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Improving Crop Classification through Attention to the Timing of Airborne Radar Acquisitions

By synchronizing the SAR data collection with the crop calendar, significant improvements in crop classification can be achieved.

Abstract: *Radar remote sensors may provide valuable input to crop classification procedures because of (1) their independence of weather conditions and solar illumination, and (2) their ability to respond to differences in crop type. Manual classification of multidate synthetic aperture radar (SAR) imagery resulted in an overall accuracy of 83 percent for corn, forest, grain, and "other" cover types. Forests and corn fields were identified with accuracies approaching or exceeding 90 percent. Grain fields and "other" fields were often confused with each other, resulting in classification accuracies of 51 and 66 percent, respectively. The 83 percent correct classification represents a 10 percent improvement when compared to similar SAR data for the same area collected at alternate time periods in 1978. These results demonstrate that improvements in crop classification accuracy can be achieved with SAR data by synchronizing data collection times with crop growth stages in order to maximize differences in the geometric and dielectric properties of the cover types of interest.*

Introduction

Remotely sensed data are being utilized increasingly to inventory and monitor the Earth's natural resources, and it is anticipated that remote sensing techniques will provide data inputs to world crop production forecasts in the future (Bauer, 1975; Lacie Symposium, 1978). The visible and infrared regions of the electromagnetic spectrum have been intensively investigated and are beginning to be used operationally in agricultural applications. Although radar remote sensors are not as well understood as optical sensors, they may provide valuable backup data collection capabilities as a result of their independence both of weather conditions and of solar illumination (Ahern *et al.*, 1978; Goodenough *et al.*, 1980).

Brisco and Protz (1980a, 1980b, 1982) used 4-channel synthetic aperture radar (SAR) imagery, acquired on 3 August and 28 September 1978, for a crop classification study of an agricultural test site near Guelph, Ontario. They reported an overall classification accuracy of 72.6 percent for the categories of forest, roughland, grain, hay-pasture, and corn. The hay-pasture and grain fields were highly confused ($\simeq$ 50 percent accuracy), but the authors suggested that a more accurate discrimination between these categories might be possible if the SAR data were to be collected at different times during the growing season.

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Early research into the crop identification capacity of radar demonstrated that crop type significantly influences radar return, and thus that discrimination is indeed possible (Simonett *et al.*, 1967; Schwarz and Caspell, 1968; Haralick *et al.*, 1970). Subsequent research substantiated this conclusion and attributed the variation in the radar backscattering coefficient (σ^o) to differences in the dielectric and geometric properties of the crops investigated (Ulaby, 1975; Bush and Ulaby, 1978; Ulaby, 1981). Because these crop properties change over time and with physiological growth stage, multidate data acquisition allows a more accurate discrimination between crops (Shanmugam *et al.*, 1981a; Brisco and Protz, 1982; Ulaby *et al.*, 1982).

This report presents the results of a study investigating the improvements obtained in crop classification of SAR data when attention is given to the timing of the airborne radar data acquisition. The test site and categories used are sufficiently similar to the site used in studies by Brisco and Protz (1980a, 1980b, 1982) to allow for a comparison of the influence of the crop calendars on the classification accuracies obtained in each study.

AIRBORNE AND GROUND-BASED DATA COLLECTION

The University of Guelph's Remote Sensing Test Strip, which extends from northwest of Elora to southeast of Hamilton, Ontario, was used as the study area (Figure 1). Airborne SAR data were collected on 20 June and 3 September 1980 by the Environmental Research Institute of Michigan's (ERIM) four-channel radar system, which is now mounted in the Convair 580 aircraft belonging to the Canada Centre for Remote Sensing (CCRS). A description of ERIM's SAR system can be found in Rawson *et al.* (1975). Initially, flights were requested in mid-June, mid-July, and mid-August to maximize the differences in the hay and grain fields' dielectric and geometric characteristics. The crop calendar for the test site (Table 1) shows why these dates were selected, i.e., mid-June is before the first hay cut, mid-July is pre-wheat harvest, and mid-August is pre-corn harvest. However, due to the limited availability of the CCRS Convair 580 aircraft, only the missions described above were flown.

