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RADAR STUDIES RELATED TO THE EARTH RESOURCES PROGRAM

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CRES Technical Report 177-26

J. Holtzman

ORIGINAL CONTAINS
COLOR ILLUSTRATIONS

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REMOTE SENSING LABORATORY

INTERIM TECHNICAL PROGRESS REPORT

RADAR STUDIES RELATED TO THE EARTH RESOURCES PROGRAM

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Interim Technical Progress Report

RADAR STUDIES RELATED TO THE EARTH RESOURCES PROGRAM

I. INTRODUCTION

Radar systems research at Kansas is directed toward achieving successful application of radar to remote sensing problems in various disciplines, such as geology, hydrology, agriculture, geography, forestry and oceanography. Such goals require understanding (1) the performance of radar systems for the various applications in terms of pertinent system and target parameters, and (2) the means for extracting information from the radar image. This involves analysis of abilities of existing radars for the different applications, and development of specifications for future radar systems and their information extraction systems.

With these ideas as a guide, our radar system efforts have included:

1. Support for modification of NASA imaging radar, related system analysis and evaluation of resulting imagery.
2. Study of digital processing for synthetic aperture system.
3. Digital simulation of synthetic aperture system.
4. Averaging techniques studies.
5. Ultrasonic modeling of panchromatic system.
6. Panchromatic radar/radar spectrometer development.
7. Measuring octave-bandwidth response of selected targets.
8. Recommendations for future systems including a 1975 spacecraft system.
9. 13.3 GHz scatterometer system analysis including data processing recommendations.
10. Technical support of sea state, sea ice and agricultural missions and analysis of the resulting scatterometry and imagery data.
11. Construction and testing of a model Fresnel-zone processor for synthetic aperture imagery.
12. Consultation with other disciplines conducting remote sensing and radar-related studies.

The following sections summarize the progress accomplished. The subsections have been numbered with reference to the Radar System Tasks of Technical and Cost Proposal BG 921-36-0-15 P, dated August 1969. Reference should also be made to Technical Report 177-13, the Interim Progress Report, and the specific reports indicated. Section 2.2.1.9 provides a good overall summary and is indicative of the interrelationships between the various subtasks. Three of the subsections are more substantive than the others since the detailed reports will be published at a later date.

II. TASK PERFORMANCE

IMAGING RADAR SYSTEMS

2.2.1.1 Testing of SLAR Performance

2.2.1.2 SLAR Procedures Guide

2.2.1.3 a, b Imaging Radar Modifications and Processing

The University of Kansas has provided technical support for NASA's Philco-Ford DPD-2 SLAR, including recommendations for modification to its present form. As presently configured this instrument is capable of producing useful imagery. The degree of the usefulness of the imagery is limited by as-yet-uncorrected system deficiencies which include recording film transport speed errors, inoperative STC circuitry, gross sensitivity difference between the like and cross polarization images and the occurrence of intermittent system malfunctions. Successive missions have shown a general improvement in the quality of the resulting imagery, with a failure in the synthetic aperture channel on Mission 168, a major exception. Imagery from DPD-2 has been used when possible, as has been reported on elsewhere. The original recommendation to acquire the DPD-2 was based primarily upon its performance in flight tests for the Army and the fact that it was the only synthetic-aperture radar unclassified at that time. Of the several modifications to the basic instrument, the dual-polarized antenna and the abandonment of quadrature detection have tended to degrade performance. One additional modification proposed by K.U. has now been incorporated; the instrument can now be operated in both the synthetic- and real-aperture modes. A review of the basic system operation, including modifications, is contained in CRES Technical Memorandum 177-18.

A brief study has been performed as to the effect of quadrature versus non-quadrature detection. The calculations and simulation on a digital processor program demonstrate the loss of imagery quality with non-quadrature detection. It remains to be seen whether the value of the additional polarizations added in lieu of the quadrature channel outweighs the loss incurred from the increased "speckle" in the radar return.

2.2.1.3 c Digital Processing Techniques

Digital processing for synthetic aperture imagers has been a major area of study. This research has culminated in a dissertation by R. Gerchberg and a report TR 177-10. The digital processor has been simulated on the University's computer with various imager-processor configurations. A great deal of flexibility is built into the program to permit simulation with varying antenna patterns, transfer functions, etc.

One of the most important aspects of this research was the inclusion of subaperture processing. In lieu of full-focussed processing of the entire synthetic aperture, subapertures could be processed more or less in parallel and then superimposed, thus reducing the storage requirements and permitting averaging several independent samples to improve the image appearance. This improvement in gray scale is traded for resolution. A digital processor system was postulated which appears feasible for the 1975 time period if advances in the state-of-the-art in storage technology proceed as expected.

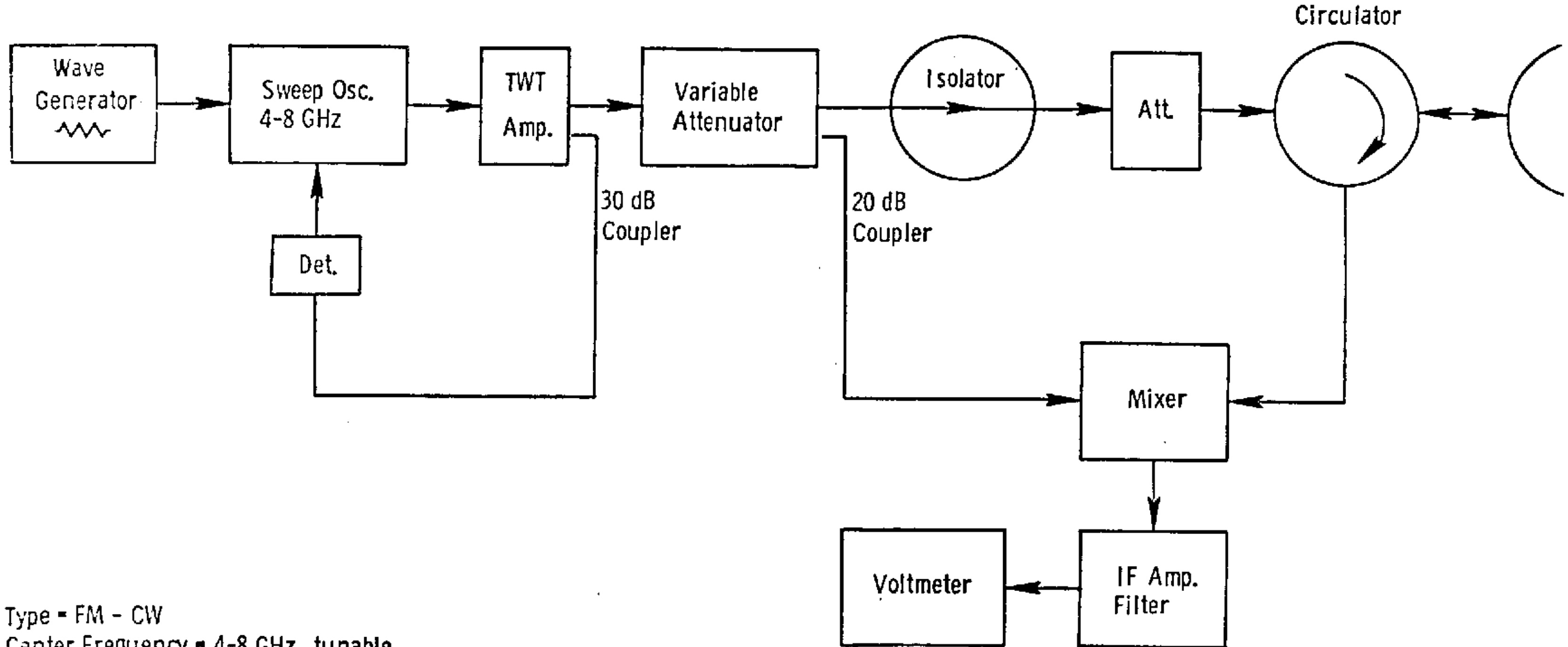
The simulated processor has been used as a basic research tool and the program has been repackaged for use on the PDP-15/20 computer at K.U. The simulated processor was used in the non-quadrature studies cited above for evaluating imaging radar performance with respect to specific target types.

2.2.1.5 Define Available Imagers

2.2.1.6 Performance Specifications for Aircraft Polypanchromatic/Polypanchromatic Radar

Due to the very nature of its efforts, the radar system group has kept abreast of the imaging radar art. This effort includes a continuing literature survey, attendance at appropriate meeting and symposia and informal contact with universities and industry.

Performance specifications have been written and described in several technical memoranda, reports and NASA presentations. Technical Report 177-18 summarizes specifications for one candidate multispectral radar. Most of the effort has been concentrated on satellite systems (see 2.2.1.9).



Type = FM - CW
Center Frequency = 4-8 GHz, tunable.
Modulation Bandwidth = 400 MHz
IF Frequency = 37 KHz
Antenna = 3' diameter dish

Figure 1. BLOCK DIAGRAM OF RADAR SYSTEM

2.2.1.7 Acoustic Modeling of Panchromatic/Polypanchromatic Radars (Partially funded by Project THEMIS—Contract DAAK02-C-0089)

This task was completed during the first year of the contract period and is reviewed in Interim Report TR 177-13. TR 177-11 is the definitive report on this task. It describes the theory of panchromatic illumination and the acoustic (ultrasonic) simulation of panchromatic imaging. Variance reduction resulting from panchromatic averaging and the improvement in image appearance was clearly demonstrated.

2.2.1.8 Panchromatic Radar System (Partially funded by Project THEMIS—Contract DAAK02-68-C-0089)

2.2.1.8a System Description

The earlier theoretical and experimental work on polypanchromatic illumination has clearly demonstrated the advantages of panchromatic averaging (c.f. TR 177-11). Initial results with a pulsed polypanchromatic system verified acoustic tank simulations. After verification of the value of panchromatic illumination was complete, a decision was made to concentrate use of the system on cataloging microwave signatures of targets of interest in environmental monitoring.

Difficulties in use of the pulse system at ranges under 20 m led to modifying the broad-band spectrometer by use of frequency modulation instead of pulse modulation. The FM system can operate at shorter ranges, and components are more suitable for frequency-range expansion. Figure 1 shows a simplified block diagram of the radar.

During the 1971 growing season, initial measurements were made of the signatures of crops. Problems with the absolute calibration and modulation techniques have necessitated a refurbishment of the system.

Analysis of the 1971 data caused us to doubt the validity of the corrections originally made on the basis of a single set of measurements of a calibration sphere. Consistent variations that appeared in all the data led to the conclusion that the corrections due to the sphere measurements were uniformly too large at some frequencies. Consequently, the data have been reprocessed into a relative format based on averages of the field observations rather than on the calibration sphere.

A thorough analysis of the observations and many additional component calibrations have led to a modification of the original system using some new components and incorporating additional internal calibration possibilities. Laboratory tests indicate that the new configuration is more satisfactory, and more accurate results are anticipated using it during the forthcoming 1972 growing season. Furthermore, a new boom truck has been obtained that will permit greater ease of operation, more stability for the antenna, and a larger minimum range.

The system originally known as the ground-based polypanchromatic radar has now been rechristened a ground-based radar spectrometer, since the imaging capability of the original pulse system is no longer included. A passive measurement capability is presently being added, so that the system will become a combined radar spectrometer—microwave spectroradiometer. This system will be described in a subsequent report.

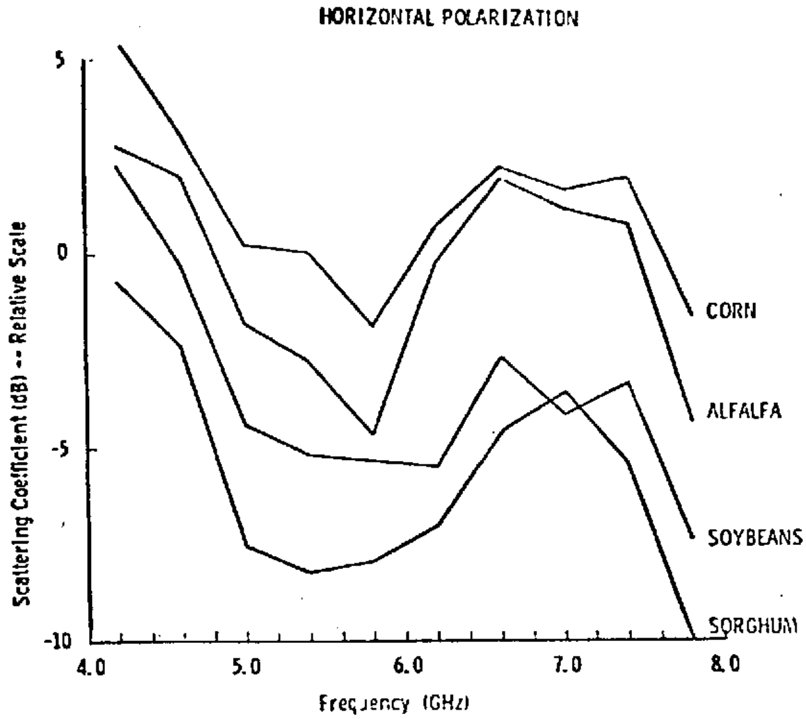
Measurements with the new system will again be made first in the 4-8 GHz spectrum, but the frequency range will be extended to 12.4 GHz shortly. The 4-8 GHz range was selected for initial use because it is the highest frequency range for which full-octave components are generally available.

2.2.1.8b 1971 Data Measurement Program

Octave-bandwidth (4-8 GHz) radar spectrometer measurements were obtained during a 2-week period in July 1971 in an attempt to associate signature definitions to agricultural crops. The spectral response data was concentrated on agricultural targets covering 71 fields with 4 crop types: corn, sorghum, soy beans, and alfalfa; and plowed ground. The experiment consisted of measuring the spectral responses of the agricultural crops across the 4-8 GHz frequency band at look angles of 0°, 10°, 20°, 30°, 50°, and 70° for both horizontal and vertical polarizations.

Using a continuously tunable sweep oscillator, radar backscatter measurements were recorded at 10 frequency points over the 4-8 GHz frequency range (4.2, 4.6, 5.0, 5.4, 5.8, 6.2, 6.6, 7.0, 7.4 and 7.8 GHz). Each measurement point was an average over a 400 MHz bandwidth. For each agricultural field considered, this procedure was followed for both polarizations (vertical and horizontal) and at each of the 6 look angles. Though the collected data included spectral measurements at 0° look angle, those measurements may be in error due to the proximity of the truck. Hence, the 0° look angle set of data was deleted.

Measurements were conducted over 28 fields of corn, 7 fields of sorghum, 18 fields of soy beans, 14 fields of alfalfa and 4 fields of plowed ground. The data was then averaged and plotted as shown in Figures 2 through 6 . The scattering coefficient is expressed in relative and not absolute scale. The plowed ground category was deleted since only four fields were covered. Variations in system performance over the frequency range were indicated by the sphere measurements, but are <u>not</u> taken into account in these illustrations. The presence of consistent variations is, however, apparent in the data.



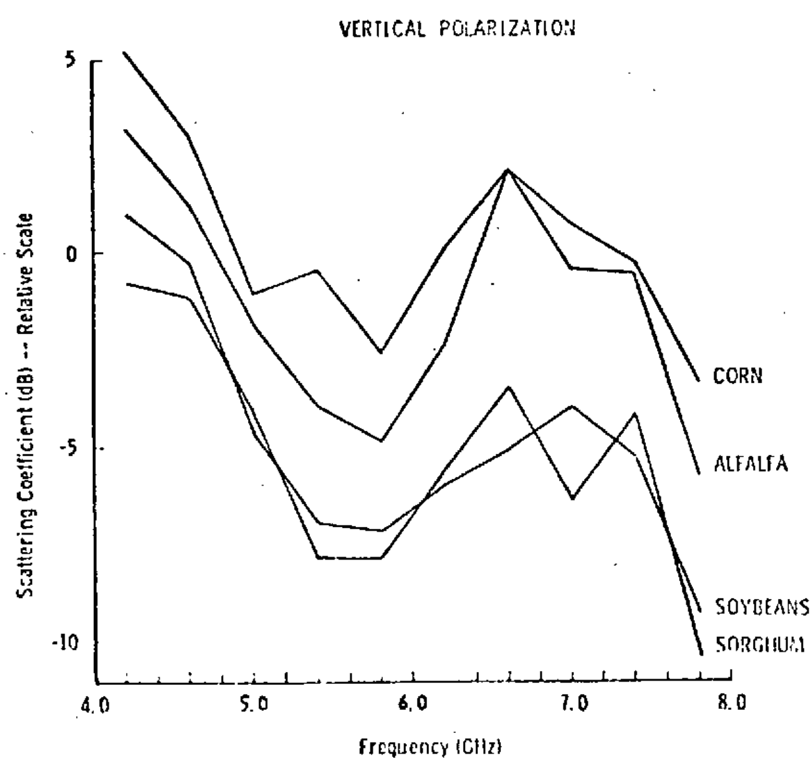
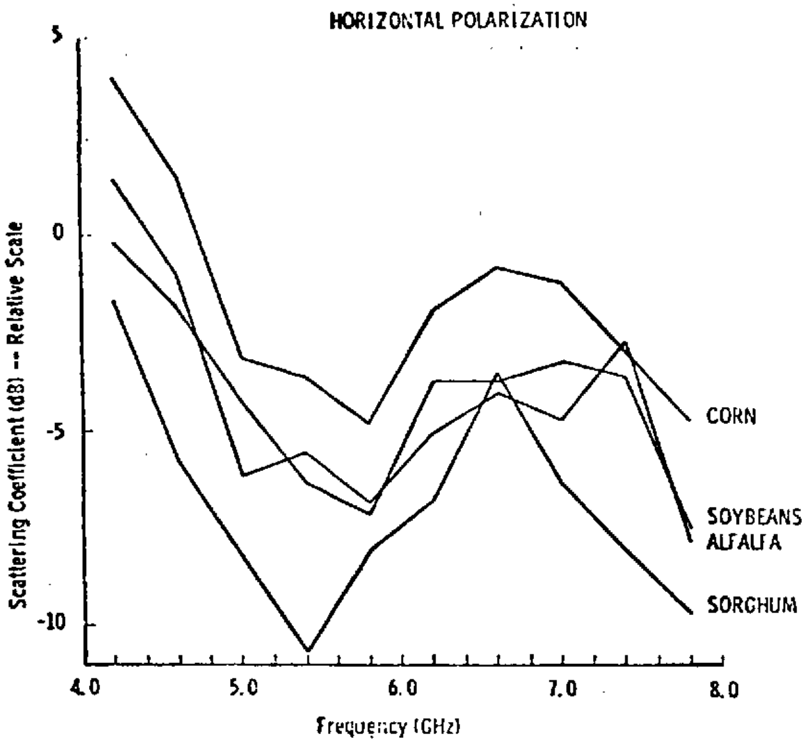


FIGURE 2. RAW BROAD BAND SPECTRAL DATA AT 10° LOOK ANGLE.



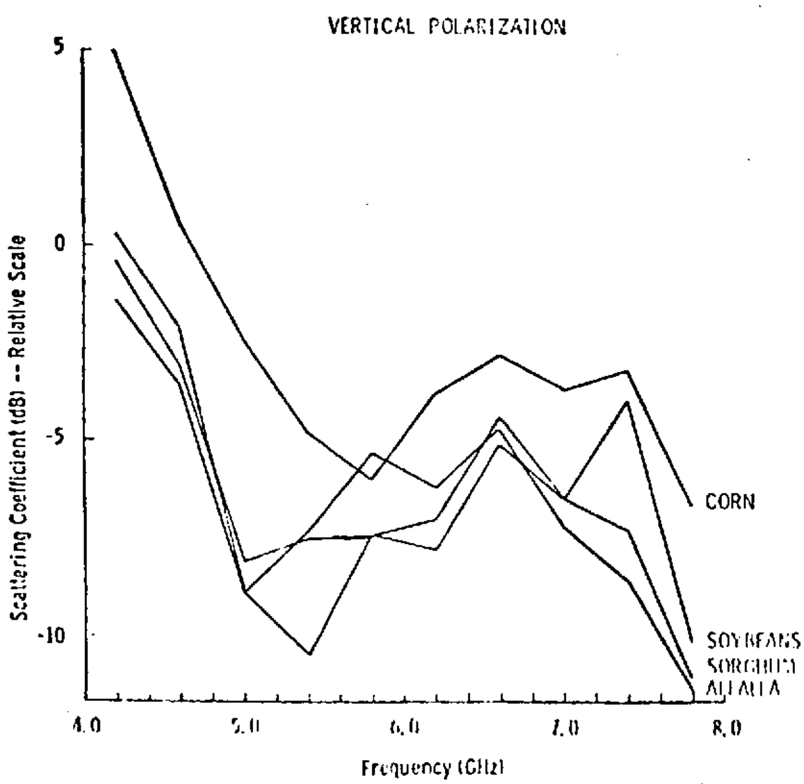
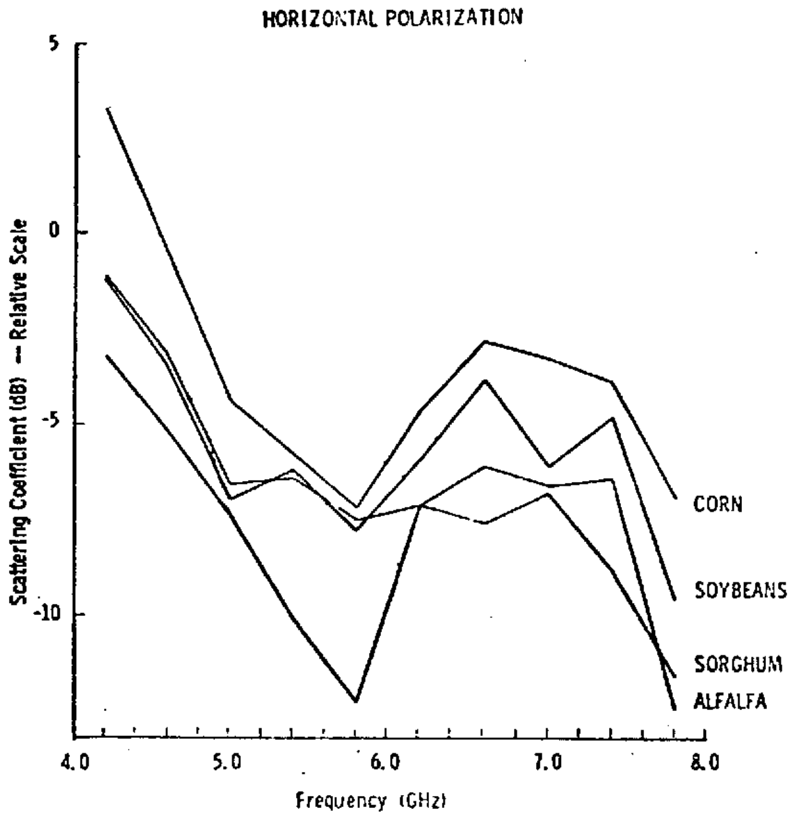


FIGURE 3. RAW BROAD BAND SPECTRAL DATA AT 20° LOOK ANGLE.



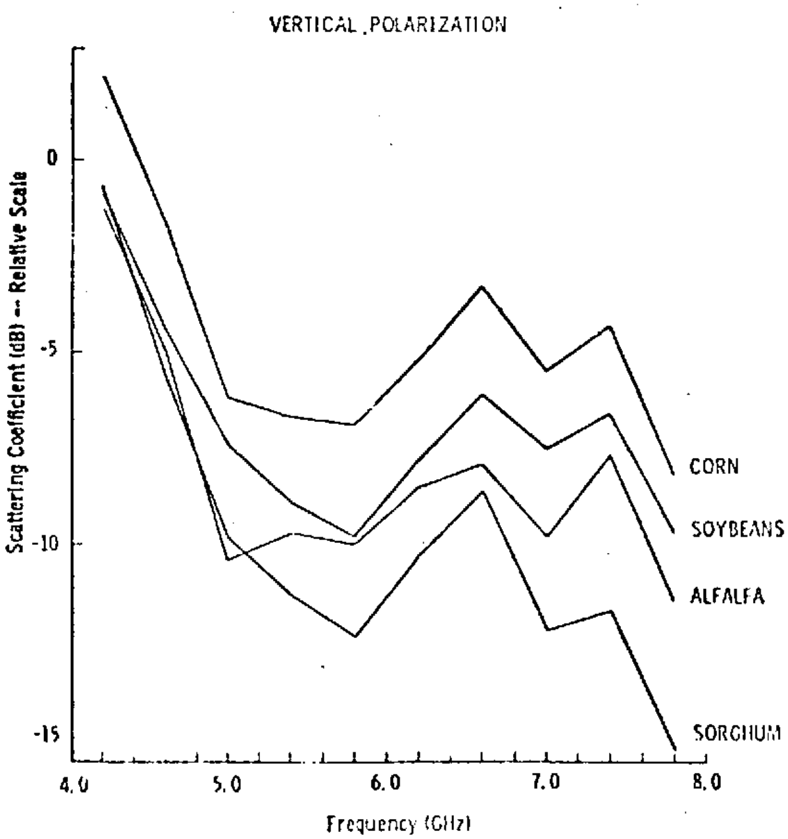
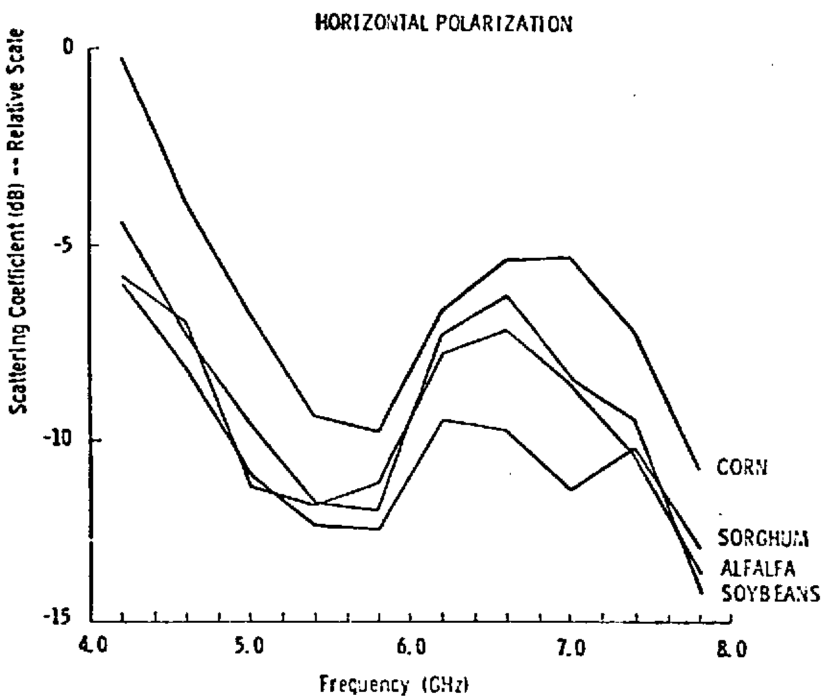


FIGURE 4. RAW BROAD BAND SPECTRAL DATA AT 30° LOOK ANGLE.



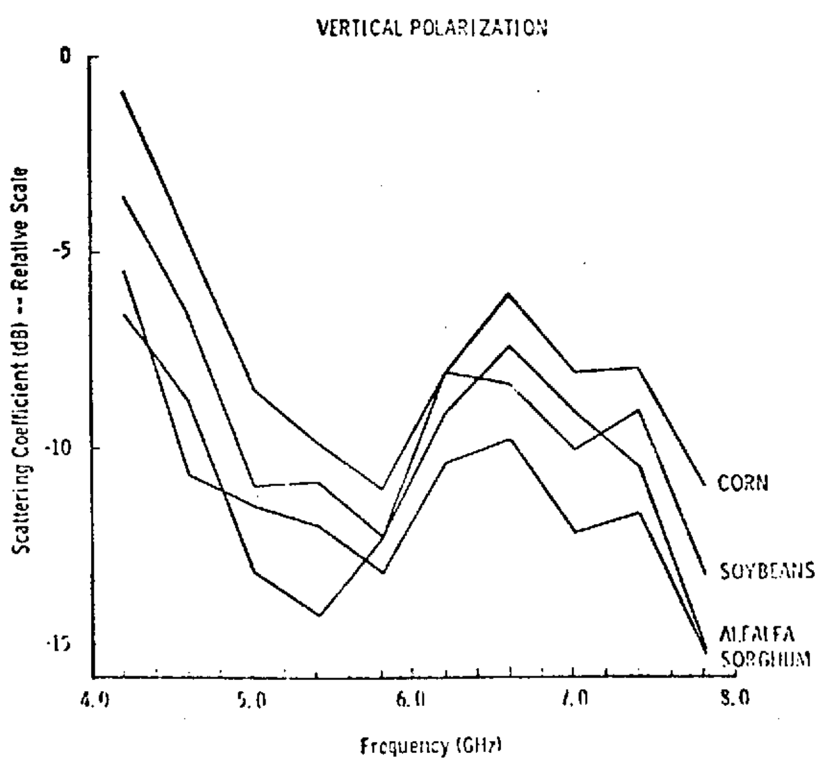
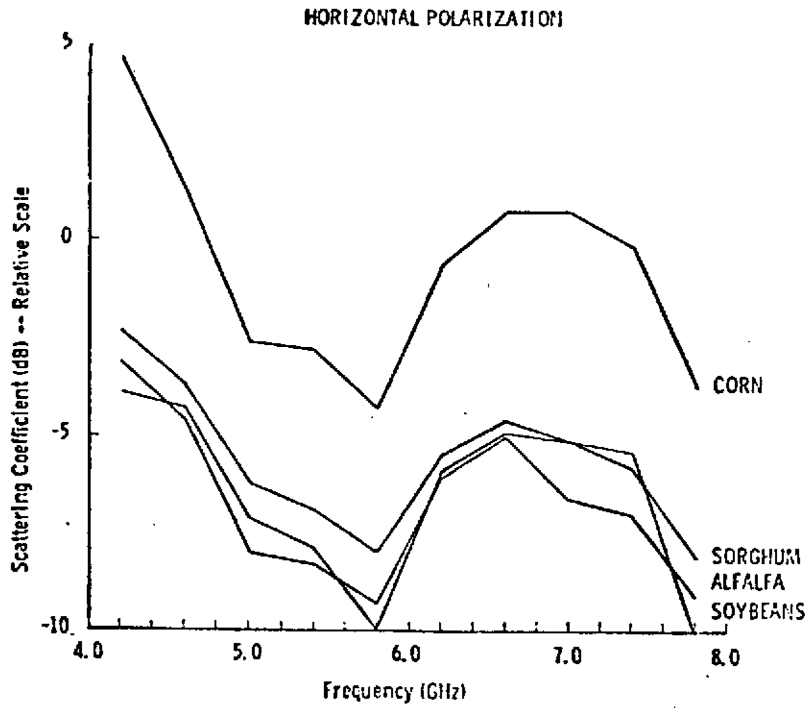


FIGURE 5. RAW BROAD BAND SPECTRAL DATA AT 50° LOOK ANGLE.



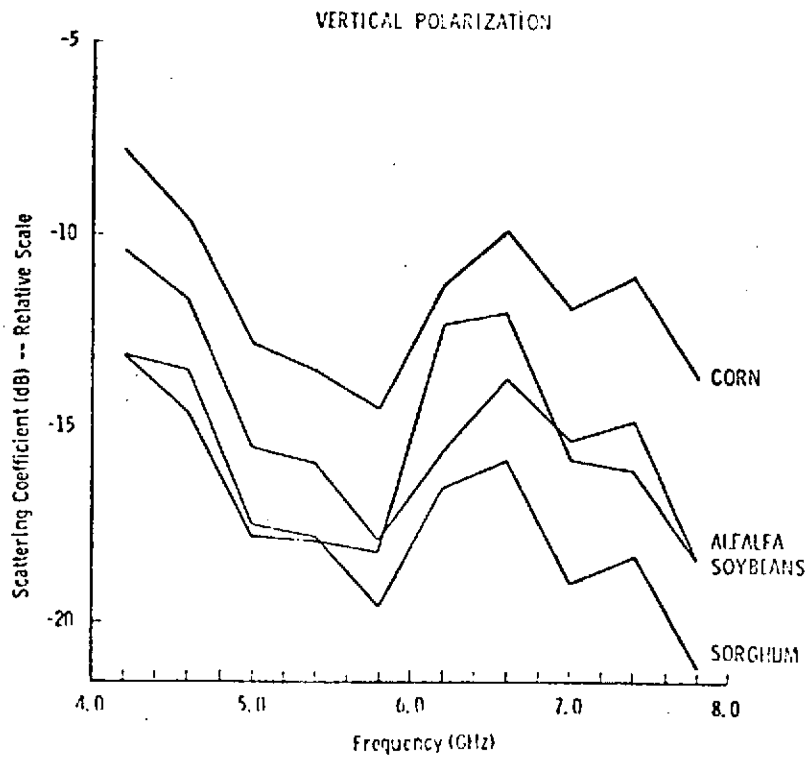


FIGURE 6. RAW BROAD BAND SPECTRAL DATA AT 70° LOOK ANGLE.

Because of the system variations with frequency, and lack of confidence in the sphere measurement, a normalization technique was required. Two methods were were used: the spectral data for the four crops may be plotted using one of the crops as a standard; or for each frequency, look angle, and polarization, the four data points corresponding to the four crops may be normalized with respect to their sum. Both techniques tend to eliminate system variations with frequency.

Using corn as a standard, the spectral response curves at 10°, 30°, 50° and 70° look angles are shown in Figures 7 through 10.

The concept of broad-band microwave imaging (polypanchromatic) radar developed from the visual analog. To illustrate the value of this approach, the observations were combined to produce visual displays of the "microwave color." For each crop, polarization and look angle, the 4-8 GHz data was divided into three sub-bands: Red Band = 4-5.2 GHz, Green Band = 5.2-6.8 GHz, and Blue Band = 6.8-8 GHz. The averaged return for each crop over each of the sub-bands was normalized to the sum of the return from the four crops (to eliminate system variations with frequency as discussed earlier) and then used to set the intensity level of the corresponding light beam of a three-beam color combiner. The color signatures of the four crop types were then grouped by look angle and polarization. Examples are shown in Figure 11 corresponding to look angles of 10°, 30°, 50°, and 70°. Though the results indicate that the four crop types can be easily discriminated using any one of the four sets (both horizontal and vertical), the 50° look angle set appears optimum.

Possible effects due to plant or soil moisture were ignored above; the study was concentrated on crop types rather than differences within a particular crop. In conjunction with the radar spectrometer measurements, ground truth data were collected including soil and plant samples. The moisture contents, by weight and by volume, were determined for both the soil and the plant samples in the laboratory. The next phase of the analysis will concentrate on variations of the radar return as a function of look angle and moisture content.

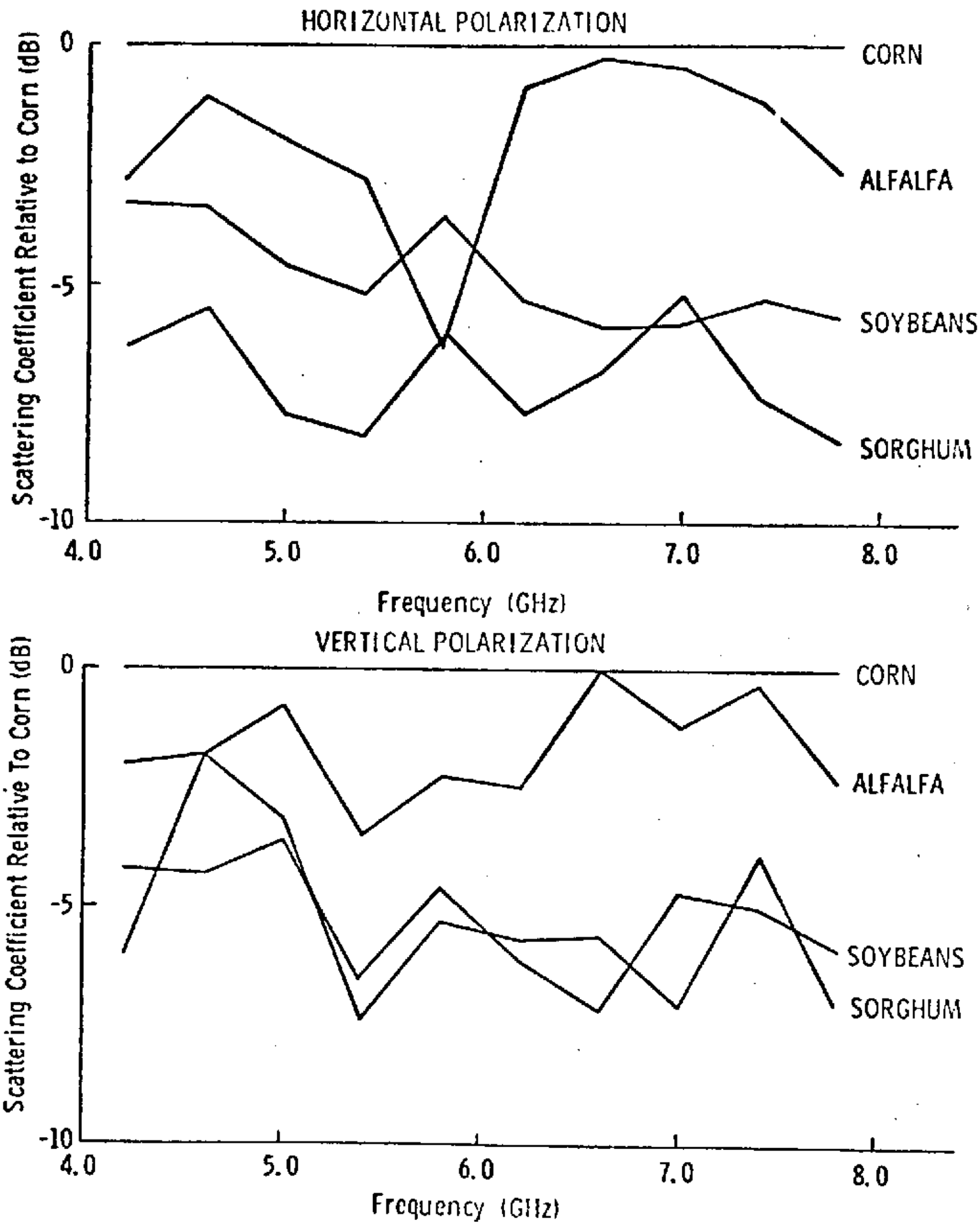


Figure 7. Broad Band Spectral Data at 10° Look Angle.

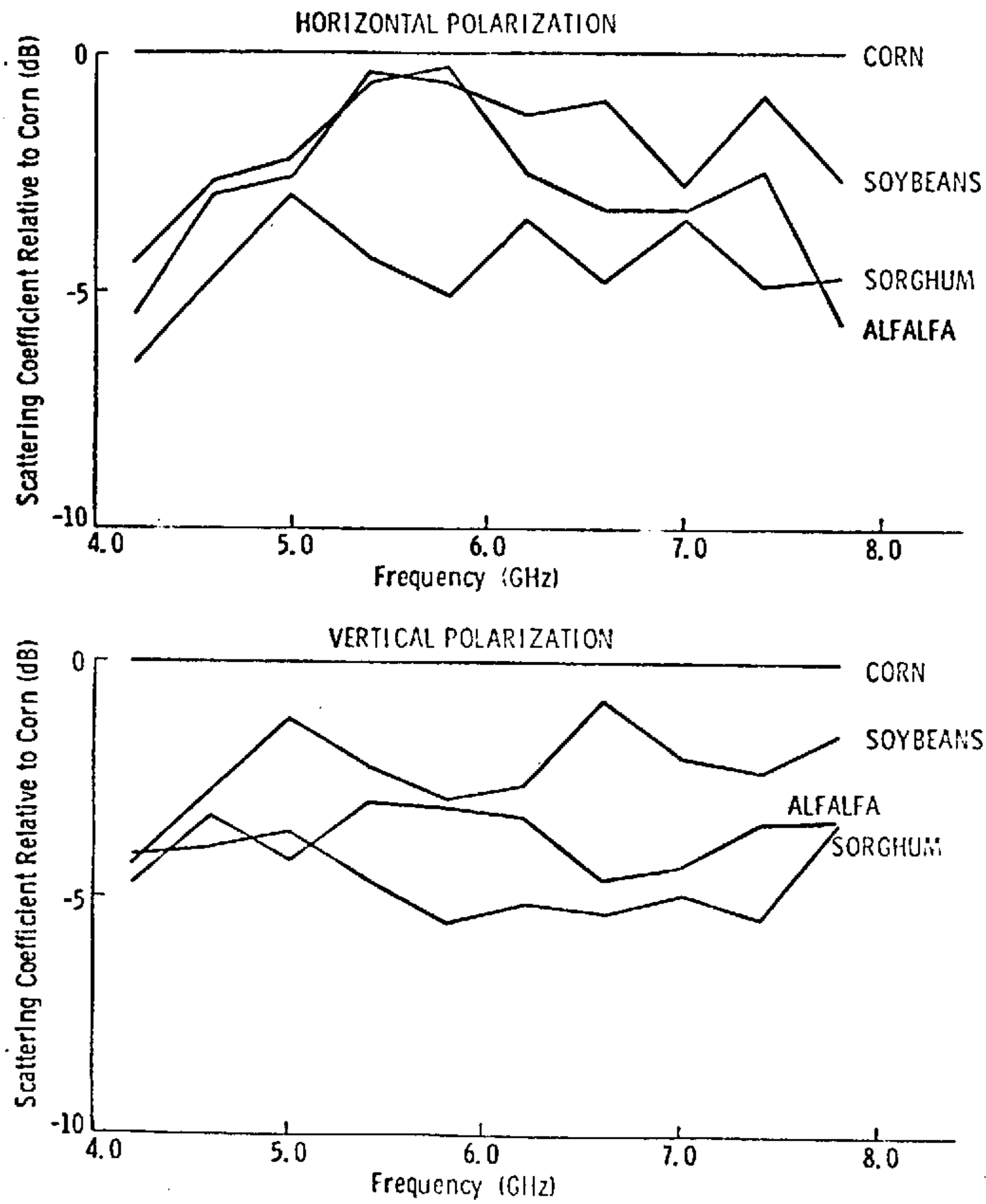


FIGURE 8. RAW BROAD BAND SPECTRAL DATA AT 30° LOOK ANGLE.

