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CROP CLASSIFICATION WITH A LANDSAT/RADAR SENSOR COMBINATION

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I. ABSTRACT

A combined Landsat/radar approach to classification of remotely sensed data, with emphasis on crops, was undertaken. Radar data were obtained by microwave radar spectrometers over fields near Eudora, Kansas and Landsat image data were obtained for the same test site. After Landsat digital images were registered and test-cells extracted, a comparable set of radar image pixels were simulated to match the Landsat pixels. The combined data set is then used for classification, and the results are examined with the best combination of sensor variables identified. Finally, the usefulness of radar in a simulated cloud-cover situation is demonstrated. The major conclusion derived from this study is that the combination of radar/optical sensors is superior to either one alone.

II. INTRODUCTION

Crop classification using multitemporal, remotely sensed data has become an established procedure in remote sensing technology. A key requirement for the success of the multitemporal approach is that of uninterrupted sensor coverage of the site or area under investigation. For visible and near-infrared sensing systems, the interruption is caused primarily by cloud attenuation in the atmosphere. The absence of coverage for even a single date often results in degradation in crop classification accuracy. Being effectively immune to the cloud-cover problem, the microwave part of the spectrum presents an attractive means of insuring the availability of the required multi-date coverage. Additionally, radar can provide high-resolution imagery that can be made compatible with MSS imagery. Another attractive feature of a combined MSS-radar system is that radar can augment the optical sensors even under clear-sky conditions. The optical reflectivity is responsive to the crop color and chlorophyll content of the plant as it changes through the growing season. The radar backscattering coefficient, on the other hand, appears to be correlated with the plant structure and its water content.

This paper evaluates the combined use of optical and radar sensors for crop classification. The study has the following objectives: (1) to evaluate the feasibility of combining the data obtained by both sensors in a multitemporal environment, (2) to perform a comparison of Landsat data and radar data in the multitemporal classification of crops, and (3) to determine the best feature combinations from channels of both sensors. The main effort involves four areas: (1) optical and near-IR (Landsat) image processing, (2) radar data processing, (3) combined data study and (4) cloud-effect simulation. They are to be described in the following sections.

III. LANDSAT IMAGE PROCESSING

A. IMAGE REGISTRATION

Landsat image data were obtained from agriculture fields near Eudora, Kansas, where the microwave data had been obtained during the summer of 1976. Data for three dates (usually 9 days apart) are selected at the beginning of the growing season (Time Segment I) and three additional dates in the latter part of the growing season (Time Segment II). In other words, we are dealing with two time periods: (1) A May-June time period which is the beginning of the growing season for the corn and milo and is the end of the growing season for the winter wheat, and (2) an August segment which is the end of the growing season for corn and milo and constitutes a middle-to-late portion of the growing season for the soybeans planted in fields which previously contained winter wheat. A further constraint on the choice of dates for each time-segment is the availability of acceptable (high-quality, cloud-free) Landsat data. The final dates selected are May 20, June 16, and June 26 for Segment I and August 9, August 19 and August 27 for Segment II.

B. SAMPLE SELECTION

After identifying image subscenes covering the Eudora test site from the full Landsat scene, the subscenes are deskewed, rescaled and registered to each other using line-printed grey maps for multi-date analysis. To accomplish the deskewing, blocks of pixels were shifted one pixel to the west.[1] The rescaling involves the duplication of every fifth column in the two-dimensional image. In order to separate the field boundaries, the image contrast has to be enhanced.[2] An equal-probability quantization is thus performed on the subscenes and the results are shown in Figure 1 for Band 7. A gradient operator, which measures the change in grey tone in the neighborhood of each cell, is also used to partition the images.[3] As a result, we have sufficient details at road and highway intersections; at river bends; and at boundaries between forest areas and crop lands. In addition, we have a color infrared aerial image providing complete coverage on a single frame in August 1978 obtained from a NASA aircraft overflight at a scale of 1:60,000. This image, shown in Figure 2, provides more information on the test site and can be projected and accurately superimposed on the grey-level maps of the Landsat imagery. Since the scene subset (260 columns by 120 rows) is small enough, the manual registration error is minimal. All field boundaries for the Eudora test sites are traced into the grey-level maps of August 9, 1976. Correct sample selections are based on the ground-truth information obtained by field investigators during the 1976 data-collection period. To minimize any adjacency effects, only the central portions of the sample fields are selected. The field boundaries are recorded in terms of their row- and column-coordinates. Then an extraction routine is used to take the pixels out from the particular field whose crop-type is known. The same procedures as mentioned above are used to extract sample data from the Landsat scenes for the remaining dates.

