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Renewable Resources Remote Sensing Research Program

1982 Report

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1982 Renewable Resources Remote Sensing Research and Analysis Research Summary

Introduction

The NASA Earth Resources Remote Sensing Research Program includes research and analysis in the areas of Renewable and Non-Renewable Resources. This report summarizes Renewable Resources Remote Sensing research and analysis activity which encompasses a variety of remote sensing science and related discipline science investigations.

The remote sensing science investigations deal with fundamental research issues aimed at improving our understanding of the remote sensing process. This fundamental research addresses topics in Scene Radiation and Atmospheris Effects Characterization (SRAEC) and Mathematical Pattern Recognition and Image Analysis (MPRIA). The SRAEC investigations include theoretical modeling verified by experimental measurements in the areas of the visible-infrared regime, atmospheric effects, and microwave regime. These investigations are examining bidirectional effects as well as the spectral, spatial, and temporal characteristics of the data. The MPRIA investigations are aimed at investigating new and improved algorithms which can be tested on data sets to improve the efficiency of pattern recognition schemes. The MPRIA research areas include preprocessing, digital image representation, and object scene inference. Approaches involving the use of scene segmentation, textural analysis and expert systems are included along with a strong emphasis on mathematical-statistical approaches. All SRAEC and MPRIA investigations were initiated in 1982.

Discipline science investigations employing remote sensing techniques are being pursued in botany, hydrology, and geography. The techniques are based on existing understanding of the remote sensing process as improved through fundamental research and remote sensing science. As shown in Figure 1, these discipline science investigations are being pursued in four spectral areas including the visible-near infrared, shortwave infrared, thermal infrared, and microwave regime.

Spectrally the research has evolved from a strong base in the visible-near infrared to emphasis on longer wavelengths in the microwave regime. The microwave regime complements surface reflectance and thermal emission by providing information about the structure and water content of land cover. The context provided by figure 1 shows that although we have made significant accomplishments in the visible-infrared regime, we have really only begun to exploit the use of remote electromagnetic measurements to better understand the earth's renewable resources. Future research will be multispectral, combining information from this broad range of the electromagnetic spectrum. In addition, discipline science investigation will evolve from a heavy emphasis on cultivated vegetation to include a wider range of natural vegetation such as forests, grasslands, and wetlands.

The majority of the effort in discipline science is concentrated in Thematic Mapper (Simulator) TM(S) data analysis which is aimed at identifying new and improved types of information which can be derived from TM data. These improvements are being related to the contributing sensor parameter(s) through factoral analysis techniques. This TM(S) data analysis has served to prepare the research community for the analysis of TM data which is being addressed in FY 1983.

Figure 2 depicts Earth Resources Emphasis and shows the parallel research efforts in remote sensing science and discipline science supported by a series of on-going and planned space data sources. These space data sources include the Shuttle Imaging Radar (SIR) experiment series, Free-Flying Imaging Radar Experiment (FIREX), Landsat-4 Thematic Mapper (TM), the Multilinear Array (MLA) and the Experimental Land Observing System (ELOS).

II. RESEARCH STATUS AND RESULTS

A. REMOTE SENSING SCIENCE

The pursuit of remote sensing science through fundamental research investigations is a new thrust motivated by the need to better understand the physics and mathematics of the remote

RENEWABLE RESOURCES REMOTE SENSING APPLICATIONS

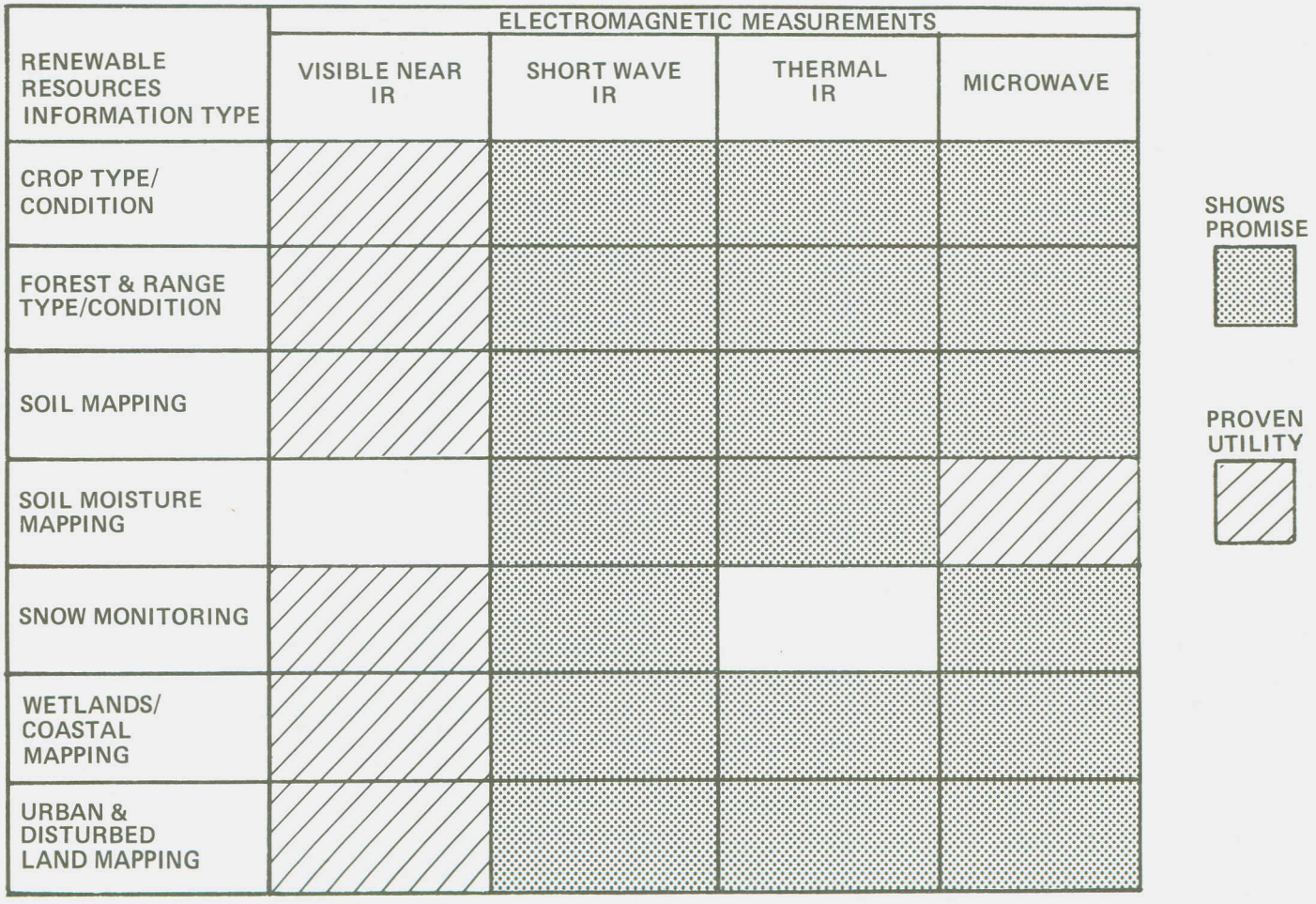


FIGURE 1

sensing process in order to exploit the full capability of the electromagnetic spectrum and take advantage of technology developments such as multilinear arrays and synthetic aperture radar. These investigations are being conducted by a broad base of university researchers as well as NASA scientists.

The investigations were initiated in FY 1982 and abstracts are presented which describe the proposed research.

1) SCENE RADIATION AND ATMOSPHERIC EFFECTS CHARACTERIZATION

SRAEC fundamental research investigations utilize a combination of laboratory, field, aircraft, and spacecraft measurements together with physical-mathematical models to relate observed properties of electromagnetic radiation to the physical and biological properties of the surface. Both active and passive observing systems are used. Wavelengths of relevance range from visible and near infrared through the shortwave infrared and thermal regions to the microwave region. Investigations are conducted at the component level (e.g., individual leaves or minerals), component aggregation levels (e.g., crowns or rocks), and segments to entire scenes (e.g., hetergenous combination of vegetation canopies, soils, and rocks, etc.). At present, the emphasis is on the properties at a

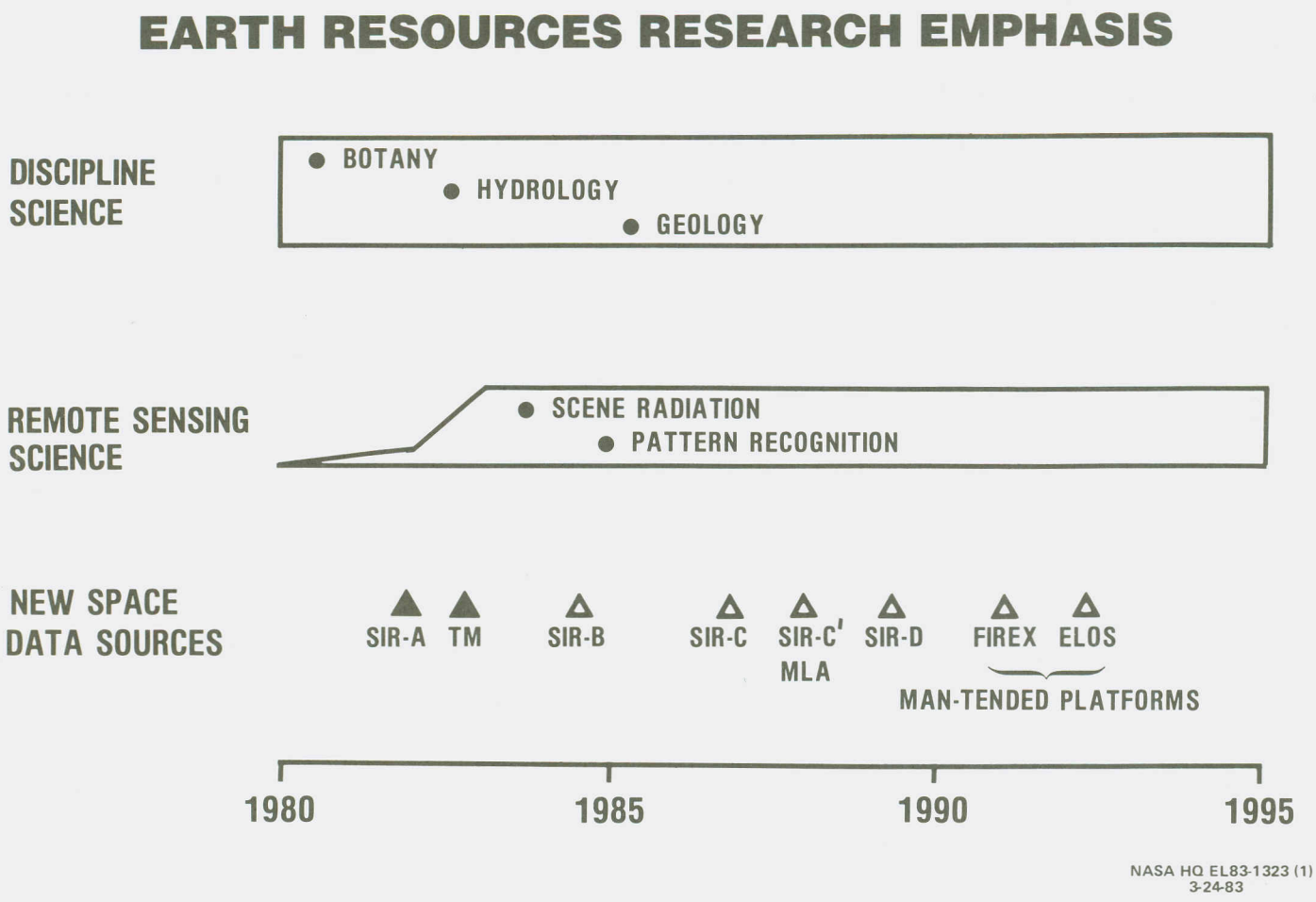


FIGURE 2

given time, but increased emphasis will be given to the temporal changes in properties as the quality of theory and observations increases.

The intervening atmosphere is an important contributor to the observed properties of a scene. Radiation scattered into the instantaneous field-of-view of a sensor degrades the information content of the scene. Experimental and theoretical studies are being conducted which will lead towards the ability of characterize and ultimately correct for this atmospheric path radiance.

The investigations being conducted in this area are described as follows:

a) VISIBLE-INFRARED REGIME

Reflectance Modeling. (J. Smith/CSU, J. Norman/U. Nebraska, A. Strahler/Hunter College)

The fundamental objective of the Reflectance Modeling project is to develop a general understanding of the interaction of the electromagnetic radiation at reflectance wavelengths with scene elements. The physical quantity which summarizes these interactions is the bidirectional reflectance distribution function BRDF. The BRDF for renewable resource targets is quite complex. Although it is useful for characterizing different kinds of soil or canopy surfaces from down looking off-nadir viewing angles, before is can be used the factors which determine the nature of this distribution must be understood. At the present time, several factors that affect the bidirectional reflectance distribution of a canopy are known. These include leaf angle distribution, leaf area index, solar zenith and azimuth angles, as well as the sky condition, component spectral properties, soil spectral characteristics, and canopy morphology including row spacing, tree spacing, tree canopy and size and shapes.

This project will develop or extend bidirectional reflectance models for hetergeneous canopies of partial cover, complete cover, and for row crops. Through modeling the above factors will be related to the overall response behavior.

Measurement and Modeling of the Optical Scattering Properties of Crop Canopies. (V. Vanderbilt/Purdue University)

The sunlight specularly reflected by such crops as corn, sorghum, and wheat is often so bright that these crops appear white instead of green when viewed off-nadir. Unlike the light diffusely reflected by the leaf, the specularly reflected light never enters the leaf. The light appears white because it has not entered the leaf to interact with the cell pigments, walls, or water. The specular reflectance originates at the leaf cuticle, which has been found to be like a "fingerprint" for identifying species. The cuticle properties change with plant development stage, water status, and temperature regime. All of this suggests that the specular portion of the canopy reflectance is an important new source of information about crop species and status.

This research is intended to measure, analyze, and mathematically model the bidirectional reflectance distribution function (BRDF), and the specular, polarized, and diffuse light scattering properties of several crop canopies and their component parts (leaves, stems, fruit, soil) as a function of view angle and illumination angle. The potential of these bidirectional radiation properties for crop discrimination and crop condition assessment will be evaluated. The three year effort will concentrate on crops of economic importance such as corn, soybeans, wheat, barley, sunflower, alfalfa, and sorghum. To properly characterize the phenomena at various scales, and to investigate the effect of the atmosphere, measurements will be made in the laboratory, in the field, and from a light aircraft. Field measurements of scene reflectance and the angular distribution of spectral sky radiance, taken under a variety of clear and overcast sky conditions, will be investigated to determine the magnitude of scene reflectance differences caused by illumination conditions and to determine the feasibility of obtaining routine reflectance data under overcast skies.

Fundamental Research for Comprehensive Understanding of Vegetated Scene Radiance Relationships. (Dr. D. Kimes/NASA-Goddard Space flight Center)

This is an extensive fundamental research effort intended to provide an improved comprehensive understanding of the relationships between radiance characteristics of vegetated scenes. The work is based upon field data collection and model development, and validation to yield functional relationships or empirical models. Of particular concern are those spectral, spatial, and temporal characteristics of the scene that are related to important biophysical attributes and to atmospheric conditions.

Plant canopy directional reflectance is the first of the three major areas addressed in this study. Directional canopy and downwelling sky radiance distribution measurements are being made to provide information valuable to the understanding of relationships between plant canopy directional scattering properties, irradiance conditions and the structural, and optical characteristics of individual canopies and their components. This will also provide a means for validating canopy-radiative transfer models and provide a data set suitable for the derivation of the Bidirectional Reflectance Distribution Function (BRDF). Another effort within this research is the study of two dimensional spatial relationships in images and atmospheric adjacency effects. This addresses current questions concerning optimum spectral, spatial, and radiometric resolutions for future sensor systems. For the third area of study in this

research, work is being done to modify an existing stochastic model designed to simulate the interaction of light with leaves in order to make for accurate simulation of a variety of monocat and dicot vegetative species. This will provide a leaf radiation model which will predict leaf spectral absorbance, reflectance, and transmissance based upon leaf biophysical variables and serve as a submodel in plant canopy radiation models.

