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CROP CLASSIFICATION USING MULTIDATE/MULTIFREQUENCY RADAR DATA

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16. Abstract

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The soil moisture conditions had changed considerably during the temporal sequence of the data; hence, the effects of soil moisture on the ability to discriminate between cover types were also analyzed. The results of the study provide useful information needed for selecting the parameters of a radar system for monitoring crops.

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C- and L-band radar data acquired over a test site near Colby, Kansas during the summer of 1978 were used to identify three types of vegetation cover and bare soil. The effects of frequency, polarization, and the look angle on the overall accuracy of recognizing the four types of ground cover were analyzed. In addition, multidate data were used to study the improvement in recognition accuracy poss le with the addition of temporal information.

The soil moisture conditions had changed considerably during the temporal sequence of the data, hence the effects of soil moisture on the ability to discriminate between cover types were also analyzed. The results of the study provide useful information needed for selecting the parameters of a radar system for monitoring crops.

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1.0 INTRODUCTION

This report summarizes the results of a crop-classification study conducted using multifrequency, multidate radar data acquired over a test site in western Kansas during the summer of 1978. Like- and cross-polarized scatterometer data in the C- and L-band frequencies (4.75 GHz and 1.6 GHz, respectively) were used to classify over 100 fields into one of four cover categories (corn, wheat stubble, pasture, and fallow). The accuracy of classification as a function of (a) frequency, (b) polarization, (c) incidence angle, (d) number of multidate passes, and (e) soil moisture was calculated and analyzed. The results of the study, reported in the following sections, provide considerable insight into the relationship between system parameters and performance.

1.1 Background

Over the past several years, Landsat's Multispectral Scanners (MSS) have provided a continuous stream of multitemporal images for a large portion of the earth's surface. The availability of such a data-source has led to numerous investigations of the crop-classification capabilities and limitations of optical sensors. One of the major conclusions of these studies is that, in order to achieve high correct-classification rates, it is necessary to have uninterrupted (cloud-free) coverage of the area under investigation for successive passes. One way to rectify this interruption problem is to use radar, which effectively is immune to the presence of clouds in the atmosphere. If used in conjunction with optical sensors, radar can, potentially: (a) improve the crop-classification rates under clear-sky conditions because it responds to the geometrical and dielectric properties of vegetation [1-4] differently than do optical sensors, and (b) serve as a "substitute" for optical sensors during cloud-cover conditions.

Several crop-classification studies have been conducted using single- and/or two-date radar imagery [5-9], but no investigations have yet been reported in which periodic, repetitive coverage with imaging radar over the full growing-season has been employed. The first attempt to evaluate the significance of multitemporal radar observations was made by simulating radar imagery based on data acquired by a truck-mounted radar system [4] and by incorporating system parameters (resolution, signal-fading, etc.) and target parameters (within- and between-field variance) in the simulation procedure. However, a simulated image is inherently limited by the assumptions and statistical distributions used in its generation. The above study was extended a step further by evaluating the combined Landsat/radar multitemporal crop classification wherein the radar data consisted of simulated images of the same scene observed by Landsat's MSS [10]. Again, the basic source of radar data was a truck-mounted radar. Similar studies also were conducted in Canada using single-date data acquired by airborne optical and radar scatterometer systems [11].

In 1978, six successful missions were flown by NASA/Johnson Space Center's C-130 aircraft over an agricultural test-site near Colby, Kansas in support of a soil-moisture investigation. Among the host of sensors used were C- and L-band radar scatterometers (nonimaging). The data acquired in these flights have been processed by NASA/JSC and made available for analysis. In an earlier report [12] we presented the results of a classification experiment performed using the data from flights 1 and 2 on a limited number of fields (34). In the current study, the data from all flights covering over 100 fields are used to:

(a) evaluate the crop-classification accuracy using single date, single channel data,

(b) evaluate the performance with single-date, dual-polarized, and dual-frequency data,

(c) analyze the performance with single and multichannel data taken over several dates, and

(d) investigate the effects of soil moisture on the ability to discriminate between cover types.

1.2 Data Collection and Processing

A. Sensor Description:

During the period from July 18 to August 9, 1978, the C-130 aircraft of the National Aeronautics and Space Administration conducted a total of six successful flights over a test site near Colby, Kansas. Data were collected at three different frequencies: 13.3 GHz (K-band), 4.75 GHz (C-band) and 1.6 GHz (L-band). In this study, though, only L- and C-band were studied because these are frequencies being considered for further satellite radars.

The K-band data were taken with a VV polarization, whereas the L- and C-band data were taken with both HH and HV polarizations. The look angle for all the above frequencies and polarizations varied from 10° to 50°. The flight dates were: 7/18, 7/20, 7/21, 7/22, 8/8, 8/9.

The soil moisture conditions changed considerably during the coverage period due to rain on 7/21 and 7/22/78. Table 1.1 gives a qualitative classification of the six different flights in terms of soil moisture. We should keep in mind though that the soil moisture content also varied between fields on any given date due to the fact that some fields had been irrigated while others had not and that rainfall was not equally distri-

Table 1.1

Soil Moisture Conditions

Date	7/18	7/20	7/21	7/22	8/8	8/9
Flt. #	1	2	3	4	5	6
Soil Moisture Conditions	Driest	Moist	Wet	Wettest	Dry	Drier

buted over the 260 km^2 test site.

The ground truth (crop type, field boundaries) was established using color IR imagery of the area obtained during flight one. Three different people, working independently, developed their own keys to identification. Only those fields on which the three concurred were used as ground truth. Most of the ambiguity was between corn and milo. Over one hundred fields were identified and used in the classification study.

B. Registration by Time-Slicing

Materials used were aerial photomosaics of the test area, field outline overlay, flight-path and -time data-point overlay, and computer plot of σ^0 amplitude (in dB) over time at various frequencies, and angles. Initial time-slicing was done by finding the field boundaries of the overlay, and determining the approximate time the aircraft was taking data on the boundary from the flight path-time overlay. The exact field boundary was then determined by examining the σ^0 plot around the approximate time, and attempting to find any discontinuities in the plot around that time. If no discontinuities were found, the approximate boundary time from the overlay was used to define the field boundary.

C. Feature Extraction and Classification

Once the field boundaries and the crop type were determined, then the σ^{o} values (in m^2m^{-2}) for each field were averaged and the mean value (for a particular frequency, polarization and look angle) was then converted to dB and used as the feature for that field.

A maximum likelihood classifier [13] was used, assuming a multivariate normal density for the features.

Let $\overline{x}_i$ be the feature vector for the i^{th} field,

$$\overline{x}_i = \begin{bmatrix} x_{i1} \\ x_{i2} \\ \vdots \\ x_{in} \end{bmatrix} \qquad i = 1, 2, \ldots N$$

where N is the total number of fields, n is the number of features. Let $\overline{\mu}_j$ be the mean feature vector for the j^{th} crop type,

$$\overline{\mu}_j = \begin{bmatrix} \mu_{j1} \\ \vdots \\ \mu_{jn} \end{bmatrix} \qquad j = 1, 2, \ldots M$$

where M is the number of different crops. Let Σ_j be the (nxn) covariance matrix for the j^{th} crop type.

P_j, $j = 1, 2, \ldots M$ are the a priori probabilities of the various crop types

$$P_j = \frac{\#\text{ of fields in } j^{th} \text{ category}}{N}$$

Let $\overline{x}_k$ be the feature vector to be classified, and

$$d_j = P_j \frac{1}{(2\pi)^{n/2}} |\Sigma_j|^{1/2} \exp -\frac{1}{2} (\bar{x}_k - \bar{\mu}_j)^t \Sigma_j^{-1} (\bar{x}_k - \bar{\mu}_j)$$
$$j = 1, 2, \ldots M$$

$\bar{x}_k$ is classified as belonging to the p^{th} category if

$d_p = \max(d_1, d_2, \ldots, d_M)$.

All the available data were used for training, and testing was done on the same data used for training. Thus the classification results presented in this report represent the best results that can be expected. A few classifications were also done by splitting the data in half for testing and training and the results were about the same, within 5%, typically.

1.3 Significant Results

A large number of classification experiments were conducted to determine the separability of the four ground-cover categories using only radar observations. The effects of soil moisture, the usefulness of temporal data, as well as the effects of frequency, polarization, and incidence angle θ on the overall accuracy of classification were evaluated and the following are the significant conclusions of this study (based on the L- and C-band data only):

(1) The overall crop classification accuracy improves significantly with increasing incidence angle for $\theta < 40°$, and is relatively constant for $\theta > 40°$.

(2) Soil moisture plays an important role in the sensor's ability to discriminate between the four cover types. Under wet soil conditions, the cross-polarized systems perform better than like-polarized systems (with incidence angle $> 40°$).

(3) Multidate (temporal) data at a single frequency and polariza-

tion leads to significantly higher classification accuracy compared to multifrequency and multipolarized data from a single coverage. That is, when temporal information is available, it is more useful than spectral and polarization data.

(4) Corn is easily identified under all soil moisture conditions, whereas wheat stubble and fallow were very difficult to separate using radar data.

(5) When wheat stubble and fallow were combined, the maximum three-way classification accuracy achieved was 98.7%.

(6) A very reasonable classification accuracy was achieved for the four different ground-cover categories at an angle of 50° under different soil moisture conditions.

Detailed results of the classification experiments are presented in the following sections.

2.0 SINGLE DATE - SINGLE CHANNEL PERFORMANCE

In this section we examine the effects of frequency, polarization and angle on the ability of a single channel system to discriminate between the four cover categories based on a single observation. Of the six dates available to perform this analysis, we shall restrict our attention to the driest and wettest soil moisture conditions which correspond to flights 1 and 4, respectively. The results are presented first on a crop-by-crop basis for dry- and wet-soil conditions, and then on the basis of overall accuracy of recognition.