IV. RADAR DATA PROCESSING

A. DATA COLLECTION

The radar data used in our study is acquired by the University of Kansas Microwave Active Spectrometer (MAS) system. This is an FM-CW radar using a dual antenna system mounted on a hydraulic boom. The system has been described by Ulaby and Bush.[4]

The radar backscattering coefficient, σ^o, was measured at 11 frequencies between 8 and 18 GHz, and at four angles from 40^o to 70^o for HH, HV, and VV antenna configurations. In total, the data have a dimensionality of 132 (11 frequencies x 3 polarizations x 4 angles of incidence). From the results of previous years on radar crop classification and initial results on Eudora this year[5], σ^o values at 10.6 and 14.2 GHz with an incidence angle of 50^o are used to represent the microwave spectral dimension.

B. INTERPOLATION

Because the data are not collected from each field on a daily basis, there are time gaps in the data history. The average number of days between data sets is 5-6 days for 90% of the growing season. The cultivation period for corn almost extends over the entire measurement period. Wheat, soybeans and milo cover only a portion of the time span. The time gaps for different crops are filled up by linearly interpolating the data. The fallow period is simulated by using data obtained from bare soil.

C. IMAGE SIMULATION

The simulation procedure[6] produces pixels for a hypothetical synthetic aperture radar having a basic single-look resolution of 12.5 meters by 12.5 meters[7], which is degraded by averaging to a resolution cell of 50 meters by 50 meters. This provides an estimate of σ^o based on 16 independent samples. The size of the simulated radar pixel is approximately equal to the Landsat pixel size.

V. COMBINED DATA STUDY

After training and test pixels are selected randomly from Landsat images, the corresponding radar image pixels are generated from the measured radar data. Each cell (pixel) contains 30 features with 10 features for a given date. These 10 features contain six radar features and four Landsat features. They are radar 10.6 GHz (HH, HV, and VV), radar 14.2 GHz (HH, HV, and VV), and Landsat Bands 4, 5, 6, and 7. The discriminant analysis is performed by a canonical-vector classifier. It develops canonical variables based on the between-group and within-group covariance matrices.[8] The feature-selection method used in the analysis is that of stepwise entry or deletion based on F-ratio, which relates to separability among classes. The F-ratio is based on a variation of Wilks' Λ-criterion:[9]

$$\Lambda(X) = \frac{\det W(X)}{\det T(X)}$$

where W(X) is the within-group cross-product matrix and T(X) is the total cross-product matrix.

From all the variables available, the variable with the largest F-to-enter value is selected unless this value is below the F-to-enter threshold. This process continues until all the variables are entered.

Both Landsat data and radar data are run independently and as a combined data-set for all three dates and for various combinations of sensor features. Both training and test pixels are used in estimating the percent of overall correct classification for each category involved. The category types include wheat, corn, soybeans, milo, trees, water and highways.

A. RESULTS FROM TIME SEGMENT I

From the May-June segment, the Landsat classification accuracies are considerably smaller than radar accuracies (Figure 3). The single-date crop classification using two-band and four-band data yields only 55.4% and 64.0% correct classification. This is considerably improved to 80.4% and 84% using two dates. Adding the third date gains about two percent more. Band 5 and Band 7 are usually the best two bands in terms of their discrimination ability. Additional bands provide little improvement. Therefore, it is reasonable to suggest that using two Landsat bands and two dates is adequate for crop classification.

