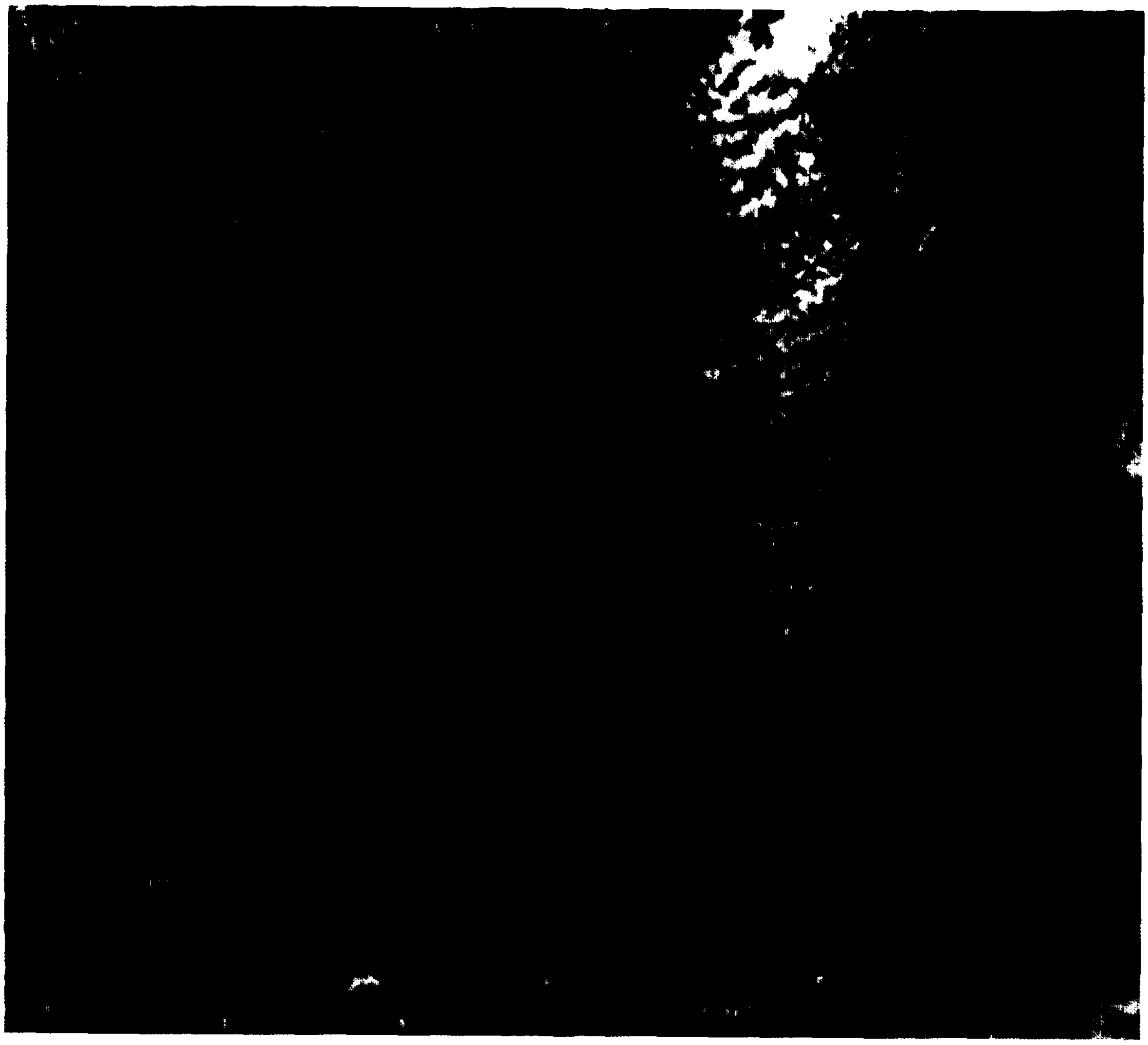
FY 1983

AgRISTARS
RESEARCH REPORT



A Joint Program for Agriculture and Resources
Inventory Surveys Through Aerospace Remote Sensing

United States Department of Agriculture

National Aeronautics and Space Administration
U.S.A.

Department of Commerce
United States of America

U.S. Department of the Interior
March 3, 1849

United States of America

COVER

This is a scene over southeastern Texas and southwestern Louisiana acquired by the advanced very high resolution radiometer (AVHRR) on board NOAA-7, which is one of the family of Polar Orbiting Environmental Satellites, on April 18, 1983. This image is composed of the first two of the five channels available on the NOAA-7 AVHRR. Channel 1 covers the green-red portion of the visible spectrum, and channel 2 covers the near-infrared portion of the spectrum. Channel 2 is displayed as red, and channel 1 is displayed as green and blue. The other three channels available on the AVHRR (not displayed in this image) are in the thermal portion of the spectrum. Areas which are deep red and magenta in color are oak-hickory-pine forests; red and pink colors are native vegetation and agricultural areas. Clouds and water appear in their natural colors. The varying tones of blue in the inland lakes and western portion of the Gulf of Mexico are due to sun glint, while the varying shades of blue in the eastern Gulf are due to turbidity. The Dallas-Fort Worth metropolitan area (blue-green in color) can be seen in the extreme top left portion of this image; the Houston metropolitan area is visible in the bottom left (northwest of Galveston Bay). Marsh Island and the Atchafalaya Bay area can be seen in the bottom right. On the right side of the image is the Red River Basin with its meandering tributaries and agricultural areas.