2.1 Discrimination Of Individual Cover Types

The classification accuracies for the four cover types for flights 1 and 4 are shown in Figures 2.1 to 2.4 as a function of angle. Analysis of the results given in these figures for the four (sensor) channels C-HH, C-HV, L-HH, L-HV indicate the following:

A. Corn-Dry Soil Conditions: C-HV channel has an accuracy between 96 to 100% for $10° \leq \theta \leq 50°$ with most of the misclassifications resulting in placing corn in the fallow category. The accuracy of C-HH channel is between 92 to 100% but only for $40° \leq \theta \leq 50°$, and once again when corn is misclassified it is mistaken for fallow.

The L-HV channel has a classification accuracy of 96 to 100% for $30 \leq \theta \leq 50°$ and the accuracy of L-HH channel is about 92% for $40° \leq \theta \leq 50°$. Thus, for dry soil conditions, all sensor channels perform equally well in recognizing corn.

B. Corn--Wet Soil Conditions: Under wet soil conditions, C-HV and L-HV channels give an accuracy of 88 to 92% for $30° \leq \theta \leq 40°$. C-HH

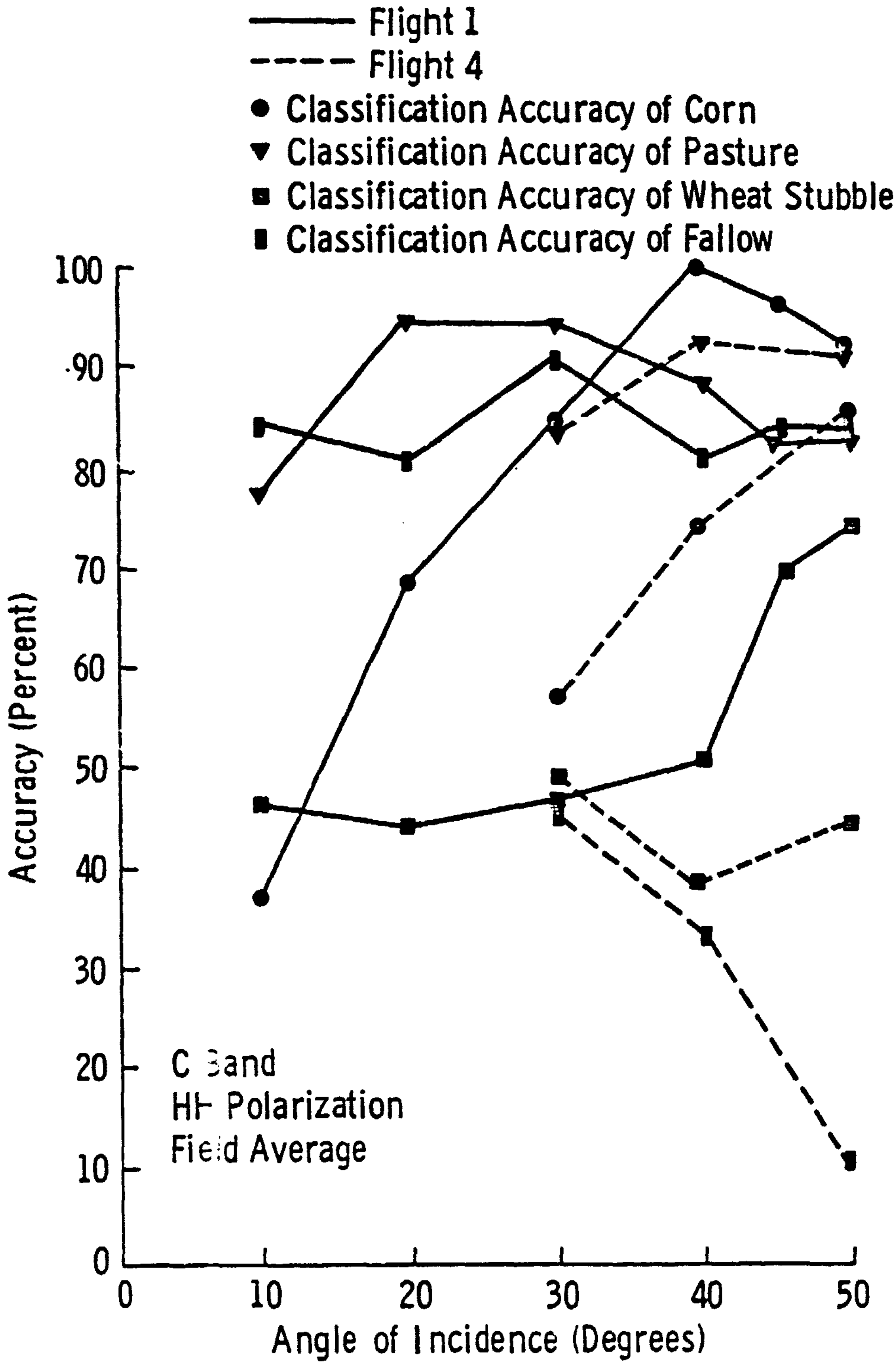

Figure 2.1. Dependence of individual crop-classification accuracies on the incidence angle for the C-band, HH system.

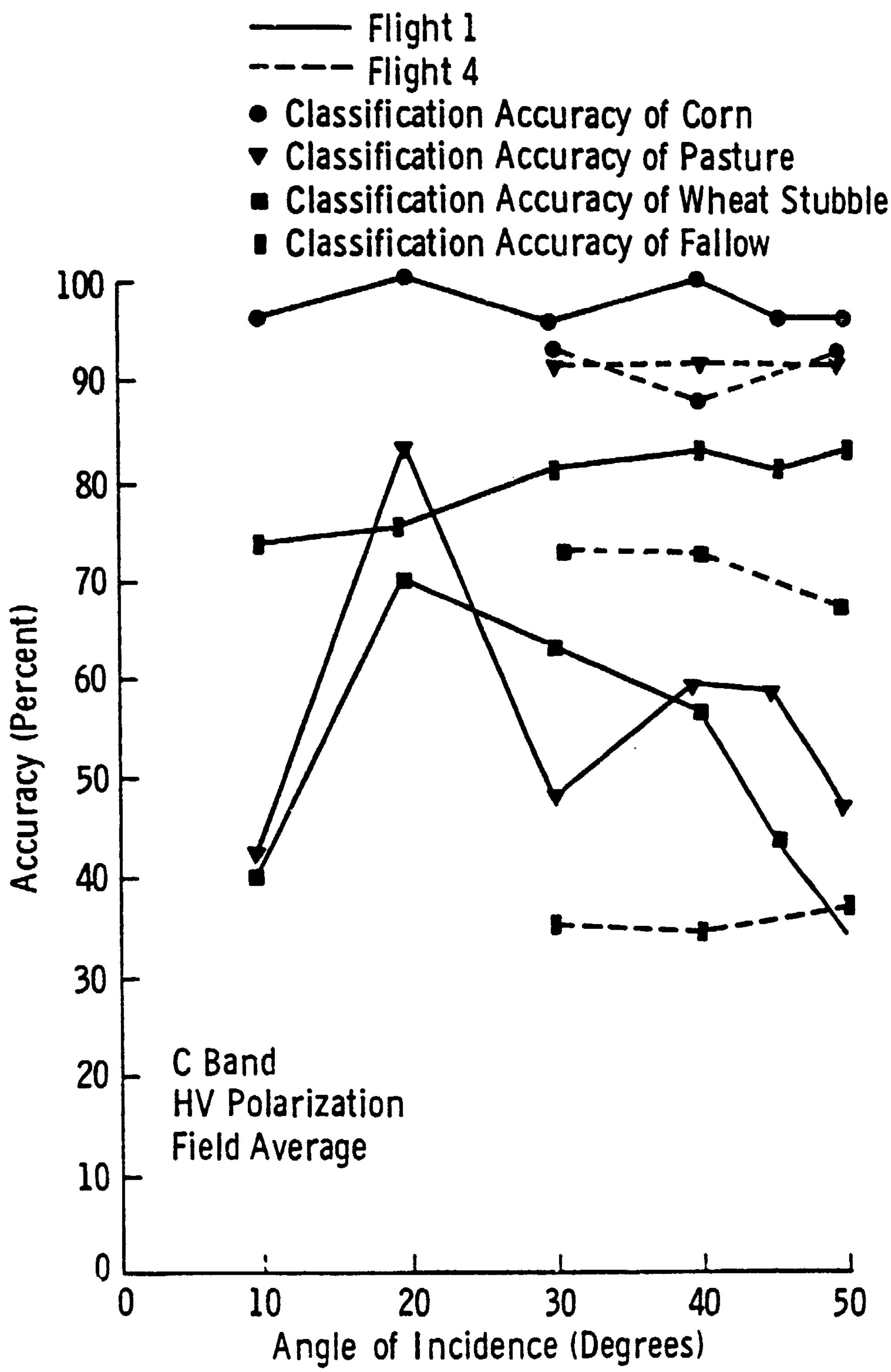

Figure 2.2. Dependence of individual crop-classification accuracies on the incidence angle for the C-band, HV system.