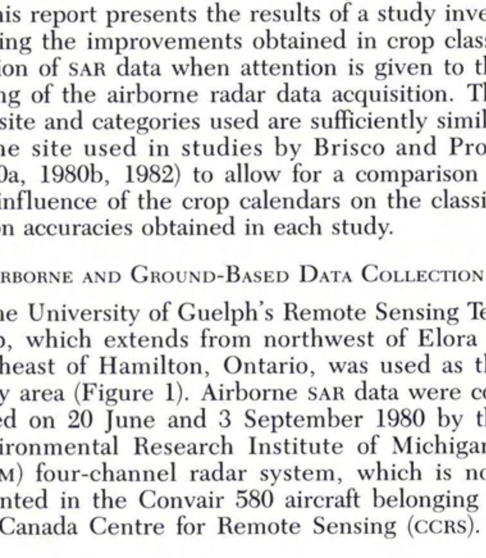

FIG. 1. The location of the University of Guelph Remote Sensing Test Strip.

Color aerial photography (scale ≃ 1:8000) was acquired over the test site by an Ontario Centre for Remote Sensing (OCRS) aircraft on 10 June 1980. Just prior to and during each date of SAR data acquisition, 165 fields bordering roadways in the test site were inventoried by crop type. By inventorying fields along roadways only, a maximum number of fields could be inventoried with a minimum amount of effort.

IMAGE INTERPRETATION PROCEDURE

The 20 June flight line was flown with the radar looking south, and covered only the northern third of the test strip. On 3 September the imagery was acquired with the radar looking north, and the swath was approximately three miles further south. Thus, only 54 of the 165 inventoried fields were covered by both flights. However, a large area common to both SAR flights, and for which aerial photography (20 June) was available, was used in selecting fields for the classification study. In the 20 June imagery, the fields are located in the near range, with an incidence angle of approximately 60 degrees, while on the September imagery the fields are located in the mid-range, with an incidence angle of approximately 65 degrees. The image quality is fairly good except in the X-HV image for 20 June. This image exhibited a bright spot in the study area, which may have been caused by a light-leak during exposure. The L-band data (both dates) also appear quite noisy for both polarizations, with a low dynamic range in the gray tones. Due to the problems posed by the different incidence angles used and the suboptimum image quality, it was decided not to proceed with digital analysis of the data set as originally planned, as a result of time and cost constraints. However, the data quality and information content of the study were considered of suitable value to warrant a manual classification.

The 54 inventoried fields common to both sets of SAR images were used for training purposes. Figure 2 presents these training fields and the testing fields, annotated for cover types. Evaluation of the tone and texture of the fields in this training site led to a four-level tonal differentiation (0-3) and a three-level textural classification (1-3). Each of the 54 fields was located on each channel of the SAR data (enlarged two times to a scale of ≃ 1:75,000), and a

TABLE 1. ESTIMATED CROP HEIGHTS FOR NORMAL PLANTING IN THE GUELPH AREA. HEIGHTS IN CM—RANGES INDICATED ARE ESTIMATES OF 10–90% PROBABILITY RANGE. SUPPLIED BY DR. T. B. DAYNARD, CROP SCIENCE, UNIVERSITY OF GUELPH.

	June		July		August		September	
	1	15	1	15	1	15	1	15
Corn	0–20	10–40	20–60	60–120	120–220	180–230	same →	
Spring grains	5–14	20–50	40–90	60–90	same	0–90	0–90	0
Winter grains	20–50	50–100	70–100	70–100	0–100	0	0	0
Alfalfa grass	40–90	10–100	same →				20–100	same

number was assigned to the tonal and textural values. These results were evaluated and a manual interpretation flowchart was developed for crop classification purposes. A four-category classification consisting of corn, forest, grain, and "other" was used, with the "other" class representing hay, pasture, and roughland cover types. A test site, consisting of 135 fields, was then used to determine the accuracy of the crop classification achievable using this interpretation flowchart. Each test field was located on the SAR image, a number assigned to the tone and texture, and a decision made as to crop type, based on these values and the interpretation flowchart. After all fields had been classified, the accuracy of the interpretation was assessed by locating each field in the color photography and determining its true crop type. The scale used in the color photography was large enough so that very few, if any, errors were introduced by this method.