AVHRR data have provided an efficient and inexpensive source of data for agricultural monitoring, condition assessment, and change detection to augment existing satellite, aircraft, and ground technologies.

JSC-18920

AgRISTARS

AGRICULTURE AND RESOURCES INVENTORY SURVEYS THROUGH AEROSPACE REMOTE SENSING

RESEARCH REPORT - FISCAL YEAR 1983

Prepared by

AgRISTARS Program Management Group

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS 77058

June 1984

PREFACE

The AgRISTARS program was initiated in fiscal year 1980 in response to an initiative issued by the U.S. Department of Agriculture. Led by the USDA, the program is a cooperative effort with the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce, the U.S. Department of the Interior, and the Agency for International Development of the U.S. Department of State.

The program goal is to determine the usefulness, cost, and extent to which aerospace remote sensing data can be integrated into existing or future USDA systems to improve the objectivity, reliability, timeliness, and adequacy of information required to carry out USDA missions.

The program is well underway, with encouraging progress having been made in fiscal years 1980,[*] 1981,[†] 1982,[§] and 1983 (as documented in this report). The outlook is that aerospace remote sensing will contribute to USDA information needs in a significant way and, more generally, that the AgRISTARS effort will advance this technology for use in other areas of national need.

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[*] AgRISTARS Annual Report - Fiscal Year 1980; AP-J0-04111, National Aeronautics and Space Administration (NASA), Lyndon B. Johnson Space Center (JSC), June 1981.

[†] AgRISTARS Annual Report - Fiscal Year 1981; AP-J2-04225, NASA/JSC, January 1982.

[§] AgRISTARS Research Report - Fiscal Year 1982; AP-J2-0393, NASA/JSC, January 1983.

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ACRONYMS AND ABBREVIATIONS

ACCS	Ambroziak Color Coordinate System
AgRISTARS	Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing
agromet	agricultural-meteorological
AID	Agency for International Development
AMMR	airborne multichannel microwave radiometer
APU	agrophysical unit
ARS	Agricultural Research Service
AVI	Ashburn vegetative index
AVHRR	advanced very high resolution radiometer
CAM	correlation area method
CCT	computer-compatible tape
CEAS	Center for Environmental Assessment Services
CERES	Crop Estimation through Resource Environment Synthesis
CMI	crop moisture index
C/P	Conservation and Pollution
CPU	computer processing unit
CRD	crop reporting district
CWSI	crop water stress index
DC/LC	Domestic Crops and Land Cover
DCM	digital count minimum values
EDIS	Environmental Data and Information Service
ET	evapotranspiration
EVI	environmental vegetation index
EW/CCA	Early Warning and Crop Condition Assessment
FAS	Foreign Agricultural Service
FY	fiscal year
GIS	geographic information system
GLAI	green leaf area index
GMI	Gray/McCrary index
GOES	Geostationary Operational Environmental Satellite
GSFC	Goddard Space Flight Center

HIRS/2	high resolution infrared radiation sounder 2
ICC	Interagency Coordinating Committee
IFOV	instantaneous field of view
IPAR	intercepted photosynthetically active radiation
ITD	Inventory Technology Development
JES	June Enumerative Survey
JPL	Jet Propulsion Laboratory
JSC	Lyndon B. Johnson Space Center
LAI	leaf area index
MIMPT	Multiresource Inventory Methods Pilot Test
MSS	multispectral scanner
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite, Data, and Information Service
NESS	National Environmental Satellite Service
NMR	nuclear magnetic resonance
NOAA	National Oceanic and Atmospheric Administration
NRI	National Resource Inventory
NWS	National Weather Service
NWSRFS	National Weather Service River Forecast System
pixel	picture element
PMG	Program Management Group
ppm	parts per million
RMSE	root mean square error
RRI	Renewable Resources Inventory
SAM	satellite, agronomic, and meteorological
SAR	synthetic aperture radar
SCS	Soil Conservation Service
SIR-A	Shuttle imaging radar A
SM	Soil Moisture
SMMR	scanning multichannel microwave radiometer
S/N	signal-to-noise
SR	Supporting Research
SRM	snowmelt-runoff model
SRS	Statistical Reporting Service

TAMW	Texas A&M wheat model
TIROS	Television Infrared Observation Satellite
TM	thematic mapper
TMS	thematic mapper simulator
TOVS	TIROS operational vertical sounder
USDA	U.S. Department of Agriculture
USDC	U.S. Department of Commerce
USDI	U.S. Department of Interior
USGS	U.S. Geological Survey
USLE	universal soil loss equation
VI	vegetation index
VIN	vegetation index number
WMO	World Meteorological Organization
YMD	Yield Model Development

I. PURPOSE

The purpose of this report is to present the major objectives and accomplishments of the Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) program and its eight component projects during fiscal year (FY) 1983.