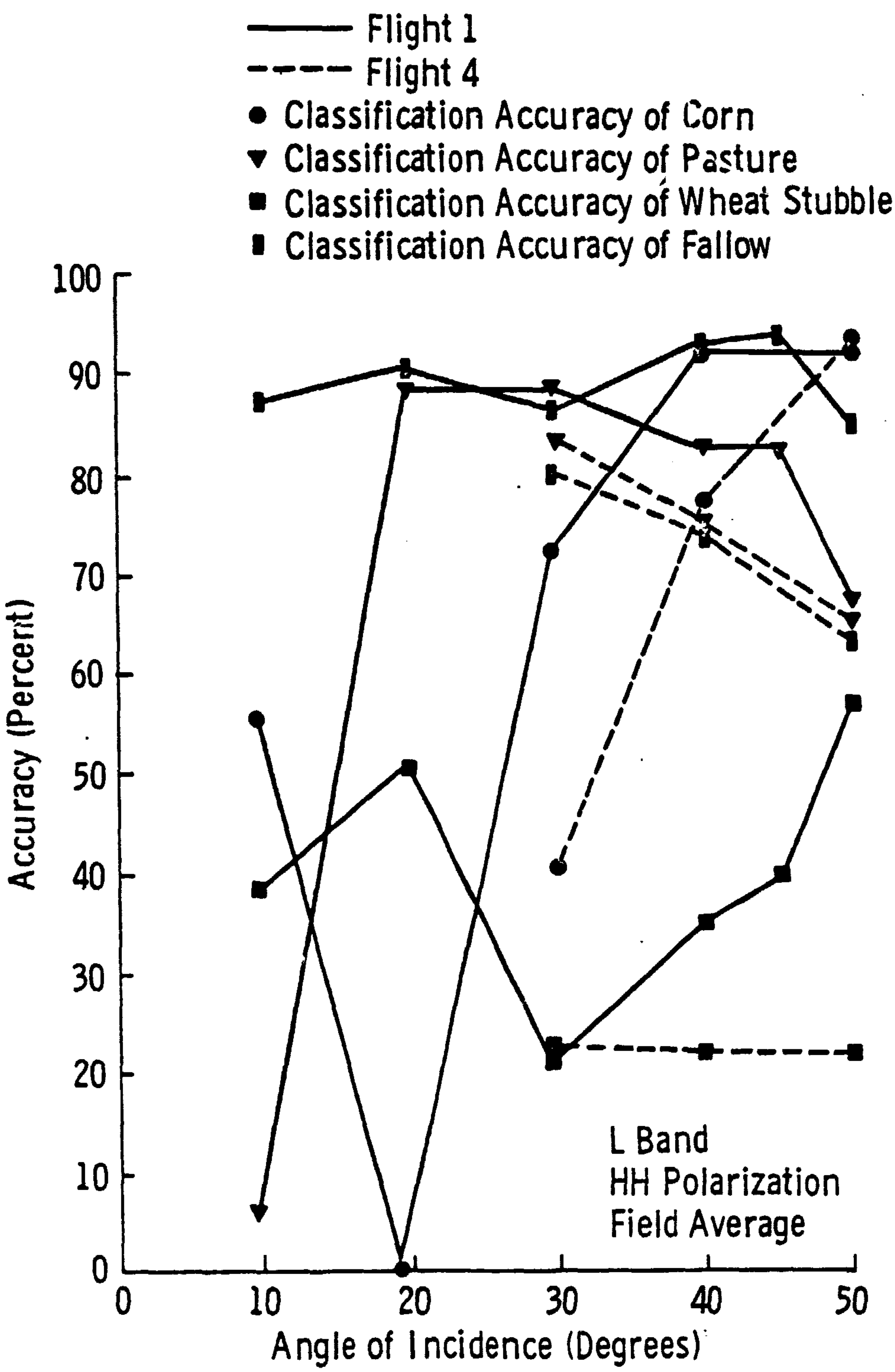

Figure 2.3. Dependence of individual crop-classification accuracies on the incidence angle for the L-band, HH system.

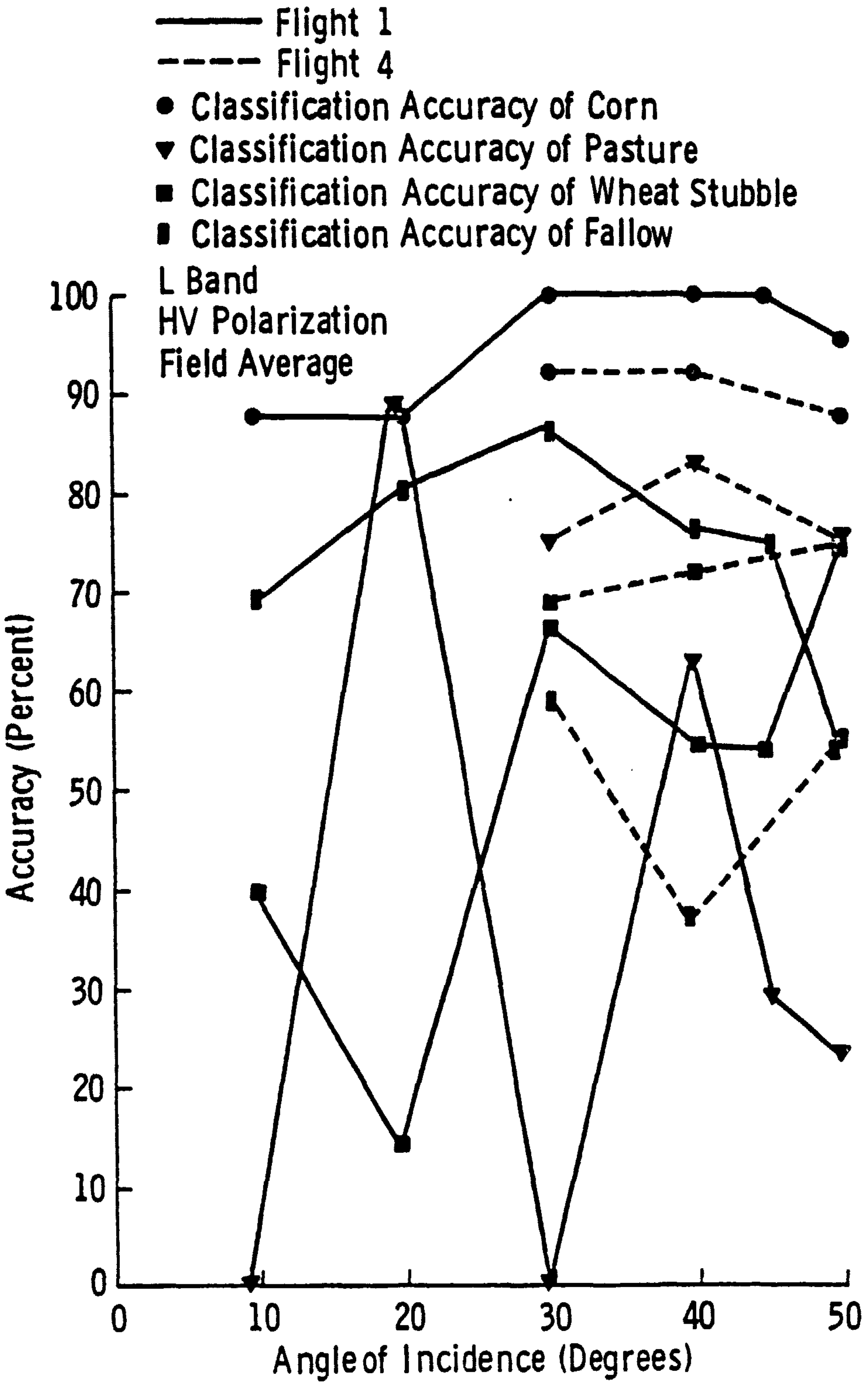

Figure 2.4. Dependence of individual crop-classification accuracies on the incidence angle for the L-band, HV system.

channel data can be used to recognize corn with an accuracy of 55% at 30° to 85% at 50°. Most of the misclassifications result from placing corn into the fallow category with an occasional misclassification into the wheat stubble category. The L-HH configuration yields an accuracy of 40% at 30° to 92% at 50°.

These results indicate that, <u>under wet conditions the HV polarization gives higher accuracies and the recognition accuracy is more polarization dependent than frequency dependent</u>.

C. <u>Pasture--Dry Soil Conditions</u>: The accuracy of correctly classifying pasture under dry soil conditions has the following range:

C-HV: below 82% at all angles

C-HH: 88 to 94% for $20° \leq \theta \leq 40°$

L-HV: very low at all angles except at 20° when it reaches a maximum of 88%

L-HH: 82 to 88% for $20° \leq \theta \leq 45°$.

When pasture is misclassified, it is usually mistaken for wheat stubble or fallow. Overall, it appears that C-HH and L-HH channels are best for the pasture category under dry soil conditions.

D. <u>Pasture--Wet Soil Conditions</u>: Under wet soil conditions the ability of the sensor to recognize pasture falls within the following ranges:

C-HV: about 91% for $30° \leq \theta \leq 50°$

C-HH: about 91% for $40° \leq \theta \leq 50°$

L-HV: 75 to 83% for $30° \leq \theta \leq 50°$

L-HH: 66 to 83% for $30° \leq \theta \leq 50°$.

Under both wet and dry conditions, pasture is usually misclassified as wheat stubble or fallow. Under wet conditions, the C-band channels have the highest recognition accuracy for pasture.

E. Wheat Stubble--Dry Soil Conditions: Wheat stubble is hard to classify at both frequencies and polarizations; for the most part it is mistaken for fallow, though misclassifications as corn or pasture are not infrequent. The best accuracy obtained was 74% in the C-band HH mode at 50° and also in the L-band HV mode at 50°. Otherwise it is below 70% for all angles considered.

F. Wheat Stubble--Wet Soil Conditions: Performance in the C-band HH and L-band HH modes is worse under wet conditions than under dry conditions, but the reverse is true in the HV mode.