Relationships Between Crop Growth and Spectral Reflectance Parameters. (G. Badwahr/NASA-Johnson Space Center)

It has been established that is it not possible to reliably identify and discriminate between certain vegetation types or determine critical vegetation biophysical characteristics using broadband reflectance measurements made at any single time using a single look angle. This investigation addresses the need for multitemporal spectral data and the need to model and understand the dynamic behavior of vegetation canopy.

The physical bases for understanding how various spectral transform temporal trajectories depend on vegetation type, condition and phenological stage is being developed. Spectral transformations suitable for observing canopy characteristics are being developed as well. It is also the aim of this investigation to derive a physical understanding of the effect of water stress on radiometric response different spectral bands.

Bidirectional Spectral Reflectance of Earth Resources: Influence of Scene Complexity and Atmospheric Effects on Remote Sensing. (D. Diner/Jet Propulsion Laboratory)

The overall objective of this investigation is to determine the effects of atmospheric contamination on the discriminatory reflectance properties of scenes containing renewable resources in the 0.4-2.5 micrometer range. The problem will be approached in steps, beginning by experimentally measuring, in the laboratory and under controlled illumination conditions, the spectral and bidirectional reflectance properties of a few representative soil and vegetative samples. Extension to multicomponent canopies at various growth stages will be the next step. Empirical modeling of the bidirectional reflectance functions will then be undertaken to attempt to relate diagnostic elements of the complex BRDF's to biophysical properties of the components. At the conclusion of this stage of the research effort, the product will be a set of quantitative boundary conditions and a theoretical basis upon which the experimental determination of atmospheric effects may be defined. The second phase begins outdoor ambient light determination of BRDF's at different wavelengths and atmospheric conditions. Subsequently, radiative transfer calculations and atmospheric models will be used in conjunction with the measurements to derive methods for accounting for and understanding the effects of the diffuse component.

b) ATMOSPHERIC EFFECTS

Characterization of Surface Reflectance Varigation Effects on Remote Sensing. (Dr. W. Pearce/EG&G Washington Analytical Services Center, Inc.)

This project seeks an improved understanding of the scattering interactions of light with the ground and atmosphere by modeling the combined effects of atmospheric scattering and ground albedo.

The model used in the study employs a Monte Carlo radiative transfer code by varying the important parameters such as patterns of surface reflectivity and reflectance type, atmospheric turbidity, aerosol particle size distribution, wavelength detector look angle, etc. A basis is being compiled for parameterizing the functions which characterize the radiance components. In general, insufficient apriori information is available to specify these functions for a given scene completely. Therefore, the sensitivity of corrections of errors in the estimates of the atmospheric and surface parameters is being analyzed and the practical implementation and effectiveness of atmospheric correction algorithms is being investigated.

Multidimensional Modeling of Atmospheric Effects and Surface Heterogeneities on Remote Sensing. (S. Gerstl/Los Alamos National Laboratory)

This research effort seeks to establish a multidimensional modeling capability to quantitatively determine the atmospheric effects upon the integrity of remote sensing data. The model will include vertical and horizontal variabilities of the atmosphere as well as nonuniformities of surface features, and provide a basis for accurate pixel correction procedures.

The development of this systematic model and code for remote sensing is based upon existing two-dimensional methods developed for nuclear shielding purposes at the Los Alamos National Laboratory. Appropriate methods and techniques in

use for nuclear applications will be exploited and adapted to atmospheric effects characterization for remote sensing. New capabilities will be added to analyze row and edge pixel effects, to describe non-Lambertian bidirectional reflectance properties, to include polarization effects, and to describe volumetric scatters above a reflectance ground as required for microwave sensing of vegetation canopies. Data for realistic model atmospheres will be employed that include measured aerosol distributions and semi-transparent cloud covers.

Atmospheric Effect on Remote Sensing of the Earth's Surface. (R. Fraser/NASA-Goddard Space Flight Center)

The prime objective of this investigation is to perform a basic study of the atmospheric effects on remote sensing of the earth's surface and on classification of surface features using models and experimental data.

This theoretical study will utilize models of the atmosphere on nonuniform surfaces for computation of radiances to simulate measurements from satellites. Parameters are to be varied to analyze their effects on the misclassification of surface features. All possible error sources will be investigated in order to determine the major causes and magnitudes of atmospheric effects. Field experiments will be conducted in order to measure some of the parameters required for the modeling. The path radiance of skylight and aerosol optical thickness will be measured simultaneously, while a lidar will measure the vertical and horizontal properties and variability of aerosols. Through such theoretical analysis and experimentation this study will help build an appropriate basis for designing future earth resources satellites and for developing atmosphere correction algorithms.

c) MICROWAVE REGIME

Determination of the Sources of Radar Backscatter. (R. K. Moore/Univ. of Kansas)

In order to determine the sources of radar backscatter in vegetation and other non-layered volume-scattering media, fine sensor resolution must be achieved in the azimuth-elevation plane as well as in the range direction. An exploratory experiment has been designed to achieve this by using microwave spectrometer. Radar backscatter sources will be investigated for various crops and trees at different stages in their growth cycles. This experiment is also looking at soils with different moisture content as well as various manmade targets that contribute to radar signal response.

Measuring and Modeling of the Dielectric Properties and Attenuation of Vegetation. (Dr. T. F. Ulaby/Univ. of Kansas Center for Research)

Although significant advances have been made during the past several years in connection with the backscattering and emission contributions of a vegetation canopy relative to the contributions by the underlying soil surface, the development of accurate models and interpretation techniques for radar and radiometer observations of vegetation-covered ground has been hampered by the lack of appropriate dielectric models and attentuation measurements of vegetation canopies. This investigation consists of four major tasks: (a) measurement of the dielectric constant of vegetation material (leaves, stalk, fruit) as a function of vegetation moisture content at 1.4, 5, and 10 GHz, (b) development of dielectric mixing models for vegetation material using the above data, (c) development of dielectric mixing models for the canopy in terms of the dielectric constant of air and of the inclusions (plant parts), and (d) testing the validity of the models obtained in (c) by comparing the attentuation coefficient of the canopy based on these models with direct field measurements of the attentuation coefficient.

The results of this investigation should have a strong impact on the major application area of soil moisture monitoring and crop-type identification and stress assessment.

Scattering Models in the Microwave Regime. (A. Fung/Univ. of Kansas)

This study is being conducted to develop scatter and emission models for testing against existing data on crops and snow. A dielectric model for vegetation will be developed in terms of the important components of a vegetated medium by generalizing published techniques. Additionally, a combined volume and surface electromagnetic scattering model will be developed. These models will be verified and refined by comparing the combined (dielectric and electromagnetic) model with sensor electromagnetic measurements and ground truth. The same task will be repeated for snow. Matrix doubling and radiative transfer approaches will also be considered and compared with the wave approach adapted during the earlier work to determine whether one is more applicable than the other.

Discrete Random Media Techniques for Mircowave Modeling of Vegetated Terrain. (R. Lang/George Washington University)

The modeling of radar signal response to vegetative terrain in the .5 - 20 GHz frequency range is the focus of this research.

Vegetation will be modeled by replacing leaves and stems with lossy dielectric discs and with finite length cylinders having prescribed position and orientation statistics. The modeling techniques will yield the relationship between satellite or aircraft sensor response and canopy scene sublement properties. The work to be accomplished is divided into four categories: scatter modeling, discrete random media analysis numerical evaluation, and data interpretation scatter modeling is concerned with calculating dyadic scattering amplitudes for the discs and cylinders and developing numerically efficient programs for these scatters is resonant and physical-optical regimes. In the discrete random media analysis, a "coherent" transport theory from Maxwell's equation will be derived where the albedo is not necessarily low. Effects of ground roughness will be accounted for by modeling the soilsurface with a composite rough surface. The results from these first two activities will be incorporated in a computer program which evaluates backscattering coefficients given canopy and soil characterisitcs. The results from the model will be compared with other available radar backscatter data.

Remote Sensing of Earth Terrain. (J. Kong/Massachusetts Institute of Technology)

This investigation aims toward developing theoretical models that are useful in remote sensing data analysis and interpretation, scene simulation, and developing new remote sensing approaches and techniques. Theoretical models that account for absorption, scattering, layering and rough surface effects of earth terrain will be developed to facilitate interpretation of active remote sensor data collected with radars and of passive remote sensor data collected with radiometers. The models will be applied to the study of (1) vegetation which can be modeled as a layered absorptive and scattering medium with rough interfaces, (2) soil moisture which is dominated by absorption and rough surface effects, (3) cloud and rainfall which can be modeled as an absorptive and scattering medium, and (4) snow-ice fields and desert areas which can be modeled as a layered absorptive and scattering medium. A unified radiative transfer theory that applies to earth terrain and the atmosphere at a frequency spectrum from microwave to optical will be developed and checked for validity and limitations.

Microwave Backscattering Properties of Crops. (J. Paris/NASA-Johnson Space Center)

This research effort is an investigation of how changes or differences in vegetation canopy structure affect the microwave scattering properties of vegetation. Through the combined use of mathematical models and supportive field measurements this research is anticipated to contribute greatly to the understanding of the role of vegetation structure in radar backscatter. An improved understanding will in turn aid in optimizing the remote sensing techniques and automatic classification procedures used for crop identification. The biophysical characteristics of crops such as corn, soybeans and milo are being analyzed with regard to structure for changes or differences such as those caused by natural variations in mosture availability, morphological differences between crop types, variations in planting date and other factors. A Monte Carlo theoretical model is being developed to mathematically characterize the structure-scatter relationships.

2) MATHEMATICAL PATTERN RECOGNITION AND IMAGE ANALYSIS

Research conducted in Mathematical Pattern Recognition and Image Analysis addresses funmental research issues that arise in developing automated approaches to the extraction of information from digital image data generated by remote sensing systems for earth resources scenes. Information extraction requires a fundamental understanding of remotely acquired data characteristics. Based on this understanding, the data can be used to identify surface classes comprising a scene, to determine the location and proportion of these classes, and to measure geographical, physical, and biological attributes of each class. The use sequence of processes needed to obtain this information is herein categorized as preprocessing, digital image representation, and object scene inference. In preprocessing, research in registration and rectification is being conducted to develop platform error models, tie point correlation techniques, and to employ transformations for use in registration and change detection problems. In digital image representation, the statistical characterization of texture is being employed by random field models; Splines are being used to fit surfaces to a scene to assist in scene segmentation and probability model selection methods are being studied to improve statistical

inference methods. In object scene inference; mixture models are being developed to derive proportion estimates without classification; regression and empirical Bayes techniques are being developed to tie Landsat data to conventional data to develop more precise estimation methods, and artificial intelligence techniques are being pursued in support of digital image processing. Methods are being studied for finding image features and their structures.

The investigations be conducted in these areas are described as follows:

a) PREPROCESSING

Registration/Rectification of Remotely Sensed Data. (E.M. Mikhail/Purdue University)

This research seeks an improved basic understanding of the operations involved in the registration and rectification of remotely sensed images. Past research in this area has been application oriented; this investigation is an attempt to satisfy the need for the fundamental knowledge necessary to derive an optimum, unified and coherent approach to the registration and rectification of remote sensing data for earth resources. Specific topics addressed in this study include sensor/platform modeling for use in the parametric approach to rectification/registration, the feasibility of sub-pixel accuracy and the conditions under which it may be achieved, and new methods of image correspondence through various means of control. The research also includes efforts to resolve questions regarding the optimum sequence of rectification/registration procedures, a study of the means of assessing accuracy in these procedures, and a pursuit of the unresolved problems regarding block adjustment of overlapping strips in the mosaicing of images.

Subpixel Accuracy and Related Estimation Problems in Image Registration. (L.N. Kanal/L.N.K. Corp.)

Typical specifications for imaging registration accuracy call for less than .5 pixel geodetic and a .3 pixel relative (between images) errors 90 percent of the time. This research addresses the problems associated with meeting these specifications through a study of subpixel location accuracy and super resolution in image matching. A variety of related topics are being considered including registration error performance for non-Gaussian image models, an estimation of the bounds on registration accuracy, and the loss of information involved in passing from a continuous to a sampled image and its effect on correlation. New robust approaches to image correlation are being examined. Another area being addressed deals with the acquisition and location of satellite image segments with distinct ground features whose geographic coordinates are known, referred to as "control points," suitable for image registration procedures.

Expert Systems for Image Registration and Change Analysis. (L.S. Davis and A. Rosenfeld/University of Maryland)

This research addresses the problems associated with the registration of multitemporal image data and the subsequent analysis of this data for the purpose of land use and land cover change detection. The objective is to develop an expert image understanding system for application to registration and change detection tasks, operating on a multiresolution or pyramid representation of the data. The expert system is viewed as a "high-level processor," capable of representation and control of knowledge for the chosen tasks. The expert system will be fed by a "low-level processor" which automatically distinguishes image texture features and local features such as road intersections, rivers, lakes, etc. This investigation represents a concentrated effort in the simultaneous consideration of both low-level and high-level knowledge for problems in remote sensing.

Scene-to-Map Registration Comparison for Landsat MSS and Thematic Mapper Data. (D.D. Dow/NASA-NSTL)

Changes in geometric correction procedures for Landsat data has presented problems of comparability for users. Prior to 1979, Landsat MSS tapes were produced by the X-format which lacked geometric corrections. MSS tapes are available today in a geometrically corrected P-format or non-corrected A-format. The map base used in geometric correction procedures also varies, as well as the resampling techniques employed.

This investigation is examining certain facets of the geometric registration comparison problems in the MSS era as well as those expected to occur with the Thematic Mapper on Landsat-4. The end result will be an intercomparison of the various MSS and TM data formats with an evaluation of scene-to-map registration accuracy for different proportions of a Landsat scene. Results will be utilized to determine optimum scene-to-map registration methods.

b) DIGITAL IMAGE REPRESENTATION

Textural Edge Detection and Sensitivity Analysis. (K.S. Shanmugan/Univ. of Kansas)

This research is directed toward the determination of a solution to the problem of finding textural edges in an image and seeks an improved understanding of the effects of the imaging process on the textural properties of an image. Texture is one of the important characteristics used in image analysis. However, before textural features can be used for characterizing and classifying a scene, the image must be segmented. Although a number of algorithms have been developed for segmenting an image, these procedures are not directly applicable to image segmentation based on textural properties. This study is developing a textural edge detection method based on mathematical models for texture that can be used for image segmentation. The other problem being addressed in this study is the effect of imaging system parameters (in particular those of a synthetic aperture radar imaging system) on the textural properties of an image. This portion of the study will rely upon mathematical models to represent terrain patterns and the imaging process.

Image Analysis for Remote Sensing. (G. Smith/SRI International)

The primary objective in this fundamental research is the development of computer models for the dual tasks of image-to-image correspondence and image segmentation in the context of land-use classification. An additional related objective is the development of a "convergence of evidence" decision model that is tolerant of missing and conflicting data. The approach being taken is a combination of image understanding (IU) and artificial intelligence paradigms. Semantic knowledge, such as the physical and geometric properties of object classes that may appear in the scene, will be used to help segment the image and determine the image-to-image correspondence. Reasoning techniques specifically designed to deal with perceptual data are to be employed in the final decision-making process in order to overcome ambiguities inherent in syntactic approaches to image interpretation. Progress on these problems will contribute valuable fundamental insights into information extraction processes for multisensor, time-displaced digital image data.

Improving Spatial Modeling in Remote Sensing. (A.H. Strahler/Hunter College)

Inherent in formation extraction procedures are assumptions about the spatial characteristics of image data. Spatial models can be either explicit, implicit, or defaulted to non spatial forms. In the past, most remote sensing models have either defaulted to nonspatial forms or made implicit assumptions of high spatial autocorrelation. This research effort is designed to develop a conceptual framework for characterizing spatial patterns in image data and to develop scene inference techniques that use spatial models directly in the inversion process. Through this work, further understanding of the fundamental nature of remotely sensed data in the spatial domain is being derived. The contribution to scene inference capabilities by spatial data is expected to increase. Closely related to this work with spatial models is the concept of image texture. This study includes the development of image texture measurements based on determinate models, rather than typical reliance upon the empirical characterization of image texture.