The radar classification shows high accuracies in the results of crop classification. Little significant difference in predicting ability occurs between the 10.6 GHz radar measurement and the 14.2 GHz measurement. The combination of the two frequencies does increase the classification accuracy. Data with two frequencies and two dates have increased the overall percentage of correctness to around 99%. The addition of data from a third date adds little new information.

Figure 3 shows that the combined radar and Landsat classification yields high accuracy. The best minimal set of combined variables (Landsat Bands 5 and 7, plus radar 14.2 GHz (HV and VV) produces 96.7% accuracy for two dates. The improvement due to adding another variable or another date is very small.

For individual crops, corn is 80.4% correctly identified by using Landsat data alone. Wheat is doing well with 91.3% accuracy. Milo has the poorest performance with 67.0%. If we use only radar data, all crops are classified correctly at about 95%. The combined data-set enhances the results to around the 96%-99% range.

B. RESULTS FROM TIME SEGMENT II

For the three days in August, the two-band (5 and 7) and four-band Landsat classifications have shown acceptable accuracies (69.3% and 72.7% respectively) for a single date. Additional increases in accuracy can be obtained by adding the data from the second date. The information from the third date is not helpful. The radar classification is generally less accurate than its Landsat counterpart. It takes three dates to get over 80.0%. Figure 4 shows that the combined radar and Landsat classification shows a clear improvement. This occurs because of the difference in the sensor response to crops.

Landsat data yields classifications that discriminate soybeans more accurately than radar data can. In turn, the radar data produces classifications that can better determine which pixels are milo. Each sensor therefore provides a complementary discrimination capability in the combined classification. In the case of corn, the data from each sensor have performed equally well in assigning corn pixels. In the combined case, both sensors are mutually reinforced to create a moderate increase (about 5%) in accuracy.

VI. CLOUD-EFFECT SIMULATION

The results in Section V are obtained under the cloud-free assumption. It is a fact, however, that classification results from optical sensors can be seriously affected by the loss of coverage due to clouds. Therefore, a Landsat data-set with enough cloud over the target area simply means that the data set has been rendered useless for that day. Deleting the measurement for that day from the multitemporal analysis can therefore be interpreted as a simulation of the real cloud-cover situation. Using the Eudora data set as an example, cloud-effects are simulated on the first and second day of both time-segments. The results are shown in Figure 5 for the May-June segment and in Figure 6 for the August segment. The results are described below.

1. With Landsat data alone, there is a significant drop in classification accuracy due to cloud cover for both time segments. For instance, a drop of 10% accuracy is reported in the May-June segment with the first day (May 20) cloud-covered. For the August segment, a drop of 15% accuracy is reported due to a single cloudy day (August 9). If the second day of the multi-day sequence is cloud-covered, there is also a drop in the final accuracy of the analysis. In comparison, the first day of the three-day sequence is probably the most vital to the success of crop classification in our experiment.

2. Suppose that there is a radar backup system to substitute for the multispectral scanner on Landsat which is hindered by weather conditions. In other words, Landsat data for a given day will be replaced by the matching radar data. From Figures 5 and 6 it is seen that the radar replacements at the first day from both segments have made the final classification accuracy 20% higher than that of interrupted Landsat coverage; 5% more than that of complete Landsat coverage. If the replacement is made for the second day, the improvements due to radar are also obvious. The overall results show that if radar is available to replace the one missing Landsat image, not only does it make up the loss due to the cloud cover, but the classification accuracy surpasses the original performance of the uninterrupted Landsat coverage.

VII. CONCLUDING REMARKS

This study is an effort to examine both remotely sensed Landsat and radar data in terms of their individual and collective ability to classify crops. The following observations are noted:

1. Radar, as a remote-sensing tool, can be effective in multitemporal crop identification even using only single-frequency and two polarizations.

2. The classification statistics show that data for each sensing system can be complementary, which will result in mutual reinforcement and substantial increase in discrimination accuracy between crop types.

3. Since some of the sensor variables are correlated, we can find a feature combination, which is a subset of the total available features, that is capable of producing satisfactory results.