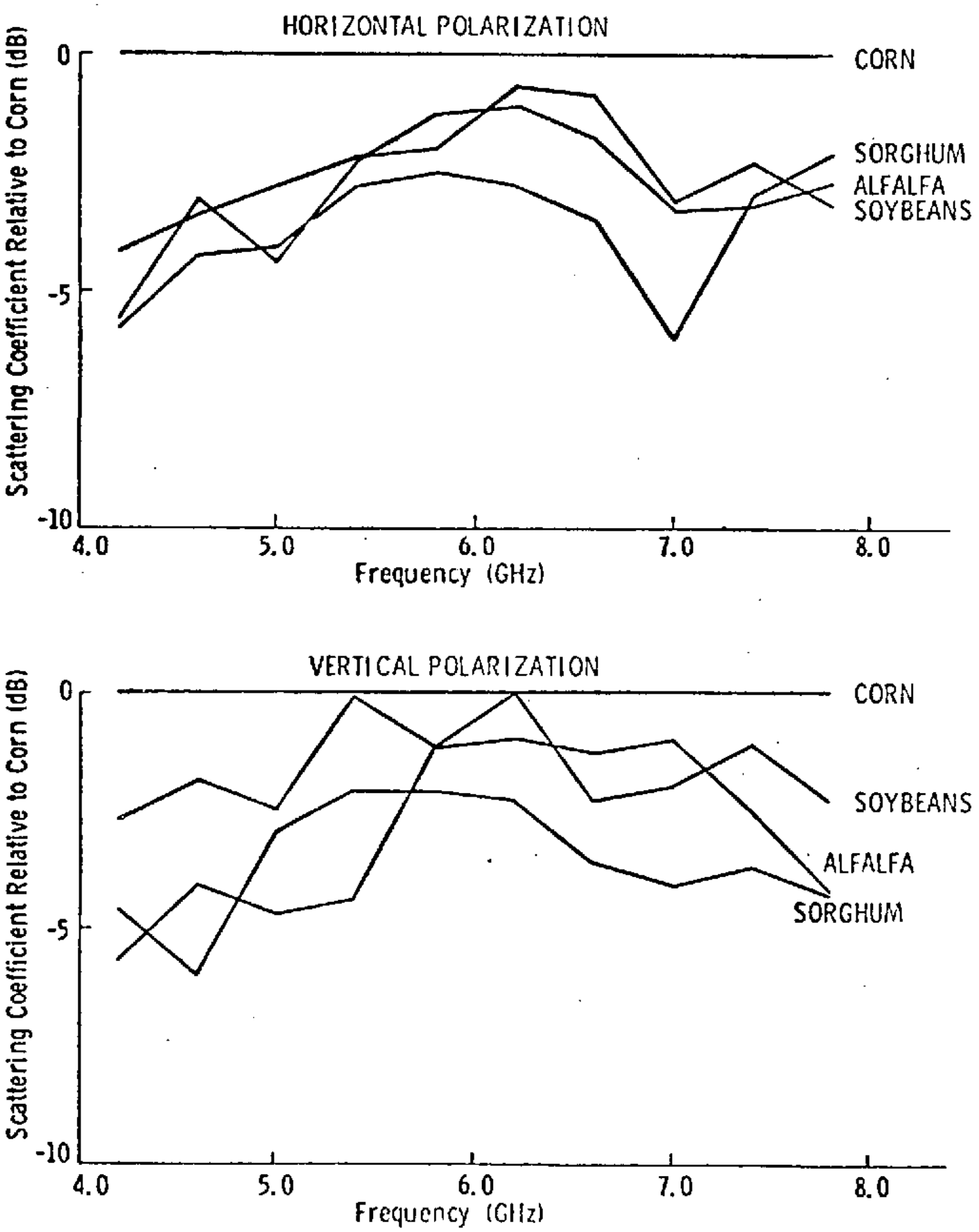


FIGURE 9. RAW BROAD BAND SPECTRAL DATA AT 50° LOOK ANGLE.

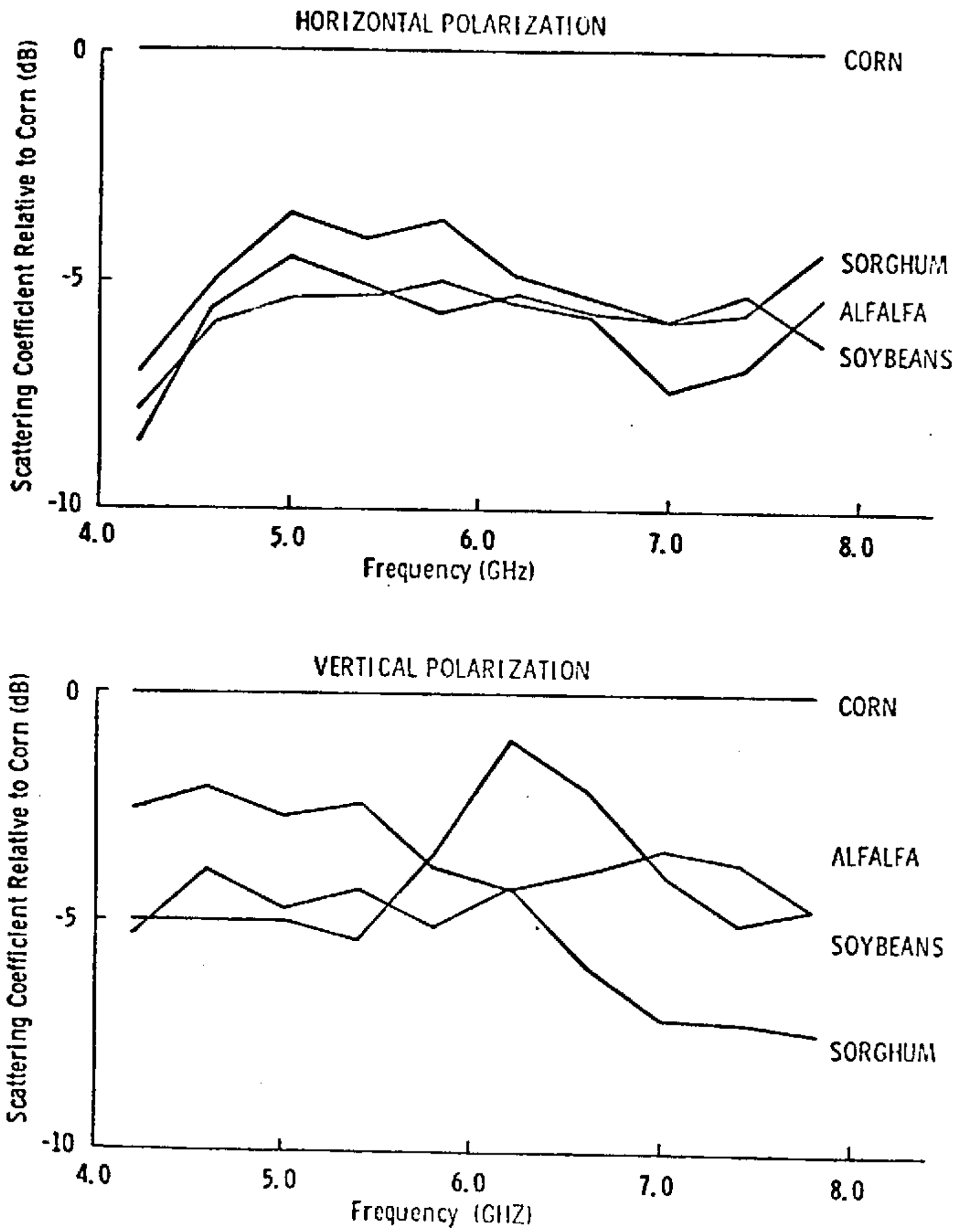


Figure 10. Broad Band Spectral Data at 70° Look Angle.


H
CORN
SORGHUM
SOYBEANS
ALFALFA
V
CORN
SORGHUM
SOYBEANS
ALFALFA
COLOR COMBINED NORMALIZED ONE-THIRD OCTAVE AVERAGES 10°
H
CORN
SORGHUM
SOYBEANS
ALFALFA
V
CORN
SORGHUM
SOYBEANS
ALFALFA
COLOR COMBINED NORMALIZED ONE-THIRD OCTAVE AVERAGES 30°
H
CORN
SORGHUM
SOYBEANS
ALFALFA
V
CORN
SORGHUM
SOYBEANS
ALFALFA
COLOR COMBINED NORMALIZED ONE-THIRD OCTAVE AVERAGES 50°
H
CORN
SORGHUM
SOYBEANS
ALFALFA
V
CORN
SORGHUM
SOYBEANS
ALFALFA
COLOR COMBINED NORMALIZED ONE-THIRD OCTAVE AVERAGES 70°

Figure 11.

2.2.1.9 1975 Space System

Specification of remote sensing imaging radar systems is complicated by economic, vehicle, and state-of-the-art considerations. The desirability of multi-polarization polypanchromatic systems has been well documented at this point in time. General recommendations for geoscience radar systems are contained in report TR 177-18. The following two figures show representative systems which might be flown on satellites. These figures are not to be considered as final specifications; they could be modified in many ways depending upon the constraints associated with the satellites.

Figure 12 shows the specifications for a radar for a small satellite capable of supplying 450 watts of primary power. With this much power the system could have a resolution as fine as 10 m with a swathwidth of 40 km. To achieve this large swath-width, however, requires erecting an antenna on the small satellite with a length of the order of 6 to 10 m. Note that, if the radar is only used 20% of the time, the average power over an orbit is only 90 watts. The system selected was to operate out to an incidence angle of 60° for geologic purposes. A 30° incident angle appears quite adequate for agricultural purposes and many geologic purposes. With such an incident angle, the power requirement could be reduced to 275 watts, which means that the average over an orbit is only 55 watts.

Such a system would, we assume, transmit raw video data to the ground via a wideband telemetry link. Processing would then take place on the ground. The power for the telemetry link is not included in the figure. Of course, a system with a poorer resolution could get by with significantly less power for both radar and telemetry.

Figure 13 shows a possible system for a large satellite such as a shuttle. Here a polypanchromatic system is postulated with a listing of first the power required with no averaging, then that with 200 MHz, and then with 400 MHz averaging. The 200 MHz averaging gives about 10 independent samples per cell due to pan-chromatic illumination, and the 400 MHz gives about 20 per cell. Note that this 4-frequency system requires a total of 975 watts without averaging, but with 10 independent samples per cell the power requirement goes up by a factor of about 10. The frequencies were chosen somewhat arbitrarily because we still do not have adequate data over a wide frequency range. However, 16 GHz appears about the highest reasonable frequency for a spacecraft imaging system both from the standpoint of available components and of atmospheric effects. The 10 GHz band is quite common and many data have been gathered at this frequency that indicate the value of radar.

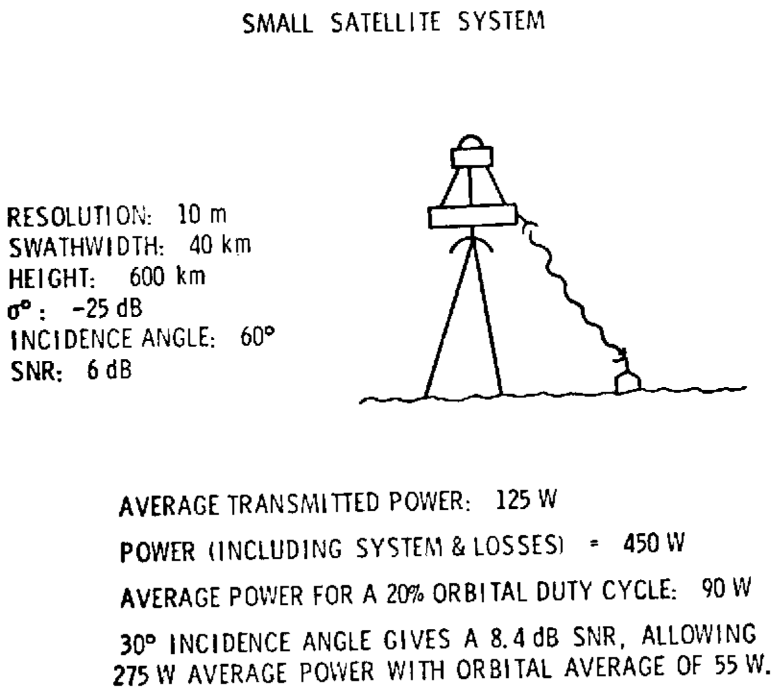


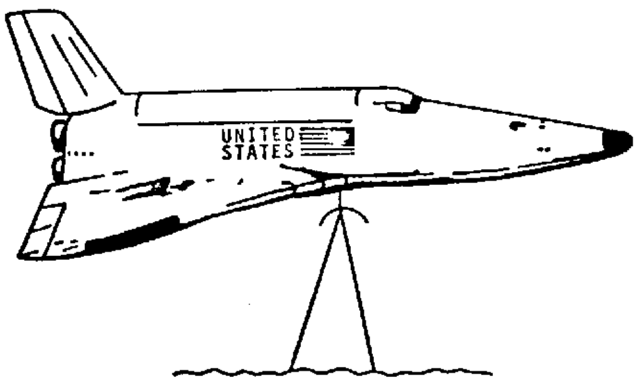
Figure 12. Representative design for SLAR for small satellite. Poorer range resolution would allow lower power.

Our recent observations over the octave bandwidth 4-8 GHz indicate the value of radar "color" in that band. All of these frequencies are near to frequencies that may be available for allocation to spacecraft imaging radar systems.

As our analysis of the data gathered both with the imaging radars and the radar spectrometer and scatterometers continues, we hope to be able to refine these specifications. Nevertheless, we believe if a radar system were to be constructed for spacecraft use immediately, these specifications should serve as a reasonable guide.

System analysis efforts have also been concerned with specifying the relationship between the radar signal and the film optical density in terms of the radar and film system parameters. Both visual interpretation of radar imagery and analysis

LARGE SATELLITE SYSTEM



RESOLUTION: 10 m
SWATHWIDTH: 40 km
HEIGHT: 300 km
$\sigma°$: −25 dB
INCIDENCE ANGLE: 60°
SNR: 6 dB

FREQUENCY (GHz)	AVERAGE RADIATED POWER (W)		TRANSMITTER POWER (W)	POWER REQUIRED FOR WIDE-BAND AVERAGING (W) 200 MHz	400 MHz	SYSTEM POWER (W)
4	26		76	1020	2220	240
8	52		157	1870	3880	↓
10	64		192	2500	5200	
16	102		303	3980	8300	
		Σ	735	9350	19400	
POWER REQUIRED →			975	9590	19640	

Figure 13. Representative polychromatic/polypanchromatic radar system for large space craft.

using densitometric data extracted from radar imagery are influenced by the photographic parameters of the recording process.

Included in the study was the development of a relation for correcting antenna pattern error effects in radar imagery. The success of such corrections is dependent on sufficient knowledge of the system and an adequate dynamic range. The pertinent relations are discussed in Technical Memorandum 177-21.

2.2.2.3 Test Synthetic Aperture Averaging

Delayed, to present Contract year. Preliminary report made in Technical Report 177-7.

2.2.2.4 Fresnel-Zone Plate Processor Test

In certain applications and under certain constraints imposed by spacecraft or telemetary limitations, on-board and/or near real-time processing of synthetic aperture radar data is required. One form of electronic processing was described in Section 2.2.1.3c.

Another technique for such processing of synthetic aperture radar data is the Fresnel zone plate processor. This processor is an analog/digital device which is capable of processing synthetic aperture data to a resolution intermediate between full-focussed synthetic and real apertures. It is less complex than is an electronic version of the full-focussed processor that is now usually implemented optically.

During the period of this contract, the electronic model of the Fresnel zone-plate processor was tested and found to provide a resolution close to that predicted by theory. A description of the processor, test procedure and results are contained in Technical Report 177-17.

It should be noted that the test model built at K.U. is designed to process the azimuth signal for one range bin only, and its implementation in a system is somewhat dependent on the electronic state of the art. Merits of Fresnel zone-plate processing were also investigated using the digital simulation.

2.2.2.1 Pattern Recognition Algorithms

The University of Kansas has taken a two-fold approach to the data processing of remotely sensed imagery. Our approach has been based upon the need to have a special purpose hardware facility for the near-real time processing of multi-image data and the need to have a general purpose digital computer facility for the more sophisticated non-real time processing. Our near-real time facility is called IDECS (Image Discrimination Enhancement Combination System) and our non-real time facility is called KANDIDATS (Kansas Digital Image Data System). These facilities have been funded from both NASA and DOD sources. In this section we discuss KANDIDATS.

A Software System for Digital Image Processing: KANDIDATS

KANDIDATS (Kansas Digital Image Data System), currently being developed, is a software package consisting of a monitor and a set of multi-image processing programs designed to run on a GE-635 computer. The multi-image processing programs are all written in FORTRAN IV and allow for image editing, registering, congruencing, quantizing, clustering, feature extraction, image size and/or dimensionality reduction, image texture analysis, and image pattern recognition. It has a variety of decision rules, data display capability with scatterograms and histograms, grey-tone image display with overprinting or digital image color map display. The KANDIDATS monitor is a GMAP assembly language program designed to integrate the multi-image processing programs by handling all bookkeeping type and I/O operations and to minimize the cost of processing image data by speeding up I/O time and overlapping I/O time with execute time. Figure 14 illustrates a block diagram of the basic KANDIDATS organization.

The KANDIDATS monitor inputs in free-format all instructions required by the image processing program, supervises the execution of the programs, provides error processing, and dynamic storage allocation and tape input and output for the programs. The monitor has been written so that during a single activity of KANDIDATS many processing programs may be sequentially executed using many different data sets. The monitor does this by treating each program as a separate task and by allocating and releasing data tapes as necessary.

BASIC KANDIDATS ORGANIZATION

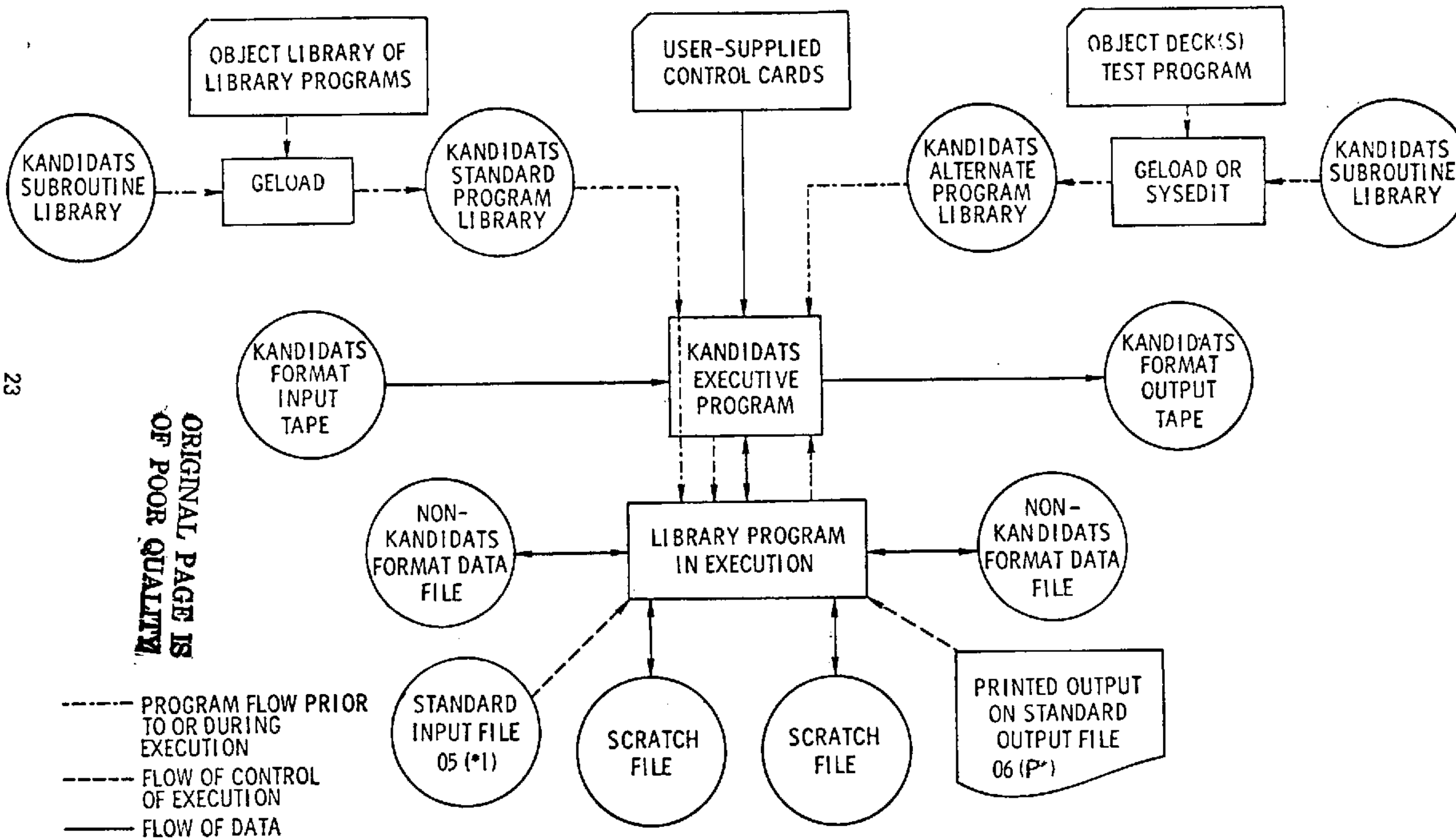


Figure 14.

Once remotely sensed data is converted to digital type format, it is necessary to check the digitized tape to see if the conversion was made successfully. Preliminary checking can be done by dumping the first few records on the tape; however, this is by no means a complete check. The KANDIDATS image display program can make a complete check by outputting the tape in picture format on the digital printer creating the grey-tones by overprinting. If the image has so many resolution cells as to make the digital picture printing awkward, a program may be utilized which reduces the image size by averaging blocks of N x N resolutions or by selecting every N^{th} column.

Examination of this picture output will indicate what kind of editing will have to be done on the sides and top and bottom of the image, as well as indicate skewing and A/D conversion distortion. (Skewing can occur because it may be impossible to start digitizing each line of the image in exactly the same place. A/D conversion distortion can occur when jitter or noise internal or external to the A/D conversion makes the conversion go awry.) If necessary, a KANDIDATS deskewing program may have to be used to remove skew and a special smoothing-replacement program may have to be used for those resolution cells which were improperly converted.

When multi-image data is being processed, it is often necessary to align the individual images to the same place. To do this KANDIDATS employs a registering program. When different sensors or the same sensors with different look directions are involved, it may be necessary to bring the images to the same geometry. In this case a congruencing program must be used.

When the geometries on the images to be congruenced are quite different, the congruencing job may be quite hard. However, where only minor geometric distortions are involved, congruencing may be done by a KANDIDATS program which treats the image as a rubber surface and expands or contracts it to best match up a set of given corresponding points.

There are two formats by which multi-image data may be stored on tapes by KANDIDATS. In the photo format all the grey-tones from the first image are stored on a matrix followed by the grey-tones from the second image and so on. In the corresponding point format the grey-tone from image one resolution cell (1,1) is followed by the grey-tone from image two resolution cell (1,1) and so on. Editing and congruencing imagery from different sensors is usually done with data in photo form as is image display and texture analysis. Most of the other programs work most easily with the data in corresponding point format. KANDIDATS has programs which convert multi-image data from one format to the other.

After initial editing and congruencing, it is convenient to obtain an intuitive idea of what is happening in the data. To help with this, programs are available which pick out specified regions on the image and display the data points in scatterogram or histogram fashion. The scatterograms or histograms may be indexed by ground truth categories when the ground truth is available. The axes of the scatterograms may be combinations of pairs of the different sensor signals or the axes of a rotated coordinate system. Rotation can be accomplished from principal component analysis or from linear discriminant functions, and there are programs available for these operations. Either of these operations will allow a significant reduction of dimensionality and, therefore, allow a reduction in storage and display of data, especially in 12 or 24 channel multi-spectral scanner data.

Before pattern discrimination or clustering is done, a feature extraction is performed which selects the relevant variables or which combines the original variables in some optimum way. Sometimes as part of the feature extraction process quantizing is done to normalize the data as well as to reduce the memory required for storage of the data. KANDIDATS has available programs which do equal interval, equal probability, minimum variance, and spatial quantizing.

When texture is an important feature for a category of interest, the dimensionality of the images may be augmented by a texture analysis program which adds dimensions providing texture type information.

Probably, the major workhorse of image data analysis consists of pattern discrimination and clustering techniques. With pattern discrimination techniques, a training set of data is gathered for which the correct category identification of each distinct entity in the data is known. Then estimates are made of the required category conditional probability distributions and a decision rule is determined from them. The decision rule can then be employed to identify any other data set gathered under similar conditions. With clustering techniques there is no training data set or decision rule. Rather, the natural data structures are determined. Distinct structures are then interpreted as corresponding to distinct objects or environmental processes.

The advantage of the discrimination techniques is that the scientist is able to decide the types of environmental categories among which he wishes to distinguish. The decision rule then determines as best as possible, to which environmental category an arbitrary data entity belongs. The disadvantage of the discrimination techniques is that they are sensitive to mis-calibrations. Any slight difference between the sensor calibrations or state of environment for the training data and the new data will cause error.

The advantage of the clustering techniques is that they are not sensitive to calibration problems. Two small-area patches of corn growing in the same field are going to be detected as being similar because they have similar grey tone associated with them. The disadvantage of the clustering techniques is that they are not able to identify the distinct environmental structures they determine.

KANDIDATS has available iterative and chaining clustering programs and pattern discrimination programs. The pattern discrimination programs use a variety of decision rule types including a distribution-free Bayes rule which can only be used on coarsely quantized data, a Bayes decision rule assuming the category conditional probabilities are of some given type of multivariate distribution, a linear decision rule, or a nearest neighbor decision rule.

Appendix A summarizes one of the things we are doing with a special purpose KANDIDATS program for preprocessing of radar imagery.

2.2.2.1 APPENDIX A: ENHANCEMENT AND NORMALIZATION OF RADAR IMAGE TEXTURE

Texture has been of interest to engineers and geoscientists alike because of its potential as a useful discriminant in image category identification. Hence, one important preprocessing operation must be concerned with the enhancement and normalization of image texture. Such an operation must bring out in normal form grey tone variation due to texture and exclude grey tone variations due to look angles or flight parameter fluctuations.

Antenna patterns and flight parameter fluctuations have been two factors most responsible for degradation of radar imagery. If we regard the degradation as additive noise, enhancement of the image would, in a sense, be appropriate if there were means of removing the added noise. The 'streaks' parallel to the line of flight in an image could be due to flight parameter fluctuations, scratches caused by handling of the image before digitization, or due to antenna pattern. Perpendicular 'streaks' could be due to scan lines.

Given below is a mathematical formulation, which in essence is the enhancement technique.

Let Lx and Ly by the x and y spatial domains, G be the set of grey tones and $P: Lx \times Ly \longrightarrow G$ be some digital picture function of some more or less 'homogeneous' object $O, O: Lx \times Ly \longrightarrow G$.

The relationship between P and O is assumed to be of the following form:

$$P(i,j) = O(i,j) + \alpha(i) + \beta(j) \tag{1}$$

where $\alpha(i)$ and $\beta(j)$ can be thought of as additive row and column distortion respectively. If we are interested in the texture of O, the average grey tone is not important, and a function $\hat{P}(i,j)$ can be determined such that

$$\hat{P}(i,j) = P(i,j) - \hat{\alpha}(i) - \hat{\beta}(j) \tag{2}$$

where

$$\sum_{i=1}^{I} \sum_{j=1}^{J} \left[\hat{P}(i,j)\right]^2 \tag{3}$$

is minimized.

The solution to (3) is

$$\hat{\alpha}(i) = \frac{P_{i.}}{J} - \frac{\gamma P_{..}}{IJ}\ , \quad \beta(j) = \frac{P_{.j}}{I} - (1-\gamma)\frac{P_{..}}{IJ}\ . \tag{4}$$

Hence,

$$\hat{\alpha}(i) + \hat{\beta}(j) = \frac{P_{i.}}{J} + \frac{P_{.j}}{I} - \frac{P_{..}}{IJ} \tag{5}$$

and the enhanced image $\hat{P}(i,j)$ is then obtained by substituting Equation (5) into Equation (2) and

$$\hat{P}(i,j) = P(i,j) - \frac{P_{i.}}{J} - \frac{P_{.j}}{I} + \frac{P_{..}}{IJ} \tag{6}$$

The enhanced image $\hat{P}(i,j)$ is found to have a zero mean, and also each row and column mean is zero.

Figure 15 shows a simulated 5 x 5 'homogeneous' image to which the enhancing technique has been applied. The 5 x 5 image shown in (c) of Figure 15 is the model with additive noise. The 5 x 5 enhanced image shown in (d) of Figure 15 clearly shows a 'diffusion' of the additive noise. For simplicity of representation, image (d) has been quantized, and therefore does not have a zero mean.

Figure 16 shows the enhancement technique applied to a radar image. Part (a) shows a digitized radar image of a sorghum field. This field was isolated from the radar image of a test site selected at Garden City, Kansas. The mission was conducted on 15 September 1965 by Westinghouse. Part (a) of Figure 16 shows a computer output of the original. Streaks running vertically and horizontally show up very clearly on the image. Part (b) shows the pictorial view of the 'noise' which was subtracted out of (a). Part (c) shows the enhanced image. All three images are represented by 13 grey tones and are quantized using an equal probability routine.

Figure 17 shows a larger area of the same test site and is made up of 14 fields. The images shown in the figure are positioned the same, relative to one another, as they were on the ground. Each image in the figure is a representation of the noise subtracted out from it. The streaks occurring in one field carry on into the neighboring fields. The vertical streaks (perpendicular to the line of flight) are almost periodic and, as stated earlier in this section, could be due to scan lines. The horizontal streaks may have been caused due to scratches on the negative or due to antenna pattern, but to pinpoint their cause at this stage, without further research, would be difficult.

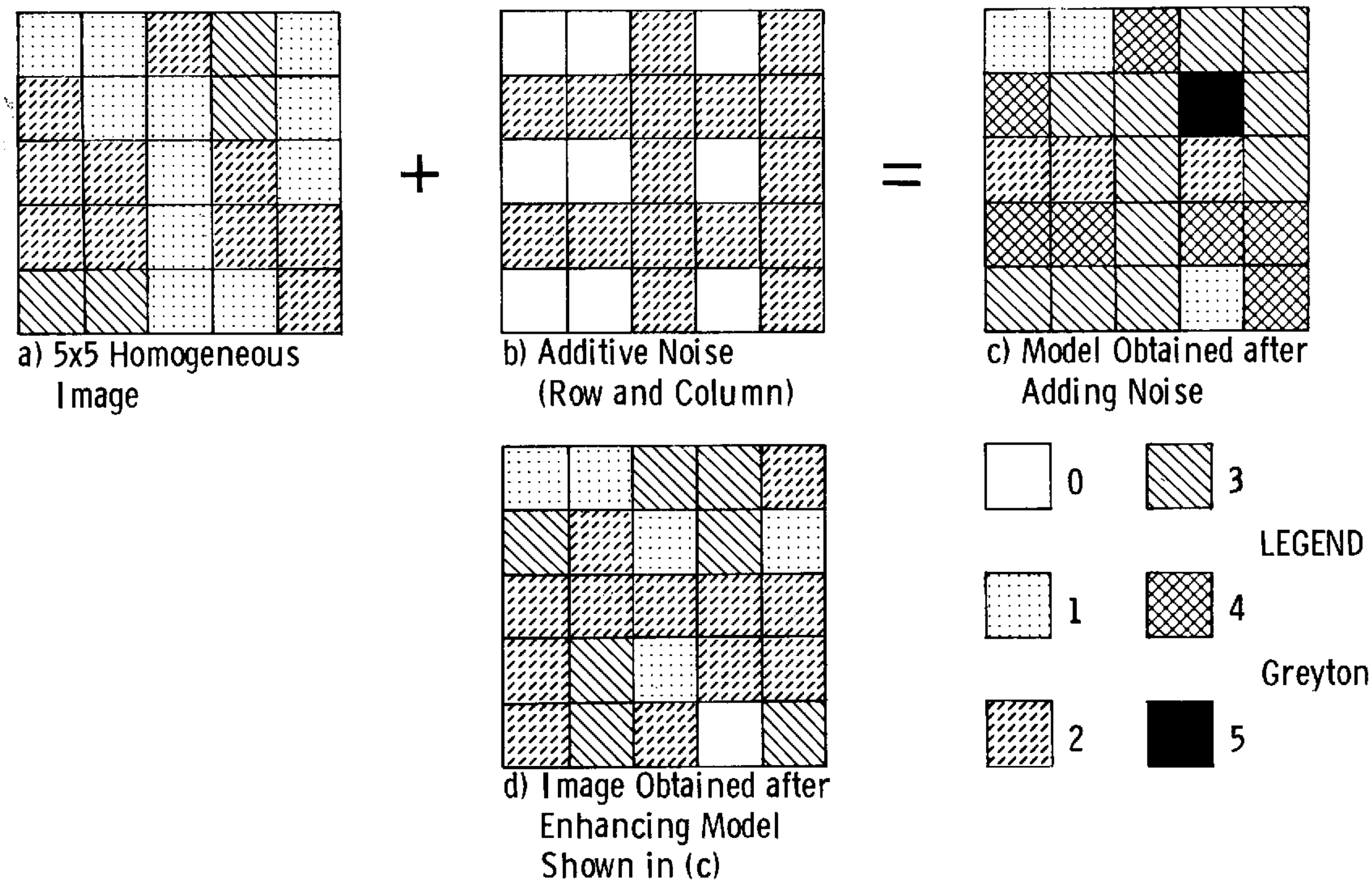
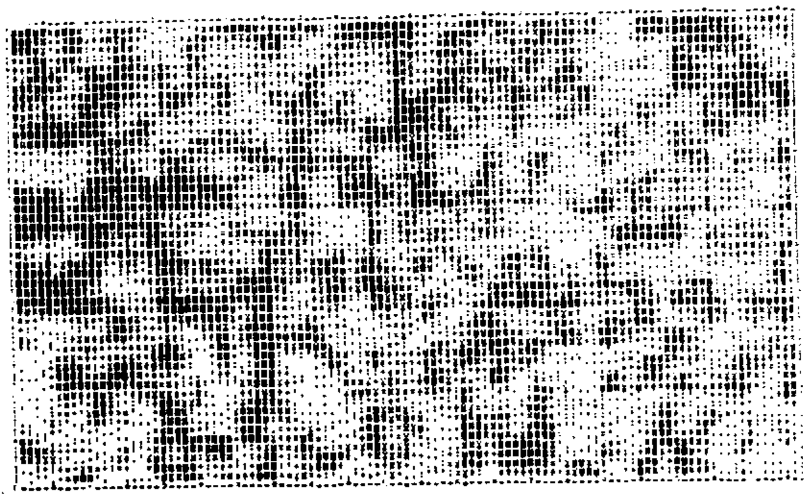
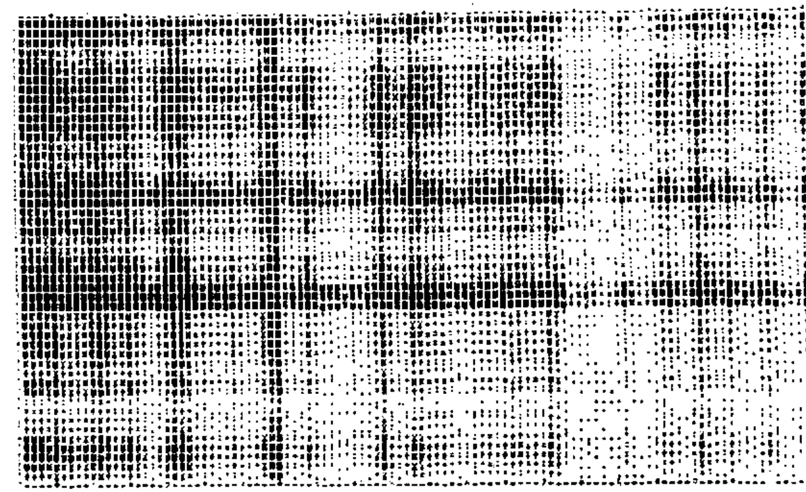


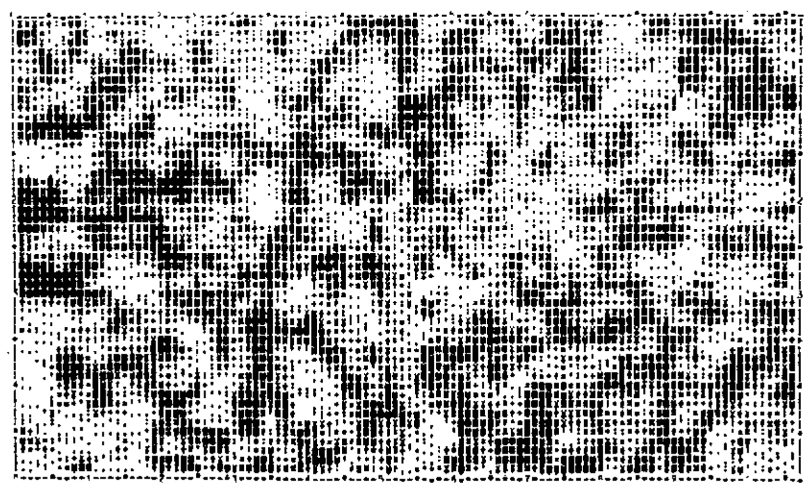
Figure 15. Shows a simulated 5x5 homogeneous image with additive noise (row and column) and its removal by the enhancement technique.



(a) Original image.



(b) Noise subtracted out of original.



(c) Enhanced image

Figure 16. Texture enhancement technique applied to a digitized radar image of a sorghum field (Garden City, Sept., 1965)

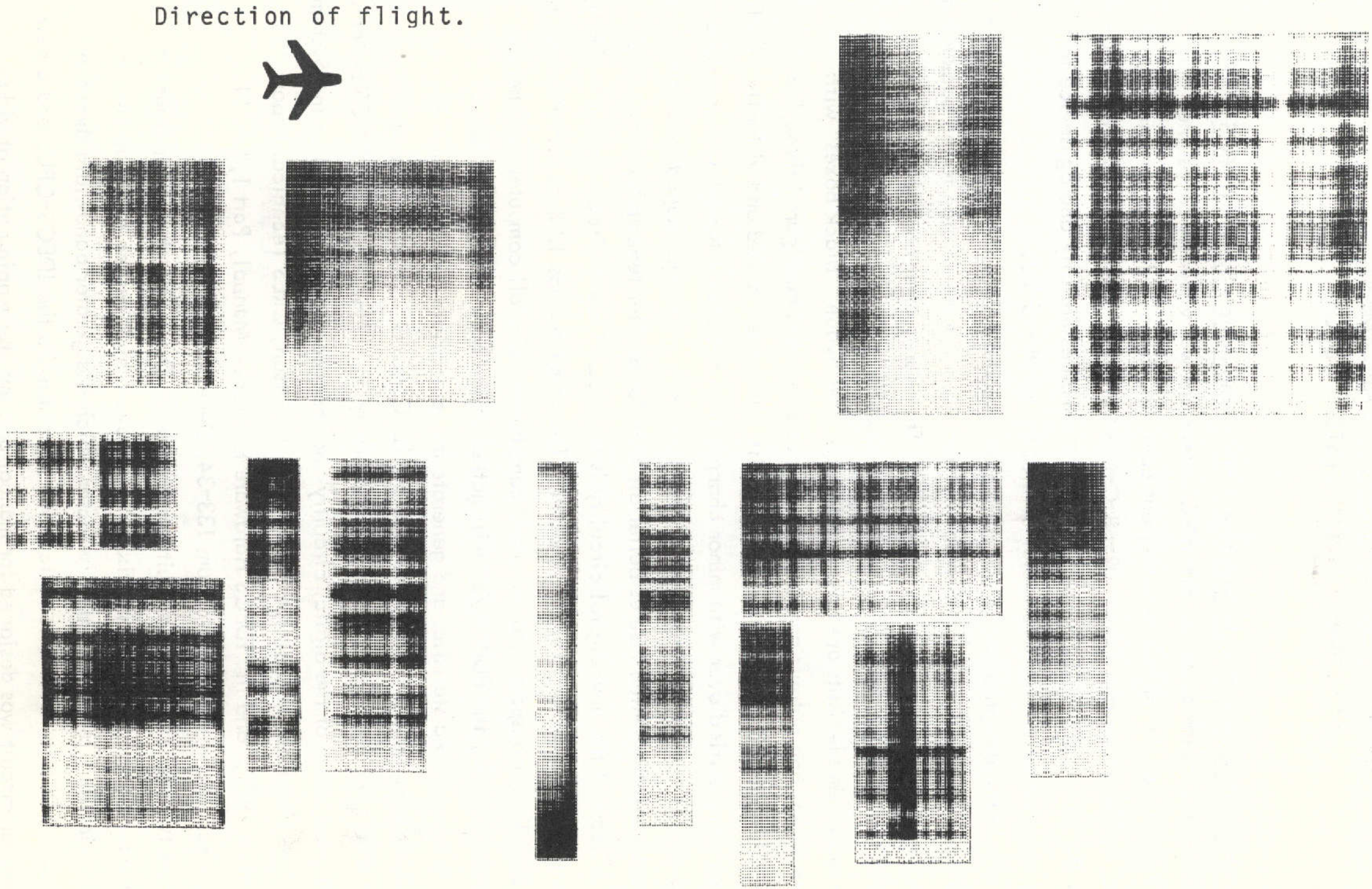


Figure 17. Part of the Garden City test site showing the 'noise' subtracted out of the 14 fields.

2.2.2.2 Image Discrimination, Enhancement and Combination System (IDECS)

During the contract period the IDECS hardware was virtually redesigned and rebuilt. Partial support for this development came additionally from a continuation of the project THEMIS Contract DAAK 02-68-C-0089 and ETL Contract DAAK 02-71-C-0482 with the Army. The IDECS was converted from an essentially analog device to a hybrid system capable of full computer control by a PDP-15/20.

Early in the design phase it was suspected that the two major problems of system noise (too much) and experiment repeatibility (too little), were related to the packaging and grounding techniques previously employed. Therefore, after a close study, it was decided that a major redesign of all IDECS subsystems be undertaken. As a result, all of the subsystem elements are now independent, removable "black boxes" with appropriate inputs and outputs capable of being selected and configured through a central switching matrix. All of the new circuits which were added and virtually all of those which were carried over with minor changes from the previous model, were made on printed circuit boards. Finally, all of the subsystems were repackaged in a new vertical rack assembly which insures better air flow for greater temperature stability.

The heart of the new digital circuitry is an IDECS Central Processing Unit (CPU), which is interfaced to a PDP-15/20 computer. The computer has 12 K of 18-bit memory plus four DEC Tape transports and the usual complement of small computer peripherals. In the computer mode, the PDP-15/20 will gather image data through the IDECS, calculate the associated statistics and generate an appropriate decision rule. The IDECS will then implement the rule through the IDECS-CPU. Thus the computer-controlled CPU is able to direct data flow and processing anywhere in the IDECS system. A detailed description of the digital circuitry and specifications can be found in "System Hardware Specification Manual/IDECS," P. N. Anderson, CRES Technical Report 133-26, September 1971, and in "IDECS Hardware Reference Manual, Part I," P. N. Anderson, CRES Technical Memorandum 133-34, December 1971.

Some twenty new analog circuits were added. The major changes included a 20 x 20 analog/digital switching matrix which allows a high degree of flexibility in system configuration, a new signature selector which has greater bandwidth than the earlier version and allows for automatic level selection via the IDECS-CPU, and a new linear combiner circuit was designed for manual or computer manipulation of video signals to fit an arbitrary linear combination. Additional new circuits include: automatic discrimination and framer, composite operator's panel, video preamplifiers, A-scan unit, and a color generating panel.

A detailed description of all the analog circuitry will be found in "IDECS Hardware Reference Manual, Part II," T. E. Polcyn and P.N. Anderson, CRES Technical Memorandum 133-35, January 1972.

