation of row crop. Therefore, the HV polarization data may be used to discriminate the specific vegetation that forms the row structure.

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I. INTRODUCTION/OBJECTIVES

This study was conducted as part of the research tasks under the AgRISTARS Domestic Crops and Land Cover (DCLC) project. The objectives were to assess the utility of using Synthetic Aperture Radar (SAR) data for crop and land cover area estimation and mapping, and to present results in such a manner that they could be a meaningful input to future sensor system design. The types of crops selected for this study included paddy rice and soybeans of central Louisiana and the truck garden vegetation of southern Florida. The truck garden vegetation included avocado, onion, tomato, potato, bush bean, cucumber, etc. Other land cover types contained in the crop discrimination study areas were residential area, highway, woodland (mostly deciduous forest), pasture, fallowed field, and exposed soil.

Since the aircraft SAR mission for data acquisition was quite expensive and difficult to schedule, only one SAR data set was acquired and used in the study, although it is known that a multitemporal data set is usually better for crop discrimination studies. To compensate for the lack of data sets, the date of data acquisition was selected when the land cover types can be most distinctively separated. In the Acadia Parish, Louisiana, study area, Landsat Multispectral Scanner (MSS) data were also acquired and combined with SAR data for a multisensor data analysis; in the Dade County, Florida, study area, only SAR data sets with different polarization and flight pass combinations were used for data analysis. Data processing tasks included preprocessing of SAR data and resampling and registration of MSS data to the SAR data base. Data analysis included the direct visual comparison of SAR and MSS data, supervised signature development, and classification through spectral pattern recognition. The classified data and field verification plots were used to evaluate the accuracy of crop and land cover classes.

II. STUDY AREAS AND DATA SOURCES

A. Dade County, Florida

The study area, as shown in Figure 1, was located in Dade County near Homestead and approximately 50 miles southwest of Miami. The area contained a strip of land approximately 25 km east-west by 40 km north-south. Homestead airport is located on the eastern boundary, while a wildlife management area is on the western boundary. The cities of Homestead and Florida City are located on the central-southern part of the study area. The area is characterized by truck garden vegetation which includes avocado, onion, tomato, potato, bush bean, cucumber, etc. More than 30 varieties of vegetables and tropical fruit trees were planted at the time of SAR data acquisition, as shown in Table 1. A number of vegetables were planted with distinctive row direction, either north-south or east-west, because all fields were rectangular and were aligned in a north-south direction and the vegetables were planted parallel to field boundaries. In addition to truck garden vegetation, the study area contained residential area, highway, woodland (mostly deciduous forest), small scattered water ponds, and an airport.

The ground data were furnished by the Statistical Reporting Service (SRS) of the United States Department of Agriculture (USDA). They used a sampling technique to select 20 segments (10.8 km by 1.6 km in size) within the study area to conduct a "wall-to-wall" ground data collection during SAR data acquisition flights. By sampling selection, the 20 segments contained the representative cover types presented in the study area. The ground data in each segment were presented in a complete cover type map with alphanumeric coded names that designated every cover type. A typical ground data segment is shown in Figure 2. SQ1 designated the first squash field in the segment.

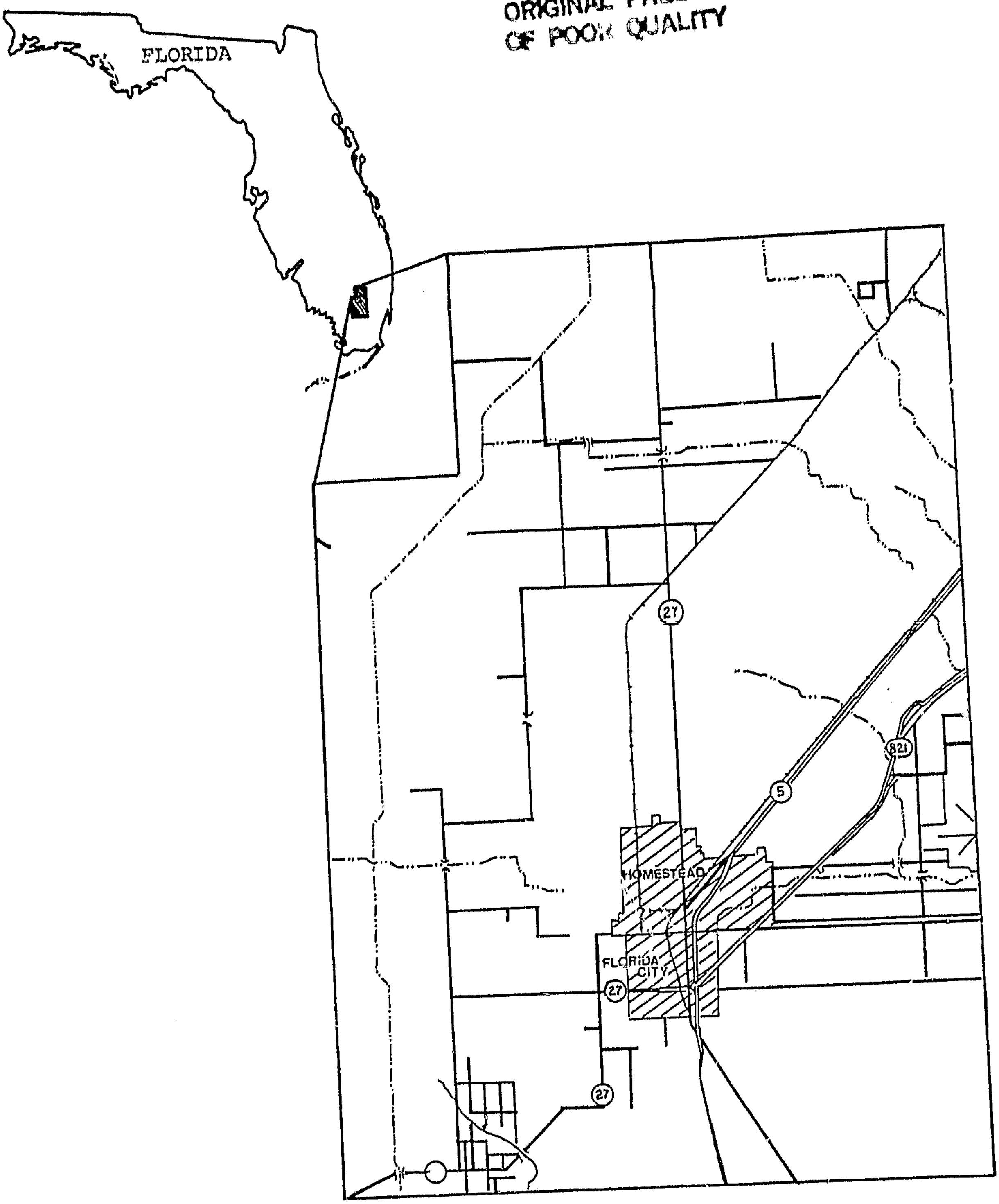

Figure 1. Dade County, Florida, Study Area

Table 1. Cover Type Designation of Dade County, Florida, Study Area.

Digital Value	Number of Pixels in the Study Area	Symbol	Cover Type Description
1	1047	SQ	Squash
2	1321	RE	Residential
3	1001	BB	Snapbeans - bush
4	2154	WO	Woodland
6	199	CM	Commercial and Services
7	823	GR	Grasses (short, pasture-like, or lawn-like)
8	2850	AV	Avocados
9	447	EM	Emerging Crop-Unknown
12	782	BH	High Brush (very high grasses bushes)
13	1104	BA	Idle Cropland
14	1398	BS	Short Brush (mostly high grasses)
20	171	OF	Outdoor Foliage
21	463	PO	Potatoes
22	912	SC	Corn-Sweet
23	1061	SW	Wetland-Unforested, Sweet Potatoes
25	132	XV	Mixed Vegetables
26	343	TO	Tomatoes - Bush
29	266	CO	Seed Corn
31	698	LS	Limes
34	162	LM	Lemons
36	577	TV	Tomatoes - Vine
44	143	GS	Sorghum
10	27	CP	Papayas
11	74	WA	Water
15	100	TU	Tunnels
16	21	XX	Unknown
19	10	PS	Peas
24	36	FW	Wetland-Forested
27	66	CA	Corn-Abandoned
35	12	AC	Abandoned-Citrus
37	15	ML	Malanga
39	67	MO	Mangoes

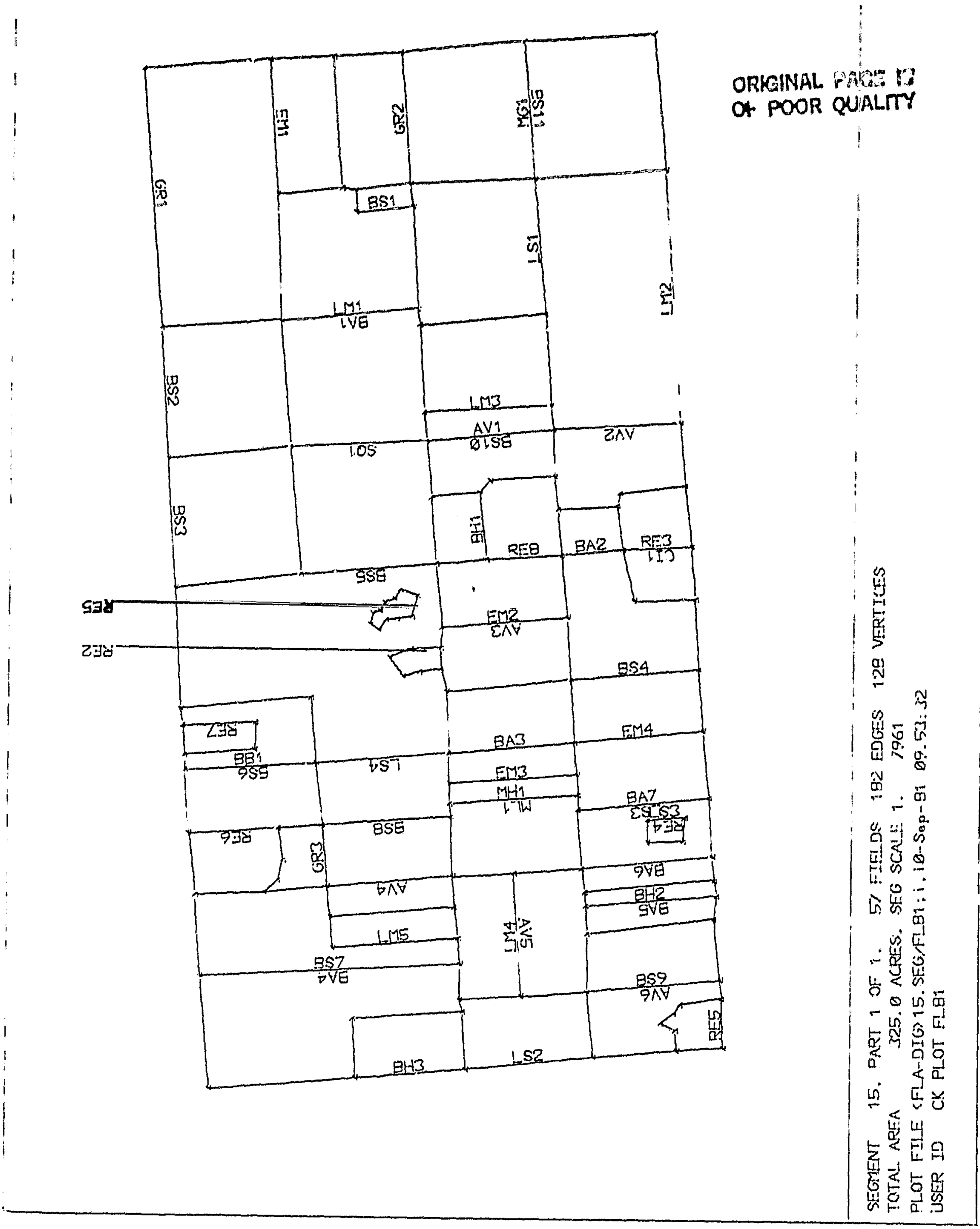

Figure 2. Typical Ground Data - Segment 15.