C-band HV gives an accuracy of about 73% for $30° \leq \theta \leq 50°$ and L-band HV gives an accuracy between 69% - 75% for $30° \leq \theta \leq 50°$, with 75% accuracy at 50°. Overall, L-band HV seems to do moderately well for wheat stubble under both wet and dry conditions.

G. Fallow--Dry Soil Conditions: The rate of correct classification for fallow under dry soil conditions falls in the following range:

C-HV: 75-82% for $20° \leq \theta \leq 50°$

C-HH: 80-90% for $10° \leq \theta \leq 50°$

L-HV: 80-86% for $20° \leq \theta \leq 30°$

L-HH: 85-94% for $10° \leq \theta \leq 50°$.

H. Fallow--Wet Soil Conditions: Under wet soil conditions, it is very difficult to separate fallow from wheat stubble. The overall accuracy for the fallow category under wet soil conditions is as follows:

C-HH: less than 45%

C-HV: less than 45%

L-HV: less than 60%

L-HH: 80% at 30° and 62% at 50°.

These results indicate that fallow is very hard to distinguish from wheat stubble when the soil is wet, and the best accuracy achievable is 80% with the L-HH channel, $\theta = 30°$.

G. <u>Summary:</u> Analysis of the single-date data, on a cover-type basis, supports the following conclusions:

(1) Corn is easily distinguishable from other ground-cover categories.

(2) Pasture can also be discriminated from other categories with good accuracy.

(3) It is very difficult to separate wheat stubble and fallow, particularly under wet soil conditions. This is to be expected since the dry vegetation cover of the wheat stubble has a negligible influence on the radar backscattering coefficient and, therefore, the only factor responsible for difference between wheat stubble and fallow fields is soil surface roughness.

(4) The accuracy of classification for corn and pasture under wet soil conditions is more polarization dependent than frequency dependent. HV channels perform better than HH channels.

2.2 Overall Classification Accuracy

The overall performance of the single-channel - single-date data set can be evaluated by comparing the multicategory recognition rate for the various channels, for wet and dry soil conditions. Figure 2.5 shows a plot of overall accuracy vs. angle for flight #1 (dry soil) and Figure 2.6 for flight #4 (wet soil). Flight #1 had a total of 144 fields as shown below:

CROP	NUMBER OF FIELDS
CORN	25
PASTURE	17
WHEAT STUBBLE	50
FALLOW	52
TOTAL	144

Flight #4 had a total of 110 fields distributed among the four categories as follows:

CROP	NUMBER OF FIELDS
CORN	27
PASTURE	12
WHEAT STUBBLE	36
FALLOW	35
TOTAL	110

Standard deviations of the estimates of the classification accuracy are shown as $\alpha \pm 1\sigma$ error bars in Figure 2.5. The results shown in Figure 2.5 indicate that, under dry soil conditions, the highest accuracy (81.25%) is obtained with the C-HH channel, θ = 50°. Figure 2.5 also illustrates the general improvement of overall classification

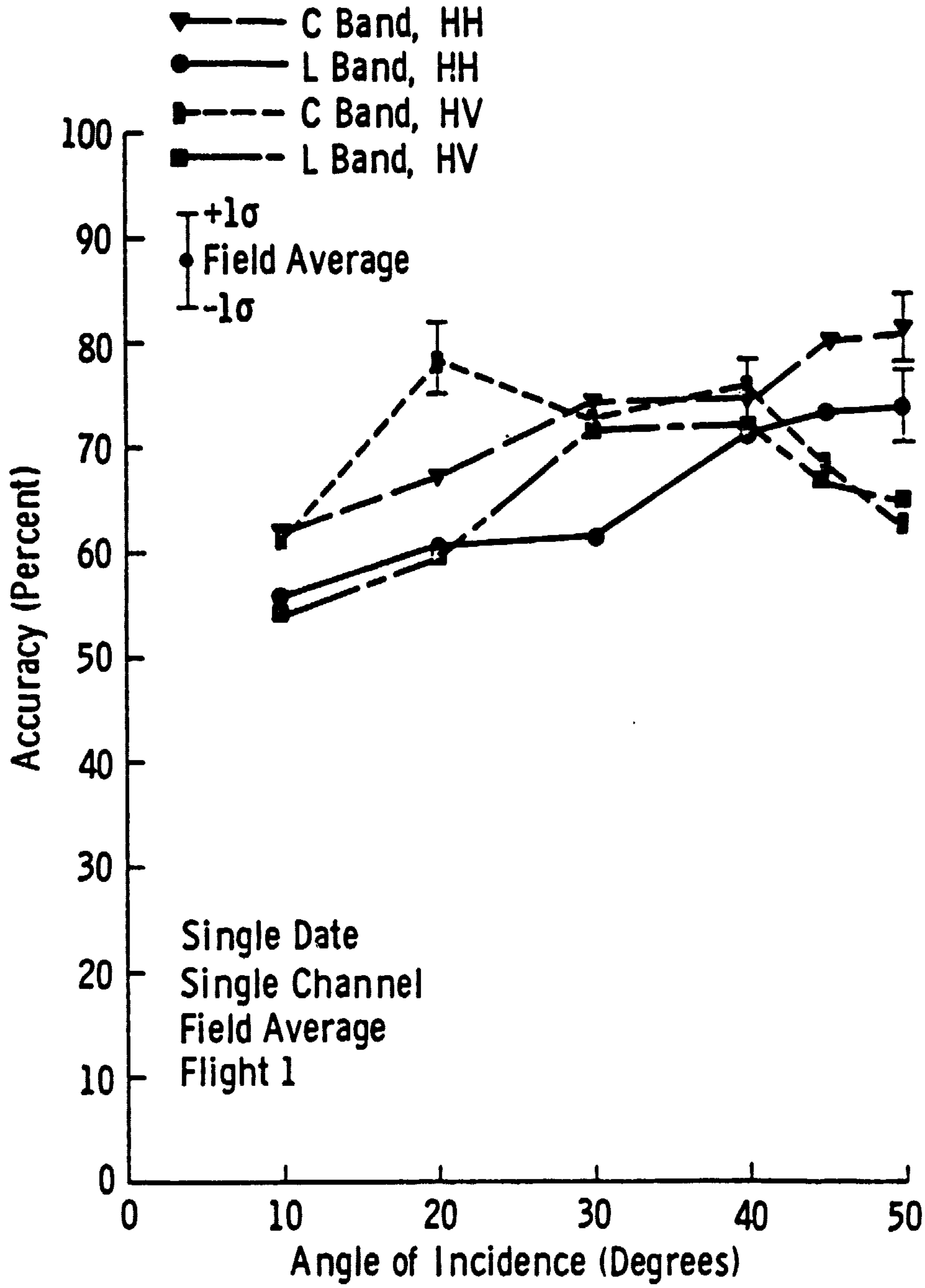

Figure 2.5. Variations in the overall classification accuracy with the angle of incidence, for the single-date, single-channel case, under dry soil-moisture conditions.

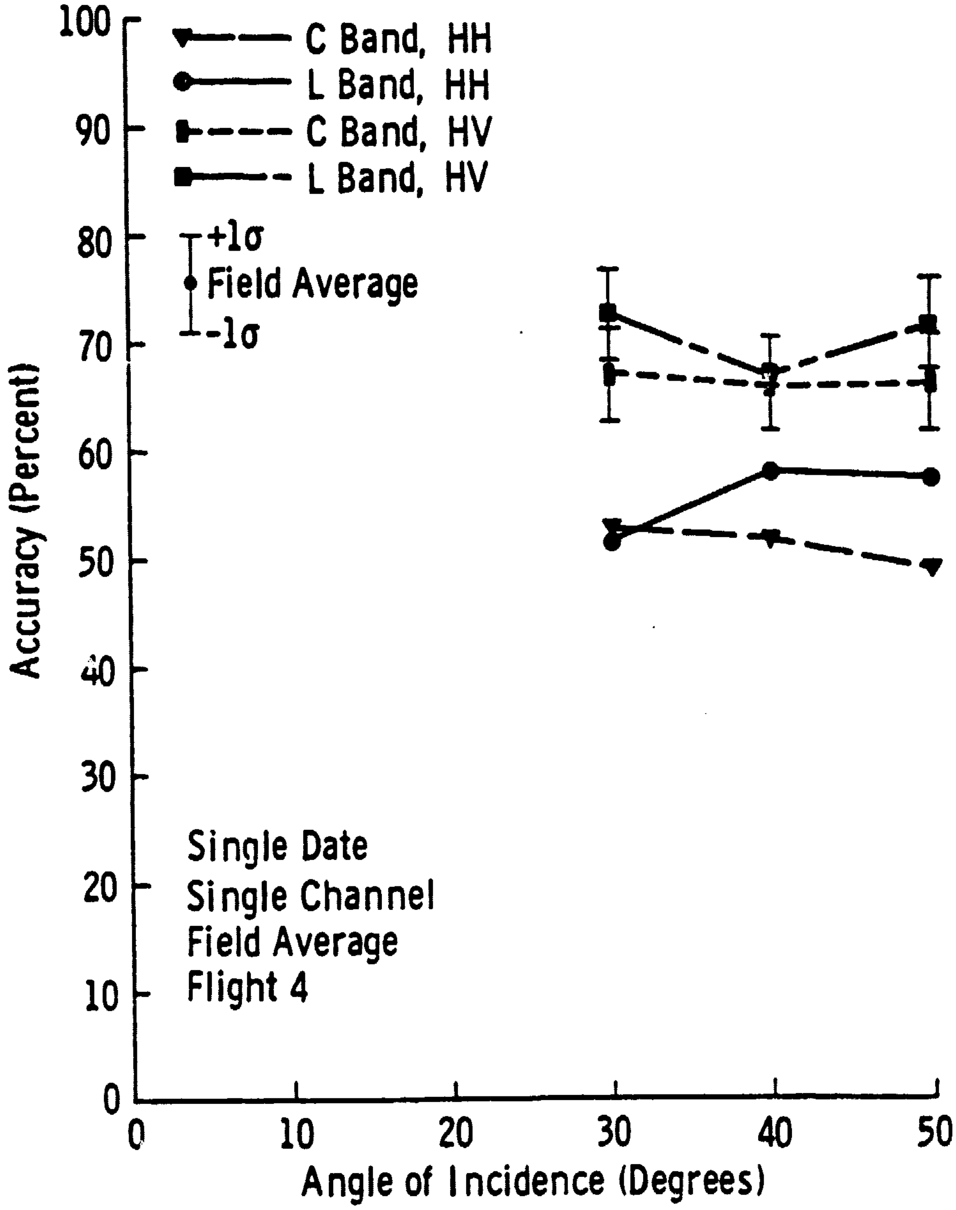

Figure 2.6. Variations in the overall classification accuracy with the angle of incidence, for the single-date, single-channel case, under wet soil-moisture conditions.

accuracy as θ increases, especially for the HH polarization.