RESULTS AND DISCUSSION

Sample images from the 20 June X:HV and L:HH channels, with the four tonal levels used in the classification procedure and sample fields of each cover type indicated, are presented in Figure 3. Although more tonal levels are present on the X-band imagery than on the L-band imagery, it was difficult to discriminate consistently and accurately among some of the more subtle differences in image tone when a manual classification procedure was used. This four-level tonal classification was thought to be sufficient for the purpose of this investigation, and allowed the interpreter to make more accurate distinctions between very similar shades of gray. Three 15× enlargements of the X:HH image are presented in Figure 4 to illustrate the three levels of textural classification used in the analysis. As is the case with tone, there are more textural levels present in the imagery; however, quantification by manual procedures is very difficult and time consuming. The value of texture of radar image interpretation is well established (Berger, 1970; Kedar and Hsu, 1972; Lowry *et al.*, 1978; Shanmugan *et al.*, 1981b) but has proven difficult to implement in classification procedures. With the three-level textural classification (1-3), most agricultural fields exhibited textural values of two, forests had values of three, and water bodies, roadways, etc., had values of 1. Although the agricultural fields in the study area were texturally diverse, it was nevertheless very difficult for the interpreter to make consistent quantifications of the texture exhibited by these fields.

On the SAR imagery, forests were a readily separable category because of the rough texture (3) they exhibited on the X-HH channels. Corn was also easily discriminated because of its bright appearance (2-3) on the September L-band channels and dark (0-1) appearance on the June L-band channels. The grain and other cover types were more difficult to discriminate, however. On the June X-HV imagery, some fields in the "other" category exhibited bright tones more often than did the grain fields, because the greater vegetation height of fields in the "other"

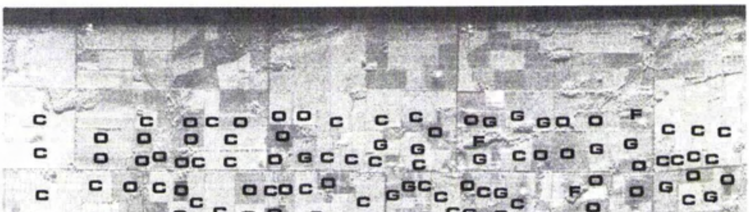

FIG. 2. Cover type map for the training and testing fields in the classification study for the categories corn (C), forest (F), grain (G), and the other (O).

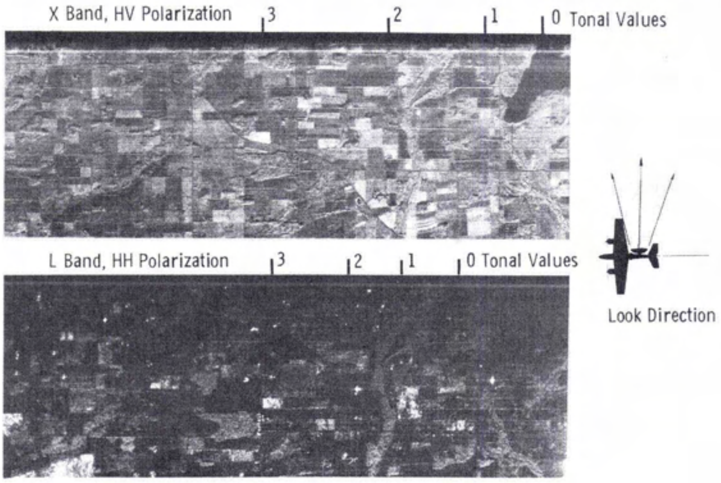

FIG. 3. Radar imagery from 20 June for X-band, HV polarization, and L-band, HH polarization, with examples of the tonal values used in manual classification.

category resulted in more volume scattering. Some grain fields also exhibited a periodic textural appearance, attributable to their row structure, while the texture of the fields in the "other" category exhibited a more random textural appearance. However, in both cases the textural value assigned was 2. This image-texture difference was even more pronounced in the September imagery. Using these criteria, an image interpretation flowchart for crop classification was developed (Figure 5). This flowchart was used to classify the 135 test fields into the corn, forest, grain, or "other" categories. In addition, other elements of image interpretation such as shape, location, etc., were used to classify a particular field. For example, an irregular shaped field located alongside a forest was more likely to be a hay-pasture field (and thus fall into the "other" category) than to be, say, a grain field, and such information might be used as an additional criterion if the tone and texture criteria were insufficient bases upon which to make a classification.