There are 57 fields with more than 10 varieties of vegetation in the segment. In addition to cover type maps, the Statistical Reporting Service also provided a digital ground data tape in which the digitized cover type map data were recorded. In Table 1, the first column indicated the digital number and the last column the cover type description. For example, a digital number one represented squash. A 30m by 30m pixel size was used in digitization. Also, the digitized data were georeferenced with the northing and easting coordinates of the Universal Transverse Mercator System.

The airborne SAR data were acquired over the study area with an AN/APQ-102A (X-band, 9.6GH_z, 3.12 cm wavelength) SAR system, flown in a NASA Lyndom B. Johnson Space Center (JSC) WB-57 aircraft on March 11, 1981. On one of 12 radar flights, the radar transmitted one polarization (either horizontal or vertical) electromagnetic wave and received both horizontal and vertical polarization returns of the same swath simultaneously on two recording channels. The radar provided a swath (across track) coverage of 18 km with ground element resolution of approximately 16 meters. The radar also operated in two modes, which provided two incidence angle variations over the swath coverage. As shown in Figure 3, Mode I viewed from 14.2^o to 51.7^o to the right of the aircraft, while Mode II viewed from 45.4^o to 63.7^o. In data acquisition, 12 flights were made to obtain 24 channels of optically correlated image films. The flight configuration and the corresponding image data are listed in Table 2.

The airborne SAR image films, furnished by the JSC airborne program office, were first visually examined to determine whether the images were adequate for further processing. For this data set 20 image films were selected for digitization. In the digitization process, appropriate brightness density scales were selected to preserve dynamic range of each image fil and compatible aperture size was used to agree with SAR resolution of 16m.

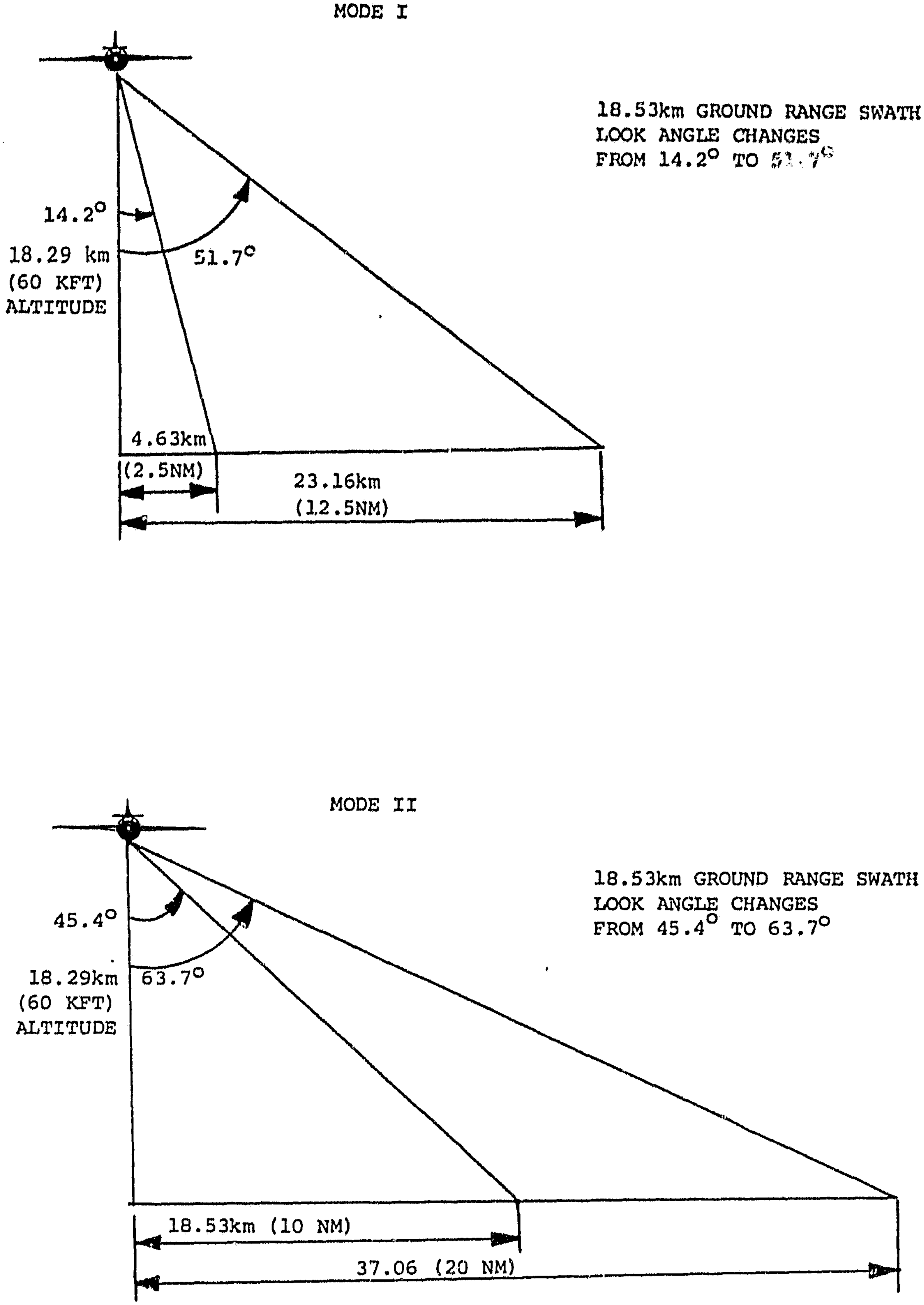

Figure 3. NASA/JSC Aircraft SAR (AN/APQ-102A) Mode Geometry

Table 2. AN/APQ-102A SAR - Data Acquisition Configurations

Study Area	Data Acquisition Date	Mode	Transmit Polarization	Direction of Flight Line	Data Sets
Acadia Parish Louisiana	6-15-81	I	Horizontal	East-West	HH VV
			Vertical	East-West	VV VH
Dade County Florida	3-11-81	I	Horizontal (two passes)	North-South East-West	HH, HV-(N-S)I HH, HV-(E-W)I
			Vertical (two passes)	North-South East-West	VV, VH (N-S)I VV, VH (E-W)I
		II	Horizontal	North-South East-West	HH, HV (N-S)II HH, HV (E-W)II
			Vertical	North-South East-West	VV, VH (N-S)II VV, VH (E-W)II

The grey scale that represented tonal variation of image film was converted to digital grey levels of 0 to 255, where 0 and 255 signified the darkest and the lightest image tone, respectively. The digitized SAR data contained a pixel size or resolution of approximately 18.5m by 18.5m.

B. Acadia Parish, Louisiana

The study area, as shown in Figure 4, was located on the central Louisiana Coastal Plain in Acadia Parish near Crowley and Rayne. It was selected to include such land cover types as intermingled vegetation, reparian forest vegetation, cropland, and pasture. Of particular interest is the large acreage of paddy rice in Acadia Parish.

Collection of ground data began with the selection of a number of training and testing sample plots from a 7.5 degree quadrangle map. After the plots were selected, detailed descriptions of surface cover types and conditions were made in the field immediately after the SAR mission. The major cover types in this area were residential, exposed soil, deciduous forest, soybean, and paddy rice. These five land cover types were used in the data analysis and evaluation presented in a later section.

The same SAR system used in the Dade County data acquisition flights was employed to acquire SAR data over this study area. The mission was flown on June 15, 1981, using Mode I configuration and two flight passes (west-east flight line with horizontal and vertical transmitter polarization), as shown in Table 2. Four image films were obtained from the JSC program office and the same processes as applied to the Dade County data sets were employed for the digitization of image films.