This report includes an introduction to the overall AgRISTARS program, a general statement on progress, and separate summaries of the activities of each project, with emphasis on the technical highlights. Organizational and management information on AgRISTARS is included in the appendixes, as is a complete bibliography of publications and reports. Additional information may be obtained from:

AgRISTARS Program Management Group
Code SC
NASA-Lyndon B. Johnson Space Center
Houston, Texas 77058
Telephone: 713-483-2548
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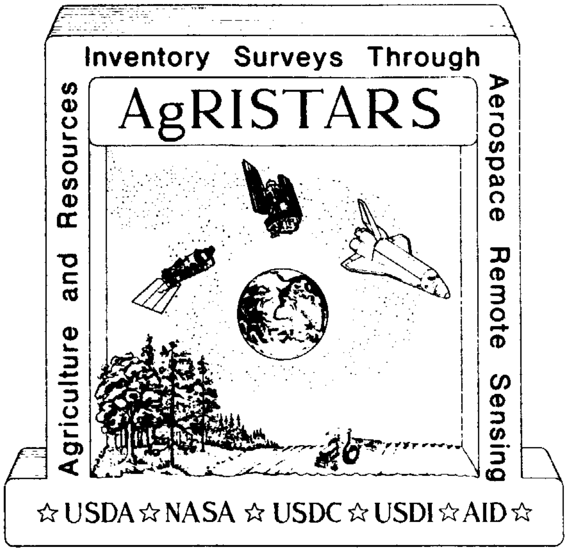

2. INTRODUCTION

AgRISTARS is a long-term program of research, development, test, and evaluation of aerospace remote sensing to meet the needs of the U.S. Department of Agriculture (USDA). The program is a cooperative effort of: the USDA; the National Aeronautics and Space Administration (NASA); the U.S. Department of Commerce (USDC) through the National Oceanic and Atmospheric Administration (NOAA); and the U.S. Department of the Interior (USDI). In addition, the Agency for International Development (AID) participates as an ex officio observer and potential future user agency.

In 1978 the Secretary of Agriculture issued an initiative,[1] in response to which the participating agencies established the AgRISTARS program. In 1980 the program was initiated as an effort based on satisfying current and future requirements of the USDA for high-priority agricultural and other renewable resources type information. This information is important to the USDA in addressing national and international issues on supply, demand, and competition for food and fiber.

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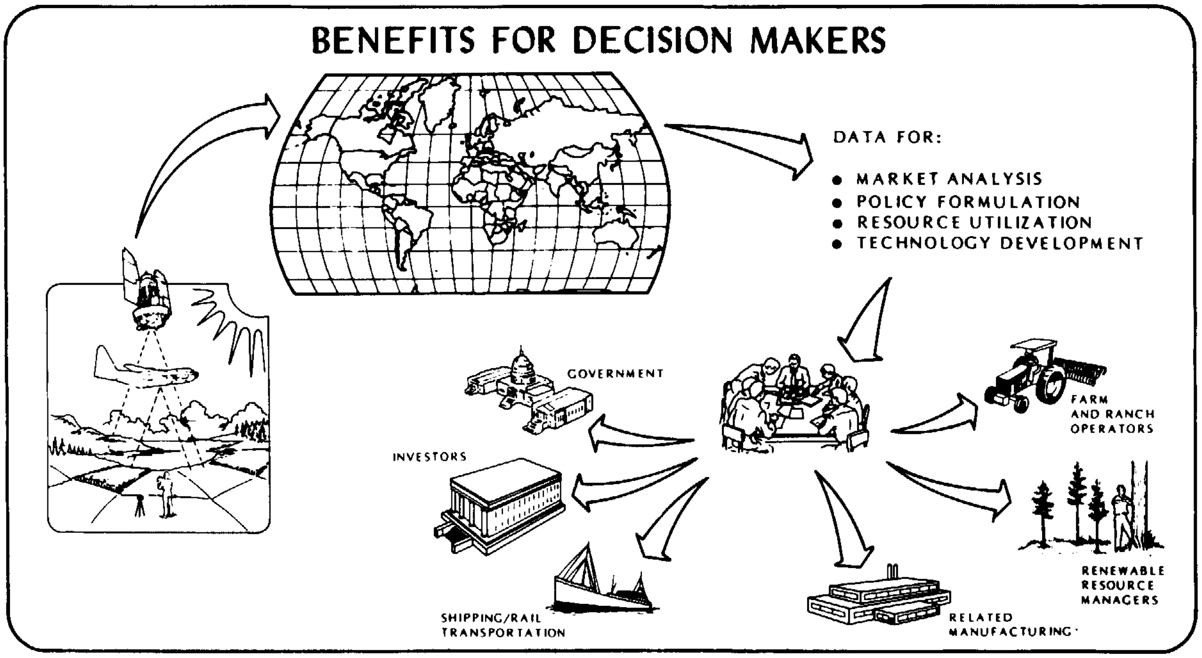
[1] Joint Program of Research and Development of Uses of Aerospace Technology for Agricultural Programs, February 1978.



Remote sensing technology is being developed to give timely, reliable information to those concerned with the worldwide status of renewable resources.

