CRES REMOTE SENSING LABORATORY

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AGRICULTURAL AND HYDROLOGICAL APPLICATIONS OF RADAR: FINAL REPORT

Remote Sensing Lab
RSL Technical Report 177-62

July 31, 1976

Fawwaz T. Ulaby
Principal Investigator

Supported by

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lyndon B. Johnson Space Center
Houston, Texas 77058

Contract NAS 9-10261

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AGRICULTURAL AND HYDROLOGICAL APPLICATIONS OF RADAR: FINAL REPORT

1.0 Introduction

This is the final report of the research performed under NASA contract NAS 9-10261 covering the period 15 August 1969 to 31 July 1976. During the initial three years, the program objectives were broad in nature covering a wide range of disciplines and activities in radar remote sensing including radar systems development and analysis, data processing and display, and data interpretation in geology, geography and oceanography. Between 1972 and the termination date of the contract, the research was focused on the evaluation of radar remote sensing applications in hydrology and agriculture based on data acquired with the Microwave Active Spectrometer (MAS) system.

Due to the large volume of information generated under this contract, the approach used to summarize the work will be as follows:

(a) Radar remote sensing is divided into three major areas of activity: 1) Radar System Studies, 2) Data Processing and Display, and 3) Geoscience Applications. Each area is subdivided on the basis of specialization within that area.

(b) Under each topic, all reports generated under this contract, the subject matter of which is closely related to the topic, are listed. Thus, in some cases a given report may appear under more than one topic. Annual or semi-annual technical reports, which presented summaries of several activities, are not listed.

(c) The title, author(s) and abstract of each of the 62 Technical Reports generated under this contract are appended. Reports 177-8, 177-16 and 177-50 have been deleted. In each of these cases the report material was integrated into another report for the sake of completeness, subsequent to assigning a number to it.

2.0 Summary of Program Activities

2.1 Radar System Studies--Modeling, Development and Analysis

2.1.1 Imaging Systems

a. "Synthetic Aperture Radar and Digital Processing," R. Gerchberg, September, 1970. (TR 177-10)

b. "Panchromatic Illumination for Radar: Acoustic Simulation of Panchromatic Radar," G. C. Thomann, September, 1970. (TR 177-11)

c. "A Fresnel Zone--Plate Processor for Processing Synthetic Aperture Data," G. C. Thomann, R. Angle and F. Dickey, May, 1971. (TR 177-17)

d. "Geoscience Radar Systems," G. C. Thomann and F. Dickey, May, 1971. (TR 177-18)

e. "Multi-Year Program in Radar Remote Sensing," R. K. Moore and J. C. Holtzman, August, 1971. (TR 177-20)

2.1.2 Airborne Scatterometer Systems

a. "An Analysis of Methods for Calibrating the 13.3 GHz Scatterometer," G. A. Bradley, November, 1969. (TR 177-1)

b. "Signal Analysis of the Single-Polarized 13.3 GHz Scatterometer," G. A. Bradley, May, 1970. (TR 177-2)

c. "An Analysis of the Effects of Aircraft Drift Angle on Remote Radar Sensors," G. A. Bradley and J. D. Young, August, 1970. (TR 177-5)

d. "Remote Sensing of Ocean Winds Using a Radar Scatterometer," G. A. Bradley, September, 1971. (TR 177-22)

2.1.3 Ground-Based Spectrometer Systems

a. "4-8 GHz Microwave Active and Passive Spectrometer (MAPS)," F. T. Ulaby, January, 1973. (TR 177-34)

b. "MAS 2-8 Radar and Digital Control Unit," J. M. Oberg and F. T. Ulaby, October, 1974. (TR 177-37)

c. "8-18 GHz Radar Spectrometer," T. Bush and F. T. Ulaby, October, 1973. (TR 177-43)

d. "Fading Characteristics of Radar Backscatter from Selected Agricultural Targets," T. Bush and F. T. Ulaby, December, 1973. (TR 177-48)

2.2 Data Processing and Display

2.2.1 Data Processing Techniques Development

a. "Discrete Pattern Discrimination Using Neighborly Dependence Information," R. M. Haralick, October, 1970. (TR 177-12)

2.2.2 Image Discrimination, Enhancement and Color Combination System (IDECS)

a. "Imaged Textural Analysis by a Circular Scanning Technique," G. O. Nossaman, June, 1970. (TR 177-3)

b. "IDECS User's Manual," J. Barr and P. N. Anderson, September, 1972. (TR 177-27)

c. "Image Processing Applications--IDECS," P. Anderson, D. Anderson J. Barr, L. Haas and G. Minden, September, 1972. (TR 177-28)

d. "A Computer to Computer Digital Data Link," L. Haas, September, 1972. (TR 177-31)

2.3 Geoscience Applications

2.3.1 Geology

a. "A Regional Study of Radar Lineaments Patterns in the Ouachita Mountains, McAlester Basin-Arkansas Valley, and Ozark Regions of Oklahoma and Arkansas," J. N. Kirk, June, 1970. (TR 177-4)

b. "Radar Lineament Analysis, Burning Springs Area, West Virginia--An Aid in the Definition of Appalachian Plateau Thrusts," R. S. Wing, W. K. Overbey, Jr., and L. F. Dellwig, July, 1970. (TR 177-6)

c. "Optimum Radar Depression Angles for Geological Analysis," H. C. MacDonald and W. P. Waite, August, 1970. (TR 177-9)

d. "Evaluation of High Resolution X-band Radar in the Ouachita Mountains," L. F. Dellwig and J. McCauley, August, 1971. (TR 177-21)

e. "Terrain Roughness and Surface Materials Discrimination with SLAR in Arid Environments," H. C. MacDonald and W. P. Waite, January, 1972. (TR 177-25)

f. "An Evaluation of Multifrequency Radar Imagery in the Florida Gulf Coast," L. F. Dellwig, August, 1972. (TR 177-29)

g. "Surface Configuration as an Explanation for Lithology-Related Cross-Polarized Radar Image Anomalies," J. R. McCauley, April, 1973. (TR 177-36)

h. "Radar Signal Return from Near-Shore Surface and Shallow Subsurface Features,Darien Province, Panama," B. C. Hanson and L. F. Dellwig, August, 1973. (TR 177-39)

i. "Geometric Fidelity Levels Inherent to all Ground Range Radar Imaging Systems," B. Hanson and A. Yukler, January, 1976.

2.3.2 Agriculture

a. "An Evaluation of Fine Resolution Radar Imagery to Making Agricultural Determinations," S. A. Morain and J. Coiner, August, 1970. (TR 177-7)

b. "Radar Sensing in Agriculture, A Socio-Economic Viewpoint," S. A. Morain, J. Holtzman and F. M. Henderson, December, 1970. (TR 177-14)

c. "Local Level Agricultural Practices and Individual Farmer Needs as Influences on SLAR Imagery Data Collection, " F. M. Henderson, April, 1971. (TR 177-15)

d. "SLAR Image Interpretation Keys for Geographic Analysis," J. C. Coiner, September, 1972. (TR 177-19)

e. "Interpretation of Side Looking Airborne Radar Vegetation Patterns: Yellowstone National Park," N. E. Hardy, September, 1972. (TR 177-24)

f. "Radar Spectral Measurements of Vegetation," F. T. Ulaby and R. K. Moore, August, 1973. (TR 177-40)

g. "Radar Response to Vegetation," F. T. Ulaby, September, 1973. (TR 177-42)

h. "Fading Characteristics of Radar Backscatter from Selected Agricultural Targets," T. Bush and F. T. Ulaby, December, 1973. (TR 177-48)

i. "The Effects of Soil Moisture and Plant Morphology on the Radar Backscatter from Vegetation," F. T. Ulaby, T. F. Bush, P. P. Batlivala and J. Cihlar, July, 1974. (TR 177-51)

j. "Monitoring Wheat Growth with Radar," T. F. Bush and F. T. Ulaby, May, 1975. (TR 177-55)

k. "Radar Return from a Continuous Vegetation Canopy," T. F. Bush and F. T. Ulaby, August, 1975. (TR 177-56)

l. "Corn Growth as Monitored by Radar," F. T. Ulaby and T. F. Bush, November, 1975. (TR 177-57)

m. "Crop Identification from Radar Imagery of the Huntington County, Indiana Test Site," P. P. Batlivala and F. T. Ulaby, November, 1975. (TR 177-58)

n. "Radar Backscatter Properties of Milo and Soybeans," T. F. Bush, F. T. Ulaby and T. Metzler, October, 1975. (TR 177-59)

2.3.3 Forestry

a. "SLAR Image Interpretation Keys for Geographic Analysis," J.C. Coiner, September, 1972. (TR 177-19)

b. "Interpretation of Side Looking Airborne Radar Vegetation Patterns: Yellowstone National Park," N. E. Hardy, September, 1972. (TR 177-24)

c. "Seasonal Variations of the Microwave Scattering Properties of Deciduous Trees As Measured in the 1-18 GHz Spectral Range," T. Bush, F. Ulaby, T. Metzler and H. Stiles, June, 1976. (TR 177-60)

2.3.4 Hydrology (Soil Type, Soil Moisture and Snow)

a. "SLAR Image Interpretation Keys for Geographic Analysis," J. C. Coiner, September, 1972. (TR 177-19)

b. "Reconnaissance Soil Surveys from Radar Imagery," S. A. Morain and J. B. Campbell, April, 1972. (TR 177-23)

c. "Reconnaissance Soil Mapping from Radar Imagery," J. B. Campbell, September, 1972. (TR 177-30)

d. "Radar Measurement of Soil Moisture Content," F. T. Ulaby, April, 1973. (TR 177-35)

e. "Agricultural Terrain Scatterometer Observations with Emphasis on Soil Moisture Variations," C. King, August, 1973. (TR 177-44)

f. "Active Microwave Measurement of Soil Water Content," F. T. Ulaby, J. Cihlar and R. K. Moore, November, 1973. (TR 177-46)

g. "Dielectric Properties of Soils as a Function of Moisture Content," J. Cihlar and F. T. Ulaby, November, 1973. (TR 177-47)

h. "The Effects of Soil Moisture and Plant Morphology on the Radar Backscatter from Vegetation," F. T. Ulaby, T. F. Bush, P. P. Batlivala and J. Cihlar, July, 1974. (TR 177-51)

i. "Rough Surface Scattering Based on Facet Model," H. R. Khamsi, A. K. Fung and F. T. Ulaby, November, 1974. (TR 177-52)

j. "Snow Backscatter in the 1-8 GHz Region," H. Stiles, F. Ulaby, B. Hanson and L. Dellwig, June, 1976. (TR 177-61)

2.3.5 Oceanography (Ocean Dynamics and Sea Ice)

a. "Remote Sensing of Ocean Winds Using a Radar Scatterometer," G. A. Bradley, September, 1971. (TR 177-22)

b. "A Theory of Wave Scatter from an Inhomogeneous Medium with a Slightly Rough Boundary and Its Application to Sea Ice," S. K. Parashar, A. K. Fung and R. K. Moore, December, 1974. (TR 177-53)

APPENDIX A : ABSTRACTS OF TECHNICAL REPORTS PREPARED FOR NASA CONTRACT 9-10261.