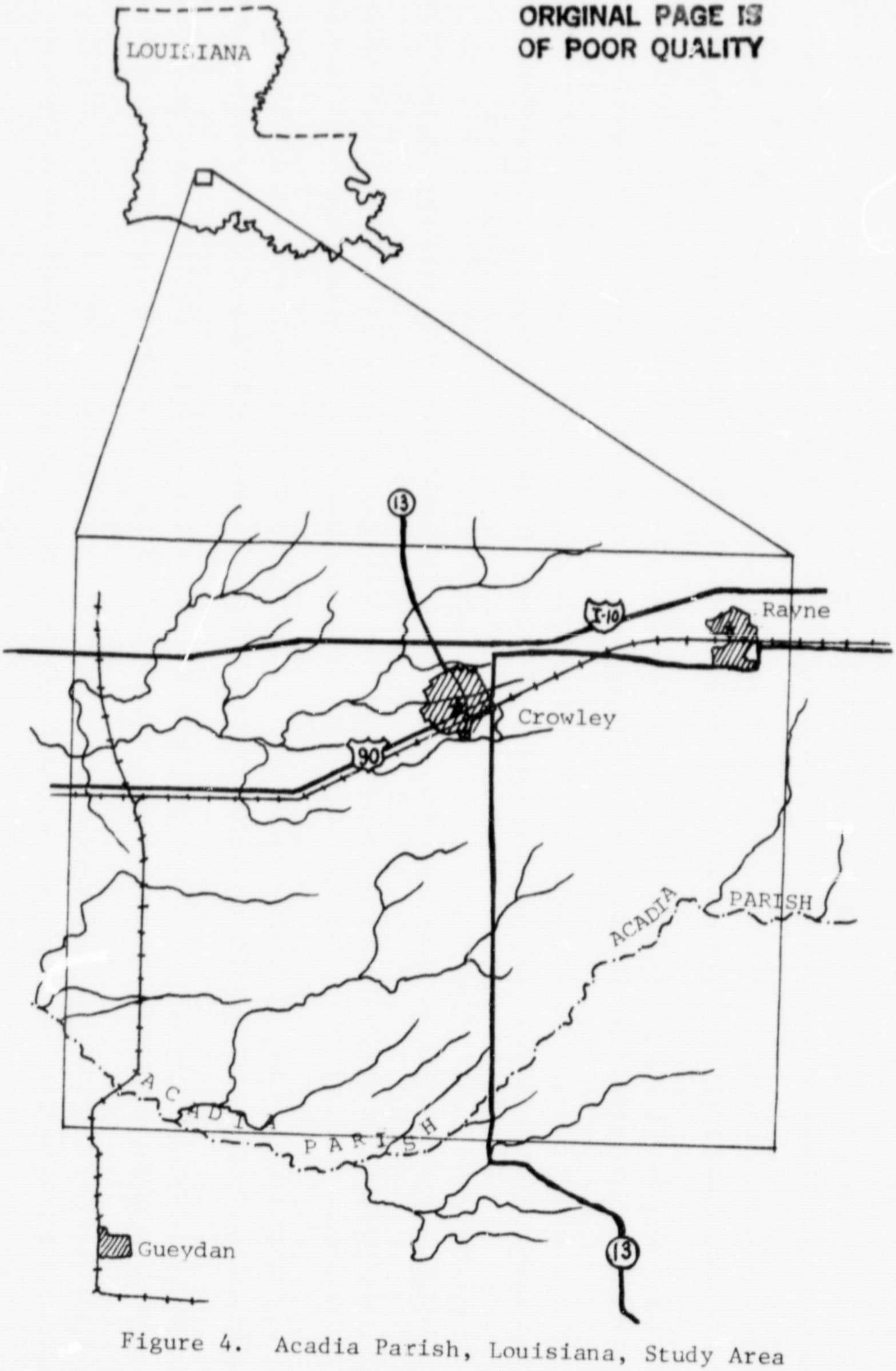

Figure 4. Acadia Parish, Louisiana, Study Area

For the purpose of multisensor data analysis, the Landsat MSS data set acquired on August 25, 1981, was selected because it contained the cloud-free MSS data closest to the aircraft SAR acquisition date. To facilitate ground truth verification, color infrared (CIR) aerial photography was also acquired immediately after the SAR data acquisition over the study area.

III. DATA PROCESSING

The digitization of SAR image films was performed by NASA Wallops Flight Center using their digital microdensitometer (Ref. 1). After receiving the digitized data tapes on which the grey levels of image films were recorded, the digital SAR data were further processed to reduce the striping and banding effects (Ref. 2). These radiometrically corrected data were then used to form a multichannel data set.

Since the aircraft SAR data were acquired using different polarizations and flight passes, and each data set was recorded on one strip of image film, these data were not aligned (pixel-wise). A scene-to-scene registration (Ref. 3) was performed to form a multichannel SAR data set for both the Dade County and Acadia Parish data sets. In the case of the Dade County data set all Mode I data were of unacceptable quality; therefore, only Mode II data were used in the scene-to-scene registration process to form an eight-channel data set, since the Dade County ground data were recorded to a map base (i.e., geo-referenced) with a 30m by 30m pixel size. To use these ground data for surface feature analysis and evaluation of classification, the Dade County SAR data were registered to map coordinates using scene-to-map registration. Since Landsat MSS data were used in the Acadia Parish study area, registration of Landsat MSS data to the aircraft SAR was performed after the SAR scene-to scene registration was completed. These two stages of scene-to-scene registration result in an eight-channel data set.

IV. SAR SIGNATURE COMPARISON OF CROP AND LAND COVER

A. Acadia Parish, Louisiana

The aircraft SAR data consisted of HH, HV, VV, and VH polarization data. The VH and HV polarization data contained the same radar signatures based on the reciprocity principle of electromagnetic scattering. This one effective cross polarization radar signature is also demonstrated in Figure 5 in which the relative frequencies of the four polarization data were plotted. Using the histogram curves given in Figure 5, the characteristics of the four-channel SAR data over the Acadia Parish area are summarized as follows: (1) HH polarization data contained a relatively higher digital grey level than the other three polarization data while HV polarization data contained the lowest grey level of the four polarization data; (2) VV polarization data on the other hand, contained the widest range of distribution among the four polarization data; (3) HV and VH polarization data contained the same type of digital grey level distribution, with approximately 24 grey levels separating the two curves. This is as expected because the two data sets provided the same spectral signatures and only one type of polarization (either HV or VH) is sufficient for image interpretation and data analysis. Since HV polarization data were displaced further from VV and HH polarization data than VH polarization data, the HV polarization was selected for digital data comparison and MSS/SAR classification.

Visual comparison of the SAR and MSS data was conducted using false color images in which surface features contained in different spectral regions were

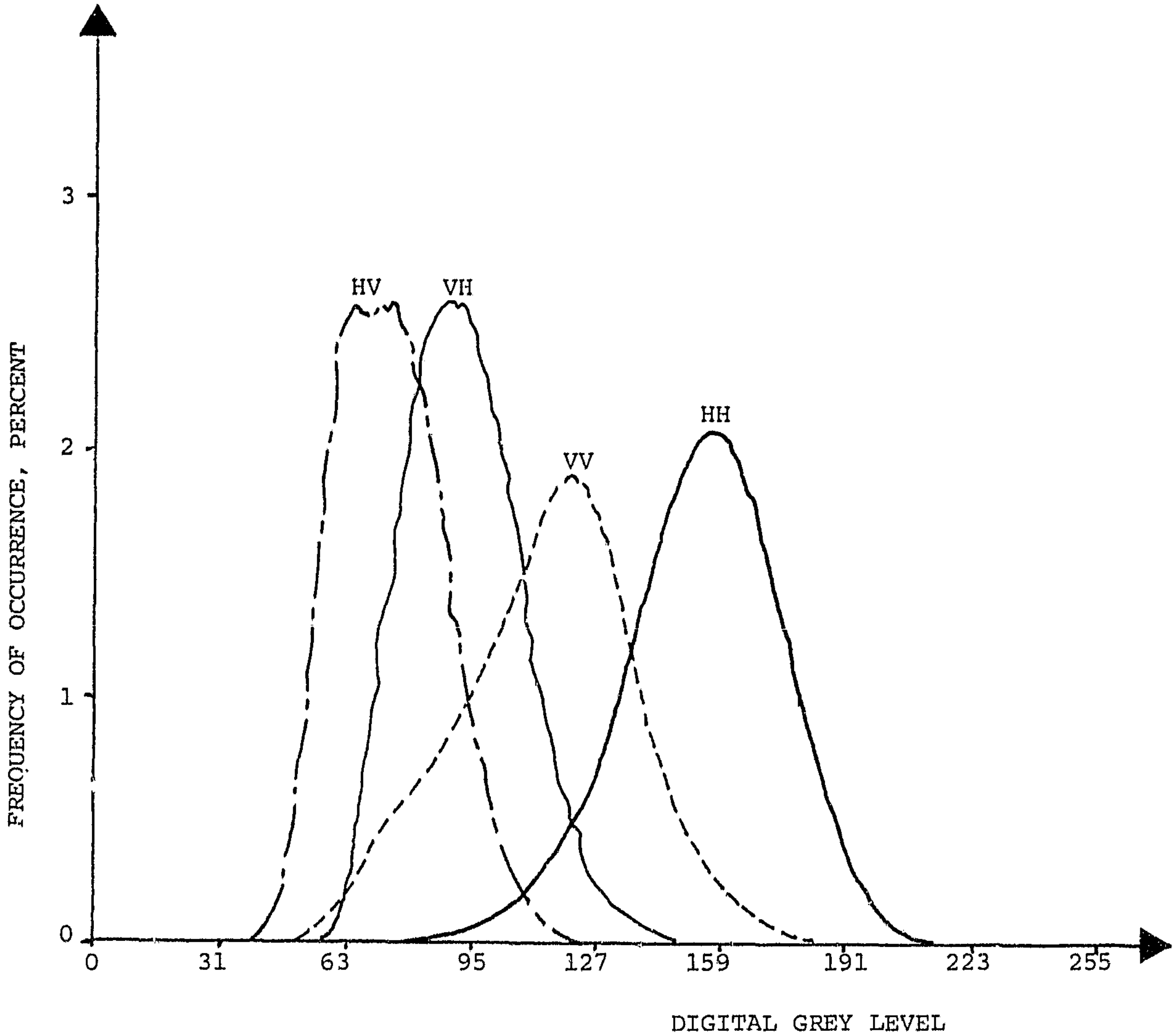

Figure 5. Histogram of SAR Data from Acadia Parish

shown as three prime colors: blue, green, and red. Hence each false color image was capable of presenting three channels of data simultaneously. The aircraft SAR and Landsat MSS false color image of the Acadia Parish study area is shown in Figure 6. In the SAR false color image shown in the lower part of Figure 6, the blue, green, and red colors represent the HV, VV, and HH polarization data, respectively. In the MSS false color image shown in the upper part of the figure, the blue, green, and red colors represent bands 4, 5, and 7 data, respectively.

Using Figure 6 and the ground data from the field trip, the crop and land cover SAR and MSS signatures are visually displayed via their distinctive color tones. Paddy rice is shown in red for SAR and MSS false color image while soybeans are shown in green in the SAR data and in bright greenish blue in the MSS. The deciduous forest, shown in the MSS false color image as dark green, can be delineated from all other land cover types. On the other hand, the residential areas, which are shown as purplish red in the MSS, are difficult to discriminate from either paddy rice or exposed soil. These different spectral overlapping characteristics of the SAR and MSS data suggested an improved discrimination capability when the two data sets were combined.

The SAR and MSS digital grey level of field verified plots, of the five major land cover types, with their means and standard deviations, are tabulated in Table 3. In the table, the highest mean grey levels resulting from the specific land cover types for the three polarization data are: paddy rice, 183.5, for HH polarization; soybean, 127.0, for VV polarization; and residential area, 100.9, for HV polarization. These digital grey levels, when displayed in the false color image of Figure 6, depict specific color tones for the three cover types: red for paddy rice, green for soybean, and