4. The utility of radar in cloud-cover situations is demonstrated, along with the potential pitfall of an interrupted Landsat coverage.

Finally, it may be useful to test additional data sets to reinforce the findings obtained here.

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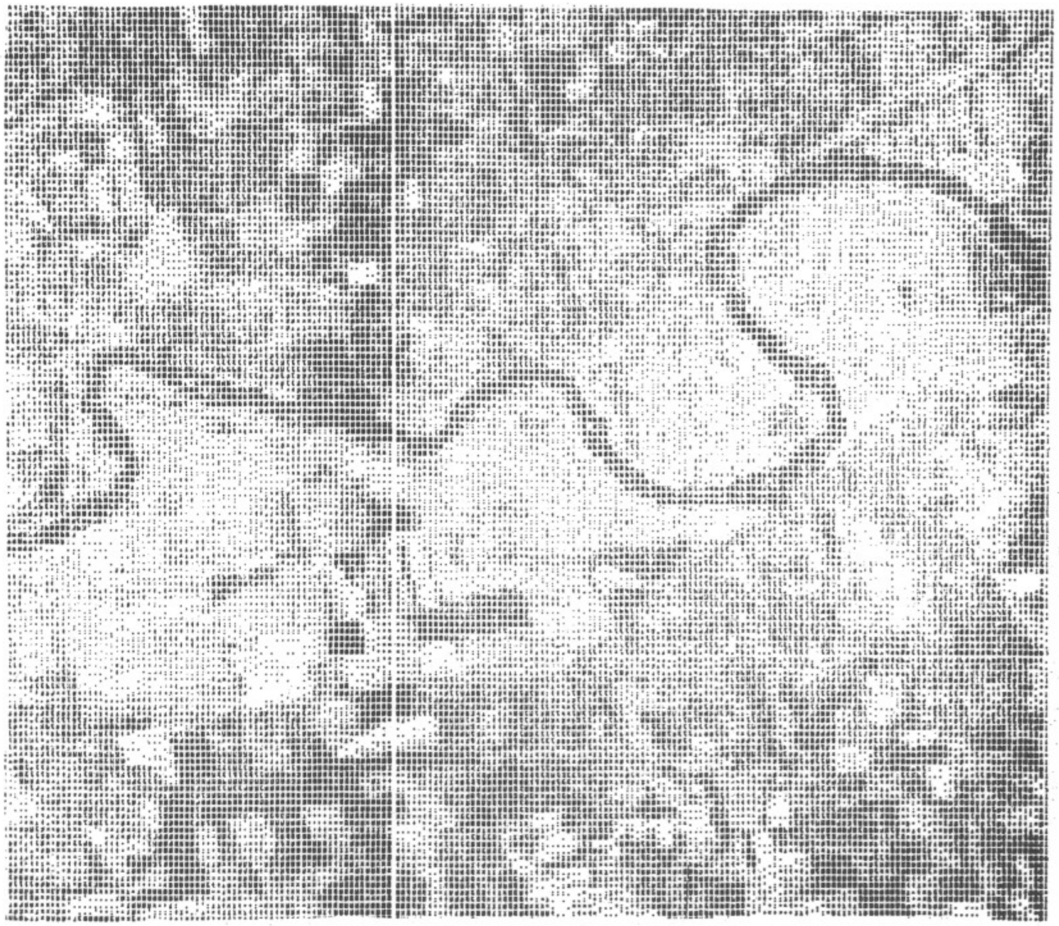