RSL TECHNICAL REPORT 177-1

AN ANALYSIS OF METHODS FOR CALIBRATING THE 13.3 GHz SCATTEROMETER
by G. A. Bradley, December, 1969.

Abstract

An analysis is presented of dynamic calibration methods that can be used in the 13.3 GHz scatterometer. Four candidate methods are considered with conclusions presented regarding the effectiveness of each method. A mathematical model is derived for each design with the signal frequency spectrum computed at critical points in the receiver. It is shown that the present method of calibration is unacceptable because the calibration signal amplitude is subject to variation. The error in scattering coefficient is shown to be especially sensitive to the bias point and linearity of the ferrite modulator. It is recommended that an injection system be incorporated in the 13.3 GHz scatterometer which uses a square-wave calibration signal. The analysis shows that this method will calibrate the scatterometer to the required accuracy with no error induced in the data record by the calibration system.

RSL TECHNICAL REPORT 177-2

SIGNAL ANALYSIS OF THE SINGLE-POLARIZED 13.3 GHz SCATTEROMETER
by G. A. Bradley, May, 1970.

Abstract

An analysis is presented of signals in the 13.3 GHz single-polarized scatterometer. A complete analytical description of the phase-quadrature operation is given together with the method used to extract fore and aft scattering data from the CW-Doppler signal. An analysis of the relation between rf and audio phase error and the resulting scattering coefficient error is also presented. It is shown that the total phase error can be as high as 20° for a scattering coefficient error less than 0.2 dB. An analysis is also given of the frequency spectrum of the scatterometer signal at several critical points in the receiver. It is shown that the amplitude of the sidebands resulting from modulation of the data signal with the calibration signal are below the system noise level. Finally, an analysis is presented of the sensitivity of the scatterometer calculated as a function of the scattering coefficient.

RSL TECHNICAL REPORT 177-3

IMAGED TEXTURAL ANALYSIS BY A CIRCULAR SCANNING TECHNIQUE
by George O. Nossaman, 1969.

Abstract

By superimposing on the linear raster of a flying spot scanner a circular perturbation, various textural properties of an image may be enhanced or suppressed by appropriate filtering of the photomultiplier output. The image transforms of such a system are developed. Edges and roads at any orientation are uniformly enhanced. Directional lineament may be separated from the imagery. D-C smoothing is also readily performed.

Use of principal-component analysis of the first 8 harmonics of the scanner output did not yield useful results for texture discrimination. On the other hand, comparison of the sum of harmonics 3 through 8 with the D-C component showed significant separation of the signals from the 5 sample targets imaged. This method, or others of similar nature yet to be tried, should be useful adjuncts to manual or automatic signature recognition.

RSL TEHNICAL REPORT 177-4

A REGIONAL STUDY OF RADAR LINEAMENT PATTERNS IN THE OUACHITA MOUNTAINS, McALESTER BASIN-ARKANSAS VALLEY, AND OZARK REGIONS OF OKLAHOMA AND KANSAS
by J. Norman Kirk, June, 1970.

Abstract

Imagery produced by airborne, side-looking radar systems was used to examine radar lineaments and their patterns in a structurally diverse region exhibiting a range of deformational intensity.

Radar lineaments appear on the image as linear boundaries between adjacent areas of differing power return and represent narrow, continuous or discontinuous features of a terrain. In the area of this study, radar lineaments almost exclusively represent surface drainage channels that exhibit patterns characteristic of fracture system control.

Properties of radar systems and terrain features that affect the recording of radar lineaments include surface roughness, incidence angle, radar shadowing, foreshortening, slant-range distortions, and look-direction.

In examining the relationship between radar lineament trends and fracture patterns, a comparison of rosette diagrams representing the patterns of joint and lineament trends indicate that in general radar lineament patterns exhibit directional trends similar to joint patterns and fault trends.

A comparison of the variations of lineament trends with variations of fold trends suggests that the fracture patterns represented by the radar lineaments in the Ouachita Mountains and Arkansas Valley Provinces are products of the same stresses that produced the folded structures, and that in the Boston Mountains area the fracture system was produced by stresses whose orientations were not everywhere the same as those responsible for the development of the folds.

RSL TECHNICAL REPORT 177-5

AN ANALYSIS OF THE EFFECTS OF AIRCRAFT DRIFT ANGLE ON REMOTE RADAR SENSORS by G. A. Bradley and J. D. Young, August, 1970.

Abstract

An analysis is presented of the relationship between aircraft drift angle and measurement errors in the Doppler scatterometers and side-looking array radar used in the NASA Earth Resources aircraft testing program. An expression is derived showing the scatterometer surface area decorrelation as a function of the drift angle. It is shown that, for the 13.3 GHz scatterometer, complete decorrelation of the nadir measurement with the 60° measurement occurs for a drift angle of 2.2°. For the 400 MHz scatterometer, complete decorrelation occurs at 6.4°. The maximum aircraft drift angle for acceptable scatterometer data measurements is shown to be critically dependent upon the boundary dimensions of homogeneous surface terrain. An expression is derived which shows the relation between homogeneous surface width and aircraft drift angle for complete scatterometer data correlation. The analysis also shows that, for drift angles less than 9°, the SLAR measurements are only dependent upon changes in drift angle with the standard deviation of the drift angle independent of the drift angle itself. Experimental data are presented which show that the standard deviation of the drift angle is nearly linear with wind speed and is equal to 0.5° for a wind speed of 50 knots and an aircraft velocity of 250 knots. The relationship between aircraft velocity and the mean value and standard deviation of the drift angle is derived and data are presented in graphical form to permit selection of the aircraft velocity which will assure optimum SLAR data measurements. For independent scatterometer or SLAR experiments, it is shown that minimum degradation of the data measurements occurs when the flight path is oriented in an upwind direction. For coordinated SLAR/scatterometer experiments involving non-homogeneous terrain, it is shown that scatterometer flight lines should be oriented in an upwind direction to maximize the surface area correlation. The SLAR flight lines are then arranged in a crosswind direction with the aircraft ground velocity selected to minimize the effects of aircraft drift angle on the measured data.

RSL TECHNICAL REPORT 177-6

RADAR LINEAMENT ANALYSIS, BURNING SPRINGS AREA, WEST VIRGINIA--AN AID IN THE DEFINITION OF APPALACHIAN PLATEAU THRUSTS
by Richard S. Wing, William K. Overbey, Jr. and Louis F. Dellwig, July, 1970.

Abstract

Geomorphic analysis of radar imagery covering an east-west 18 kilometer wide swath, from Sandyville to Camden, West Virginia, has revealed a striking polygonal topographic pattern. This pattern is apparently an erosional response to varying combinations of at least six fracture sets (strike, dip, and two conjugate shear pairs), related to one-time movement of a great thrust sheet, extending westward from the Appalachian Front to the Burning Springs anticline. The preferred fracture sets were apparently rotated up to 10° counterclockwise in the Burning Springs area in accordance with "pileup" of the leading edge of the thrust sheet. The decollement movement permitted a maximum of the possible fracture sets to advance beyond the incipient stage of development. Immediately west of the Burning Springs anticline there is notably less expression of the polygonal pattern and only two fracture sets are strongly expressed.

There was good correspondence between air photo lineament patterns, radar imagery lineament patterns, and surface joint strikes measured in the Burning Springs area. However, air photos generally revealed short lineament segments, whereas the synoptic radar presentation revealed lineups of segments: hence, long integral fracture zones.

The fracture pattern inferred through radar imagery interpretation and confirmed by surface measurement is reflected in the outlines of some oil fields in the area.

RSL TECHNICAL REPORT 177-7

AN EVALUATION OF FINE RESOLUTION RADAR IMAGERY FOR MAKING AGRICULTURAL DETERMINATIONS
by S. A. Morain and J. C. Coiner, August, 1970.

Abstract

In this report two types of analysis are performed on high resolution imagery of the Garden City test site (NASA site 76). The imagery was obtained in early October, 1969 by the University of Michigan radar system; the ground truth by Kansas University. The first analysis is strictly a visual interpretation of the imagery. Its major objective is to explore possibilities for creating identification keys of crop types and states. Preliminary results from this investigation are moderately encouraging and have been extremely valuable in 1) documenting the need for high resolution radar imagery in agriculture; 2) directing the aims of subsequent non-visual studies; 3) highlighting needs for improving terrain data collection; and 4) providing initial experience in the joint use of photographic and radar sensors for identifying crops.

The second approach focuses on extracting Quantalog spot densities from the X-1 resolution and investigating, through a set of categorization strategies, various ways of presenting the data. Film density data for the major land uses at Garden City are displayed in a series of scattergrams representing each of the grouping strategies. The order of presentation of these plots follows a logical sequence in attempting to spotlight the influence of particular terrain and system variables on crop optical densities. In a real sense this technique is a "longhand" method for "explaining variation" in density-type data, but it is worth doing in this fashion because it draws attention to graphic form in improvements realized by every iteration in the strategy.

In the past the scattergram method of data portrayal has often been used, but never thoroughly evaluated for its worth in singling out the influence of particular variables. Results presented here suggest that the unconstrained plotting of all densities irrespective of crop purity,

incidence angle, etc. can distort the data and complicate its interpretation. Better segregation of crops in measurement space (HH vs. HV density) can be achieved if such differences as incidence angle, crop purity, row direction, stage of growth, and combinations of these are taken into account. Nevertheless, spot densitometry derived from 2-polarization, single pass imagery will, by itself, rarely give unambiguous crop discrimination. Multiple looks throughout the growing season will be required if image tone is to be the only discriminant. Distinctions impossible to make in October may be quite possible earlier in the growing season or with a different frequency, polarization, incidence angle, or look direction. Both look direction and incidence angle are shown in this report to have significant effects on the return signal for particular crops.

RSL TECHNICAL REPORT 177-8

DELETED

RSL TECHNICAL REPORT 177-9

OPTIMUM RADAR DEPRESSION ANGLES FOR GEOLOGICAL ANALYSIS
by H. C. MacDonald and W. P. Waite, August, 1970.

Abstract

Side-looking imaging radars have proven to be a major sensor for geological reconnaissance studies in cloudy environments. Results have been sufficiently encouraging to support investigation of high-resolution radars as a spacecraft sensor for mapping and resource evaluation. For geological practicality, it is assumed that radar's most significant contribution would be in those geographic regions containing relatively inaccessible, poorly mapped, mountainous terrain where photography cannot be obtained. However, data analysis from this study reveals that for certain terrain configurations, the amount of retrievable geologic information will be of marginal utility unless careful consideration is given to the geometry of both the imaging system and the terrain itself.

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 interpretive 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.

RSL TECHNICAL REPORT 177-10

SYNTHETIC APERTURE RADAR AND DIGITAL PROCESSING
by Ralph Gerchberg, September, 1970.

Abstract

This is a study of the operation of Synthetic Aperture Radar (SAR) systems for generating radar images of terrain. The study is made with the purpose in mind of determining whether such an electronic system could be built, using digital techniques, to image in real time. Although the literature abounds with information on the optical processor for generating SAR images, little has been published on the possibility of real time imaging with or without digital techniques.