Random Field Models for Use in Scene Segmentation. (M. Naraghi/JPL)

This study focuses on the use of random field models in the development of scene segmentation and classification procedures for Landsat images. The research is designed to determine theoretically optimal scene segmentation and classification procedures for a class of random field models. These models will account for interpixel correlations of multispectral inagery, scene-variable model parameters, and utilize prior knowledge of scene geometry and/or geometrical constraints. A test will be performed on the robustness of the procedures for computer-generated images which conform to model assumption as well as some which do not. After fitting a training set of Landsat data to the class of models to which the theory applies, tests will be conducted to evaluate the performance of the procedures on actual Landsat data.

c) OBJECT SCENE INFERENCE

Density Estimation and Feature Selection Using Spline Approximation. (L.L. Schumaker/Texas A&M University)

The cost efficiency of using statistical pattern classification algorithms to analyze co-registered

digital images depends to a great deal upon the algorithm's ability to reduce the dimensionality of the measurement space by usning feature selection/combination techniques. This research is concerned with the development of improved algorithms feature selection techniques through the application of approximation theory. Investigations are being conducted into the use of spline functions to approximate univariate and multivariate density functions for classes of interest, and the incorporation of the models into numerically tractable classification procedures for which estimates of the probability of misclassification are computable. Feature selection techniques will be developed based upon these models and classification procedures.

Mathematical Pattern Recognition and Image Analysis. (A.P. Decell, Jr./University of Houston)

This research addresses the numerical and statistical problems arising in procedures which relate maximum liklihood estimates of multivariate mixture model parameters to important remotely sensed scene attributes. To support further development of these estimation procedures for remote sensing applications, the feasibility of introducing important a priori knowledge of spatial relationships into the sampling procedure or into parametric models for the class density functions is being studied. Modeling of randomly sampled quasi-fields (multipixel subsegments of a digital image) of a given size and a given class as data from a finite length, low order autoregressive process or stationary gaussian Markov process is being explored. If the viability of a low order autoregressive model is established, steps will be taken to incorporate the model into statistical procedures for determining scene attributes. The approach will relate features of interest (e.g., crop area proportions) to the parameters of a multivariate mixture distribution and the estimation of distribution parameters by any of several general parameter estimation methods.

An Empirical Bayes Approach to Some Spatial Analysis Problems. (C. Morris, University of Texas

In this study an Empirical Bayes approach is investigated for estimating parameters of interest associated with a pixel in a remotely sensed digital image. The parameter for example, could be the crop type label associated with a pixel. Recent results which relate Stein estimators to Empirical Bayes estimators provide the basis for this research. Particular consideration is being given to Empirical Bayes Estimators in cases where there is spatial correlation between pixels. Specific questions of concern relate to the effect on the distribution of the parameters induced by spatial correlation, Empirical Bayes estimators for the nonnormal distributions found in satellite data, and the precision of these estimates.

Statistical Methods for Image Representation. (E. Parzen/Texas A&M University)

This study is designed to contribute to the information extraction process in remote sensing through the application of recent developments in statistical methodology. This research brings together a team of statisticians whose individual expertise in modern statistical techniques will ultimately be combined to provide a unified approach to the analysis of digital image data. Analyses of remotely sensed images are being conducted on both a global basis where independence among the observation vectors may be assumed, and on a local bias where vector intercorrelations exist. In the global case, nonparametric density estimators and robust methods are being applied to the estimation of single and mixed probability distributions. Multivariate time series methods in the plane will be developed to analyze local characteristics and mixed boundary pixels. Data dimensionality will be reduced to aid in the time series analysis.

Mathematical Pattern Recognition and Image Analysis of Coherent SAR Imagery. (D.N. Held/JPL)

This study deals with both the problem of reducing the speckle in Synthetic Aperture Radar (SAR) imagery to facilitate processing by conventional classification or pattern recognition algorithms, and the problems of utilizing the statistics of the speckle in order to provide additional measurable attributes which can facilitate image classification. The speckle reduction portion of the study is concentrating on development and evaluation of a variety of speckle filters and the quantification of their performance with simulated imagery and Seasat SAR data. The speckle utilization portion of the study emphasizes analysis of the statistics of the speckle phenomenon for a variety of targets in a Seasat SAR image and supports development of algorithms to descriminate between otherwise ambiguous targets based upon these statistical measures. This research effort is expected to aid substantially in the automatic and efficient usage of radar imagery for earth resources applications.

Crop Acreage Proportion Estimation Using Mixture Models. (R.P. Heydorn/NASA-JSC)

Previous attempts have been made to estimate the proportion of acreage in an area that is of a given crop type using Landat multispectral data. Results have shown that classification error due to realizable separability between crop classes generally leads to bias in acreage estimates. This experience has suggested that methods which are at least theoretically unbiased should be considered. Under correct conditions, this requirement is satisfied through the use of the direct proportion estimation methods being investigated in this study, based upon the concept of a mixture model. The mixture model allows derivation of a set of weights, or proportions, through a linear decomposition of the probability density of a scene into density classes. The probability density is the function that describes the frequency with which one expects to observe given spectral values in a scene. The component densities are related to particular vegetative and nonvegetative class types. Various versions of the mixture model are being investigated with both a parametric and nonparametric approach.

Theoretical Investigation of Crop Area Estimators Based on Remotely Sensed Data with an Accurate but Costly Subsample (A. Houston/JSC)

The purpose of this study is to investigate techniques for improving area estimates of ground cover class of interest based on remotely sensed data when accurate, but costly, data are available for a subsample of the population of interest. It is presumed that estimates of the proportion of some ground cover class of interest in some population of interest (e.g., a county) are desired; moreover, the precision required is considerably larger than that which can be obtained using the simple random sample of more accurate (e.g., ground gathered) data alone. It is further presumed that a rapid, but less accurate, estimate of the proportion of the ground cover class of interest can be made for each sample unit in the population of interest using remotely sensed data, while, by a more costly scheme, a more accurate estimate (the correct value in the case of ground-gathered data) can be determined for a simple random sample of the sample units in the population of interest. Initially, this research will investigate the relative theoretical merits of various techniques when the accurate costly subsample is obtained from ground gathered data assumed to be error-free. Later studies will relax this assumption to allow error in the more costly subsample. The first technique to be investigated will be simple linear regression, with a remote sensing based proportion estimator as auxiliary variable, and post-stratified random sample estimation with a remote sensing based classification technique as the stratifier.

B. DISCIPLINE SCIENCE

The focus of the research in the discipline sciences has been on the development of techniques which employ Thematic Mapper (Simulator) data. These discipline investigations included studies of cropland, soils, forest, rangeland, wetlands, disturbed lands, and urban areas. Additionally research has been performed including examination of AVHRR for its utility in large area vegetation biomass surveys, and in the use of microwave techniques for both land cover and hydrologic-related measurements. The investigations conducted in these areas are described as follows:

1) VISIBLE-INFRARED REGIME

Renewable Resources Field Research and Spacecraft Data Analysis (Murphy/GSFC)

An extensive research effort was continued in FY 1982 to improve, develop and apply remote sensing data analysis techniques for the study of renewable resource problems. The research is composed of six tasks with particular emphasis during FY 1982 placed on tasks employing Thematic Mapper Simulator data and Advanced Very High Resolution Radiometer (AVHRR) data.

In the Thematic Mapper Land Resources Studies segment of the research, simulated Thematic Mapper data is being analyzed to quantitatively evaluate the improvement of TM data over MSS data for land use and renewable resources applications. The intent is to determine the relative contribution of individual TM sensor parameter improvements (e.g., spatial, spectral) to improved scene information extraction capabilities. An analysis of both Thematic Mapper Simulator (TMS) and Landsat MSS data for two test areas were completed in FY 1982. Simulated Thematic Mapper data acquired from an aircraft platform requires radiometric corrections to account for differential reflectance across the scene due to the variation in look geometry at aircraft altitudes. Figure 3 shows the TMS image before and after this correction procedure is applied. Results from the

experiment in the North Carolina Pine Plantation test site have shown that for detailed cover-type classifications (e.g. Level III), TMS data provides superior performance. This improvement in general classification performance is due to the TM sensor's sensitivity to subtle changes in spectral response over a smaller field of view. For broad forest cover-type classifications (Level II), areas with large tracts of fairly homogeneous categories, TMS and MSS data produced similar results. The Denver, Colorado area served as the study area for the analysis of land cover classification performance in an urban environment. In the Denver analysis, MSS provided higher classification accuracy than TMS for the residential category. This is attributed to the spatial complexity and spectral heterogenity of the residential cagegory at higher spatial resolutions. The present analysis techniques do not adequately utilize this additional information (see next paragraph). TMS produced higher classification accuracies for the more homogenous categories such as commercial/industrial, rangeland, and irrigated pasture. This is attributed primarily to the new spectral information provided by Thematic Mapper's additional bands.

In another research task, an analysis is being conducted into the specific effects upon land cover classification accuracy with both per-pixel and contextual classifiers by factors such as spatial resolution and radiometric sensitivity. To improve classification performance when using high resolution data, a contextual classification program has been developed by GSFC personnel. The program is being implemented and tested in the investigation as a potential means to overcome the problems in classification presented by spatially complex and spectrally heterogeneous land cover types such as those evident with the residential category.

In the other major research task conducted during FY 1982, the utility of low resolution AVHRR data was evaluated for renewable resource applications. Studies were conducted for a areas in Sainai, the Senegalese Sahel, Lake Chad Basin, the Lake Turkana area, Baluchistan, Thar desert, and the Amazon Basin. The AVHRR study has shown that useful satellite monitoring of moderately sized areas (greater than 1,000,000 sq. km) is feasible with limited resources.

The potential for using AVHRR imagery to estimate land biomass was demonstrated in the Sengalese Sahel study. From nine cloud-free AVHRR images taken during a three month period during the 1981 rainy season, normalized index values indicating the variation in green leaf density from scene to scene were derived with data from the 0.55-0.68 and 0.725-1.10 um bands. Progressive changes in these normalized values were found to be closely associated with the occurrence of precipitation in the study area. A cumulative index generated from six of the images spanning an eight week period quantitatively agreed with field sampling of land biomass.

The normalized difference spectral response for various biomass levels and atmospheric aerosol loadings was also simulated for NOAA-6 and NOAA-7 as a function of scan angle. Figure 4 shows the results based on NOAA-7 at winter solstice. NOAA-7 data were shown to be of better quality than NOAA-6 because of the higher sun angle associated with the later equatorial crossing time. Atmospheric path radiance is minimized for high illumination angles and viewing between a nadir and forward scanning geometry.

AVHRR data collected between May and October, 1982 over the Nile River Valley and Nile Delta in Egypt were used to study the growth dynamics of vegetation in the region. An analysis of the successive images showed definite trends in vegetation response with respect to time which correlated with known growing conditions and agricultural practices. In a study in Rondonia, Brazil, a 100 × 400 km area subjected to massive deforestation was identified using NOAA-7 AVHRR data and verified through field investigation. The results obtained from these studies indicate that AVHRR data can be useful for monitoring large areas of vegetation.

Other tasks included in the scope of this research effort address topics fundamental to a comprehensive understanding of remote sensing process. In one of these tasks, scene synthesis techniques are being developed for TM, MSS and MLA in an attempt to definite the relationships between ground cover characteristics and the geometric distribution of scene radiance. Another task conducted in FY 1982 and continuing into FY 1983 is developing models to investigate and characterize the effects of the atmosphere on TM and MSS measurements. The final element of this research is investigating techniques for the remote use of Laser Induced Fluorescence (LIF) on plant pigments for use in the detection of water stress, nutritional stress, and plant speciation.