The third major element which was redesigned during this period was the flying spot scanner package. Three synchronous flying spot scanners were developed which are comparable with a wide range of film formats. The scanner assemblies were constructed to allow for rapid changing of images, and the associated circuitry enables the operator easily to congruence and register images of different scales. The basic scan mode is a raster, but a dot scan is available, and the scanner circuitry is interfaced to the computer so that an arbitrary computer generated scan is possible. Details of the scanner circuits are found in the previously mentioned "IDECS Hardware Reference Manual, Part I and Part II." A description of the scanner hardware is found in "IDECS Users Manual," J. C. Barr and P. N. Anderson, CRES Technical Report 177-27, January 1972.

2.2.2.2a TEST IDECS APPLICATION

During most of the contract period the IDECS was unuseable while new circuitry was being added and while the overall package was being rebuilt. Therefore, comprehensive experiments could not be performed until the end of the period when the entire system was operable. With the new design it was possible for the first time to repeat thematic mapping experiments at widely spaced intervals and receive identical results. Two of the earlier problems of noise, which manifested itself in pictures which seemed fuzzy or out of focus, and jitter, which was similar to a misthreaded movie projector, are now gone, thereby simplifying the process of category definition by grey tone selection on multi-imagery.

With the new signature selector, up to four video channels may be manipulated in real time. The upper and lower levels of grey tone for each of the channels may be independently set and the resultant selected signals combined with a logical AND. The ANDed output signal is then available to the switching matrix for further manipulation or display in any color. An experiment was conducted in which several people independently constructed thematic maps from multi-image data, by using the signature selector and the digitizing capabilities of the IDECS for category storage. These maps were compared and the only significant differences were in the aesthetic preference towards different colors for display.

In experiments with radar imagery it was found that the inconsistent grey level for a single category from near to far range could be compensated by inputting the video signal from one image into two of the signature selector channels. In this way, one channel would be keyed to the category in the near range and the other channel to the same category in the far range. By switching between the two the category was adequately selected.

Multi-image category selection has been semi-automated through the use of a scattergram program which will be described in Section 2.2.2.2c. A detailed description of the techniques employed in category selection is to be found in "Image Processing Applications—IDECS," P. N. Anderson, et al., CRES Technical Report 177-28, January 1972. Other applications of the IDECS will be found in geoscience subtasks associated with this contract and others.

2.2.2.2b IDECS INTERACTION HARDWARE

As mentioned in the introduction, the IDECS was interfaced to a PDP-15/20 computer, and an extensive Central Processing Unit (CPU) was designed and built to direct the configuration of the IDECS subsystems. A twenty-four channel digital disc is the central element of the current IDECS, providing the synchronization for the sweep circuitry in the scanners, the monitors and the vidicon, as well as providing the timing necessary for data transfers throughout the system. The most commonly used algorithms between disc channels, e.g., logic AND, OR, EXCLUSIVE-OR, have been built into the CPU as hardware elements.

The CPU is capable of interpreting 256 different instructions from the PDP. The outputs of a set of storage registers in the CPU can be used as control signals for some of the analog circuits, such as providing reference levels for the signature selector. A buffer memory associated with the disc has been incorporated to allow for data transfers between the disc and the PDP. In this way the computer could configure the IDECS, monitor the results, calculate appropriate statistics and then reconfigure the IDECS to display the "second level" results.

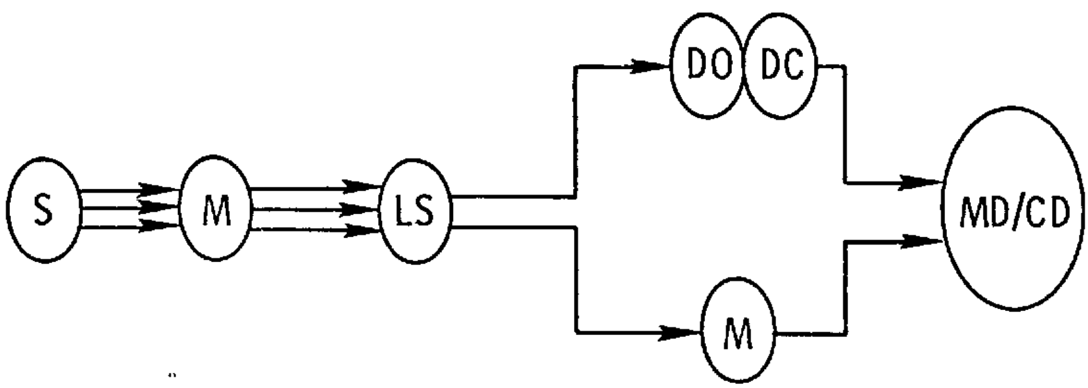
Another hardware task associated with this contract had to do with the flying spot scanners. New circuits were designed and built which greatly simplified congruencing and registering multi-images. The operation of this circuit is easily understood by a description of the image handling procedure. A set of images is placed in film holders and slipped into the scanners where they are individually focused and enlarged to approximately the same size as viewed on a black and white television monitor. One image is then used as a reference for the rest. One at a time the other images are registered to the reference. One method of performing the operations is to have the IDECS alternate rapidly between the reference and the other on the monitor so they appear superimposed. Through the new hardware each image may be translated horizontally or vertically, elongated or compressed horizontally or vertically and rotated about an axis perpendicular to the center of the face of the screen. In this way, exact superposition is possible, even if the film transparencies are of different sizes or are not spatially true in one direction. An experienced operator can perform the operation described above in five minutes or less.

Another hardware task covered by this contract had to do with construction of new color generating circuitry. The IDECS will not normally be used for direct film-density-to-hue conversion, but rather discrete colors will be arbitrarily assigned to categories. Hence, an intrinsic problem occurred of determining the number of colors that could be used without confusion. The human eye has a remarkable capability for arranging subtle changes in hue into a continuous spectrum; however, very few people are able to correctly identify the same color if it is separated by other colors or even a solid background of another color. For example, small spots of yellow and biege on a green background may be indistinguishable if random spots of other colors are also present. Because of this problem considerable experimentation and research was done before settling upon a set of ten colors (including white) for automatic encoding. The circuit was designed for three modes of simultaneous operation: any of the twenty-four disc channels may be displayed in any of the colors; any signal input to the 20 x 20 switching matrix may be displayed in any of the ten colors; and any signal input to the matrix may be displayed in any color in a <u>continuous</u> spectrum from violet to red.

Another circuit which was redesigned and built is a combined, framer/automatic discriminator. This circuit is operated in the following manner. The framer is switched through the matrix to the monochrome monitor. By adjusting the framer controls the operator is able to define a white rectangle (or "frame") of arbitrary dimensions upon a black background, and position it anywhere on the screen. The IDECS is then configured to alternate rapidly between the frame and one of the video signals, so that the frame appears superimposed and may be positioned over some category in the image. The video signal is also fed via the matrix to the automatic discriminator. This circuit examines that portion of the image which lies "under" the frame and determines the maximum and minimum values of intensity, i.e., grey level, present. These values are applied as references for a circuit which gives an output only when the video signal of the image lies within this min-max range. The output is available to the matrix for display in any of the previously mentioned colors. As an example, consider that the framer was positioned over, say, a wheat field in an air photo, and the output of the automatic discriminator was displayed in yellow. Then on the color monitor all fields which had the same range of grey levels as that under the framer would be displayed in yellow. The outputs of both the signature selector and the automatic discriminator are capable of being digitized, and stored on an arbitrary disc channel by pressing a button on the composite operator's panel or by a command from the computer.

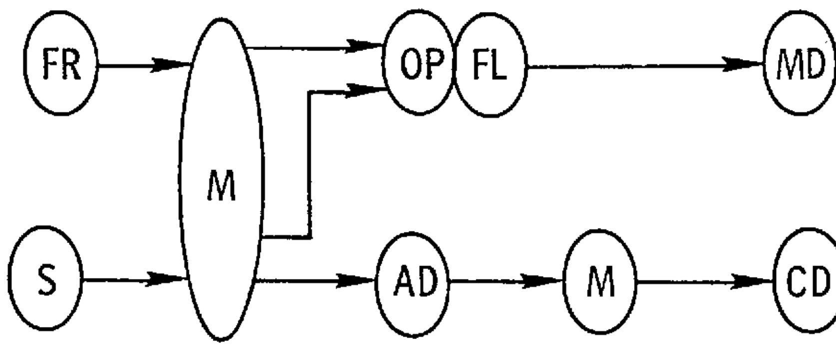
Some typical configurations which are possible using the switching matrix are given below to illustrate how the IDECS is used in practice.

<u>Level Selection, Storage and Display.</u>



Three video signals (S) are switched through the matrix (M) to the level selector (LS) where grey level slicing is independently done for each signal with the outputs ANDed together. The ANDed output from the level selector is then routed to the disc operating panel (DO), where it may be directly displayed on the color monitor. After disc storage (DC) the digitized image may also be displayed from the disc operating panel. The output of the level selector is also available on the matrix where it can be routed to either the monochrome or color monitors.

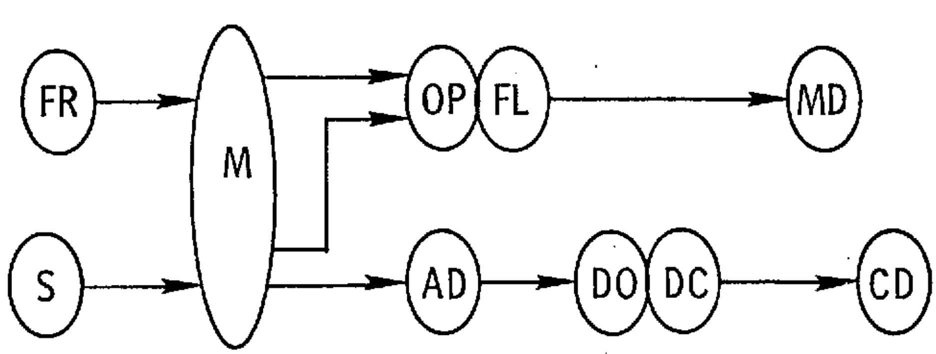
Automatic Discrimination and Display.



A video signal (S) and the framer (F) are routed via the matrix (M) to the composite operating panel (OP) where they are alternately displayed or flickered (FL) on the monochrome display (MD). The rapid alternation causes the frame to appear superimposed on the video image. The frame size is adjusted and the frame positioned over a category of interest in the image.

The video signal is also routed through the matrix to the automatric discriminator (AD) and then back through the matrix to the color display (CD). The framer circuitry and the automatic discriminator circuitry work together so that the output of automatic discriminator is only that part of the image which is within the range of grey levels beneath the frame.

Automatic Discrimination, Storage and Display.



This is the same as the previous example except the output of the automatic discriminator (AD) goes to the disc operating panel (CO) where it is stored on the disc (DC) and the stored information is viewed on the color monitor (CM).

A complete description of the analog and digital circuitry is found in the previously mentioned "IDECS Hardware Reference Manuals, Part I and II."

2.2.2.2c IDECS INTERACTION SOFTWARE

Two types of software have been written for the IDECS: diagnostic and processing/control. The diagnostic programs are designed to test all of the subsystems and locate any malfunctions. Within the CPU the matrix registers, the parameter registers, the buffer memory, the circuitry for program-controlled scans and the computer-driven displays are configured and monitored to test for faults. It is also possible to monitor the various supply voltages within the system and compare them to a reference generated by the computer. A complete description of the diagnostic programs is found in "IDECS Maintenance Manual," L. Haas and P. N. Anderson, CRES Technical Memorandum 133-33, October 1971.

Processing/control programs relate to image data processing and control of the IDECS. As mentioned above, through the IDECS-CPU the PDP is able to control almost all of the subsystems in the IDECS. For example, if several sets of images were to be processed on the IDECS according to the same rules, it is possible to have the IDECS repeat all the steps normally made by an operator in creation of a thematic map. That is, the operator would manually manipulate the first set, and then the computer would duplicate his actions for the remaining sets. The only steps the computer cannot duplicate are those which obviously need human actions like positioning the framer around a specific field or registering a set of images.

Processing programs have been written which analyze image data, calculate associated statistics and use these statistics for IDECS control or display.

As an example, a two-dimensional scattergram program has the operator position the framer over a field of interest, say, wheat, and then it determines the range of grey levels within the frame for both images. This grey level data is stored on a disc channel in a format which when displayed corresponds to having as axes the grey levels of one image versus the grey levels of the other. The program then asks the operator for another category and the process is repeated, with the scattergram stored on a different disc channel. After all the categories have been selected, all the calculated scattergrams are simultaneously displayed, each in a different color, on the color monitor. Typically, the scattergrams will overlap somewhat. The program then names each of the categories and directs the operator to position the framer over that portion of the composite scattergram which he desires to define the category. In this way the operator is able to make a decision as to which part of the overlapped areas are to be called which category. The computer will read these values and then direct the IDECS to level select each category and store the results on different disc channels for thematic map display.

Other examples of programs which have been written include: generation of histograms of the grey levels in single images; calculating the area of a selected category in any type units, e.g., the total area in acres of a selected category is calculated and printed on the teletype; and displaying any information which can be stored in matrix form.

All of the programs have been written in a form which either directs the operator via the teletype to do some task, e.g., "position the framer over such and such," or else asks the operator simple questions, e.g., "what is the name of the next category?" A detailed description of these programs is found in the previously mentioned "Image Processing Applications."

2.3 Altimetry, Scatterometry and Oceanographic Applications of Radar

Various subsections of this task relating to scatterometry system analysis and oceanography have been combined in a single section 2.3.1.0. They represent a completed study and will be the subject of a definitive report in the near future. The substantial summary presented here is felt to be necessary in view of the importance of the results and timeliness of the conclusions.

It should also be noted that all tasks relating to altimetry were deleted at the the request of NASA/MSC. Additionally, no missions relating to the Gulf Coast and Hurricane tasks were flown.

2.3.1.0 Scatterometry

The radar scatterometer is an instrument designed to measure the radar scattering coefficient σ^o (radar cross-section normalized to the illuminated area) as a function of the illuminated incidence angle Θ (angle measured from vertical). The purpose of these measurements is to determine the scattering signature data for various types of terrain as well as the ocean surface and to determine the ability of radar to discriminate between various terrain types. In addition, the σ^o vs Θ data may be used to aid in understanding radar imagery. The primary radar scatterometer used in the NASA Earth Resources program operates at 13.3 GHz.

Eight missions were conducted over the North Atlantic ocean to investigate the applicability of the 13.3 GHz radar scatterometer to measuring the instantaneous wind field over the surface of ocean. The purpose of these missions was to determine the relationship between radar scattering coefficients and ocean surface wind speed and direction. Analysis of 13.3 GHz scatterometer data from the first few missions indicated operational problems with the scatterometer. Thus a program of theoretical analysis was begun to thoroughly study the operation of the system and thereby recommend changes in order to improve the performance of the scatterometer. Of particular importance was the study of the system calibration method, the signal analysis of the receiver, the effect of non-linearities on the measurement data and the interaction of navigational parameters on the system operation.

A complete signal analysis and computations of system sensitivity and data measurement accuracy were made for the 13.3 GHz scatterometer. The effect of phase errors on the data measurement was also considered. The effect on the backscatter measurement of non-linearities and aircraft-flight parameters data were also taken into account. An analysis of the calibration system showed that the absolute level of the returns was not accurately known.

As a result of these analyses, the scatterometer performance was improved and the data measured subsequently with the system could be more readily interpreted and adjusted to compensate for the system operation.

The 13.3 GHz scatterometer system contains two vertically polarized phased-array antennas, a CW transmitter and a two-channel homodyne receiver. The receiver and transmitter antennas have a combined gain pattern that is narrow in the direction normal to the flight direction (cross-track) and is wide in the direction parallel to the flight direction (along-track). The transmitter continuously illuminates an area corresponding to nominal angular dimensions of 3° in the cross-track and $\pm 60^{\circ}$ in the along-track directions. The energy incident at the receiving antenna corresponds to the backscatter response of the surface illuminated. Because of aircraft motion in the along-track plane, the radar returns at the illuminated incidence angles are "coded" by Doppler shift to frequencies displaced from the radar center frequency. The return signal is immediately translated down in frequency with the carrier shifting to zero frequency. The negative Doppler frequencies, corresponding to aft information are folded onto the positive Doppler frequencies corresponding to fore information. Separation of the information is achieved by using a two-channel receiver with one channel in quadrature phase with respect to the other channel. It is then possible to separate fore and aft information by appropriately summing and differencing the outputs of the two channels. This operation is performed in the digital data processing operation. During data processing, returns at the angles at the angles between $\pm 60^{\circ}$ are selected by selecting the appropriate frequencies.

The radar differential scattering coefficient σ° is calculated by solving the classical radar equation for radar cross-section, then normalizing the cross-section to the resolved surface area. The scattering signature for a specific area on the surface is constructed by plotting σ° as a function of the incidence angle Θ. Since the σ° is measured at different times for different incidence angles, the time must be "compressed" to yield a σ° vs Θ plot for a particular patch on the surface.

Figure 18 shows the system block diagram, including the data processing technique used at MSC.

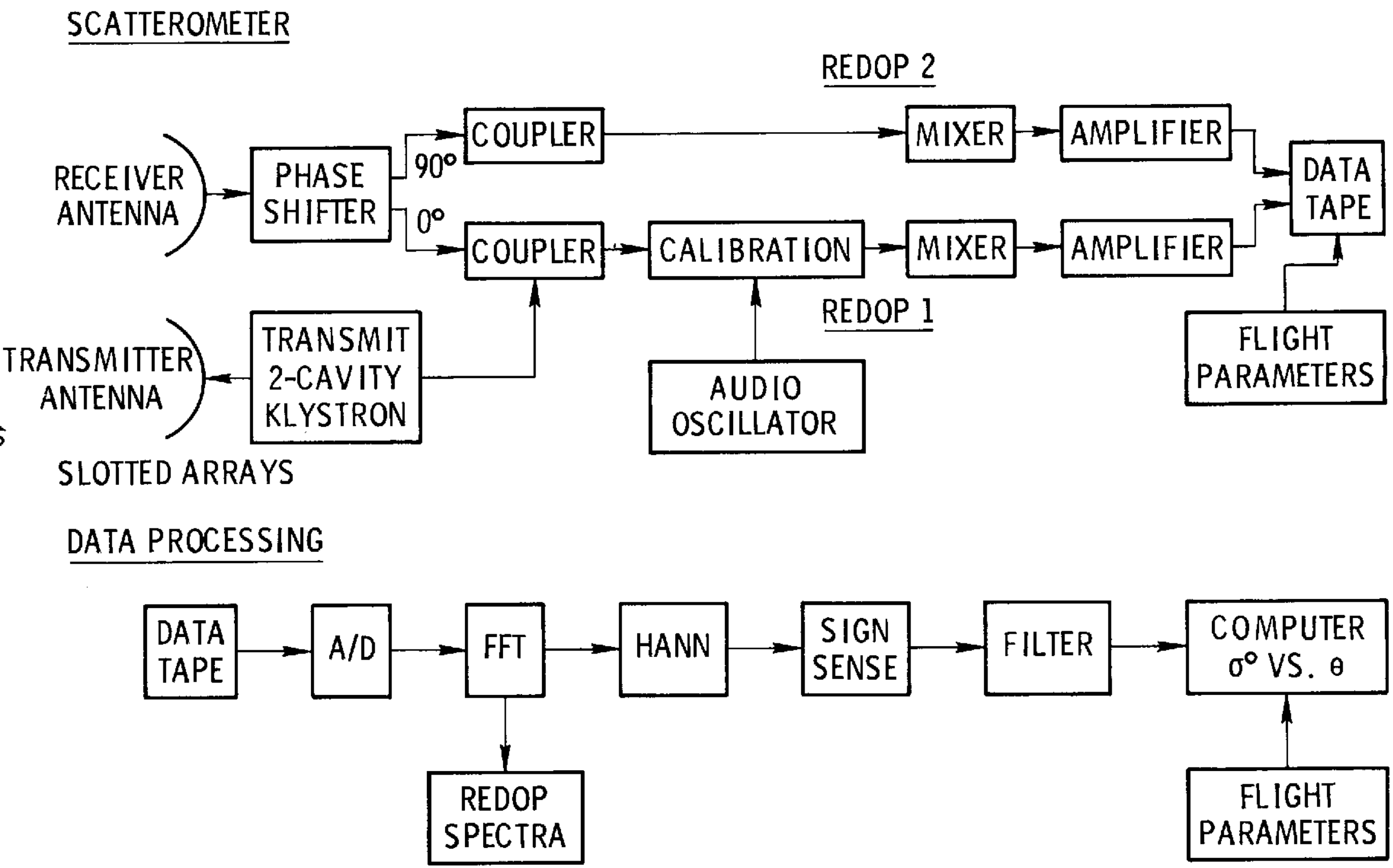

SCATTEROMETER
REDOP 2
RECEIVER ANTENNA
PHASE SHIFTER
90°
0°
COUPLER
COUPLER
MIXER
AMPLIFIER
DATA TAPE
CALIBRATION
MIXER
AMPLIFIER
REDOP 1
TRANSMITTER ANTENNA
TRANSMIT 2-CAVITY KLYSTRON
AUDIO OSCILLATOR
FLIGHT PARAMETERS
SLOTTED ARRAYS
DATA PROCESSING
DATA TAPE
A/D
FFT
HANN
SIGN SENSE
FILTER
COMPUTER σ° VS. θ
REDOP SPECTRA
FLIGHT PARAMETERS

Figure 18.

Scatterometer Sensitivity and Data Measurement Accuracy

It was shown that the scattering coefficient must be greater than -24.4 dB for a signal-to-noise ratio of 10 dB at the receiver output, with aircraft altitude 3,000 ft, velocity of aircraft 180 kts, and incidence angle 60°. If the minimum signal-to-noise ratio required for acceptable data quality is 0 dB, then the minimum scattering coefficient that can be measured accurately is -34.4 dB.

In order to determine the signal-to-noise ratio required for an acceptable measurement, the distribution of the mean power measured was considered for non-homogeneous terrain (agriculture, sea ice). The number of independent scatterers for the 0.3275 integration time of a single point is about 200, which gives the standard deviation of the measurement as approximately 10% of the mean signal for signal-to-noise ratio of 10 dB. The standard deviation increases to 16% and 22% of mean signal received if the signal-to-noise ratio is decreased to 3 dB and 0 dB, respectively. Thus, scattering coefficients of less than -34.4 dB can be measured with the scatterometer, but with a substantial increase in the standard deviation of the measurement.

In the case of homogeneous terrain (ocean surface) measurements, the minimum number of independent scatterers increases to about 800 due to longer time averaging. The scatterometer can then measure scattering coefficients down to -40 dB with a standard deviation of about 16% of the measured mean signal. Scattering coefficients lower than this can be measured with a corresponding increase in the standard deviation of the measured signal. The calibration signal recorded on tape is proportional to the product of transmitter output power and total gain of the receiver. Fluctuations in the operating parameters should be reflected by a corresponding fluctuation in the calibration signal.

Signal Analysis

The purpose of this exercise was to better understand the operation of the several stages in the scatterometer. It was shown that the side bands appearing from the interaction of the calibration signal and data signal are below the noise level and therefore do not interfere with the data signal.

Phase Error

Analytical treatment of the passage of the signal through the dual quadrature channels of the receiver and digital processor shows the insensitivity of the calculated radar scattering coefficient to phase error introduced prior to the sign-sensing operation in the data reduction procedure. It was shown that the total phase error between the two Redop channels can be as high as 20° before seriously affecting the calculation of scattering coefficient. The scattering coefficient error was found to be less than 0.2 dB for a phase error as high as 20°.

Calibration System

The purpose of the calibration system in the 13.3 GHz radar scatterometer is to provide a reference signal to permit compensating for variations in the system parameters. This reference signal, when properly calibrated, provides an absolute calibration of the value calculated for σ^{o}. In the present 13.3 GHz scatterometer a sample of the transmitted power is amplitude modulated by a ferrite modulator and the sidebands are used as reference signals. The ferrite modulator is driven by an audio oscillator and operates as a variable attenuator utilizing controlled Farraday rotation to attenuate the rf energy passing through the modulator. It was shown that the voltage transfer response of the ferrite modulator as a function of the solenoid voltage is linear in most of the region. The bias, or quiescent, point is established by the remanent magnetism of the ferrite material. The amplitude of the modulation sideband which becomes the calibration signal is critically dependent upon the location of the quiescent point and thereby on the linearity of the transfer response. Since the quiescent point is determined by the remanent magnetism of the ferrite material, it can change as a result of changes in temperature, nearby magnetic fields, vibration, or accidental direct currents. Thus, it was found that the present technique does not provide a stable calibration of the scattering measurements.

A number of different calibration techniques were investigated and proposed. The one recommended utilized a PIN diode modulator as a switching device to inject the reference signal into the RF receiver circuitry. It was shown that the calculation of σ^{o} depends only on the insertion gain of the PIN diode which is a stable constant. This, then, would certainly offer a better calibration of the calculation of σ^{o}.

Effect of Receiver Nonlinearity on Measurement Data

Agricultural missions conducted in summer of 1968 over Garden City, Kansas, produced saturated data. An effort was then made to determine the effect of non-linearity of the receiver and the recorder on calculation of σ^o. Bradley showed that the effect of nonlinear amplification of a multi-frequency input signal resulted in intermodulation distortion within the Doppler frequency signal spectrum. A third order power series with variable coefficients was used to approximate the amplifier transfer function and the percentqge distortion at two points in the Doppler signal spectrum was calculated. The greatest distortion, i.e., the greatest error in the calculation of backscatter coefficients, occurred at the highest Doppler frequency. A typical value of distortion at 6 KHz, the higher end of the Doppler spectrum, is 5.14% which corresponds to an error of 0.44 dB in the calculation of σ^o.

Aircraft Flight Parameters and Measurement Data

It was shown that the aircraft flight parameters have significant effect in the measurement of backscatter coefficient from inhomogeneous terrain, notably sea ice and agricultural terrain. In the measurement and analysis of backscatter coefficient from sea ice and agricultural terrain, it is important, therefore, to assure that flight parameters are maintained. The effect of drift, pitch, velocity and altitude variations on the computation of scattering cross-section was considered.

2.3.2.1 Ocean Wind Measurements

Measurements of the response of the radar scattering coefficient at 13.3 GHz have been made using MSC aircraft since 1966. Four major missions were mounted over the North Atlantic in 1968 (Mission 70), 1969 (Mission 88), 1970 (Mission 119, JOSS I), and 1971 (Mission 156, JOSS II). In each case, the radar cross-section σ^o was observed to increase with increasing wind speed up to the highest winds observed. Missions 70 and 88 were flown in the vicinity of weather ships permanently stationed by various nations in the North Atlantic and North Sea; Mission 119 was flown near the Argus Island "Texas Tower" near Bermuda, and Mission 156 was flown off the U.S. east coast near the unmanned weather buoy XERB-1. Because of the nature of observations made routinely on the weather ships, the surface wind conditions during Missions 70 and 88 are less accurately known than those during the later missions, and the observations scatter more widely for the earlier missions as a consequence.

Improvements were made in the programs used for processing the scatterometer data at MSC after the initial processing of Mission 70 and 88 data, and only the Mission 88 data were reprocessed. Consequently the subsequent study of the data has concentrated on Missions 88, 119, and 156. Because of the improved wind monitoring during Missions 119 and 156, particular emphasis was given to analyzing data from these missions, but Mission 88 encountered 49 kt winds as contrasted with a maximum of 33 kts for the later missions, so these data have also been included in the analysis.

Absolute calibration of the returned radar signals is in question because of the problem with the ferrite modulator calibration scheme used, as described above. For this reason the analysis has concentrated on use of the ratio of the scattering coefficient at the angle being studied to that at a reference angle, which has been selected as 10°. This ratio is insensitive to changes in system gain and transmitter output power, the two quantities the calibration system is intended to cover. The kinds of parameter changes that might affect this ratio are (1) changes in the frequency response of the receiver audio system, (2) changes in the antenna pattern, (3) errors in measured aircraft speed that cause a given return frequency to be assigned to the wrong angle, and (4) errors in aircraft pitch information that cause the wrong antenna gain to be assigned to a particular angle. The first two quantities are not likely to change over long periods of time, although a change in antenna pattern occurred from Mission 119 to Mission 156 because the antenna was moved from the P3 to the C130 aircraft. All measurements made with the Doppler navigator for speed determination should be as accurate as the Doppler navigator itself; for a few runs this instrument was inoperative, and the speed measurement may have larger error, which was considered in the analysis. The amount of error introduced by erroneous readings of aircraft pitch is not known.

Results of the observations with the three missions for incident angles of 25° and 35° are summarized in Figures 19 and 20. Here the scattering coefficient ratios for Mission 156 have been adjusted to the same scale used for the previous missions, since they were different because of the different antenna pattern on the C130. Clearly the wind speed dependence has been established as being significant, but somewhat lower for crosswind than for upwind-downwind observations; hence, knowledge of the direction of the wind is essential if a scatterometer is to be used for anemometry.

Analysis of the variability of the Argus Island anemometer record as contrasted

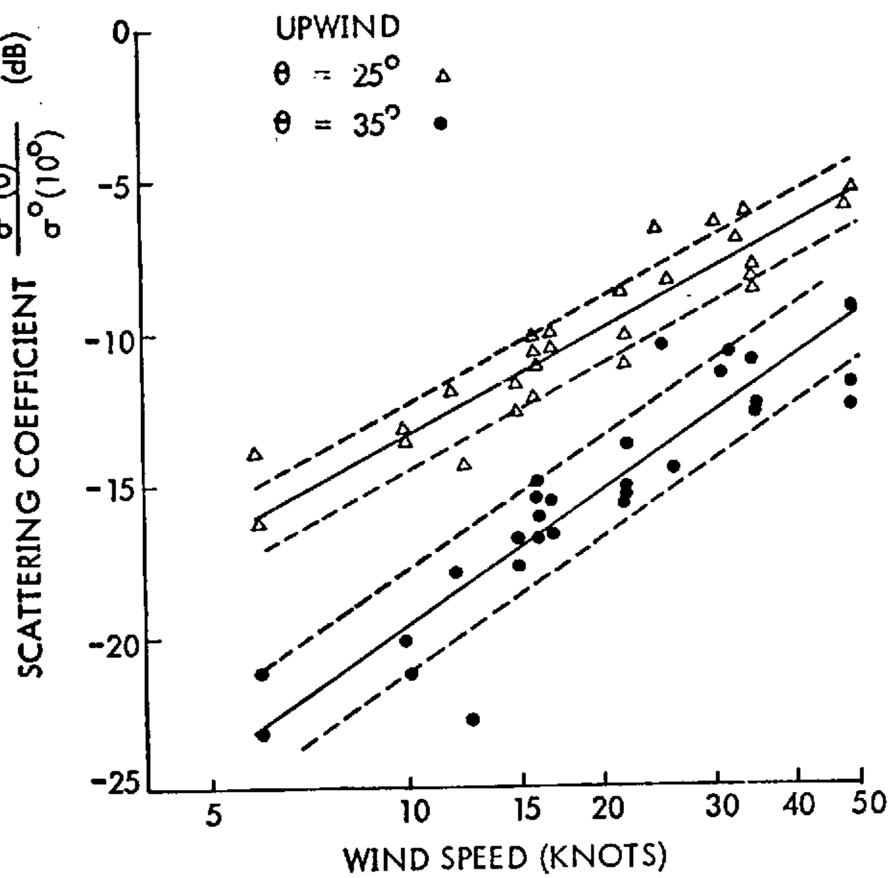
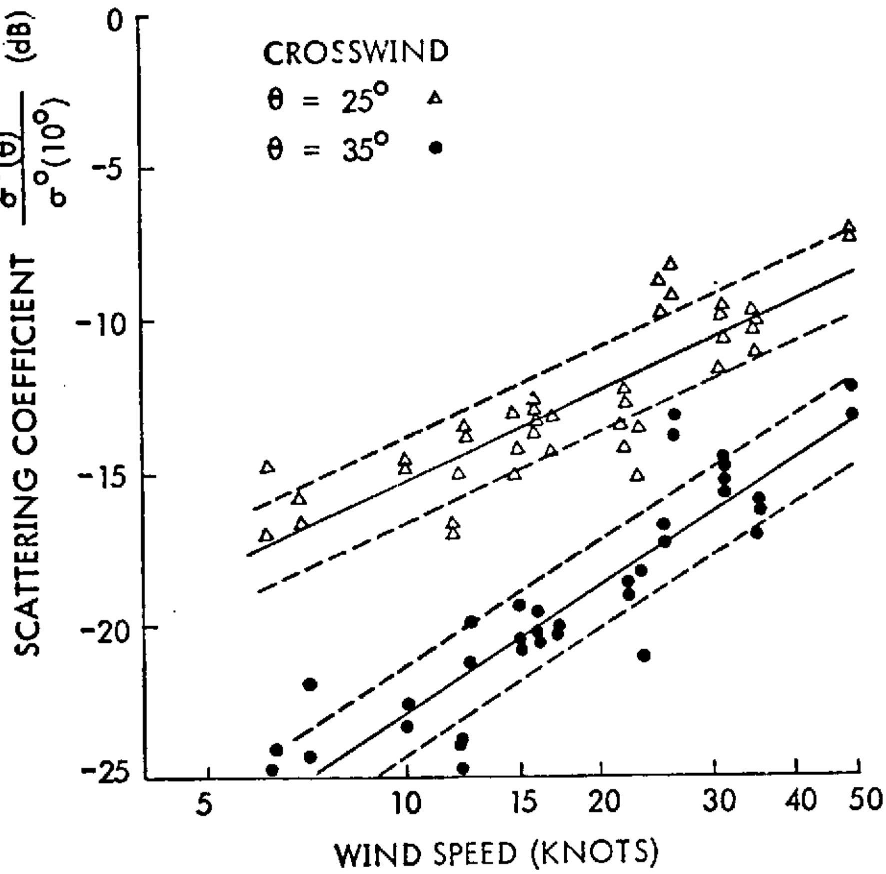

SCATTERING COEFFICIENT $\frac{\sigma^o(\theta)}{\sigma^o(10^o)}$ (dB)
UPWIND
θ = 25°
θ = 35°
0
-5
-10
-15
-20
-25
5
10
15
20
30
40
50
WIND SPEED (KNOTS)

Figure 19.



SCATTERING COEFFICIENT $\frac{\sigma^o(\theta)}{\sigma^o(10^o)}$ (dB)
0
-5
-10
-15
-20
-25
CROSSWIND
θ = 25° △
θ = 35° ●
5
10
15
20
30
40
50
WIND SPEED (KNOTS)

Figure 20.

with that of the radar return from nearby indicated that much of the fluctuation of the radar return could be accounted for in terms of wind speed fluctuations, but that an additional component of variability remained after these corrections. This analysis is continuing.

The entire sea backscatter program has been a joint effort involving, in addition to many NASA, Navy, and NOAA personnel, very close cooperation between Professor Pierson's group at New York University and the Kansas group. Numerous papers have been published separately and jointly by these groups. A major part of the analysis of the Mission 119 and 156 data is contained in a Ph. D. dissertation by G. A. Bradley, soon to be published as a technical report.

2.3.2.4 Experiments (Agricultural Terrain)

Five scatterometer missions were flown in the period from September 1969 to September 1972 over the Garden City, Kansas, test site. The purpose of the scatterometer agricultural missions is to help determine the ability of a radar to identify agricultural features such as crop type, crop vigor, soil moisture content, and crop maturity throughout the agricultural growing season. The optimum radar parameters (such as incidence angle, frequency, bandwidth, etc.) for discriminating agricultural features will be determined using results from the scatterometer, spectrometer and imaging radars.

Missions 130, 133 and 153 were conducted in May, June, and October of 1970 respectively, and Missions 165 and 168 in May and June of 1971. Missions 130 and 133 contained data from both the 13.3 GHz and 400 MHz scatterometers, whereas Missions 153, 165 and 168 had only the 13.3 GHz data. With the exception of Mission 153, all scattering data have recently been received and analysis has just begun. A summary of the missions and data is presented in Table I.

2.3.2.5 Analysis of Sea Ice Observations

Ice Scatterometry

The ability of radar to discriminate different types of sea ice was demonstrated by J. W. Rouse, Jr. in Technical Report 121-1. It was shown that it is possible to identify different categories of sea ice by the radar backscatter. A number of analyses were carried out on the data obtained from Mission 47. The main effort was concentrated on finding the "roughness factor," for each ice type based on the Kirchhoff-Huygens principle. The results were encouraging but not definitive because of the limited amount of data available.

Table I.

Site 76 (Garden City, Kansas) Scatterometer Inventory

Date Received	Mx #	Date of Mx	Frequency	Data	Copy	Line	Run
11/18/71	130	5/70	400 MHz	σ^o time history	2	1-6	1
				Reflect plots	2	1-6	1
				PSD plots	2	2-5	1
3/9/72				Output tape	1	1-6	1
			13.3 GHz	Dump of first & last ten records of each file	1	1-6	1
				Reflect plots	1	1-5	1
				PSD plots, filter tab	1	1-5	1
				σ^o time history plot	1	1-5	1
				Output tape (6 files)	1	1-6	1
11/18/71	133	6/70	400 MHz	σ^o time history plot	2	1-6	1
				Reflect plot	2	1-6	1
				PSD plots	2	1-6	1
3/9/72				Output tape (6 files)	1	1-6	1
			13.3 GHz	σ^o time history plot	1	1-6	1
				PSD plots, filter plots	1	1-6	1
				Reflect plots	1	1-6	1
				Output tape	1	1-6	1
	153	10/70	13.3 GHz	Not received			
2/16/72	165	5/71	13.3 GHz	Output tape	1	1-6	1
				Filter plots & tab, PSD plots	1	1-6	1
				σ^o time history plot	1	1-6	1
				Reflect plots	2	1-6	1
2/16/72	168	6/71	13.3 GHz	Output tape & format	1	1-6	1
				σ^o time history plot	1	1-6	1
				Reflect plots	1	1-6	1
				PSD plots, filter plots	1	1-6	1

Interpretation for backscatter radar returns were presented in TM 185-1 in terms of surface roughness, volume scatter, effective conductivity, and relative dielectric constant of the scattering media. These interpretations were discussed with respect to statistical analysis of 13.3 GHz backscatter of various categories of sea ice at different angles of incidence. Results obtained from the statistical analysis carried out on the data obtained from Mission 47 indicated that it is possible to identify both water or thin ice and multi-year ice from first-year ice without any misidentifications using angles of incidence greater than 15°. Further, it seemed possible to identify a few additional ice categories within the first-year ice group.

The area coverage requirement of a given sea ice category was described in terms of aircraft operating altitude, speed, antenna patterns, and signal frequency. This description also covered the minimum terrain area necessary for discrimination against other sea ice categories.

The presence of volume scattering was considered to be a factor, but further studies were recommended to study its effect.

The statistical analysis of Mission 47 data was carried out using pattern recognition techniques. The purpose of this was to determine whether it was at all reasonable to expect that certain basic ice types could be differentiated on the basis of their 2.5 cm radar-backscattered return profiles. Each return profile (σ^{o} vs Θ curve) contained values of σ^{o} at incidence angles of 2.5^{o}, 3^{o}, 7^{0}, 15^{o}, 25^{0}, 35^{o}, 45^{o}, 50^{o}, and 65^{o}. From the Arctic mission, there were 363 backscattered profiles, each taken of a small area (30 m x 30 m) ground patch of an ice type reliably observed by ground or air. Initially, the ice identifications were divided into three major ice categories: water or thin ice, multi-year ice, and first-year ice. If ice types could be distinguished on the basis of their radar backscatter profiles, certainly these major groups would be distinguished.

One approach (and an optimum one at that) to the discrimination problem involves the use of a simple Bayes decision rule. Such a rule assigns the cross-section to the most likely ice categories. This approach was used here to discriminate ice types.

From the data sample of 363 measurements, 195 measurement profiles were selected at random for the training set. Assignments of ice categories were made on the basis of photo interpretation and comments during flight by a U.S. Navy ice observer. The prediction set consisted of the remaining 168 measurements. Each measurement was assigned an ice category by the constructed decision rule. Table

Table II.

Contingency table for prediction set using all 9 angles of scatterometer data. Rows are true category identification, and columns are category identifications assigned by a Bayes decision rule based upon multivariate normal conditional distribution.

	Water, Thin Ice	1st-Year Ice	Multi-Year Ice
Water, Thin Ice	5	3	1
1st-Year Ice	4	71	6
Multi-Year Ice	0	0	78

II illustrates the resulting contingency table of true ice identifications versus assigned ice identifications.

Other analyses were conducted using different training sets. A detailed list of the results obtained is given in TM 185-1.

The current research effort is concerned with analysis of Mission 126 (see 2.3.2.4). A detailed discussion of the objectives and location of the mission is given in TM 177-14. The experimental data included multi-polarization 400 MHz scatterometry, vertical polarization 13.3 GHz scatterometry, dual polarization 16.5 GHz imagery and aerial photography.

The preliminary analysis of the data has only permitted qualitative conclusions. The real value of the data can only be demonstrated when a detailed analyses of the data is carried out. Figures 21, 22 and 23 illustrate some of the preliminary results.

Figures 21 and 22 show the spread of the average scattering coefficient for nine different ice types as a function of angle of incidence. Figure 23 shows this converted into dynamic range requirements for the ice imager. Clearly an imager operating at steep angles of incidence would need dynamic range from about -12 to +15 dB; whereas an imager whose closest angle of incidence is only about 35^{o} can get by with a dynamic range of considerably less than 20 dB as shown, but must have a sensitivity of at least -14 dB. Analysis of the data along these lines is continuing.

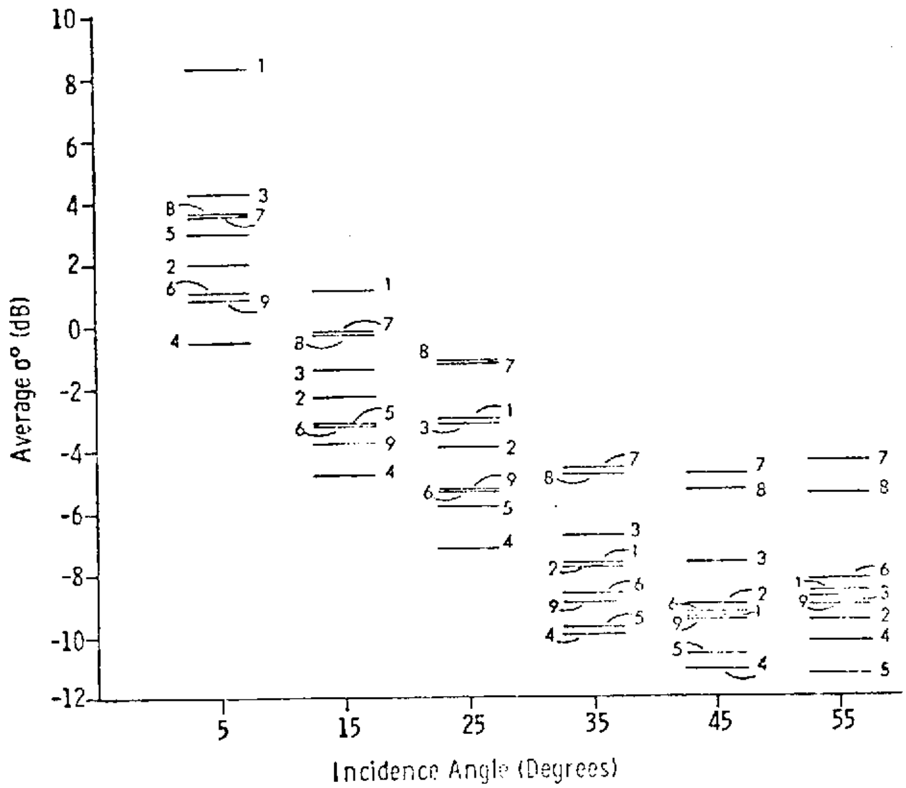


Figure 21. Means for 9 Ice Types Observed on Mission 126.