Under wet conditions, the HV polarizations do significantly better than HH polarizations. Both C-HV and L-HV yield an accuracy of 65 to 70% under wet soil conditions. Compared with dry soil conditions, this represents a drop of about 10% in the classification accuracy. Some of the crop confusion matrices are shown in Tables 2.1, 2.2 and 2.3 to illustrate the details of errors in classification. As mentioned earlier, most of the errors result from misclassifying wheat stubble and fallow. Table 2.3 shows that the confusion between wheat stubble and fallow gets worse when the soil is wet.

Table 2.1

Crop Confusion Matrix
Maximum Likelihood Classifier
Features Used: Field Average,
C-Band, HH, 50°, Flight #1

ACTUAL \ CLASSIFIED AS	CORN	PASTURE	WHEAT STUBBLE	FALLOW
CORN	92.	0.	0.	8.0
PASTURE	0.	82.35	17.65	0.
WHEAT STUBBLE	0.	0.	74.0	26.0
FALLOW	1.92	1.92	13.46	82.69

OVERALL ACCURACY = 81.25%

CROP	# OF FIELDS
CORN	25
PASTURE	17
WHEAT STUBBLE	50
FALLOW	52
TOTAL	144

Table 2.2

Crop Confusion Matrix
Maximum Likelihood Classifier
Features Used: Field Average,
C-Band, HH, 50°, Flight #4

ACTUAL \ CLASSIFIED AS	CORN	PASTURE	WHEAT STUBBLE	FALLOW
CORN	85.19	0.	0.	16.81
PASTURE	0.	91.67	8.33	0.
WHEAT STUBBLE	36.11	5.56	44.44	13.89
FALLOW	42.86	2.86	42.86	11.43

OVERALL ACCURACY = 49.09%

CROP	# OF FIELDS
CORN	27
PASTURE	12
WHEAT STUBBLE	36
FALLOW	35
TOTAL	110

Table 2.3

Crop Confusion Matrix
Maximum Likelihood Classifier
Features Used: Field Average,
L-Band, HV, 50°, Flight #4

ACTUAL \ CLASSIFIED AS	CORN	PASTURE	WHEAT STUBBLE	FALLOW
CORN	88.89	0.	0.	11.11
PASTURE	0.	75.0	25.0	0.
WHEAT STUBBLE	0.	0.	75.0	25.0
FALLOW	11.43	2.86	31.43	54.29

OVERALL ACCURACY = 71.82%

CROP	# OF FIELDS
CORN	27
PASTURE	12
WHEAT STUBBLE	36
FALLOW	35
TOTAL	110

3.0 SINGLE-DATE, TWO-CHANNEL PERFORMANCE: (DUAL POLARIZATION AND DUAL FREQUENCIES AT θ = 50°)

To evaluate the improvement in performance that results from a two channel configuration, we analyzed single-date data for the following combinations: 1) L-HV/HH, C-HH/HV and L-C/HH. The results of the two channel configuration are shown in Figure 3.1, with single-channel results shown in Figure 3.2 for comparison purposes.

The results shown in Figure 3.1 indicate that there are no significant differences between the three systems for flights #1 and #2 (dry soil conditions). When the soil is very wet (flight #4), the dual-polarization systems perform better than the dual-frequency system. As the soil gets very dry (flight #6), the C-band dual-polarization system gives significantly higher recognition accuracy.

Comparison between Figures 3.1 and 3.2 shows the improvements that two-channel systems offer over single-channel systems. The improvement in classification accuracy is about 10-20% for most cases.

3.1 Dual-Polarization Systems

For flight #1 the C-band dual-polarization system offers only a slight improvement over C-HH. For flight #4 the dual-channel system offers a 12% improvement over the C-band single-channel system and the improvement is about 10% for flight #6. The L-band dual-polarization system does not show any significant improvement over the single-channel L-band systems. Table 3.1 shows the confusion matrix for the C-band dual-polarization system (θ = 50°) for flight #4. Comparison with Table 2.3 shows the improvement due to the addition of the C-band cross-polarized channel.

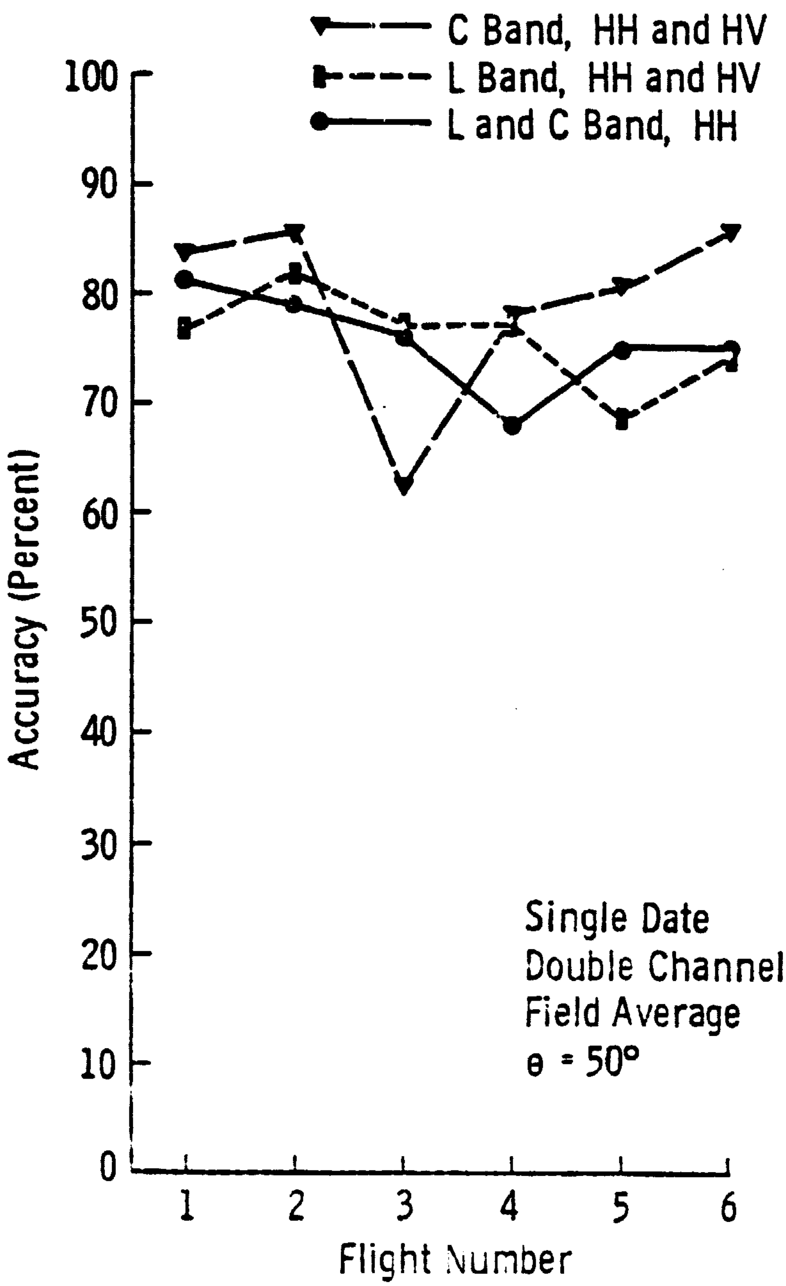

Figure 3.1. Variations in the overall classification accuracy for different soil moisture conditions, for a single-date, double-channel case.