COMPARISON OF THEMATIC MAPPER SIMULATOR DATA BEFORE AND AFTER THE RADIOMETRIC CORRECTION

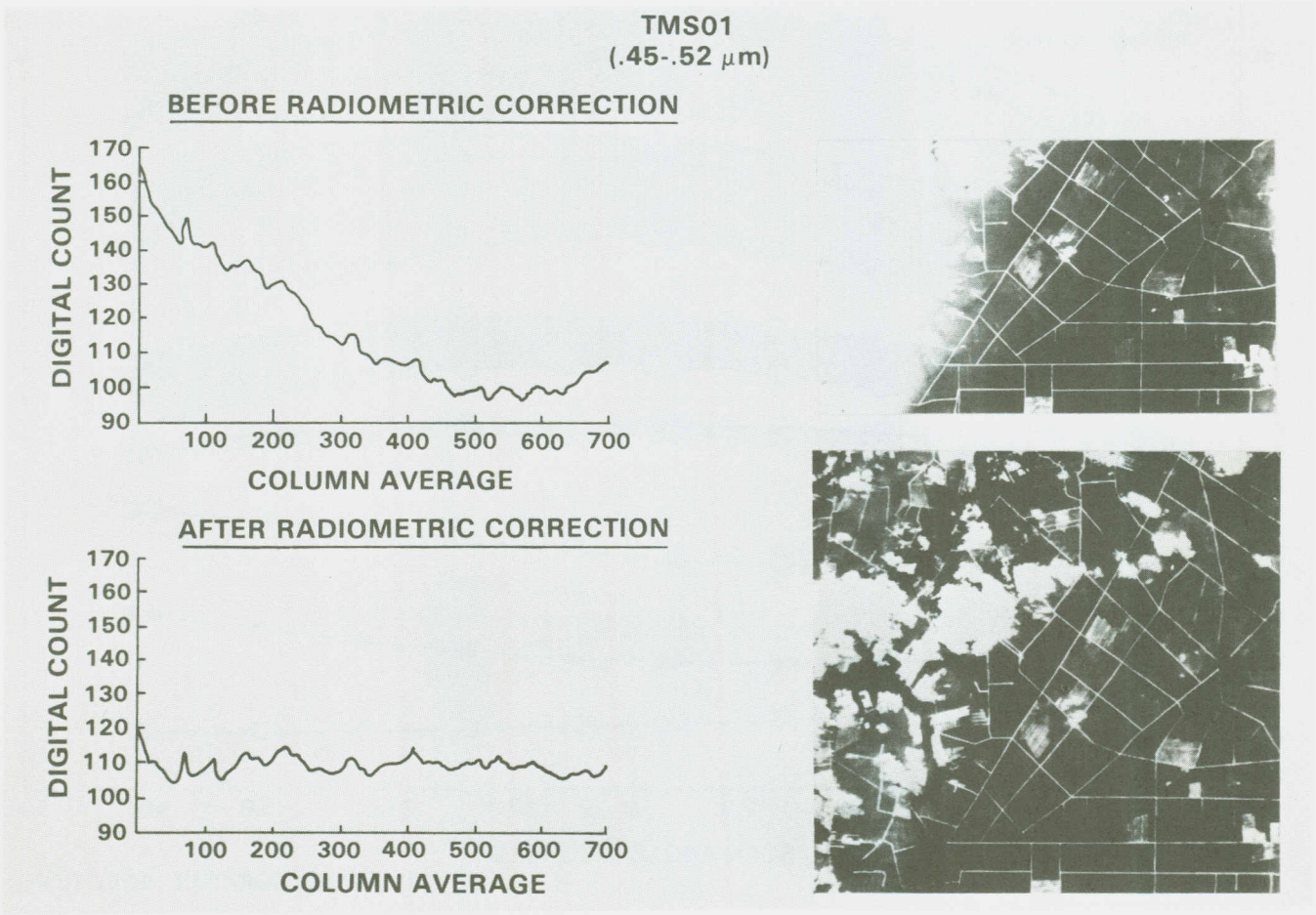


FIGURE 3

NOAA-7 AVHRR SIMULATION, WINTER SOLSTICE, LATITUDE = 30°

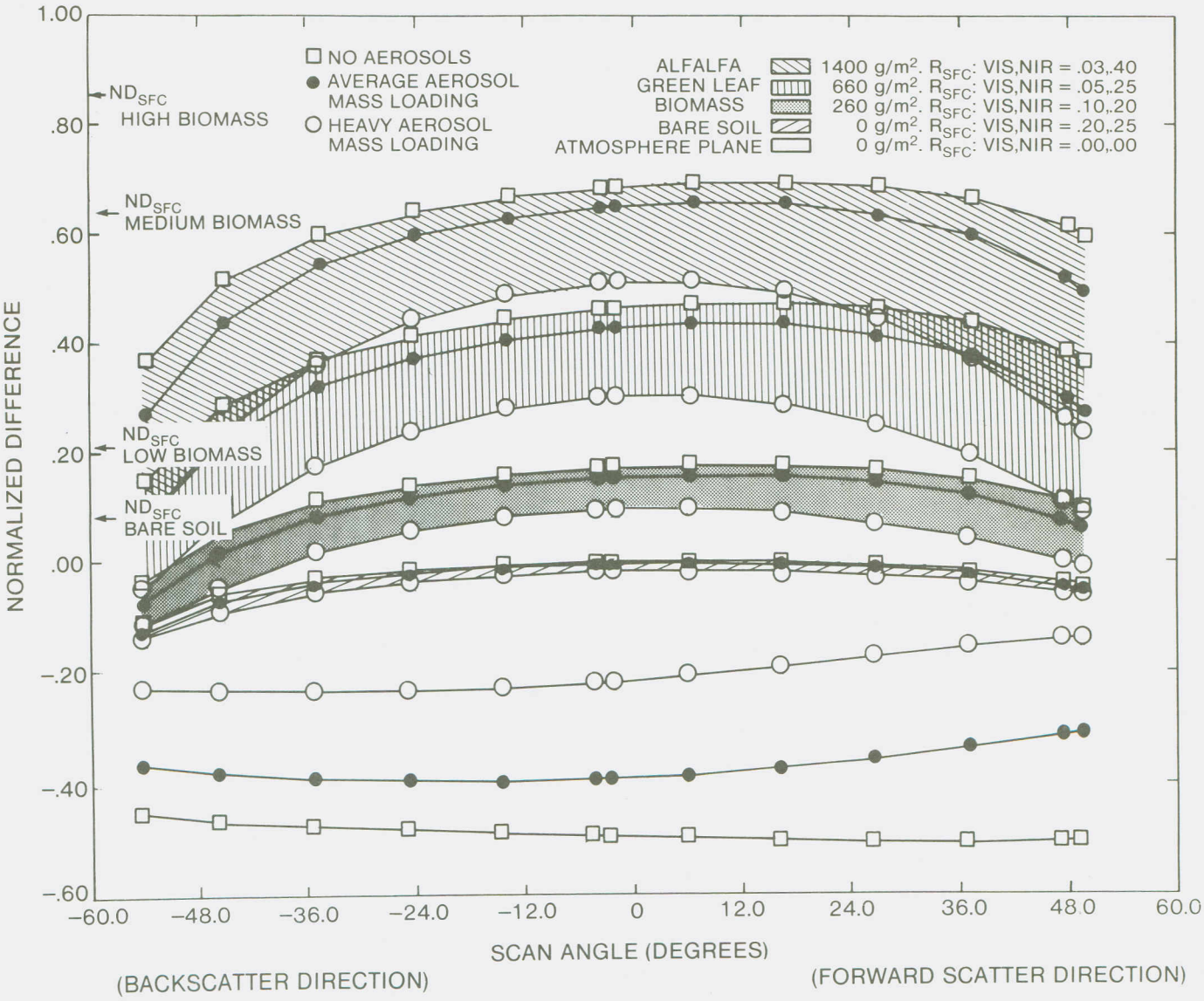


FIGURE 4

Land Resources Applied Research (Joyce/NSTL)

Research is being conducted at NASA-National Space Technology Laboratories to develop new remote sensing techniques for land resources applications. During FY 1982 the research has been conducted for three major tasks, each task investigating new remote sensing approaches to a different land resource topic: the degradation of semi-arid rangelands; the discrimination of surface mines; and soil type delineation.

The objective of the first task is to develop remote sensing techniques useful in assessing, monitoring, and predicting the degradation of semi-arid rangelands. During FY 1982, unsupervised spectral signature development and maximum-liklihood classification was performed on both Landsat MSS data and Thematic Mapper Simulator data acquired for the Jornada test site in southern New Mexico. A comparison of classification performance showed that classification accuracy was up to 20 percent greater for TMS data than for MSS data. Analysis of TMS data further indicated a potential for monitoring green biomass in arid regions using thermal band information. Efforts have also been initiated to develop techniques which use remotely sensed data in a geographic information format to assess wind erosion hazard.

Band ratioing and principle component analysis techniques developed during FY 1981 for the detection of surface mine features were applied in FY 1982 to TMS data collected over an eastern Kentucky coal field study area. The technique produces a thematic "mask" of surface mines as small heterogeneous features by using values calculated as a ratio of the first and second principle components of the data. Spectral signatures were developed using the ELAS Within Class Cluster algorithm to which a miximum liklihood classifier was applied. In comparison with MSS results, TMS data provided superior performance in the discrimination of surface mines and discrete spatial entities.

Reflectance measurements were taken for four soil samples taken from the southeastern United States using a Barnes multiband radiometer, covering the six Thematic Mapper spectral bands in addition to a near IR band from 1.15 to 1.30 um. The reflectance properties of these soils varies according to their characteristic iron oxide and organic matter content. The red band (0.63 - 0.69 um) and middle IR band (2.08 - 2.35 um) were found to be most sensitive to these parameters and therefore may hold the most promise for delineation of these soils. Actual Thematic Mapper data will be analyzed when it becomes available.

Thematic Mapper Simulator Land Resource Studies in Western Ecozones (Wrigley/ARC)

During FY 1982, researchers at NASA-Ames Research Center began a variety of experiments designed to increase knowledge and understanding of the characteristics of Thematic Mapper data and to assess its utility in land resources studies. The experiments use Thematic Mapper Simulator data from test sites in California representing unique and important western ecozones. This research supports the development of effective and efficient TM data handling strategies that will allow the greatest benefit to be obtained from Thematic Mapper data in future land resource studies.

The increased number of spectral bands provided by the Thematic Mapper sensor produces for a given scene a quantity of data significantly larger than was produced by the MSS, creating new problems in digital processing. It is desirable to develop techniques for selection of the optimum set of TM bands to be used for a particular scene classification task in order to obtain the highest degree of accuracy and maximum processing efficiency. During the first year of this experiment, software has been developed for two parallel approaches to developing such a technique (Figure 5). One is designed to maximize the average inter-class separabilities, or distances, of classes upon analysis of a statistical data file describing the image data in each band. The second approach determines the maximum probability of correct classification (PCC) of classes for each band combination using a maximum likelihood classifier. The researchers conducting this experiment believe the distance and PCC methods may complement each other to arrive at the most reasonable solution to the band selection problem.

Five image processing systems used today to process Landsat MSS data are being examined for comparison of their capabilities to process Thematic Mapper Simulator data. The IDIMS, EDITOR, VICAR, and ELAS systems are being tested for performance in training field delineation, clustering, spatial (texture, edge) analysis, classification, and statistics manipulation. Preliminary results have identified some difficulties and blockages in process flow for TM analysis, e.g. matrix of systems vs. image analysis functions.

Further research is planned to investigate and compare the classification accuracy between TM and MSS data using per-pixel digital classification techniques. For a test site in the San Jouquin Valley,

OPTIMUM BAND COMBINATION: TWO APPROACHES

OBJECTIVES: ***A) Provide method of selecting optimum bands on an Ad Hoc basis***
B) Minimize computation classification; maintain accuracy

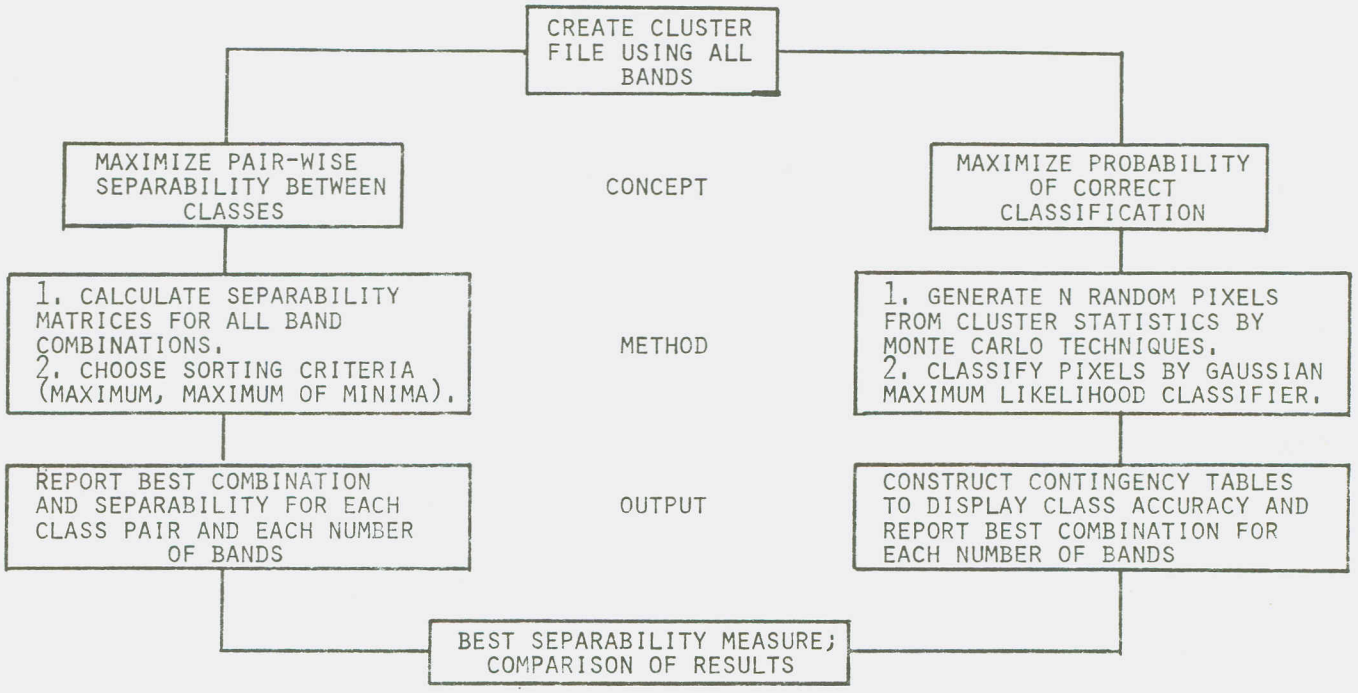


FIGURE 5

simulated Thematic Mapper data with concurrent MSS and simulated MSS data will be classified and accuracies compared.

The improved information content of TM data over MSS data is being investigated in a factorial experiment isolating the resolution, radiometry and spectral character parameters. TMS and MSS data sets are to be analyzed for a study area covering portions of Fresno and San Jouquin Counties.

A study of image texture as a means to incorporate spatial correlation into scene classification is also being planned. Algorithms will be developed and along with currently existing algorithms will be evaluated for their capability to detect within field variation or homogeneity, boundaries, and directionality.

In the inventory technique development segment of this investigation, the effectiveness of TM data alone and in combination with ancillary data is being evaluated for its effectiveness in the mapping and/or inventory of irrigated croplands and major crops in the West. Experiments are being conducted using San Joaquin Valley and Sacramento Valley test sites to evaluate the sensitivity of sample design parameters (correlation coefficients, stratification) to TM/TMS data. Results from this experiment will be integrated with other current TMS research.

Alaska Wetlands Delineation (Morrisey/ARC)

Techniques which utilize Landsat MSS data to distinguish wetlands from non-wetlands cover types in Alaska were developed and evaluated in a research effort which culminated in FY 1982. Researchers at NASA-Ames Research Center collaborated with personnel from the Alaska Department of Environmental Conservation and Department of Natural Resources, the Army Corps of Engineers, and the Soil Conservation Service to conduct this two-year experiment. Technical support was provided through the participation of the University of Alaska and the University of Washington.

An area within the Nenana Region of the Tenana River Basin in Alaska was selected as the test project for the experiment. An analysis of Landsat MSS data was conducted with the aid of color infrared photography to produce a vegetation map covering the test site area. Ancillary data sets containing soils and geology information were digitized and spatially registered to the Landsat-derived vegetation map. Approaches were taken to derive wetlands/non-wetlands maps through analysis based upon the geology data alone, the soils data alone, the Landsat-derived vegetation map stratefied by physigraphic region, combined Landsat/geology and combined Landsat/soils data sets. A reference data set was concurrently established to enable an assessment of the reliability of each approach by registering, overlaying and comparing each resulting wetlands/non-wetlands map with the reference map.

In the combined Landsat/ancillary data approaches, each vegetative cover type was compared to the reference data set for determination of wetlands/non-wetlands status. When 75 percent or more of a given vegetation cover correspond to wetlands (or non-wetlands) as assigned in the reference data set, that cover type was designated wetlands (or non-wetlands). The reliability assessment showed reliability for the five approaches varied from 75.4 percent to 97 percent. Highest reliabilities were obtained with the combined Landsat/soils and Landsat/geology techniques.

Irrigated Lands Assessment for Water Management (Bauer/ARC)

A major Joint Research Project conducted by NASA-Ames Research Center, University of California, and the California Department of Water Resources was completed during FY 1982. The project consisted of individual research tasks designed to research, develop and test both manual and digital approaches using Landsat MSS visual and digital image products to: 1) map and estimate the areal extent of irrigated land in California, and 2) identify and map specific agricultural crop types. Contributions to Landsat application technology resulting from this JRP include new sampling as well as new procedures for full frame classifications at reasonable cost, efficient photo-processing methods, and full-frame image registration procedures.

The first of the four tasks in the project concentrated on manual analysis techniques to complement current DWR mapping programs. A low-cost, accurate system of photointerpretation utilizing Landsat MSS images and supportive ground truth was developed capable of producing statewide maps of irrigated lands at least once during a given year, a significant improvement over existing DWR inventory capabilities. The stratified sampling technique developed was determined to produce the most reliable area estimates in the scheme tested. Precise estimation of irrigated land area by county, basin and statewide is now possible by linking the

Landsat-produced maps with sample units from ground survey maps with a regression equation estimator. These timely, cost-effective techniques have proven Landsat a viable tool to inventory and map irrigated lands in a semi-arid environment.

Techniques for classification of irrigated land categories using computer-based methods were developed in the second task for possible replacement of the manual classification employed in the first task, where cost effective. A full frame image registration procedure was developed to support the automated procedure. A Landsat MSS band 7/band 5 ratio technique was proved to be an effective approach to classifying irrigated lands in the major agricultural areas. Classification accuracy was found to improve when the scene was stratified according to land use. The acerage estimates produced from the regression showed less than 8 percent error at the 95 percent confidence level. These digital techniques are ready for operational implementation.

The third task was directed toward development of manual image interpretation techniques for mapping of specific agricultural crop types. Based on expertise gained in the first task, cost-effective methods for image enlargement and overlaying were developed. It was established that for limited areas and specialized needs these manual image analysis techniques, with Landsat data collected on several key dates, should provide an effective method for mapping and estimating the area of crop types.

The final task developed digital techniques for estimating and mapping crop types at a reasonable cost over full Landsat image frames. Accomplishments attained from this element of the project include the development of a relatively low cost procedure for image stratification to enhance classification accuracies and the development of a preliminary sample segment allocation scheme for the simultaneous estimation of several crop types with varying accuracy goals. It was determined that while the present technique utilizing an automated approach and MSS data does not perform well for rare or small-area crops, most crops which cover at least 10 percent of an agricultural area can be estimated for area and mapped with a high degree of accuracy using the techniques developed in the project.

Monitoring Insect Defoliation of Hardwood Forests Using Landsat (Nelson/GSFC)

Also completed during FY 1982 was a Joint Research Project demonstrating the technical feasibility of using Landsat data to conduct automated annual assessments of the extent and severity of insect defoliation of hardwood forests. This was a three year project involving NASA/Goddard Space Flight Center and the Pennsylvania Bureau of Forestry/Division of Forest Pest Management.

Each year, Gypsy Moth larvae defoliate large tracts of hardwood forest in the Northeast. Over the years, state and federal agencies have spent millions of dollars developing integrated pest management programs in order to prevent further spreading of the insect. The success of these programs are heavily dependent upon accurate, timely and efficient methods of detecting and mapping incipient damage to the forest from insects defoliation. This project focused on the development of techniques to provide needed information using Landsat data and the establishment of an operational map-registered, state-wide Landsat digital information system to aid in assessing, monitoring and managing the defoliation problem. The project focused on Pennsylvania, a state extremely affected by gypsy moth infestation, for development and application of the system.

The capability to detect and estimate the areal extent of insect damage using Landsat MSS data was demonstrated during the first year of the project in FY 1979. NASA-GSFC personnel have developed a straightforward approach to digitally classify various levels of defoliation using Landsat MSS data. Corresponding classified geo-referenced images are compared, one of which is of a scene coverage date containing defoliated forest cover, the other serving as a reference image containing healthy forest for which non-forest areas have been masked out. Multiplication of corresponding pixels within the two images produces an 'defoliated forest' image to which a band ratioing technique (MSS band 7/MSS band 5) is applied on each pixel. An 'assessment image' is thus produced for which low ratio values indicate heavy defoliation, high ratio values indicate healthy forest, and zeroes indicate non forest land. Comparison of a Landsat-derived defoliation map and photointerpreted ground reference information has shown that Landsat cannot distinguish moderately defoliated canopy (30-60 percent canopy removed) from healthy forest (0-30 percent canopy removed) with any reliability. However, overall accuracies on the order of 77 percent are obtained when heavy defoliation (60-100 percent canopy removed) is distinguished from a moderate defoliation-healthy forest class.