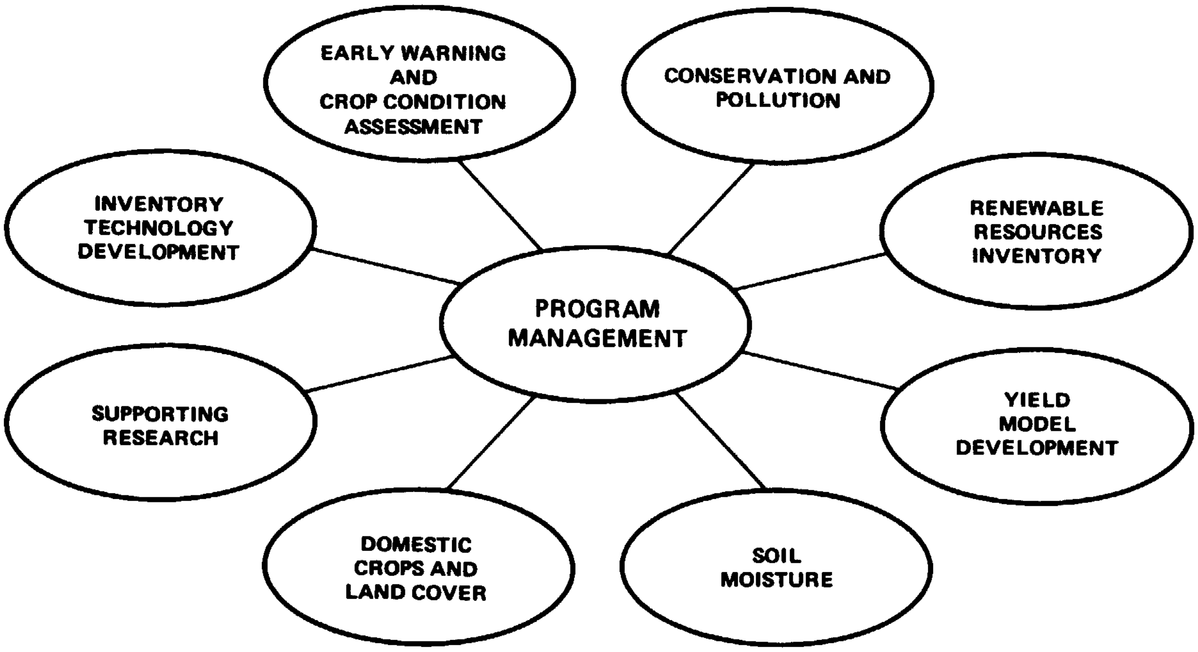
The overall goal of AgRISTARS is to determine the feasibility of integrating aerospace remote sensing technology into existing or future USDA data acquisition systems. Determining feasibility depends upon the assessment of numerous factors over an extended period of time. Determinations of the reliability, costs, timeliness, objectivity, and adequacy of information required to carry out USDA missions are planned in the program. The overall approach consists of a balanced program of remote sensing research, development, and testing which addresses a wide range of information needs on domestic and global resources and agricultural commodities.

In this initiative the USDA identified the following seven information requirements:

- Early warning of change affecting production and quality of commodities and renewable resources
- Commodity production forecasts
- Land use classification and measurement
- Renewable resources inventory and assessment
- Land productivity estimates
- Conservation practices assessment
- Pollution detection and impact evaluations

Based on these information requirements, as well as on a specific immediate need for better or more timely information on crop conditions and expected production, the AgRISTARS technical program was developed. It consists of eight projects which address all seven of the USDA information needs with a clear emphasis on the first two, early warning

AgRISTARS PROJECTS



of change and commodity production forecasts. The eight projects include the following:

- Early Warning and Crop Condition Assessment (EW/CCA)
- Inventory Technology Development (ITD)
- Supporting Research (SR)
- Yield Model Development (YMD)
- Soil Moisture (SM)
- Domestic Crops and Land Cover (DC/LC)
- Renewable Resources Inventory (RRI)
- Conservation and Pollution (C/P)

Even though each project has its specific set of objectives, the projects are interrelated both through mutuality of data needs and through much common technology.

3. PROGRAM SUMMARY

The AgRISTARS program has been underway for 4 years. During this time significant progress has been made in evaluating, analyzing, and using various types of remote sensing data for agricultural applications.

Research conducted by the AgRISTARS projects has been evaluated by USDA agencies, and selected techniques have been incorporated into the domestic and foreign operational crop production estimation programs. During FY 1983, the AgRISTARS program focused on three areas: technology transfer, basic research, and evaluation of the NOAA satellites.

Technology Transfer

The USDA Statistical Reporting Service (SRS) used acreage estimates generated from Landsat multispectral scanner (MSS) data to support U.S. crop estimates. Acreage estimates for seven states - Arkansas, Colorado, Illinois, Iowa, Kansas, and Missouri - calculated by combining Landsat MSS with ground data, were twice as efficient as estimates using ground data alone; projected costs per state associated with using Landsat data have been drastically reduced, thereby enhancing Landsat's utility to domestic crop production estimation.

- A revised wheat yield reduction model was transferred to the Foreign Agricultural Service (FAS) and tested in both the USSR and China. Model results compared favorably with non-satellite data sources.

- FAS also used the Crop Estimation through Resource Environment Synthesis (CERES) winter wheat model to produce operational yield estimates for the USSR.

- The CERES-maize model was used in real time (1983 crop season) to evaluate the U.S. corn crop and the impact of the drought on corn yield.

- The Soil Conservation Service (SCS) is reviewing Landsat change detection techniques for possible use in the National Resource Inventory (NRI) program.

- The USDA Forest Service placed considerable emphasis on transferring remote sensing techniques to field users by conducting several advanced remote sensing and photo interpretation workshops.