Using the interpretation flowchart and the other elements of image interpretation described above, an overall accuracy of 83 percent was achieved for corn, forests, grain, and "other" cover types (Table 2). These classification accuracies include errors of both omission and commission, and thus are conservative estimates of the percentages of correct classification. Thus, if a grain field is incorrectly classified as "other," this is tabulated as both an error

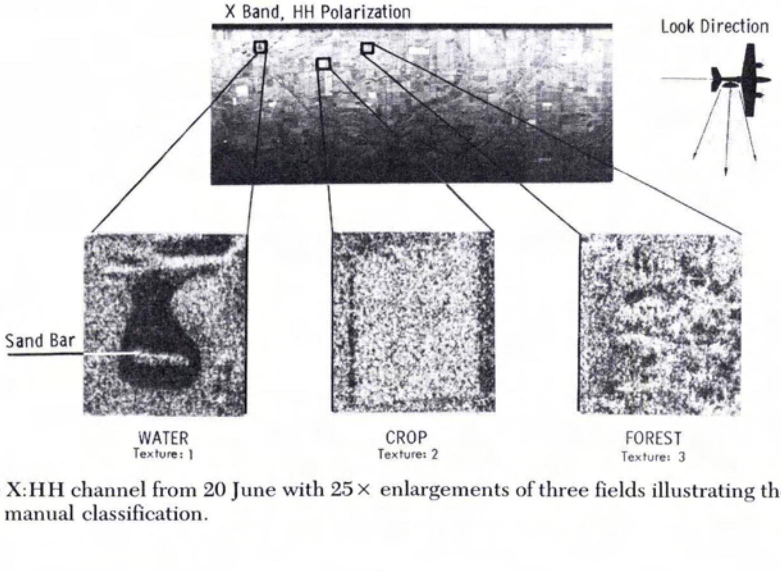

FIG. 4. The X:HH channel from 20 June with 25× enlargements of three fields illustrating the textural values used in the manual classification.

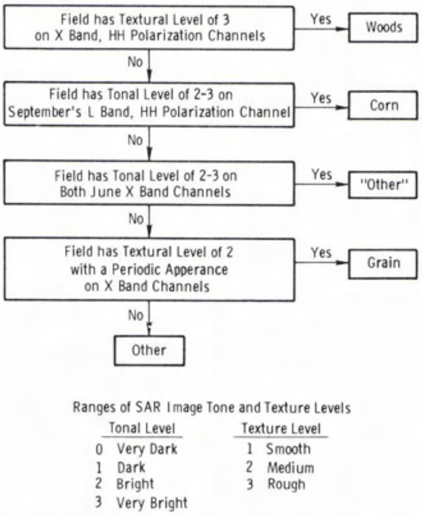

FIG. 5. Image interpretation flow chart for crop classification with multichannel multidate Guelph SAR data.

of omission for the grain field, and an error of commission for the "other" field. The percentages of correct classification would improve for each cover type (corn 91.7 to 93.6 percent, forests 87.5 to 100 percent, grain 51.2 to 87.5 percent, and "other" 65.5 to 70.2 percent) if errors of ommission only were considered. Corn and forests were most accurately identified (92 and 88 percent, respectively) because the rough image texture (3) of forests on X-band channels and the bright image tone (2-3) of corn on the September L-band channels enabled accurate discrimination of these two cover types. Thus, once the corn is sufficiently tall to create significant backscattering at L-band frequencies, a single date of SAR data acquisition using one X-band and one L-band channel allows accurate identification of these two cover types. On the September L-band channels it was observed that forests exhibit more depolarization on the HV channel than corn because of significantly more volume scattering, suggesting that a single frequency with two polarizations may be enough for the accurate discrimination of corn from forests. Note that for the forests only one field was misclassified (a pine plantation was incorrectly identified as a corn field), but because only eight forests were present in the testing fields, this accounted for a 12.5 percent error. The discrimination of corn and forest was the subject of previous analyses using 3 August and 28 September, 1978 SAR data (Brisco and Protz, 1980a). A larger area, containing more forests and corn fields, was used in this study. The results also demonstrated that the texture exhibited by forests on X-band, in combination with the tone of forests and corn fields on L-band, allows one to distinguish these two cover types.