A data base was created at Pennsylvania State University providing the capability to retrieve, digitally process and store the image data to support an ongoing assessment and monitoring program at the University. A 'front end' management system for the data base was designed and installed on the data base to enable personnel without extensive experience in image processing to use the system effectively.

A workshop was held in December 1982, at the Gypsy Moth Review Board meeting in Harrisburg, Pennsylvania, to publicize the existence and demonstrate the use of the data base and accompanying assessment procedures generated from this Joint Research Project. It is anticipated that the higher spatial resolution and additional spectral information provided by the Thematic Mapper sensor onboard Landsat 4 will improve the capability to discriminate and assess forest defoliation and serve to enhance the effectiveness of the data base.

Agriculture Land Cover Mapping with the Aid of Digital Soil Survey Data (Stoner/NSTL)

Existing remote sensing technology was utilized and new techniques developed to test the potential of using Landsat MSS data as a means of providing digital agricultural land cover maps suitable for inclusion in a geo-based information system. Within the information system framework, Landsat-derived landcover maps and digital soil maps were used to provide specific information useful to cooperative managers, such as the productive capacity of land areas, fertilizer needs, irrigation suitability, and trafficability of soil for planting.

This project was conducted on three study areas within separate agricultural cooperative trade areas operated by MFA, Inc. in Missouri representing a variety of land resources and farming intensities. The project tested two approaches to the production of land cover maps through the classification of Landsat data both with and without the use of soil strata. Both classification methods used multiple-date Landsat data sets in an effort to maximize discrimination of crop types. Many of the crops have dissimilar crop calendar growth patterns which yield differential radiometric responses most dramatic during particular time periods in the growing season, especially in Landsat MSS spectral bands 5 and 7. Scene coverage dates were chosen which maximized these differences, based upon phenologies for individual crops. An unsupervised statistical "clustering" algorithm was applied in both classification procedures, only the method of application differed between them.

The first approach used only the Landsat data in the classification process. The classifier algorithm was applied to the entire data set for each study area. In this approach, spectral overlap of crop features presented problems in the discrimination of such crops as corn and soybeans. This problem was related not so much to similar spectral characteristics in these crop types as to the confounding effects of differing crop managing practices and the effects of soil background. The second approach used soil information in the classification process as another channel of data in addition to the Landsat MSS data.

For this approach, soil types maps with as many as 37 different soil types were aggregated into two or three stratified units for each study area. The same multidate Landsat date sets were used in the stratified soil approach, however, the classifier algorithm was applied separately within each soil strata.

Results of the approach using layered soil strata showed significant improvement over the conventional multidate approach in corn, pasture, and wheat identification. Further improvements in classification accuracy are now believed possible if soil types are aggregated into a greater number of strata, approximately 8-10, thus preserving more of the soil information related to the particular spectral behavior of a crop. This approach is considered more appropriate for the capabilities of the Thematic Mapper and will be investigated further as TM data becomes available.

Digital Mapping of Irrigated Cropland (Jones/ARC)

Digital Mapping of Irrigated Croplands is a NASA-funded Applied Research Project conducted jointly by NASA-Ames Research Center and the National Mapping Division and Water Resources Division of USGS. Remote sensing techniques which utilize Landsat multispectral image data are being developed and tested to detect and map irrigated croplands located over aquifers in the western United States. The digital maps produced by these techniques are being used to help meet in a timely and cost-effective manner the informational needs of the Regional Aquifer Systems Analysis Program (RASA). RASA is organized to assess the extent and significance of the currently widespread and apparently increasing phenomenon of a decline in water table levels of the large aquifers in the High Plains, one of the most productive and economically important agricultural regions in the world.

During FY 1982, the feasibility of using Landsat digital data to map irrigated cropland has been shown. Three different approaches were taken to map irrigated lands in two Colorado counties, using classified ground source materials, manual interpretation and computer classification of Landsat imagery. Comparisons showed less than two percent difference in the mapped irrigated cropland acerage using Landsat imagery. The digital Landsat data was also found to be quite compatible with the needs of the USGS model to be used in the prediction of effects resulting from continued water extraction.

Other accomplishments for FY 1982 include the generation of maps covering all land cover types for the entire High Plains Aquifers using 1978 Landsat MSS data. Irrigated croplands in particular have been mapped using multidate Landsat scene coverage collected during 1980 and with the aid of crop phenology information. New image processing software was developed and utilized to apply a 7/5 band ratio technique to the data and for subsequent classification and interpretation procedures. The thematically classified images which have been produced were aggregated by one-minute grid cells with each cell assigned a number indicating the percentage occupied by irrigated agriculture. These data are entered into a computer model of the ground water system to be converted into water pumpage estimates.

The investigation is continuing into the development of methods for finer water use estimates involving the mapping of specific agricultural crop type groups. Ground data has been acquired and 1980 multidate Landsat data has been prepared for analysis, and the testing of several data analysis techniques is in progress. Investigations are also being conducted into the potential for measuring recharge back into the aquifer and the utility of coarse but quickly available Advanced Very High Resolution Radiometer (AVHRR) image data for scene coverage of the region. Thematic Mapper data will be employed and evaluated in the context of this project during FY 1983.

Wetlands Productive Capacity Modeling (Butera/NSTL)

In FY 1982, researchers from the Earth Resources Laboratory at NASA-National Space Technology Laboratories and the Southeast Fisheries Center of the NOAA National Marine Fisheries Service began a four-year cooperative endeavor to research and develop Thematic Mapper technology useful in the determination of the value of wetlands to living marine resources.

An integral part of this project is a model developed by ERL which identifies specific variable influencing the "Productive Capacity" of a wetlands, i.e. the potential of a wetlands ecosystem to contribute detrital food by export to the estuary food chain(figure 6.) The model combines ancillary data with Landsat MSS data to quantify wetland biomass as the source of nutrients, and to quantify distance-to-water, shoreline density and water body type as agents in the potential export of these nutrients to estuarine waters. The model is now being refined and techniques are being developed for its use in conjunction with Thematic Mapper data, initially through the testing of Thematic Mapper Simulator data. The Lake Calcasieu Basin in Louisiana is the study area for the project. Information from the TM-based model will provide input to a model developed by SEFC to determine the quantitative relationship between detritus availability and fisheries production, ultimately assigning an economic value to wetlands as an aid in wetland management decisions.

Remote Sensing Application for Facility Site Selection and Waste Disposal Impact Assessment (Mouat/ARC)

A four-year Joint Research Project was begun in FY 1982 to assess the contribution of Thematic Mapper data to the acquisition of information supportive of major facility site selection and waste disposal impact analysis. Investigators at NASA-Ames Research Center are collaborating with personnel from Woodward-Clyde Consultants to conduct this project.

The improved waveband configuration and spatial resolution of the Thematic Mapper sensor combined with digital analysis techniques are believed capable of providing a cost-effective and timely alternative to current data collection and analysis methods. The initial phase of this investigation has been devoted to the testing of data collected by a Thematic Mapper Simulator (TMS) flown aboard a NASA U-2 high altitude aircraft. Data was collected over a test site at the Carquinez Straits near northern San Francisco Bay for the waste disposal impact studies, and over an area in Southeast Utah for the facility site selection portion of the project. The chart in figure 7 depicts the systematic design of the approach being taken in the TM-based site selection experiment on the Utah test site. Actual Thematic Mapper data will be analyzed in both experiments as the required scene coverages become available. Image screening techniques are being developed to aid in the site selection process based on specific hydrologic, ecological, geological and cultural factors derived

WETLANDS PRODUCTIVE CAPACITY MODEL DIAGRAM

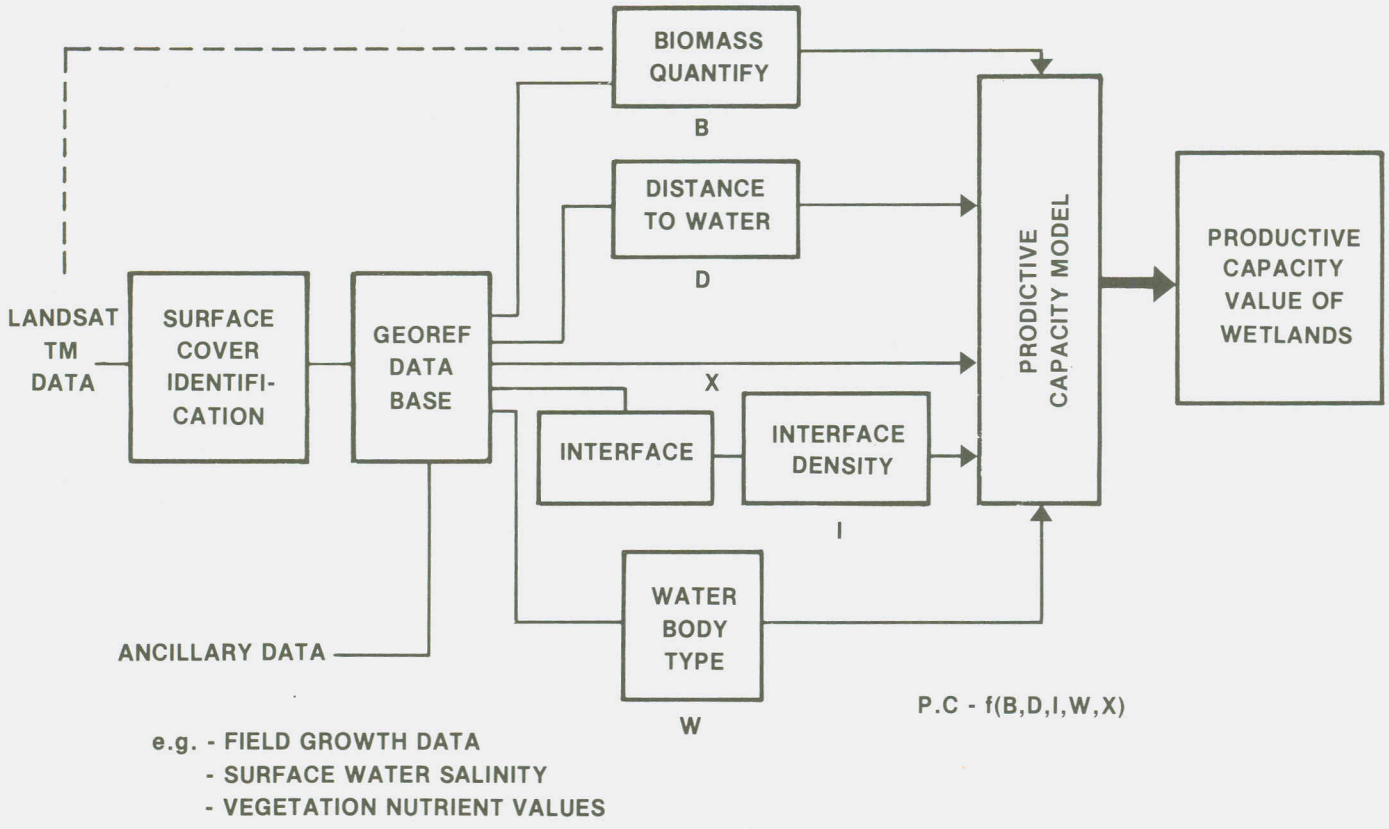


FIGURE 6

REMOTE SENSING APPLICATION FOR FACILITY SITE SELECTION

UTAH TEST SITE

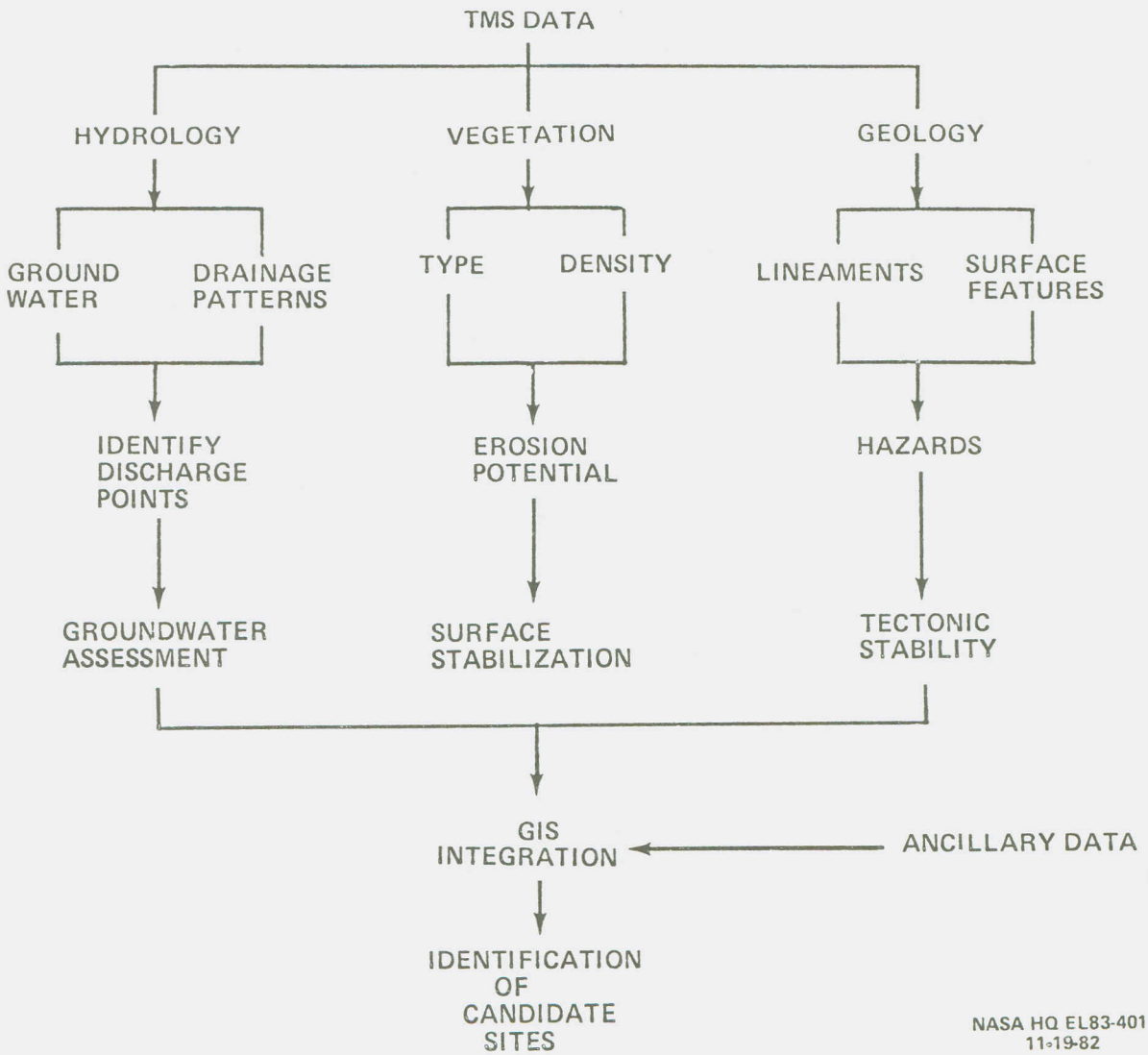


FIGURE 7

from analysis of TMS and TM data. Other digital analytic techniques to assess water quality for waste disposal impact assessment are being developed and evaluated. Later phases of the project are intended to integrate derived data with ancillary data in a geo-based information system format for implementation, testing and evaluation of the newly developed TM-based techniques.

Crop Mensuration and Mapping (Brannon/NSTL)

Investigators at NASA-National Space Technology Laboratories are working with personal at International Harvester in a coordinated effort to develop, test, and evaluate data analysis techniques for extracting useful agricultural information from Thematic Mapper data. This joint Research Project was begun in FY 1982 and planned for completion in 1985.

The project is designed to conduct research which addresses the agricultural information needs of the farm implement manufacturing and service industry, and simultaneously provides a framework for a systematic examination of the characteristics and information content of Thematic Mapper data. The major elements of the approach being taken for this investigation are summerized in figure 8. Technical objectives of the project include a quantification of the improvement of TM performance over MSS performance in providing crop-related information which may be attributed to the developed techniques and the improved spatial and spectral capabilities of the Thematic Mapper. The capability of TM data to yield first-order agricultural information such as crop-type, land management practice and land use conversions will be tested.