Fig. 1 Landsat Band 7 Grey-Level Map
August 9/76

Center Coordinates: $38^{0}57'30''$N
$95^{0}07'30'$W

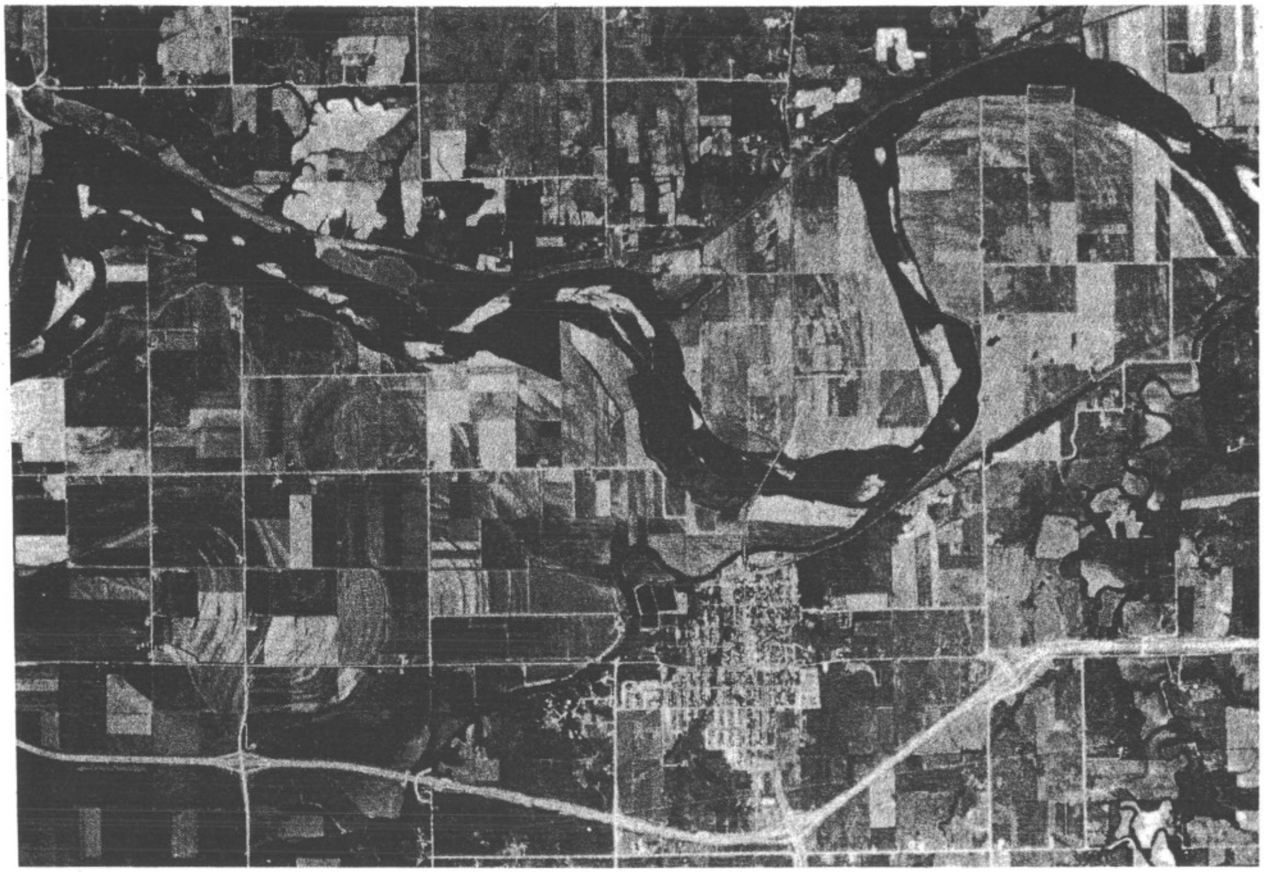
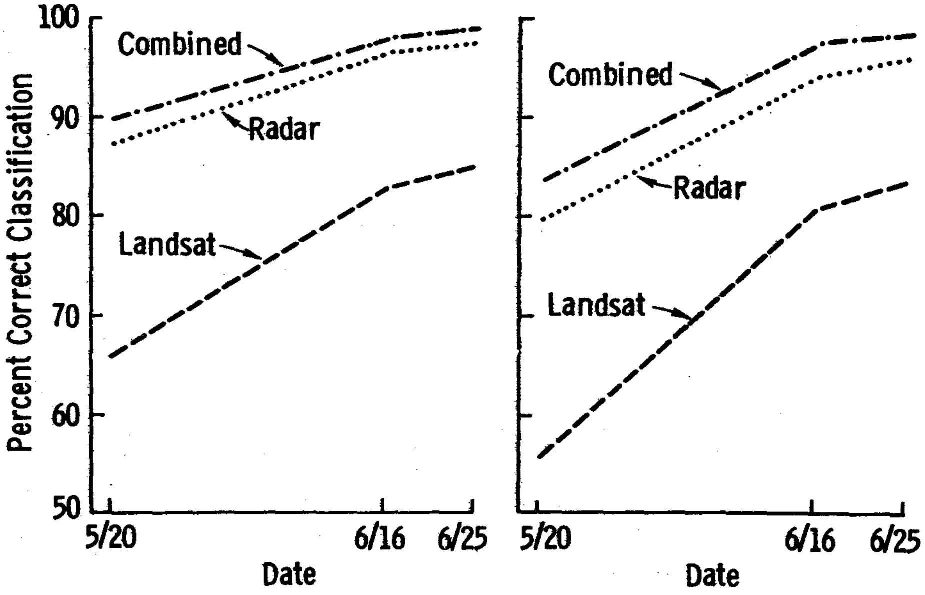