The dominant motivation for performing this study is the idea of instrumenting an earth orbiting platform with a real time SAR imager for monitoring earth resources. Therefore, a situation which will be used throughout this paper as an illustrative example will be that the SAR is carried aboard a spacecraft "flying" in a circular orbit at an altitude of 600 nautical miles. This means that the ground speed of the satellite is approximately 7 kilometers per second. It will be assumed that the ground map that is to be generated by the orbiting radar will have a 30 meter resolution and will image a swath (parallel to the satellite track) 40 kilometers wide. Several studies have discussed the problem of resolution in terrain imagery from space and it is clear that 30 meters is a useful resolution for thematic land use maps. The SAR will be a side-looking radar.

The SAR system studied here employs a homodyne technique so that the output of the receiver is translated to a zero carrier frequency. An optimum algorithm is shown which requires the processor to use quadrature coherently detected return signals. The processor must store in each range bin, for the example situation, the last 4820 returns or 9640 numbers (with quadrature detection) for correlation at any instant to achieve Full Focused processing. The correlation process requires 19280 products to be formed in a time period of the $(PRF)^{-1}$ in each range bin.

RSL TECHNICAL REPORT 177-11

PANCHROMATIC ILLUMINATION FOR RADAR; ACOUSTIC SIMULATION OF PANCHROMATIC RADAR
by Gary C. Thomann, October, 1970

Abstract

Monochromatic or near monochromatic signals suffer from fading caused by the coherent addition of signals scattered from facets within a target or resolution cell. Fading in communication systems, glint in tracking radars, lower probabilities of detection in a search system, and grain and target break up in an imaging radar result from the use of narrow band signals. Panchromatic (wide bandwidth) signals can be transmitted and the return averaged over the bandwidth to reduce the fading.

The use of wide bandwidth signals in tracking and detection radar systems is reviewed. Panchromatic illumination is shown to improve performance in both systems. The improvement for an imaging system is derived as a function of bandwidth. A sharp edged scattering target composed of many isotropic scatterers is used as a model. This model leads to the Rayleigh distributed return characteristic of most natural targets. The variance of the signal scattered from this model is expressed as an integral over the signal spectral density. For relatively large bandwidths, the variance reduction is shown to be directly proportional to the averaging bandwidth. The generation of wide bandwidth signals is not restricted to any particular type of modulation; the effects of pulse modulation are shown, as is the equivalence of frequency and spatial averaging. Practical methods of generating panchromatic signals are considered.

An ultrasonic system operating as a side-looking real aperture imaging radar was used to demonstrate image improvement using panchromatic signals. An electronic system was already available. Piezoelectric transducers were used for imaging; their bandwidth was increased using quarter-wave mechanical matching and electrical tuning. Transducer bandwidths were quadrupled using the matching and tuning.

Statistical and imaging experiments were done. The return distribution from a homogeneous surface was shown to be close to Rayleigh. A frequency averaging experiment was done to demonstrate variance reduction. Monochromatic and panchromatic images of area-extensive model targets were made. The monochromatic images demonstrate image grain and target break up; the panchromatic images show a reduction of these effects and demonstrate the degree of improvement to be expected in an electromagnetic system.

RSL TECHNICAL REPORT 177-12

DISCRETE PATTERN DISCRIMINATION USING NEIGHBORLY DEPENDENCE INFORMATION
by Robert M. Haralick, October, 1970.

Abstract

The pattern identification problem is concerned with identifying a sequence of units on the basis of the sequence of pattern measurements made of them. The simplifying assumption which is usually made in the pattern identification problem is that the units may be treated independently. However, for many kinds of data, the sequential order in which the units are taken contains useful information regarding the identification of these units; such information is thrown away when the units are treated independently. Our discussion here suggests a Markov model for taking into account the neighborly or first-order dependence the units have on one another because of their sequential order. We develop one- and two-dimensional sequential models which we can use for the Bayes decision rule construction.

RSL TECHNICAL REPORT 177-13

INTERIM TECHNICAL PROGRESS REPORT: RADAR STUDIES RELATED TO THE EARTH RESOURCES PROGRAM
by J. Holtzman, et al., March, 1971.

Abstract

Research during 1970 at the University of Kansas into radar systems, data processing systems, and their application to observation of the earth and its resources is summarized. Particularly significant is reporting of octave bandwidth active microwave spectral responses and proof of the value of panchromatic averaging in radar systems. Better understanding and further analysis of 13.3 GHz radar return from the sea continues to confirm previous tentative conclusions regarding wind speed dependence of radar sea return. A simulation has been completed of a potential digital processor for synthetic aperture radar that might, by 1975, be feasible for moderate-sized spacecraft.

Coupling of the analog multi-image processor IDECS to a digital computer is partially complete, and the results already indicate the advantages of this hybrid approach. The Kansas Digital Image Data System (KANDIDATS), a large scale operating system for processing multiple images on a GE 600 series computer is nearly complete. Development of processing programs based on texture in images is well along.

The importance of proper selection of angle of incidence for radar imaging in mountainous areas and for soil moisture determination has been documented. Potential of radar for snow moisture determination has been shown, although only qualitatively. The potential of dichotomous keys as aids to interpretation of agricultural radar images has been shown. A preliminary study of application of radar to a problem in forestry is reported.

RSL TECHNICAL REPORT 177-14

RADAR SENSING IN AGRICULTURE, A SOCIO-ECONOMIC VIEWPOINT
by Stanley A. Morain, Julian Holtzman and Floyd Henderson,
December, 1970.

Abstract

After a brief overview of radar signal-terrain interactions and an introduction to Great Plains agriculture, the meaning of both seasonal and year-to-year changes in image appearance between the within crops is discussed in terms of potential socio-economic benefits. As a means for obtaining crop statistics usable at several levels in the policy and planning hierarchy, a strategy for using dichotomous keys to identify crops for radar is presented. An ability to monitor within-crop seasonal variations in image attributes (traceable as surrogates associated with crop calendar, yield, or quality) is regarded as most significant for the world's burgeoning population. Radar is beginning to demonstrate its range of applications in the Great Plains and these are extended to world scale monitoring tasks of such basic statistics as amount of land under cultivation, and progress of regional harvests. Non-cyclic changes in crop backscatter as revealed through change detection strategies are regarded as useful, socio-economically, to ascertain diffusion rates and directions of crop (varieties?) introductions, adoption rates of agricultural innovations and similar man-land relationships. With the "Green Revolution" a controversial reality, the all-weather synoptic inventory capability of radar may be necessary in charting future food supplies.

RSL TECHNICAL REPORT 177-15

LOCAL LEVEL AGRICULTURAL PRACTICES AND INDIVIDUAL FARMER NEEDS AS INFLUENCES ON SLAR IMAGERY DATA COLLECTION
by Floyd M. Henderson, July, 1971.

Abstract

Crop identification has long been one of the objectives and proposed benefits of radar imaging systems. Yet, there are many phenomena that can be studied apart from this one simple aspect. Other parameters inherent in the agricultural landscape may prove very susceptible to radar interpretation if we are cognizant of them. 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 pertaining to land use practices that is desirable and obtainable apart from mere crop identification.

The Finney County-Garden City, Kansas, test site has been studied by the personnel of the University of Kansas Center for Research, Inc., for over six years. The physical setting, changing land use practices, and aspects of the environment susceptible to investigation by remote sensors, specifically radar, will be described briefly in the following paragraphs. It is hoped that both the engineers and geographers will have a better understanding of the problems inherent in making agricultural interpretations from radar imagery. In addition, when both the engineer and geoscientist understand the other's problems, interdisciplinary research efforts can be undertaken with more efficiency and better defined purpose.

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RSL TECHNICAL REPORT 177-17

A FRESNEL ZONE--PLATE PROCESSOR FOR PROCESSING SYNTHETIC APERTURE DATA by Gary Thomann, Rodney L. Angle and Fred M. Dickey, May, 1971.

Abstract

Presently, high resolution radar images are obtained by storing the received signal on photographic film and then processing the stored data using coherent optical techniques. The main disadvantage of optical processing is that the necessity of storing data on film and stability requirements make real-time on board processing impractical.

Processing can also be accomplished by strictly electronic systems. However, electronic processing is much more difficult to implement than is optical processing. This is especially true for the fully focused synthetic aperture radar system. For example, a delay line equivalent of the conical lens used in an optical processor would consist of several hundred delay lines.

This report describes the design and testing of an electronic Fresnel zone-plate processor. The processor was built as a pilot model to study the feasibility of an electronic Fresnel zone-plate processor for processing synthetic aperture radar data.

RSL TECHNICAL REPORT 177-18

GEOSCIENCE RADAR SYSTEMS
by G. C. Thomann and F. M. Dickey, May, 1971.

Abstract

In the past few years imaging side-looking airborne radars (SLAR's) have proven valuable remote sensors for geoscience exploration. A partial bibliography of radar experiments is given by Moore. Systems for geoscience research incorporating several radar techniques are considered here. The techniques -- multispectral sensing, panchromatic illumination, polypolarization reception, and calibration are reviewed briefly in Section II. Section III presents radar parameter derivations at the frequencies chosen for sensing; synthetic-aperture systems are used at frequencies below 15 GHz; real-aperture SLAR's are considered at frequencies of 35 and 94 GHz. In Section IV assignment of the various radar techniques to frequencies is considered and polypanchromatic systems for implementation are proposed.

RSL TECHNICAL REPORT 177-19

SLAR IMAGE INTERPRETATION KEYS FOR GEOGRAPHIC ANALYSIS
by Jerry C. Coiner, September, 1972.

Abstract

This study suggests a means for SLAR imagery to become a more widely used data source in geoscience and agriculture by providing interpretation keys as an easily implemented interpretation model. Interpretation problems faced by the researcher wishing to employ SLAR are specifically described, and the use of various types of image interpretation keys to overcome these problems is suggested. With examples drawn from agriculture and vegetation mapping, direct and associate dichotomous image interpretation keys are discussed and methods of constructing keys are outlined. Initial testing of the keys, key-based automated decision rules, and the role of the keys in an information system for agriculture are developed.

RSL TECHNICAL REPORT 177-20

MULTI-YEAR PROGRAM IN REMOTE SENSING
by R. K. Moore and J. C. Holtzman, August, 1971.

Abstract

This report is an outline of a proposed multi-year program of radar research both in the system and application areas. The ultimate goal is to define the role of radar for aircraft and spacecraft in the Earth Observations Program. Since the resulting information system is at least as diverse and complex as the multitude of users and planners, the activities presented must be carried out by interdisciplinary teams of scientists. Accordingly, the tasks and programs are not strictly engineering, geography, geology, etc.

Part I is an outline of the proposed research in Radar Systems and Applications and Part II is a series of flow diagrams illustrating the interaction and logical research progress. The flow charts can be viewed on a time base, if desired.

RSL TECHNICAL REPORT 177-21

EVALUATION OF HIGH RESOLUTION X-BAND RADAR IN THE OUACHITA MOUNTAINS
by Louis F. Dellwig and James R. McCauley, August, 1971.

Abstract

Comparison of AN/APQ-97 and high-resolution X-band radar imagery verifies the advantages of APQ-97 for suppression of detail and synoptic coverage. High-resolution radar is judged better for terrain and vegetation analysis although, for regional studies, it may be desirable to use imagery produced from radars with coarser resolution to minimize distracting detail.