Thematic Mapper and Thematic Mapper Simulator data has been collected over a study area in Poinsett County, Arkansas and its performance is being evaluated in comparison with MSS performance in its potential for delineating agricultural land covers within the study area. Preliminary results have been obtained from a classification of the Poinsett County study area using a Landsat MSS data set consisting of data collected on three dates in 1981, and a classification performed with a single date of TM data (August 22, 1982). An unsupervised spectral signature development technique was applied in both instances. Spectral signatures were identified as belonging to one of five land cover categories: soybeans, rice, fallow/bare soil, hardwood, or water. Assessment of the classification accuracies resulting from each attempt indicate that TM data performed significantly better than MSS in discriminating the fallow and water classes (land covers typically small in area within the region being studied) attributed to the finer spatial resolution of the Thematic Mapper. MSS and TM performed equally well in the soybeans, rice, and hardwood categories. In this classification, the overall accuracy for the single date of TM data was 97.06 percent correct, significantly greater than the 80.91 percent value obtained with MSS using multi-date data.

Crop Condition Assessment and Monitoring (Irish/NSTL)

Analysis techniques to extract agricultural information from Landsat 4 Thematic Mapper data are being developed and tested by researchers at the Earth Resources Laboratory of the NASA-National Space Technology Laboratories and the Monsanto Agricultural Products Company.

The first phase of this four-year Joint Research Project was conducted during FY 1982. The systematic structure of the research is shown in figure 9. Agriculture study areas were selected at Gentry County, Missouri and Poinsett County, Arkansas (a test site held in common with the Crop Mensuration and Mapping JRP). Thematic Mapper Simulator data was collected in July. Ground truth observations were made during the month of August to support TMS data analysis procedures. Efforts to develop techniques for crop-type discrimination and determination of crop or field conditions using TMS data are now being emphasized and will continue through FY1983 when the emphasis will include analysis of actual TM data.

TMS data and supporting ground truth that was collected during the summer of 1982 were used to perform a crop discrimination classification and to investigate the effects of weed infestation on the spectral signature of soybeans.

The crop discrimination classification divided the area into 8 classes of land use, 6 of which were agricultural types. Overall accuracy of the classification was 75.8%. This figure is only slightly less than the 79.2% accuracy obtained by Stoner (1982) for the same area in Gentry County using a 3 scene, multi-temporal MSS data set. Confusion in the TMS classification for the crops of interest was between: corn and forest, alfalfa and soybeans, red clover and soybeans, and pasture and soybeans. A multi-temporal data set would eliminate most of such confusion from the data. The TMS classification, however, produced better separation between corn and soybeans than did Stoner's (1982) multi-temporal MSS data set.

CROP MENSURATION AND MAPPING TECHNIQUE DEVELOPMENT AND TEST RATIONALE

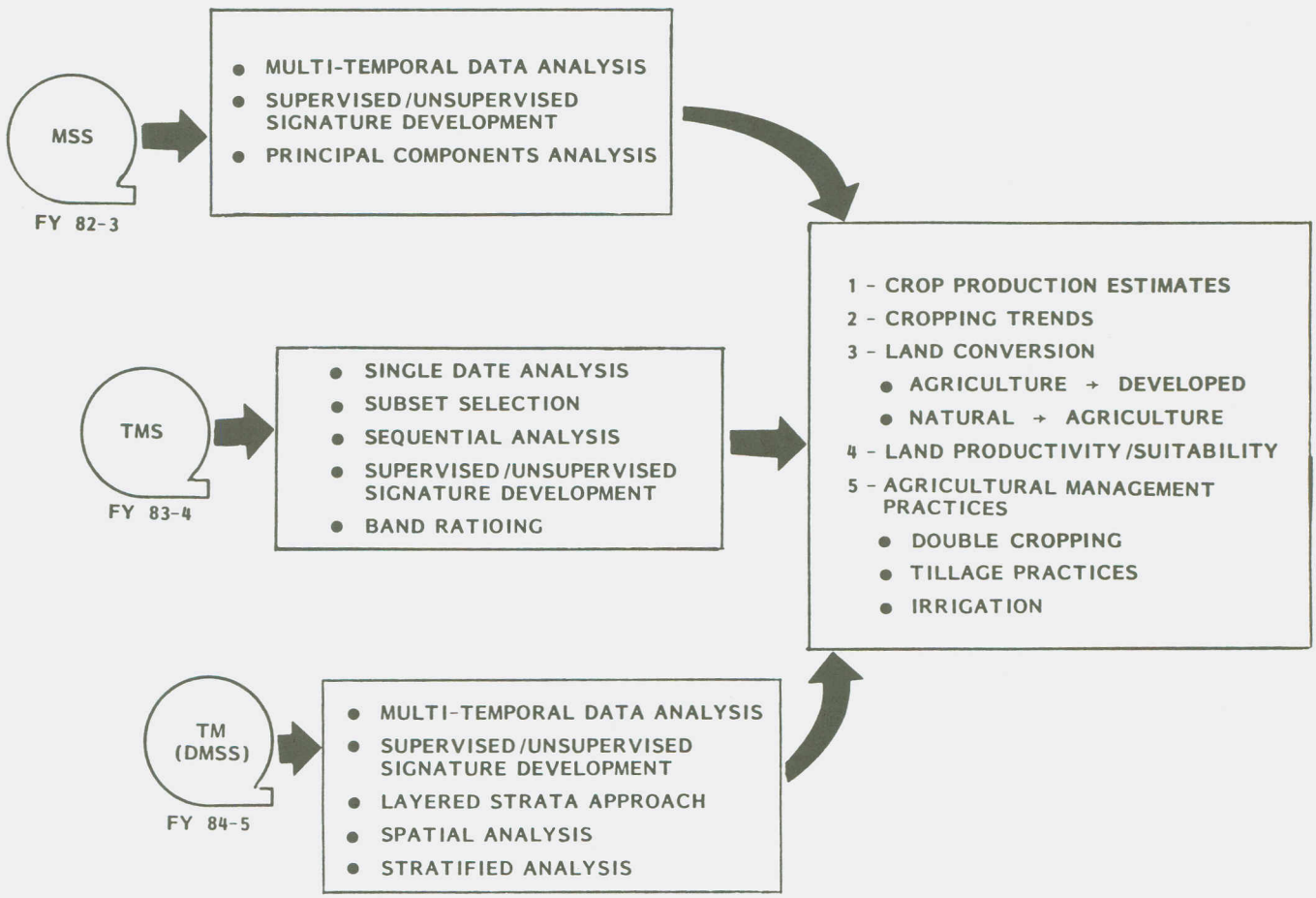


FIGURE 8

CROP CONDITION ASSESSMENT AND MONITORING

STRUCTURE OF TECHNIQUE DEVELOPMENT AND TESTING

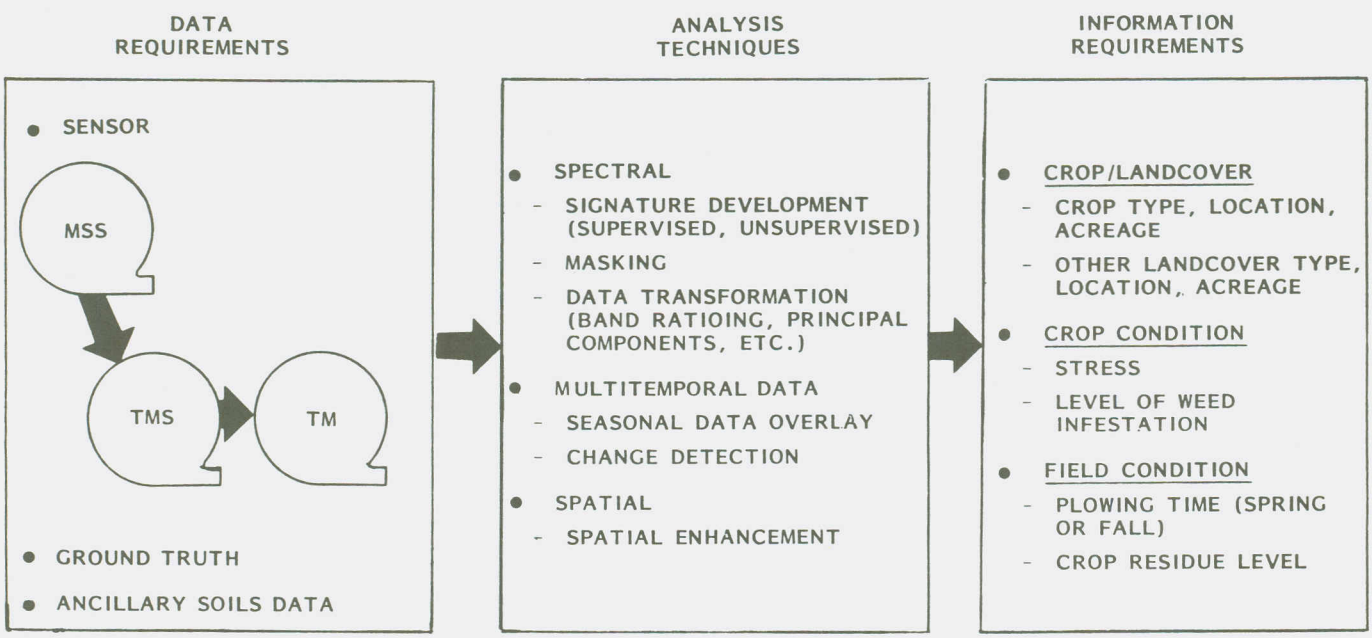


FIGURE 9

A TMS analysis of the effects of weed infestation on the spectral response of soybeans on upland soils in the Gentry County study area has yieled preliminary findings. The investigation has shown that detector response decreased with increasing weed infestation in all TMS bands except band-4. Band 4 has provided mixed results but severely infested fields generally appear to have an increased radiometric response, which may be attributed to increased biomass in the fields. The greatest differences in detector responses are between severely infested fields and those with no weed infestation. Because the degree of infestation exists in continuum, it is difficult to detect slight differences in weed infestation, and variations in crop density, soil background and topography may be contributing factors to variable responses from similar weed infestation levels.

Timber Resources Inventory and Management (Hill/NSTL)

The Joint Research Project in Timber Resources Inventory and Management is designed to conduct research for the development of new digital analysis methods appropriate for use with Thematic Mapper data to extract improved forest resource information (figure 10.) Investigators at the Earth Resources Laboratory of NASA-National Space Technology Laboratories are working with personnel from International Paper Company to conduct this four year research effort.

The capability of TM data to yield forest stand condition information useful to the forest products industry such as species composition, age, density and silviculture activities is being addressed in this research. During the first year of the project in FY 1982, forest related landcover information was derived using MSS data from Landsat 2 and 3 and existing analysis techniques. Thematic Mapper Simulator data was collected over a test site in Baldwin County, Alabama.

Analysis of the TMS data set has yielded preliminary fundings. Loblolly Pine (Pinus taeda) was separated from other southern yellow pines using TMS Band 2 (0.52 - 0.60 um). A low response in the Band 6 thermal channel (10.40 - 12.50 um) permitted detection of fire-damaged forest stands. Areas of regeneration pine were successfully separated from site-related areas based on regeneration pine's higher response in Band 3 and lower response in Band 6. However, the consistency of the thermal channel in data set dependent (time of day, thermal dynamics of the target, atmospheric moisture content, etc.). Duplicate results have not been demonstrated with similar data sets collected during the same season.

Early results tend to indicate a need for an additional data set or multitemporal approach to discriminate species composition for some timber stand types (e.g., Mature Longleaf Pine/Mixed Hardwood with a evergreen understory).

Electrical Utility Transmission Corridor Siting and Analysis (Bauer/ARC)

In a Joint Research project being conducted by NASA-Ames Research Center and the Pacific Gas and Electric Company the use of Thematic Mapper data is being examined in an application to the analysis and siting of electrical utility transmission corridors. NASA research objectives expected to be achieved through this project seek to quantify the improvement in remote sensing capabilities derived from the Thematic Mapper over those available with the MSS sensor on previous Landsat satellites.

The research is being conducted with special attention given to TM-based identification of crop-types (especially rice, tomatoes, orchards and vineyards), detection of image edge features which characterize the infrastructure of agricultural areas, identification of riparian vegetation and small water bodies, and delineation of urban or built-up areas. All of these factors have important implications in powerline corridor siting. A pilot study was conducted during FY 1982 for a test site covering two 7.5 minute quandrangles in Fresno County, California. A single date analysis of four Daedalus scanner channels (approximately equivalent to TM bands 1-4) was performed which indicated insufficient separability of orchards and vineyards. The incorporation of textural features is being examined to improve separability.

During the first year of the project in FY 1982, efforts have been devoted to project coordination and preliminary activities in the development of techniques for TM-based crop-type identification and agricultural infrastructure characterization. A pilot study was conducted for a test site in Fresno County, California which included a single date analysis of four Daedalus scanner channels (approximately equivalent to TM bands 1-4). Results indicated insufficient separability of orchards and vineyards. The incorporation of textural features is being investigated as an approach to improve the separability of these crop types. Before culmination of the project in 1985, research will focus on test sites

TIMBER RESOURCE INVENTORY AND MONITORING

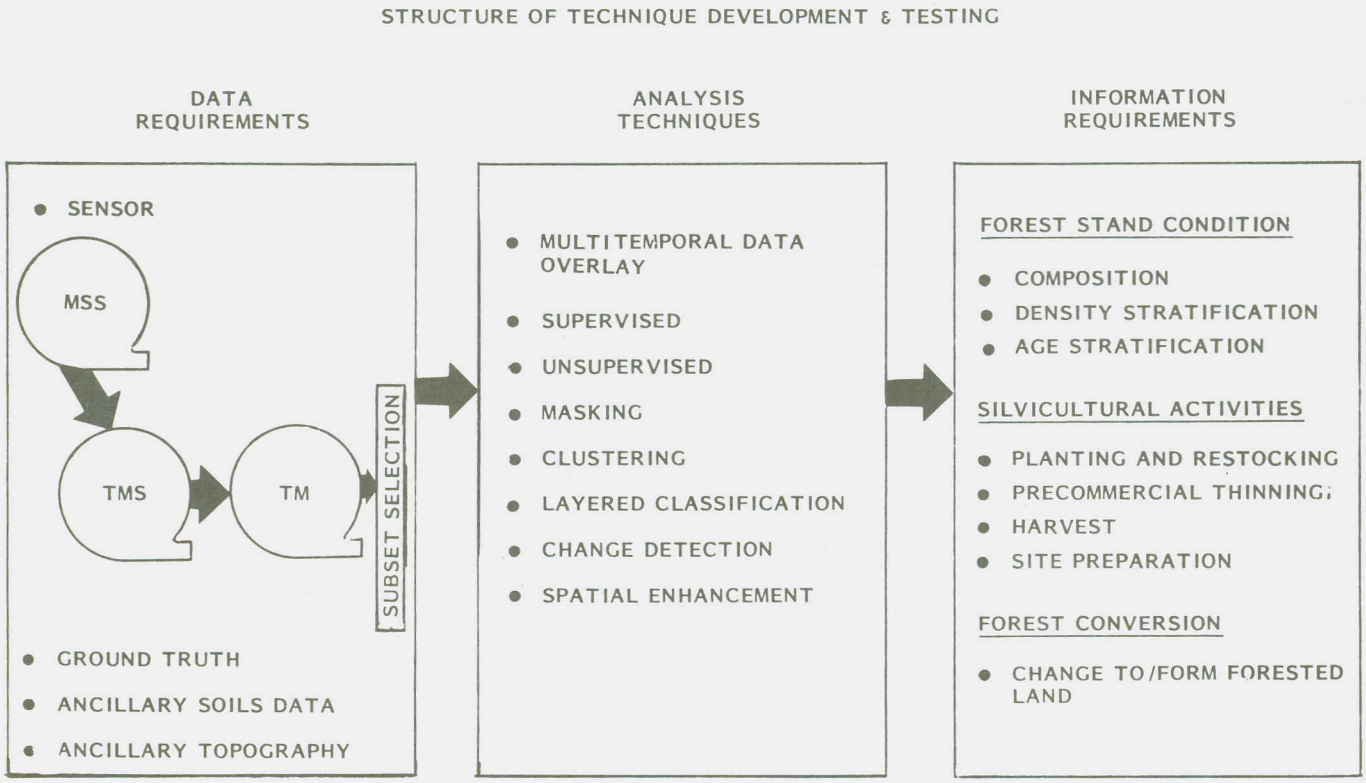


FIGURE 10

representative of other ecozones. Spectral and spatial analysis of TMS data will be conducted to develop and evaluate techniques for identification of riparian vegetation, small water bodies, and delineation of urban areas.