- Results from 14 international basins indicate that the accuracy of the snowmelt-runoff model (SRM) for simulating seasonal water yield (volume) is 97 percent and for daily flows is 85 percent. This model is ready for conversion to operational forecasting.

- Vegetation indices developed in AgRISTARS, using the Landsat MSS or the NOAA advanced very high resolution radiometer (AVHRR), are used operationally by estimating and forecasting groups in USDA, NOAA, and AID.

Principal Technical Accomplishments

- A major technical interchange meeting was held between AgRISTARS participants and other government and non-government researchers on the use of the NOAA satellites AVHRR for agricultural applications.

- Methods to estimate precipitation, daily temperature extremes, canopy temperatures, insolation, and snow cover from meterological satellites are in the final phases of testing and evaluation.

- Continued evaluation of thematic mapper (TM) data for crop identification, land cover separability, and forest species discrimination has shown that TM data can discriminate to levels II and III of the U.S. Geological Survey (USGS) land cover categories. The TM's improved accuracy is attributed to better spatial and radiometric resolution, improved wavelength (band) coverage, and better signal-to-noise (S/N) ratio.

- Improved spectral and spatial resolution of TM offers the potential to separate important soil properties even in regions with similar soils and under a dense vegetation canopy.

- A soybean phenology (growth stage) model was developed and tested. The results indicate that the model will generate reliable estimates of soybean growth stages over a wide range of climatic conditions.

- Agroclimatic reference handbooks were prepared for Argentina, Brazil, and Australia.

- Microwave remote sensing of bare soil produced repeatable and quantifiable results regardless of geographic location and sensor system used, thereby demonstrating the potential of microwave remote sensing for estimating soil moisture over large areas.

- The Multiresource Inventory Methods Pilot Test (MIMPT) was completed. The MIMPT demonstrated the potential use of Landsat data for conducting recurrent forest inventory and assessment activities over large areas.

- Preliminary data analysis during FY 1983 indicated that some conservation practices could be successfully detected in Landsat TM data, but a number of existing practices are of such size and definition that present sensors and standard techniques cannot detect them with great accuracy.

- A new hydrologic model has been developed to incorporate remote sensing information from various sensors for water resources management. This model will be field tested in FY 1984.

Major Research Focus During FY 1983

During FY 1983 a major part of the research effort focused on the use of the NOAA polar-orbiting satellites for agricultural monitoring and condition assessment. The NOAA satellites have AVHRR's onboard that collect data in the visible, infrared, and thermal bands. The spectral response of the visible and near-infrared bands is similar to bands 5 and 7 on the Landsat MSS. The AVHRR continuously scans the globe at a resolution of 1 kilometer. The 1-kilometer data is aggregated automatically to a resolution of 4 kilometers onboard the satellite in order to conform to data storage constraints. About 10 minutes of selected higher resolution 1-kilometer data can be stored onboard during each orbit. The advantage of the NOAA satellites for monitoring vegetation is that they provide daily observations, while Landsat has a repeat time of 16 days. Problems with cloud cover are much less severe with daily observations. The trade-off for daily coverage is resolution. Only a small part of the Earth can be observed daily at the full 1-kilometer AVHRR resolution; daily global coverage is obtained at a 4-kilometer resolution.

During FY 1983, basic research was conducted on improving the processing efficiencies of the AVHRR data through cloud screening techniques, geometric rectification, registration, scan angle corrections, and swath width studies (fig. 1). Additional studies investigated the use of the thermal bands for estimation of precipitation, temperature, surface evaporation, and ocean water reflectances.

In the applications area, various daily, global, and composite vegetation indices (VI's) were produced (fig. 2) and used within the assessment groups at USDA, NOAA, and AID.

Figure 1.- NOAA AVHRR image of the Southern United States. This image product is the western half of a full AVHRR scan. It illustrates the effects of scan angle on data distortion. The Winter Wheat belt of Oklahoma and Kansas is the red area in the central portion of the image.