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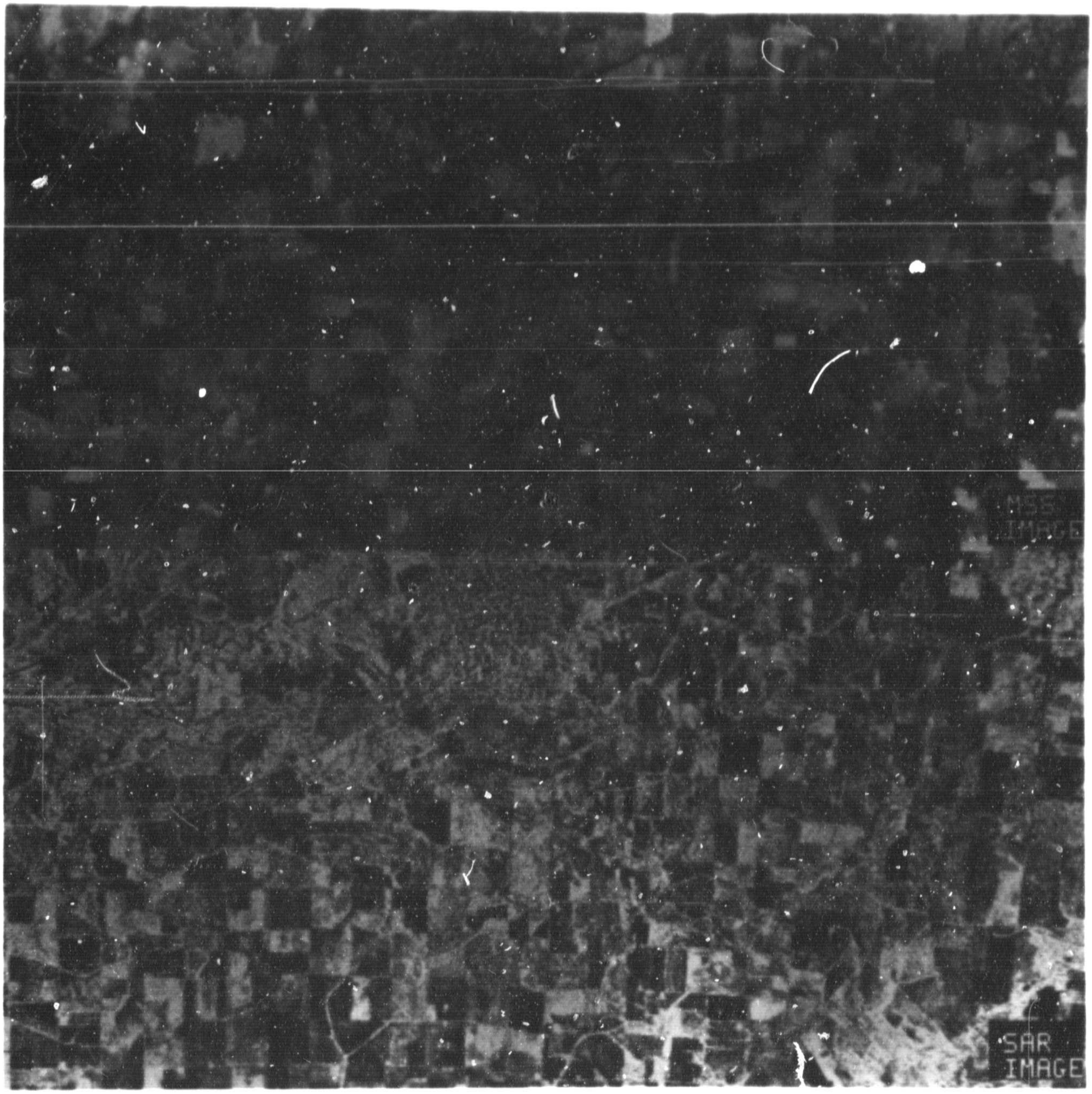

Figure 6. False Color Image of Acadia Parish Study Area

Table 3. Means and Standard Deviations of Five Land Cover Types

Land Cover Description	SAR DATA						LANDSAT MSS			
	HH Pol.		HV Pol.		VV Pol.		Band 5		Band 7	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Residential	156.5	24.7	<u>100.9</u>	17.4	120.3	19.2	25.6	2.3	41.4	2.3
Soybean	151.5	13.1	68.2	7.8	<u>127.0</u>	8.4	18.6	2.2	66.10	6.1
Paddy Rice	<u>183.5</u>	9.1	81.3	5.4	114.7	10.0	30.9	10.3	47.2	8.2
Exposed Soil	93.2	8.9	51.5	3.0	62.6	7.0	25.0	1.3	23.3	2.2
Deciduous Forest	157.9	12.0	89.7	7.1	126.9	9.2	17.6	1.2	33.0	5.3

purplish blue for the residential area. Exposed soil exhibits the lowest mean grey level for all three polarizations (shown in black in Figure 6) because it is not only unvegetated but also relatively smooth and dry. The degree of surface roughness (and/or irregularity) is also closely correlated with the magnitude of the cross polarization (HV polarization) return and the standard deviation contained in the specific land cover. For example, the residential area exhibits the highest mean grey level in the HV polarization and the highest standard deviation for all three polarizations, while the exposed soil results in the lowest. This exemplifies that residential area contains the roughest surface structure while the exposed soil contains the least surface roughness among the five land covers present in Table 3.

In the Landsat MSS spectral region shown in Table 3, paddy rice contains the highest value of 30.9 for band 5 data while soybean contains a value of 66.1 for band 7 data. These digital values, when displayed in the false color image of Figure 6, depict red for paddy rice and bright bluish green for soybean. Digital mean values of 41.4 and 47.2, for residential and paddy rice classes, respectively, in the band 7 data indicate some spectral overlap between these two land covers.

To help visualize the spectral signature overlap of the five land covers, the digital grey levels are plotted against the five land covers in Figure 7 using the data given in Table 3. Close observation of Figure 7 depicts the following:

(1) Residential (RES) and deciduous forest (DFS) classes are highly overlapped in the microwave spectral region for all three polarizations, while these two classes are distinctively separable in the MSS bands 5 and 7 data. These different spectral overlap characteristics of the

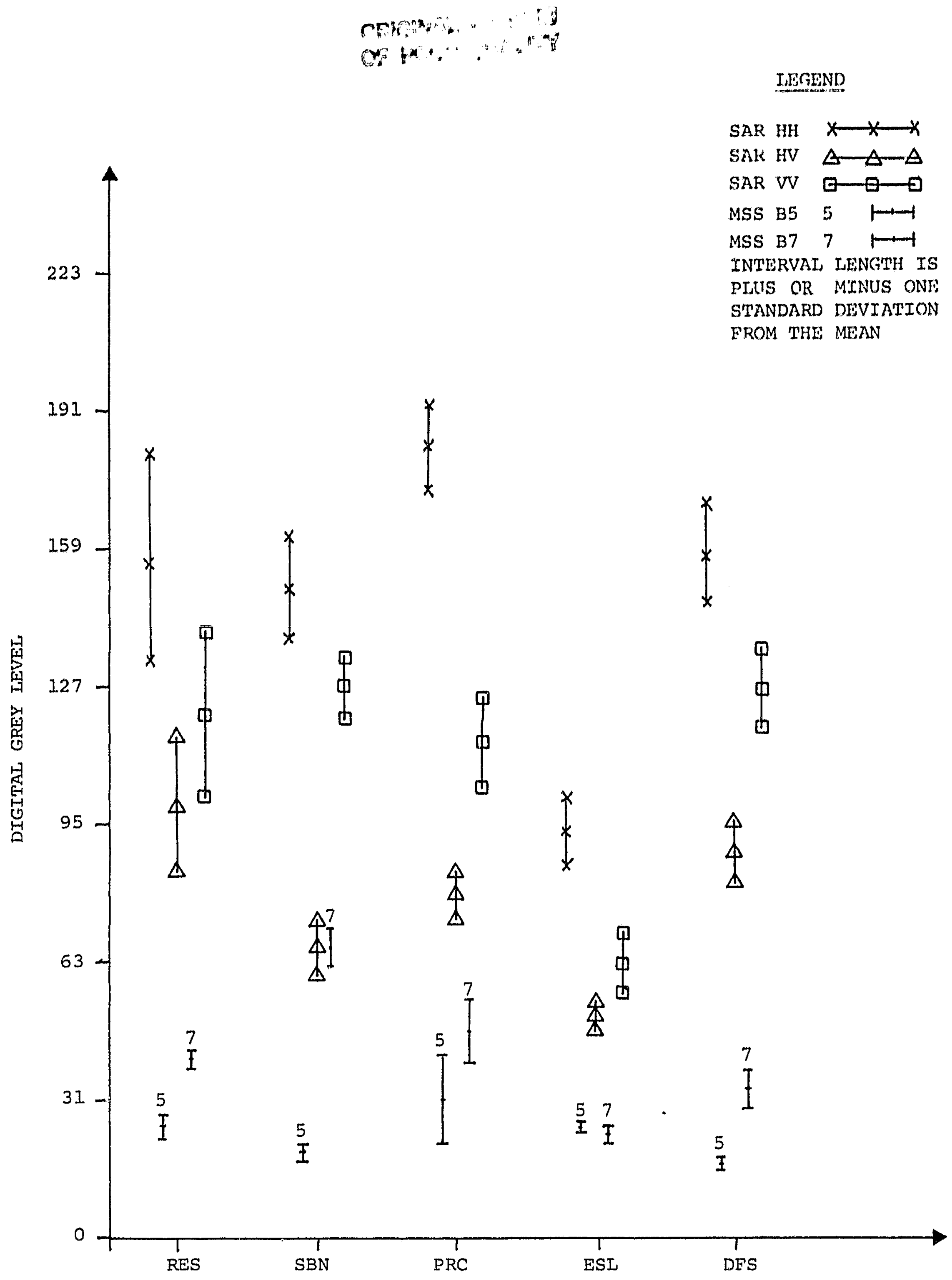

Figure 7. Means and Standard Deviations of Five Land Cover Types from Acadia Parish

SAR and MSS data indicate the advantage of using MSS data to help improve the discrimination of residential versus deciduous forest classes.

(2) Paddy rice (PRC) contains high HH polarization return, which makes it spectrally overlap with residential and deciduous forest classes if only HH polarization is used. Because of its relatively low HV polarization return, the separation of paddy rice from the residential and deciduous forest classes is significantly improved if HV polarization is used in view of the different spectral overlap characteristics of the SAR data. The HH, HV, and VV polarizations would provide better discrimination capabilities than that of a single polarization data set, such as Seasat SAR or SIR-A data, in which only HH polarization was available.

(3) Using HV polarization as the surface roughness index, the ranking of surface roughness from very smooth to very rough is expressed in the following orders: exposed soil (ESL), soybean (SBN), paddy rice, deciduous forest, and residential area.

B. Dade County, Florida

In this study area, 24 data sets were planned for the aircraft mission. The mission was configured with north-south and east-west flight passes, two transmitter polarizations, and two modes of look angle configuration, as shown in Table 2. Twenty images obtained from the mission were digitized. The 12 data sets acquired by using the Mode I look angle configuration contained data that were of very poor quality radiometrically and geometrically as compared to the eight data sets acquired by using the Mode II look angle configuration. Therefore, only the Mode II data sets were used for data analysis and evaluation. Since HV and VH polarization data sets contained similar radar signatures, the eight data sets contained two redundant channels; only six data sets (three each for the north-south and east-west flight passes) were needed. In the east-west flight pass, the quality of the HV and VH polarization data sets was very poor and the data sets were deleted. The final data sets considered useful for data analysis are the five data sets shown in Figures 8 through 12. These five data sets consist of three polarizations (HH, HV, and VV) from the east-west flight pass.

To help visualize the grey level distribution of the five data sets, histograms, in which the grey levels are plotted against the frequency of occurrence, are shown in Figure 13. The histograms indicate that most of the data are clustered around digital grey levels of 30 to 75 and 35 to 90 for the north-south and east-west flight passes, respectively. The lack of grey level variation is apparent compared with the Acadia data sets, which contain digital grey scale variation ranging from 35 to 210. This relatively narrow spreading of digital grey level indicates that the majority of surface covers contain very similar SAR signatures, and thus are very difficult to discriminate from each other. Further difficulty of discrimination is caused by more than 30 varieties of vegetables present in the study area. Due to these two reasons, it is impossible to visually delineate all 30 land cover classes using the SAR images shown in Figures 8 through 12.