Fig. 2 High Altitude CIR Aerial Photograph June 15/78

Center Coordinates: 38°57'30"N
95°07'30"W

	Percent Correct Classification		
Date	5/20	6/16	6/25
Radar			
All Classes	86.9	96.1	97.3
Crops	79.1	93.8	95.6
Landsat ----			
All Classes	65.6	82.4	85.1
Crops	55.4	80.4	83.4
Combined ·—·—·—			
All Classes	89.5	97.8	98.7
Crops	83.6	96.7	98.0

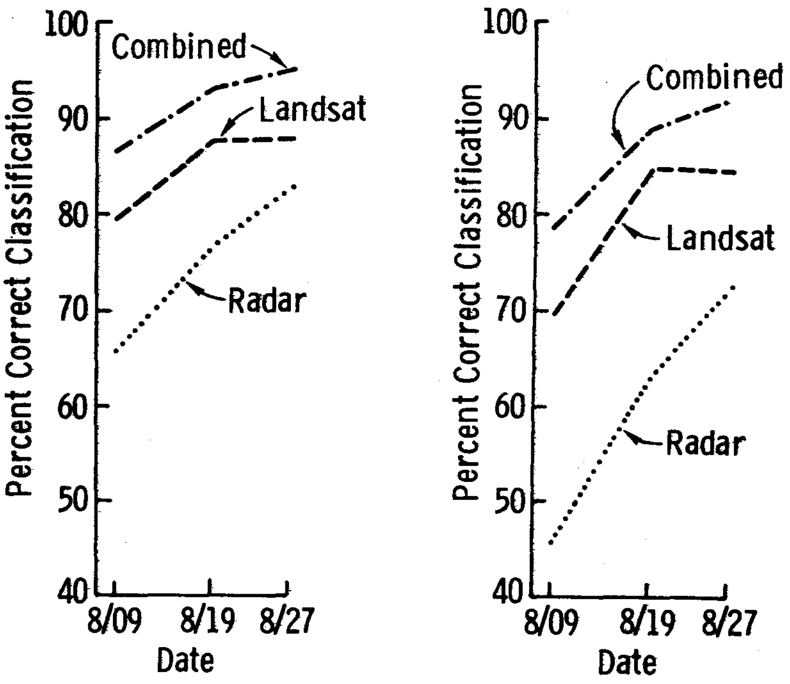


All Classes

Crops

Fig. 3 Minimum Set of Sensors
Classification--First Segment
Radar (14.2 GHz (HV, VV)
Landsat (Bands 5 and 7)
Combined: Radar (14.2 GHz (HV, VV)) and
Landsat (Bands 5 and 7)