An anomalous vegetative pattern, which does not conform to lithologic control, is better displayed on radar imagery than on aerial photographs due to shadowing.

RSL TECHNICAL REPORT 177-22

REMOTE SENSING OF OCEAN WINDS USING A RADAR SCATTEROMETER
by G. A. Bradley, September, 1971.

Abstract

Remote sensing of the earth has recently been given considerable attention in an effort to improve measurements of the available resources and natural phenomena of the earth. One application of remote sensing using a radar system located on a remote platform is to measure the ocean surface wind speed by measuring the radar scattering coefficient of the ocean surface. A map of remotely measured ocean winds could then be developed which would aid in weather prediction both over the ocean as well as over the continents.

The purpose of the research presented in this paper is to show the relationship between radar scattering coefficient and ocean wind speed and direction using measurement data taken by a radar scatterometer operating at a frequency of 13.3 GHz with vertical polarization. It is shown that past experimental and theoretical results have indicated a possible dependency of the radar scattering coefficient σ^o on the ocean wind speed and direction. The experimental program sponsored by the National Aeronautics and Space Administration (NASA) is then briefly described. It is shown that problems encountereed early in the research program with the radar equipment required a system analysis study to be performed in order to assure valid data measurements during the latter experiments. The results are presented in this study and are used to interpret and adjust the measured data in order to investigate the relationship between σ^o and ocean wind information. Results from these analyses can also be used in the design of future scatterometers used in the ocean wind measurement application.

The system analysis includes a complete signal analysis of the system plus a derivation of the system sensitivity and data measurement accuracy. The effect of phase errors on the data measurements is considered. An analysis of the calibration system shows that the data is not calibrated and must be adjusted in the data analysis. The effect of non-linearities

on the measurement data is also considered. The relationship between aircraft flight parameters and the measurement data is derived.

Analysis of the measurement data from two NASA missions is presented. The optimum sample rate of the radar is derived considering the frequency spectrum of anemometer wind data together with radar data reduction costs. The relationship between σ° and wind speed is derived from the measured data for various incidence angles and wind directions. It is shown that a power law relation exists between σ° and wind speed with an exponent of 1.493 for incidence angle 35° and upwind flight direction. In general, the exponent increases with incidence angle and is higher for upwind flight direction than for crosswind. Five scatterometer data points are used as a test for the hypothesis relationship with the result that the error in predicting the wind speed varies from 0.73% to 21% of the mean wind speed measured by an anemometer. It is shown that the rms error in prediction is 13.75% of the mean wind speed. This is comparable to the standard deviation of 12.5% for the anemometer data and therefore the radar predicted wind speed has an accuracy approximately the same as the anemometer and can be used as a remote sensor for ocean surface wind speed and direction.

The results of this research can be used to design an operational radar scatterometer to remotely sense the ocean surface wind speed and direction either from an aircraft platform or from a satellite. The relationship between σ° and wind speed at a radar frequency of 13.3 GHz can be used to convert the radar data to wind information. It is recommended that future experimental research explore the frequency and polarization dependence of this relationship. It is also recommended that a system design study be performed for a satellite installation of a radar scatterometer operating at 13.3 GHz to be used to remotely sense the ocean wind fields.

RSL TECHNICAL REPORT 177-23

RECONNAISSANCE SOIL SURVEYS FROM RADAR IMAGERY
by S. A. Morain and J. B. Campbell, October, 1972.

Abstract

This paper explores relations between radar signals and soil surfaces and cites field examples. Sensor parameters governing reflectivity from soils are frequency, polarization and viewing angle. Important soil parameters include texture and microrelief, which vary surface roughness and alter the reflectivity; and moisture, which increases reflectivity. Theoretically low frequencies are sensitive to boulder surfaces and higher frequencies to textures as fine as coarse sand. In nature, however, image interpretation problems might arise at a given frequency between dry/coarse-textured soils and moist/fine-textured soils. Soil patterns on imagery obtained by a 3 cm wavelength system over Tucson were compared to the USDA soil map. Field confirmations showed that image patterns corresponded both to vegetation and to soil. Wherever flat, barren, uniformly textured surfaces existed, radar reflectivity conformed as predicted for this frequency (X-band). In another example, soil moisture patterns were detected on .86 cm imagery (Ka-band) for an area in Minnesota. Topographic depressions with peat and muck soils had brighter tones than surrounding soils, especially at near vertical angles.

RSL TECHNICAL REPORT 177-24

INTERPRETATION OF SIDE LOOKING AIRBORNE RADAR VEGETATION PATTERNS: YELLOWSTONE NATIONAL PARK

by Norman E. Hardy, June, 1972.

Abstract

Radar imagery has several characteristics which make it valuable to the geoscientist. Perhaps the most important feature from the standpoint of the geographer is the ability of radar to cover large areas in a relatively short period of time. The present study was undertaken because radar coverage of Yellowstone Park was readily available, and the results of much previous research was available.

The study undertook to extract the vegetation information present on the image, through traditional image interpretation techniques. Through these techniques, the interpreter was able to set up seven broad vegetation categories. These categories were defined on the basis of tonal and textural characteristics in relation to the range on the image, and verbal and pictorial matrix keys were produced to aid in the interpretation. The categories were refined, and radar based vegetation map was produced.

On the basis of the seven vegetation categories, spatial frequency analysis, using a four milliwatt laser, was undertaken, in an attempt to develop a more quantitative technique for interpreting imagery. This method proved capable of distinguishing certain categories on the basis of frequency characteristics of the vegetation, as well as the linear features present within the structure of the vegetation.

RSL TECHNICAL REPORT 177-25

TERRAIN ROUGHNESS AND SURFACE MATERIAL DISCRIMINATION WITH SLAR IN ARID ENVIRONMENTS
by H. C. MacDonald and W. P. Waite, January, 1972.

Abstract

Regions having a continuous vegetal canopy provide the radar interpreter with a relatively difficult terrain configuration for inferring surface roughness and surface materials. Where vegetation covers the ground surface, the radar reutrn signal may be influenced by the combination of the vegetation and the terrain surface beneath the vegetation. Where vegetation is sparse or absent, however, an imaging radar becomes extremely sensitive to the actual surface roughness and surface particle size and texture dominate the microwave return signal.

The physical characteristics of desert valleys and playas are of concern to the geoscientist. Desert valleys are being exploited for their potential hydrologic-land use significance, while desert playas may provide potential aircraft or spacecraft landing sites. In this unique arid environment the dual-sensor combination of an imaging radar and aerial photography provide a practical method of monitoring gross changes in surface textures of alluvial fans and playa surface conditions. In addition, it appears feasible that surface materials and relative surface roughness may be inferred with an improved degree of interpretive reliability.

RSL TECHNICAL REPORT 177-26

RADAR STUDIES RELATED TO THE EARTH RESOURCES PROGRAM--INTERIM TECHNICAL PROGRESS REPORT
by J. Holtzman, et al., March, 1972.

Abstract

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.

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.

RSL TECHNICAL REPORT 177-27

IDECS USER'S MANUAL
by J. C. Barr and P. N. Anderson, September, 1972.

Abstract

The purpose of this report is to provide the user with a basic understanding of the IDECS processor, its uses,and the necessary knowledge to manually operate the system. The report consists of four sections which are:

Section 1.0 - Introduction

Provides a general overview of the IDECS system and its intended application.

Section 2.0 - Processing Subsystems of the IDECS

A discussion of each system component, its function, and the operating procedures associated with it.

Section 3.0 - Processing Capabilities

This section describes the processing functions from an experimentor's viewpoint. Processing features are presented in combinations to describe various methods of experimentation. Therefore, if a user wants a particular result from the processing of his input images, he may select the appropriate experimental method from this section.

Section 4.0 - Step by Step Procedure for a Typical Experiment

This section describes the logical order in which a user should perform the steps necessary for a selected experiment from Section 3.0. Effectively, it is a "walk-thru" experiment.

RSL TECHNICAL REPORT 177-28

IMAGE PROCESSING APPLICATIONS - IDECS
by P. Anderson, D. Anderson, J. Barr, L. Haas and G. Minden, September, 1972.

Abstract

The purpose of this report is to describe initial application experiments that have been performed on IDECS. Each chapter represents a performed experiment or application, and the chapters are not necessarily related.

Applications such as image scanning, image combining, image enhancement and display, scattergram generation, and pattern discrimination are included.

RSL TECHNICAL REPORT 177-29

AN EVALUATION OF MULTIFREQUENCY RADAR IMAGERY IN THE FLORIDA GULF COAST
by Louis F. Dellwig, August, 1972.

Abstract

Imagery produced by SLARs of diverse frequencies along the Gulf Coast near Destin, Florida confirmed the conclusion reached earlier in a study of the Pisgah Crater, California area that the return signal from certain cultural and natural phenomena is strongly wavelength dependent. Whereas in the Pisgah Crater area surface roughness appeared to be the parameter most strongly influencing radar return; in the Destin, Florida area, for a long wavelength radar the contribution of the smoothing effect to the return signal could not be separated from the contribution due to vegetation penetration capability.

RSL TECHNICAL REPORT 177-30

RECONNAISSANCE SOIL MAPPING FROM RADAR IMAGERY
by James B. Campbell, Jr., September, 1972.

Abstract

This study examines the use of Side-Looking Airborne Radar (SLAR) imagery for reconnaissance soil mapping by considering not only the image itself, but also soil, vegetation, and landform characteristics in relation to image interpretation techniques. Two image interpretation techniques are outlined. The first analyzes image characteristics, such as depression angle, frequency, and polarization; in theory this method can yield information on relative roughness and moisture content of soil surfaces. In practice, it is currently restricted to a few special cases.

The second method employs surrogates such as terrain features, vegetation patterns, and drainage networks to interpret soil patterns. This approach requires that the relationship between the surrogate and the soil be known from information gained independently of the image, and that the soils interpreted from the image can be related to an accepted soil classification scheme. This second technique is employed in an example interpretation of a desert landscape in Arizona to produce a reconnaissance soil map using order and suborder categories in the USDA comprehensive system. A world survey of factors important in reconnaissance mapping indicates that SLAR imagery could be applied to large areas of the inadequately mapped regions of the earth.

RSL TECHNICAL REPORT 177-31

A COMPUTER TO COMPUTER DIGITAL DATA LINK
by Larry Haas, September, 1972.

Abstract

A digital interface has been designed for transfering data or programs between a PDP 15 computer and an IBM 7094 computer. This will be particularly useful for inputing training region data or image parameters to image processing algorithms on the IBM 7094 from the University of Kansas Image Discrimination Enhancement and Combination System (IDECS).

The functional units of the hardware are described and a complete set of logic diagrams are included in this report. A description of software applications as well as diagnostic programs used to verify proper operation are described.

RSL TECHNICAL REPORT 177-32

RADAR STUDIES RELATED TO THE EARTH RESOURCES PROGRAM, QUARTERLY PROGRESS REPORT, 1 APRIL 1972 - 30 JUNE 1972
by J. C. Holtzman, et al., November, 1972.