1. OPEN WATER.
2. NEW ICE. A GENERAL TERM FOR RECENTLY FORMED ICE WHICH INCLUDES FRAZIL ICE, GREASE ICE, SLUSH, & SHUGA.
3. NILAS. A THIN ELASTIC CRUST OF ICE HAVING A MATTE SURFACE AND A THICKNESS OF UP TO 10 CMS.
4. YOUNG ICE (COMPACT PACK). ICE IN THE TRANSITION STAGE BETWEEN NILAS AND FIRST YEAR ICE, 10–30 CMS IN THICKNESS, AND HAVING A CONCENTRATION OF $^{8}/_{8}$. NO WATER IS VISIBLE.
5. YOUNG ICE (VERY CLOSE PACK). SAME AS ABOVE BUT WITH A CONCENTRATION OF $^{7}/_{8}$ TO LESS THAN $^{8}/_{8}$.
6. FIRST YEAR ICE (COMPACT PACK). ICE OF NOT MORE THAN ONE WINTER'S GROWTH HAVING A THICKNESS OF 30 CM TO 2 M. CONCENTRATION $^{8}/_{8}$.
7. SECOND YEAR ICE (COMPACT PACK). ICE WHICH HAS SURVIVED ONLY ONE SUMMER'S MELT. CONCENTRATION $^{8}/_{8}$.
8. MULTI-YEAR ICE (COMPACT PACK). ICE WHICH HAS SURVIVED MORE THAN ONE SUMMER'S MELT. THICKNESS UP TO 3 M. CONCENTRATION $^{8}/_{8}$.
9. MULTI-YEAR ICE (VERY CLOSE PACK). SAME AS ABOVE. CONCENTRATION $^{7}/_{8}$ TO LESS THAN $^{8}/_{8}$.

Figure 22. Classification of Sea Ice for Figure 21.

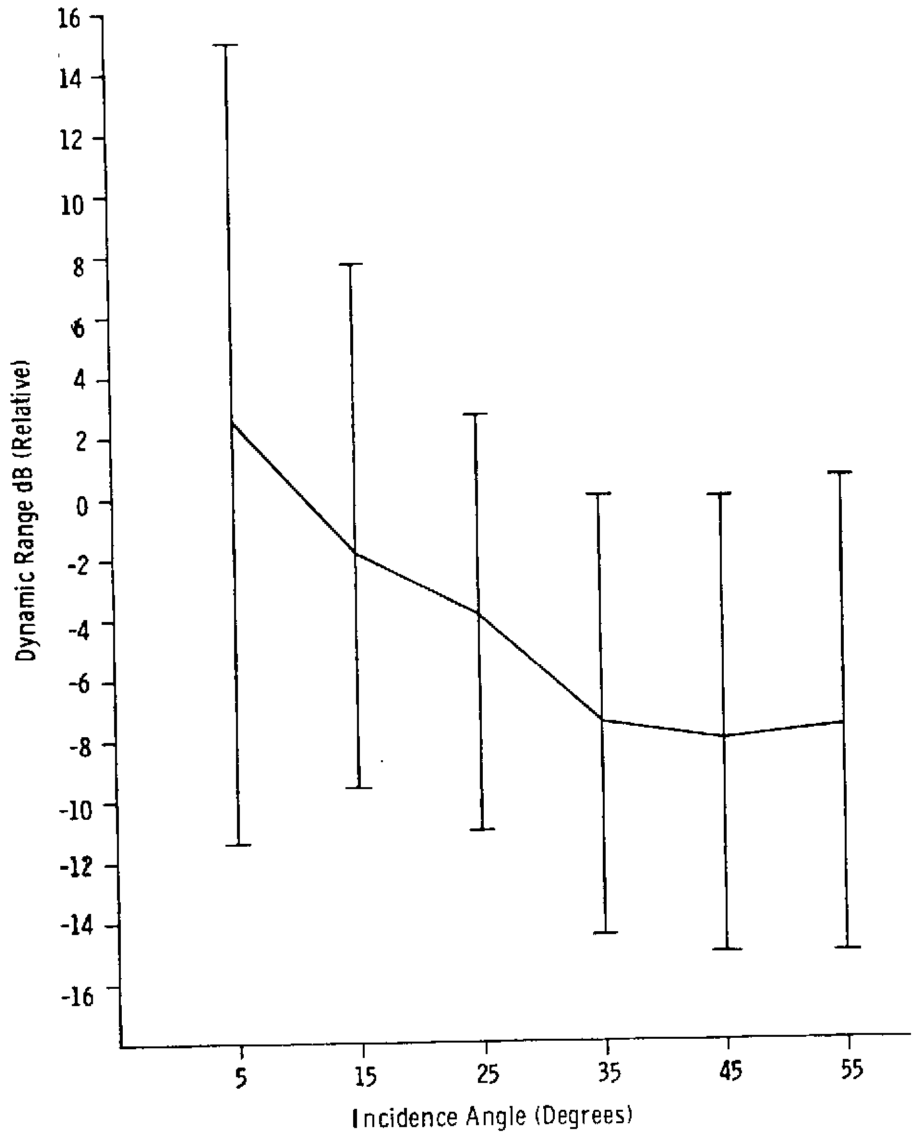


Figure 23. Dynamic Range Requirements for Ice Imager-Radar.

2.3.2.6 Mission 126

Technical/scientific support was provided for Mission 126 of the NASA/MSC aircraft to Pt. Barrow, Alaska, for a sea ice experiment. This included assistance in arranging the flight plan and ground support both in advance of and during the mission. Mission 126 was conducted in April 1970, with Dr. A. W. Biggs, Dr. G. A. Bradley and Mr. R. L. Walters acting as scientific observers on the experiment team.

2.4 Radar Geology

The utilization of imaging radars in geologic research must be preceeded by the development of an understanding of both system and surface parameters. This has been the stated goal of the geologic research group since its organization and participation in the program for radar studies related to earth resources. Briefly outlined, our objectives have been:

1. System Parameter Evaluation

   Look Direction
   Frequency
   Depression Angle
   Polarization
   Resolution

2. Target Parameter Evaluation

   Moisture
   Vegetation
   Slope and Relief

3. Applicability

   Geologic Structure
   Geologic Materials
   Geomorphology

Our research objectives under contract NAS 9-10261 have to some degree been modified because of modifications in the flight and data acquisition programs. However, whereas this has resulted in de-emphasis in some areas of investigation, it has also resulted in more intensive investigation in other areas. With a sparsity of new imagery, one becomes increasingly aware of the vast amount of existing imagery in which still may be locked the solution to many problems of interpretation.

RESULTS OF INVESTIGATIONS

Geologic Cross-Polarized Anomalies

A prime example of the utilization of existing imagery is seen in the investigation of cross-polarized anomalies in selected areas of volcanics and sandstones in the western United States (McCauley, 1972). Utilizing imagery over essentially arid areas in which the time lapse between imaging and field study would be least significant, it was determined that surface roughness, not rock type, was the key factor in the development of tonal reversals in the cross-polarized imagery evaluated.

Outcrops of these rock types share certain features; planar rock surfaces that are large in comparison with the wavelength of the incident radar are abundant and detrital material and vegetation are of secondary importance; the planar surfaces appear to significantly contribute to the returning radar energy with this energy maintaining a constant polarization; and the outcrop areas are of sufficient size and sufficiently uniform character to be delineated on small scale K-band imagery.

These rock types, for differing reasons, produce terrains in which radar return is dominated by specular reflection from planar surfaces. For a specular reflector to be recorded on the radar image, its orientation should be orthogonal to the path of the impinging radar; and for such an orientation, the depolarized component of the reflected radar energy is at a minimum. The result would be a higher return on the like-polarized image and a lower return on the cross-image. This is in compliance with the observed behavior of the volcanics and sandstones evaluated.

Look Direction Significance

The need was early recognized for a study of the effect of look direction. In fact, as a result of a study of imagery in the Ouachita Mountains of Arkansas (Dellwig, et al. 1966) multiple looks from diverse diverse directions were requested and obtained during the NASA imaging program utilizing the AN/APQ-97 radar. Conclusions reached regarding the relationship between the look-direction and detectability of geologic features in this environment conflicted with the conclusions reached by MacDonald in his evaluation of Darien Province, Panama imagery (MacDonald, 1969).

Evaluation of NASA flight program imagery from additional areas in which multiple coverage was available provided sufficient data to reconcile the differences and provide a better understanding of the effect of look-direction in diverse environments (MacDonald, et al., 1970).

It was apparent that look-direction did indeed influence the detectability of geologic features expressed in the terrain configuration. Depending on the relative topographic relief, effective incident angle of radar energy, and look-direction, geologic features would be advantageously enhanced or completely suppressed. Thus, to obtain the maximum benefit from geological reconnaissance studies utilizing radar in poorly mapped areas, it would be desirable to image the specific region from four orthogonal look-directions. For more detailed studies where a known terrain configuration would be imaged, a minimum of two opposing look-directions would suffice for optimum geologic interpretation.

Depression Angle

Shadow enhancement of terrain configuration has proved to be a reasonably adequate compensatory mechanism for the lack of stereoscopic coverage. As useful as shadowing is in low relief terrain, it is equally undesirable in areas of extreme high relief. Recognizing the need for consideration of depression angle variation relative to relief, MacDonald and Waite (1971) evaluated terrain relief on a world-wide basis and calculated the optimum depression angles for various terrain categories.

In low relief areas, the oblique illumination and resultant shadowing by imaging radars can generally provide enhancement of topographically expressed geological features, but in mountainous terrain , radar shadowing can deter geological interpretation. Especially in rugged terrain, two inherent disadvantages of a radar imagery format which can hinder geologic interpretation are extensive shadowing and layover. Radar depression angle and terrain slope define the range over which shadow and layover will occur, but the extent of either parameter is defined by relative relief. For most operational side-looking radar systems, the interpretative data loss increases as terrain slopes exceed 35 degrees and local relief surpasses 1000 meters. Trade-offs between loss of geologic data due to radar shadow and layover, versus swath-coverage, have been evaluated. Similarly, the advantage of slight radar shadowing in low relief areas is considered. Near and far range depression angles have been recommended according to five global terrain categories, and imaging altitudes are considered for both airborne and spaceborne platforms.

Resolution

The comparative evaluation of coarse and fine resolution radar imagery was first realized with the acquisition of the University of Michigan's high resolution imagery in the Ouachita Mountains, an area previously imaged by several coarser resolution systems (Dellwig and McCauley, 1971).

In general the value of increased detail is offset by the distraction of minor topographic and vegetal features and the loss of the distinctive pattern of major features. Although judged to be real, this undesirable feature may be in part due to the loss of the synoptic presentation with the decrease in swath width. As has been demonstrated on numerous occasions in the past, the synoptic presentation and the all weather capability of radar are its major advantages. In a relatively heavily vegetated area, the increased resolution provides distracting detail and the decrease in swath width compounds this loss; thus only the all weather capability remains as the capability not offered by the aerial photography. The conclusions reached in this study, although possibly adaptable to other terrain environments are only preliminary in nature and await verification through evaluation of terrain in other environments.

Frequency

The determination of the value of imagery of other than K-and X-bands for geologic investigations continues to be a significant problem in need of further investigation. A preliminary study in the Pisgah Crater, California area (Dellwig, 1969) pointed out the need of controlled comparisons and a nearly completed similar study of imagery of diverse sources and acquisition dates in the Florida Panhandle emphasizes the need. Based on a bare minimum of data, it appears that simultaneous imaging with high and low frequency radars will be of greater value to geomorphologists, hydrologists, and geographers, than to geologists.

TARGET PARAMETER EVALUATION

Moisture

Unfortunately a great deal of the present imagery was produced without the benefit of simultaneous acquisition of ground truth data. Whereas studies in areas such as Pisgah Crater or Mono Craters, California are not so dependent on simultaneously acquired surface data (because of lack of vegetation and aridity), investigation of the effect of vegetation and soil moisture on the return signal are hampered in more humid environments when ground truth acquisition and imaging are widely spaced in time. Fortunately some more recent data were obtained in the Gulf Coast area which demonstrated a correlation between results obtained from a controlled measuring device and ground conditions (MacDonald and Waite, 1971).

The data presented in that study suggest that presently available dual polarized, K-band, side-looking imaging radars provide a capability for revealing a qualitative estimate of soil moisture content. When used as a supplement to aerial photography in temperate climates, radar imagery analysis will decrease the ambiguity of soil type reconnaissance. In the Arctic, an imaging radar may provide data for mapping regions of permafrost, and this process could be accomplished in a sequential manner regardless of weather or time of day. The use of additional multifrequency multipolarization imaging radars and the relative foliage penetration of each should be investigated as a possible means of gathering quantitative soil moisture information.

Vegetation Penetration

Utilizing the same Gulf Coast imagery, a closely allied study concerning vegetation penetration provided valuable data for the user community (MacDonald and Waite, 1971). Although limited in scope, some progress was indicated in the understanding and separation of effects of soil moisture and vegetation. In this study it was suggested that within specific terrain environments, the penetrative effects of Ka-band radar energy can be recognized on the imagery format. Boundaries were defined on the radar imagery that are directly related to differences in soil moisture content, irrespective of either the vegetation type or density. Use was made of the depolarized return signal to distinguish between differences due to soil moisture and gross vegetation differences, thus providing a practical advantage for a multipolarization mode.

Applications

Studies aimed primarly at evaluation of system and terrain parameters necessarily pointed out the potential of radar as a device for geological investigation. In addition to these studies, other reports dealt with the utilization of radar in a variety of investigations in diverse terrains (Kirk, 1970; MacDonald and Waite, 1972; Wing and Dellwig, 1970; Wing, et al., 1970). The best demonstrated utilization appears to be in the area of fracture detection and analysis, regardless of the degree of development of masking vegetative cover, relief, or overall structural complexity.

With the completion of these studies, documentation of radar as an operational tool for geologic investigation has been realized. This to more than a limited degree has been substantiated by the development and widespread utilization of three commercial radar systems.

This does not imply that the evaluation of SLAR as a geoscience tool is complete. We visualize that with further investigation as outlined below, the full capability and limitations of radar will be more precisely defined.

1. Multifrequency imaging for geologic and geomorphic studies.
2. Varying combinations of dual polarization imaging in geologic, hydrologic, and geomorphic studies.
3. Radar as a detector of soil moisture, swamps, ice and permafrost.
4. Resolution ranges for geologic and geomorphic studies for a wide range of map scales.
5. Radar imagery data content as compared with high altitude and orbital photography.

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MacDonald, H. C. and W. P. Waite, 1971, "Soil Moisture Detection with Imaging Radars," Water Resources Research, vol. 7, no. 1, pp. 100-110.

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Waite, W. P. and H. C. MacDonald, 1971, "Vegetation Penetration with K-Band Imaging Radars," IEEE Transactions on Geoscience Electronics, vol. GE-9, no. 3, July 1971, pp. 147-155.

Wing, R. S. and L. F. Dellwig, 1970, "Radar Expression of Virginia Dale Precambrian Ring-Dike Complex, Wyoming/Colorado," Geol. Soc. America Bull., vol. 81, pp. 293-298.

RADAR APPLICATIONS IN AGRICULTURE / FORESTRY

Table of Contents

General Introduction

The following report summarizes Geoscience research efforts under the Agriculture/Forestry tasks of Contract NAS 9-10261 (tasks 2.5.2 and 2.5.3). Subtasks under each of these are keyed specifically to work proposed under Technical and Cost Proposal BB321-55-0-60-P dated June 1970. The report has been subdivided into three parts: I. General Introduction, System Design and Recommendations; II. Summary of Research on Tasks 2.5.2 and 2.5.3, and III. Appendices and References.

In Part I. we outline our current estimate of requirements for an operational agricultural radar and for the utilization of its data in an information system. A list of general conclusions and recommendations is presented as derived from the subtasks.

Part II opens with an overview of the use of radar imaging in Agriculture (2.5.2) and is followed by a series of brief subtask reports (2.5.2.1-4). Each of these is a condensed version of technical reports and/or published documents. The interested reader is referred to them for more details. Following the subtask reports for Agriculture, a summary for Forestry (task 2.5.3) is given. An overview for resource mapping in general is presented for the specific case of Arid Zones and this is followed by subtask reports 2.5.3.1-3.

Finally, in Part III we present sample data and results from studies reported in the subtasks. The amount of data and computer print-outs is so vast that only a sample is feasible.

Conclusions and Recommendations for Tasks 2.5.2 and 2.5.3

Task 2.5.2

(a) Multi-frequency radar imagery will be required for accurate crop identification. The wider use of imagery is presently hindered by (1) the need for parametric information on σ^o, incidence $\measuredangle$, polarization and the effects of terrain variations; and (2) the development of interpretation techniques.

(b) Using automated interpretation keys, radar data hold great promise in providing early crop statistical estimates. Timely and efficient interpretation throughout the growing season could provide statistics such as acres in production, acres harvested, progress of harvest, etc.

(c) We recommend systematic σ^o vs Θ investigations on crops in various stages of growth, under varying kinds of stress, etc., to begin unraveling within-category changes in image appearance.

Subtask 2.5.2.1

(a) It is axiomatic that every time a farmer performs an operation in his field the radar ground echo will change. It is small wonder that interpretation anomalies and ambiguities result considering the mutual interactions of farmer operations and physical variables. Nevertheless, experienced interpreters can utilize information contained in the radar image to make accurate determinations.

(b) The complexities of land use changes and the unique kinds of agricultural information requested in interviews with farmers strongly suggest that initial interpretation of radar data should take place at the county level. Interpretation techniques, such as keys, seem the most advantageous for satisfying information needs, especially when combined with the county agents' in-depth knowledge of local conditions and trends.

Subtask 2.5.2.2

(a) Visual image attributes can be effectively used to prepare dichotomous keys to aid interpretation of radar imagery. A variety of single purpose keys can be produced by concentrating on different attributes. When these are automated and combined with ADP techniques, rapid and consistent information extraction is possible.

(b) Interpreter tests of a series of preliminary keys yielded crop identification accuracies of slightly less than 50%. Though these are unacceptable in practice,the tests showed where the keys could be improved.

(c) Results from preliminary tests of automated keys are encouraging but inconclusive. Correct identification is on the order of 50%.

Subtask 2.5.2.3

(a) Row direction appears to be a major factor in the reflectance of crops such as corn, grain sorghum, and sugar beets. By extension, row direction may be an important parameter in identifying all such row crops. The data hint that there is more angular dependence in the HH signal return from crops with rows orthogonal to the look direction than in those with rows parallel to the antenna.

(b) Return is influenced by polarization in that like polarizations tend to be brighter than cross polarizations under similar gain conditions. Bare ground is an exception to this statement.

(c) In the case of available systems (X- and K-bands) range variations for non-row crops does not appear to effect radar return significantly. Similar means and standard deviations are characteristic of near, mid and far ranges for wheat and pasture. However, the radar returns for corn, sorghum and sugar beets appear to be angularly dependent.

Subtask 2.5.2.4

(a) For soils, variation in backscatter appears to increase at steeper depression angles and this variation is believed to be due largely to effects of moisture.

(b) Shallow depression angles appear to be most useful in making distinctions in soil roughness, although vegetation effects may cause confusion.

(c) It is very likely that cross-over points in radar backscatter, arising from combined effects of moisture and roughness, exist in the frequency and angular domains such that a moist fine textured soil "looks" identical to a dry, coarse textured soil — all other parameters equal.

(d) Our studies suggest that the generally quoted value of $\lambda/10$ for a smooth surface needs re-evaluation for angles greater than 30°. We recommend modeling studies to simulate the effects of soil texture under uniform conditions of moisture, slope and vegetation.

(e) The unique potential for sub-surface soil information from long wavelength systems should be evaluated along with panchromatic imagers.

Subtasks 2.5.3.1 and 2.5.3.2

(a) Interpretation of Ka-band imagery from Yellowstone Park Wyoming, Horsefly Mountain, Oregon, and Buck's Lake, California all reveal that regional, physiognomic vegetation mapping is possible with SLAR—especially in regions with markedly contrasting plant community structures.

(b) For vegetation analysis from SLAR, best results are obtained in regions where little information is lost due to shadowing. In mountainous areas better interpretation is possible when the flight line is orthogonal to the "grain" of the mountains.

(c) Recommendations for future vegetation data collection include: 1) multiple look directions; 2) 40% sidelap between passes.

(d) Frequency analysis of 50' resolution radar imagery is expected to yield information on plant community structure enabling identification of broad regional types.

(e) Estimates of timber volume seem impractical with coarse resolution imagery except insofar as gross values may be useful in highly remote areas. The possibility for calculating usable timber volume estimates from fine resolution, poly frequency imagery should be explored for use in monitoring the growth progress of large plantations, etc. The strategy may be very similar to that proposed for crop statistical estimates, i.e., average volume/acre X number of acres as calculated from imagery.

System Preferences for an Airborne Agricultural Imaging Radar

The studies which follow this section address various aspects of the type of imaging presently considered necessary to obtain agricultural data. Any active microwave sensor designed for an image output should approach the parameters given in Table 1.

Table 1

Parameters of a SLAR
for Agricultural Data Collection

frequency	Ka, X, L* (ultimately we suggest a broadband system in the 4-16 GH_z region)
resolution	1 - 5m
polarization	HH/HV/VV
geometry of output image	ground range display
dynamic range	expanded in low medium signal return, sliced in very low-high signal return.
depression angle	range limited to 10° at approximately 30 to 40° depression.

*L, although only limited work has been done, this may be important in collection of soil information.

The final image is a result not only of the SLAR system but the aircraft planning constraints. Our estimate, based on the following research, has shown that flight planning considerations may be as critical as systems parameters. These flight planning parameters include (1) the temporal sequencing of flights; (2) the time of day of acquisition; (3) the number and direction of flight lines; and (4) the consistency of equipment operation. Table 2 summarizes some preliminary findings related to flight planning.

Table 2

Time interval of missions:	20 to 30 days
Diurnal frame:	nearly identical time of day from mission to mission. Pre-noon to minimize effects of turbulence.
Mission coverage:	multiple look directions
Side lap:	multiple coverage; 40% for extensive area analysis.
Set operation:	as nearly consistent as possible from mission to mission; data should include flight information on roll, pitch, yaw, etc.

The above considerations are derived from analysis of available imagery, all of which is SLAR. We have no spaceborne data on which to approximate radar design parameters for Agriculture. Nevertheless, we feel that on a cost/benefit basis, a satellite system would be most appropriate. It is increasingly apparent that in order to chart future research efforts, a mechanism for information extraction and dissemination from microwave imagery is needed. The types of information obtainable for various levels in the decision-making hierarchy, the timeliness of the information extraction and the interpretation approach are all uniquely dependent on the system used to disseminate knowledge. For example, a federal or state agency monitoring the agricultural status of any given county seems hardly worthwhile (and may not even be relevant) if the results are not made immediately available to that county. At the other extreme, monitoring by local county agents may be inefficient, if their immediate needs differ from information required at the state or national levels. The purpose in this next section is to propose and discuss one strategy for an information system.

1.2 An Information System for Agriculture

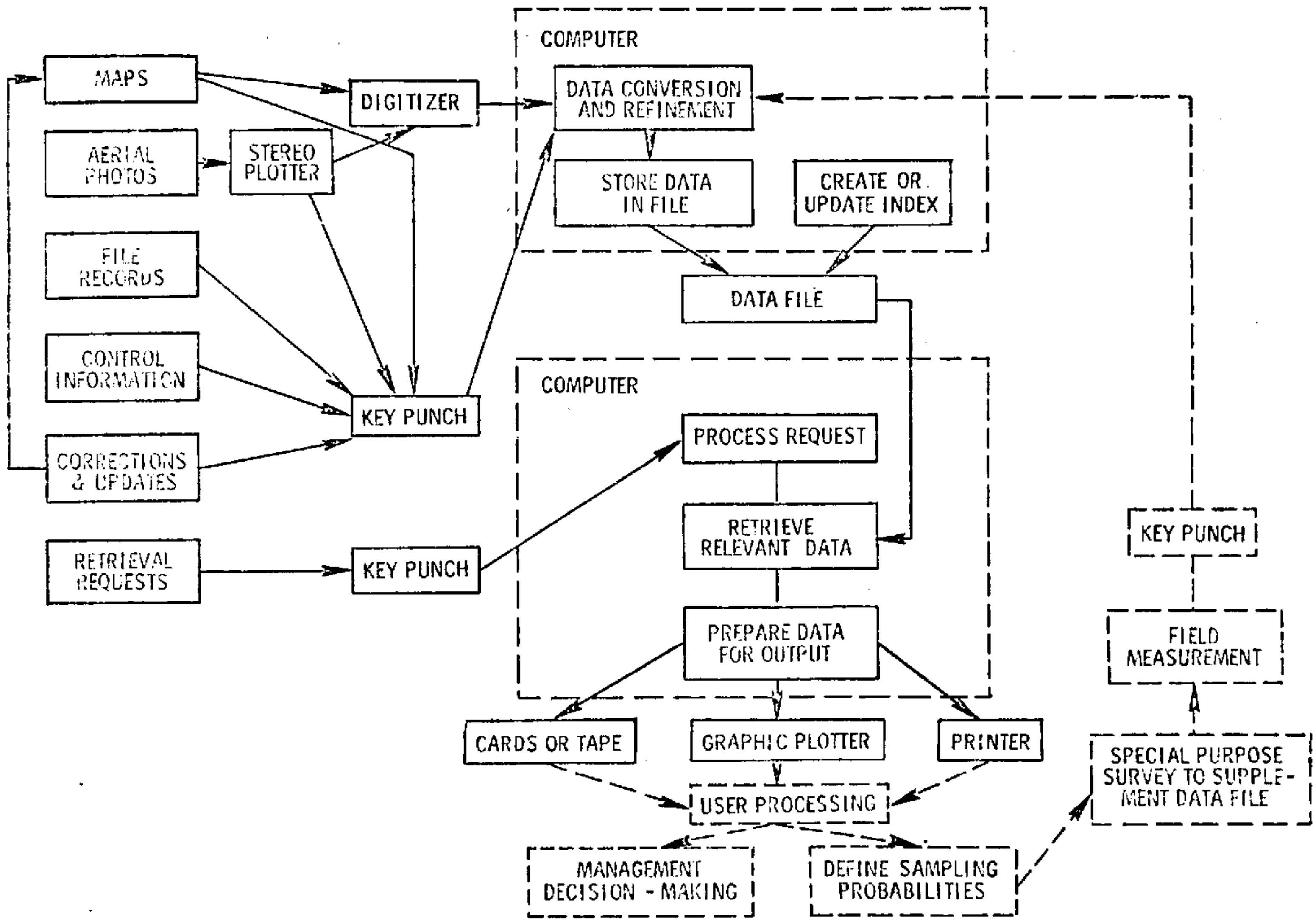
So much has been written about "information systems" for remote sensing that clarification of its use in the present context is essential. Holmes (1968), Fu, et al.(1969), Holmes and MacDonald (1969) and Langley, et al.(1970) have all described segments of an "information system" for agriculture based on multispectral scanner and photographic data, its manipulation and interpretation. These reports all concentrate on the means for converting data to information, but they fail to suggest where in the management hierarchy such conversion should take place or how the resulting information should be used. As Holmes and MacDonald state (1969, p. 629), "Recorded or telemetered data are put through preliminary data handling and reformating for delivery to a data processing section where data analysts correlate photographic and scanner or electronic camera data." When considered in terms of a system complete with feedback loops, these reports describe data acquisition and conversion systems rather than information systems. In short, there seems to be a preoccupation with automatic data processing (ADP) for discrimination and categorization in advance of clearly defined user needs. Those people who really need remote sensor data are "primary" users. Once they have extracted this information, data can be annotated and held for retrieval for use throughout the hierarchy.

Rather than regard the "user" as a nebulous entity who periodically makes predetermined requests of information from a computerized data bank, a more viable system would be one capable of catering to expected as well as "unusual" information needs from specific user groups. The system described in this report extends the strategies described elsewhere by focusing attention on the location for data conversion and the flow of information throughout the agribusiness community. In other words, it begins where most other systems terminate...at the user interface. In diagrammatic form the difference between this and previous approaches is shown in Figure 24.

Design and Function of the Information System

Heany (1968) outlines eight steps in the development of information systems for use in business. These are: (1) establish or refine an information requirement; (2) develop gross system concepts; (3) obtain approval; (4) detail the design; (5) test; (6) implement; (7) document; and (8) evaluate. Although it is true that the acquisition and processing aspects of remote sensor data in agriculture (that is, the ADP part) are now in stages four and five, the flow of results as information are, clearly, only in stage 2. It is essential that these two aspects be re-alligned, lest the former (by virtue of strength) leads us along uncertain paths, or the latter (by contrasting weakness) delays implementation.

Figure 24.



WRIS FLOW CHART (FROM LANGLEY ET AL. 1970)

Figure 25 outlines a concept of an information system for agriculture. In the terminology of systems design (Heany 1968) it can properly be regarded as a "manual information system." This implies that its utility lies fundamentally in human operations assisted by necessary computer and office hardware. However, it is more than a manual system in that to function successfully it will require ADP hardware and its associated software. These latter components are described elsewhere (Lorsch, 1968; Bernstein and Cetron, 1969); and usable versions are now being developed at The Kansas University Center for Research (Anderson, 1971).

According to stage 1 of the system, broadband microwave data are collected by a satellite designed specifically for agricultural monitoring (here referred to as AGRISAT). These data are then transmitted to a Data Return Facility, perhaps like the one planned for Sioux Falls, South Dakota to handle ERTS and EROS data (Geotimes, September 1971, p.26).

Stage 2 of the design takes advantage of information and expertise available at the local level (see subtask 2.5.2.1). The strategy thus enables agricultural county agents (representative of ASCS, SCS and AES) to "call" data as required from the Return Facility to extract both their routine and specific information needs.

As presently conceived, information may be extracted most easily through a combination of human interpretation and ADP techniques. For routine determinations of agricultural statistics (e.g. wheat acreage planted and harvested) automated dichotomous keys provide one approach (Coiner and Morain, 1971). By this strategy the in-depth knowledge of events and trends in agriculture provided by local agents is retained in the system. Furthermore, this knowledge can be put to effective use implicitly and explicitly in the process of creating interpretation keys for their own county (see subtask 2.5.2.2).

Once created, the keys should be able to rapidly process data coming in on a regular basis. The variety of keys and related ADP algorithms would depend upon the kinds of information desired by local users and by the needs of higher levels in the agricultural chain-of-command. The obvious advantage of beginning information extraction at the "grass roots" level is that non-aggregate data can be employed. Timely maps of agricultural production, of diseases and other crop damage, trends in cropping practices, introduction and diffusion of new crops, and a host of other local phenomena could be more readily produced and monitored by beginning data interpretation at the county level. Figure 26 is an artist's conception of a future county

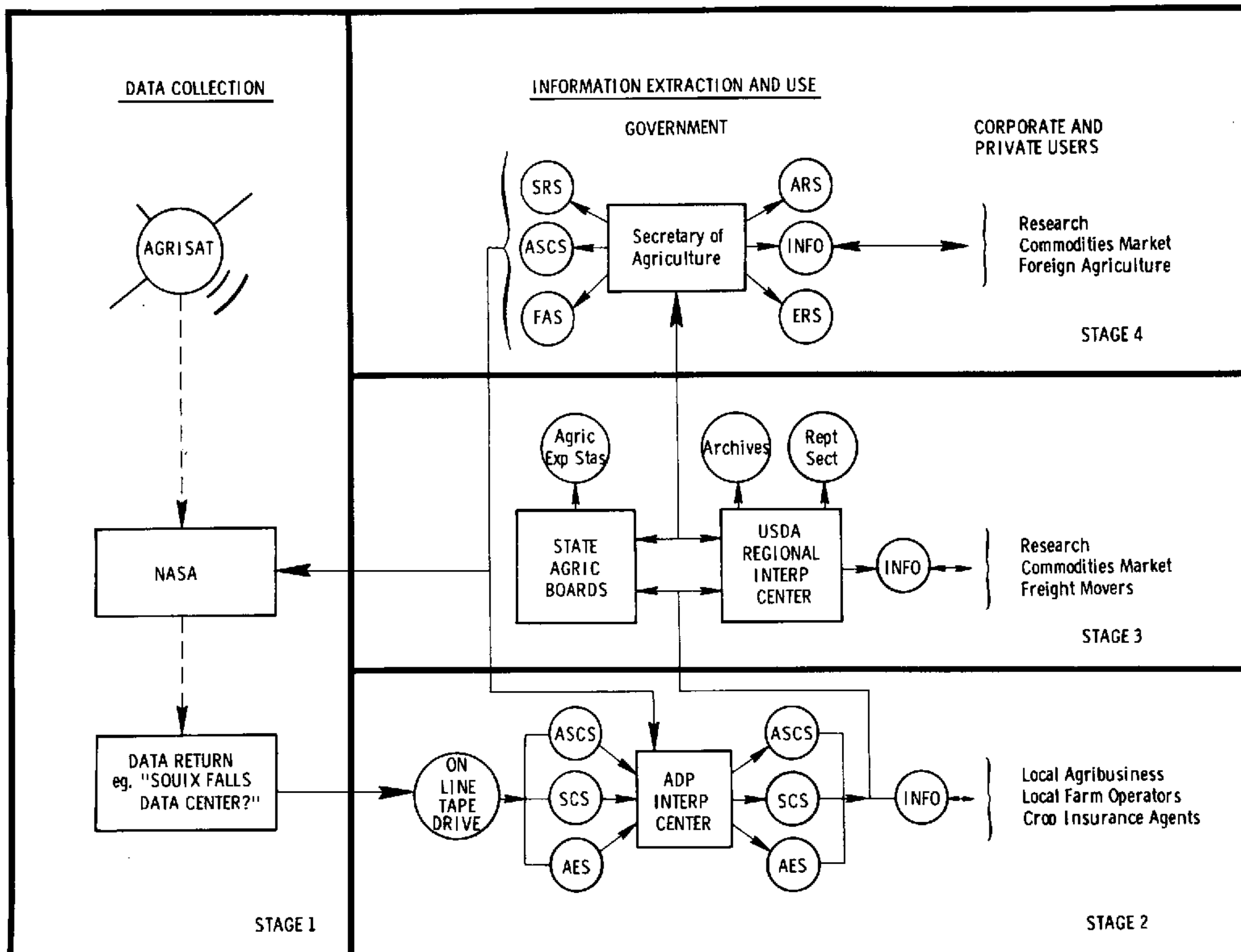
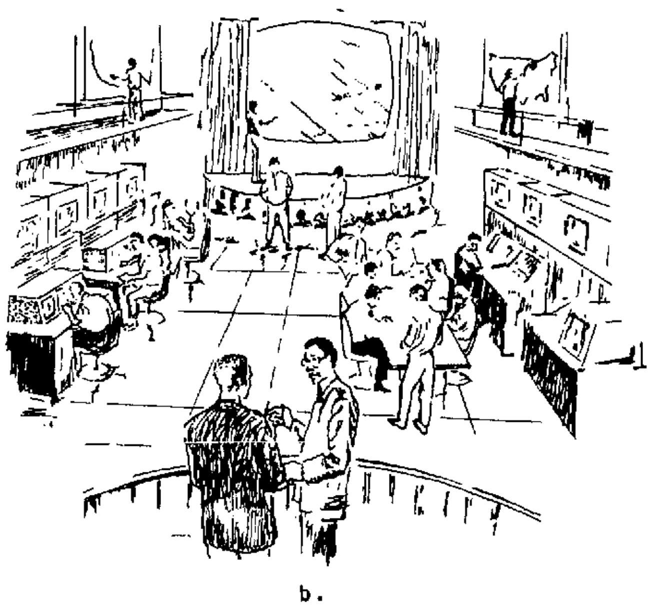

DATA COLLECTION
INFORMATION EXTRACTION AND USE
GOVERNMENT
CORPORATE AND PRIVATE USERS
AGRISAT
SRS
ASCS
FAS
Secretary of Agriculture
ARS
INFO
ERS
Research
Commodities Market
Foreign Agriculture
STAGE 4
Agric Exp Stas
Archives
Rept Sect
STATE AGRIC BOARDS
USDA REGIONAL INTERP CENTER
INFO
Research
Commodities Market
Freight Movers
STAGE 3
NASA
DATA RETURN eg. "SOUIX FALLS DATA CENTER?"
ON LINE TAPE DRIVE
ASCS
SCS
AES
ADP INTERP CENTER
ASCS
SCS
AES
INFO
Local Agribusiness
Local Farm Operators
Croo Insurance Agents
STAGE 1
STAGE 2

Figure 25.

a.



b.

Data Processing Facilities in Agriculture
a) The County Agent's Office; b) The Regional Office.
(After Lorsch, 1968)

Figure 26.

agricultural office with automatic image and digital processing equipment.

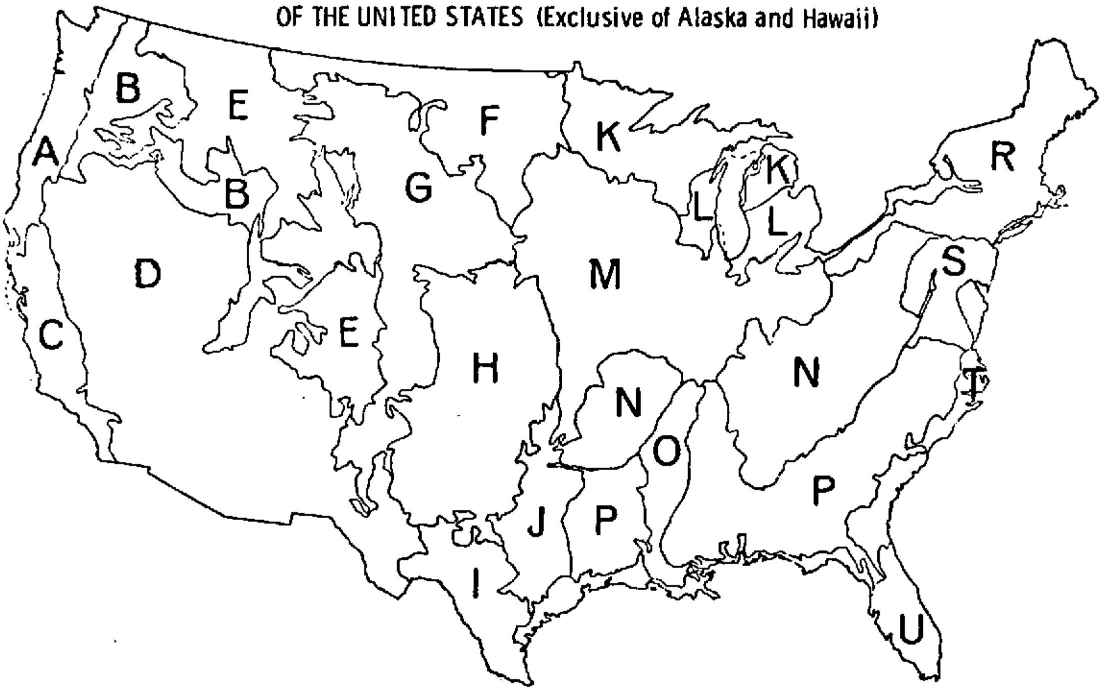
Following the initial data review and information extraction by county agents, stage 3 of Figure 25 indicates a vertical flow to state agricultural boards and USDA regional centers. What was considered "information" at the county level now becomes essentially "non-aggregate data" requiring further synthesis and re-evaluation to meet the information needs of regional analysts and state statisticians. It is at this level that policy decisions begin to play a significant role in national agribusiness. Thus, these intermediate levels in the hierarchy are as important as the primary level, but for quite different reasons.

Remote sensing centers for agricultural information might be located in each of the presently recognized 20 farm production regions of the United States (Figure 27). Counties within each of these regions would pass their processed non-aggregate data and the information derived from them to similar ADP units at the center (Figure 26B). By following this path, and remembering that each county has based its interpretation on locally prepared algorithms, much of the distance-decay problem associated with identification and categorization over large areas is effectively avoided. In the parlance of probability theory, each county in the region becomes a "training area," thus diminishing greatly the "prediction area."

Taking the Central Great Plains Winter Wheat and Range Region as an example (H), a total of ±250 counties, one can more easily picture the kinds of information extractable at stage 3. A sensing program aimed specifically at winter wheat with data arriving bi-monthly from April through July would provide the following near "real-time" information: (1) acres planted and harvested; (2) northward progress of ripening and harvest; (3) direction and rate of spread of infestations; (4) estimates of soil moisture status and drought prediction; (5) allocation of railroad stock; (6) yield prediction (probably based on per/acre yield estimates coupled with acreage data). Together with the archival function of regional centers, one might add to the above list: (7) spread of innovation (cultivation practices and new crops or crop varieties); (8) historical summaries.

In the scheme presented here, regional centers are regarded as the seat of archival data; namely, digital tapes, imagery, supporting ground data, etc. From these inputs information can be assembled for use at the national and international levels. Stage 4 of the design represents the top of the agricultural hierarchy in

LAND RESOURCE REGIONS AND MAJOR LAND RESOURCE AREAS
OF THE UNITED STATES (Exclusive of Alaska and Hawaii)



A NORTHWESTERN FOREST, FORAGE, AND SPECIALTY CROP REGION

B NORTHWESTERN WHEAT AND RANGE REGION

C CALIFORNIA SUBTROPICAL FRUIT, TRUCK, AND SPECIALTY CROP REGION

D WESTERN RANGE AND IRRIGATED REGION

E ROCKY MOUNTAIN RANGE AND FOREST REGION

F NORTHERN GREAT PLAINS SPRING WHEAT REGION

G WESTERN GREAT PLAINS RANGE AND IRRIGATED REGION

H CENTRAL GREAT PLAINS WINTER WHEAT AND RANGE REGION

I SOUTHWESTERN PLATEAUS AND PLAINS RANGE AND COTTON REGION

J SOUTHWESTERN PRAIRIES COTTON AND FORAGE REGION

K NORTHERN LAKE STATES FOREST AND FORAGE REGION

L LAKE STATES FRUIT, TRUCK, AND DAIRY REGION

M CENTRAL FEED GRAINS AND LIVESTOCK REGION

N EAST AND CENTRAL GENERAL FARMING AND FOREST REGION

O MISSISSIPPI DELTA COTTON AND FEED GRAINS REGION

P SOUTH ATLANTIC AND GULF SLOPE CASH CROP, FOREST, AND LIVESTOCK REGION

R NORTHEASTERN FOREST AND FORAGE REGION

S NORTHERN ATLANTIC SLOPE TRUCK, FRUIT, AND POULTRY REGION

T ATLANTIC AND GULF COAST LOWLAND FOREST AND TRUCK CROP REGION

U FLORIDA SUBTROPICAL FRUIT, TRUCK CROP, AND RANGE REGION

Figure 27.

this country. It consists of a host of Services, Sections and Branches, the information needs for which are so complex that they cannot be considered in detail here. The most immediate needs are discussed by Houseman (1969), ERS (1967), Park (1969) Mayer and Heady (1969) and others. As examples of the information derivable from the system described here, we cite particularly the work of Mayer and Heady.