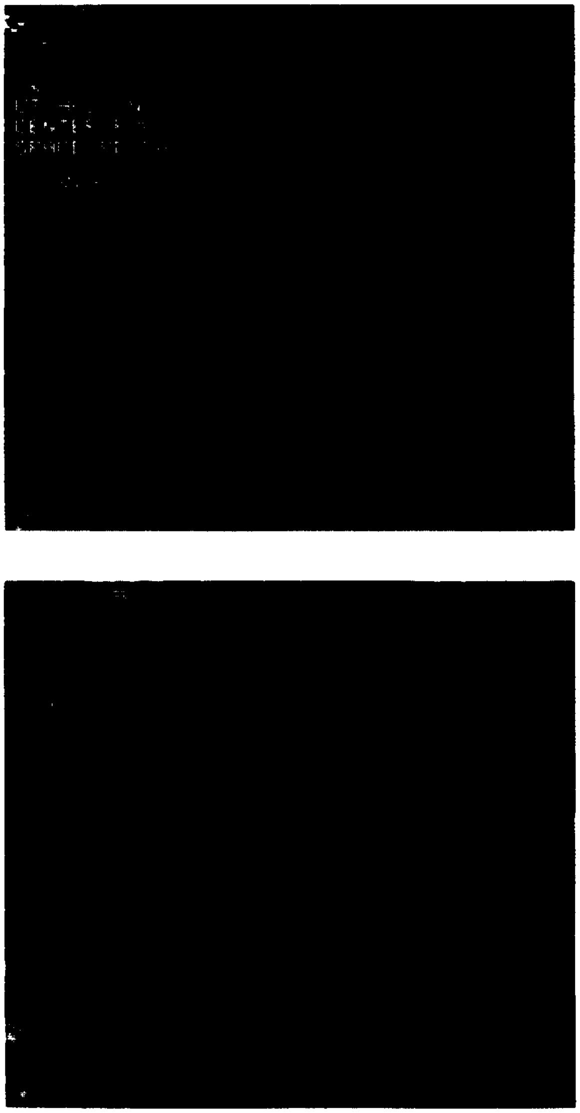


Figure 2.- Progression of severe drought in the Orinoco and Mehta River Basins of Columbia and Venezuela during early 1983. This new operational product of aggregated AVHRR daily data is available weekly and is designed to give analysts a quick-look of the overall environmental trends.

The browns in Columbia and Venezuela document the dessication of the grasslands that was associated with El Nino of 1982-83. Also noticeable is the greenness contrast between the two nations of Haiti and the Dominican Republic on the Island of Hispaniola. The cause of the lower greenness in Haiti (western end of the island) is due to severe deforestation (less than 2% of the country remains as forest) and subsequent erosion.

The AVHRR was able to track catastrophic or large area events - Mexico's El Chicon volcano eruption, drought in the African Sahel, and reductions in the water level of Lake Chad, and a massive phytoplankton bloom off the northeast coast of Australia (fig. 3).

The NOAA polar-orbiting satellites have provided an efficient, inexpensive source of data for agricultural monitoring, condition assessment, and change detection to augment existing satellite and ground technologies.