Therefore, instead of using more than 30 land cover classes, only seven special feature classes are used in the visual comparison analysis. These classes are highways, airports, residential area, N-S row crops, E-W row crops, high return A, high return B, and open water; they are also designated in Figures 8 through 12.

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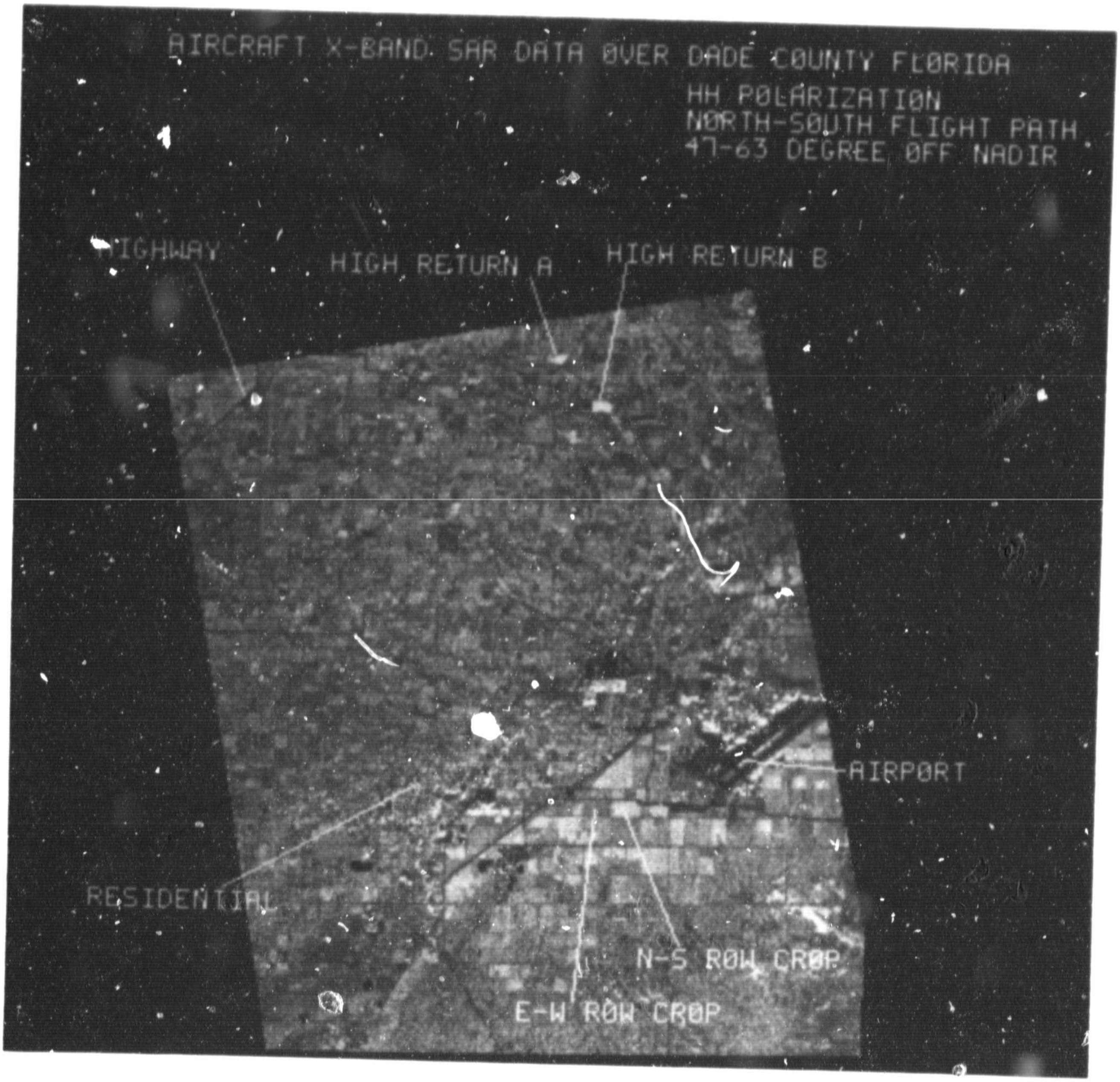

Figure 8. Aircraft X-band SAR Data Over Dade County, HH Polarization, North-South Flight Path

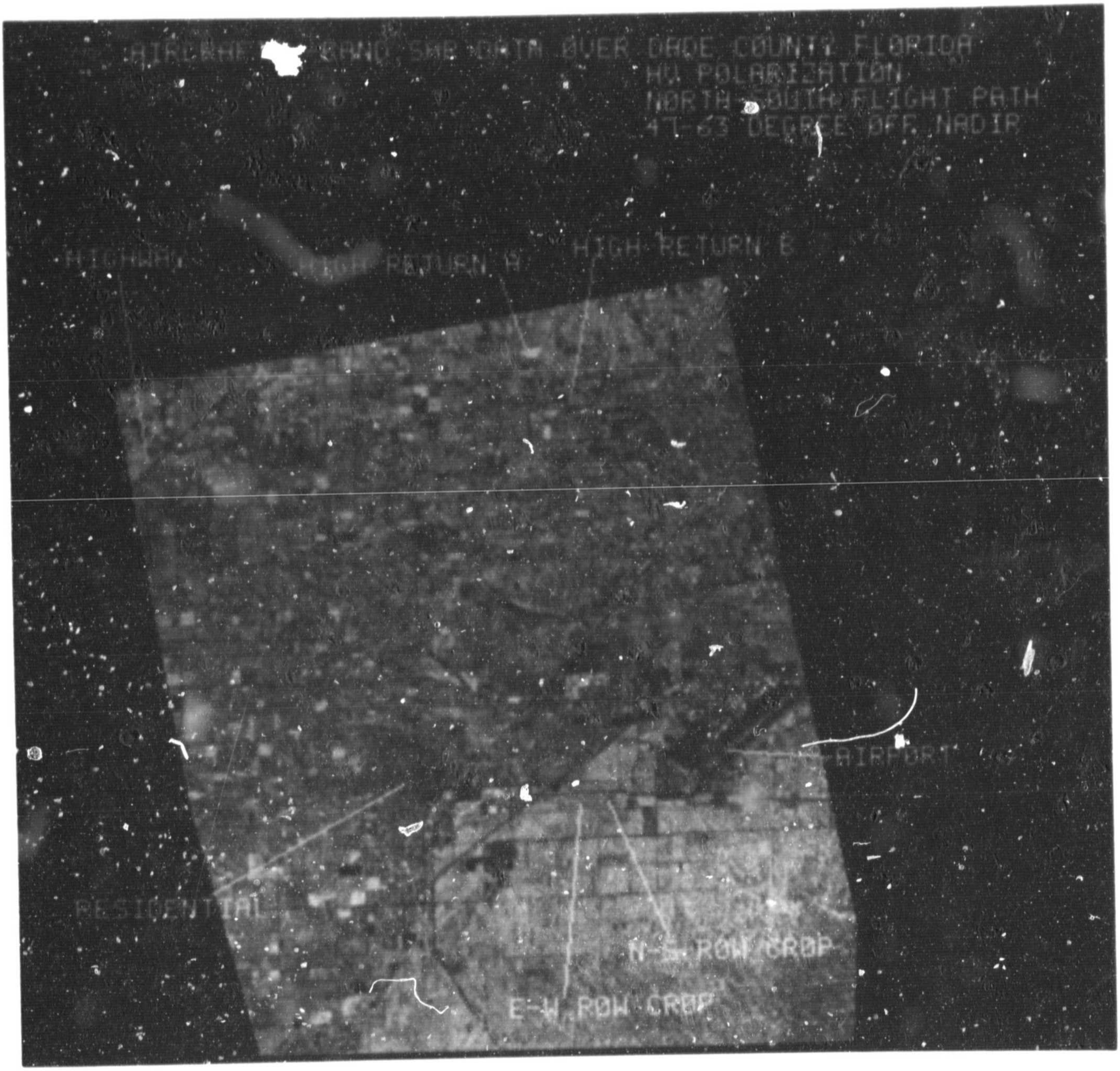

Figure 9. Aircraft X-band SAR Data Over Dade County, HV Polarization, North-South Flight Path

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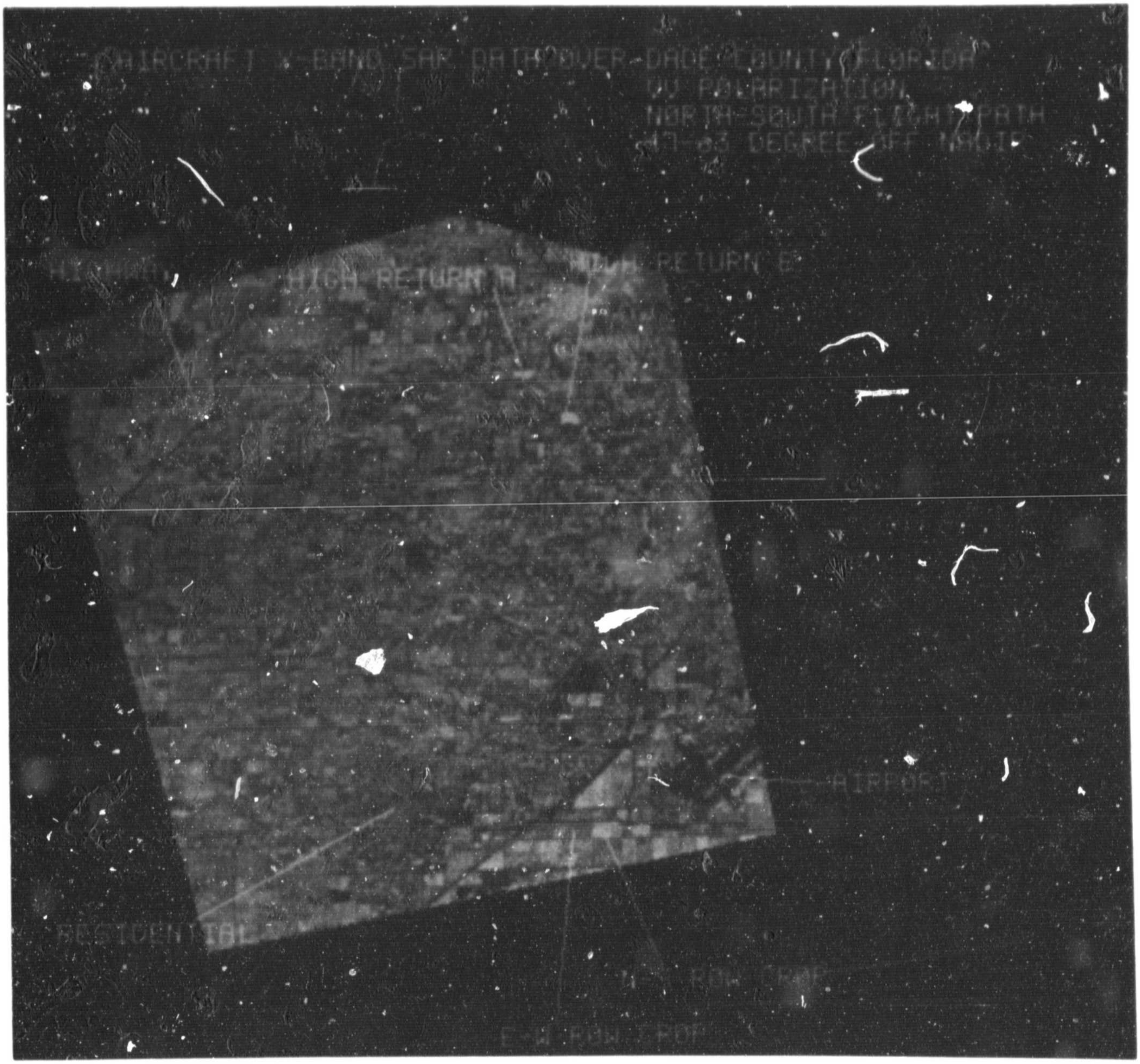