Among the most sweeping needs facing policy makers in American agriculture are those describing rates of change. Especially important are the mutually related causes influencing farm size and number, farm employment, capital investment, effectiveness of production control programs, yield trends, and the supply and demand of crop land. As will be shown, information pertaining to some of these changes can be obtained by remote sensors.

EXAMPLE 1

In Mayer and Heady (1969), for example, the potential land available in the United States by 1980 for the seven major crops is given at 252 million acres (p.381). The distribution of these acres, including land idled by government programs in 1965, is given in Figure 28. Among other parameters, it is almost certain that the distribution of idled land will change in the intervening decade before 1980 according to supply and demand functions created by changes in government programs. Retired land in one region may come under renewed cultivation forcing land in another region to pass out of production. In Figure 29 (a-d) the geography of idle land in 1980 is predicted on the basis of 4 distinct production and trade programs. Even a quick glance reveals the difference between an acreage quota program (29a) and crop production under a free market economy (29c). The quota system apparently distributes idle land fairly equitably throughout the 144 recognized producing regions. The free market situation, however, eliminates from production those regions that cannot compete.

EXAMPLE 2

Production on land not idled can be estimated by appropriate strategies. Average feed grain yields for 1980, for example, are predicted by Mayer and Heady by the equation (1):

$$Y_{fgk} = \sum_{i=1}^{4} P_{ik} Y_{ik} \qquad (1)$$

where Y_{fgk} = weighted average feed grain yield in the k^{th} production region, $k = 144$

P_{ik} = proportion of feed grain acreage devoted to i^{th} feed grain crop in 1964 (calculated as $P_{ik} = A_{ik} / \sum_{i=1}^{4} A_{ik}$ where A = acreage)

Y_{ik} = actual average yield of the i^{th} crop in the k^{th} region

Figure 28a.

Cropland for major field crops by regions projected for 1980.*

Region	1980	
United States	251,171	(Thousands of Acres)
A. Northeast	5,711	
B. Lake States	24,708	
C. Corn Belt	70,306	
D. Northern Plains	60,613	
E. Appelachian	11,654	
F. Southeast	11,483	
G. Delta States	11,265	
H. Southern Plains	30,712	
J. Mountain	16,434	
K. Pacific	8,285	

* Land base is for wheat, corn, oats, barley, grain sorghum soybeans, and cotton. Other cropland used for fruits, vegetables, and minor crops has been subtracted from the total. The figures do not include land devoted to tame hay in rotation with other crops or grown alone. But the figures do include cropland idled under government programs in 1965.

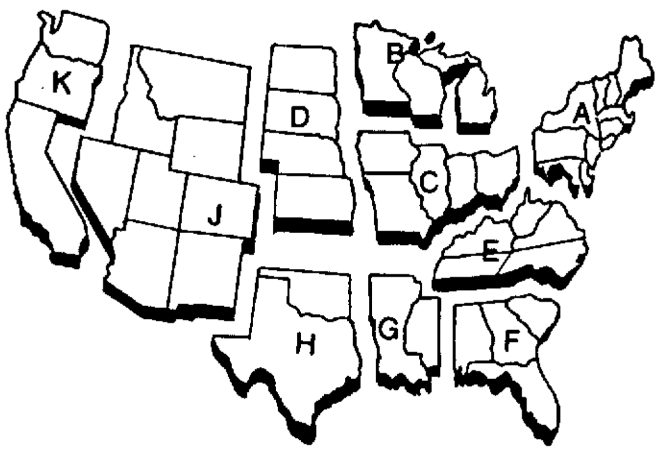
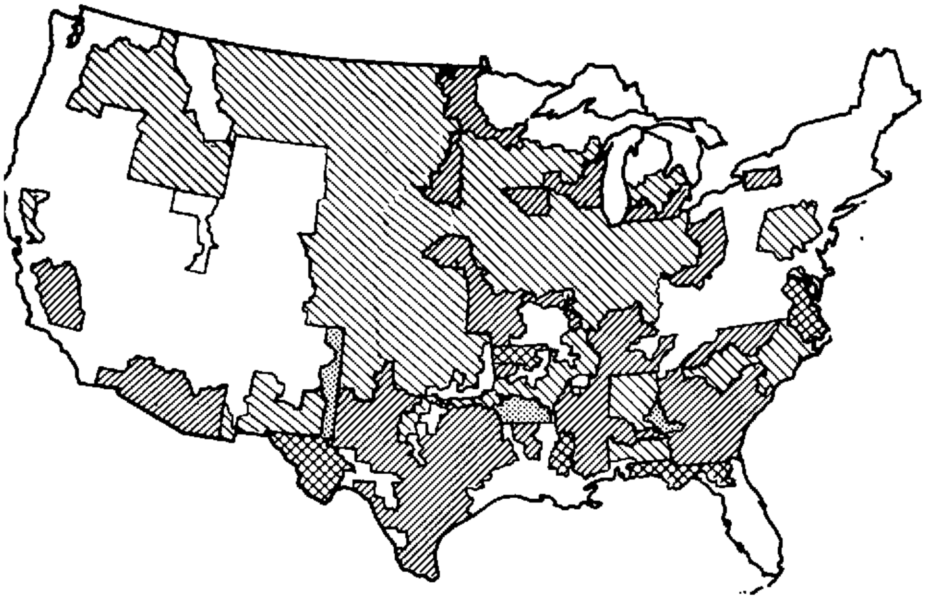


Figure 28b. The 10 farm production regions of the United States.

Note: The Farm production regions shown in 5b. are not the same as Crop production regions as delineated by Mayer and Heady. The acreages in 5a. are derived from aggregating data for all 144 CPR's and partitioning according to FPR'S.

Figure 29.



a. PROPORTION OF TOTAL CROPLAND UNUSED FOR MAJOR CROPS IN EACH OF THE 144 CROP PRODUCING REGIONS UNDER AN ACREAGE QUOTA PROGRAM WITH TREND LEVEL EXPORTS IN 1980.

b. PROPORTION OF TOTAL CROPLAND UNUSED FOR CROPS IN EACH OF THE 144 PRODUCING REGIONS UNDER A FREE MARKET WITHOUT COTTON QUOTAS AND WITH TREND LEVEL EXPORTS IN 1980.

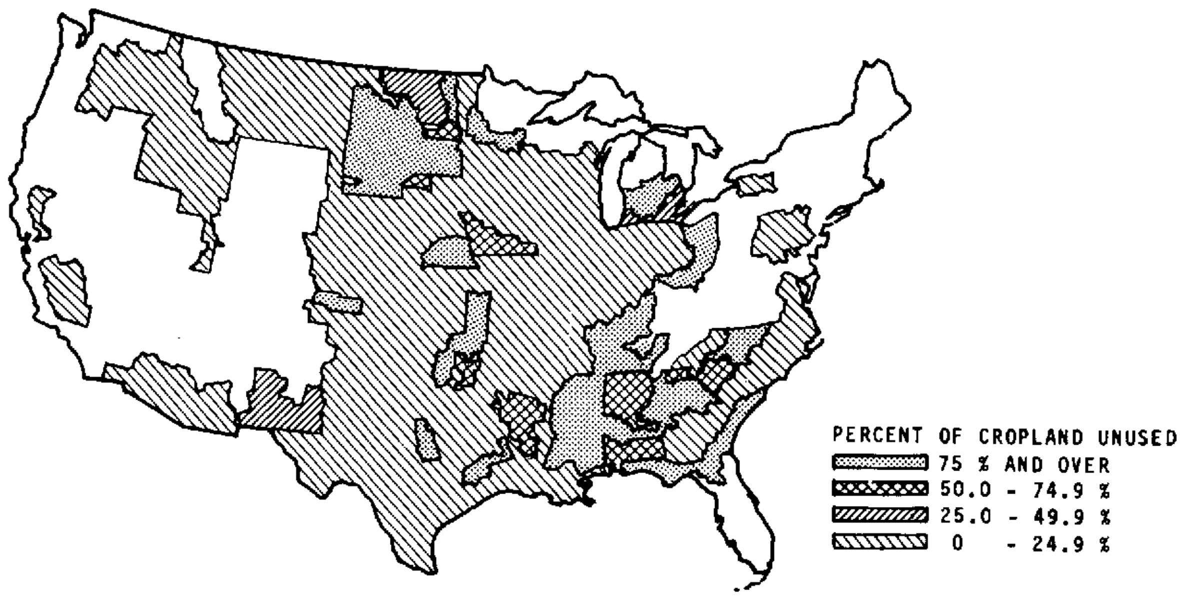
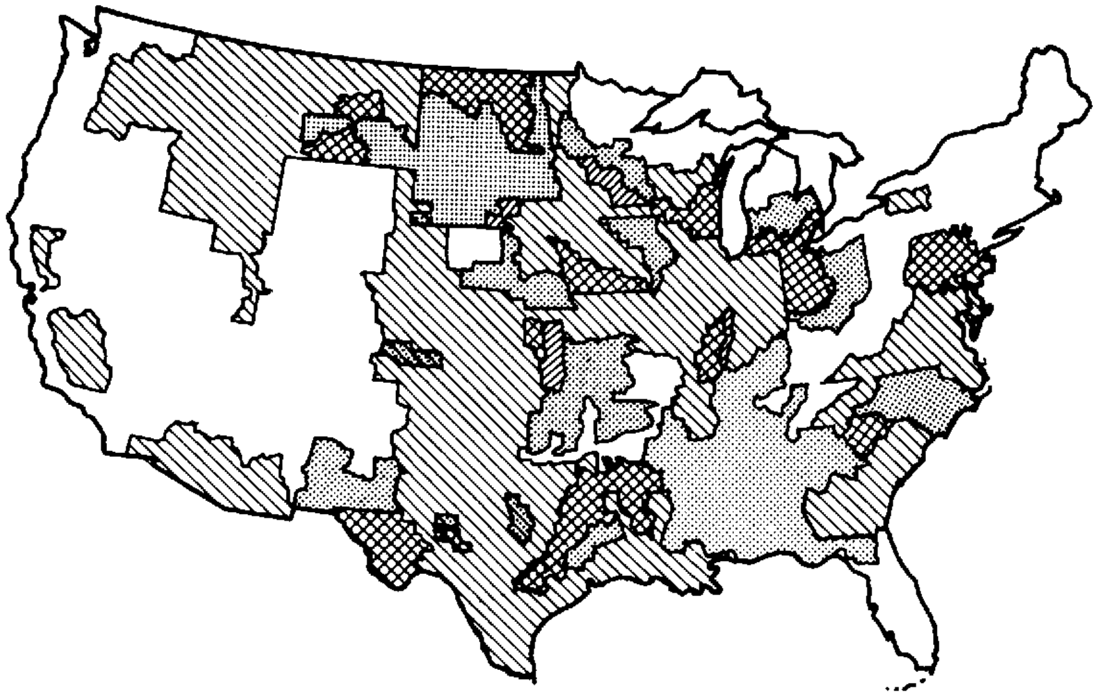
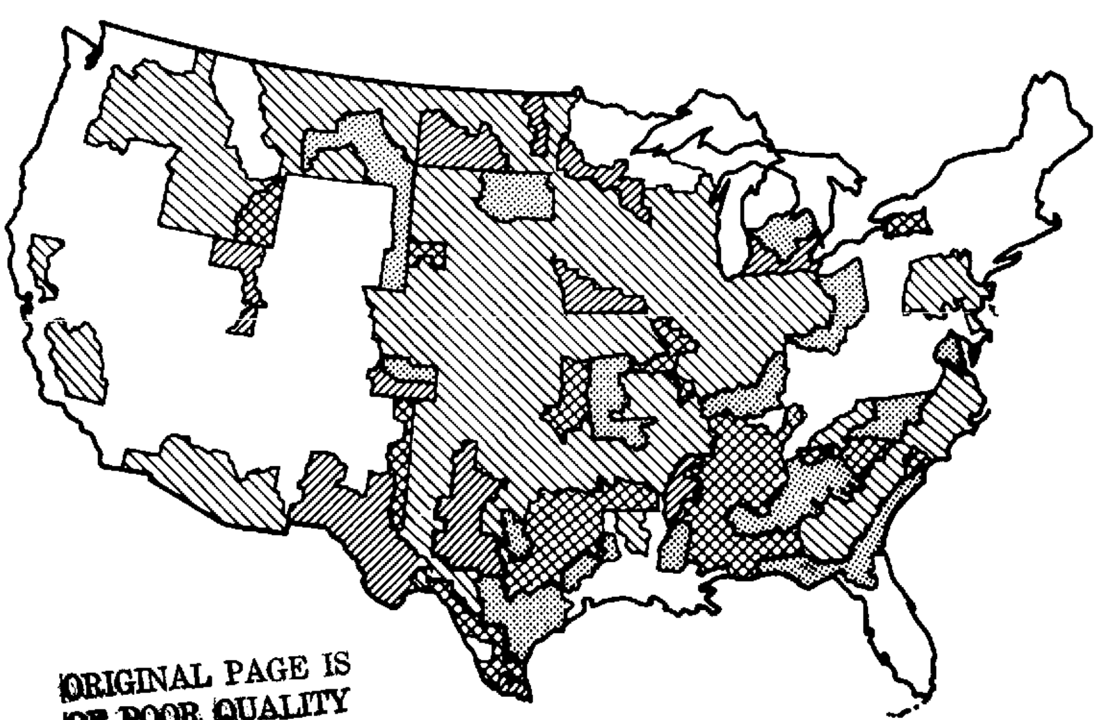


Figure 29.



c. PROPORTION OF TOTAL CROPLAND UNUSED IN EACH OF THE 144 CROP PRODUCING REGIONS FOR MAJOR CROPS UNDER A FREE MARKET MODEL WITH 1965 LEVEL EXPORTS IN 1980.

d. PROPORTION OF TOTAL CROPLAND UNUSED FOR MAJOR CROPS IN EACH OF THE 144 CROP PRODUCING REGIONS UNDER A FEED GRAIN PROGRAM WITH TREND LEVEL EXPORTS IN 1980.



In both of the above examples (distribution of idle land and crop yield), it is obvious that acreage data for various agricultural land uses is of central importance. It has always been so in agricultural monitoring, and, at least in American agriculture, this information has traditionally been supplied from lower to upper levels in the community. Consequently, the case for utilizing remote sensors for data acquisition and for dissemination of information by the scheme suggested here needs further clarification and justification. On-going work in this area will focus on a cost/benefit analysis of the proposed system.

RADAR SENSING IN AGRICULTURE: AN OVERVIEW*

Stanley A. Morain

Task 2.5.2 Radar Sensing in Agriculture: An Overview*

For any sensor system time is a key discriminant. Research on the spectral reflectivities of plants has shown that instantaneous unique signatures are unlikely to exist and that time-sequential imaging may be required to identify crops (Haralick, et al., 1970; Park, 1969; Wiegand, et al., 1969). Basically there are two temporal frameworks in which to work: seasonal and year-to-year. Under both there exist within- and between-crop radar variations, but the economic and social implications attendant upon each are vastly different. Radar work to date has been largely under the heading of seasonal change between crops (cf. Schwarz and Caspall, 1968). Results from these efforts have shown that numerous variables must be considered to make even the simplest determinations.

The intent of this summary is to outline current capabilities for radar in agriculture and to sketch a few economic benefits attending their use.

Seasonal Changes Between Crops

Schwarz and Caspall (1968), Morain, et al. (1970), and Morain and Coiner (1970), working with imagery from Ka-, Ku-, and X-band frequencies respectively, have shown that major agricultural crops can be segregated, though not unambiguously identified, using simple two-dimensional plots of HH and HV film densities. In Table 3 percentages are given to indicate the degree of isolation by crop type for each of the systems.

Although the data** represent only a few crops and at present fall below acceptable levels of accuracy for most crop reporting services in this country,

*Condensed from: CRES Technical Report 177-14, December 1970.

**These values should not be used to judge system capabilities. They were derived from imagery taken at different times in the growth cycle and from images of highly varying quality.

TABLE 3

CROP SEGREGATION ON SCATTERGRAMS
AS A FUNCTION OF RADAR FREQUENCY
AND DATE IN THE GROWING SEASON

Crop Type	7 - 66 Ka-Band %	9-4-69 Ku-Band %	9-15-69 Ka-Band %	10-69 X-Band %
Wheat	Not Present	--	--	
Grain Sorghum		--	69	77
Corn	82 (cropped)	28	92	
Alfalfa		50	--	
Sugar Beets	92	--	97	64
Bare Ground	91	90	83	91

they suggest a capability that might benefit agriculture in several ways. It is well known that reliable crop statistics for many developing countries do not exist, or, become available too late for any but historical use. Regional and world-wide figures for total cultivated acreage, crop diversity, or acres in particular crops would be welcome input for agricultural planners both here and abroad. Tracing trends in global cultivated acreage would aid significantly in formulating population policies and in making production or carrying capacity predictions (Ehrlich and Ehrlich, 1970). Bachman (1965), Kellogg (1963), and others have stressed that most developing countries still have scope for increasing agricultural acreage, though this potential should decrease with increasing population. As illustrated in Table 3, the bulk of all cultivated acreage would be revealed at some time during the cropping cycle as bare ground. The advantage of using either airborne or spaceborne radars as monitors for this is their ability to operate in clouded environments, where low sun altitudes prevent photographic sensing, or where small scale synoptic coverage is demanded.

It is not, in fact, the ability of radar to collect useful information that stymies its wider application, but our ability to interpret the data. As Haralick, et al. (1970) point out, it will take a Herculean effort to create automatic data processing routines for crops whose spectral properties vary continuously in time and space. Wheat, the world's most important crop, is produced in scores of varieties under as many cultivation practices. Clearly, it is unrealistic to expect radar or any other sensor to provide interpretable agricultural data without knowing the nature or magnitude of within-crop geographic and phenologic variations. Basically, the problem reduces to knowing which radar and terrain parameters are critical in making accurate land use identifications. In searching for these we have overlooked one of the simplest, most useful aids to identification yet devised -- the dichotomous key (see subtask 2.5.2.2).

Using keys, and provided imagery can be disseminated quickly enough for primary agencies to interpret the data in at least a sampling framework, improvement in statistics from the crop reporting services could be realized. At present, data are gathered by an army of volunteer observers in coordination with regularly mailed questionnaires. By the end of the year it is often true that acreages, and yield predictions for wheat in the Great Plains are accurate to within 3 per cent. However, predictions prior to harvest are often gross estimations. It is not in improving accuracy for which radar holds great promise but in providing early estimates and in decreasing uncertainties inherent in the predictions.

Prompt and efficient interpretation of radar imagery generated at regular intervals throughout the growing season could dramatically improve such statistics as number of acres in particular crops, progress of the harvest, number of acres harvested and others. All of these would result in better planning at the county and state level, even if the margin of improvement in accuracy were small.

Seasonal Changes Within Crops

Detecting within-crop changes assumes that the crop has been identified. The most dramatic benefits to accrue from agricultural sensing reside in our ability to unravel these within-category changes. The following paragraphs outline the magnitude of these benefits and the evidence behind our belief that they can eventually be achieved.

Figure 30 illustrates actual and anticipated radar images for crops as they might appear at Ka-band four times in the growing season. Wheat is especially interesting. It suggests that in the Winter Wheat Belt economy, statistics such as acres planted, harvested, and lost could be calculated. In June the drop in return from these fields would signal that harvest had occurred. Such changes through time could almost certainly be tallied. One requirement, however, since wheat is harvested somewhere in the world all the time (Thompson, 1969) is the ability to obtain synoptic coverage every 2-3 weeks regardless of weather conditions.

During Spring in the Winter Wheat Belt natural pasture, perennial alfalfa, and wheat represent the only growing crops and should be mutually distinguishable on the basis of terrain context and image attributes. By March or April an estimate of winter wheat acreage could be made and compared to estimates from the previous season. Under the present system the first forecast in Kansas is made in December, followed in the Spring by monthly up-dates beginning in April. Final tabulations appear six months after the harvest (Pallesen, 1970).

What value would radar derived crop statistics have for society? One answer is that by improving the precision of weekly and monthly crop reports,better yield predictions could be made. Errors of a few tenths per cent in acreages for a crop as important as wheat may send shock waves throughout the network of domestic

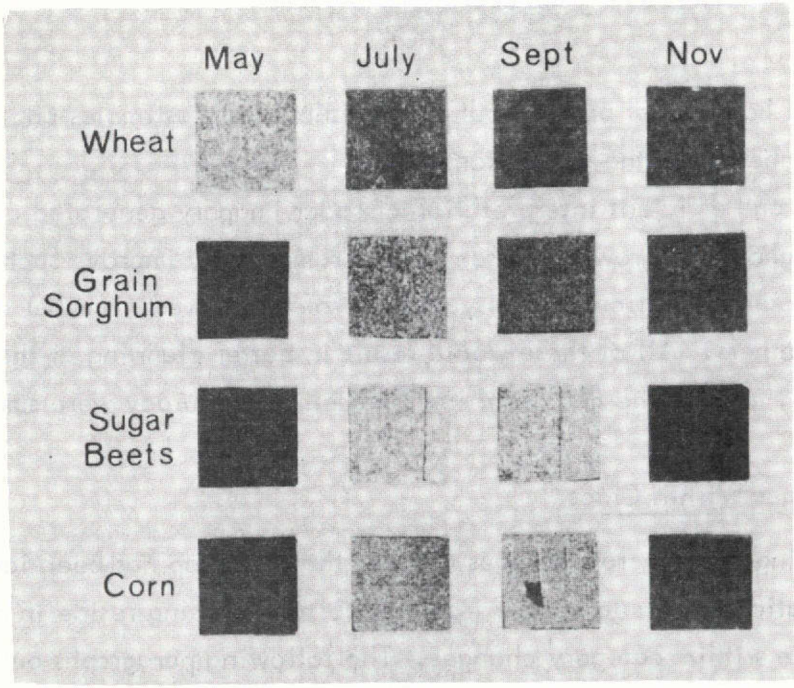


Figure 30. Typical radar appearance at Ka-band for economically important crops at Garden City, Kansas (derived from July and September imagery) arrayed against their expected appearances at the beginning and end of the growing season (May and November).

and foreign trade. World-wide surveillance of wheat by radar might help alleviate problems associated with planning acreage allotments, periodically reassessing estimated production. Recommendations might be feasible early in the season to either graze or plow under surplus acreage, preventing excessive production; or to increase southern hemisphere acreage (Australia, Argentina) to compensate for poor harvests in the northern hemisphere.

The most important aspects of within-crop seasonal change are those subtle differences associated with crop quality or variety. Both are part of a complex yield function the discerning of which lies at the foundation of agricultural reconnaissance. With the "Green Revolution" in progress in Asia (Wharton, 1969) it is imperative that both acreage and variety be considered in production estimates. Willett (1969) reports that farmers in southwest Asia have already shown their enthusiasm for adopting new varieties, but that at the national level marked inequalities exist in the rates of adoption. By the 1967-68 reporting period India had converted 20 per cent of its wheat acreage to new varieties whereas Pakistan had converted only 12 per cent.

At present there is no evidence that radar, or any other sensor, can detect (at acceptable levels of confidence) differences between varieties, let alone identify them. There may be hope for some estimates, however, by using surrogates related to time (if some varieties ripen earlier or permit double or triple cropping) or space (if they occur in restricted localities) (Brown, 1968). Unlikely to be detected are small differences in σ^o arising from increased head size, longer stalks, or other geometric parameters. For the foreseeable future it seems that radar's most valuable contribution to yield prediction rests largely with acreage calculations inserted into a more comprehensive yield function.

Two aspects of crop quality lend themselves to radar monitoring. One is moisture status; the other is physical damage due to lodging, hail damage, or extreme defoliation. Present evidence of how moisture status influences σ^o is inconclusive. This evidence resides in mottling patterns within fields. We have observed, for instance, that tonal irregularities exist for both corn and sorghum in October. At this time of year these crops are harvestable but differences in planting date, irrigation history, and local variations in ripening are manifested as tone mottling. In most instances crop geometry within corn or sorghum fields can be assumed to be uniform and that differences within fields are due to moisture patterns. To confirm this assumption, experiments are needed to derive crop dielectric as a function of changing moisture and to establish the backscattering cross-sections of crops at various moistures and stages of growth.

Physical damage (lodging or extreme defoliation) arising from heavy rain or hail can be detected on fine resolution data as a change in tone or texture. In mature corn, when row orientation is orthogonal to look direction, differences are observable which pinpoint areas of damage or poor quality (see subtask 2.5.2.3). As a parameter of the yield function, cause of poor quality is not important. It is sufficient to know simply that low quality fields are also low yielders and should be weighted accordingly in making production predictions. However, if causes and effects can be related by using radar, tremendous economic benefits accrue. By following the rapid expansion of diseased areas or by tracing damage along storm tracks (both of which demand near all-weather capability) assessment of economic loss or preventive measures could be quickly made. The cost of monitoring would be small compared to the savings. In Kansas alone loss of sorghum from aphid infestations, which spread across the state in two weeks, amounted to $14,733,000 in 1968-69 (Kansas Board of Agriculture, 1970). Over $13 billion was lost to American agriculture in 1969.

Year to Year Changes Between Crops

The benefits of long term agricultural sensing have not been seriously considered. Land use histories compiled from data collected over the years and stored for rapid retrieval could be useful in developing production control measures. In higher echelons there is a tradition of juggling the amount of land planted to control surplus and deficit (Doll, et al., 1968). However, problems of cross compliance* and input substitution have hindered any startling successes. By using automatic data processing, accurate regional histories and local land use trends could be mapped. Such projects are not possible today because historical records of field size, crop type, or production are not available. It would be highly desirable to trace diffusion rates and directions of new crops (varieties?) or of the development of farm-to-market road nets (Brown, 1968); to follow the geographic spread of innovation such as the use of polyethylene protectors on sugar beet seedlings or the use of sub-surface asphalt layers; and to monitor the progress of land reform policies. Efficiency of production has been the keynote of 20th Century agriculture; yet, the policies instituted to achieve that efficiency are mostly based on inadequate aggregate** statistics rather than detailed local data. Disaggregation may hold promise for substantially improving agricultural economic theory, and for this reason alone radars may prove their value by supplying synoptic coverage of any desired region.

Year to Year Changes Within Crops

The least studied aspect of agricultural surveillance, the gradual changes in crop reflectivities over the years, may ultimately be the most important in aiding plans for world food supplies and production since these indicate the spread of the "Green Revolution" or improvements in crop vigor. Most of the increase relates to gradually improving yields which leads us to agree with Pendleton (1970) that the

* Cross-compliance refers to participation in several government programs sometimes with conflicting requirements.

**Aggregate statistics refers to averages rather than individual values. See, for example, Grunfeld and Griliches, 1960.

concept of a "yield plateau" is a myth. Increasingly man must rely on greater production from each acre to feed expanding populations. The best mechanism for doing this is by creating better varieties and engaging in other forms of input substitution; namely, fertilizer application, irrigation, etc. We are quite uncertain how radar will prove economically beneficial, but certainly a most worthy pursuit would be to explore the numerous possibilities.

Subtask 2.5.2.1

LOCAL LEVEL AGRICULTURAL PRACTICES AND INDIVIDUAL FARMER NEEDS AS INFLUENCES ON SLAR IMAGERY DATA COLLECTION*

Floyd M. Henderson

Introduction

Crop identification has long been one of the objectives of radar imaging systems. Yet, there are many phenomena that can be studied apart from this one simple aspect. It is the purpose of this paper (1) to discuss the complexities and variables in land use practices that affect crop variation and lead to observed differences in landscape patterns from region to region, (2) to illustrate that everything in the environment is so closely interrelated that an attempt to isolate one factor is extremely complicated, and (3) to describe and list other information obtainable from radar apart from crop identification.

Remote Sensing at the Local Level

What a farmer thinks and how he perceives his land are important variables determining the patterns ultimately imposed on the landscape. His perceptions of what crop and variety to plant; when to plant it; how much to plant; where to plant it and in how large a field; whether to irrigate; how to irrigate and when; how to plow and plant a field; his idea of the future market and government programs; and

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*Condensed from CRES Technical Report 177-15, July 1971.

how and when to control weeds will affect each and every field. The ways and extent to which such decisions affect the imagery will vary among sensors, but it is a variable confronted by the interpreter in analyzing the inter-connected and related aspects of the environment. It is small wonder that imagery anomalies and inconsistencies result when all the physical variables possible are crossed with all the cultural perceptions of how to vary an environment. It is apparent that land use practices are as variable as the mechanical parts of the sensor. Data that are needed to improve farm management as perceived by the farmer and county agent are assessed with regard to radar's potential to supply answers.

Until recently, the information needs of users at primary levels (farmers and county agents) have been largely neglected (Lorsch, 1969). Yet, it is at this level that many of our broadest claims for uses of remote sensor data are made. In July, 1970, data were collected in interviews with 112 farmers and agricultural agents. By working at the local level, it was possible to determine some of the needs regarding land use and farming practices as perceived by these people. Three counties (Finney, Wichita, and Grant) in the High Plains of Western Kansas were selected to serve as a study area.

This is admittedly a small sample considering the total number of farm types and operations in the United States. Problems paramount in other environments have not been determined but will surely have an impact on the potential usefulness of radar programs. In compiling responses to the interview, a decision was made to include only those answers most often given to avoid minor or singular requests. Those designated with an asterisk (*) indicate possible radar applications. Clearly, many of the problems listed are not amenable to radar analysis or to radar analysis alone. It should be noted also that asterisks represent present as well as potential future capabilities. A complete defense of each present or future application is beyond the scope of this report; consequently, a brief summary follows relevant responses.

In reply to the first question "Which aspects of your farm and its operation would you like to know better but cannot now determine or predict?" farmers answered:

(1) Proper fertilizer application -- optimum time and amount.

*(2) Land production capability -- This might prove possible by measuring (1) crop yield by field; (2) the slopes and drainage systems of the land;

(3) soil condition, i.e. existing nutrients in soil, what fertilizers are needed, degree of soil salinity; and (4) determining better crop rotation strategies. The ability of radar to monitor and aid the calculation of (1) and (4) might enable algorithms to be applied to indicate a field or area's production capability. To date, however, only radar's ability to determine slope and drainage system (2) has been proven (McCoy, 1969). The detection of soil salinity and other soil condition changes might prove feasible in the future if the dielectric properties of these soils can be more accurately defined. Use of dichotomous keys indicates that consistent crop identification may be possible in the near future with fine resolution radar. With these data it should be possible to relate ground truth information and expand the key to detect other crop parameters.

(3) Knowledge of expected market prices early in planting season.

(4) Long range accurate rainfall prediction before planting.

(5) What the next government price supports are going to be.

(6) Which crops to plant and how many acres per crop.

*(7) Accurate irrigation guidelines (e.g., optimum time and duration of application). Periodic analysis of fields could be made by a sensor system capable of determining soil moisture and/or crop vigor. At a specified soil moisture content or degree of plant stress, a signal from the sensor could be sent to a computer center which would in turn send a signal to the automatic irrigation system and water would be applied to the field. The actual implementation of such a system is obviously somewhere in the future. Due to present system limitations it is impossible to know if such a radar - satellite - computer - automatic field water applicator chain will function on a large scale. However, studies by MacDonald and Waite (1971) and Hardy, et al., (1971) have shown that microwave imaging systems carry moisture content information in their near-range presentation. It seems possible that with further study, the moisture relationship viewed in the radar image may be correlated with moisture requirements of crops.

*(8) Soil moisture and content -- Differences in soil moisture might be detectable by radars capable of penetrating the surface. The differences in

return (e.g. grey level or texture) of certain fields would indicate the amount of soil moisture present. See also number 7 above.

(9) Water Table level.

(10) Prediction of hazards (e.g. hail, tornadoes).

*(11) Periodic soil analysis to determine soil fertility -- This might be possible in very general terms. It must also be remembered that a soil's fertility is relative to the crop being grown. A change in crop yield or changes in a bare field's appearance, as seen from time sequential imagery over a period of years, might indicate a change in soil nutrients. Extreme cases such as a rise in salt content, which will in turn influence the dielectric properties of the soil, might be more easily "spotted." A dichotomous key might be used to develop a detection capability.

(12) Income stability.

(13) How to make a profit on a farm.

(14) How to increase yields.

*(15) Early plant disease and insect infestation detection -- Variation or anomalies in a field's texture and/or tone pattern might indicate a disease or infestation in a crop. If a sensor could relay this information fast enough and early enough to the farmer, proper preventive measures could be completed to minimize crop loss. Other farmers in the area could be warned, so precautions could be taken by them. Again a dichotomous key procedure might be developed to indicate if field anomalies were a result of disease, or of crop and soil variations. Although some pre-visual detection may be possible, caused by shifts in the gross surface roughness not otherwise observable from single point locations on the ground, the probability of active microwave detection of insect or plant disease infestation in a single field seems unlikely. The more realistic role is in the determination of areas in the path of migrating infestation, as a system to provide data to develop infestation control strategies and direction of spread.

(16) Insect and disease elimination prior to and after field infestation.

(17) How to cut operation costs -- By reviewing historical trends on broad scale imagery, it might be possible to develop better crop rotation systems, field arrangement patterns and shapes, irrigation applications,

and soil conservation practices. Such information and imagery could be made available to local county agents (provided with some training and/or interpretation keys). The farmer should realize a cut in operation costs when these recommended farm operation practices are employed.

After answering question (1), farm operators were asked "What kind of information might come from remote sensing experiments that would be of use to you?" Their most frequent replies were:

*(1) Prediction of pests and disease in crops -- See 15 above.

*(2) Changes in soil fertility -- See 11 above.

*(3) Optimized water application -- Limited capability in soil moisture detection has already been demonstrated by MacDonald and Waite (1971). More accurate delimitation of soil moisture might be possible if the complex inter-relationship of the dielectric constant to moisture, salt content, and nutrients in the soil can be defined and consistently identified. It would then be necessary to calibrate and detect variations in each of these at small calibrated intervals.

*(4) Current field and crop conditions -- Such information could be made available to the farmer, if automatic data processing of current field conditions (e.g. soil fertility, crop stress) could be incorporated into image analysis. This information would have to be available to the county agent or directly to the farmer by phone. An integral part of such a system is the development of dichotomous keys that can analyze field variables quickly as automatic data inputs.

(5) Drought prediction.

(6) Location of ground water.

(7) What nutrients soils need.

*(8) Accurate acreage measurements -- The degree of accuracy needed to improve present methods varies according to the level of economic development existing in parts of the world. Using a system of equations developed by Sabol (1968) it is possible to determine field acreages on certain parts of a radar image. Such information would permit the computation of the amount of land under cultivation; expansion, contraction, or changes in areas regarding land use alterations; and better field size

and arrangement to improve farm management. Houseman (1970) states that remote sensing data could provide highly valuable supplementary and collateral information regarding crop statistics and forecasts.

*(9) When and how much to irrigate -- See 7, question 1.

Answers to the third question, "If such information as periodic analysis of predicted crop yields, soil moisture content, or plant vigor were available, how would you use them on the farm?" were:

(1) To increase profits.

*(2) More efficient farm management -- See 2, 7, 8, 15, and 18 of question 1.

*(3) Optimize water application -- See 7, Question 1.

*(4) To increase yields -- See 2, 7, 11, and 17 of Question 1; 4 and 8 of Question 2.

(5) Optimize planting time.

*(6) Detect and control disease and insects -- See 15, Question 1.

(7) Be informed of problems and correct them.

(8) Make me a better farmer.

(9) Income prediction.

(10) What crops to plant and knowledge of their yields.

*(11) For farm planning -- See 2, Question 3.

*(12) Knowledge of soil fertility -- See 8 and 11, Question 1.

*(13) To make government reports more accurate -- A sensor capable of monitoring crop acreages periodically throughout the growing season would vastly improve world harvest and even U.S. crop harvest estimates. Present methods rely on volunteer reports by farmers and/or government agents. A radar data collection and interpretation system having all-weather capability and providing synoptic coverage could detect and rapidly report crop acreages, predict losses due to environmental hazards, and forecast market prices. Although not operable with present systems, this objective should be studied in developing future generation radars. See also 8, Question 2.

(14) What to plant and when.

Five local agricultural officials were asked, "What information would improve your ability to aid farm operations and farm planning?" Although this represents a small sample, it represents not only their needs but the needs of hundreds of farmers as viewed by persons immediately involved with them. Their replies were:

*(1) The prediction of yields by soil moisture depth in fall seeding time for dryland crops (see above) -- See 8 and 11, Question 1.

*(2) The effect of irrigation water on the soil with specific information on soil salinity -- See 7, Question 1.

*(3) Insect and disease detection -- See 15, Question 1.

*(4) Soil permeability by field.

(5) Compaction of soil.

(6) Soil classification by texture and structure.

*(7) A better overall picture of a farm than could be obtained by walking. This included: (a) drainage and erosion - topography; (b) optimum land use versus actual use in relation to slope and conservation practices; and (c) better field and building arrangement -- See 2 and 17, Question 1; 8, Question 2.

(8) More accurate survey of livestock numbers and feedlot arrangements.

(9) Pollution control measures.

*(10) Flood control measures -- Past studies have proven the capability of radar to delimit drainage basins, stream networks and topography (McCoy, 1969; Lewis, 1971; and MacDonald, 1969). The average amount and time of precipitation for an area could be obtained from weather bureau stations and state water resources (USGS) personnel. Knowing the general soil types and degree of hill slope the potential areal runoff could be computed using a combined formula. These areas could then be checked by local county agents to see if remedial or preventive erosion control measures existed or needed to be constructed. Increased land productivity and more efficient farm management should accrue from such efforts.

(11) Moisture stress on crops on a weekly basis.

*(12) Degree of water weeds in irrigation ditches and larger water bodies -- Present systems cannot adequately detect such changes in small irrigation ditches. Changes in larger water bodies might be possible with fine resolution imagery in a time sequential framework to monitor changes in the size of the water body and its reflective properties. Such changes could be analyzed and the result related to loss of water area due to drought, silting, or weed and plant growth in the water. It should be

noted that, at present, such data seem to be obtainable only with classified systems of high resolution. For this kind of monitoring, low incidence angle may be preferred.

The description of problems and variables presented here may leave the impression that the interpreter is faced with an insurmountable task. The diverse land use practices appear so complex, and the local needs so detailed that there may appear little hope for radar. This is certainly not the case. These variables are not only problems, but also significant clues in analyzing and interpreting agricultural land uses from radar imagery. With this information the reason for the non-homogeneous appearance of a single field or the different appearance of two identical corn fields may be resolved. These relatively minute changes, differences, and perceptions are meaningful inputs to the development and refinement of: (1) radar systems and (2) such interpretive aids as the dichotomous key and tone-texture analyses.

In essence, these data bits may provide some of the information necessary to explain anomalies and inconsistencies in a radar image. When this information is incorporated into interpretation keys, identification and monitoring accuracy should rise several levels. The more ambiguities that can be explained and eliminated, the better present and future radar systems will function as a viable research tool.

Subtask 2.5.2.2

IMAGE INTERPRETATION KEYS TO SUPPORT ANALYSIS OF SLAR IMAGERY*

Jerry C. Coiner and S. A. Morain

Introduction

Before SLAR can be used generally as a method of agricultural investigation, a number of technical difficulties involving both the sensor and the interpretation of the imagery must be overcome. One of the most pressing of these difficulties is the lack of an interpretation technique for SLAR imagery that is simple to develop and accurate to use. Ideally, such a technique should require a minimum of image interpretation expertise while providing accurate and repeatable interpretations. As a contribution toward filling this need, the present study is an investigation into the

*Condensed from ASP Fall Meeting Proceedings, San Francisco, Sept. 1971, paper #71.

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adaptation of image interpretation keys for analysis of SLAR imagery.

The subject matter of the keys developed and studied in this paper are drawn from two areas: agricultural crop discrimination and natural vegetation mapping. Three agricultural keys were developed utilizing imagery from Garden City, Kansas (NASA test site 76) and two natural vegetation keys were developed for imagery of Horsefly Mountain, Oregon and Yellowstone National Park, Wyoming. Examples of some of them are included solely to illustrate the methodology; they in no way exhaust the variety of foreseeable approaches, nor do they represent limits on the applicability of the technique.

Examples of Keys

The use of keys to interpret radar imagery for agricultural information was initially conceived by Morain and Coiner (1970). The first attempt was developed for X-band radar imagery obtained in October 1969. The ground truth data were compared with the imagery on a field by field basis to determine the status of the crops in the fields. Then, for each crop in each of several growth stages, imagery work sheets were prepared. These work sheets constituted the basis for preparing the dichotomous key shown in Table 4. This table is a revised and simplified version of the previous key. Table 5 is another example, but from Ka-band imagery acquired in September 1965. This key relates specifically to crop type discrimination and is not the limit of information contained in the image. It is based on data from the mid radar range (depression angles between18 and 23°) and the HH/HV image pair. There is little quantitative information other than gray scale (tone) on which to base the key.

The construction of keys for natural vegetation is more involved than that for agriculture because the interpretation requires integration of both tone and texture information. One way to handle this added level of complexity is to alter the key format, as shown in Table 6. This key was necessarily constructed subsequent to the interpretation, thus it represents a method by which the generalization of the interpretation can be validated. Such "matrix keys" may also provide an excellent training aid for other interpreters.