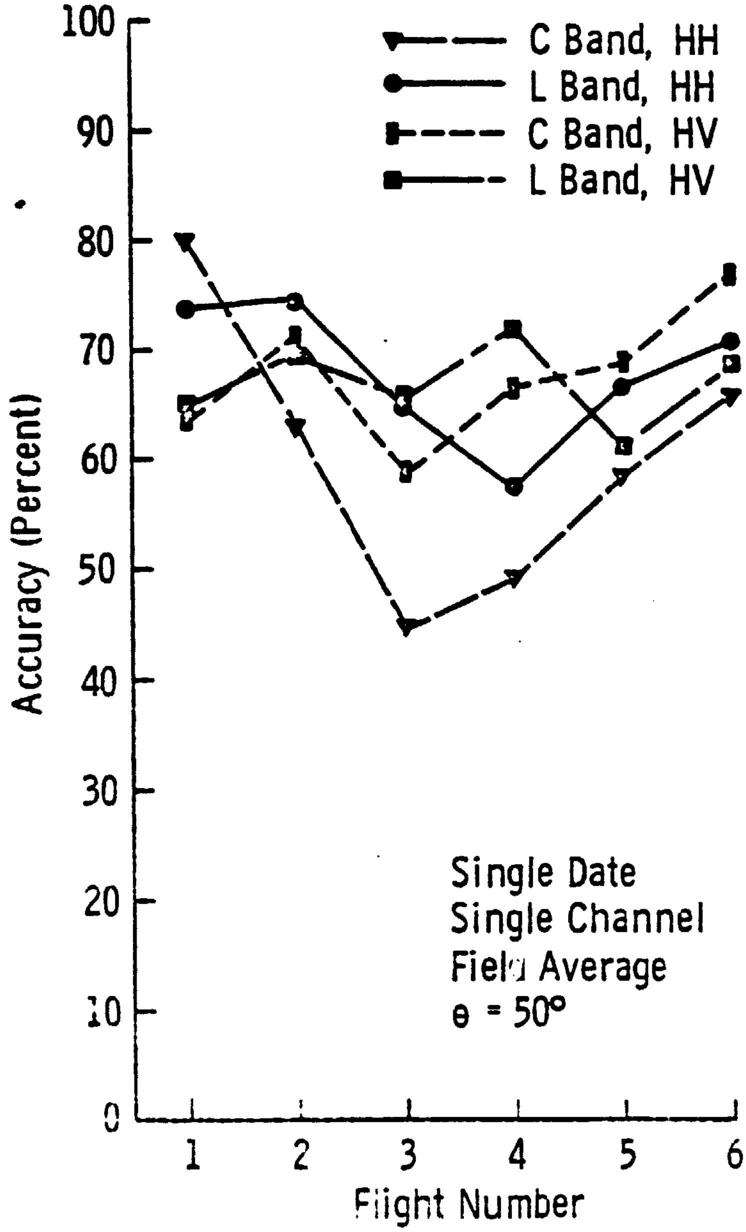

Figure 3.2. Variations in the overall classification accuracy for different soil moisture conditions, for a single-date, single-channel case.

Table 3.1

Crop Confusion Matrix
Maximum Likelihood Classifier
Features Used: Field Average,
C-Band, Dual Pole, 50°, Flight #4

ACTUAL \ CLASSIFIED AS	CORN	PASTURE	WHEAT STUBBLE	FALLOW
CORN	96.3	0.	3.7	0.
PASTURE	0.	91.67	8.33	0.
WHEAT STUBBLE	6.06	3.03	63.64	27.27
FALLOW	6.06	3.03	18.18	72.73

OVERALL ACCURACY = 78.1%

CROP	# OF FIELDS
CORN	27
PASTURE	12
WHEAT STUBBLE	33
FALLOW	33
TOTAL	105

3.2 Dual-Frequency System

The dual-frequency system (HH polarization) does not show any significant improvement over the dual-polarization systems. When the soil is moist (flight #4), the dual-frequency system performance is about 8% lower compared to the dual-polarization systems. However, the dual-frequency system performs better than the single-channel systems for all the flights.

4.0 MULTIDATE PERFORMANCE

It is well known that temporal information is extremely useful in recognizing crop types from Landsat MSS data. While a limited number of experiments using radar data have been carried out, no results have been presented yet which show the improvement in classification accuracy possible with the use of temporal radar data. The Colby data set provides, for the first time, an opportunity to perform a detailed analysis of the effectiveness of multidate - multichannel radar data for discriminating between various crops and ground-cover types. The results of this analysis are presented below.

Figures 4.1 - 4.4 show the classification accuracy for single-channel and two-channel systems as a function of the number of multidate passes. Each point in these figures represents the classification accuracy based on all the data available up to the particular date. As we proceed from left to right on these figures, more temporal information has been used in the classification procedure.

Figures 4.1 and 4.2 show the classification accuracy for single- and dual-channel systems. For the single channel systems, if the classification is done using flight #1 data alone the accuracy is about 70%. When data from flight #2 is added, the accuracy increases significantly, to 90% and as more dates are added the improvement is marginal beyond the second date.

A similar trend showing significant improvement when data from flight #2 is added to data from flight #1 holds for the two-channel systems also. It is clear from Figures 4.1 and 4.2 that temporal information is most useful in recognizing crops. A rather surprising trend showing up in these figures is that <u>temporal information is more useful</u>

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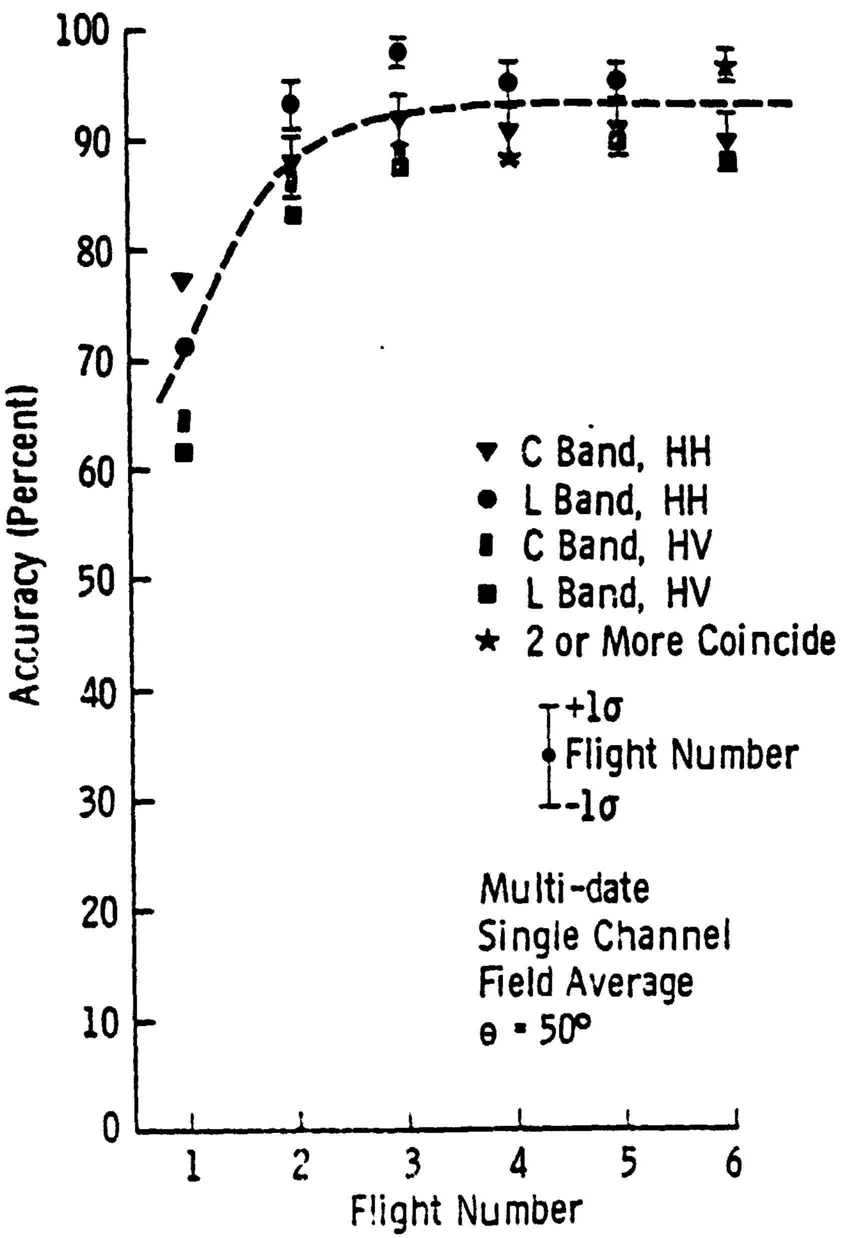

Figure 4.1. Effect of multidate classification (starting with a dry flight) on the overall accuracy for a single-channel system.