Figure 10. Aircraft X-band SAR Data Over Dade County, VV Polarization, North-South Flight Path

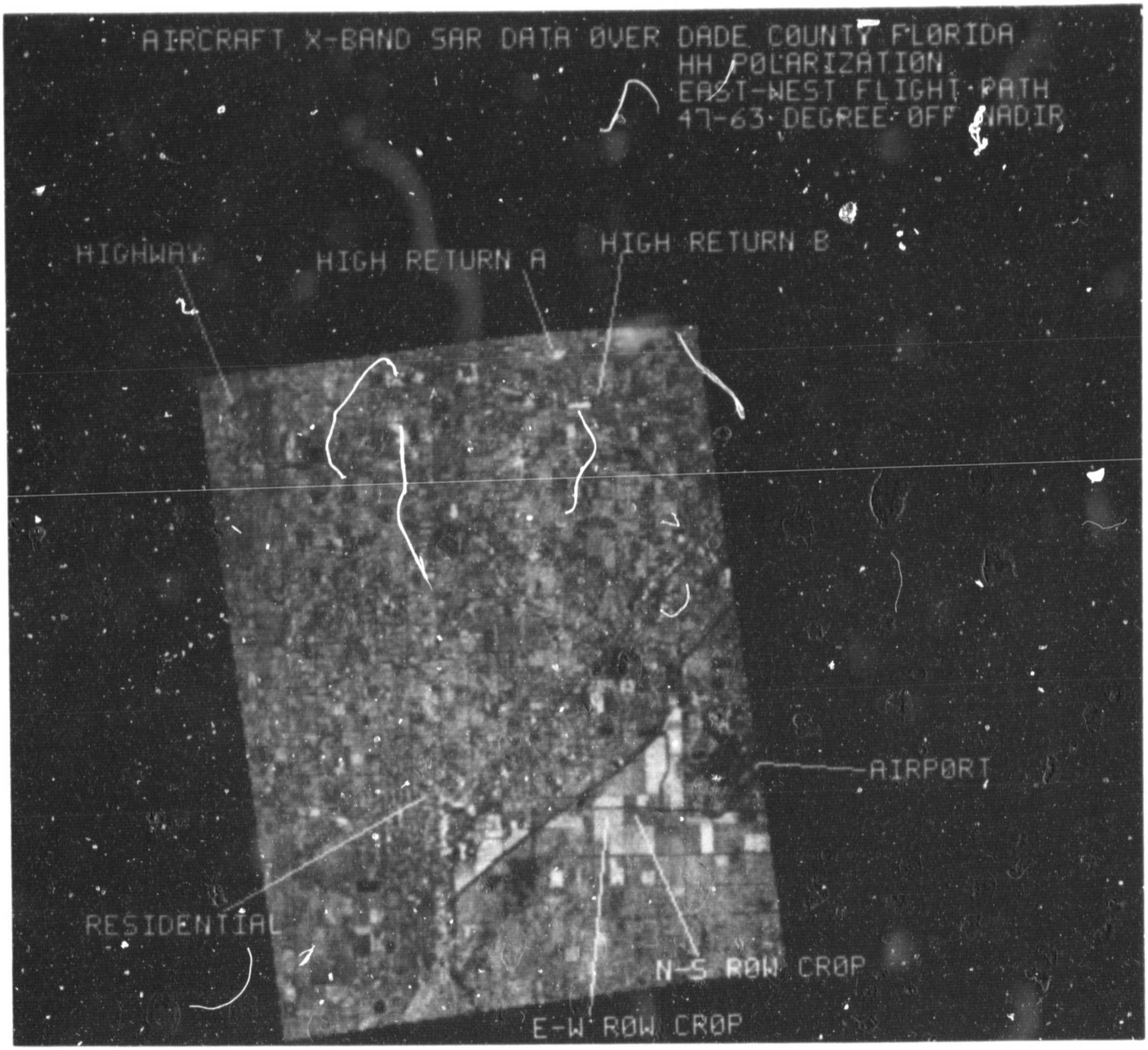

Figure 11. Aircraft X-band SAR Data Over Dade County, HH Polarization, East-West Flight Path

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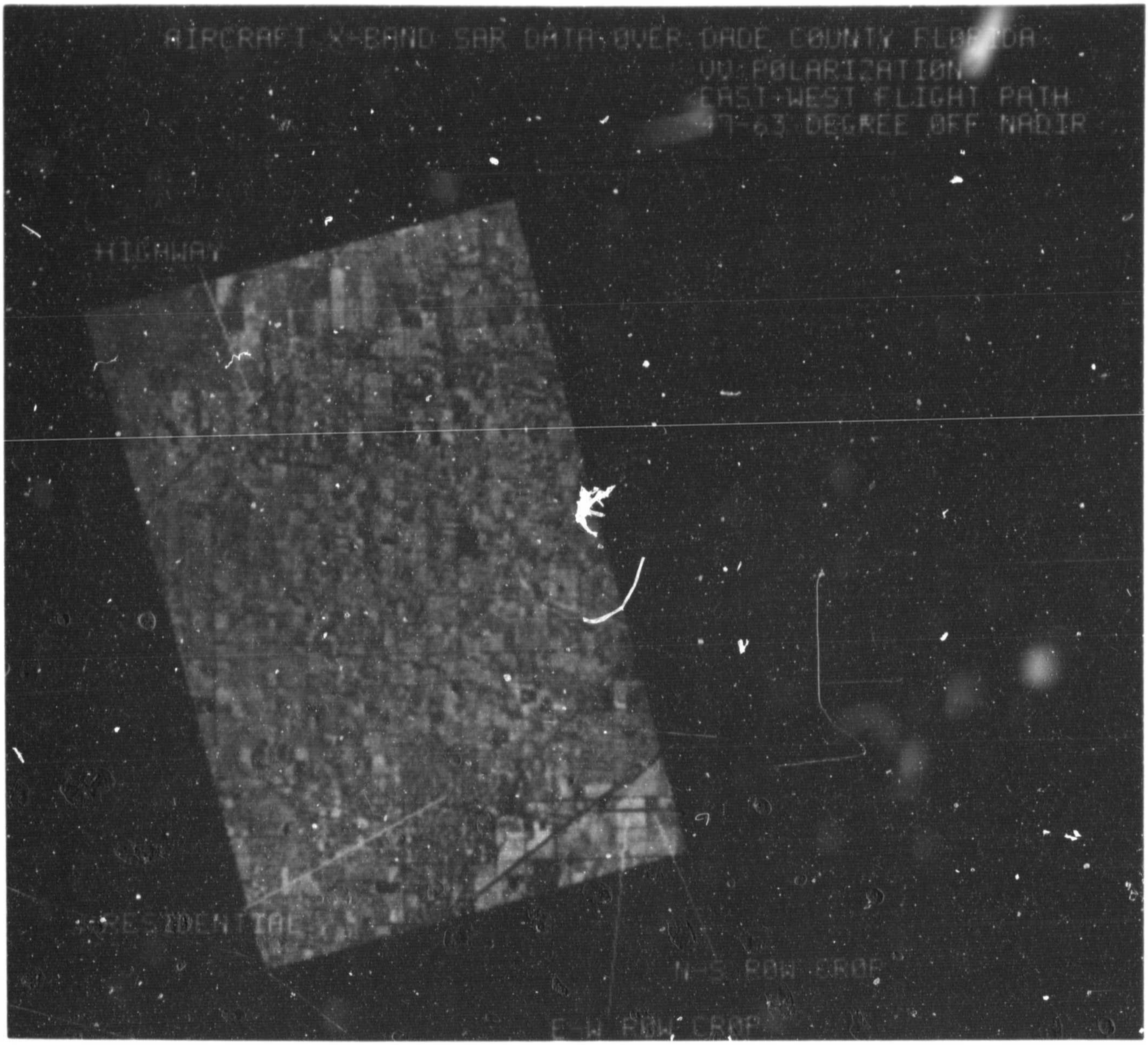

Figure 12. Aircraft X-band SAR Data Over Dade County, VV Polarization, East-West Flight Path

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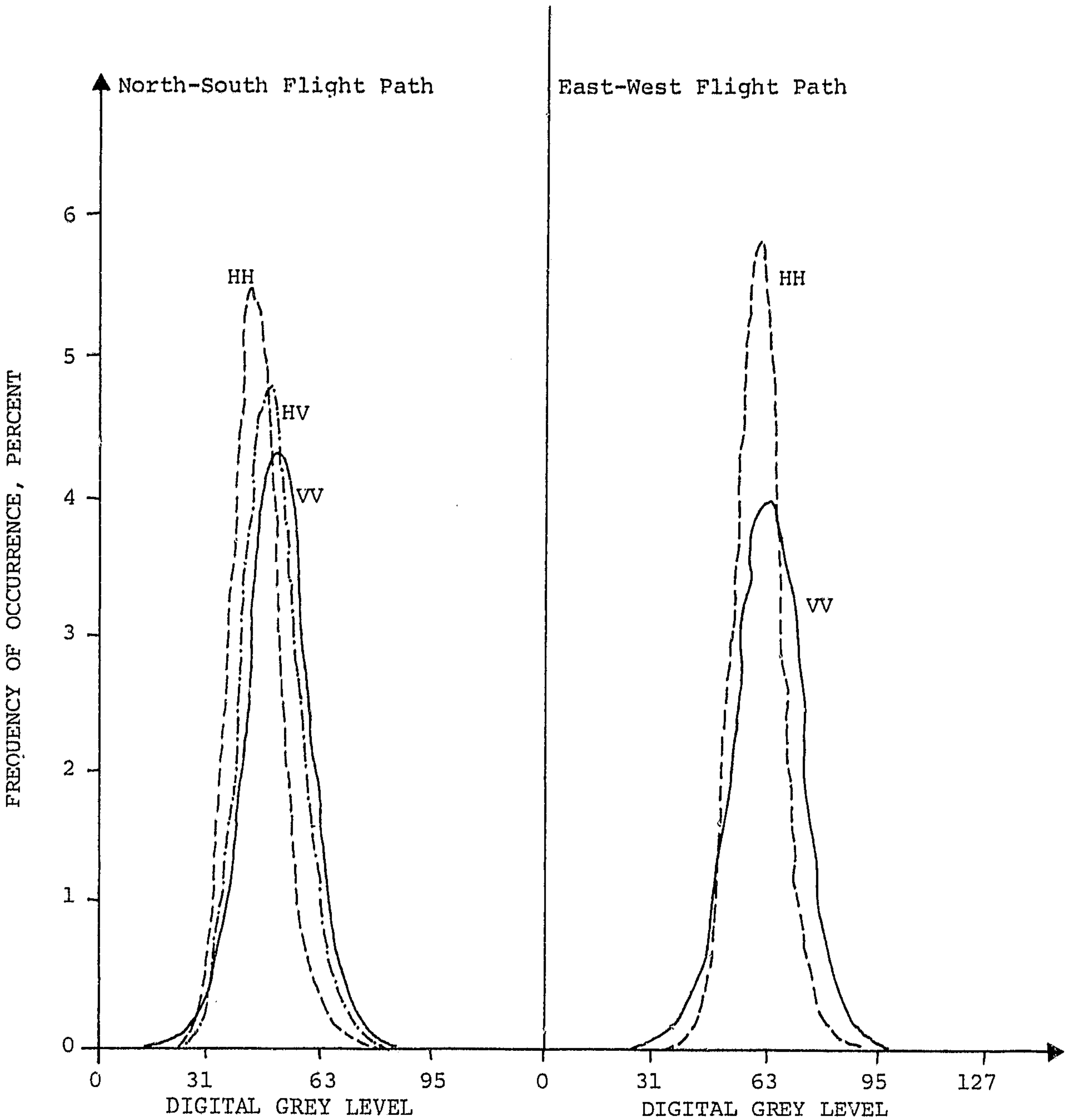