The matrix key offers several advantages to the more experienced interpreter. (1) It is not necessary to retrace the entire logic of the interpretation, as is necessary

TABLE 4
DIRECT DICHOTOMOUS KEY FOR CROP TYPES AT GARDEN CITY, KANSAS
(For use with fine resolution X-band imagery for October)

A	Field is light gray to white on HH	Go to B
A'	Field is not light gray to white on HH	Go to D
B	Field gray tone shifts from light gray/white HH to medium gray HV	Go to C
B'	Field gray tone shifts HV lighter than HH	cut alfalfa
C	Field gray tone on HV homogeneous	sugar beets; or wheat >3"
C'	Field gray tone on HV not homogeneous	fallow
D	Field has medium to dark gray tone on HH	Go to E
D'	Field has very dark gray tone on HH	recently tilled
E	Field gray tone is homogeneous	Go to F
E'	Field gray tone is not homogeneous	Go to I
F	Field has lineations parallel to long axis	maturing alfalfa
F'	Field does not have lineations	Go to G
G	Field has medium coarse texture	grain sorghum (rows $\perp$ flight line)
G'	Field does not have medium coarse texture	Go to H
H	Field has same gray tone on HH and HV	wheat >3"
H'	Field has moderate gray tone shift HH to HV	alfalfa >12"
I	Field has a cultivation pattern observable	emergent wheat
I'	Field does not have cultivation pattern observable but displays pronounced boundary shadowing	mature corn

TABLE 5

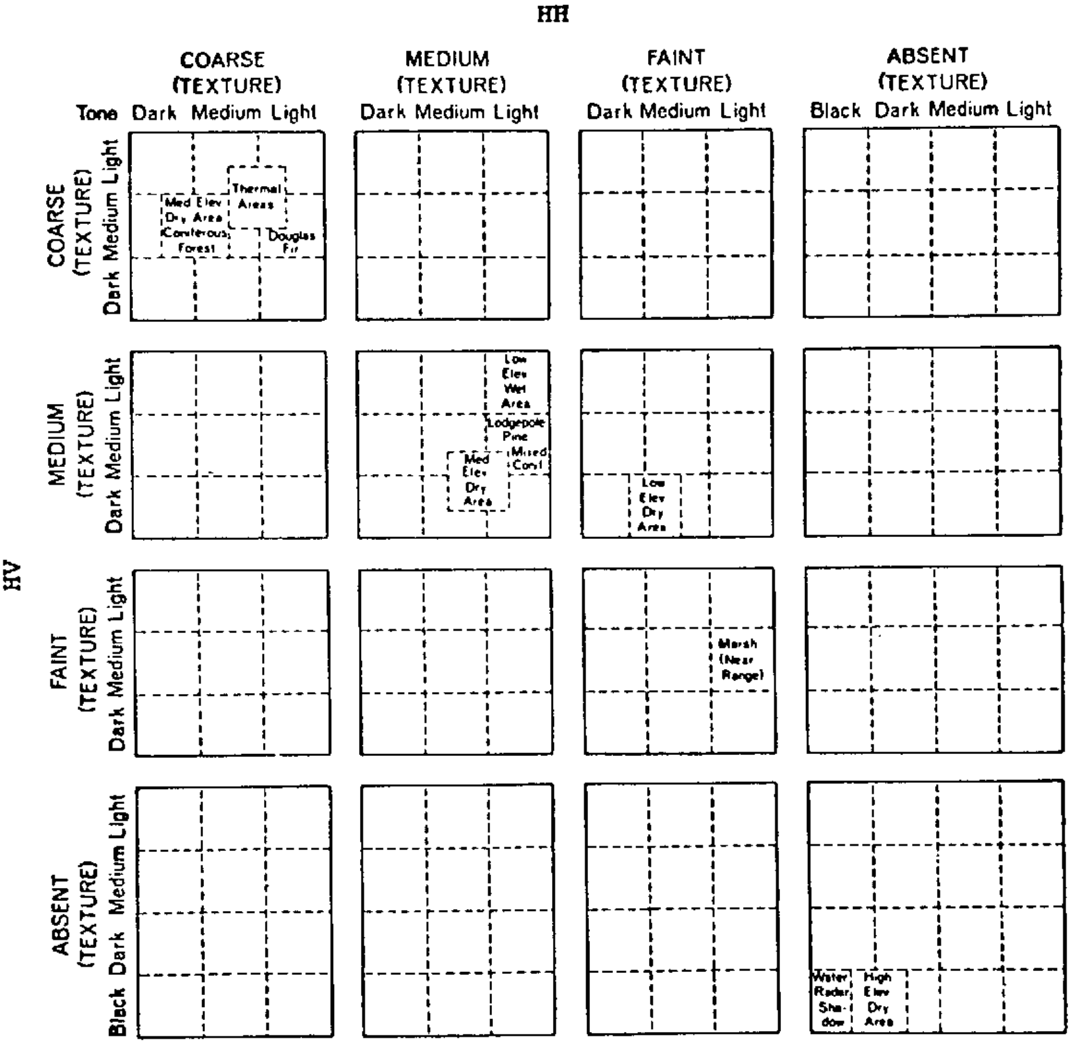
DIRECT DICHOTOMOUS KEY FOR CROP TYPES AT GARDEN CITY, KANSAS

(For use with AN/APQ-97 Ka-band imagery for September)

A	HH and HV are white		sugar beets
A'	HH is not white	Go to B	
B	HH is light gray	Go to C	
B'	HH is not light gray	Go to D	
C	HH and HV are light gray		corn
C'	HH is light gray, HV almost white		alfalfa
D	HH is gray	Go to E	
D'	HH is not gray	Go to G	
E	HH has even gray tone	Go to F	
E'	HH has uneven gray tone (also HV)		fallow
F	HV has similar gray scale to HH		wheat
F'	HV has lighter gray scale than HH		sorghum
G	HH is dark gray to black, even gray scale	Go to H	
G'	HH is dark gray to black, uneven gray scale (possibly more noticeable in HV)	Go to I	
H	Area has regular boundaries		recently tilled
H'	Area has irregular boundaries		standing water
I	HV shows major shift toward gray to light gray		pasture
I'	Field shows only minor shift toward gray		fallow

TABLE 6

MATRIX KEY FOR AN/APQ-97 RADAR IMAGERY
YELLOWSTONE NATIONAL PARK *



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in the case of the dichotomous key. (2) The key provides an excellent method of information transfer from one interpreter to another and may substantially increase the consistency of a given interpretation. (3) The matrix key surfaces those points within the interpretation where the image fails to clearly separate categories of information, for example the overlap between Lodgepole Pine, Mixed Conifer and Medium Elevation Dry Area. Identification of ambiguity allows the interpreter to concentrate on associate information (in the form of associate keys) for those categories where clear-cut identification is not possible.

Testing Keys

Two of the direct dichotomous keys were subjected to interpreter testing, primarily to determine whether, in practice, results were sufficiently rewarding to warrant additional research. Secondarily, we needed to learn which of the human and system factors most influenced the successful use of keys. Lastly, we attempted to better appreciate the nature and type of collateral inputs required to make high validity interpretations.

The tests were relatively simple in nature. Each interpreter was given a packet consisting of materials providing a brief background to the subject area; images and keys for Garden City for July 1970 (Ku-band) and September 1965 (Ka-band); and appropriate instructions. Individually, ten experienced radar interpreters from around the U.S. were asked a series of questions relating to their interpretation experience. They were also requested to describe the method they used to interpret the images. No attempt was made to control interpretation technique, as it was felt that this would not provide a measure of the key's effectiveness and would place undue emphasis on a given method of interpretation. Each interpreter was asked to make an interpretation using each of the two keys provided. The interpreters used the direct dichotomous key to identify crops in 55 fields selected by the investigators. Slant ranges for the fields were the same as those used in developing the key.

The test of a Ku-band was based solely on the use of a textual key with no supporting graphic. Range of correct interpretations varied from 25 per cent to 68 per cent, with the average at 49 per cent (Table 7). Higher percentages were achieved by interpreters who had the least overall experience in interpretation.

The test for a Ka-band key was based on a textual key accompanied by a visual graphic showing typical crop responses. It required a finer degree of

TABLE 7
PERCENTAGE CORRECT CROP IDENTIFICATION BY TEN IMAGE INTERPRETERS USING KEYS DERIVED FROM Ka-BAND AND Ku-BAND IMAGERY

Interpreters (Ranked according to general interpretation experience; 1 = high)	% Correct Crop Identification: AN/APQ-97 Ka-band 9/65		DPD-2 Ku-band 7/70	
1	44		34	
2	31		35	
3	57	43%	55	45%
4	48		52	
5	35		50	
6	43		68	
7	33		68	
8	44	39%	25	51%
9	52		41	
10	26		57	
Average	41		49	

TABLE 8
IDENTIFICATION OF CROP GROUPS*

Crop Group	sugar beets	corn	alfalfa	wheat	sorghum	pasture	fallow	tilled	Per cent Correct
	Number of fields identified by interpreters								
I. Recently Tilled, Fallow, Pasture		7	1	36	10	**8**	**43**	**95**	73
II. Sorghum, Wheat, Corn		**29**	8	**48**	**59**		13	2	86
III. Alfalfa, Corn, Sorghum	1	**20**	**12**	7	**27**		1		87
IV. Sugar beets, Alfalfa	**52**	2	**35**		1				98

*Derived by combining the responses of all interpreters.
**Bold type = fields correctly identified; regular type = incorrect identification.

differentiation of crops than that needed by the other key. This resulted in a narrower range of correct interpretations (26 per cent to 57 per cent) with somewhat lower average correct interpretations (41 per cent). When individual crops were grouped into clusters simulating agricultural scenes typical of different times in the growing season, however, it was clear that accuracies exceeding 75 per cent could be achieved by using keys. The figures in Table 8 compare very well with similar crop groupings derived through cluster analysis by Haralick, et al. (1970).

The accuracy of the initial keys was below that acceptable as a minimum by the authors. However, the tests showed areas where the direct dichotomous key could be improved. Therefore, results of these tests should be assessed from a research point of view as a basis on which to build an operational interpretation key.

Several factors entered into the limited effectiveness of this "first approximation:"

1) the lack of extensive coverage of the test site by any given system,
2) the lack of time sequential coverage, and
3) the lack of non-image information for use with the direct dichotomous key.

Even in the light of the above problems, the key appears to provide a capability for increasing interpretation accuracy. When the key is coupled with a test sequence for research purposes, a feedback loop can be established to identify areas of low accuracy.

The two tests conducted on the preliminary keys have given some estimate of the initial accuracy and the problems inherent in the construction of interpretation keys. The tests have pointed out the need for feedback and collateral information in achieving high validity interpretations. Prior knowledge of an area under interpretation and expertise in the type of information being identified (in this case agriculture) may be advantageous for users of keys. Although the tests resulted in only a 50 per cent accuracy, for individual crops, improved visual support graphics and the expansion of the key to categorize more cases on the image, should increase the level of accuracy. However, to reach extremely high (over 90%) correct interpretations, the use of collateral information and time sequential imagery (introduced into the interpretation in the form of associate keys) will be essential.

Key Automation

The procedure for automating keys is essentially one of substituting actual values for qualitative word descriptions of tone and texture. For the key shown in

Table 5, only image tone was used. The imagery for both the horizontal and vertical polarizations was digitized using 256 channels and a 50μ cell size. By producing frequency distributions for each of the images, it was possible to compress the 256 channels into 5 equal probability classes (arbitrarily designated as 0,1,2,3,4). These classes were assumed to be roughly equivalent to the five levels of gray visually detectable on each image. Following this, the tape coordinates for each test field were tabulated so that the newly defined 5 levels could be summed and a simple average "gray tone" calculated. On the basis of these gray tone designations for both the HH and HV images, each field could be classified according to crop type. Appendix A is a discussion of the algorithm used in this approach and provides documentation for programs as they are presently developed.

Results from preliminary tests of the computer algorithm are encouraging but inconclusive. The number of correct crop identifications so far has been on the order of 50 per cent; no better nor worse than that achievable by human interpretation. The testing program is continuing, however, and we are hopeful of better results as we refine the strategy for calculating gray levels. We suspect for example that the use of equal probability classes does not adequately portray the scene as it was originally imaged, and that better identifications can be obtained by preselecting regional concentrations within the frequency distribution.

With additional research into methods and problems of preparation and automation, there is a high expectation that accurate and repeatable interpretations from radar data can be achieved -- even perhaps in the absence of fully calibrated systems. This approach to radar interpretation could provide a method of analysis adaptable to government agency (mission oriented) needs, as well as the more specific and individual needs of academic research.

Subtask 2.5.2.3

BASIC PARAMETRIC STUDIES: THE STANDARD FARM DESIGN PHILOSOPHY AND INITIAL RESULTS*

William Lockman & Phillip Jackson

Introduction

It is quite impossible to evaluate the full matrix of radar frequencies, polarization, times, incidence angles, and resolutions for the Garden City Test site if one keeps in mind the myriad terrain parameters affecting backscattering cross-sections (crop types, height, cover, moisture, row direction, stage of growth, etc.). Consequently, we are attempting to model the data in such a way as to hold constant as many of the system/terrain variables as possible. For each imaging date over Garden City we are producing a set of "standard farms" with each farm consisting of pure, weed-free, uniform fields representing the major crop types. Such models will be created for each frequency, polarization, incidence angle, and resolution presently available. These models are to be prepared according to a standard format for human interpretation as well as pattern recognition and IDECS interpretation. In addition, the model can be digitized on a scanning densitometer so that image density may be studied in a quantitative manner. The Standard Farm model will provide us with a method to "fingerprint" average film tones for high quality fields on a crop by crop basis in order that we may eventually be able to assess departures from these ideal levels.

On radar imagery, vegetation and crop information depends not only on vegetation type and growth, but also on a number of other variables. Phase I of the Standard Farm Project is a controlled parametric experiment where crop quality, a terrain parameter, has been held constant. Key radar system parameters to be considered as variables are incident angle ($\measuredangle$), polarization (P), and frequency (f). Pert charts as exemplified by Figure 31 demonstrate the design. Studies include experiments to determine the influences of individual radar parameters on crop identification. If successful results are obtained from the isolation of these parameters,

*Condensed from CRES Technical Report 177-   (in preparation).

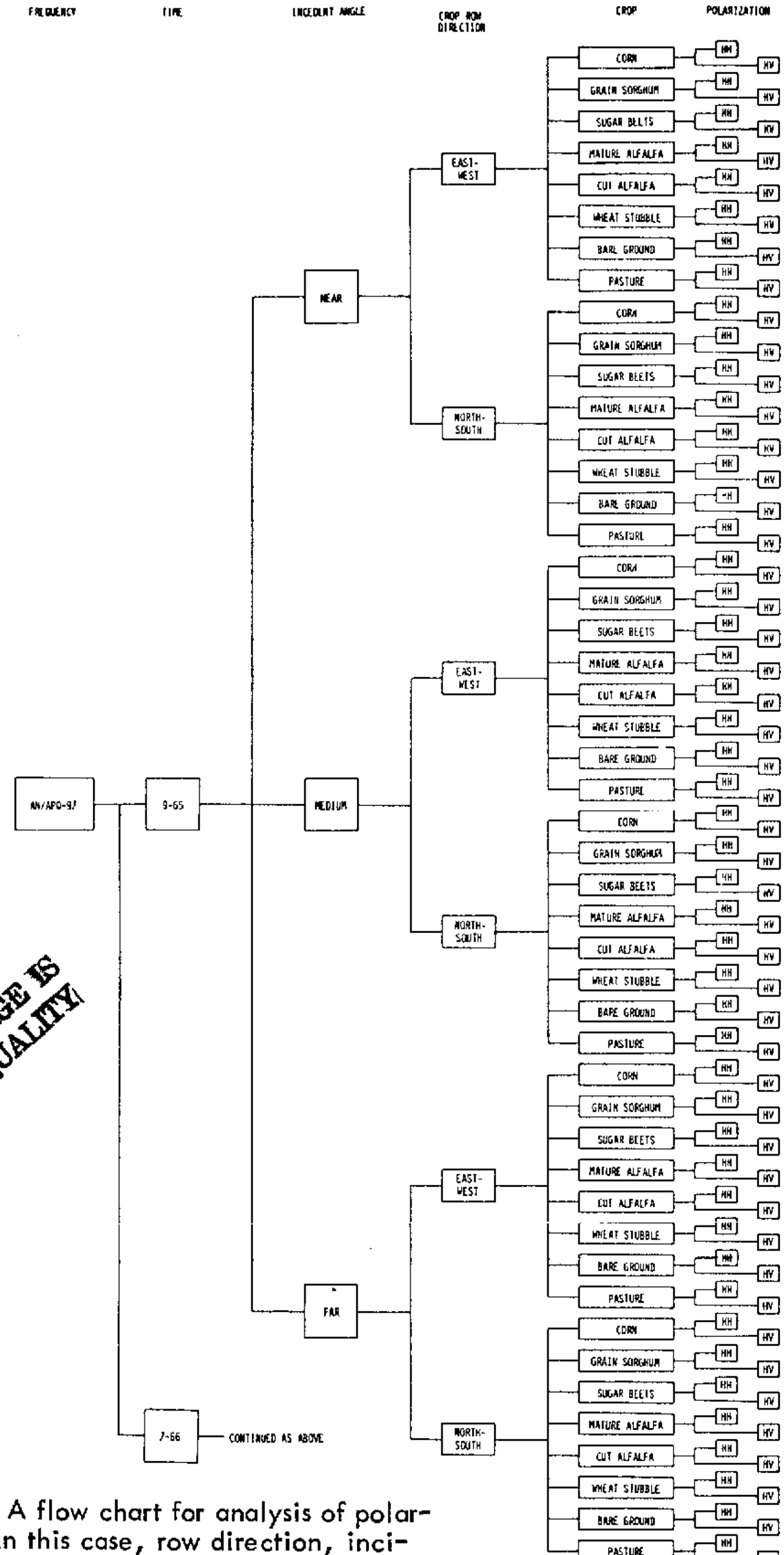

Figure 31. A flow chart for analysis of polarization. In this case, row direction, incidence angle, time (growth stage) and radar frequency are held constant for each of several crop types so that the effects of polarization can be studied. For each of the polarization boxes a film density histogram along with statistical measures will be compiled into a catalog.

more complicated studies will be undertaken using less than optimum field conditions.

"Standard farm" provides the framework by which the above experimental design is being pursued. To assemble it, a single high quality field from each image is selected from each of eight crop categories (corn, grain sorghum, sugar beets, mature alfalfa, cut alfalfa, wheat, bare ground and pasture) along each of three roads for each of two crop row directions (N-S and E-W). Ideally, roads are parallel to the line of flight; therefore, all of the fields along a given road are imaged at the same depression angle. An example of one standard farm is given in Figure 32. In all we have created 100 standard farms for parametric analysis, using the data listed in Table 9.

Methodology

The first step after collection of imagery is digitization. The scanning parameters are as follows: raster, 50 microns; aperture, 50 microns; optical density range, 0 to 2D (we are now adopting 0-3D); gray levels, 256.

Depending on the particular radar system, the 50 micron aperture is on the order of 0.5 to 1.0 resolution cell on the film transparency (i.e. the raster and aperture size is compatible with the system resolution). The 50 micron raster (samples taken every 50 microns) corresponds to a minimum of approximately 400 samples per field for the smaller fields and over 10,000 samples per field for larger fields. The optical density range of 0 to 2D has been divided into 256 gray levels. The smallest measurable level corresponds to a density interval of 2/256 = 0.0078. Thus, a σ_D for film of 0.0064 is approximately equal to the minimum measurable interval.

Due to film characteristics and the 0-2D range, mean values and histograms that approach or extend beyond the 0D or 2D (O or 256 for 256 levels in the 0-2D range) are of questionable value. A number of fields in the models under study approached these limits. Small values for standard deviation (approximately zero) were obtained when the mean density was greater than 2D as would be expected. It should be noted that the statistics of imagery from different radar systems are not directly comparable due to differences in system parameters, film type, and processing.

In order to locate standard farms on the map print-outs so that field statistics could be obtained, it was necessary to collect coordinates. For each field involved,

FIGURE 32.

STANDARD FARM FORMAT

DATE July 27, 1966 RADAR SYSTEM Westinghouse AN/APQ-97

ROAD 2 INCIDENCE ∡ 20-29o

ROW DIRECTION E-W

POLARIZATION HH

ENLARGEMENT 5X

N

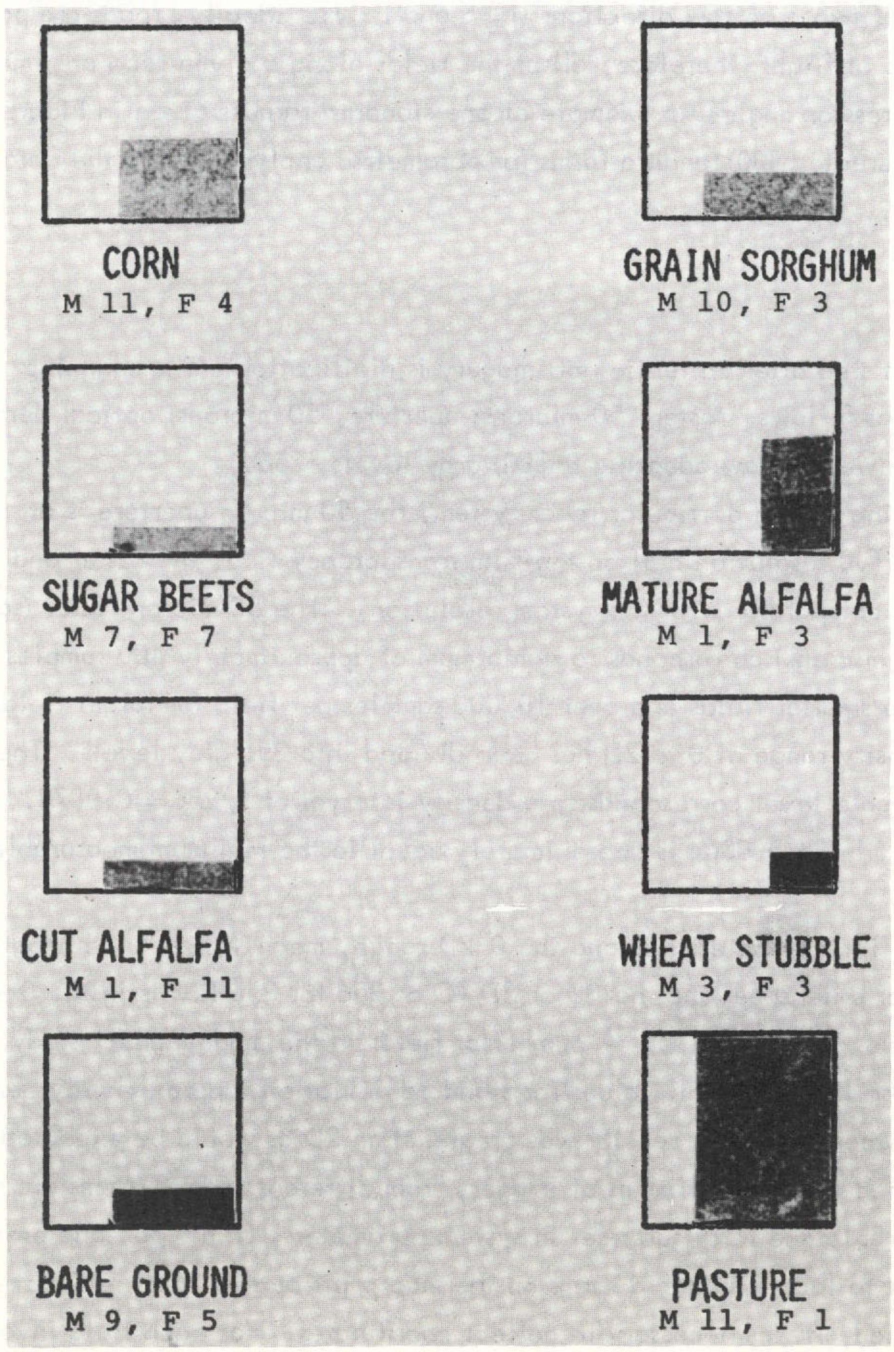

Table 9

GARDEN CITY DATA BASE
Test Site 76

Date	Radar System	Polarization	Field Data
September 1965	Westinghouse AN/APQ-97	4	Crop Parameters
July 1966	Westinghouse AN/APQ-97	4	Crop Parameters
October 1969	Michigan High Resolution	2	Crop Parameters
September 1971 (expected)	Michigan High Resolution	2	Crop Parameters Crop and Soil
June 1970	16.5 GHz 13.3 GHz 400 MHz Scatterometers	2	Crop Parameters
May 1971	NASA DPD-2 16.5 GHz Scatterometers	2	Crop Parameters Crop and Soil Moisture
June 1971	NASA DPD-2 16.5 GHz Scatterometers	2	Crop Parameters Crop and Soil Moisture
July 1971	Michigan High Resolution KU Scatterometer	2	Crop Parameters Crop and Soil Moisture

it was necessary to obtain four figures - a row and a column coordinate for the upper left corner of the field, and then a "down" and an "across" value to provide field dimensions. From these coordinates and dimensions it was possible to retrieve the digitized standard farm fields from the tapes containing the entire digitized test site and to put them on a single tape in order that they may be rapidly obtained for statistical work.

For analysis, three descriptive statistics were obtained by computer programs -- means, standard deviations, and histograms. Other statistics can be obtained at a later date if desired. The analysis presented in the following section is a human comparison of histograms, means, and standard deviations.

Distinctive differences or similarities between attributes of a parameter are the main concern for the first part of the analysis. For example: the parameter Row Direction has two attributes: (1) east-west (parallel to line of flight) and (2) north-south (orthogonal to line of flight). To assess the effect of row direction on radar return, the attributes are compared under similar conditions of radar frequency, polarization, incidence angle, crop type and growth stage. The statistical variation of the two histograms is assessed to determine if the attributes of row direction affect radar return differently. If no difference is found for example between the parallel and orthogonal attributes then the suggestion is that row direction is not a significant factor influencing radar return for that specific crop situation. Conversely, if a discernable major difference is observed for row direction in either the means or standard deviation (or both), there is some evidence that this attribute is a factor influencing radar return. Typical output from the standard farm is given in Appendix C .

Preliminary Results

Table 10 presents means and standard deviations characteristic of the radar returns for "developing" crops holding frequency, row direction, polarization and incident angle constant. The higher the value for mean density, the brighter (whiter) the crop appears on imagery. To take an extreme example, compare sugar beets (row 3, column 2a) with bare ground (row 6 column 2a). Sugar beets appear almost white with a mean density of 219 while bare ground with a mean density of 93 appears almost black.

Table 10

Comparative Radar Return from Crops in their "Developing"* Stage

Crop	Radar Variables: 1 Row direction (orthogonal to LOF) a**	1 b	2 Polarization (HH) a	2 b	3 Incidence ∢ (Mid range) a	3 b
1 Corn	155(29)	249(13)	209(26)	237(26)	193(14)	240(16)
2 Grain sorghum	221(22)	221(12)	213(27)	206(47	182(28)	204(52)
3 Sugar Beets	201(63)	222(18	219(39)	252(49)	--	171(72)
4 Cut Alfalfa	--	--	184(22)	212(50)	184(22)	225(52)
5 Wheat	--	253(5)	--	253(5)	--	107(5)
6 Pasture	--	--	185(10)	254(4)	185(10)	117(8)
7 Bare Ground	80(13)	191(25)	93(28)	175(15)	123(10)	214(13)

* By selecting a stage in the growth cycle, time becomes a variable. Wheat, for example, is "developing" in May whereas corn develops in July and August.

** Column a under each of the system variables represents Ka-band imagery; column b represents Ku-band data. They cannot be compared except internally.

Return from row crops was found to have consistently high standard deviations. These were interpreted as being a function of scatter due to rows. Although alfalfa is not a row crop, it too was often observed to have a high standard deviation. This may be explained by the irrigation ridges which are highly visible when alfalfa is at a low growth stage.

It appears that (especially in the HH polarization Ku band) bright but textured return is characteristic of developing row crops, whereas high but purer tone return is distinctive of wheat or pasture. Low return (less bright) is characteristic of bare ground in all cases. Textural effects may be due to soil surface conditions or stubble in the field, but low mean brightness is a good indication of bare ground.

Other findings include the following:

1. For row crops having rows parallel to the flight line, crop growth stage appears to be reflected in the standard deviation. Larger standard deviations are characteristic of emerging crops and this statistic becomes smaller with maturation.

2. Return is influenced by polarization in that <u>like</u> polarizations tend to be brighter than <u>cross</u> polarizations under similar conditions except on bare ground where the opposite is the case.

3. Range variation for non-row crops does not effect radar return. Similar means and standard deviations are characteristic of near, mid and far ranges for wheat and pasture. Corn, sorghum and sugar beets show distinct variations in return with change in range.

The standard farm experiment seems then, on the basis of initial results, to be yielding useful data concerning the relative importance of radar parameters to crop identification. An expansion of the original design to include a larger number of sample fields and more quantitative analysis is presently forthcoming.

Subtask 2.5.2.4

REMOTE DETERMINATION OF SOIL TEXTURE AND MOISTURE USING ACTIVE MICROWAVE SENSORS*

S. A. Morain & J. B. Campbell

Soil texture and moisture, under certain circumstances, are susceptible to measurement by active microwave sensors. The most useful sensor parameters relating to radar backscatter (σ^o) from soils are: (1) frequency, (2) polarization, and (3) angle of illumination. The primary soil characteristics contributing to backscatter are: (1) soil texture, which, as it ranges from clay through boulder categories, varies in surface roughness and thus influences the amount of backscatter; and (2) soil moisture, which alters electrical conductivity of the soil, thus influencing the depth of signal penetration and the amount of re-radiation. In theory, low frequency radar (L-band) should best be able to detect boulder surfaces (assuming a flat, dry surface free of vegetation and of uniform roughness) and higher frequencies (V-band) should be sensitive to soils comprised of medium sand. Analysis of side-looking airborne radar (SLAR) imagery of an area near Tuscon, Arizona, produced soil texture patterns corresponding to soil survey patterns.

As soil moisture increases, soil reflectance in the microwave also increases. The effects are most pronounced at steep depression angles (small angles of incidence). SLAR imaging of soil moisture is illustrated in the report by imagery of Hutchinson, Minn. In this region topographic depressions containing peat and muck soils image stronger than surrounding soils, especially at steep angles.

The combined effects of moisture and roughness should be considered in order to properly characterize radar backscatter from soils. It is likely, for example, that at low frequencies and steep depression angles, ambiguities will arise between high returns from dry boulder surfaces and those from moist loamy surfaces. Additional complications may result at shallower depression angles because the roughness component resides more in vegetation patterns than in soil patterns.

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*Excerpted from 177-23 (in preparation).

The past decade of research on the microwave properties of soils has focused on two approaches. The first is illustrated by research conducted by Lundien (1966, 1971) in which the reflectance of soils was measured at selected frequencies under artificial conditions of texture and/or moisture. The results of these works lead toward an understanding of basic parametric interactions. They provide a link between radar theory and application in a controlled environment. More recently, since 1965, a second approach has appeared. Sheridan (1966) and Barr (1970), among others, have shown that a correspondence exists between known soil patterns and patterns observed on radar imagery. They have described these trends and speculated on their utility for engineering soil studies and for other "user needs." Both approaches are essential if we are to extend our knowledge and capitalize on microwave reflectance from soil. We see, however, that in order to increase interpretive skill, we need yet a third approach; one which strives to explain image patterns on the basis of parametric interactions. The thrust of this paper is toward that approach.

The discussion in Technical Report 177-23 is divided into two segments. The first is largely a consideration of important radar system and soil variables; their mutual interactions; and their theoretical appearance on radar imagery. In the second part, examples are used to illustrate the degree to which theory carries over to practice. For the present report we summarize only our research efforts with the polypanchromatic radar system developed at KU.

Backscatter from Soils in the Field

In an effort to further investigate radar scattering from soil surfaces the authors have conducted preliminary experiments at the Center for Research, Inc. at Kansas University. Field conditions were altered to study the interaction of soil moisture and roughness with frequency, polarization, and incidence angle. Three roughness categories and two moisture conditions were investigated. The soil was a Grundy Silty Clay Loam developed from shale interbedded with limestone. Normal field capacity for the soil is reported to be between 30 and 40% by weight. Our measurements were taken at about 15% (considerably below field capacity) and at about 30% moisture content. Microrelief was altered by roto-tilling and raking the surface to desired roughness.

A frequency modulated, continuous wave (FM-CW) scatterometer was used to take data at 10 frequency bands, each .4 GHz wide, between 4 GHz and 8 GHz;

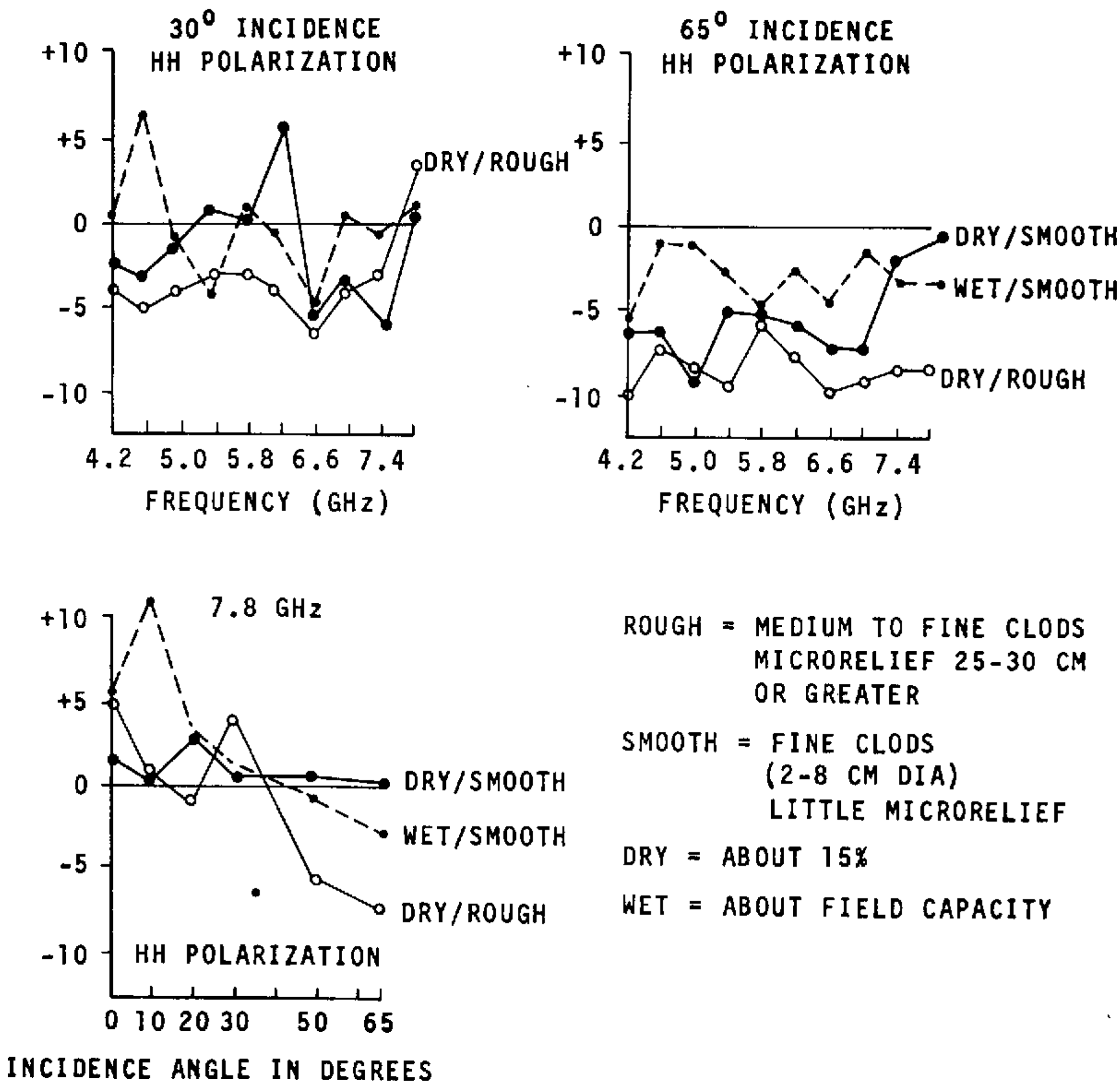
this frequency range corresponds to portions of C and X bands. Backscatter data were collected for two polarizations (HH and VV) at 6 look angles between 0^o and 65^o. Sample data are presented in Appendix B .

The curves in Figure 33 a,b,c represent selected examples from the complete data set and should be regarded as preliminary. At present we are unprepared to discuss cause and effect between soil and radar parameters. We include the information only to demonstrate the range of variation observed in the frequency and angular domains as roughness and moisture are altered. Curves A and B illustrate the response over the frequency range (4-8 GHz) at 30^o and 65^o incidence angles, respectively. Only the HH polarization is shown here. Curve C shows the angular response for the .4 GHz band centered at 7.8 GHz.

In comparing the backscattering characteristics for the curves in A and B the following points emerge. First, an immediate observation is that greater fluctuations occur at steeper depression angles (shallow incidence angles). The response at 65^o is considerably flatter than the one for 30^o. Of particular interest is the apparent effect of moisture on the curves for smooth soils at 30^o (curve A).

Second, the effect of roughness (comparing the two dry curves in A and B) is to influence the frequency response more at near range than at far range. Also there are fewer crossover points at 65^o than at 30^o. These crossover points could aid in interpretation if seen in the context of a broad bandwidth over a period of time -- however, when seen at isolated frequencies these points can only confuse any attempt to identify soil characteristics, since the effect of moisture and roughness appear to have similar responses at certain frequencies. This effect suggests that there may be optimum frequencies (not yet ascertained) for distinguishing certain soil characteristics.

Analysis of the angular data (c) yields the following observations. First, at higher frequencies (7.8 GHz) there is a considerable flattening of the curves at shallow depression angles for all soil conditions studied. Although it would be difficult to distinguish dry from wet smooth surfaces, there appears to be a significant difference between a rough and a smooth surface, at least at the frequency illustrated. At present we have little knowledge of the capability of existing imaging radar systems for making the kinds of distinctions important in soil studies. From both the geo-science point of view and the engineering point of view, this topic merits further consideration.



RADAR BACKSCATTER FOR SOIL SURFACES AT SELECTED FREQUENCIES AND INCIDENCE ANGLES FOR GRUNDY SILTY CLAY LOAM.

Figure 33.

RADAR USES FOR VEGETATION: AN OVERVIEW WITH EMPHASIS ON ARID ZONES*

Stanley A. Morain

Task 2.5.3 Radar for Vegetation Studies: An Overview

It has been argued that imaging radars will serve an ancillary role to photography in sensing dry environments (Simonett, et al., 1969a). Normally the atmosphere over arid lands is cloud free and contains little moisture; hence the number of hours available annually for conventional and infra-red photography is much higher than would normally be experienced in either the humid low latitudes or in high latitudes. Spectacular photographs obtained by Gemini and Apollo spacecraft over the Middle East, Australia and the southwestern United States testify to the potential of photography for acquiring resource data from these regions (OSSA, 1970).

Data losses can occur, however, through the combined effects of high albedos with dust and aerosol concentrations in the atmosphere. These phenomena tend to reduce image contrast and scatter short wavelength signals. In addition there are film and terrain related color ambiguities which confound the job of terrain identification (Artsybashev, 1962; Simonett, et al., 1969b). Considering that the arid lands of the world constitute almost 36% of the land area, are poorly known, remote, sparsely mapped, and largely unphotographed from aircraft altitudes, it is important to investigate sensors which are independent of solar illumination and most weather conditions. This leads naturally to the consideration of an active microwave remote sensor as a potential data collector for these areas.

Arid Zone Applications

Initially, space oriented resource inventories will focus on such broadscale topics as soil, vegetation, geology (geomorphology), drainage and hydrology (including irrigation) and agriculture. As thematic maps and other land use information become

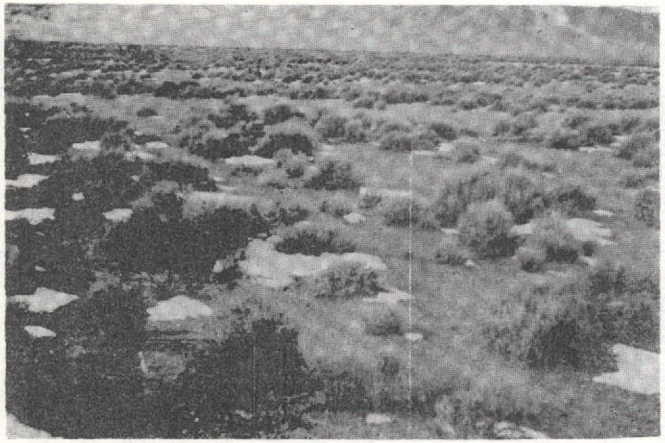
*Condensed from Morain, S.A. (1970), Radar Uses for Natural Resources Inventories in Arid Zones, presented at First World Symposium on Arid Zones, Mexico City, November 1970. In press by McGraw-Hill of Mexico.

available for these interests, more comprehensive management and development schemes can be implemented. It is therefore important to appreciate the role radar data might play in some of these initial surveys. The following section deals specifically with mapping natural vegetation.

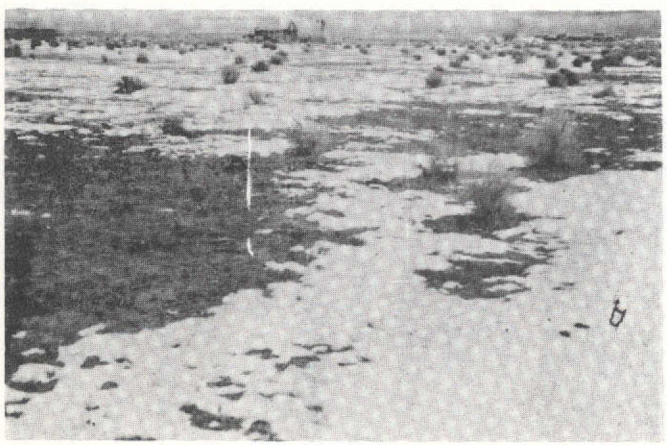
Vegetation patterns have been observed on radar imagery from a wide variety of environments. In only a few cases, however, have desert communities been identified directly rather than as a surrogate related to soils or topography (Morain and Simonett, 1966). The reason, primarily, is that desert communities are generally low and sparse. Consequently, their backscattering cross-sections are complicated by "noise" from lithology, soil surfaces, moisture contents, and possibly by salinity patterns. This is precisely the kind of problem confronting interpretation of coarse resolution color space photography. For this and other reasons it is widely agreed that unambiguous identification of area-extensive terrain categories can seldom be achieved by a single sensor without the aid of local surrogates, perhaps not even then. Given a basic pattern, local interpreters could make sound judgments regarding the distribution of plant communities.

Figure 34a,b shows two aspects of the desert vegetation in Escalante Valley, southwestern Utah. The region is largely characterized by great basin sage (Artemisia tridentata) but in lower lying and more saline localities shadscale scrub (Atriplex confertifolia) becomes the dominant type. In moister, less saline situations a variety of grasses form the association and on the upper slopes of the alluvial fans juniper woodlands occur. The sagebrush type is uniformly low but has a variable density. In more open areas a sandy (pebbly) surface is often exposed to radar signals, but in denser stands there may be relatively little return contributed by soil -- especially at higher incidence angles where objects protruding from a flat surface intercept most of the impinging signal.