Abstract

Earth resources radar study at the University of Kansas is approached from a system point of view. The ultimate goal is specification of optimum radars for space and aircraft use. The activities encompass radar-target interaction research, radar system development studies, research aimed at optimum automatic and semi-automatic processing of images, and applications studies to assure that all the other activities are intimately related to user needs. The organization of this report is based upon contractual tasks relating to all these activities.

RSL TECHNICAL REPORT 177-33

RADAR STUDIES RELATED TO THE EARTH RESOURCES PROGRAM, PROGRESS REPORT,
1 JULY 1972 - 30 NOVEMBER 1972
by J. C. Holtzman, et al., February, 1973.

Abstract

Parametric studies designed to evaluate interactions between terrain (here agricultural) and radar system parameters as expressed in tonal, textural and related variations on SLAR imagery were conducted using X-band and L-band imagery of the Garden City, Kansas, test site for July, August, and September, 1971.

The most significant effort in the scatterometry program is the observation of moisture dependence. Scattered 2 cm radar signals from agricultural targets were found to increase 5-7 dB at angles within 45° of vertical as the radar flies from dry to irrigated portions of the same field. Differences observed at 75 cm were less conclusive. Future plans include the expansion of the data set and continued study of influence of moisture on radar return.

RSL TECHNICAL REPORT 177-34

4-8 GHz MICROWAVE ACTIVE AND PASSIVE SPECTROMETER (MAPS)
VOLUME 1: RADAR SECTION
by Fawwaz T. Ulaby, April, 1973.

Abstract

The purpose of this report is to document the performance characteristics of the radar section of the 4-8 GHz Microwave Active and Passive Spectrometer (MAPS) system. The system was designed, built and tested at the University of Kansas Center for Research, Inc., during spring and early summer of 1972. Data collected during August and September of 1972 includes two types of targets: bare ground (about 5000 data points were collected) and agricultural crops such as corn, milo, soybeans, and alfalfa (over 45,000 data points were collected). The data is undergoing processing and analysis and will appear in forthcoming volumes.

RSL TECHNICAL REPORT 177-35

RADAR MEASUREMENT OF SOIL MOISTURE CONTENT
by Fawwaz T. Ulaby, April, 1973.

Abstract

The effect of soil moisture on the radar backscattering coefficient was investigated by measuring the 4-8 GHz spectral response from two types of bare-soil fields: slightly rough and very rough, in terms of the wavelength. An FM-CW radar system mounted atop a 75-ft. truck-mounted boom was used to measure the return at 10 frequency points across the 4-8 GHz band, at 8 different look angles (0° through 70°), and for all polarization combinations. A total of 17 sets of data were collected covering the range 4-36 percent soil moisture content by weight. The results indicate that the radar response to soil moisture content is highly dependent on the surface roughness, microwave frequency, and look angle. The response seems to be linear, however, over the range 15-30 percent moisture content for all angles, frequencies, polarizations, and surface conditions.

RSL TECHNICAL REPORT 177-36

SURFACE CONFIGURATION AS AN EXPLANATION FOR LITHOLOGY-RELATED CROSS-POLARIZED RADAR IMAGE ANOMALIES
by James R. McCauley, May, 1973.

Abstract

Radars ordinarily transmit either horizontally or vertically polarized radiation and receive the same polarization transmitted. Because planetary surfaces return the two polarizations differently, and because components orthogonal to those transmitted may also be observed, experiments had been initiated as early as 1966 to determine the value of multiple polarization images to geologists. One problem that has persisted since the development of multipolarized radar is the cause or causes of differential depolarization which is expressed as tonal reversals between like- and cross-polarized images of certain outcrops. On AN/APQ-97 Ka-band radar imagery, rocks producing anomalously low returns on the cross-polarized image could be classed into three general types: (1) certain geologically recent lava flows (late Pleistocene and Holocene), (2) some Tertiary volcanics and (3) certain massive sandstones. Differential depolarization has been produced by volcanic rocks of various compositions including rhyolite, rhyodacite, dacite, andesite, and basalt. The sandstones which are responsible for an anomalous cross-polarized return include eolian sandstones and terrestrially derived arkoses. As is apparent, composition is diverse in this group of rocks, as is nearly every other lithologic character, including grain size, grain orientation, internal structures, etc. This has led to the conclusion that differential depolarization is not directly caused by any compositional factor. However, the study of aerial photos and subsequent field observation have led to the conclusion that the weathering and other surface characteristics of the outcrops are responsible for their appearance on multipolarized imagery.

It is believed that these three 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 three rock types mentioned above.

Outcrops of the three 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, this energy maintaining a constant polarization; the outcrop areas are of sufficient size and sufficiently uniform character to be delineated on small scale K-band imagery.

RSL TECHNICAL REPORT 177-37

MAS 2-8 RADAR AND DIGITAL CONTROL UNIT
by J. Michael Oberg and Fawwaz T. Ulaby, October, 1974.

Abstract

MAS 2-8 (2-8 GHz Microwave Active Spectrometer) is a ground-based sensor system used by the Remote Sensing Laboratory at the University of Kansas. The system has been continually modified since its first use in 1972. The most recent major modification was that of a control subsystem to automate the data-taking operation. The system operation and a detailed discussion of the design and operation of the control unit will be presented.

RSL TECHNICAL REPORT 177-38

RADAR STUDIES RELATED TO THE EARTH RESOURCES PROGRAM, QUARTERLY PROGRESS REPORT, 1 DECEMBER 1972 - 28 FEBRUARY 1973
by R. K. Moore, J. Holtzman, F. T.Ulaby and L. F. Dellwig, May, 1973.

Abstract

Data collected from bare ground have been analyzed for the dependence of the scattering coefficient on soil moisture, frequency, polarization and look angle. The results represent the first step toward an understanding of the complex mechanisms responsible for the backscatter return from natural targets as a function of the various sensor and target parameters. The results are very encouraging.

During an investigation involving imagery of Coastal Panama, it was noted (as suspected) that revelation of wave patterns along the shore was a function of look direction and depression angle. All imagery of the Panama Coast has been evaluated in the light of system data (look direction, depression angle, time of flight, etc.).

RSL TECHNICAL REPORT 177-39

RADAR SIGNAL RETURN FROM NEAR-SHORE SURFACE AND SHALLOW SUBSURFACE FEATURES, DARIEN PROVINCE, PANAMA

by Bradford C. Hanson and Louis F. Dellwig, August, 1973.

Abstract

Initial analysis of AN/APQ-97 radar imagery over eastern Panama was directed toward extraction of geologic and engineering data and the establishment of operational parameters. Subsequent investigations emphasized landform identification and vegetation distribution, accompanied by an analysis of the parameters affecting the observed return signal strength from such features.

One subject area described but not analyzed by previous investigators was near-shore ocean phenomena. Tidal zone features such as mud flats and reefs are more vividly expressed in the near range whereas they are subdued or non-detectable in the far range. Falloff is also observed within surf zones oriented parallel to range direction. Whereas surface roughness in large part dictates the nature of reflected energy (specular or diffuse), depression angle also appears to be an important factor in return signal intensity for tidal flats, reefs, and surf zones. In surf zones changes in wave train orientation relative to look direction, the slope of the surface and the physical character of the wave must be considered. Furthermore, the establishment of the areal extent of the tidal flats, distributary channels, and reefs appear to be practical only in the near to intermediate range under minimal low tide conditions.

RSL TECHNICAL REPORT 177-40

RADAR SPECTRAL MEASUREMENTS OF VEGETATION
by Fawwaz T. Ulaby and Richard K. Moore, August, 1973.

Abstract

4-8 GHz radar backscatter spectral data was gathered during the 1972 growing season at look angles between 0° and 70° and for all four possible polarization linear combinations. The data covers four crop types (corn, milo, alfalfa, and soybeans) and a wide range of soil moisture content. To insure statistical representation of the results, measurements were conducted over 128 fields corresponding to a total of about 40,000 data points. This paper investigates the use of spectral response signatures to separate different crop types and to separate healthy corn from blighted corn.

RSL TECHNICAL REPORT 177-41

RADAR STUDIES RELATED TO THE EARTH RESOURCES PROGRAM, QUARTERLY PROGRESS REPORT, 1 MARCH 1973 - 31 MAY 1973
by R. K. Moore, F. T. Ulaby and L. F. Dellwig, October, 1973.

Abstract

Final testing of the 8-18 GHz spectrometer will be completed by 1 July and it is expected to start collecting radar return data at 20 frequency points for each of eight incidence angles between 0° and 70°. Five types of targets will be under investigation: bare ground, corn, alfalfa, soybeans and milo. In addition to monitoring each crop as a function of time (and hence growth and maturity), three corn fields which had been planted at different times will be monitored for differences in the radar return due to plant height and maturity under identical soil moisture conditions.

The 1972 data from vegetation has been analyzed to determine the ability of radar to measure soil moisture through vegetation at low incidence angles and to discriminate between crop types at the large angles. Two reports will be issued in the near future describing the details of the findings.

RSL TECHNICAL REPORT 177-42

RADAR RESPONSE TO VEGETATION
by Fawwaz T. Ulaby, September, 1973.

Abstract

Active microwave measurements of vegetation backscatter were conducted to determine the utility of radar in 1) mapping soil moisture through vegetation and 2) mapping crop types. Using a truck-mounted boom, spectral response data were obtained for four crop types (corn, milo, soybeans, and alfalfa) over the 4-8 GHz frequency band, at incidence angles of 0°-70° in 10° steps, and for all four linear polarization combinations. Based on a total of 125 data sets covering a wide range of soil moisture content, system design criteria are proposed for each of the aforementioned objectives. Quantitative soil moisture determination was best achieved at the lower frequency end of the 4-8 GHz band using HH polarized waves in the 5°-15° incidence angle range. A combination of low and high frequency measurements are suggested for classifying crop types. For crop discrimination, a dual-frequency dual-polarization (VV and Cross) system operating at incidence angles above 40°is suggested.

RSL TECHNICAL REPORT 177-43

8-18 GHz RADAR SPECTROMETER
by Thomas F. Bush and Fawwaz T. Ulaby, September, 1973.

Abstract

This report discusses the design, construction, testing and accuracy of an 8-18 GHz radar spectrometer. The spectrometer is an FM-CW system employing a dual antenna system. The antennas, transmitter and a portion of the receiver are mounted at the top of a 26 meter hydraulic boom which is in turn mounted on a truck for system mobility. HH and VV polarized measurements are possible at incidence angles ranging from 0° to 80°. Calibration is accomplished by referencing the measurements against a Luneberg lens of known radar cross section.

RSL TECHNICAL REPORT 177-44

AGRICULTURAL TERRAIN SCATTEROMETER OBSERVATIONS WITH EMPHASIS ON SOIL MOISTURE VARIATIONS
by C. King, August, 1973.

Abstract

Airborne scatterometer observations were made for agricultural terrain in May and June, 1970 at a NASA test site near Garden City, Kansas. Data from 13.3 GHz and 400 MHz scatterometer were analyzed. It was observed that for incidence angles less than 40°, the 13.3 GHz data showed a difference in backscatter from wet and dry fields of the order of 7 dB. The averages of the various crop types were within a spread of only 5 dB. Other ground parameters such as cultivation pattern and vegetation row effects showed even less distinguishing characteristics on the backscatter. The 400 MHz data also showed a slight moisture dependency.