Hydrologic Feature Definition (Gervin/GSFC)

The Hydrologic Feature Definition Joint Research Project with the Army Corps of Engineers was initiated in FY 1982 to examine the capabilities and improvements as well as limitations offered by Landsat Thematic Mapper data in environmental and hydrological applications. In particular, it has been designed to examine the capabilities of Landsat Thematic Mapper (TM)/Thematic Mapper Simulator (TMS), and Landsat MSS data in a wide range of water resources and related environmental models in a geographic information system.

Activities during the first year have focused on the comparison of information obtained from TMS data with MSS and conventional data. Several study sites have been selected representing a variety of geographic environments and technical challenges. Analysis of two of these sites produced results during FY 1982. These are: Clinton River, a rural and forested watershed just north of Detroit, Michigan, which is experiencing industrial and residential growth and increasingly severe flooding; and the Upper Mississippi River System, a major navigation waterway network.

Landsat MSS data were classified to produce land cover information for a 100 km long segment of the Upper Mississippi River System study site, with an overall mapping accuracy of 78 percent. The least reliable categories were pasture/grass and residential, which are fairly uncommon in this area. Agriculture, forestry and water exhibited accuracies of 88, 75, and 74 percent correct, respectively, with much of the uncertainty associated with the location of boundaries between these predominant classes. The application of satellite-derived information to developing large-scale resource descriptions, monitoring vegetation community trends and locating disposal sites for dredged material was demonstrated. The limitations cited may be relieved by the improved spectral and spatial characteristics of data from the Thematic Mapper. For on 7.5 minute USGS topographic map, TMS data produced a considerably improved classification, with an overall mapping accuracy of 85 percent for a single date. However, the area examined was small and contained very little residential or wetland. Therefore, TMS results do indicate a promising improvement over multitemporal MSS imagery, but these results should not be regarded as conclusive.

Based on preliminary results for the Clinton River Basin, TMS data produced a more accurate and spatially contiguous classification than MSS. While the accuracy of the 4-band TMS data set was almost as good as the 7-band, the 3-band TMS data sets were only moderately better than the MSS. These results indicate that the increased spectral resolution contributes to the improved classification accuracy. The possibility of reducing the analysis burden associated with large TM volumes through effective band selection therefore appears promising. The combination of bands selected based on the transformed divergence technique provided one band in each of the major regions of the spectrum: visible (band 3), near IR (band 4), middle IR (band 5), and thermal IR (band 7). This selection agrees reasonably well with results obtained by other research scientists.

The implications of the improved classification accuracy of TMS data are important for the Corps' hydrological and economic modeling. In particular, the higher accuracies for the developed categories (residential and commercial) should improve the predictions of runoff in flood forecasting models and of flood damage for damage calculation models appreciably. Moreover, the promising results with band selection will permit users of the data to benefit from the improved classification capability without having to deal with the entire data volume.

2) MICROWAVE REGIME AND MULTISENSOR RESEARCH

Radar Sensor Calibration Experiment (Paris/JSC, Brown/JPL)

Between August 16 and 27, 1982, research teams from NASA-Johnson Space Center, NASA-Jet Propulsion Laboratory, the University of Kansas and Texas A&M University gathered at a test site near Lawrence, Kansas to conduct an experiment in the cross calibration of their respective ground platform-mounted microwave scatterometer sensor systems. The sensor systems involved are tabulated below:

NASA-JSC
- — Scatterometers at L, C, and Ku-Bands
- — 50′ crank-up tower on trailer

NASA-JPL
- — Scatterometer at 2 - 16 GHz
- — 23′ boom on rear of camper

University of Kansas
- — Scatterometers at 1 - 18 GHz (MAS)
- — 70′ boom on truck

Texas A&M University
- — Scatterometers at L, C, and X-Bands
- — 70′ boom on truck

During the course of the experiment, several different but common targets were used to measure relative sensor responses. These included a segment of a corn field, a grass plot, a water surface, and a rough surface turntable. In addition, each sensor was used to measure the microwave backscatter from point targets including a sphere, a corner reflector, and a Luneberg Lens (a multiple layer dielectric disk).

The collected data is being analyzed and compared for calibration. With fully calibrated instruments, researchers will be able to report backscatter measurements on an absolute scale. This will facilitate the comparison of data results from independent investigations and induce more meaningful and comprehensive conclusions from microwave remote sensing research.

Multispectral Remote Sensing of Saline Seeps (Krishen/JSC, Carver/New Mexico State University)

A Joint Research Project designed to conduct research into the potential for multispectral remote sensing to detect the presence of saline seeps was completed during FY 1982. The project was a coordinated effort of researchers representing NASA, the College of Engineering at New Mexico State University, and the Remote Sensing Institute at South Dakota State University.

A saline seep is an area of land rendered unproductive due to the surfacing of concentrated salt-laden groundwater. Widespread use of the alternate crop/fallow farming system is primarily responsible for the increase in seep formation in the Great Plains region of the United States during the past forty years. The problem continues to worsen resulting in tremendous losses in productivity for one of the world's major cereal producing regions. Remote sensors in the visible and infrared regions of the electromagnetic spectrum have been shown to be capable of identifying certain intermediate-to-mature, salt-crusted seeps. Saline seeps have been mapped using Landsat MSS data by the detection of salt crusts in the spring and by indicator plants such as kochia in fall. There is indication that remote sensors in the microwave region of the electromagnetic spectrum can be useful to identify saline seeps. The imaginary portion of the dielectric constant of a saline soil shows marked dependence on salinity resulting in increased microwave reflectance and decreased emissivity for increasing levels of soil salinity.

The objective of this project was to continue efforts conducted in 1978 in the development of multispectral remote sensing techniques for detection of existing and impending saline seeps and bring these techniques closer to feasibility. The conclusions drawn from this earlier study were based upon data obtained over a single test site on a single date when the soil moisture content was high. The research project most recently completed sought more meaningful results by collecting data on several dates over three test sites with varied ground conditions. Two of these test sites were located in Montana and one in South Dakota. Data was collected from NASA aircraft with a color infrared camera, a thermal infrared sensor, a microwave radiometer and a microwave scatterometer.

Although the feasibility of remote sensing was not definitely established in this experiment, several important conclusions were drawn which further the understanding of the capability of remote sensors in various spectral regions to detect saline seeps. It was determined that color infrared photography is a useful tool in the remote sensing of mature seeps but may be ineffective to detect areas of potential seeps. Thermal infrared imagery was found to be useful in discriminating wet and dry areas, but the thermal infrared approach does not appear to be a reliable method for detecting impending saline seeps. On the basis of the data collected in this experiment, the microwave radiometer (a passive remote sensing device) would appear to have the greatest promise for saline seep detection if a resolution of 100 meters or better can be obtained. The radiometer was found to be effective in detecting the surficially wet areas which include seeps but no definite relationship was established. Concentrated site-specific work is required to investigate the response in presence of subsurface moisture. The scatterometer (an active microwave remote sensing device) appeared to be ineffective in delineating wetness and subsequent saline seeps by itself. However, when used in complement to the radiometer the scatterometer is valuable in its capability to detect changes in surface roughness which may be associated with the wetness and/or subsurface water movement related to the occurrence of saline seeps.

Land Cover Multisensor Analysis (Bryant/JPL)

At NASA-Jet Propulsion Laboratory, techniques were developed for the creation of a multiple layer data set

containing image and cartographic data and investigations were conducted into the utility of data from Synthetic Aperture Radar (SAR) systems in the analysis of urban area scenes. This research was conducted in FY 1982 as part of a continuing multiple task research effort aimed at advancing the state-of-the-art in land resource analysis using a variety of remotely sensed data types.

The comprehensive data set was developed and established to provide registered disparate data to scientists engaged in land resources research. The data will provide exposure to the resolution and spectral data characteristics of the Thematic Mapper and sensors anticipated in the future. It will free scientists from the time-consuming tasks involving data acquisition, reprojection, and calibration, and permit them to concentrate their efforts on their own particular research concerns. Seven channels of Thematic Mapper Simulator data, a digital terrain model and land-use coordinate files all covering the Los Angeles area were spatially registered by reprojecting each data type to a UTM base map. The integrated data set has been transferred to EROS Data Center for distribution to interested researchers. The National Science Foundation is currently funding two research efforts which are utilizing the data set. The Geography Department at the University of South Carolina is conducting a study of the Burbank area, and at SUNY Albany the investigation is focusing on the morphology of backscatter at X, L, microwave bands with HH and HV polarization in selected regions of Los Angeles.

The purpose of a second major task was to investigate the utility of imaging radars, alone and in combination with other sensors, for mapping land cover in and near urban areas. SIR-A orbital radar imagery has been registered with the existing Los Angeles data set to permit a study of the orientation and geometry of surfaces affecting the scattering of microwave energy. Aircraft X and L-band radar imagery is also being prepared for analysis. This investigation has so far made it clear that, due to the sensitivity of the SAR sensor to scene geometry, the relationship between land-use, land cover, and scene geometry needs to be properly defined and understood. Empirical definition of this relationship with respect to the test scenes is being pursued.

Multisensor Technique Development (Zetka/NSTL)

Research was continued during FY 1982 at the Earth Resources Laboratory of NASA-National Space Technology Laboratories to determine the basic remote sensing parameters associated with land surface cover and to develop techniques to better discriminate and delineate those land cover forms. A number of different sensor types and analysis methods are being utilized in the research. The research tasks emphasized during FY 1982 focused on middle and thermal IR remote sensing data analysis for general land cover types as well as radar land cover analysis.

Thematic Mapper Simulator data was acquired in a field measurement mode to test the sensivity of the short wave infrared bands to crop stress. Exploratory studies were also designed and initiated using aircraft-acquired six band thermal infrared data from 8.5 - 12.5 micrometers.

In the radar land cover analysis segment of the study, research was completed on the integration of Landsat MSS image data with Synthetic Aperture Radar (SAR) image data for a study area in the western Kentucky Coal Region. Seasat L-Band and aircraft X-Band dual polarized SAR image data were examined, preprocessed and combined with the MSS data to form a seven band multisensor data set. Multisensor data analysis included separate evaluation of the 3-band SAR data and the 4-band MSS data and the combined 3-band SAR and Landsat bands 5 and 7. The information extraction technique consisted of digital count value comparison and spectral pattern recognition classification for the sar and MSS data. Analysis of classified data sets showed that the 3-band SAR data contain good-to-low discrimination accuracy for strip mine and other land cover classes. This was also true for the 4 band MSS data. However, the integrated 5 band SAR/MSS data showed significant improvement in classification accuracy. Overall classification accuracies achieved are given in figure 11. Also in FY 1982, Shuttle Image Radar (SIR-A) image data was acquired over an agriculture/forest oriented test site in Baldwin County, Alabama. This data is being prepared for processing and analysis in FY 1983.

Hydrologic Information Extraction Technique Development (Rango/GSFC)

Remote sensing technique developments as applied to specific hydrologic elements such as snowpack properties, soil hydraulic conductivity, and evapotranspiration were pursued at the Goddard Space Flight Center and supporting universities.

A Plan of Research for Snowpack Properties Remote Sensing was published (Hartline, June 1982) to guide

KY MULTISENSOR CLASSIFICATION ACCURACY

LAND COVER TYPES	SENSOR USED		
	LANDSAT MSS 4 BAND	SAR X AND L 3 BAND	SAR X AND L AND MSS BAND 5, 7
PASTURE	81.3	46.9	96.7
FOREST	88.0	92.3	92.5
RESIDENTIAL	59.4	10.0	79.0
SOYBEAN	59.4	89.5	90.9
CORN	32.5	88.3	99.0
WATER	97.4	99.9	99.9
STRIP MINE	47.7	64.9	77.4
OVERALL ACCURACY	64.2	48.2	81.1

FIGURE 11

future NASA research. The plan is the recommendation of the Snowpack Properties Working Group. The recommended approach is shown in Figure 12 and combines model development and verification through field experiments. The specific recommendations of the Working Group were that:

- Fundamental studies should be performed to determine how the dielectric and optical properties of snow vary with the depth, structure, and wetness of the pack. These controlled laboratory and field experiments should be coordinated closely with radiative transfer modeling, both to test predictions made by the models and to provide measurements the modelers need.
- Medium-to large-scale field experiments should be done to determine the amount and type of snow information that can be extracted by sensors and combinations of sensors of various frequencies.
- New models should be developed to accept the best mix of remotely sensed data and ground-based measurements to provide forecasts of resources, weather, or danger (collaborate with operational agencies and the private sector).
- Field techniques should be improved and standardized to provide better "ground-truth" for remote-sensing experiments and ultimately for calibrating the sensors operationally.
- Small-scale processes within the snowpack should be studied so that we understand better how snow crystals metamorphose, how the pack evolves, melts, stores liquid water, and releases it, and how these changes affect snow's electromagnetic signature.

Two examples of on-going research in the use of microwave techniques for determining snowpack properties include a study on the U.S. Great Plains and Ishikari Plain on the Island of Hokkaido in Japan using NIMBUS-7 Scanning Multichannel Microwave Radiometer (SMMR) data, and field experiments in Danville, Vermont and at Hokkaido University in Japan. This research was conducted in support of the U.S.-Japanese Joint Research Project on the remote sensing of snow. The 18 GHZ and 37 GHZ SMMR channels were found to be useful in correlating microwave brightness temperature and snow depth. Figure 13 shows the seasonal variation of snow depth, night air temperature and SMMR microwave brightness temperature (T) gradient. TB correlates with increasing snow depth but fluctuates during freeze thaw cycles. Ground truth was obtained from the National Weather Service Cooperative Stations and Bulletins. These results are being compared with similar experiments on Hokkaido. Comparative U.S.-Japanese snowpack properties microwave field measurements are shown in Figure 14. Note the non-uniformity of the Vermont data caused by ice layers in the snowpack. The Hokkaido measurements were made over a homogeneous snowpack and correspond to U.S. results which showed decreasing brightness temperature with increasing incidence angle.

Another element of the U.S.-Japanese joint research project concerns comparative studies in the development of remote sensing techniques for evapotranspiration estimation. Numerical boundary layer surface energy balance models are being tested with meterologic satellite temperature data to make estimates fo surface moisture availability which are useful for estimating evapotranspiration.

A combination of theoretical modeling and field experiments is being used to estimate the hydraulic character of soils. Sand, loam, and clay soils were used in microwave field measurements at the Beltsville Agricultural Research Center to compare drydown rates and correlate with theoretical predictions and ground truth.