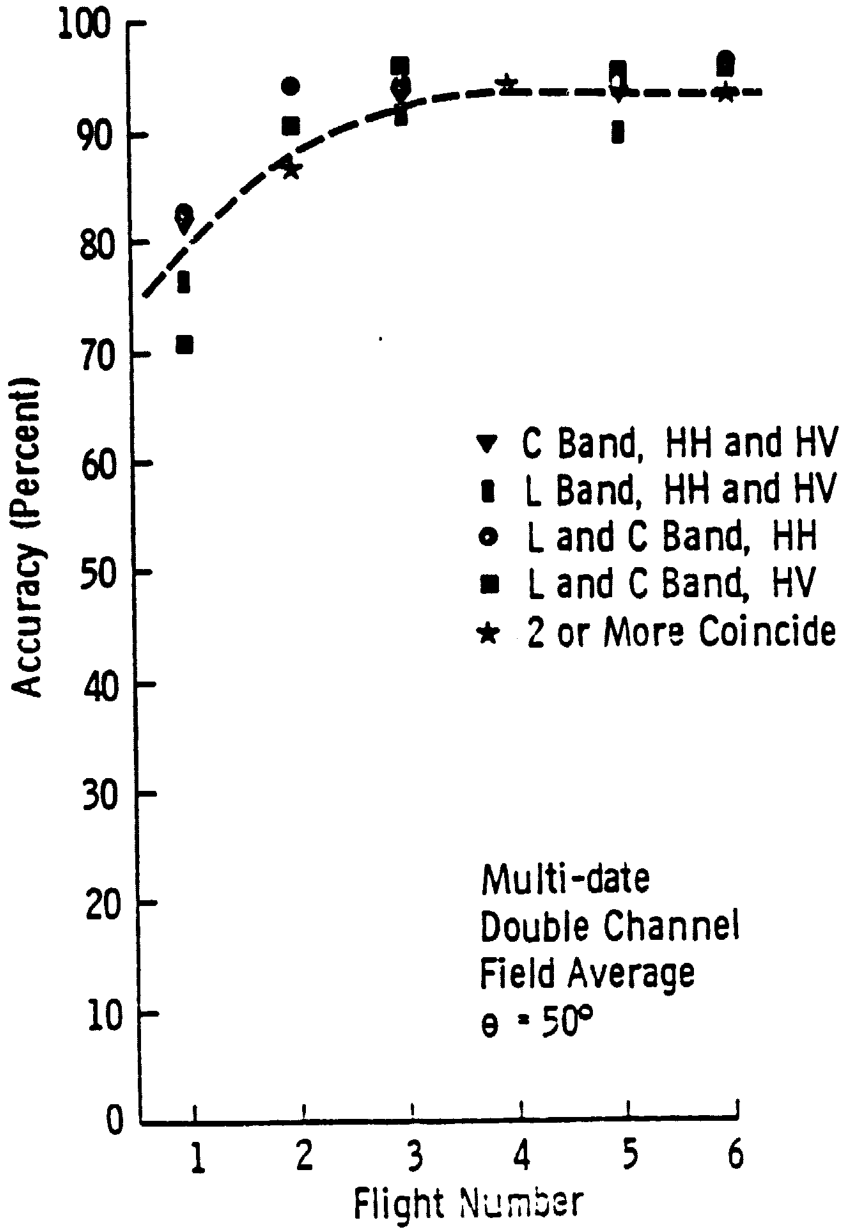

Figure 4.2. Effect of multidate classification (starting with a dry flight) on the overall accuracy for a double-channel system.

than additional information gained from different polarizations and frequencies for classification purposes. When temporal information is available, there seem to be no significant differences in the classification accuracies of various systems.

The results discussed in the preceding paragraphs were derived for the temporal sequence in which the soil moisture condition is dry to start with, becomes wet and dries again. The results were rederived by starting the temporal sequence from flight #3 in which case the soil moisture condition goes from wet to dry, and the classification accuracies are shown in Figure 4.3 for a single-channel system. The classification accuracy improves significantly again as more temporal information is used in the classification procedure and the cross-polarized system is significantly better than the HH system when the temporal sequence is started with wet soil conditions. The dual-polarization and dual-frequency systems show a trend similar to the single-channel systems (Figure 4.4) but the increase in accuracy is smaller when the temporal sequence starts with wet soil conditions.

A representative crop-confusion table for the multidate case is shown in Table 4.1.

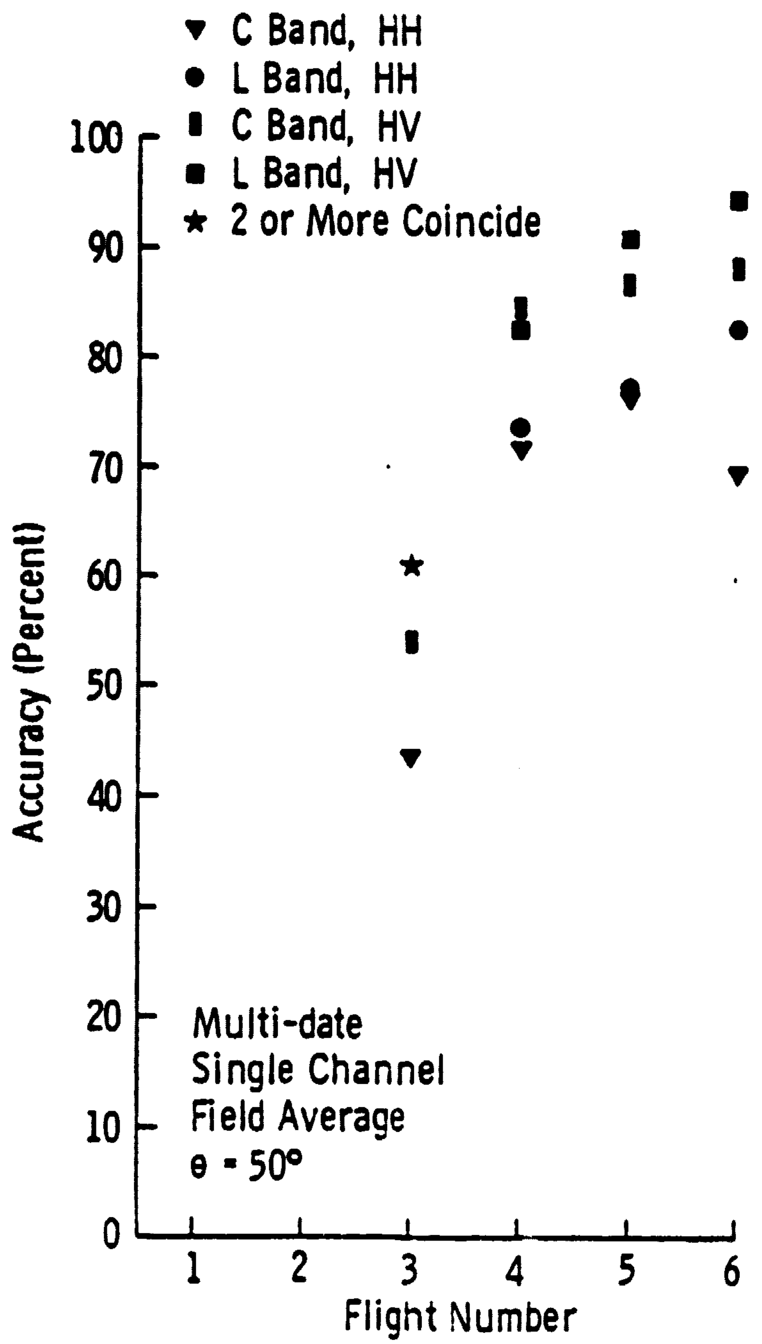

Figure 4.3. Effect of multidate classification (starting with a wet flight) on the overall accuracy for a single-channel system.

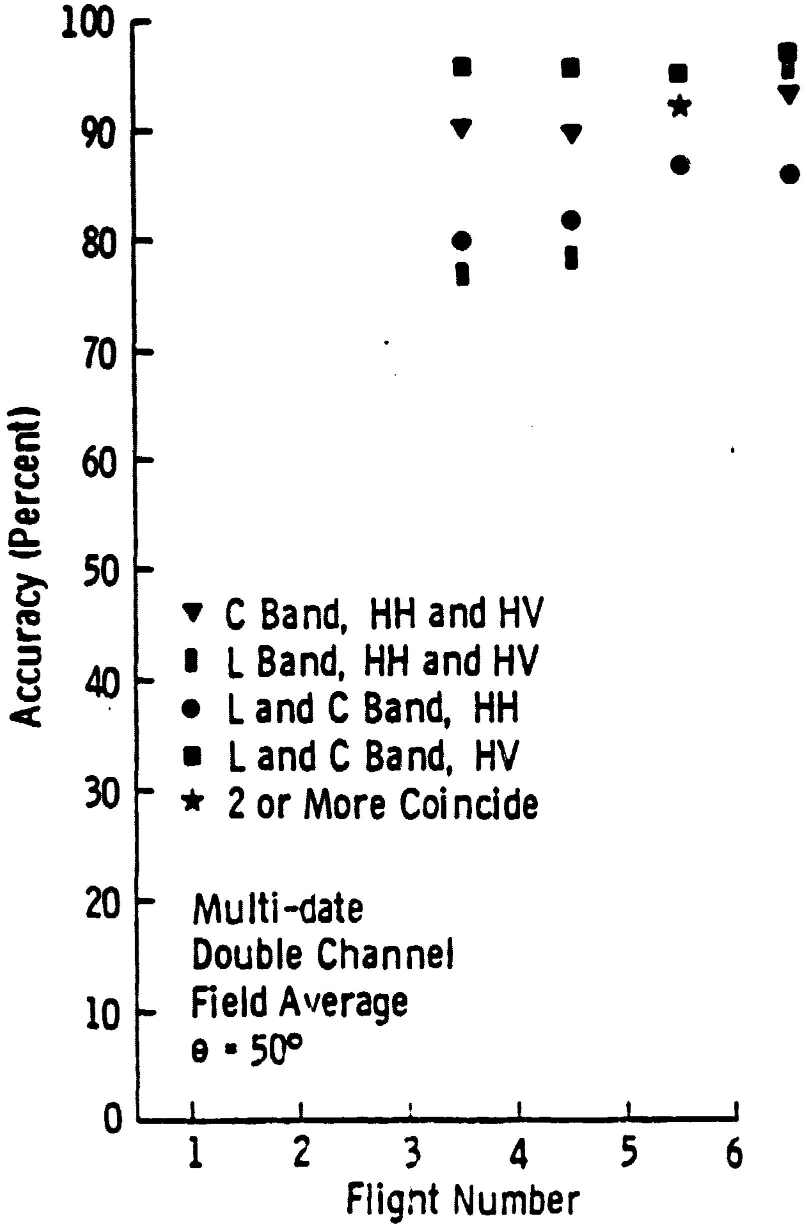

Figure 4.4. Effect of multidate classification (starting with a wet flight) on the overall accuracy for a double-channel system.