Fields of grain and "other" cover types were confused with each other quite often, as the crop confusion table indicates. In the presentation of classification accuracies in Table 2, when a grain field is classified as "other," it is considered to be both an error of omission for the grain fields and of commission for the "other" fields. Thus the classification accuracy presented for these two cover types (51.2 percent for grain and 65.5 percent for "other") is lower than what they contribute to the computation of overall accuracy, which considers a misclassification as one error. This considerable confusion between these two cover types was also reported by Brisco and Protz (1980b, 1982) with SAR data from the same test site, collected by the ERIM System in August and September, 1978. Although a bright tone appearing on the June 1980 X-HV channel helps to identify "other" fields as a result of their volume scattering, and a periodic texture helps to identify grain fields due to their row structure, these trends are not consistent enough for highly accurate discrimination to be made between these two cover types. This is due to the large variability in moisture conditions, surface roughness, and growth stage (i.e., harvest dates) that occurs between the hay and grain fields in the study area. Row-direction changes in the grain fields can also lead to a variety of tonal values for this cover type (Batlivala and Ulaby, 1976; Ulaby and Bare, 1978).

The overall correct classification accuracy of 83 percent is 10 percentage points higher than the accuracy achieved with similar SAR data collected on 3 August and 28 September 1978 (Brisco and Protz, 1982). Although part of this improvement is related to the grouping of hay, pasture, and roughland cover types into the "other" category, some of the increased classification accuracy is due to the time of data collection. For example, on 20 June many of the fields in the "other" category had vegetation that was considerably taller than the grain plants, which were just beginning their vegetative growth stage. This resulted in the previously described bright return at X-HV of the "other" category, due to volume scattering. Similarly, the harvested wheat fields on the 3 September image acquisition date often exhibited a periodic textural pattern, which also aids in the discrimination between grain and "other" fields.

TABLE 2. CROP CONFUSION TABLE FOR MULTIDATE MULTICHANNEL GUELPH SAR DATA ANALYSIS

	% Classified			
Class	Corn	Woods	Grain	Other
Corn	91.7	2.1	2.0	4.2
Woods	12.5	87.5	0	0
Grain	2.4	41.5	51.2	4.9
Other	3.3	0	31.2	65.5

Overall accuracy = 83% $\left(\frac{112}{135}\right)$

The results of the crop classification analyses of the 1978 SAR imagery reported by Brisco and Protz (1982) were quite similar, for corn and forest, to those reported above for the 1980 SAR data. However, the earliest flight in 1978 was 3 August, at which time the wheat was being harvested and the hay was about to be cut or had just been cut (see Table 1). This leads to high confusion between hay and grain fields, resulting in a classification accuracy of approximately 50 percent. This problem was alleviated somewhat in the 1980 data, which acquired the first SAR overpass in June, i.e., before the first cut of hay. Further reductions in the confusion between hay and grain crops might have been possible if SAR data had been available for mid-July, i.e., before the wheat was ready to harvest.

Multidate imagery enhances crop classification and accuracy by reducing ambiguity between similar cover types (Bush and Ulaby, 1978; Shanmugam *et al.*, 1981; Ulaby et al., 1982). It has long been recognized that timing the acquisition of remote sensing data with the crop's growth stages increases classification accuracy (Goodman, 1959). The results reported above suggest that improvements in crop-classification accuracy using SAR data can be expected if data acquisition is synchronized with the crop calendar, thus maximizing the differences between the geometric and dielectric properties of the various crop types.

CONCLUSIONS

An overall classification accuracy of 83 percent was obtained using manual classification of 1980 multidate SAR imagery for corn, forests, grain, and "other" cover types. This represents an improvement of 10 percentage points when compared to the classification accuracy of similar SAR data obtained in 1978.

Forests and corn fields were classified with accuracies approaching or exceeding 90 percent. Grain fields and "other" fields were often confused, yielding accuracies of 51 and 66 percent, respectively.

The increase in crop classification accuracy was attributed to greater differences in the geometric and dielectric properties of the grain and "other" fields at the time of the SAR data collection. This substantiates the conclusion that an improvement in crop discrimination can be achieved by synchronizing the acquisition of SAR data with the stages of growth of the various crops of interest.

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