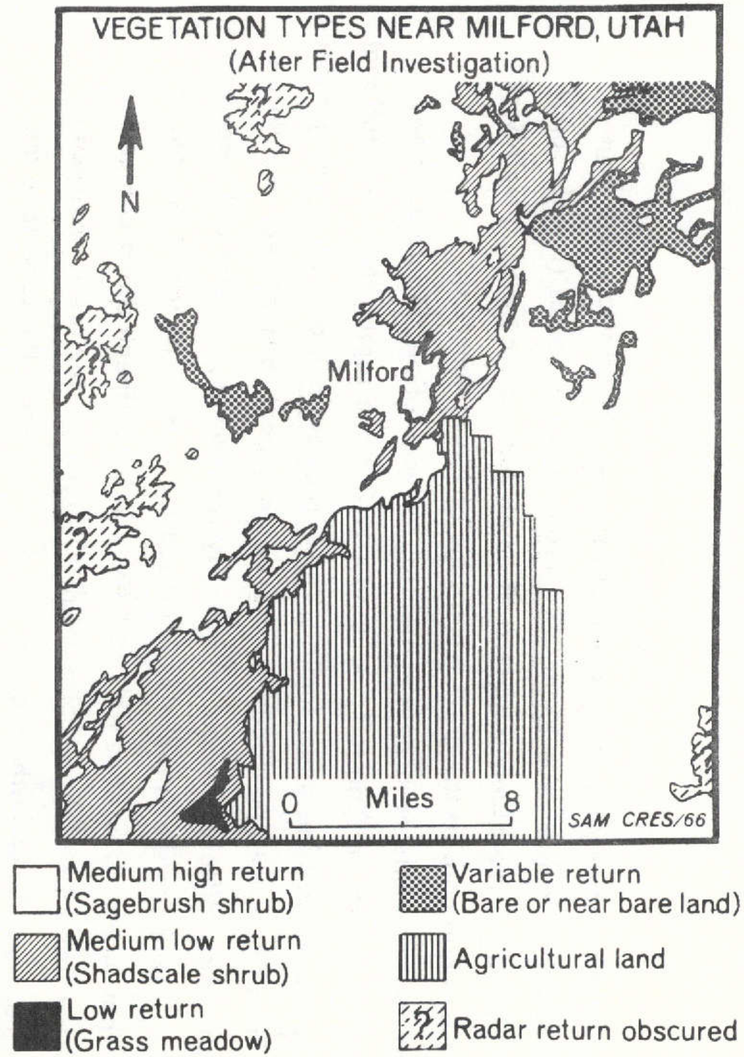
From the radar imagery it is possible to delimit the shadscale scrub community, the larger localities of grass, and, by inference, the area dominated by sagebrush (Figure 34c). Juniper woodlands cannot be confidently located due to their association with rough topography. Preliminary field investigations have confirmed that plant cover more than soil differences influence the radar return from this area, though a more detailed examination might show equal dependence. Unquestionably, the soil and vegetation patterns are highly correlated. Figure 34c suggests that the most important influences on backscatter from desert terrain are height and density of vegetation and soil texture. If so, significant differences in image texture, tone and



a



b



c

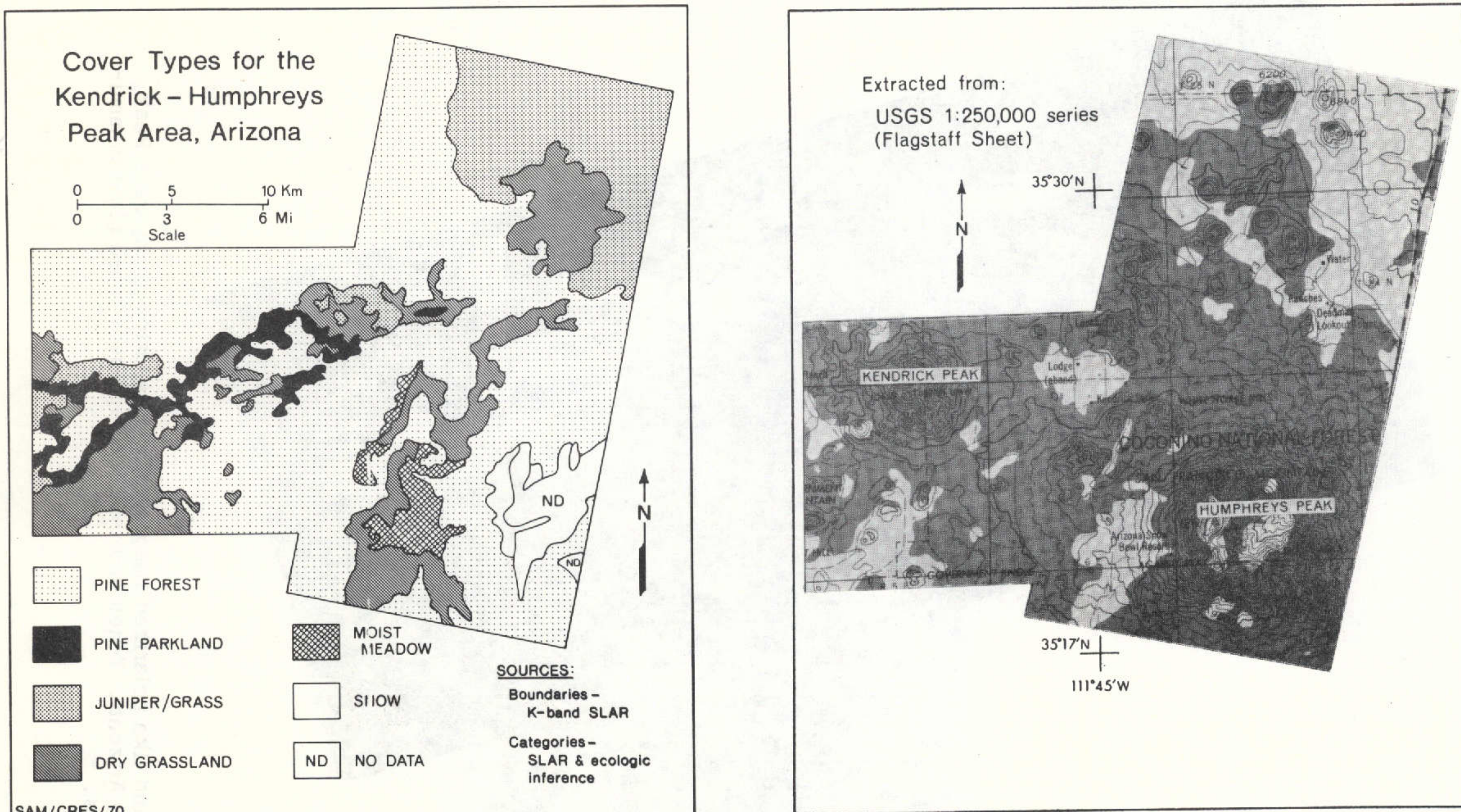
Figure 34

polarization should be observable in places such as central Australia where huge areas are dominated by mulga scrub (Acacia aneura), spinifex plains (Triodia spp.) or mixtures of the two. The bluebush deserts of South Australia consisting mainly of Kochia should be analogous to the great basin sage of North America.

As a second example of mapping potential for vegetation, Figure 35 shows a high altitude area north of Flagstaff, Arizona. Within the region three vegetational zones are known to exist; pine forest (mainly Pinus ponderosa); grassland; and juniper woodlands. From the preceding discussion one would expect to find clear boundaries attending such grossly different height and density phenomena, at least at higher incidence angles. Inspection shows that this is indeed the case. The variations are so great in fact that image textures as well as tones can be delineated and categorized. For areas of pine forest (see Figure 36) a definite "popcorn" texture is observed on the original imagery. Since both polarizations display nearly the same tone and texture, it appears that ponderosa forests have little depolarizing potential. "Texture" is a complex combination of phase relationships between trees of varying height and resonances associated with needle spacing. Phase may be particularly important in mature stands where scattering facets facing the receiver are added in time phase (giving a bright spot on the imagery) and those facing away from the receiver are subtracted (giving a dark spot).

On enlarged versions of the cross and like polarized components, intricate patterns of tone and texture can be recognized, then categorized according to known ecological relationships and image appearance. Figure 35 demonstrates the capacity for mapping not only the broad structural groups, but several subgroups as well. Although the cross polarized image is not shown in Figure 36, the addition of this information permits a few boundaries only marginally distinguishable on the HH to become clear. The technique is analogous in photography to adding a different film-filter combination. Presumably, if the full complement of polarizations and viewing directions were available, highly reliable delineations could be made. The reasons why some plant communities depolarize signals more than others are not fully known. Some preliminary statements can be found in Morain (1967) and Morain and Coiner (1970).

In the subtask reports that follow, we summarize our research efforts and those under subcontract to the Forestry Remote Sensing Laboratory at Berkeley in more temperate regions of the U.S.



Cover Types for the Kendrick – Humphreys Peak Area, Arizona
0 5 10 Km
0 3 6 Mi
Scale
ND
N
PINE FOREST
PINE PARKLAND
JUNIPER/GRASS
DRY GRASSLAND
MOIST MEADOW
SNOW
ND NO DATA
SOURCES:
Boundaries - K-band SLAR
Categories - SLAR & ecologic inference
SAM/CRES/70
Extracted from:
USGS 1:250,000 series
(Flagstaff Sheet)
35°30′N
N
KENDRICK PEAK
COCONINO NATIONAL FOREST
HUMPHREYS PEAK
35°17′N
111°45′W

Figure 35.

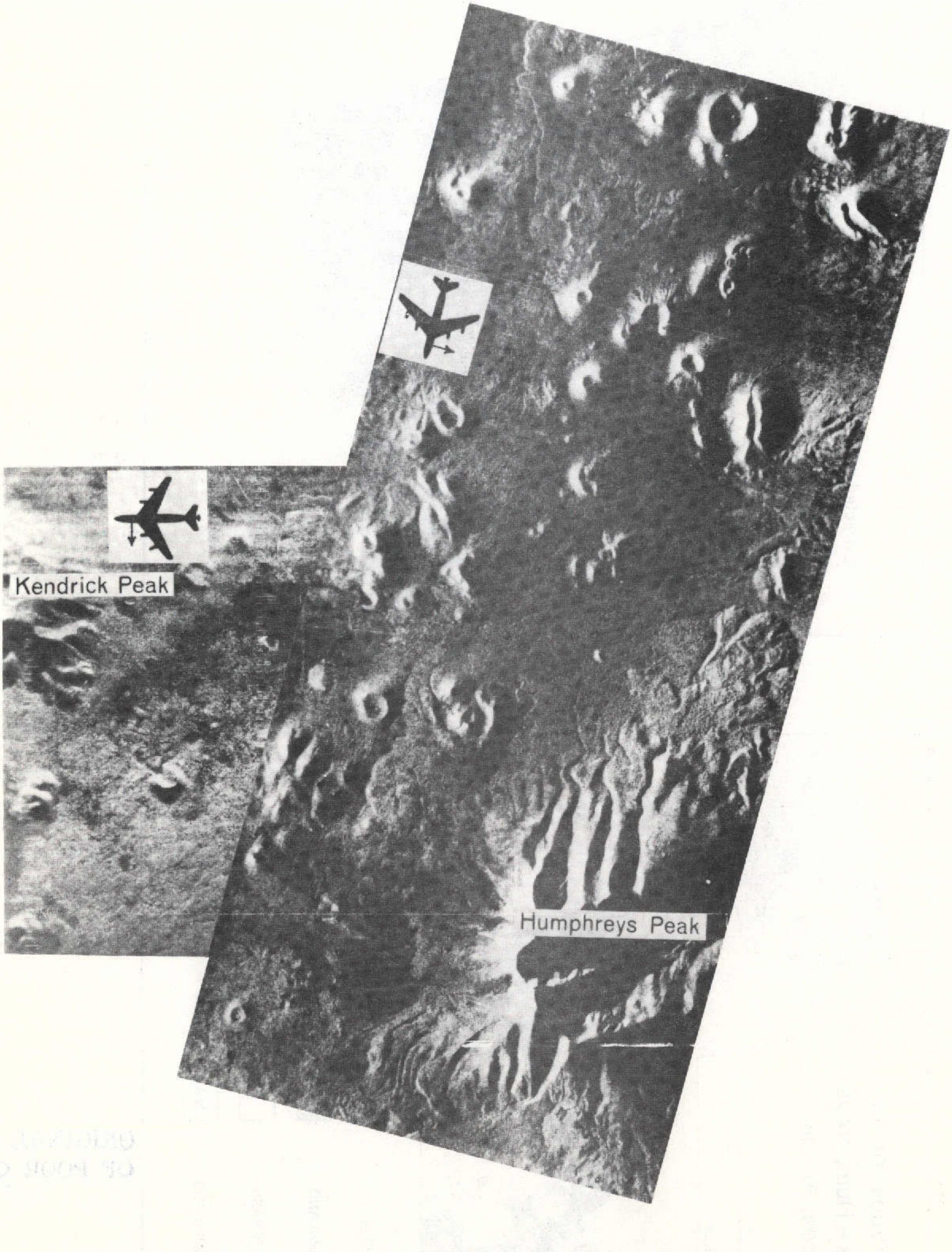


Figure 36. K-band like polarized imagery of the Kendrick-Humphreys Peak area, Arizona. Tones and textures represent broad plant communities.

Subtask 2.5.3.1

VEGETATION MAPPING WITH SIDE-LOOKING AIRBORNE RADAR: YELLOWSTONE NATIONAL PARK*

Norman E. Hardy

The purpose of this study is to delimit the vegetation communities of Yellowstone Park from SLAR imagery and to explore the feasibility of identifying vegetation types by power spectrum analysis.

The park was chosen for three reasons: (1) the availability of AN/APQ-97 SLAR imagery for the greater part of the park, (2) the willingness of the National Park Service to provide ground support data including a vegetation map, and (3) plant communities in the park are structurally simple and conform to those typical of the eastern Rocky Mountains.

The interpretation approach was to define the boundaries of the vegetation communities. After boundary definition, a classification of vegetation types was established based upon elevations, moisture and slope features evident in the SLAR image. Image boundaries corresponded well with those on the ground truth map, but the classification derived from the imagery was not in total agreement with that shown on the ground truth map. To assist in the classification of the vegetation communities, a matrix interpretation key was constructed (see subtask 2.5.2.2).

Comparison of the radar produced map (Figure 37) with the pre-existing National Park Service map (Figure 38) suggests that most of the physiognomic changes detectable on the ground, are also clearly defined on the radar imagery. However, the radar map does contain varying degrees of reliability (Figure 39), since much of the park has only received single coverage. Consequently, most of the park is covered by only a fraction of the incidence angle range available from the system. Only an area at the north end of the Park has received multiple coverage, and it is this area where plant communities are most accurately defined (compare Figure 37 with 38 and 39).

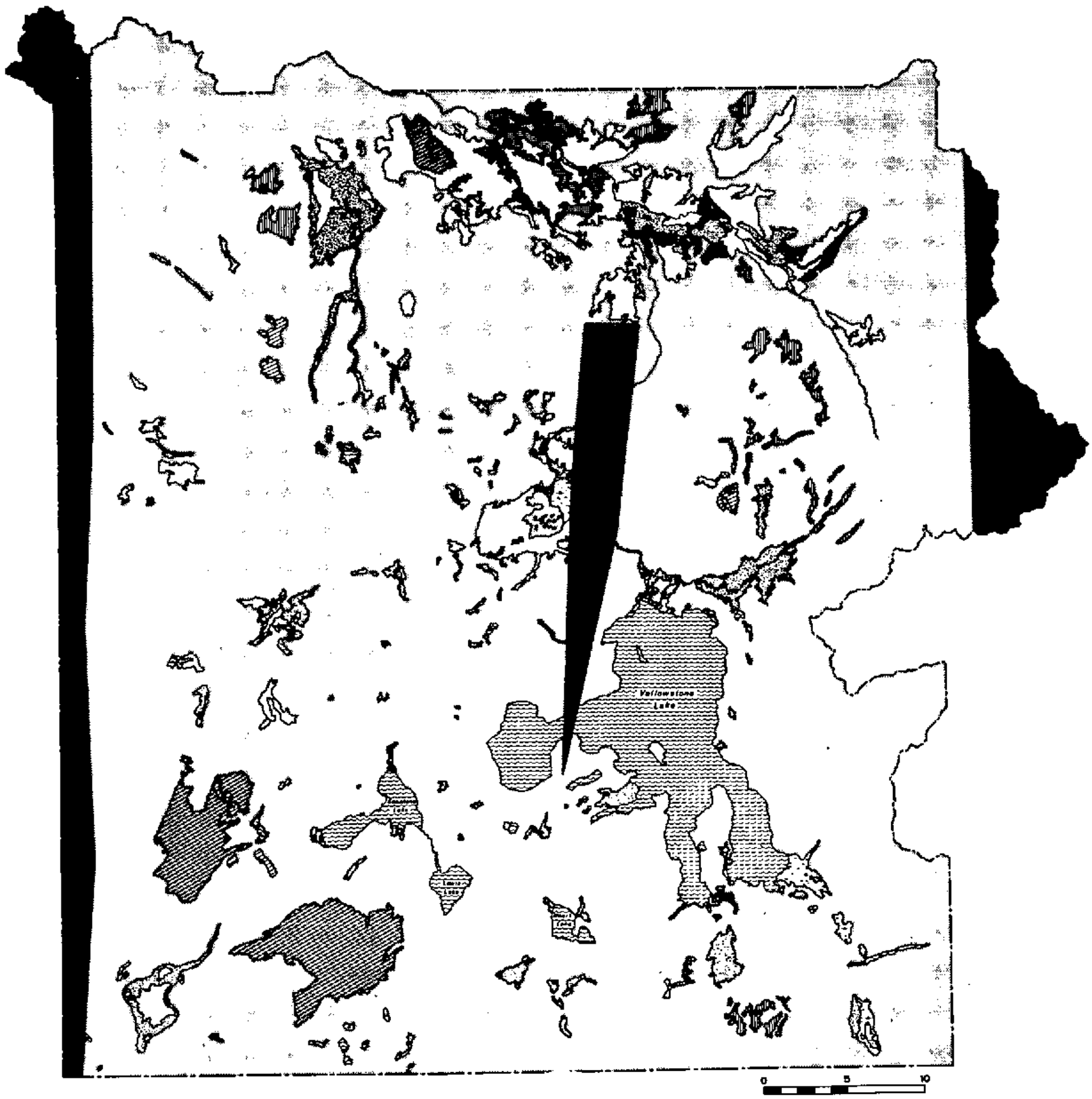
Although problems of interpretation have been encountered, this study has

*Condensed from an article of the same name in NATO Advisory Group on Aerospace Research and Development (AGARD) Conference Proceedings No. 90 on Propagation Limitations in Remote Sensing, 1971, pp. 11/1–11/19.

FIGURE 37

RADAR VEGETATION MAP

YELLOWSTONE NATIONAL PARK



- Lodgepole Pine - Mixed Coniferous Forest
- Douglas Fir Forest
- Marsh (Sedges, Wetland Grasses)
- Moist Sedgegrass / Shrub Complex (2200 - 2700 m.; Willows, Wetland Sage, Grasses)
- Dry Lowland Grass / Sagebrush Complex (2200 - 2700 m.; Dryland Sage, Drought Tolerant Grasses)
- Dry Sub-Alpine Sagebrush Meadow (2700 - 3000 m.)
- Dry Alpine Grassland (Above 3000 m.; Short Grasses, Some Sedges, Flowering Plants)
- Dry Sub-Alpine Grassland / Conifer Complex (Lodgepole Pine, Drought Tolerant Grasses)
- Thermal Areas (Varying Vegetation Types)
- Water Mass
- No Radar Coverage

FIGURE 38

FIELD DERIVED VEGETATION MAP

YELLOWSTONE NATIONAL PARK

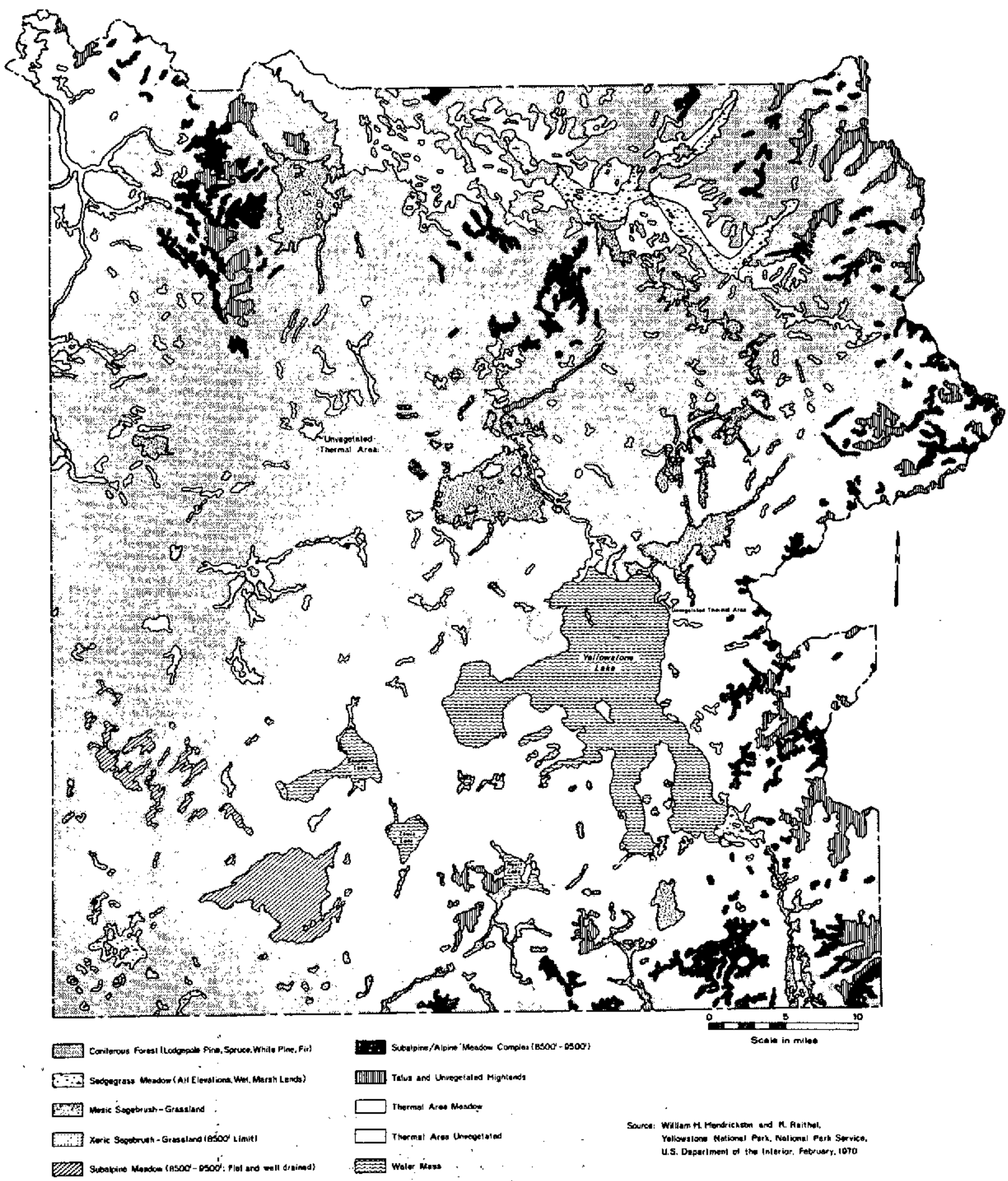


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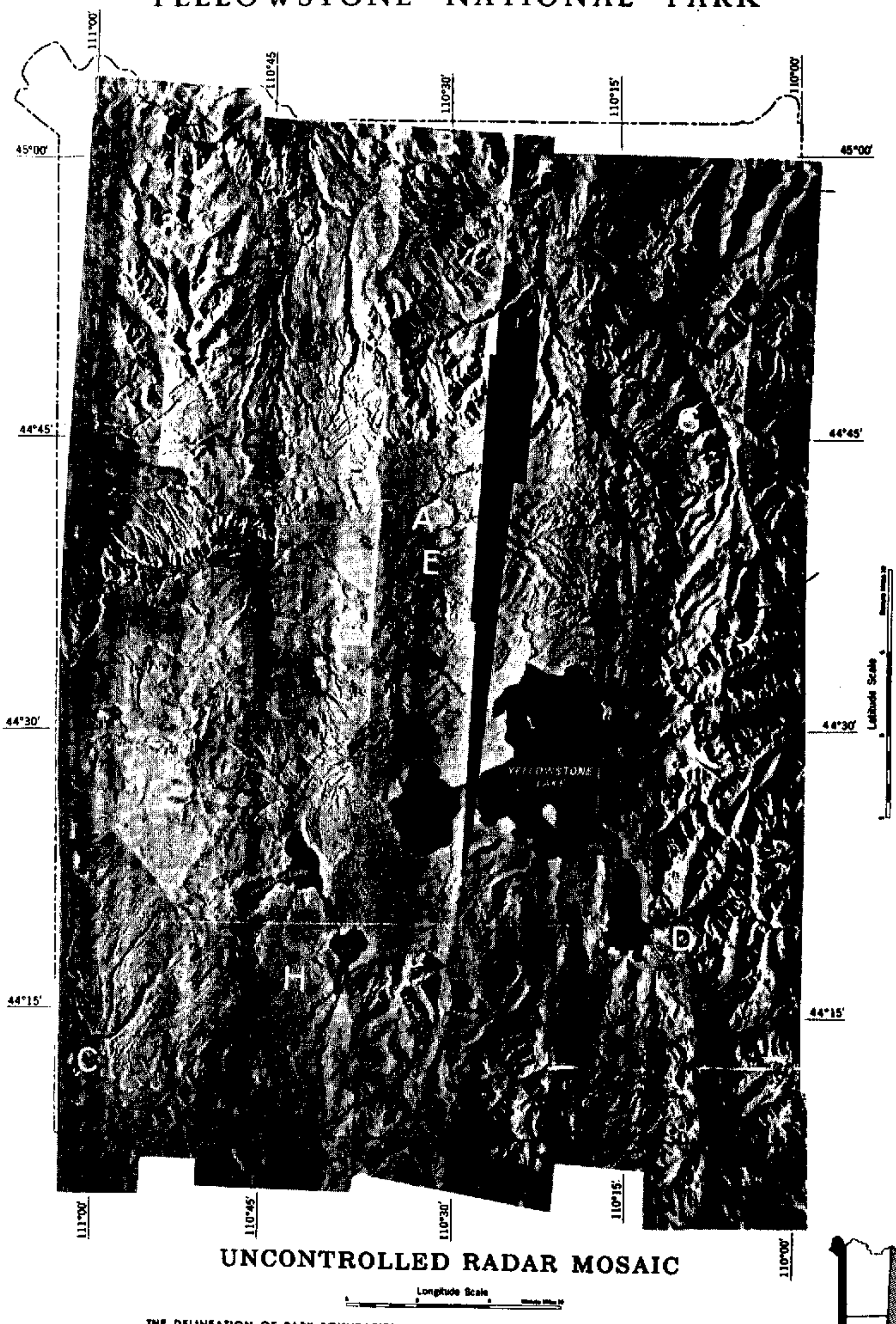
FIGURE 39

RADAR MOSAIC

YELLOWSTONE NATIONAL PARK



UNCONTROLLED RADAR MOSAIC

Longitude Scale

THE DELINEATION OF PARK BOUNDARIES, GRID, AND SCALE ON THIS MOSAIC IS APPROXIMATE.

COMPILED BY THE U. S. GEOLOGICAL SURVEY.
IMAGERY WAS OBTAINED ON OCTOBER 15 AND 21, 1965 FOR THE EARTH RESOURCES SURVEY PROGRAM OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION THROUGH THE COOPERATION OF THE U. S. ARMY ELECTRONICS COMMAND.

SENSOR WAS THE AN/APQ-97 SIDELOOKING RADAR, DEVELOPED BY THE AEROSPACE DIVISION, WESTINGHOUSE ELECTRIC CORPORATION FOR THE U. S. ARMY ELECTRONICS COMMAND.

1968

been successful. The major recommendation relates to mission planning. From this study, it is concluded that analysis of natural vegetation communities is dependent upon at least a 40% sidelap. This ensures that all areas covered will be found at least once in near, mid and far range, thus allowing comparison between vegetation reflectivity at different look angles. Unlike geology, where it has been suggested that flights parallel to topographic features are most advantageous, we recommend that vegetation analysis requires flights which are perpendicular to, as well as parallel to, major topographic features.

In an effort to glean vegetation information from the imagery beyond routine boundary delineation and categorization, we are extending the investigation to include the use of lasers. For the purposes of this report it is not necessary to go into detail regarding the internal workings of lasers. Nevertheless, a brief discussion is worthwhile to understand the strategy and evaluate the results.

The term "laser" is an acronym meaning light amplification by stimulated emission of radiation. It is a device for producing a powerful monochromatic light beam in which the waves are coherent. Once produced, the light must be filtered to eliminate extraneous noise; then refocused. The refocused light is then passed through a preselected "scan" area on an image. The pattern within the scan area is transformed and a Fraunhofer Diffraction Pattern is produced in the transform plane of the lens. Once the transform has been created, wedge and annular ring filtering techniques, which are the basis of this study, are applied to the FDP. Measurements of transmitted power representing various terrain directions and periodicities can then be noted.

Wedge Filtering

When a coherent light beam is passed through an image, any angular characteristics present on the image will be manifested as axes within the FDP. These axes are symmetrical in opposite quadrants of the transform and pass directly through the origin of the pattern. The object of wedge filtering is to filter all but a very small amount of the total light in the transform over a sequence of small discrete angles from 0° to 180°. As the filter is rotated about the origin of the transform, light passes only if some degree of directionality is present. If the surface possesses strong directionality, it will be a fairly intense axis in some direction; by integrating the light energy of the FDP along a radial line, the total contribution in one direction is obtained independent of frequency (and independent of location in the scan area).

This will be represented as a strong peak on the INTENSITY vs. Θ curve (Figure 40).

Annular Ring Filtering

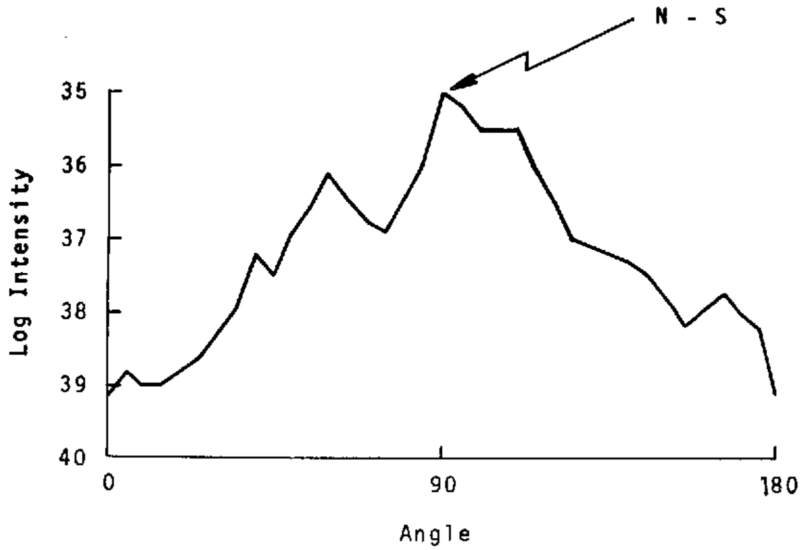
When coherent light is passed through an image it is transformed and linear features are displayed as axes in the transform, while high frequency features and periodic features are displayed as points of high intensity at various distances from the center of the transform. It is this characteristic of the transformed image which is the basis of the annular ring filtering technique, and the resultant intensity vs. radius curves. For this study, the annular rings are a series of 27 rings which range from approximately 0.5 mm to 22 mm in diameter, with a ring width of approximately 0.5 mm. To generate a data set, the rings are moved across the transform and power readings taken from each. When values have been derived for each of the 27 rings, they are plotted as intensity vs. radius curves. For the area scanned, any peaks on the curve will show if the surface has a distinct periodic characteristic; if it has, the location along the X-axis of the curve will indicate whether the phenomenon responsible is of high or low frequency (Figure 41).

Optical Processing As a Potential Aid to Image Interpretation

At this point we need to discuss the kinds of imagery used in the Yellowstone experiment, how each type lends itself to optical processing, and the kinds of data to be expected from each type. Remember that as image scale and resolution relative to the ground surface increase, different characteristics of the surface will influence the appearance of the image. This simply means that as the interpreter examines several types of imagery, different characteristics of the surface will influence his interpretation.

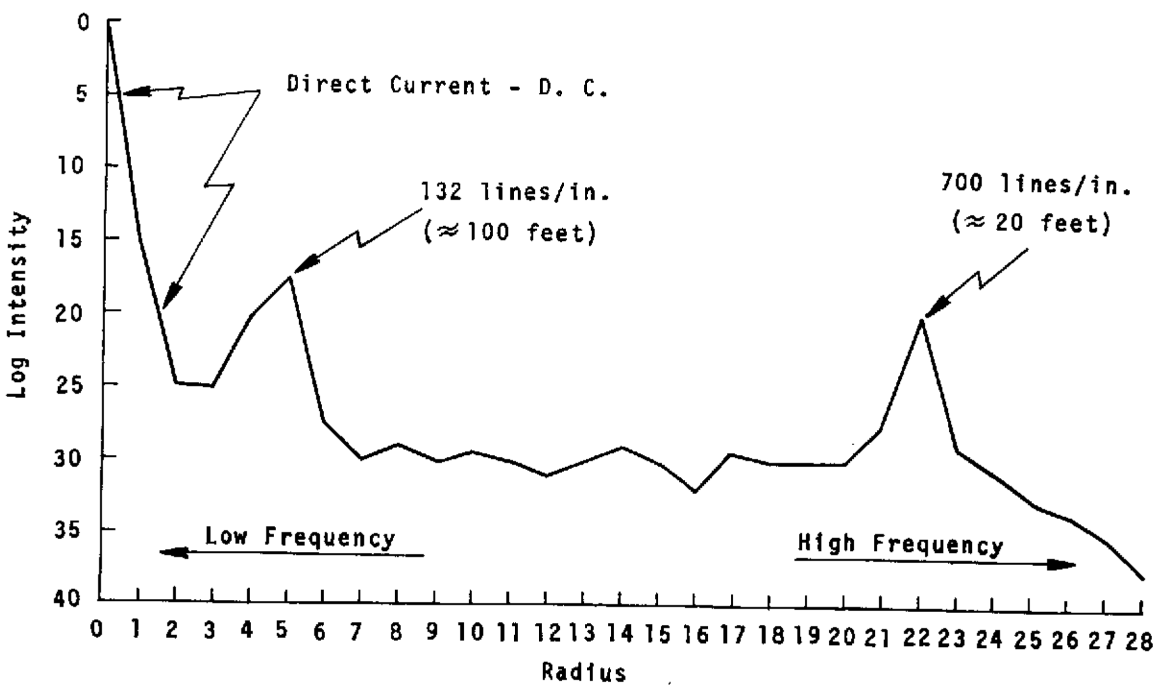
In the Yellowstone example we employed: (1) 35 mm photographs taken from an altitude of about 2000' and having a ground resolution of one foot; (2) USGS black and white aerial photography at a scale of 1:37,400 and ground resolution of $\pm$ 5'; and (3) Ka-band imagery at a scale of 1:155,000 and a ground resolution of about 50'.

Figure 40



Angular curve displaying a strong peak representing a dominant North-south directionality within the 1: 155,000 image. Note also the less prominent directionality characteristics of weaker surface phenomena.

Figure 41



Frequency curve displaying strong high and low frequency characteristics associated with strong surface periodicities.

35mm Aerial Photography

For photography with 1' resolution the interpreter must consider individual plants and their geometries when attempting to obtain optical data from the image. A coherent light beam of 2 mm passing through an image of large scale and high resolution will be transformed largely according to the characteristics of individual trees, and the local environment in which the trees are located. Therefore, the intensity vs. Θ curves (wedge filtering) for a forest may show a distinct linearity which is related to the branches and branchlets of a tree. Meanwhile, the intensity vs. radius curves (annular ring filtering) may show frequencies related to the number of branches per unit area of the tree, and if the tree is sparsely branched they may show features relating to the understory and even the ground. Thus, from imagery of this type, it is reasonable to expect to distinguish the tall, straight, sparsely branched Alpine Fir from the shorter, much bushier Douglas Fir. However, it is essential that the interpretation be made using both the curves and the original photography or image in order to determine which feature is responsible for any periodicity.

Vertical Aerial Photography

The imagery employed in this stage of the experiment was standard aerial photography of 5' resolution. In terms of image interpretation this implies that grasses, flowering plants and many shrubs (such as small willows or sagebrush) should appear as a relatively smooth, homogeneous surface. For the application of the optical processor, this suggests that meadowland would not likely show any frequency or periodicity characteristics, but that forest would have a distinctive pattern dominated by relatively low frequency components (e.g. trees spaced rather far apart).

From the standpoint of vegetation structure the resolution of the system demands that the interpretation be focused upon frequency relationships of the trees and their environments; upon the biotope and localized structure rather than on physiological characteristics of individual plants, as was the case in the previous example using 35 mm photography. It is at this scale that the study begins to assume a spatial characteristic, and as a result becomes more of a geographic study than a purely botanical project. From this point, it becomes possible to examine the characteristics of intraspecific tree spacing, as well as interspecific distribution of trees, or trees and shrubs.

Ideally, if trees of a given species tended to exhibit a fairly even distribution, as do many of the plants of arid zones, it would be possible to derive Intensity vs. Radius curves which would reflect this periodic nature.

SLAR Imagery

The radar imagery for Yellowstone Park is at a scale of 1:155,000, with a ground range resolution of approximately 50 feet. At this scale and this resolution, it is obvious that individual branches, branchlets, or even individual trees will not be detectable on the image. Thus, to make optimum use of the information contained within the radar image, the interpretation approach will probably have to be based upon the broader community study of individual plants. This means that the research must be directed toward the analysis of ecosystems, with emphasis placed upon complexes such as ecclines and ecotones and the problems of specific ecologic range.

With these concepts as a basis, it is assumed that the optically derived radar data will not show characteristic signatures for the individual plants; however, it is likely that the curves produced will reflect broad community structure for each community studied. Thus, it is quite likely that the biomes of grassland, desert, savanna, and forest will be readily distinguishable, and inter-community compositions within each biomes will be possible through analysis of gross frequency characteristics of communities which are larger than the resolution of the system. Therefore if the optical system can derive data of this nature from the imagery, it will probably be possible to break the communities down to the species level through inferences based upon knowledge of regional and local environments.

Analysis of Optically Processed Radar Imagery

In the analysis, five areas which appear totally different to the naked eye were selected from the radar imagery. These areas were optically scanned for frequency and directionality data, as were the corresponding areas on the photographs. For this report only the results from Lodgepole Pine Forest are presented.

Lodgepole Pine is the dominant conifer in Yellowstone. It forms the main portion of the upper canopy, and homogeneous stands are relatively easy to locate on the radar image.

The examination of the frequency analysis for radar must take cognizance of the 50' resolution (Figure 42a,b). High frequency indicators are related to the film grain, system noise, flaws in the film, or scan lines but definitely not to surface related phenomena. The inspection must be restricted to the low frequency portion of the Intensity vs. Radius curve. Within this portion of the curve two peaks appear. The first is at 97 feet (132 lines per inch) and the second at 65 feet (200 lines per inch). Comparing this with the curve derived from aerial photograph (suitably reduced to the radar scale) a comparable pair of peaks can be observed (94 feet and 62 feet). Since the images are of comparable scale, it is possible that these frequences genuinely represent unique surface phenomena. We must explore further the question of whether the phenomena are vegetation related.

Turning briefly to the directional data derived from the wedge filtering operation, it appears that for radar a strong directional characteristic is present. However, detailed comparison of the curve and the imagery reveals that the high intensity peaks at 0° and 180° represent mechanically caused scratches. The peak at 90° represents the cross range dominance of the radar scan lines. These are discrete lines imparted to the film by the radar pulse as it is returned and transferred through the C.R.T.

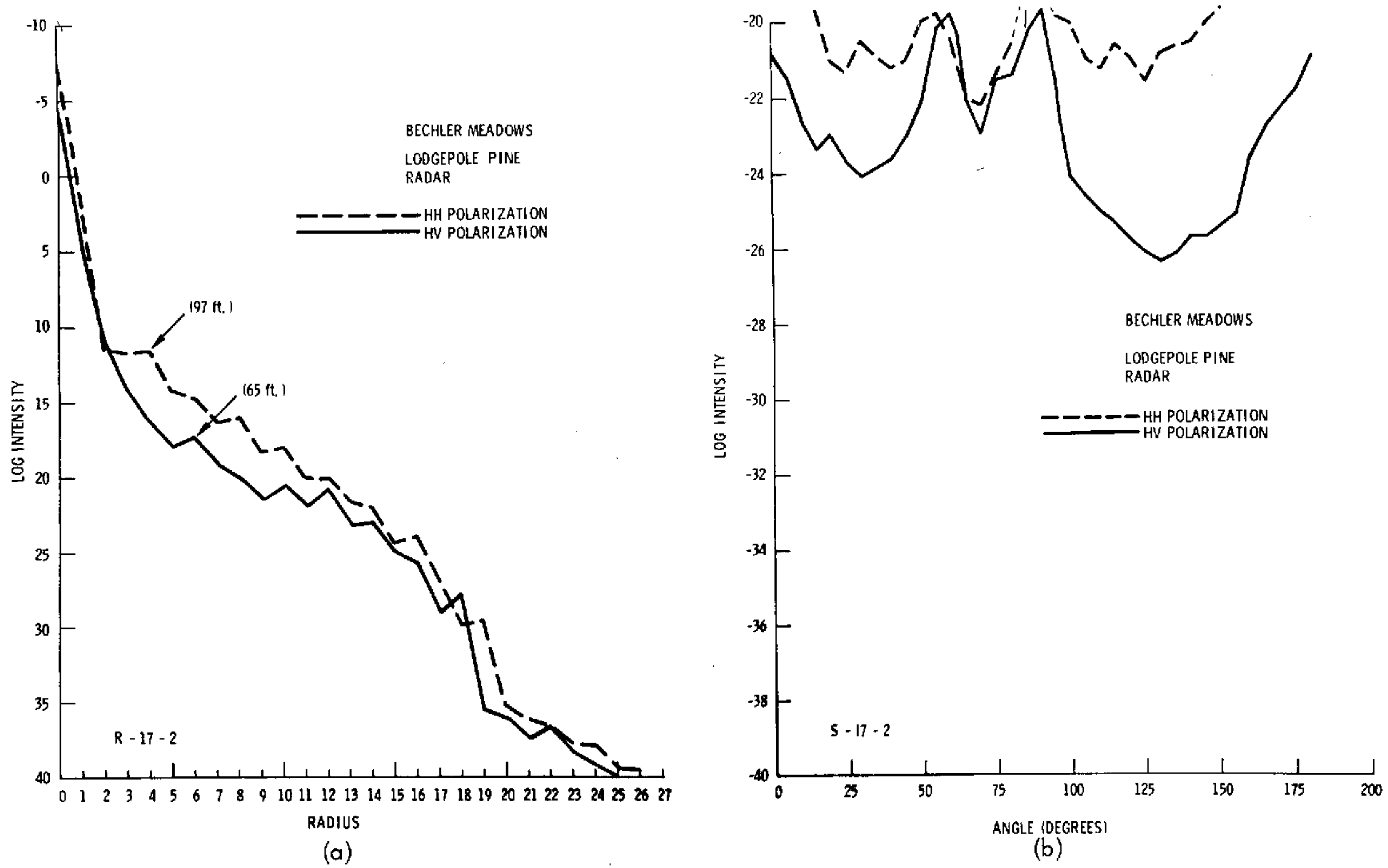

BECHLER MEADOWS
LODGEPOLE PINE
RADAR
HH POLARIZATION
HV POLARIZATION
(97 ft.)
(65 ft.)
LOG INTENSITY
R - 17 - 2
RADIUS
(a)
BECHLER MEADOWS
LODGEPOLE PINE
RADAR
HH POLARIZATION
HV POLARIZATION
LOG INTENSITY
S - 17 - 2
ANGLE (DEGREES)
(b)

Figure 42

Subtask 2.5.3.2

SLAR IMAGERY FOR EVALUATING WILDLAND VEGETATION RESOURCES*

Steven J.Daus & Donald T. Lauer **

Introduction

The objective of the research reported here was to determine the utility of SLAR imagery for evaluatingwildland vegetation resources. Specifically, comparisons were made, with the help of a group of skilled photo interpreters, between certain ground features such as aspect, slope and major vegetation/ terrain type and corresponding tonal/texture image characteristics for each feature or groups of features as seen on the SLAR imagery. In addition, qualitative evaluations were made regarding the overall usefulness of SLAR imagery.