Figure 13. Histograms of SAR Data from Dade County

The results of visual comparison using Figures 8 through 12 are described as follows. Highways can be easily delineated from the other land covers due to the dark tone and linear form. By the same token, airports and open water can also be delineated due to their dark tone and distinctive shape. The north-south row crops contain high returns from both HH and VV polarization data which were acquired by using the north-south flight pass as shown in Figures 8 and 10. Similarly, east-west row crops contain high returns from both HH and VV polarization data which were acquired by using the east-west flight pass as shown in Figures 11 and 12. This observation of the N-S and E-W row crops shows that the high returns of the HH and VV polarization data are primarily the result of row orientation, not the type of vegetation which formed the row structure. To put it another way, HH and VV polarization data are very sensitive to row structure effect. On the other hand, the cross (HV) polarization data shown in Figure 9 depicts similar grey level for the north--south and east-west row crops. This fact indicates that the cross polarization data are less sensitive to the row structure effect and thereby may be used to further delineate the surface cover types which formed the row structure. The residential area contains no distinctive grey level that can be easily separated from the other land cover but the street pattern, which formed a grid type texture, can be easily recognized visually; however, it may be very difficult to separate from the other land cover classes using conventional pattern recognition techniques. Last, the high returns A and B shown in Figure 8 through 11 are quite different. They look the same in Figures 8 and 10 but different in Figures 9 and 11. These facts indicate that high return A, unlike high return B, is not a north-south oriented row structure. The cover type of high return A may be a very rough surface with high reflectivity, such as randomly piled up auto junk yards which contain microwave signatures similar to those found in another investigation (Ref. 4).

To help visualize the digital grey levels of the seven special classes, the means and standard deviations are tabulated and ploted for the five data sets as shown in Table 4 and Figure 14. The following may be concluded from Figure 14:

(1) A very rough surface with high reflectivity such as "high return A" exhibits high grey level from all four data sets. On the other hand, a highly N-S oriented surface cover such as "high return B" exhibits high grey level from the HH and VV polarization with N-S flight pass data, but relatively low grey level from the HV polarization and HH polarization with E-W flight pass data.

(2) The N-S oriented row crop exhibits high grey level from the HH and VV polarization with N-S flight pass data, but relatively low grey level from the HH and VV polarization E-W flight pass data. Similar results are obtained for E-W oriented row crop. Both N-S and E-W oriented row crops result in relative low grey levels from the cross (HV) polarizations.

(3) Residential area, airport, and open water were insensitive to polarization and flight pass variation, since these land covers were either flat or randomly oriented.

The false color image of SAR data is shown in Figure 15. The three prime colors of red, blue, and green are represented by the HH polarization data acquired on the north-south flight pass, the HH polarization data acquired on the east-west flight pass, and the HV polarization data acquired on the north-south flight pass, respectively. Since both HH and VV polarization data are sensitive to row direction variation, the east-west and north-south oriented

Table 4. Means and Standard Deviations of Seven Land Cover Types

LAND COVER / DATA CONFIGURATION	PIXEL USED	NORTH-SOUTH FLIGHT PATH						EAST-WEST FLIGHT PATH			
		HH POL.		HV POL.		VV POL.		HH POL.		VV POL.	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
High Return A	26	79.35	3.75	91.35	15.75	93.69	21.00	85.15	5.53	-	-
High Return B	46	75.20	6.53	55.43	5.74	98.50	13.34	54.91	2.59	-	-
NS Row Crop	286	65.25	5.43	52.94	5.67	70.03	10.98	57.46	2.39	62.82	6.48
EW Row Crop	326	46.18	3.95	53.07	3.65	53.11	6.16	74.50	3.03	79.31	8.91
Residential Area	254	43.62	5.66	42.43	4.22	47.70	5.23	59.98	4.63	60.47	6.30
Airport	367	28.72	4.57	30.53	4.20	30.82	4.61	41.07	5.09	-	-
Water	245	24.64	8.89	24.18	9.42	24.11	12.03	35.99	9.95	29.19	22.34

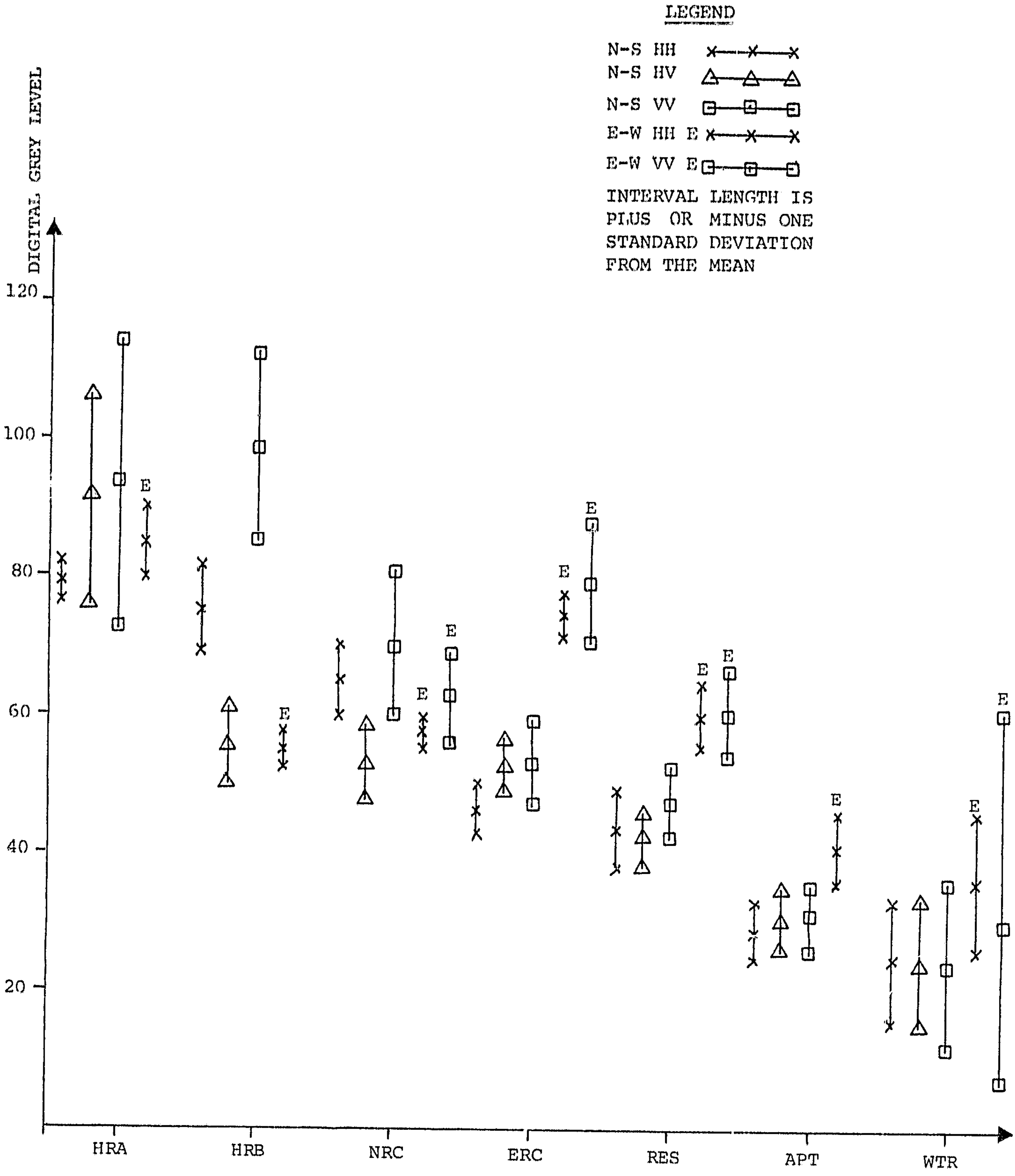

Figure 14. Means and Standard Deviations of Seven Land Cover Types from Dade County