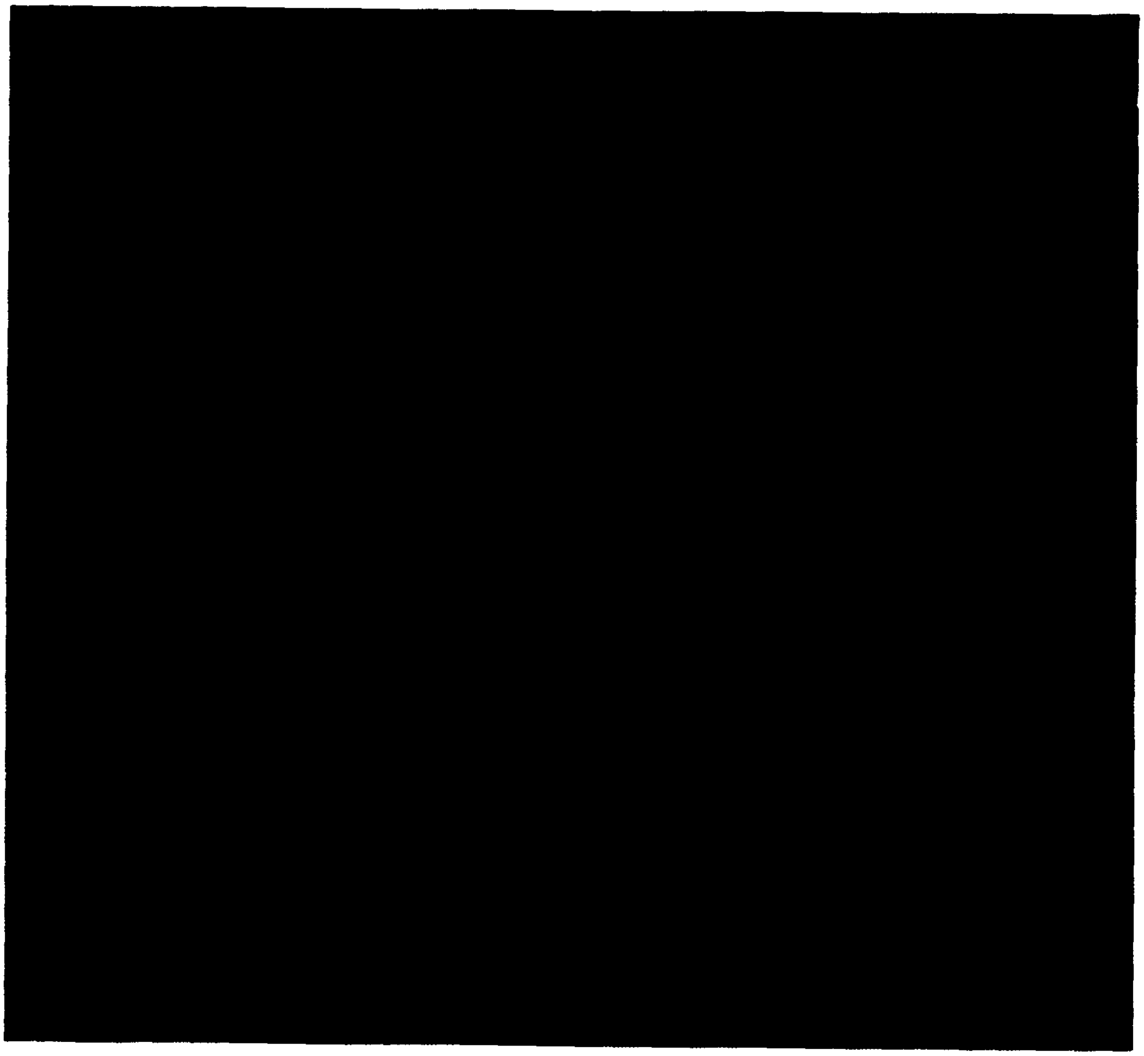


Figure 3.- NOAA-8 image of phytoplankton bloom off northeast coast of Australia. This image was taken in December 1983 of a portion of the Great Barrier Reef. The chlorophyll greenness signature being exhibited by this mass of single-celled blue-green algae covered about 30,000 square kilometers of the Capricorn Channel off the coast of Queensland, Australia. The greenness of this phytoplankton bloom equals that measured for soybeans previously. Water depths in this region are generally less than 100 feet over a coralline sandy bottom. The entrapment of this phytoplankton concentration in the Capricorn Channel is probably related to entrainment in a warm-core gyre being spun out of the Coral Sea, a normal occurrence in this region during the Southern Hemisphere summer.

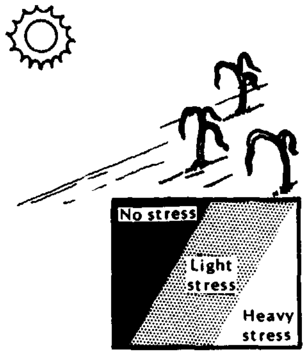
4. PROJECT TECHNICAL HIGHLIGHTS

Technical highlights of the eight AgRISTARS projects are given in this section. Project overview, FY 1983 objectives, and accomplishments are discussed.

4.1 EARLY WARNING/CROP CONDITION ASSESSMENT

The EW/CCA research project is designed to develop remote sensing technology and crop simulation models that provide early warning of actual or potential plant stress and that provide alerts for optimal crop conditions. The project activity includes development and testing of techniques for monitoring and assessing conditions that may impact crop production in foreign and U.S. areas. Major commodities for which technology is being developed include: small grains (wheat and barley), corn, soybeans, sorghum, sunflowers, and cotton.

EARLY WARNING OF CONDITIONS AFFECTING CROPS



This project will assist the USDA in tracking the condition of major crops in the United States and foreign countries.

Techniques using data from satellites to measure the effects of drought on crops are well developed, and the areas of the crops affected can be accurately measured. Other types of crop stress are also being studied.

Technology developed in the EW/CCA project will be transferred to elements within USDA. For example, the USDA/FAS is responsible for providing early warning of changes that may affect crop production in foreign countries and for assessing crop conditions in general. They have provided research requirements and have requested that specific technology be transferred to their Foreign Crop Condition Assessment Division.

The EW/CCA project is managed by the USDA Agricultural Research Service (ARS) with participation by NASA, NOAA, and other USDA agencies.

4.1.1 Technical Objectives

The FY 1983 objectives were:

- To continue development and evaluation of various simulation models and satellite data to provide timely alerts of abnormal conditions on a global basis.
- To provide improved definition of the relationships between plants and their environment and factors affecting the growth cycle.
- To determine and quantify relationships between factors such as crop stress, the environment, and spectral responses.
- To investigate the utility of multisensor data for agricultural applications and to improve the capabilities for using NOAA satellite data for indicating and monitoring crop conditions.

4.1.2 Crop Stress Indicator Models

Models are being developed, tested, or improved to provide information concerning crop stress.

A satellite, agronomic, and meteorological (SAM) data base for Missouri, North Dakota, and South Dakota was developed to test and evaluate the accuracy of the wheat, corn, and sorghum stress indicator models. The SAM data base was established using ground-truth information obtained from the USDA/SRS weekly crop weather bulletins, plus data extracted from the EW/CCA geographic data base. The stress models track crop phenology and soil water status and provide stress alerts. Each component is being evaluated for accuracy and for relationships among available soil water, crop phenology, stress alerts, and various vegetative indices computed from satellite data. The crop stage model components appear to be quite accurate for corn (fig. 4).

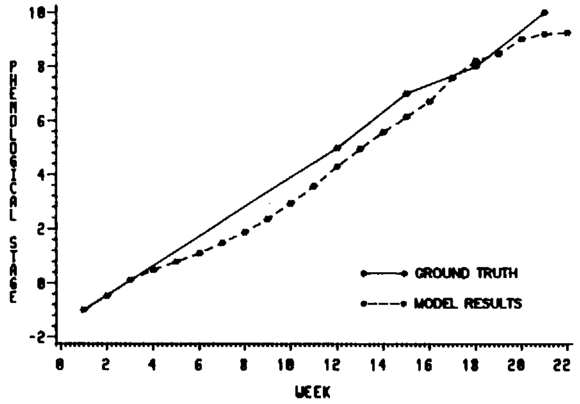


Figure 4.- Comparison of model-estimated corn phenology with ground data.

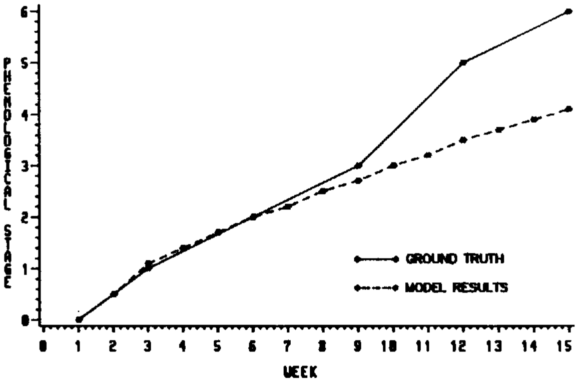


Figure 5.- Comparison of model-estimated wheat phenology with ground data.