Description of Study Area and SLAR Imagery

The Bucks Lake-Meadow Valley site, in Plumas County, California, was chosen as the study area for four reasons: (1) the site is located in the north-central Sierra Nevada Mountains in the heart of a mixed conifer forest type which encompasses a variety of types, compositions, species, densities and age classes of vegetation; (2) the site possesses a variety of topographic conditions ranging from 80% slopes adjacent to the middle fork of the Feather River to flat pasture lands in Meadow Valley; (3) a large portion of the site previously had been flown with a SLAR system and the resulting imagery was considered to be of excellent quality; and (4) an abundance of ground data was available about the site.

Analysis Procedure

Conventional photo interpretation performed on vertical aerial photographs involves a complex process of evaluating a number of image characteristics such as

* Condensed from ASP-paper 71-333 presented at ASP-ACSM Fall Convention, San Francisco California, September 1971.

**The authors are located at the Forestry Remote Sensing Lab, University of California. This study was performed under subcontract 1775-9. A final report is in preparation.

size, shape, texture, tone, shado / and stereo parallax. The analysis of these factors combined with the additional powers of the human brain (i.e., subjective reasoning, intuition, convergence of evidence, past experience, etc.) allows the interpreter to recognize, identify and deduce the significance of objects or conditions seen on the photographs. However, this task is further complicated when working with SLAR imagery. Rarely are size, shape, shadow and stereo parallax useful inputs to the interpretation process because either they do not exist in the imagery or cannot be recognized. Consequently, the interpreter generally relies on his ability to discriminate levels of image tone and texture. Thus, when attempting to map wildland vegetation types on SLAR imagery, a reference key illustrating discrete tonal/texture categories for each type of interest would be useful to the interpreter. First, however, it is necessary to determine if there is a consistent tone or texture value that can be assigned to any one of several vegetation/terrain types.

Photo interpretation tests were performed whereby numerous systematically selected plots on the SLAR imagery were classified into one of nine tonal/texture categories. The interpreters were not asked to identify objects and conditions on the SLAR imagery; they were instructed only to categorize the plots in terms of tone and texture.

Three skilled interpreters working independently with the same SLAR imagery classified each plot. A reference key, showing examples of each tonal/texture category, was used by the interpreters as they evaluated the image characteristics of each plot. The interpretation key was constructed in such a manner that each point could be matched with one of nine chips representing a particular tonal-texture category. Once the interpreters classified all of the plots as to image tone and texture, it was possible to relate their results to ground truth data collected for each plot (i.e., aspect or orientation of terrain with respect to sensor, steepness of slope and major vegetation/terrain type). Thus, with the tabulated data, correlations could be made between the tonal/texture properties of an image and the corresponding ground features (see Tables 11 and 12). Note that the first row in Table 11 should be read as follows: 78 image plots were classified as smooth-white; 86% of those plots were on slopes normal to the beam while 14% were on slopes oblique to the beam; 30% of the plots were on 20-40% slopes; and 20% on 40-60% slopes and 50% on 60-80% slopes; and 9% were in dense conifer, 33% in sparse conifer and 58% in dry site hardwoods. The remaining rows in Table 11, as well as those in Table 12, should

TABLE 11

RESULTS GROUPED BY TEXTURAL/TONAL CATEGORY

Textural/Tonal Category (and number of points in each category)	Texture/Tonal Points (Percent of Total For Each Category Falling Within Each Type)													
	Aspect			Slope				Vegetation/Terrain						
	Normal to beam	Facing away from beam	Oblique to beam	0–20%	20–40%	40–60%	60–80%	Dense conifer	Sparse conifer	Dry site hardwood	Brushfield	Bare ground	Riparian and meadows	Water
Smooth White (78)	86	0	14	0	30	20	50	9	33	58	0	0	-	0
Smooth Grey (104)	46	35	19	35	42	10	8	16	25	43	4	12	-	0
Smooth Black (108)	2	72	26	20	18	27	36	4	30	52	0	3	-	11
Medium White (127)	76	9	15	17	36	24	22	15	35	44	8	6	-	0
Medium Grey (206)	40	23	37	35	40	16	9	14	48	31	10	6	-	0
Medium Black (123)	8	60	32	34	26	19	21	20	46	28	4	4	-	0
Rough White (29)	52	14	34	24	38	31	7	4	49	43	0	4	-	0
Rough Grey (81)	5	75	20	46	30	4	10	20	54	21	1	3	-	0
Rough Black (44)	6	71	23	30	41	10	19	18	55	27	2	2	-	0

TABLE 12

RESULTS GROUPED BY VEGETATION/TERRAIN TYPE

Vegetation/ Terrain Type (and number of points in each type)	Vegetation/Terrain Points (Percent of Total Within Each Type Falling Within Each Category)															
	Aspect			Slope				Textural/Tonal Category								
	Normal to beam	Facing away from beam	Oblique to beam	0-20%	20-40%	40-60%	60-80%	Smooth-white	Smooth-grey	Smooth-black	Medium-white	Medium-grey	Medium-black	Rough-white	Rough-grey	Rough-black
Dense Conifer (134)	34	25	41	27	38	5	30	6	13	3	16	24	19	1	12	7
Sparse Conifer (369)	35	26	39	24	38	22	16	7	8	9	12	23	15	4	13	7
Dry Site Hardwood (338)	37	31	32	24	31	23	22	13	14	16	16	18	10	3	5	4
Brushfield (15)	80	20	0	100	0	0	0	0	33	0	7	14	33	0	7	7
Bare Ground (46)	26	0	74	67	20	7	6	0	26	7	15	30	11	4	4	2
Riparian-meadow (0)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Water (13)	0	100	0	100	0	0	0	0	0	100	0	0	0	0	0	0

be read in the same manner.

Discussion of Results

The data in Table 11 show a consistent relationship between certain tonal/texture categories and slope aspects. In fact, aspect of the terrain, in relationship to the positioning of the sensor system, seems to have a profound effect on the image characteristics. There does not appear, however, to be any consistent relationship between image tone and texture, and vegetation/terrain types (except for large bodies of water) as indicated in Table 12.

The data suggest that vegetation typing will be inaccurate in areas of rugged terrain. However, this does not mean that radar imagery is useless. It was discovered that an interpreter could effectively delineate a variety of tonal and textural anomalies on a SLAR image, and he could also consistently identify (1) bodies of water, (2) drainage networks, (3) aspect and relative steepness of slope, and (4) watershed boundaries. In addition, in relatively flat areas, delineated boundaries often relate to changes in vegetation type. The types on each side of the boundary can rarely be identified on the SLAR imagery alone, but stratifications indicating differences in vegetation type and condition can be made. Basic map information showing homogeneous terrain features can be coupled with supplemental data derived from other sources to produce preliminary maps and statistical data about the vegetation resources.

Subtask 2.5.3.3

THE POTENTIAL OF RADAR FOR SMALL SCALE LAND USE MAPPING*

F.M. Henderson

Although many studies have employed SLAR imagery for one purpose or another, no one has analyzed its ability to create small scale general land use maps over an extensive area containing a variety of geographic settings. This study attempts to create such a map. Specifically, the practicality of Side-Looking Airborne Radar (SLAR) to study and delimit general land use regions for small scale maps will be investigated. This study will analyze an imaged area from eastern Minnesota to northern Utah to test the hypothesis that SLAR imagery can be used to create small scale land use maps.

The study area consists of an area approximately fifteen miles wide and 1500 miles long stretching from eastern Minnesota, across South Dakota and Wyoming to Northern Utah. The area was flown by Westinghouse on October 10, 1965. This imagery is the longest traverse available and transects a number of agricultural land uses, soil types, vegetation communities, physical land forms and topography, and climatic regions.

A map delimiting "SLAR land use regions" has been completed using the SLAR imagery without _a priori_ knowledge of the study area. That is, no ground work had been done nor was the interpreter familiar with the area. Land use regions were delimited solely on their appearance on the radar imagery. As land use borders were drawn, criteria for their selection were recorded. Figure 43 illustrates two SLAR land use regions and describes the decision making process involved in identifying them.

To be considered a region, the combination and inter-action of the five factors had to produce a homogeneous area that was different from adjacent areas. Initially, twenty-one different land use regions were delimited. The characteristics of each region in terms of the five factor criteria were recorded. The next step will be to compare the characteristics of the twenty-one areas and to consolidate regions with nearly identical criteria.

*This report represents a new effort for which only the formative stages are complete.

Topography: Region A is one of gentle relief and appears almost level while Region B appears much more dissected and eroded. Region B also contains plateaus and more obvious relief features.

Natural Vegetation: Almost none is visible in Region A as the entire area is cultivated except for the stream banks. Some texture coarseness in Region B might imply a low vegetation pattern on many of the non-cultivated slopes.

Settlement: Although scattered there are more farmsteads in Region A and they are more regularly spaced than in Region B.

Field Geometry: Region A obviously contains a rectangular field pattern with some borders conforming to terrain limitations. In addition the pattern is virtually ubiquitous. Region B contains fewer fields, and the general pattern is one of larger fields and natural pastures with some ponds confined to plateau areas.

Transportation: A rectangular system is visible in Region A with major and minor arteries. Power lines are also visible across the image. In contrast, there are fewer roads in Region B, and they are less visible except on the plateau areas. In addition only parts of one power line are visible.

Figure 43

In the follow-on phase we will devise an interpretation key using the criteria originally employed to determine a "SLAR land use region." This key will then be tested using two groups: (1) "non-remote sensers" -- geographers who have a background in mapping and land use terminology but not in remote sensing or photo interpretation, and (2) "remote sensers" -- geographers who have experience in working with land use regions, remote sensing and radar interpretation. The degree of accuracy of each group in detecting land use regions using the key will then be computed. Those areas identified correctly and incorrectly will be examined to determine what possible factors aided or hindered identification. Last, an evaluation of SLAR for mapping land use regions will be made based on (1) the success of the interpretation key, (2) terrain phenomena visible, (3) training required to analyze SLAR imagery, and (4) possible uses for maps of "SLAR land use regions."

If land use regions comparable to those compiled by Anderson (1970), Marschner (1959), or Austin (1965) can be consistently delineated from SLAR (using the same or different category criteria) such maps could be updated much faster and kept current. A change in land use such as the introduction of irrigation to a grazing area, or the progress of certain land reforms could be easily monitored. The need for small scale general land use maps exists, but no one knows if SLAR can be used to fill this need.

It is hoped this study will at least mitigate some of the voids between theory and proven fact. First, by analyzing a large, extensive area, it is possible to study radar's consistency between environments. For example, is the same level of information and detail identifiable from region to region? Second, by comparing the "radar land use regions" with regions already delimited on existing maps, the degree of compatibility can be derived. Third, the development of a radar interpretation key will test the validity and consistency of radar land use regions created by various interpreters.

Task 2.5 APPENDIX A: An Automatic Interpretation Program Derived from a Radar Interpretation Key

Percy P. Batlivala and J. C. Coiner

Purpose: To use radar data that has been digitized to interpret crops by converting a human based interpretation key into a form that can be employed as a computer algorithm.

Method: The radar image is digitized using 50 micron spot size. It is stored on tape, and then printed out as a computer map using the KANDIDATS Picture Program. The fields to be interpreted are then selected and called out onto a separate tape with each field having two files (one for the HH polarization image and one for the HV polarization image). The field is called from the tape with each file being reduced by mean and mean assignment to a single integer value between 1 and 5. The HH file integer value then is used as value I while the HV integer value is used as value J. These integers (I and J) are used to define allocation within the matrix A, which consists of crop labels to be applied to the field (i.e., if the HH value is reduced to 3 and the HV value to 3, the location in matrix A is then defined as A_{IJ} and contains the label "grain sorghum". This crop label with field identification is then printed out. Figure 44 is a simplified flow diagram of the program, and Figure 45 is a pictorial representation of a preliminary label matrix derived from an image interpretation key.

Subroutine Name: DIKEY

Calling Statement: CALL DIKEY (ILABEL, NLEVEL, IARRAY, NROWM, NCOLM, II, IMIN, IMAX, IDUM1, IDUM2, NIMAGE, NFILE, IFILE)

Arguments:

ILABEL	is the input array of labels used for classification.
NLEVEL	are the number of levels used for classification. ILABEL is dimensional (NLEVEL, NCEVEL)
IARRAY	is the field to be classified.

NROWM	is the largest number of rows on any field.
NCOLM	is the largest number of columns on any field.
II	is an integer value from 1 to 10 depending on the type of processing to be done.
IMIN	is the minimum brightness level on any field.
IMAX	is the maximum brightness level on any field.
IDUM1 IDUM2	are scratch vectors of size NIMAGE.
NIMAGE	is the number of fields to be classified.
NFILE	is the file code used to designate the file on which the images are placed. The images are read a line at a time. An "end of file" mark must designate the end of an image.
IFILE	is the file array of dimension NIMAGE.

FIGURE 44. DIGITIZED IMAGE FLOW DIAGRAM FOR SUBROUTINE DI KEY

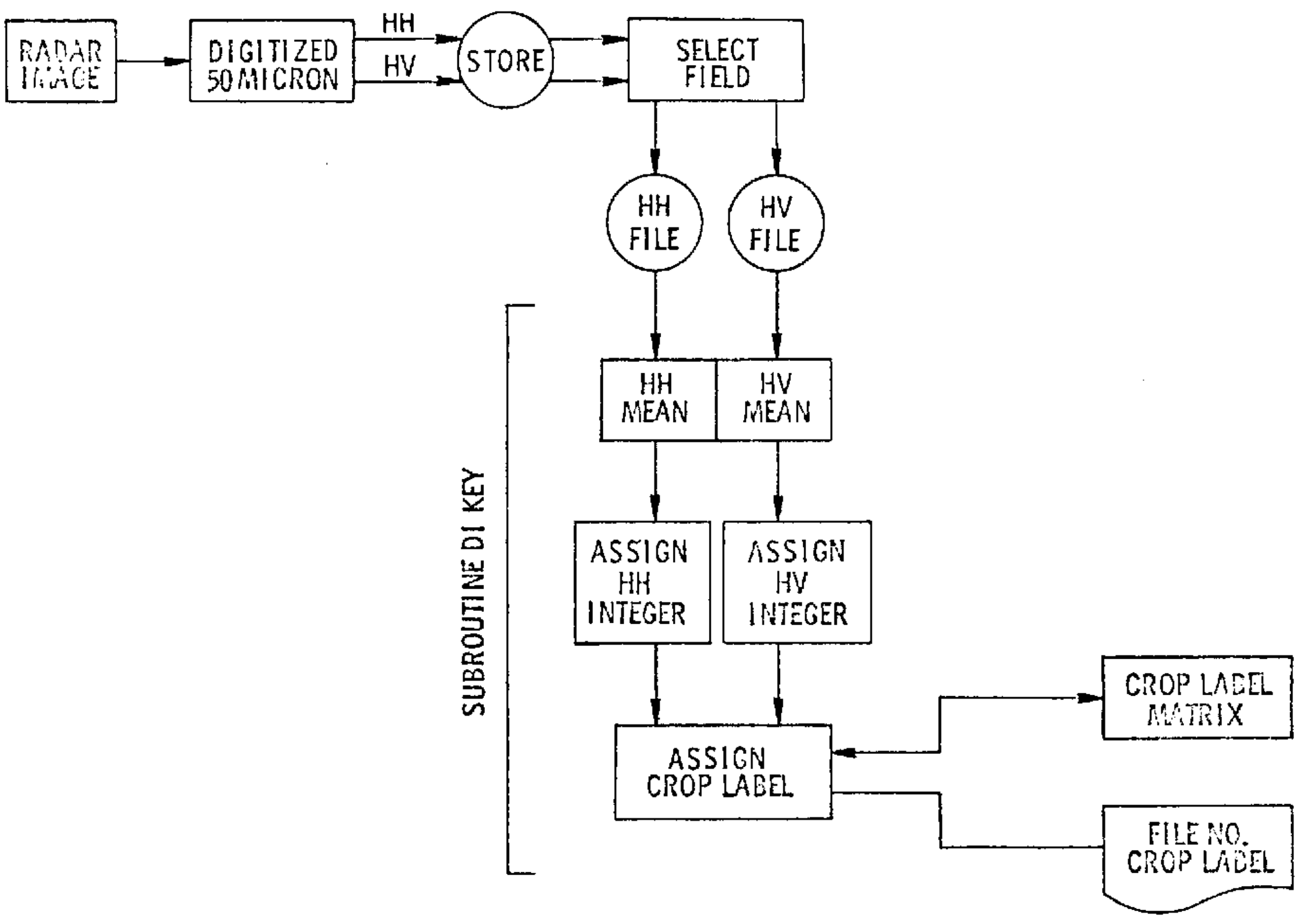


FIGURE 45. PICTORIAL REPRESENTATION OF A PRELIMINARY LABEL MATRIX DERIVED FROM AN IMAGE INTERPRETATION KEY.

HH DARK 1	RECENTLY TILLED	FALLOW	NCA*	NCA*	NCA*
2	FALLOW	FALLOW	WHEAT	WHEAT	NCA
3	NCA	NCA	SORGHUM	ALFALFA	NCA
4	NCA	NCA	NCA	ALFALFA	SUGAR BEETS
LIGHT 5	NCA	NCA	NCA	NCA	SUGAR BEETS
	HV DARK 1	2	3	4	5 LIGHT

* NO CROP ASSIGNED

02-22-72 15.584

```
      DIMENSION ILABEL(5,5),IARRAY(133,149),IDUM(34,2),IFILE(34)
C     MAIN LINE
      NLEVEL=5
      NROWM=133
      NCOLM=149
      NIMAGE=34
      IMIN=0
      IMAX=255
      NFILE=1
      II =2
      CALL DIKEY(ILABEL,NLEVEL,IARRAY,NROWM,NCOLM,II,IMIN,
     2IMAX,IDUM,NIMAGE,NFILE,IFILE)
      STOP
      END
```

```
      SUBROUTINE DIKEY(ILABEL,NLEVEL,IARRAY,NROWM,NCOLM,II,
     1IMIN,IMAX,IDUM,NIMAGE,NFILE,IFILE)
      EXTERNAL NINBIT
      DIMENSION IARRAY(NROWM,NCOLM),ILABEL(NLEVEL,NLEVEL),IDUM(NIMAGE,
     *2),IFILE(NIMAGE),LBL(11)
      INTEGER RLABEL
C     ****************************************************************
C     THIS SUBROUTINE USES TECHNIQUES OF VISUALLY INTERPRETTED
C     RADAR IMAGERY.THE CATEGORY MATRIX'ILABEL'IS PREDETERMINED
C     AND IS USED AS A INPUT PARAMETER.
C     ****************************************************************
      READ(5,101) ((ILABEL(I,J),J=1,NLEVEL),I=1,NLEVEL)
  101 FORMAT(13A6)
      WRITE(6,105)
  105 FORMAT(1X//,'THE CATEGORY MATRIX'//)
      WRITE(6,104) ((ILABEL(I,J),J=1,NLEVEL),I=1,NLEVEL)
  104 FORMAT (5(5X,1A6))
      DO 11 IIF=1,NIMAGE
      READ(5,102) IFIL
  102 FORMAT(6X,I3)
      IFILE(IIF)=IFIL
   11 CONTINUE
      MIMAGE=2*NIMAGE
C     ****************************************************************
C     START READING IN DATA
C     ****************************************************************
      DO 1 KKKM=1,MIMAGE
      IF(RLABEL(KKKM,11,LBL).LT.0) STOP
      NROW=LBL(3)
      NCOL=LBL(4)
      WRITE(6,106) NROW,NCOL
  106 FORMAT(1X,'NROW=',I3,1X,'NCOL=',I3)
      NROW=NROW+1
      DO 10 I=2,NROW
      IF(LREAD(KKKM,I,IARRAY(1,I-1)).LT.0) CALL ABORT(2HEP)
   10 CONTINUE
      NROW=NROW-1
      CALL JMEAN(IARRAY,NLEVEL,NCOL,NROW,NROWM,NCOLM,II,IMIN,IMAX,GMEAN
     1,KKKM,NIMAGE,IMEAN)
C     ****************************************************************
C     STORE IN DUMMY ARRAY IDUM THE MEANS OF THE HH AND HV
C     POLARIZED IMAGES RESPECTIVELY.
C     ****************************************************************
      IF(KKKM.LE.NIMAGE) GO TO 110
      KKKF=KKKM-NIMAGE
      IDUM(KKKF,2)=IMEAN
      GO TO 1
  110 IDUM(KKKM,1)=IMEAN
    1 CONTINUE
C     ****************************************************************
C     SEARCH THE CATEGORY MATRIX 'ILABEL' AND CLASSIFY THE FIELDS.
```

01   02-22-72   15.586

```
C       ****************************************************************
        DO 3 III=1,NIMAGE
        II=IDUM(III,1)
        JJ=IDUM(III,2)
        WRITE(6,103)IFILE(III),ILABEL(II,JJ)
  103   FORMAT(1H0,'THE IMAGE NUMBER',I3,' WAS CLASSIFIED AS A ',A6,' FIEL
       1D')
    3   CONTINUE
C       ****************************************************************
C       PRINT AND PUNCH THE RESULTS.
C       ****************************************************************
        DO 7 KKM=1,NIMAGE
        WRITE(43,107) IFILE(KKM),IDUM(KKM,1),IFILE(KKM),IDUM(KKM,2)
        WRITE(6,107)  IFILE(KKM),IDUM(KKM,1),IFILE(KKM),IDUM(KKM,2)
  107   FORMAT(1X,' HH FIELD NO. ',I3,' MEAN=',I5/,
     1          1X,' HV FIELD NO. ',I3,' MEAN=',I5)
    7   CONTINUE
        RETURN
        END
```

02-22-72   15.594

```
      SUBROUTINE JMEAN(IARRAY,NLEVEL,NROW,NCOL,NROWM,NCOLM,II,IMIN,IMAX
     1,GMEAN,KKKM,NIMAGE,IMEAN)
C     ******************************************************************
C     THIS SUBROUTINE FINDS THE MEAN OF EACH IMAGE AND THEN
C     ACCORDING TO THE OPTION 'II' TRANSFERS THE CALL TO A APPROPRIATE
C     SUBROUTINE.
C     ******************************************************************
      DIMENSION IARRAY(NROWM,NCOLM)
C     ******************************************************************
C     FIND THE MEAN OF THE IMAGE
C     ******************************************************************
      NUM=0
      DO1I=1,NROW
      DO1J=1,NCOL
    1 NUM=NUM+IARRAY(I,J)
      GMEAN=(FLOAT(NUM))/(FLOAT(NROW*NCOL))
      WRITE(6,101)  GMEAN
  101 FORMAT(1X,'GMEAN=',F6.2)
C     ******************************************************************
C     ACCORDING TO OPTION II GO TO PROGRESS IMAGE
C     ******************************************************************
      IF(II.EQ.1)  CALL EQINT(NLEVEL,IMIN,IMAX,GMEAN)
      IF (II.EQ.2) CALL SLTINT(GMEAN,KKKM,NIMAGE,IMEAN)
      RETURN
      END
```

23753 WORDS OF MEMORY USED BY THIS COMPILATION

ORIGINAL PAGE IS
OF POOR QUALITY

02-22-72   15,598

```
      SUBROUTINE EQINT(NLEVEL,IMIN,IMAX,GMEAN)
C     ****************************************************************
C     THIS SUBROUTINE QUANTIZES THE MEAN INTO NLEVEL CLASSES,USING AN
C     EQUAL INTERVAL QUANTIZATION.
C     FIND THE INTERVAL SIZE
C     ****************************************************************
      INT=(IMAX-IMIN)/NLEVEL
C     ****************************************************************
C     NOW RE-EVALUATE THE VALUE OF GMEAN
C     ****************************************************************
      DO 1 I=1,NLEVEL
      ALEVEL=INT*I
      IF(GMEAN.LT.ALEVEL) GO TO 2
      GO TO 1
    2 GMEAN=I
      GO TO 3
    1 CONTINUE
    3 WRITE(6,101)  GMEAN
  101 FORMAT(1X,'NEW GMEAN=',F5.2)
      RETURN
      END
```

23668 WORDS OF MEMORY USED BY THIS COMPILATION

1 02-22-72 15.601

```
      SUBROUTINE SLTINT (GMEAN,KKKM,NIMAGE,IMEAN)
C     ******************************************************************
C     THIS SUBROUTINE IS USED TO INPUT PREDETERMINED CLASS
C     INTERVALS FOR THE MEANS OF THE HH AND HV FILES
C     ******************************************************************
      IF(KKKM.LE.NIMAGE) GO TO 101
C     ******************************************************************
C     DETERMINES IF FILE IS AN HH OR HV FILE AND DIRECTS TO
C     PROPER INTERVAL GROUPING
C     CONVERTS HV MEAN TO INTEGER USING PREDETERMINED INTERVAL
C     ******************************************************************
      IF(GMEAN.GT.0..AND.GMEAN.LT.65.) IMEAN = 1
      IF(GMEAN.GT.65..AND.GMEAN.LT.90.) IMEAN = 2
      IF(GMEAN.GT.90..AND.GMEAN.LT.115.) IMEAN = 3
      IF(GMEAN.GT.115..AND.GMEAN.LT.150.) IMEAN = 4
      IF(GMEAN.GT.150..AND.GMEAN.LT.250.) IMEAN = 5
      GO TO 102
C     CONVERTS HH TO INTEGER WITH PREDETERMINED INTERVAL
  101 IF(GMEAN.GT.0..AND.GMEAN.LT.70.) IMEAN = 1
      IF(GMEAN.GT.70..AND.GMEAN.LT.105.) IMEAN = 2
      IF(GMEAN.GT.105..AND.GMEAN.LT.140.) IMEAN = 3
      IF(GMEAN.GT.140..AND.GMEAN.LT.190.) IMEAN = 4
      IF(GMEAN.GT.190..AND.GMEAN.LT.250.) IMEAN = 5
  102 RETURN
      END
```

23601 WORDS OF MEMORY USED BY THIS COMPILATION

ORIGINAL PAGE IS
OF POOR QUALITY

APPENDIX B-1

Differential Scattering Cross Sections (σ v_s Θ in dB)
for Silty Clay Loam Soil
Surface conditions: rough, dry (15% H_2O by vol)

FREQ IN GHZ	LOOK ANGLE IN DEGREES 0	10	20	30	50	65	POL
4.2	-4.10025	-8.53398	-4.33096	-4.97766	-6.14679	-10.37384	H
4.6	-4.99192	-2.42560	0.27752	-5.36902	-7.83545	-7.58954	H
5.0	-4.90254	-4.83620	-3.63303	-4.27942	-7.00815	-8.29152	H
5.4	-1.33827	-0.27191	-7.56866	-3.21495	-9.17605	-9.99099	H
5.8	-1.30450	-2.73813	-8.03483	-3.18102	-3.34848	-6.69740	H
6.2	0.18875	-2.74486	-8.54153	-4.18765	-6.03851	-8.42396	H
6.6	1.64749	-4.28610	-5.08275	-7.72880	-5.24253	-9.16726	H
7.0	1.56054	-1.37307	-3.66969	-4.81570	-8.47367	-8.44064	H
7.4	5.41731	-5.51630	-1.31290	-3.45883	-12.24393	-7.75644	H
7.8	5.24957	0.81598	-0.98059	3.87351	-6.02262	-7.08440	H
4.2	-4.10025	-4.03398	-5.83096	-5.97766	-9.64679	-11.87384	V
4.6	-2.99192	-0.92560	-5.22248	-6.36902	-6.33545	-8.58954	V
5.0	-6.40254	-5.33620	0.86697	-4.27942	-4.00815	-7.79152	V
5.4	-7.83827	-7.77191	-5.06866	-7.21495	-10.17605	-8.99099	V
5.8	-3.30450	-10.73813	-6.03483	-5.18102	-8.34848	-7.19740	V
6.2	-0.31125	-7.24486	-10.54153	-2.18765	-12.03851	-8.92396	V
6.6	-0.35251	-3.28610	-7.58275	-7.22880	-6.24253	-11.16726	V
7.0	-0.43946	-5.87307	-2.66969	-9.31570	-13.47367	-14.44064	V
7.4	2.41731	-4.51630	-4.81290	-1.45883	-12.74393	-12.75644	V
7.8	5.74957	0.31598	-0.48059	-4.12649	-2.02262	-8.08440	V

APPENDIX B-2

Differential Scattering Cross Sections ($\sigma v_s \Theta$ in dB)
for Silty Clay Loam Soil
Surface conditions: <u>Uneven</u>, <u>dry</u> (13% H_2O by Vol)

FREQ IN GHZ	LOOK ANGLE IN DEGREES 0	10	20	30	50	65	POL
4.2	-4.60025	-3.03398	-7.33096	-0.97766	-4.64679	-7.87384	H
4.6	-0.49192	-8.42560	-0.72248	4.63098	-2.83545	-7.08954	H
5.0	0.59746	-4.33620	-4.63303	-4.77942	-2.00815	-6.79152	H
5.4	3.66173	-2.27191	-7.56866	-3.21495	-5.17605	-7.99099	H
5.8	2.19550	1.76187	-4.03483	-3.68102	-3.34848	-4.69740	H
6.2	4.68875	3.25514	-1.04153	-5.68765	-2.53851	-6.92396	H
6.6	0.64749	-3.28610	-12.58275	-5.22880	-4.74253	-8.16726	H
7.0	2.06054	-0.37307	-5.16969	-6.81570	-6.97367	-8.44064	H
7.4	5.41731	2.98370	-0.81290	-8.45883	0.25607	-3.25644	H
7.8	8.24957	1.31598	3.01941	3.87351	2.47738	-2.58440	H
4.2	2.39975	-1.03398	0.66904	-1.47766	-2.64679	-9.37384	V
4.6	6.50808	4.07440	4.27752	-1.36902	-2.83545	-5.58954	V
5.0	5.09746	1.16380	-1.63303	-2.77942	-2.00815	-4.29152	V
5.4	2.16173	-3.27191	-0.56866	-8.21495	-8.17605	-6.99099	V
5.8	-0.30450	-3.23813	-6.53483	-1.68102	-6.84848	-4.69740	V
6.2	3.18875	0.25514	-2.54153	-0.18765	-6.03851	-3.92396	V
6.6	1.14749	-4.28610	-3.58275	-6.72880	-3.24253	-12.16726	V
7.0	-0.93946	-9.37307	-14.16969	-11.81570	-14.97367	-9.44064	V
7.4	1.41731	-5.51630	-10.31290	-8.45883	-4.74393	-5.25644	V
7.8	3.74957	-0.18402	-0.98059	-0.12649	-1.52262	-1.08440	V

APPENDIX B-3

Differential Scattering Cross Sections ($\sigma v_s \Theta$ in dB)

for Silty Clay Loam Soil

Surface conditions: smooth, dry (15% H_2O by Vol)

FREQ IN GHZ	LOOK ANGLE IN DEGREES 0	10	20	30	50	65	POL
4.2	2.89975	0.96602	0.16904	-3.47766	-4.64679	-7.87384	H
4.6	9.00808	-1.42560	-2.22248	-3.86902	-3.33545	-7.58954	H
5.0	2.09746	-6.33620	-8.13303	-2.27942	-3.50815	-9.29152	H
5.4	5.66173	-6.27191	-2.06866	1.28505	-0.67605	-5.49099	H
5.8	1.69550	-8.73813	-2.53483	0.31898	-2.34848	-6.69740	H
6.2	7.18875	0.25514	1.45847	5.31235	-7.53851	-4.92396	H
6.6	1.14749	3.71390	0.41725	-6.22880	-2.24253	-7.66726	H
7.0	0.06054	3.52693	-3.66969	-4.81570	-5.97367	-5.94065	H
7.4	0.91731	-0.01630	-2.81290	-7.45883	-4.74393	-2.75644	H
7.8	2.24957	-0.18402	3.51941	0.87351	-0.52262	-0.08440	H
4.2	4.39975	3.96602	2.66904	-6.47766	2.35321	-1.87384	V
4.6	3.00808	-0.92560	-1.72248	-2.36902	-2.33545	-4.58954	V
5.0	1.09746	0.16380	-2.63303	-1.27942	-1.50815	-4.79152	V
5.4	-10.83827	-7.77191	-4.06866	-0.21495	-3.67605	-3.99099	V
5.8	-0.80450	-4.73813	1.96517	3.31898	0.15152	-6.69740	V
6.2	-0.31125	-5.24486	6.45847	8.31235	-2.53851	-1.92396	V
6.6	27.64749	3.21390	-4.58275	-2.22880	-3.24253	-5.66726	V
7.0	-7.93946	2.62693	-7.16969	-8.31570	-7.47367	-4.44064	V
7.4	-6.58269	-8.51630	5.18710	-4.95883	-5.74393	-1.75644	V
7.8	0.74957	9.81598	5.01941	2.37351	3.97738	-2.58440	V

APPENDIX B-4

Differential Scattering Cross Sections ($\sigma v_s \Theta$ in dB)
for Silty Clay Loam Soil
Surface conditions: rough, wet (31% H_2O by Vol)

FREQ IN GHZ	LOOK ANGLE IN DEGREES 0	10	20	30	50	65	POL
4.2	-10.60025	-2.03393	-4.33096	-6.97766	-1.14679	-3.37384	H
4.6	-2.49192	-0.92560	-2.22248	-3.86902	2.16455	-5.08954	H
5.0	-1.90254	-2.83620	-2.13303	-0.77942	0.49185	0.20848	H
5.4	-7.83827	-4.27191	-7.06866	-10.21495	-2.67605	0.50901	H
5.8	-3.80450	4.26187	-2.53483	-4.18102	-0.84848	2.30260	H
6.2	-5.31125	-2.24485	-5.04153	-1.18765	2.96149	6.57604	H
6.6	-8.85251	-6.78610	-3.08275	-5.22880	-2.74253	-8.16726	H
7.0	-9.43946	-1.37307	-2.16969	-3.31570	-5.47367	-9.94064	H
7.4	-11.58269	-1.01633	-0.81290	-9.45883	-9.74393	-12.25644	H
7.8	-0.75043	1.31598	1.51941	-1.12649	-1.02262	-4.08440	H
4.2	-0.10025	0.96602	-8.33096	-1.47766	-1.64679	-2.87384	V
4.6	4.00808	3.57440	-3.72248	-3.86902	2.16455	-0.08954	V
5.0	-1.90254	-3.83620	0.36697	1.22058	1.99185	-2.29152	V
5.4	-9.83827	-3.77191	-8.06866	-9.21495	-7.17605	-2.49099	V
5.8	-6.80450	-2.23813	-3.03483	-4.18102	-1.34848	1.80260	V
6.2	-3.81125	-4.74485	1.95847	1.31235	1.96149	7.07604	V
6.6	-4.35251	-9.78610	-5.08275	-5.22880	-1.24253	2.33274	V
7.0	-4.43946	-11.37307	-9.66969	-8.81570	-8.97367	-4.44064	V
7.4	-4.58269	-8.01633	-10.31290	-9.95883	-9.74393	-13.75644	V
7.8	0.74957	4.31598	1.01941	1.37351	2.97738	-6.08440	V

APPENDIX B-5

Differential Scattering Cross Sections ($\sigma v_s \Theta$ in dB)

for Silty Clay Loam Soil

Surface conditions: Uneven, wet (29% H_2O by Vol.)

FREQ IN GHZ	LOOK ANGLE IN DEGREES 0	10	20	30	50	65	POl
4.2	1.99975	-0.53398	6.36904	-2.97766	-4.64679	-7.87384	H
4.6	1.50808	-0.92560	2.27752	3.13098	2.16455	-2.08954	H
5.0	-0.40254	-3.33620	-1.13303	-1.77942	3.49185	-0.29152	H
5.4	-5.33827	-3.77191	0.43134	-1.21495	-8.67605	-1.49099	H
5.8	0.19550	-2.23813	0.46517	-3.18102	-0.34848	1.30260	H
6.2	5.68875	12.25514	-0.54153	2.31235	-0.53851	-5.42396	H
6.6	3.64749	5.71390	-2.58275	-1.22880	-3.74253	-6.66726	H
7.0	3.56054	3.12693	-2.16969	3.18430	-3.47367	-5.94065	H
7.4	5.91731	1.98370	-3.81290	-5.95883	-3.24393	-5.75644	H
7.8	12.74957	-0.68402	1.51941	-0.62649	3.97738	-4.08440	H
4.2	-10.10025	-8.53398	-1.33096	0.02234	-2.64679	-5.37384	V
4.6	-1.49192	-0.92560	-1.72248	-0.86902	-6.33545	-1.58954	V
5.0	1.09746	1.16380	0.86697	1.72058	3.99185	-0.29152	V
5.4	-10.33827	-8.77191	-8.56866	-7.71495	-7.17605	-0.99099	V
5.8	-5.30450	-4.73813	-5.03483	-4.18102	-2.84848	-4.69740	V
6.2	0.68875	-4.74485	-0.04153	0.81235	2.46149	-5.42396	V
6.6	-6.85251	-4.78610	-5.08275	-5.22880	-0.24253	-8.16726	V
7.0	-8.93946	-9.87307	-9.16969	-9.31570	-8.47367	-10.44064	V
7.4	-10.08269	-8.51630	-10.31290	-9.45883	-9.24393	-14.25644	V
7.8	1.24957	0.81598	1.01941	0.37351	1.97738	-5.08440	V

APPENDIX B-6

Differential Scattering Cross Section ($\sigma v_s \Theta$ in dB) for Silty Clay Loam Soil

Surface conditions: smooth, wet (33% H_2O by Vol.)

FREQ IN GHZ	LOOK ANGLE IN DEGREES 0	10	20	30	50	65	POL
4.2	-1.60025	1.46602	-5.83096	1.02234	-2.14679	-6.37384	H
4.6	7.50808	6.57440	4.77752	7.13098	1.16455	-1.08954	H
5.0	3.59746	3.16380	3.36697	-2.27942	-0.50815	-1.29152	H
5.4	1.16173	2.72809	2.43134	-5.71495	-3.17605	-3.49099	H
5.8	3.69550	5.26187	3.96517	1.31898	-0.84848	-5.19740	H
6.2	-3.81125	-1.74485	5.95847	-0.68765	-1.53851	-3.92396	H
6.6	3.64749	6.21390	-2.08275	-5.22880	-2.74253	-4.16726	H
7.0	5.06054	9.62693	2.83031	0.68430	-2.97367	-2.44064	H
7.4	5.41731	11.98370	-0.31290	-1.45883	1.75607	-3.25644	H
7.8	5.24957	12.81598	3.01941	1.37351	-0.52262	-3.08440	H
4.2	5.89975	3.96602	2.66904	0.02234	-2.64679	-5.37384	V
4.6	10.00808	6.07440	0.77752	7.63098	0.66455	-1.08954	V
5.0	1.59746	2.16380	3.36697	-1.27942	1.99185	-1.29152	V
5.4	-0.33827	-4.77191	-0.06866	-0.71495	-8.17605	-4.49099	V
5.8	5.19550	-5.73813	0.46517	0.31898	-3.34848	-3.19740	V
6.2	-0.81125	7.25514	-2.54153	-0.18765	-0.53851	-1.42396	V
6.6	-3.85251	2.21390	3.41725	-5.72880	-3.24253	-7.66726	V
7.0	-2.43946	-0.37307	0.83031	-1.81570	-14.47367	-4.44064	V
7.4	5.41731	5.98370	1.68710	1.54117	-2.24393	-3.25644	V
7.8	11.24957	9.81598	2.51941	2.87351	3.97738	-1.08440	V

TYPICAL CROP HISTOGRAM FOR 7/66 (Ka-BAND)

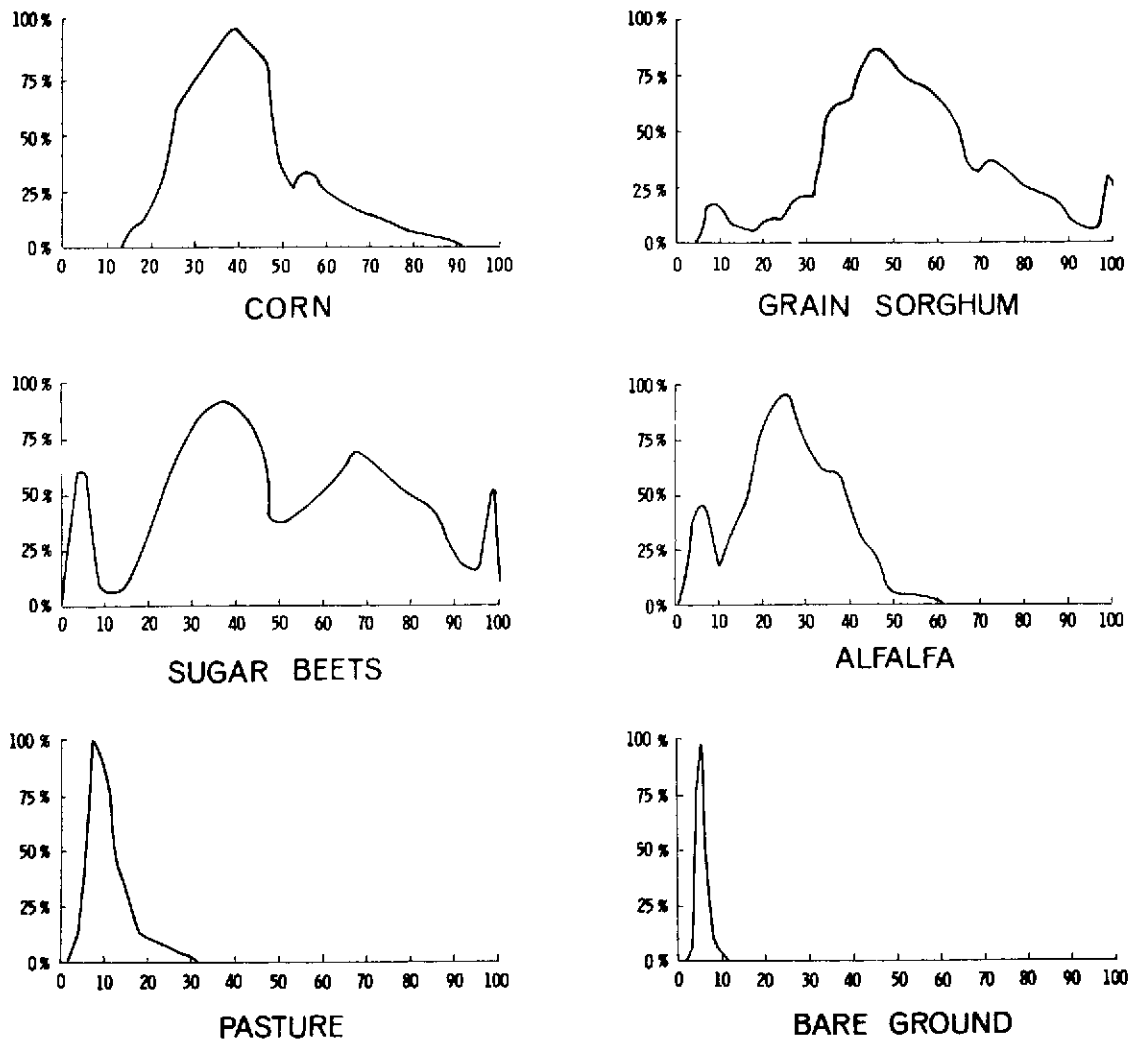


Figure 46

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