ORIGINAL PAGE
COLOR PHOTOGRAPH

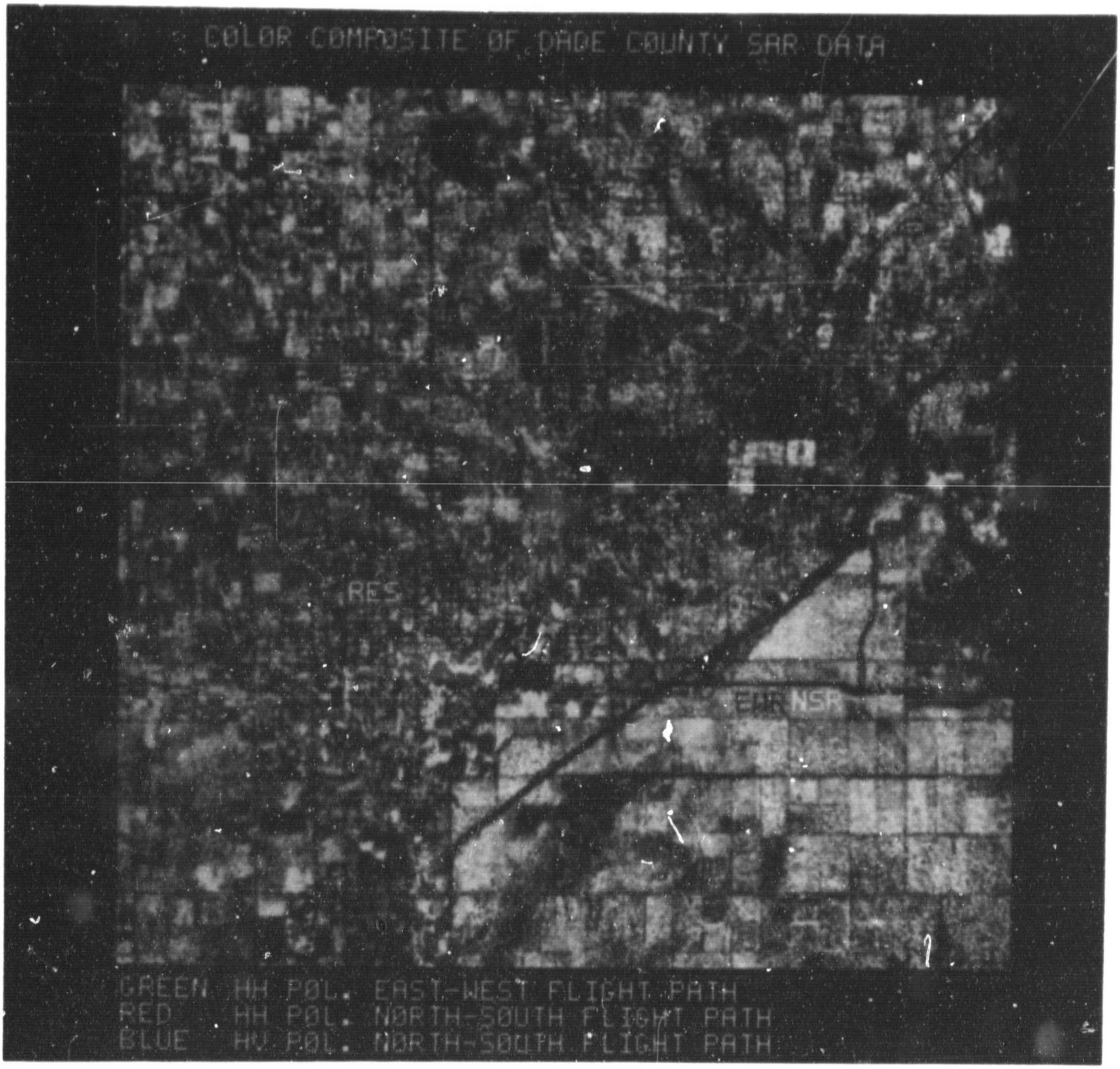

Figure 15. SAR Data Color Composite of Dade County

row crops contained two prime colors and they are represented by cyan and magenta, respectively. These row crop cover types, due to their distinctive color, can easily be separated from each other. The distinctive color tone difference between high returns A and B as shown in Figure 15 indicates that these two high returns contain different kinds of surface features, which have been mentioned previously.

The unique texture consisting of the criss-cross grid pattern can be clearly recognized in the residential area. The aircraft and water bodies, due to their low grey level in all three polarizations, are shown in black.

IV. EVALUATION OF CLASSIFICATION RESULTS

A. Acadia Parish, Louisiana

Since comparative analysis concerning the use of a multidate set of 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 signature classes were developed from the 24 training plots. These plots were selected by the use of CIR and extensive field verification. The mean values for three SAR and four MSS channels are shown in Table 5. Five of the 24 land cover classes were used previously for radar signature comparison.

The 24 developed statistics, which included mean, standard deviation, covariance, etc., and 99.9 percent threshold, were input into the maximum likelihood Bayesian classifier (Ref. 2) to classify the three-polarization SAR and MSS bands 5 and 7 data sets. Since not all surface features can be related to the five land cover classes named, and since the larger the percent threshold used the fewer data cells are left unclassified, a 99.9 percent threshold was used to minimize the number of data cells which are left unclassified.

Table 5. SAR and MSS Signature of 24 Selected Classes - Mean Value

Land Cover Class	No. of Pixels	X-BAND SAR			LANDSAT MSS			
		HH	HV	VV	B4	B5	B6	B7
Residential	195	173	92	130	27	28	50	45
	457	156	101	120	25	26	46	41
	276	159	91	121	24	23	46	43
	359	160	81	122	24	24	46	43
Soybean	387	152	68	127	21	19	64	66
	351	152	70	122	22	20	61	63
	498	137	63	109	20	17	67	72
	331	146	65	105	20	17	68	73
	395	143	63	116	21	17	69	73
Paddy Rice	575	184	81	115	27	31	52	47
	413	164	65	89	30	40	54	46
	226	174	77	115	27	34	47	38
	207	182	78	82	21	19	42	37
	228	141	63	90	34	50	60	50
Exposed Soil	89	93	52	63	23	25	31	23
	157	112	48	77	20	18	68	72
	206	104	51	73	19	16	66	71
	147	122	52	87	29	35	53	46
	233	101	49	72	22	18	61	62
Deciduous Forest	181	158	90	127	19	18	36	33
	202	159	87	132	18	15	43	42
	112	158	93	133	19	16	42	43
	183	173	102	163	18	16	46	48
	290	159	90	166	30	30	56	52

Because of this, the classified data sets contain a very small number of unclassified data cells.

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 conditions. The test sample plots were used exclusively for accuracy evaluation and they were completely separated from the training sample plots which were used to develop spectral signatures.

A computer program called Accuracy of Classification Table (ACTB), documented in ELAS (Ref. 2), 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 five land cover classes are given in Table 6. The off-diagonal numbers represent percent classification. Using the residential class as an example, a large percentage of misclassification appears in the deciduous forest and paddy rice classes of the SAR data, but when the MSS and SAR data are combined the results are significantly improved: the residential classification accuracy changes from 29.9 to 82 percent. The same kind of comparison can be made for other land cover classes using Table 6. The SAR data do better than the MSS data with the exposed soil class. The combined SAR/MSS data not only significantly improve the delineation of the residential class that the SAR-only data classified poorly, but they also improve the classification accuracy of all five land cover classes. The overall classification accuracies are 59.5, 73.4, and 87.7 for SAR-only, MSS-only, and SAR/MSS data, respectively.

Table 6. Verification Values of the Three Classifications for Five Land Cover Classes

Ground Truth Classes	Deciduous Forest	Residential	Soybean	Paddy Rice	Exposed Soil
Deciduous Forest	69.1 86.1 92.2	9.7 4.9 5.3	10.7 0.5 0.2	8.4 6.3 0.9	2.1 1.1 0.1
Residential	38.7 8.7 6.2	29.9 72.3 82	8.3 0.3 1.1	20.3 14.1 9.0	2.8 4.2 0.1
Soybean	9.6 0.3 0.1	2.3 0 0	63.0 67.6 95.1	20.6 1.3 1.6	4.5 30.7 0.4
Paddy Rice	3.6 1.3 0.7	4.6 2.3 2.0	9.9 3.8 3.2	77.3 84.4 92.2	4.7 7.2 2.0
Exposed Soil	0.9 0.6 0.2	0.1 0.4 0.2	12.9 43.7 11.4	10.2 13.8 0.3	75.9 41.4 87.9

Percent Correct Overall

SAR: 59.5
MSS: 73.4
SAR/MSS: 87.7

Within each block upper left = SAR
center = MSS
Lower right = SAR/MSS

B. Dade County, Florida

The supervised classification, described previously for the evaluation of Acadia Parish data sets, was employed to classify the five-channel SAR data acquired over the study area. The training sample plots for the 18 land cover classes with more than 100 pixels inside the 16 ground segments were used to develop the SAR spectral signatures. The 18 land cover classes are tabulated in Table 1 together with some very minor land cover classes. These 18 land cover classes contained a number of vegetation types which were difficult to separate from some distance. Highly visually spectral signatures of the 18 land cover classes were expected, as well as very poor classification accuracy. The classified results using ACTB tabulation are shown in Table 7 for the six data set combinations. The verification value of the water class is the highest among all other land cover classes, which implies that the water class is less spectrally confused with the other land cover types. Due to the poor results, no evaluation was made. For future investigations, several vegetation classes such as vine tomato, bush tomato, bush bean, squash, etc. should be combined into one class.

VI. SUMMARY

The aircraft X-band SAR data acquired over Acadia Parish and Dade County were processed, compared, and analyzed. An evaluation of the supervised classification and SAR signature comparison using various land cover types in the study areas resulted in the following findings:

1. In the case of the Acadia Parish study area, the highest mean grey levels contained in the specific land cover type for the three polarization SAR data are: paddy rice (with flooded water), 183.5, for HH

Table 7. Dade County Classification Accuracy Evaluation

Flight Pass	NS		EW	NS and EW	NS and EW	NS and EW
Polarization	HH, HV	HH, HV, VV	HH, VV	HH, VV	HH, HV, VV	HH, HV, HH
Squash	23.06	8.33	0.87	14.24	10.47	24.71
Residential	39.35	25.70	32.22	30.93	26.76	30.33
Bush Bean	14.92	14.30	9.84	20.21	17.62	18.03
Woodland	3.40	0.98	2.51	5.07	3.35	23.08
Commercial	3.39	-	-	-	-	7.91
Grass Field	8.02	9.44	15.78	25.87	7.76	11.51
Avocado	4.94	26.58	44.12	43.81	49.39	34.59
Emerging Crop	0.45	12.30	5.37	13.20	20.13	6.49
Water	85.00	-	40.00	65.00	-	65.00
Idle Crop	17.92	20.11	3.56	15.73	16.55	17.37
Short Brush	14.95	15.93	8.85	12.29	11.60	12.39
Potato	25.92	-	-	-	-	37.58
Sweet Corn	18.44	4.16	7.53	7.66	8.70	20.00
Wetland	10.74	-	-	-	-	-
Bush Tomato	27.76	33.06	34.29	35.10	37.14	29.39
Limes	4.92	18.48	1.20	2.26	4.39	1.06
Vine Tomato	55.46	12.48	-	-	-	-
Sorghum	2.10	4.90	18.88	11.89	22.38	4.90
Overall	13.53	11.93	17.11	21.89	15.20	17.87

polarization; soybean, 127.0, for VV polarization; and residential area, 100.9, for HV polarization. These results indicate that surface wetness, vegetation, and very-rough-surface are highly sensitive to the HH, VV, and HV polarizations, respectively. Similar results were reported in other investigations (Ref. 4). The combined SAR/MSS data set results in an improved classification accuracy of the five land cover classes as compared with the SAR-only and MSS-only data sets. Specifically, the residential class shows the largest accuracy improvement; it changes from 29.9 percent for SAR-only data to 82 percent for SAR/MSS data. This large improvement suggests the MSS data are most useful in delineating residential class from deciduous forest class, because the two classes contain very similar SAR signatures and they are very difficult to separate using SAR-only data.

2. In the case of the Dade County study area, both HH and VV polarization data are highly responsive to the row orientation of the row crop but not to the specific vegetation which forms the row structure. On the other hand, the HV polarization data are relatively insensitive to the orientation of row crop. Therefore, the HV polarization data may be used to discriminate the specific vegetation that forms the row structure. The disadvantage of using HV polarization is that the data usually contain much less grey level variation than that of the HH or VV polarization data and they primarily respond to surface-roughness, not the composition of the specific land cover. The very poor classification accuracies for all SAR data set combinations are as expected and the reasons for poor results are: (1) too many land cover