RSL TECHNICAL REPORT 177-45

RADAR STUDIES RELATED TO THE EARTH RESOURCES PROGRAM, QUARTERLY PROGRESS REPORT, 1 JUNE 1973 - 31 AUGUST 1973
by R. K. Moore, J. C. Holtzman, F. T. Ulaby and L. F. Dellwig, November, 1973.

Abstract

During the months of July and August, the 8-18 GHz radar spectrometer was used to collect scattering coefficient data from five types of targets: corn, alfalfa, milo, soybeans, and bare ground. About 30 data sets were collected, where each data set corresponds to measurements at eight incidence angles between 0° and 70° in 10° steps, HH and VV polarizations and over 20 frequency points between 8 and 18 GHz. Each measurement is an average of several measurement points taken from different parts of the field at the same frequency, polarization and incidence angle. The multiple measurements were performed to reduce the variance caused by fading. Thus, each data set comprises about 3000 data points, making the total number of data points acquired about 90,000.

In addition to the radar data, ground truth information was gathered. This included soil moisture profile with depth, crop height, density and maturity state, and weather conditions. The next phase of this part of the program will involve data processing and analysis.

RSL TECHNICAL REPORT 177-46

ACTIVE MICROWAVE MEASUREMENT OF SOIL WATER CONTENT
by F. T. Ulaby, J. Cihlar and R. K. Moore, November, 1973.

Abstract

Measurements of radar backscatter from bare soil at 4.7, 5.9 and 7.1 GHz for incident angles of 0-70° have been analyzed to determine sensitivity to soil moisture. Because the effective depth of penetration of the radar signal is only about one skin depth, the observed signals were correlated with the moisture in a skin depth as characterized by the attenuation coefficient (reciprocal of skin depth). Since the attenuation coefficient is a monotonically increasing function of moisture density, it may also be used as a measure of moisture content over the distance involved, which varies with frequency and moisture content. The measurements show an approximately linear increase in scattering with attenuation coefficient of the soil at angles within 10° of vertical and all frequencies. At 4.7 GHz this increase continues relatively large out to 70° incidence, but by 7.1 GHz the sensitivity is much less even at 20° and practically gone at 50°.

An inversion technique to determine how well the moisture content can be estimated from the scattered signal indicates good success for near-vertical angles and middle ranges of mositure density, with poorer success at smaller moisture densities and an anomaly in the data at the highest moisture density that must be resolved by further experimentation.

RSL TECHNICAL REPORT 177-47

DIELECTRIC PROPERTIES OF SOILS AS A FUNCTION OF MOISTURE CONTENT
by Josef Cihlar and Fawwaz T. Ulaby, November, 1974.

Abstract

In studying applications of microwave remote sensing techniques to agricultural, hydrological, and other related problems, the soil dielectric properties are of considerable importance. In recent years, numerous soil dielectric constant measurements have been made. Due to the complexity of the data acquisition procedure, however, the number of measurements in a single experiment is usually too small to permit a systematic analysis of the effects of the various parameters that influence soil dielectric properties.

The objective of this report is twofold: 1) to present soil dielectric constant measurements obtained by various researchers in one publication, thereby assisting in analysis and utilization of microwave remote sensing data and 2) based on these measurements, to determine the dependence of the dielectric constant on various soil parameters. Moisture content is given special attention because of its practical significance in remote sensing and because it represents the single most influential parameter as far as soil dielectric properties are concerned. From the experimental measurements collected in this report, relative complex dielectric constant curves are derived as a function of volumetric soil water content at three frequencies (1.3 GHz, 4.0 GHz, and 10.0 GHz) for each of three soil textures (sand, loam and clay). These curves, presented in both tabular and graphical form, were chosen as representative of the reported experimental data. Calculations based on these curves showed that the power reflection coefficient and emissivity, unlike skin depth, vary only slightly as a function of frequency and soil texture.

RSL TECHNICAL REPORT 177-48

FADING CHARACTERISTICS OF PANCHROMATIC RADAR BACKSCATTER FROM SELECTED AGRICULTURAL TARGETS
by Thomas F. Bush and Fawwaz T. Ulaby, December, 1973.

Abstract

An experiment was performed to empirically determine the fading characteristics of backscattered radar signals from four agricultural targets at 9 GHz. After a short review of the statistics of Rayleigh fading backscatter, the data processing method and results of the data are analyzed. Comparison with theory shows adequate agreement with the experimental results, provided of course, the targets are modeled in a correct manner.

RSL TECHNICAL REPORT 177-49

RADAR STUDIES RELATED TO THE EARTH RESOURCES PROGRAM, PROGRESS REPORT, 1 SEPTEMBER 1973 - 31 JANUARY 1974
by R. K. Moore, J. C. Holtzman , F. T. Ulaby and L. F. Dellwig, February, 1974.

Abstract

The 8-18 GHz spectral data gathered during July and August 1973 have been processed, catalogued and plotted. A detailed description of the system is contained in CRES Technical Report 177-43 entitled "8-18 GHz Radar Spectrometer" by T. F. Bush and F. T. Ulaby. Preliminary analysis has been performed in each of the following tasks as a function of frequency, incidence angle and polarization:

1. Radar response to soil moisture and surface condition (roughness) of bare soil. Also comparison is made with one particular case where short grass had grown.

2. Radar response to soil moisture of vegetated fields. These include corn, alfalfa, milo and soybeans.

3. Crop classification with radar.

RSL TECHNICAL REPORT 177-50

DELETED

RSL TECHNICAL REPORT 177-51

THE EFFECTS OF SOIL MOISTURE AND PLANT MORPHOLOGY ON THE RADAR BACKSCATTER FROM VEGETATION
by Fawwaz T. Ulaby, Thomas F. Bush, Percy P. Batlivala and Josef Cihlar, July, 1974.

Abstract

This report presents the results of experimental studies on the backscattering properties of corn, milo, soybeans and alfalfa. The measurements were made during the summer of 1973 over the 8-18 GHz frequency band. The data indicate that soil moisture estimation is best accomplished at incidence angles near nadir with lower frequencies while crop discrimination is best accomplished using two frequencies at incidence angles ranging from 30° to 65°. It is also shown that temporal plant morphology variations can cause extreme variations in the values of the scattering coefficients. These morphological changes can be caused by growth, heavy rain and in the case of alfalfa, harvesting.

RSL TECHNICAL REPORT 177-52

ROUGH SURFACE SCATTERING BASED ON FACET MODEL
by H. R. Khamsi, A. K. Fung and F. T. Ulaby, November, 1974.

Abstract

A theoretical investigation was performed to develop a model for the radar return from bare ground. The validity of the model was tested by comparing its theoretical prediction with measured data collected by the University of Kansas Remote Sensing Laboratory 8-18 GHz radar spectrometer system.

It was assumed that the target area consists of a collection of small, medium and large size facets. Then this model was used to calculate the radar cross section of bare ground and the effect of the frequency averaging on the reduction of the variance of the return.

It was shown that by assuming that the distribution of the slope to be Gaussian, and by assuming that the distribution of the length of the facet to be in the form of the positive side of a Gaussian distribution, the results are in better agreement with experimental data than the results of previous facet models. It was also shown that for this calculation we do not need to know the exact correlation length of the small structure on the ground, instead an effective correlation length was calculated based on the facet model and the wavelength of the incident wave. Hence, the parameters necessary to specify the surface are: standard derivations of slope in x and y directions, standard deviation of the distribution of the facet size, and the dielectric constants of the target.

For investigating the effect of the frequency averaging we expanded the previously available results based on the uniform scatterer model and took into consideration the penetration effect. It was shown that at small incidence angles, the number of independent samples predicted is significantly larger and in better agreement with measured data from alfalfa.

It was also shown that based on the facet model assumption the reduction in the variance of the return is not only a function of the product of the sweep band and the time span of the target, as the uniform scatterer model indicates, but it is also a function of the geometrical properties of the surface, center frequency of the incident wave and the polarization.

RSL TECHNICAL REPORT 177-53

A THEORY OF WAVE SCATTER FROM AN INHOMOGENEOUS MEDIUM WITH A SLIGHTLY ROUGH BOUNDARY AND ITS APPLICATION TO SEA ICE
by S. K. Parashar, A. K. Fung and R. K. Moore, December, 1974.

Abstract

An analytical theory of electromagnetic wave scattering from an inhomogeneous medium with a slightly rough boundary surface is formulated. The inhomogeneity in the medium is assumed to vary continuously in the vertical direction. In addition, it is also assumed to have a small random variation in the horizontal direction. The medium is assumed to consist of two layers. Maxwell's equations are solved by using the small perturbation method together with Fourier transform technique. The resulting differential equations are solved by using WKB and variation of parameter methods. Field amplitudes in each medium are determined by taking boundary conditions into account. The expressions for first order polarized radar backscatter cross-section $\sigma°$ are obtained.

An attempt is made to apply the developed theory to compute sea ice scatter. The complex permittivity of sea ice, which depends on both the temperature and salinity, varies with the depth of sea ice. In addition, there is certainly some variation in the horizontal direction. Thus, the developed model may be able to give useful estimates when applied to sea ice scattering. Numerical calculations are performed for polarized radar backscatter cross-section ($\sigma_{VV}°$ and $\sigma_{HH}°$) at two frequencies, 13.3 GHz and 400 MHz. It can be shown that WKB method is applicable at both of these frequencies. These theoretical results are compared with the experimental results obtained from NASA Earth Resources Program mission 126. Theoretical results give the same absolute value of $\sigma°$ and the relative variation among the six ice types as is given by the experimental results.

RSL TECHNICAL REPORT 177-54

GEOMETRIC FIDELITY LEVELS INHERENT TO ALL GROUND RANGE RADAR IMAGING SYSTEMS
by B. Hanson and A. Yukler, January, 1976.

Abstract

Side-looking airborne imaging radar systems have proven to be a major sensor for geological reconnaissance studies in areas where environmental restraints hamper aerial photography. However the amount of retrievable data depends upon the geometry of the terrain plus the operational parameters inherent to the imaging system.

Geometric fidelity affects all radar systems, regardless of display format. For areas of low or negligible relief, the effects of layover/foreshortening, and therefore relief displacement, are negligible when compared to the scale of the image. However as the relief of positive terrain features increase, the optimum geometric fidelity levels vanish. The acceptance level of fidelity depends not only on changes in relief, but also upon range variations.

The layover-foreshortening nomogram for ground range radar enables the user to rapidly determine the magnitude of layover or foreshortening plus the degree of relief displacement either prior to the actual flight or from the radar imagery itself.

RSL TECHNICAL REPORT 177-55

REMOTELY SENSING WHEAT MATURATION WITH RADAR
by Thomas F. Bush and Fawwaz T. Ulaby, May, 1975.