	Percent Correct Classification		
Date	8/09	8/19	8/27
Radar			
All Classes	65.7	76.5	82.5
Crops	45.5	62.6	72.2
Landsat ----			
All Classes	78.9	87.9	87.9
Crops	69.3	84.2	84.0
Combined -·-·-			
All Classes	86.4	92.8	94.7
Crops	78.4	88.6	91.6



All Classes

Crops

Fig. 4 Minimum Set of Sensors Classification--Second Segment Radar (10.6 GHz (HV, VV)) Landsat (Bands 5 and 7

Combined: Radar (10.6 GHz (HV, VV)) and Landsat (Bands 5 and 7)

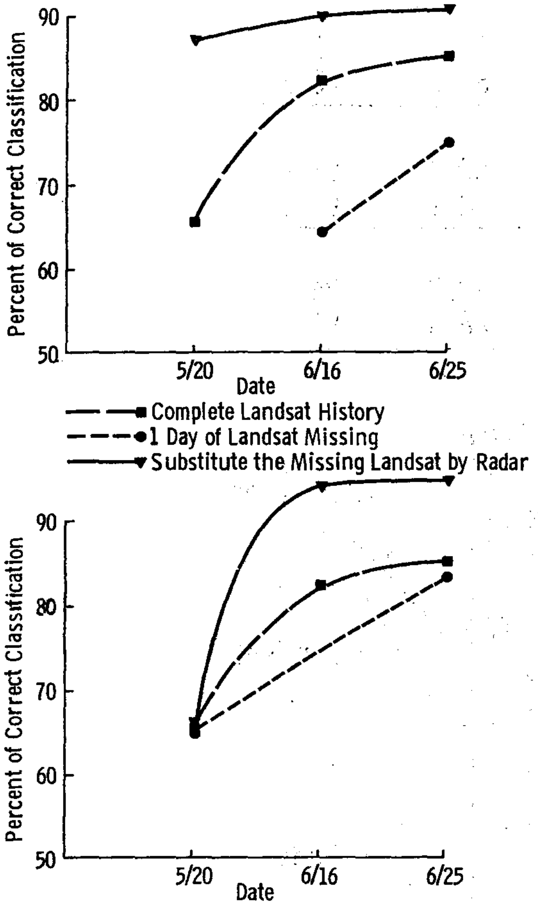


Fig. 5 Cloud-Effect Simulation For First Time Segment

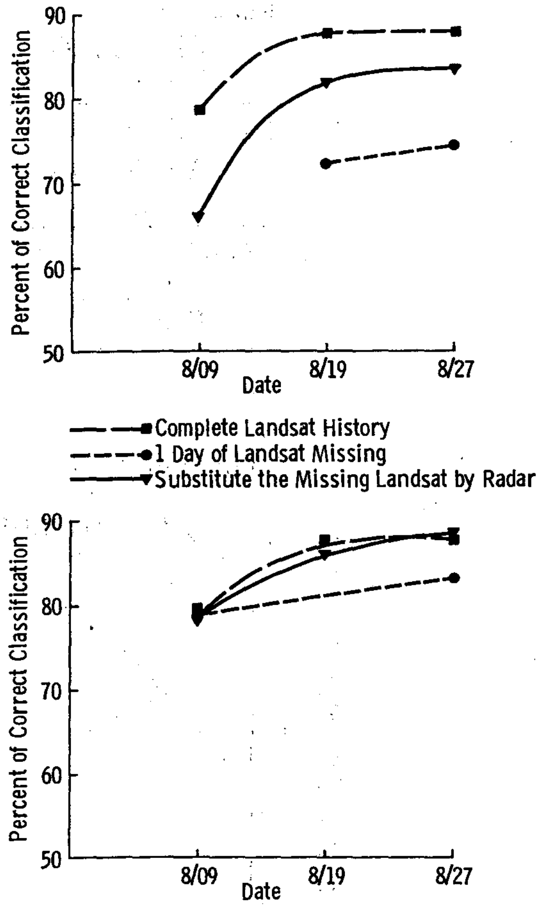


Fig. 6 Cloud-Effect Simulation For Second Time Segment

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