Table 4.1

Crop Confusion Matrix
Maximum Likelihood Classifier
Features Used: Field Average,
Multidate } L, HH, 50°,
Single Channel }
Flight (1+2+3+4+5+6)

ACTUAL \ CLASSIFIED AS	CORN	PASTURE	WHEAT STUBBLE	FALLOW
CORN	100.	0.	0.	0.
PASTURE	0.	100.	0.	0.
WHEAT STUBBLE	0.	0.	93.75	6.25
FALLOW	0.	0.	4.0	96.0

OVERALL ACCURACY = 96.53%

CROP	# OF FIELDS
CORN	29
PASTURE	17
WHEAT STUBBLE	48
FALLOW	50
TOTAL	144

5.0 EFFECTS OF MERGING FALLOW AND WHEAT STUBBLE CATEGORIES

In the results presented in the preceding sections, one major source of classification error was the confusion between the wheat stubble and fallow categories. To investigate the extent to which this error affects the overall classification accuracy, some of the classification experiments were repeated with only three ground cover categories: corn, pasture and bare soil (fallow and wheat stubble). Given the time of the planting calendar in (Colby) western Kansas, these ground cover categories will be quite appropriate.

The results of three-way classification experiments are shown in Tables 5.1 to 5.7. From Table 5.1 we see that the data from wet soil conditions yield very poor results for the four-way classification (57.27%) but gives an accuracy of 83.64% when treated as a three-way classification problem. This represents an improvement of 26%. Similar results shown in Table 5.2 reveal the same effect for the two-channel system. For the multidate data set, the results given in Tables 5.3-5.7 show that an overall accuracy of about 98% is possible in resolving corn, pasture and bare soil categories. On examining the other systems, an increase of about 10% is achieved for the C- and L-band dual pole systems and the C-band HH system. For all systems, the overall accuracy, when treated as a three-way classification problem, is between 96% and 98%. These results indicate that unless a considerable number of spectral and temporal data are available, it is not meaningful to attempt to separate wheat stubble from fallow. This separation can be done successfully only if sufficient data are available.

Table 5.1

L-Band, HH, 50°,
Flight #4 (Field Average)

CLASSIFIED AS / ACTUAL	CORN	PASTURE	WHEAT STUBBLE	FALLOW
CORN	92.59	0.	0.	7.41
PASTURE	0.	66.67	33.33	0.
WHEAT STUBBLE	9.56	16.67	22.22	55.56
FALLOW	8.57	2.86	25.71	62.86

OVERALL ACCURACY = 57.27%

CLASSIFIED AS / ACTUAL	CORN	PASTURE	BARE
CORN	92.59	0.	7.41
PASTURE	0.	66.67	33.33
BARE	7.04	9.86	83.1

OVERALL ACCURACY = 83.64%

Table 5.2

C-Band, Dual Pole, 50°,
Flight #3 (Field Average)

CLASSIFIED AS / ACTUAL	CORN	PASTURE	WHEAT STUBBLE	FALLOW
CORN	85.71	0.	14.29	0.
PASTURE	0.	93.33	0.	6.67
WHEAT STUBBLE	17.39	0.	65.22	17.39
FALLOW	4.35	6.52	56.35	34.78

OVERALL ACCURACY = 62.22%

CLASSIFIED AS / ACTUAL	CORN	PASTURE	BARE
CORN	85.71	0.	14.29
PASTURE	0.	93.33	6.67
BARE	10.9	3.3	85.9

OVERALL ACCURACY = 86.67%

Table 5.3

Multidate, L-Band, HH, 50°
Flights (1+2), (Field Average)

CLASSIFIED AS / ACTUAL	CORN	PASTURE	WHEAT STUBBLE	FALLOW
CORN	93.1	0.	0.	6.9
PASTURE	0.	88.24	11.76	0.
WHEAT STUBBLE	0.	0.	91.67	8.33
FALLOW	0.	2.0	2.0	96.0

OVERALL ACCURACY = 93.06%

CLASSIFIED AS / ACTUAL	CORN	PASTURE	BARE
CORN	93.1	0.	6.9
PASTURE	0.	88.24	11.76
BARE	0.	1.02	98.98

OVERALL ACCURACY = 96.53%

Table 5.4

Multidate, C-Band, HH, 50°
Flights (1+2), (Field Average)

ACTUAL \ CLASSIFIED AS	CORN	PASTURE	WHEAT STUBBLE	FALLOW
CORN	100.	0.	0.	0.
PASTURE	0.	96.12	5.88	0.
WHEAT STUBBLE	0.	6.25	75.0	18.75
FALLOW	0.	0.	10.0	90.0

OVERALL ACCURACY = 87.5%

ACTUAL \ CLASSIFIED AS	CORN	PASTURE	BARE
CORN	100.	0.	0.
PASTURE	0.	94.12	5.88
BARE	0.	3.06	96.96

OVERALL ACCURACY = 97.22%

Table 5.5

Multidate, C-Band, (HH+HV)
Flights (1+2), (Field Average)

CLASSIFIED AS / ACTUAL	CORN	PASTURE	WHEAT STUBBLE	FALLOW
CORN	100.	0.	0.	0.
PASTURE	0.	96.12	5.88	0.
WHEAT STUBBLE	0.	5.88	66.71	29.41
FALLOW	0.	1.96	0.	98.04

OVERALL ACCURACY = 86.49%

CLASSIFIED AS / ACTUAL	CORN	PASTURE	BARE
CORN	100.	0.	0.
PASTURE	0.	94.12	5.88
BARE	0.	3.92	96.08

OVERALL ACCURACY = 96.62%

Table 5.6

Multidate, L-Band, (HH+HV), 50°
Flights (1+2), (Field Average)

CLASSIFIED AS / ACTUAL	CORN	PASTURE	WHEAT STUBBLE	FALLOW
CORN	100.	0.	0.	0.
PASTURE	0.	94.12	5.88	0.
WHEAT STUBBLE	0.	3.92	74.57	21.57
FALLOW	0.	0.	11.76	88.24

OVERALL ACCURACY = 86.49%

CLASSIFIED AS / ACTUAL	CORN	PASTURE	BARE
CORN	100.	0.	0.
PASTURE	0.	96.12	5.88
BARE	0.	1.96	98.04

OVERALL ACCURACY = 97.97%

Table 5.7

Multidate, (L+C), HH, 50°
Flights (1+2), (Field Average)

CLASSIFIED AS / ACTUAL	CORN	PASTURE	WHEAT STUBBLE	FALLOW
CORN	100.	0.	0.	0.
PASTURE	0.	88.24	11.76	0.
WHEAT STUBBLE	0.	0.	90.2	9.8
FALLOW	0.	1.96	0.	98.04

OVERALL ACCURACY = 94.59%

CLASSIFIED AS / ACTUAL	CORN	PASTURE	BARE
CORN	100.	0.	0.
PASTURE	0.	88.24	11.76
BARE	0.	0.98	99.02

OVERALL ACCURACY = 97.97%

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7.0 REFERENCES

[1] Ulaby, F.T., "Radar Response to Vegetation," IEEE Trans. on Ant. and Prop., vol. AP-23, no. 2, January 1975.

[2] Ulaby, F.T., G.A. Bradley, and M.C. Dobson, "Microwave Backscatter Dependence on Surface Roughness, Soil Moisture and Soil Texture, Part II: Vegetation-Covered Soil," IEEE Trans. on Geosci. Electr., vol. GE-17, no. 2, pp. 33-40, April 1979.

[3] Ulaby, F.T., T.F. Bush and P.P. Batlivala, "Radar Response to Vegetation, Part II: 8-18 GHz Band," IEEE Trans. on Ant. and Prop., vol. AP-23, no. 5, pp. 608-618, September 1975.

[4] Bush, T.F. and F.T. Ulaby, "An Evaluation of Radar as a Crop Classifier," Remote Sensing of Env., vol. 7, pp. 15-36, 1978.

[5] Simonett, D.S., J.E. Eagleman, A.B. Erhard, D.C. Rhodes and D.E. Schwarz, "The Potential of Radar as a Remote Sensor in Agriculture, Part I: A Study with K-Band Imagery in Western Kansas," CRES Report 61-21, University of Kansas, Lawrence, Kansas, 1967.

[6] Haralick, R.M., F.R. Caspall and D.S. Simonett, "Using Radar Imagery for Crop Discrimination: A Statistical and Conditional Probability Study," Remote Sensing of Env., vol. 1, pp. 131-142, 1972.

[7] Schwarz, D.E. and F.R. Caspall, "The Use of Radar in the Discrimination of Agricultural Land Use," in Proc. 5th Symp. Rem. Sens. of Env., vol. 1, pp. 233-247, 1968.

[8] Ulaby, F.T., P.P. Batlivala and J.E. Bare, "Crop Identification with L-Band Radar," Photogrammetric Eng. and Remote Sensing, vol. 46, no. 1, pp. 101-105, January 1980.

[9] Brisco, B. and R. Protz, "Corn Field Identification Accuracy Using Airborne Radar Imagery," Canadian J. Rem. Sens., vol. 6, no. 1, pp. 15-25, July 1980.

[10] Li, R.Y, F.T. Ulaby and J.R. Eyton, "Crop Classification with a Landsat-Radar Sensor Combination," Proc. Symp. on Machine Processing of Remotely Sensed Data, Purdue University, West Lafayette, Indiana, June 2-6, 1980.

[11] Ahern, F.J., D.G. Goodenough, A.L. Grey, R.A. Ryerson and R.J. Vilbikaitis, "Simultaneous Microwave and Optical Wavelength Observations of Agricultural Targets," Canadian J. Rem. Sens., vol. 4, no. 2, pp. 127-142, August 1978.

[12] Ulaby, F.T., R. Li and K. Shanmugan, "Crop Classification Using Airborne Radar and Landsat Data," RSL Technical Report 360-13, University of Kansas, Lawrence, Kansas, February 1981.

[13] Duda, R.O. and P.E. Hart, Pattern Classification and Scene Analysis, Wiley-Interscience, pp. 119-120, 1973.