Abstract

An experiment was conducted during the late spring of 1974 to study the scattering properties of wheat in the 8-18 GHz band as a function of frequency, polarization, incidence angle and crop maturity. Supporting ground truth was collected at the time of measurement. The data indicates that $\sigma°$, the radar backscattering coefficient, is sensitive to both system parameters and crop characteristics particularly at incidence angles of near nadir. Linear regression analyses of $\sigma°$ (dB) on both time and plant moisture content result in rather good correlation, as high as 0.9, with the slope of these regression lines being 0.55 dB/day and -0.275 dB/% plant moisture at 9.4 GHz at nadir. Furthermore, by calculating the average time rate of change of $\sigma°$ (real units) it is found that $\sigma°$ undergoes rapid variations shortly before and after the wheat is harvested. Both of these analyses suggest methods for estimating wheat maturity and for monitoring the progress of harvest.

RSL TECHNICAL REPORT 177-56

RADAR RETURN FROM A CONTINUOUS VEGETATION CANOPY
by Thomas F. Bush and Fawwaz T. Ulaby, August, 1975.

Abstract

The radar backscatter coefficient, σ°, of alfalfa was investigated as a function of both radar parameters and the physical characteristics of the alfalfa canopy. Measurements were acquired with an 8-18 GHz FM-CW mobile radar over an angular range of 0°-70° as measured from nadir. The experimental data indicates that the excursions of σ° at nadir cover a range of nearly 18 dB during one complete growing cycle. An empirical model for σ° was developed which accounts for its variability in terms of soil moisture, plant moisture and plant height.

RSL TECHNICAL REPORT 177-57

CORN GROWTH AS MONITORED BY RADAR
by Fawwaz T. Ulaby and Thomas F. Bush, November, 1975.

Abstract

Results of an experiment to determine the feasibility of monitoring corn growth with radar are reported. Radar backscattering data were acquired with a ground based 8-18 GHz radar spectrometer during the summer of 1974. Supporting ground truth data were also collected. At angles of incidence of 40° or greater, the results of the data analysis indicate a strong correlation between the radar backscattering coefficient σ° and the "normalized plant water content" w_{pn}, where w_{pn} is the mass of water in the corn plant divided by its height. The correlation coefficient between σ° and w_{pn}, which was calculated for each of 176 different combinations of radar parameters (signal frequency, angle of incidence and polarization), was highest (0.96) at 17.0 GHz, 50° and VV polarization. Considering the fact that the data used covered a period of four months during which the corn plants underwent considerable change in geometry and dielectric properties, the high correlation of 0.96 between σ° and w_{pn} points to a promising future for radar as a tool for monitoring corn development.

RSL TECHNICAL REPORT 177-58

CROP IDENTIFICATION FROM RADAR IMAGERY OF THE HUNTINGTON COUNTY, INDIANA TEST SITE
by P. P. Batlivala and F. T. Ulaby, November, 1975.

Abstract

The results of a study to discriminate crop types using L-band, dual polarization (HH and HV) radar data are reported. X-band data unfortunately were not available for analysis due to problems encountered during the flight. The flight was made over Huntington County, Indiana on September 13 using the ERIM radar. The test site consisted of fields of corn, soybeans, woods and pasture.

The analysis resulted in the following observations:

a) Like polarization was successful in discriminating corn and soybeans, however pasture and woods were consistently confused as soybeans and corn, respectively. The probability of correct classification was about 65%.

b) The cross polarization component (highest for woods and lowest for pasture) helped in separating the woods from corn, and pasture from soybeans and when used with the like polarization component, the probability of correct classification increased to 74%.

RSL TECHNICAL REPORT 177-59

RADAR BACKSCATTER PROPERTIES OF MILO AND SOYBEANS
by T. F. Bush, F. T. Ulaby and T. Metzler, October, 1975.

Abstract

During the summer months of 1974 an experiment was performed to determine the relationships between the radar scattering coefficient, $\sigma°$, of five crop types and the physical characteristics of these crops. The crops studied were corn, alfalfa, wheat, milo and soybeans. The intent was to test the feasibility of monitoring the growth of these crops with radar. By functionally relating $\sigma°$ to certain crop development descriptors it was determined that it is possible to monitor the growth of wheat, alfalfa, and corn. However, an analysis of the data collected from fields of milo and soybeans indicates that effective radar monitoring of these crops may not be possible. For the sake of completeness however, the results of the experiment pertaining to the milo and soybeans fields will be summarized in this report.

RSL TECHNICAL REPORT 177-60

SEASONAL VARIATIONS OF THE MICROWAVE SCATTERING PROPERTIES OF DECIDUOUS TREES AS MEASURED IN THE 1-18 GHz SPECTRAL RANGE
by T. Bush, F. Ulaby, T. Metzler and H. Stiles, June, 1976.

Abstract

Employing two FM-CW radar spectrometers, scattering data were acquired from stands of deciduous trees during the spring and autumn. The data suggest that the trees act as a volume scatter target particularly in the 7-18 GHz region. A comparison of data collected in spring and autumn indicates that the radar scattering coefficient, σ°, as measured in spring can be substantially larger (as much as 10 dB) than σ° as measured in the autumn.

RSL TECHNICAL REPORT 177-61

SNOW BACKSCATTER IN THE 1-8 GHz REGION
by H. Stiles, F. Ulaby, B. Hanson and L. Dellwig, June, 1976.

Abstract

The 1-8 GHz Microwave Active Spectrometer (MAS 1-8) system was used to measure the backscatter response of snow covered ground between 21 February and 23 April 1975. The scattering coefficient was measured for all linear polarization combinations at angles of incidence between nadir and 70°. Ground truth data consisted of soil moisture, soil temperature profile, snow depth, snow temperature profile, and snow water equivalent. The results of the experiment indicate that the radar sensitivity to snow water equivalent increases in magnitude with increasing frequency and is almost angle independent for angles of incidence higher than 30°, particularly at the higher frequencies. In the 50°-70° angular range and in the 6-8 GHz frequency range, the sensitivity is typically between 0.4 dB/.1 g/cm^2 and -0.5 dB/.1 g/cm^2 and the associated linear correlation coefficient has a magnitude of about 0.8.

APPENDIX B : LIST OF TECHNICAL REPORTS AND MEMORANDA PREPARED FOR NASA CONTRACT NAS 9-10261.

177 TECHNICAL REPORTS

Supported by NASA/JSC Contract NAS 9-10261

RSL Technical Report 177-1

"An Analysis of Methods for Calibrating the 13.3 GHz Scatterometer," G. A. Bradley, November, 1969.

RSL Technical Report 177-2

"Signal Analysis of the Single-Polarized 13.3 GHz Scatterometer," G. A. Bradley, May, 1970.

RSL Technical Report 177-3

"Imaged Textural Analysis by a Circular Scanning Technique," G. O. Nossaman, June, 1970. (M.S. Thesis)

RSL Technical Report 177-4

"A Regional Study of Radar Lineaments Patterns in the Ouachita Mountains, McAlester Basin-Arkansas Valley, and Ozark Regions of Oklahoma and Arkansas," J. N. Kirk, June, 1970.

RSL Technical Report 177-5

"An Analysis of the Effects of Aircraft Drift Angle on Remote Radar Sensors," G. A. Bradley and J. D. Young, August, 1970.

RSL Technical Report 177-6

"Radar Lineament Analysis, Burning Springs Area, West--Virginia-An Aid in the Definition of Appalachian Plateau Thrusts," R. S. Wing, W. K. Overbey, Jr., and L. F. Dellwig, July, 1970. (Partially supported by USAETL Themis Contract DAAK02-68-C-0089). Published in: Geological Society of America Bulletin, v. 8, pp. 3437-3444, November, 1970.

RSL Technical Report 177-7

"An Evaluation of Fine Resolution Radar Imagery to Making Agricultural Determinations," S. A. Morain and J. Coiner, August, 1970.

RSL Technical Report 177-8 Deleted

RSL Technical Report 177-9

"Optimum Radar Depression Angles for Geological Analysis," H. C. MacDonald and W. P. Waite, August, 1970.

RSL Technical Report 177-10

"Synthetic Aperture Radar and Digital Processing," R. Gerchberg, September, 1970. (Ph. D. Dissertation)

RSL Technical Report 177-11

"Panchromatic Illumination for Radar: Acoustic Simulation of Panchromatic Radar," G. C. Thomann, September, 1970. (Ph. D. Dissertation)

RSL Technical Report 177-12

"Discrete Pattern Discrimination Using Neighborly Dependence Information," R. M. Haralick, October, 1970.

RSL Technical Report 177-13

"Interim Technical Progress Report, Radar Studies Related to the Earth Resources Program," J. Holtzman, et al., March, 1971.

RSL Technical Report 177-14

"Radar Sensing in Agriculture, A Socio-Economic Viewpoint," S. A. Morain, J. Holtzman and F. M. Henderson, December, 1970. Published in: Convention Record Electronic and Aerospace System (EASCON'70), pp. 280-287, published by IEEE.

RSL Technical Report 177-15

"Local Level Agricultural Practices and Individual Farmer Needs as Influences on SLAR Imagery Data Collection," Floyd M. Henderson, April, 1971.

RSL Technical Report 177-16 Deleted

RSL Technical Report 177-17

"A Fresnel Zone-Plate Processor for Processing Synthetic Aperture Data," G. Thomann, R. Angle and F. Dickey, May, 1971.

RSL Technical Report 177-18

"Geoscience Radar Systems," G. Thomann and F. Dickey, May, 1971.

RSL Technical Report 177-19

"SLAR Image Interpretation Keys for Geographic Analysis,"J. C. Coiner, September, 1972. (M.S. Thesis)

RSL Technical Report 177-20

"Multi-Year Program in Radar Remote Sensing," R. K. Moore and J. C. Holtzman, August, 1971.

RSL Technical Report 177-21

"Evaluation of High Resolution X-band Radar in the Ouachita Mountains," L. F. Dellwig and J. McCauley, August, 1971.

RSL Technical Report 177-22

"Remote Sensing of Ocean Winds Using a Radar Scatterometer," G. A. Bradley, September, 1971. (Ph. D. Dissertation)

RSL Technical Report 177-23

"Reconnaissance Soil Surveys from Radar Imagery," S. A. Morain and J. B. Campbell, April, 1972.

RSL Technical Report 177-24

"Interpretation of Side Looking Airborne Radar Vegetation Patterns: Yellowstone National Park," Norman E. Hardy, September, 1972. (M.S. Thesis)

RSL Technical Report 177-25

"Terrain Roughness and Surface Materials Discrimination with SLAR in Arid Environments," H. C. MacDonald and W. P. Waite, January, 1972.

RSL Technical Report 177-26

"Interim Technical Progress Report, Radar Studies Related to the Earth Resources Program," J. Holtzman, et al., March, 1972.

RSL Technical Report 177-27

"IDECS User's Manual," J. Barr and P. N. Anderson, September, 1972. (Partially supported by USAETL Themis Contract DAAK02-68-C-0089). Also partly included in: The Bulletin of Engineering, No. 64, University of Kansas, Lawrence, 1972.

RSL Technical Report 177-28

"Image Processing Applications--The IDECS," P. Anderson, D. Anderson, J. Barr, L. Haas and G. Minden, September, 1972.

RSL Technical Report 177-29

"An Evaluation of Multifrequency Radar Imagery in the Florida Gulf Coast," L. F. Dellwig, August, 1972.