PLAN OF RESEARCH FOR SNOWPACK PROPERTIES REMOTE SENSING (PRS)² APPROACH

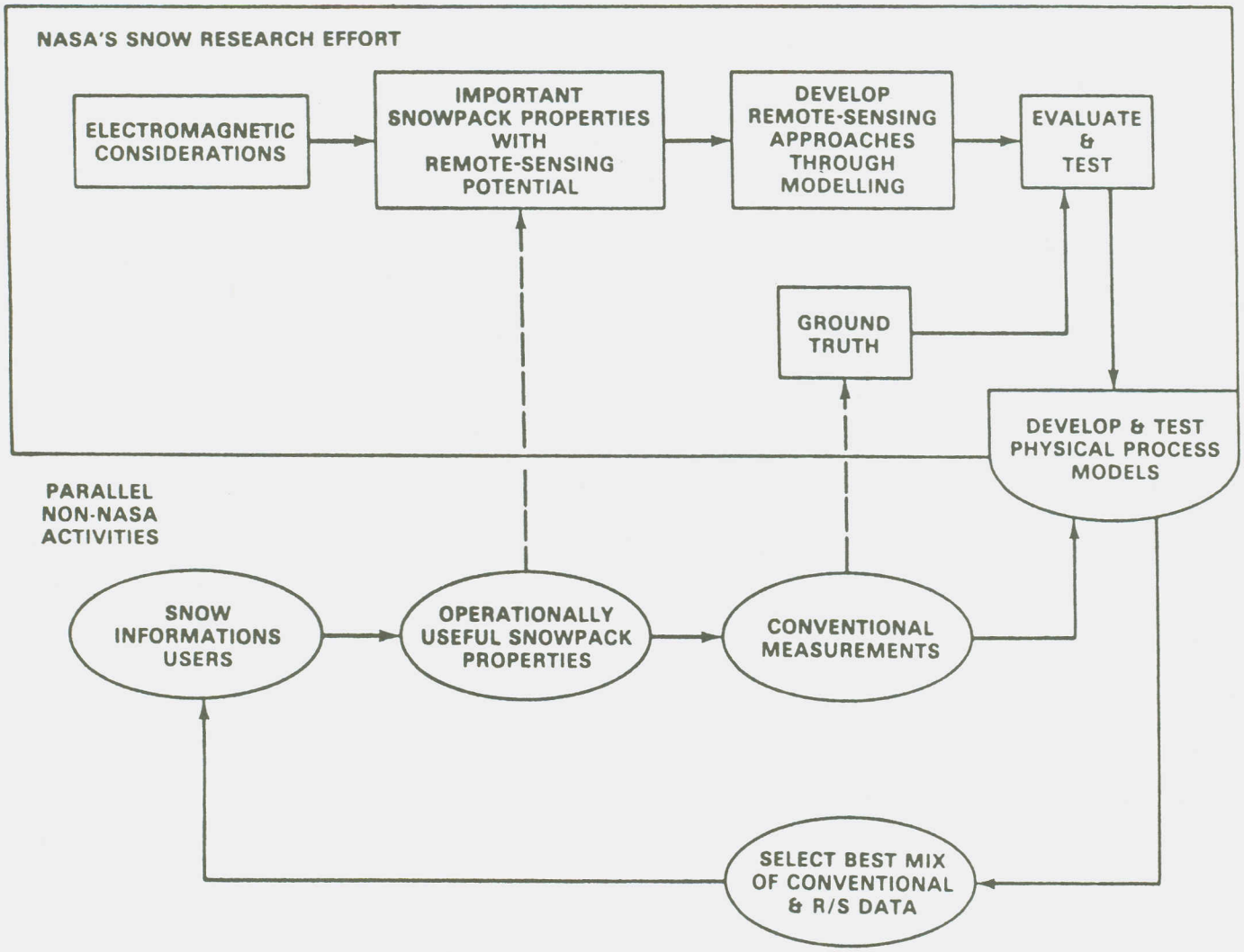


FIGURE 12

SEASONAL VARIATION OF SNOWPACK AND MICROWAVE EMISSION

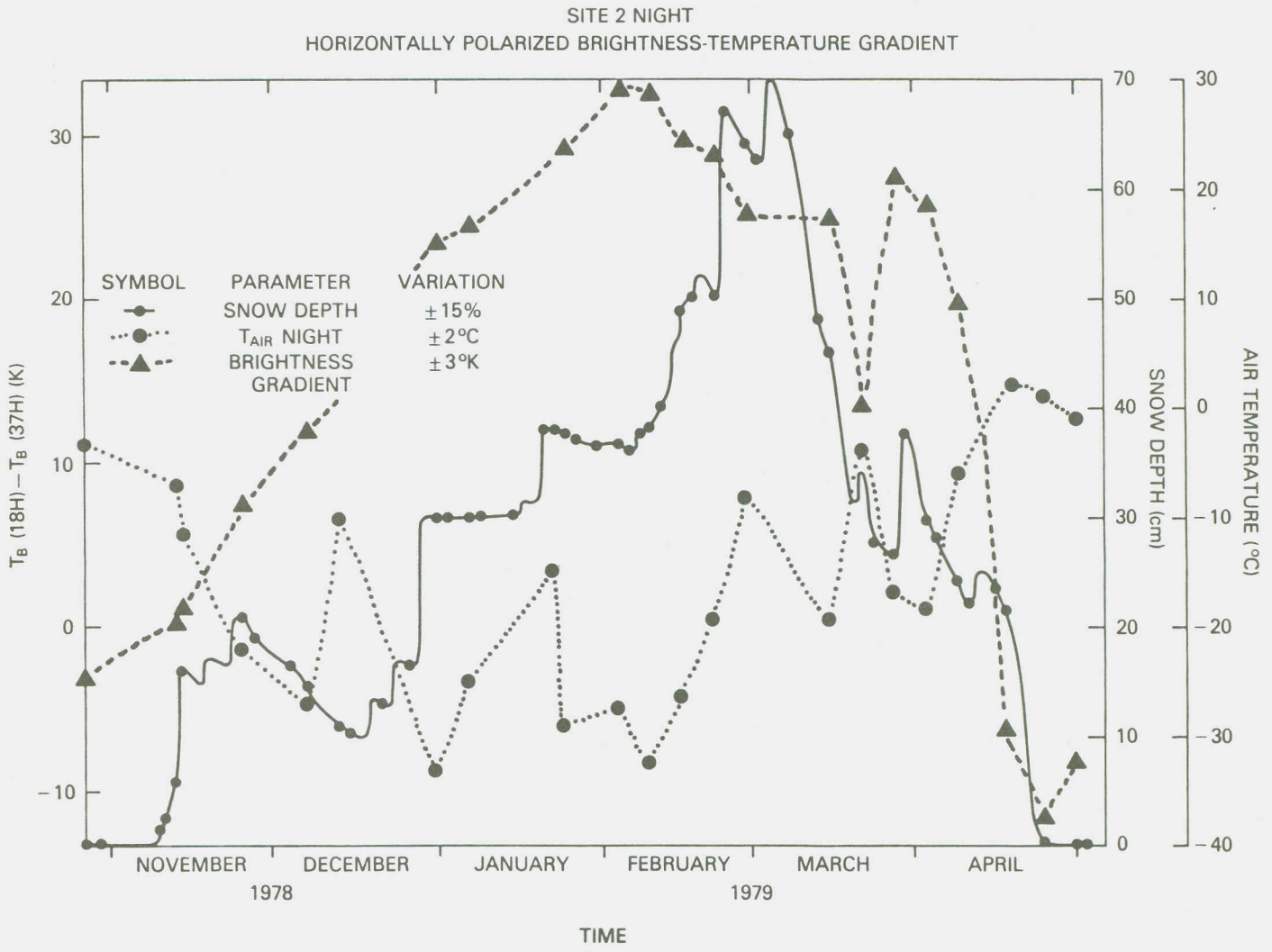
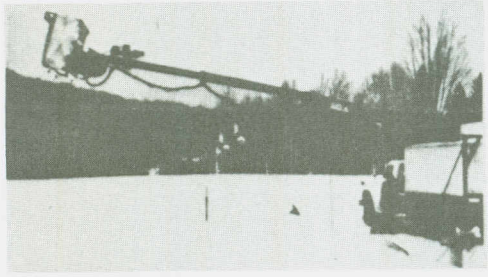


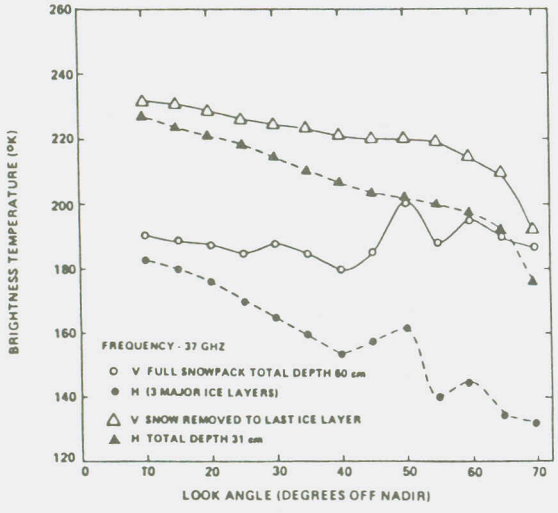
FIGURE 13

US/JAPAN JOINT RESEARCH PROJECT

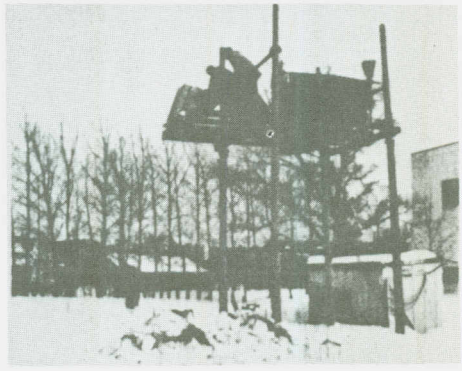
SNOWPACK PROPERTIES MICROWAVE EMISSION FIELD MEASUREMENTS

6.6 GHZ, 10.7 GHZ, 18.0 GHZ AND 37.0 GHZ
FIELD MEASUREMENTS AT DANVILLE, VT.





23 GHZ & 31.4 GHZ FIELD MEASUREMENTS
AT HOKKAIDO UNIVERSITY



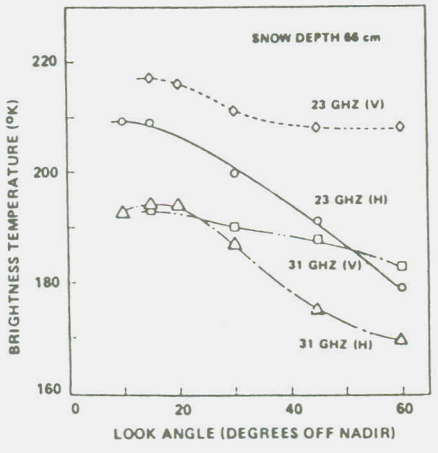


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FIGURE 14

III. Publications and Presentations

As a result of the research projects described in this report, 34 articles were published in referreed journals and 19 technical reports were written. In addition 32 papers were presented at the workshop and symposia. A listing by project is attached.

Scene Radition and Atmospheric Effects Characterization

Badhwar, G.D., Understanding the Temporal Reflectance Behavior of Cultivated Crops Using Population Biology Models. Presented at National Radio Science Meeting, Boulder, CO., January 1983.

Diner, D.J., Atmospheric Influence Upon Observation of Surface Bidirectional Reflectances. Presented at National Radio Science Meeting, Boulder, CO., January 1983.

Eom, H.J., Karem, M. A., and Fung, A.K., Scattering from a Layer of Arbitrarily Oriented Circular Disc with Application to Vegetation. Presented at National Radio Science Meeting, Boulder, CO., January 1983.

Gerstl, S.A.W., Atmosphericeffects in Satellite-sensed Vegetative Surface Features. Presented at National Radio Science Meeting, Boulder, CO., January 1983.

Jedlicka, R. P., and Ulaby, Fawwaz T., Measurements of the Microwave Dielectric and Attentuation Properties of Plants. Presented at National Radio Science Meeting, Boulder, CO., January 1983.

Kaufman, Yoram J., The Apparent Spatial Resolution of Non-uniform Surface Imagery. Presented at National Science Meeting, Boulder, CO., January 1983.

Jiang, J., Moore, R. K., Swanson, R., and Zoughi, R., Microwave In-situ Measurements of the Dielectric Properties of Terrain. Presented at National Radio Science Meeting, Boulder, CO., January 1983.

Kimes, D.S., Dynamics of Directional Reflectance Factor Distribution for Vegetation Canopies. Presented at National Radio Scene Meeting, Boulder, CO., January 1983.

Kong, J. A., Lin, S.L., Chuang, S.L., and Shin, R.T., Remote Sensing of Soil Moisture and Vegetation. Presented at National Radio Science Meeting, Boulder, CO., January 1983.

Lang, R., Backscattering from a Vegetation Layer – a Multiple Component Model. Presented at National Radio Science Meeting, Boulder, CO., January 1983.

Murphy, R.E., 1982 Project Plan for Fundamental Research in Scene Radiation and Atmospheric Effects Characterization, NASA/goddard Space Flight Center.

Paris, Jack F., Effects of Vegetation Canopy Structure on Microwave Backscatter. Presented at National Radio Science Meeting, Boulder, CO., January 1983.

Pearce, William A., Monte Carlo Modeling of Remote Earth Sensing with Varigated Ground Albedos. Presented at National Radio Science Meeting, Boulder, CO., January 1983.

Smith, J.A., Randolph, M.H. and Winder, D., An Rte Phase Function Description of Vegetation Canopies. Presented at National Radio Science Meeting, Boulder, CO., January 1983.

Strahler, Alan H., Li Xiaowen and Janet Franklin, Modeling The Reflectance of a Discontinuous Forest Company. Presented at National Radio Science Meeting, Boulder, CO., January 1983.

Vanderbilt, V.C., Grant, L., biehl, L.L., and Robinson, B.F., Specular and Diffuse Reflectance of Two Wheat Canopies Measured at Many View Angles. Presented at National Radio Science Meeting, Boulder, CO., January 1983.

Mathematical Pattern Recognition and Image Analysis

Heydorn, R.P. 1982. Project Plan for Fundamental Research in Mathematical Pattern Recognition and Image Analysis, NASA/Johnson Space Center.

Land Resources Applied Research

Burns, Gregory S. and Armond T. Joyce. Evaluation of Land Cover Change Detection Techniques Using Landsat MSS Data. Presented at: Pecora VII Symposium, Sioux Falls, South Dakota, October 1981.

Butera, M. Kristine. Remote Sensing of Wetlands. Presented at: IGARSS 1982 Symposium, Munich, Germany, June 1982.

Butera, M. Kristine. A Distance Measurement Derived from Landsat MSS Data with Application to March Productivity, Efficient Crop Transport, and Environmental Disturbance Assessment. NASA TM-84671 (In press)

Butera, M. Kristine. Identification of Water Bodies Using Remotely Sensed Multispectral Scanner Data with Applications for Inventory, Hydrologic Assessment, and Habitat Evaluation. NASA TM-84672 (In press)

Musick, H.B. Analysis of Dry Season Thematic Mapper Simulator and Landsat Multispectral Scanner Data for Jornada Test Site. NSTL-ERL Report No. 211 (In press)

Quattrochi, D. Utilization of Principal Components Analysis and Band—Rationing for the Discrimination of Surface Mines from Landsat MSS Data. Presented at: Association of American Geographers Annual Convention, San Antonio, Texas, April 1982.

Quattrochi, D. Anderson, J; Brannon, D; and Hill, C. An Initial Analysis of Landsat 4 Thematic Mapper Data for the Classification of Agriculture, Forested Wetland, and Urban Land Covers. NSTL-ERL Report 215, November 1982.

Quattrochi, D. A Technique for Using Multidate Landsat MSS Data to Discriminate Small, Heterogeneous Surface Mine Features in Eastern Kentucky. NSTL-ERL Report No. 206, March 1982.

Renewable Resources Field Research Spacecraft Data Analysis

Dottavio, C.L. and F.D. Dottavio, "Potential Benefits of New Satellite Sensors to Wetland Mapping," submitted to Photogrammetric Engineering and Remote Sensing, January 1983.

Dottavio, C.L. and D.L. Williams, Mapping a Southern Pine Plantation with Satellite and Aircraft Scanner Data: A comparison of

Present and Future Landsat Sensors, Journal of Applied Photographic Engineering, Vol. 8, No. 1, February 1982, pgs. 58-62.

Dottavio, C.L. and D.L. Williams, "Satellite Technology: An Improved Means for Monitoring Forest Insect Damage," in press in Journal of Forestry, January 1983.

Holben, B.N., J.B. Schutt and J. McMurtrey, "Detection of Leaf water Stress in Soybean Plants Utilizing Thematic Mapper Bands 3, 4, and 5," accepted for publication in International Journal of Remote Sensing, 1983.

Irons, J.R. and M.L. Labovitz, "A Data Analytic Approach to Look-Angle Radiance Adjustment," Journal of Applied Photographic Engineering, Vol. 8, No. 3, June 1982, pp. 128-137.

Kimes, D.S., "Dynamics of Directional Reflectance Factor Distributions for Vegetation Canopies," Applied Optics, within journal review, 1983.

Kimes, D.S., "Remote Sensing of Row Crops Structure and Component Temperatures Using Directional Radiometric Temperatures and Inversion Techniques," Remote Sensing of Environment, in press, 1983.

Kimes, D.S., "Diurnal Variation Canopy Structure," International Journal of Remote Sensing, in press, 1983.

Kimes, D.S. and J.A. Kirchner, "Irradiance Measurement Errors Due to the Assumption of a Lambertian reference Panel," Remote Sensing of Environment, 12:141-149, 1982.

Kimes, D.S. and J.A. Kirchner, "A Radiative transfer Model for Heterogeneous Three-Dimensional Scenes," Applied Optics, 21:4119, 1982.

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