RSL Technical Report 177-30

"Reconnaissance Soil Mapping from Radar Imagery," J. B. Campbell, September, 1972. (M.S. Thesis)

RSL Technical Report 177-31

"A Computer to Computer Digital Data Link," L. Haas, September, 1972. (M.S. Thesis)

RSL Technical Report 177-32

"Radar Studies Related to the Earth Resources Program, Quarterly Progress Report, 1 April 1972 - 30 June 1972," J. C. Holtzman, et al., November, 1972.

RSL Technical Report 177-33

"Radar Studies Related to the Earth Resources Program, Quarterly Progress Report, 1 July 1972 - 30 September 1972," J. C. Holtzman, et al., February, 1973.

RSL Technical Report 177-34

"4-8 GHz Microwave Active and Passive Spectrometer (MAPS)," F. T. Ulaby, January, 1973.

RSL Technical Report 177-35

"Radar Measurement of Soil Moisture Content," F. T. Ulaby, April, 1973. Published in: IEEE Transactions on Antennas and Propagation, v. AP-22, n. 2, pp. 257-265, March, 1974.

RSL Technical Report 177-36

"Surface Configuration as an Explanation for Lithology-Related Cross-Polarized Radar Image Anomalies," J. R. McCauley, April, 1973. (M.S. Thesis)

RSL Technical Report 177-37

"MAS 2-8 Radar and Digital Control Unit," J. M. Oberg and F. T. Ulaby, October, 1974.

RSL Technical Report 177-38

"Radar Studies Related to the Earth Resources Program, Quarterly Progress Report, 1 December 1972 - 28 February 1973," R. K. Moore, J. Holtzman, F. T. Ulaby and L. F. Dellwig, May, 1973.

RSL Technical Report 177-39

"Radar Signal Return from Near-Shore Surface and Shallow Subsurface Features, Darien Province, Panama," B. C. Hanson and L. F. Dellwig, August, 1973.

RSL Technical Report 177-40

"Radar Spectral Measurements of Vegetation," F. T. Ulaby and R. K. Moore, August, 1973.

RSL Technical Report 177-41

"Radar Studies Related to the Earth Resources Program, Quarterly Progress Report, 1 March 1973 - 31 May 1973," R. K. Moore, F. T. Ulaby and L. F. Dellwig, October, 1973.

RSL Technical Report 177-42

"Radar Response to Vegetation," F. T. Ulaby, September, 1973. Published in: IEEE Transactions on Antennas and Propagation, v. AP-23, n. 1, pp. 36-45, January, 1975.

RSL Technical Report 177-43

"8-18 GHz Radar Spectrometer," T. Bush and F. T. Ulaby, October, 1973. (M.S. Thesis-Bush)

RSL Technical Report 177-44

"Agricultural Terrain Scatterometer Observations with Emphasis on Soil Moisture Variations," C. King, August, 1973.

RSL Technical Report 177-45

"Radar Studies Related to the Earth Resources Program, Quarterly Progress Report, 1 June 1973 - 31 August 1973," R. K. Moore, J. Holtzman, F. T. Ulaby and L. F. Dellwig, November, 1973.

RSL Technical Report 177-46

"Active Microwave Measurement of Soil Water Content," F. T. Ulaby, J. Cihlar and R. K. Moore, November, 1973. Published in: Remote Sensing of Environment, v. 3, pp. 185-203, 1974.

RSL Technical Report 177-47

"Dielectric Properties of Soils as a Function of Moisture Content," J. Cihlar and F. T. Ulaby, November, 1974.

RSL Technical Report 177-48

"Fading Characteristics of Radar Backscatter from Selected Agricultural Targets," T. F. Bush and F. T. Ulaby, December, 1973. Published in: IEEE Transactions on Geoscience Electronics, v. GE-13, n. 4, pp. 149-157, October, 1975.

RSL Technical Report 177-49

"Radar Studies Related to the Earth Resources Program, Progress Report, 1 September 1973 - 31 January 1974," R. K. Moore, J. C. Holtzman, F. T. Ulaby and L. F. Dellwig, February, 1974.

RSL Technical Report 177-50 Deleted

RSL Technical Report 177-51

"The Effects of Soil Moisture and Plant Morphology on the Radar Backscatter from Vegetation," F. T. Ulaby, T. F. Bush, P. P. Batlivala and J. Cihlar, July, 1974. Published in: IEEE Transactions on Antennas and Propagation, v. AP-23, n. 5, pp. 608-618, September, 1975: "Radar Response to Vegetation II: 8-18 GHz Band," by F. T. Ulaby, T. F. Bush and P. P. Batlivala .

RSL Technical Report 177-52

"Rough Surface Scattering Based on Facet Model," H. R. Khamsi, A. K. Fung and F. T. Ulaby, November, 1974. (Ph. D. Dissertation - Khamsi)

RSL Technical Report 177-53

"A Theory of Wave Scatter from an Inhomogeneous Medium with a Slightly Rough Boundary and Its Application to Sea Ice," S. K. Parashar, A. K. Fung and R. K. Moore, December, 1974.

RSL Technical Report 177-54

"Geometric Fidelity Levels Inherent To All Ground Range Radar Imaging Systems," B. Hanson and A. Yukler, January, 1976.

RSL Technical Report 177-55

"Monitoring Wheat Growth with Radar," T. F. Bush and F. T. Ulaby, May, 1975. Published in: Photogrammetric Engineering and Remote Sensing, 1976.

RSL Technical Report 177-56

"Radar Return from a Continuous Vegetation Canopy," T. F. Bush and F. T. Ulaby, August, 1975. Published in: IEEE Transactions on Antennas and Propagation, May, 1976.

RSL Technical Report 177-57

"Corn Growth as Monitored by Radar," F. T. Ulaby and T. F. Bush, November, 1975. Published in: IEEE Transactions on Antennas and Propagation, November, 1976.

RSL Technical Report 177-58

"Crop Identification from Radar Imagery of the Huntington County, Indiana Test Site," P. P. Batlivala and F. T. Ulaby, November, 1975.

RSL Technical Report 177-59

"Radar Backscatter Properties of Milo and Soybeans," T. F. Bush, F. T. Ulaby, and T. Metzler, October, 1975.

RSL Technical Report 177-60

"Seasonal Variations of the Microwave Scattering Properties of Deciduous Trees As Measured in the 1-18 GHz Spectral Range," T. Bush, F. Ulaby, T. Metzler and H. Stiles, June, 1976.

RSL Technical Report 177-61

"Snow Backscatter in the 1-8 GHz Region," H. Stiles, F. Ulaby, B. Hanson and L. Dellwig, June, 1976.

RSL Technical Report 177-62

"Agricultural and Hydrological Applications of Radar: Final Report," F. T. Ulaby, Principal Investigator, July, 1976.

177 TECHNICAL MEMORANDA

Supported by NASA/JSC Contract NAS 9-10261.

RSL Technical Memorandum 177-1

"An Analysis of RF Phase Error in the 13.3 GHz Scatterometer," G.A. Bradley, November, 1969.

RSL Technical Memorandum 177-2

"Mathematical Theory of Filtering Program," Robert M. Haralick, December, 1969.

RSL Technical Memorandum 177-3

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RSL Technical Memorandum 177-4

"Informal Log, 13.3 GHz Single-Polarized Scatterometer, 400 MHz Dual-Polarized Scatterometer, Mission 119, Argus Island, Bermuda, 19 January 1970 - 27 January 1970," G. A. Bradley, February, 1970.

RSL Technical Memorandum 177-5

"Principal Component Analysis," R. M. Haralick, April, 1970. (Partially supported by USAETL Themis Contract DAAK02-68-C-0089).

RSL Technical Memorandum 177-6

"Informal Log, Mission 126, Pt. Barrow, Alaska," G. A. Bradley, June,1970.

RSL Technical Memorandum 177-7

"Frequency Averaging for Imaging Radars," G. C. Thomann, June, 1970.

RSL Technical Memorandum 177-8

"Informal Log, Mission 130, Garden City, Kansas," J. D. Young, May, 1970.

RSL Technical Memorandum 177-9

"Informal Log, Mission 133, Garden City, Kansas, Site 76," G. A. Bradley, August, 1970.

RSL Technical Memorandum 177-10

"Ninety-Day Mission Analysis Report, Mx 108, DPD-2, Side-Look Radar, Pisgah Crater, California," L. F. Dellwig, July, 1970.

RSL Technical Memorandum 177-11

"Correlated Averaging to Enhance Radar Imagery," Ralph W. Gerchberg, September, 1970.

RSL Technical Memorandum 177-12

"Analysis of Sea State Missions 20-60," J. Young, September, 1970.

RSL Technical Memorandum 177-13

"A Note on the Antenna Beamwidth Term Used in the Scatterometer Data Reduction Program," J. D. Young and G. A. Bradley, October, 1970.

RSL Technical Memorandum 177-14

"Mission 126, 90 Day Report, Pt. Barrow, Alaska, April, 1970," G. A. Bradley, December, 1970.

RSL Technical Memorandum 177-15

"NASA Earth Observation Survey Program 90-Day Mission Report, Garden City, Kansas, Site 76, Mission 133, July 9, 1970," W. O. Lockman, L. T. James, J. C. Coiner, December, 1970.

RSL Technical Memorandum 177-16

"Satellite Radar Power Calculations," G. C. Thomann, December, 1970.

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"Informal Log, Mission 156, JOSS II, North Atlantic Ocean, Site 166, February 8-19,1971," G. A. Bradley, March, 1971.

RSL Technical Memorandum 177-18

"DPD-2 System Analysis Review," F. Dickey and J. Holtzman, May, 1971.

RSL Technical Memorandum 177-19

"Informal Log, Mission 165, Garden City, Kansas," J. D. Young, June, 1971.

RSL Technical Memorandum 177-20

"NASA Earth Observation Survey Program, 90-Day Mission Report, Garden City, Kansas, Site 76, Mission 165, May 20, 1971," F. M. Henderson and F. M. Dickey, August, 1971.

RSL Technical Memorandum 177-21

"Basic Considerations for Extracting Quantitative Data from Photographically Stored Radar Imagery," F. Dickey and J. Holtzman, August, 1971.

RSL Technical Memorandum 177-22

"NASA Earth Observation Survey Program, 90-Day Mission Report, Garden City, Kansas, Site 76, Mission 168, June 18, 1971," F.M. Henderson and F. M. Dickey, November, 1971.

RSL Technical Memorandum 177-23

"Densitometric Data for Agricultural Analysis of Fine Resolution Radar Imagery," J. C. Coiner and James B. Campbell, November, 1971.

RSL Technical Memorandum 177-24

"Preliminary Agricultural Data Analysis," J. D. Young, December, 1971.

RSL Technical Memorandum 177-25

"Image Interpretation Keys to Support Analysis of SLAR Imagery," J. C. Coiner and S. A. Morain, May, 1972. Published in: Proc. ASP/ACSM Fall 1971 Convention of the American Society of Photogrammetry, September 7-11, 1971, pp. 393-412, San Francisco.

RSL Technical Memorandum 177-26

"IDECS System Development September 70-September 71," P. N. Anderson, et al., September, 1971.

RSL Technical Memorandum 177-27

"Mission 126, 90-Day Report, Pt. Barrow, Alaska, February, 1972," S. K. Parashar and F. M. Dickey, February, 1972.

RSL Technical Memorandum 177-28

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