However, the spring wheat phenology component (Robertson's crop calendar) appears to estimate inaccurately crop phenology after the heading stage (fig. 5). This conclusion is based on limited testing; additional testing is continuing, and modifications will be made to improve the model's accuracy.

Efforts continued toward the development of a meteorologically driven stripe rust indicator model and spectral responses associated with rust-infected wheat and barley. Figure 6 illustrates the influence that rust has on spectrally derived VI values [(channel 7 - channel 5)/(channel 7 + channel 5)] computed from data collected with a handheld radiometer. Spectral VI's began to decrease soon after wheat plants were inoculated with rust spores. As the

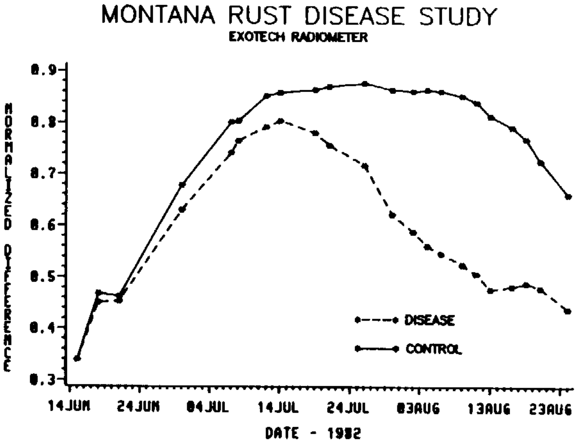


Figure 6.- The effect of leaf rust on remotely sensed vegetation index numbers during the growing season for wheat.

plants matured and the disease level increased, VI values became increasingly smaller than those from nondiseased plants. This provided evidence that crop conditions may be monitored from satellite platforms for the presence of disease if favorable conditions exist for disease outbreaks. The meteorologically driven rust indicator model should provide information suggesting which moisture conditions are favorable for rust epidemics. Since good moisture conditions must exist for rust outbreaks to occur, a decline in VI numbers may be attributed to disease and not to drought.

A conceptual design was developed for a harvest loss wheat model based on 3 years of field and laboratory studies conducted in North Dakota. The model will provide information relative to sprouting, quality, and yield loss. A major problem associated with model development is the inability to determine drying rates following a period of precipitation. Humidity measurements, if available from first order weather stations, would be useful in predicting the dry-down rate.

4.1.3 Condition Assessment

Major modifications were made to a wheat yield reduction model developed in 1982. The revised model was transferred to FAS and tested in both the USSR and China. Figure 7 illustrates the results obtained for three major winter wheat producing provinces in the North China Plain. The model suggests that the potential for yield reductions was greater in 1982 (53 percent) than in 1983 (42 percent). Reports from China verify that better yields were obtained in 1983 than in 1982. Additional testing of this model will be accomplished using the SAM data base and ARS experimental plot data from various research locations in the United States.

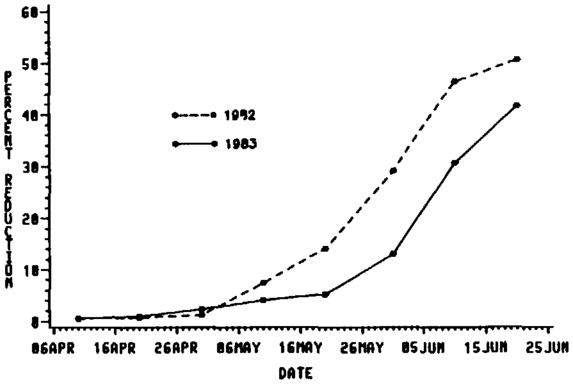


Figure 7.- Estimated 1982 and 1983 wheat yield reduction potentials for major wheat provinces in China.

A crop water stress index (CWSI) was calculated for cotton plants exposed to different early season irrigation treatments. It was responsive to plant water status, attaining minimum values following an irrigation and then increasing gradually as plants depleted soil moisture reserves. The final yield of seed cotton was significantly and inversely correlated with the average midday CWSI observed over a 3-month fruitsetting interval. This information can be used to establish guidelines for using infrared thermometry for scheduling cotton irrigations and for quantifying the magnitude and duration of stress between irrigations in order to achieve the appropriate balance between vegetative and reproductive patterns of growth. Infrared thermometry provides several important advantages over conventional approaches for quantifying stress and monitoring yield potential. It is a rapid, nondestructive technique which can be used to survey large acreages in a cost effective fashion while circumventing many of the sampling problems associated with point measurements.

In 1982 the EW/CCA project reported that Landsat VIN's of native rangelands could be used to monitor drought stress in adjacent croplands. Continued research in 1983 suggests that VI's computed for all picture elements (pixels) within a segment may provide drought stress information similar to that of native rangelands (fig. 8). The results show that VI's computed for rangeland areas and those for all pixels within the segment followed similar patterns throughout the season and that both trajectory curves respond to increasing or decreasing crop moisture index levels. These findings suggest that NOAA-AVHRR satellite data (1-kilometer resolution) can provide adequate information to monitor crop moisture stress in the U.S. Great Plains or in other semiarid regions of the world.

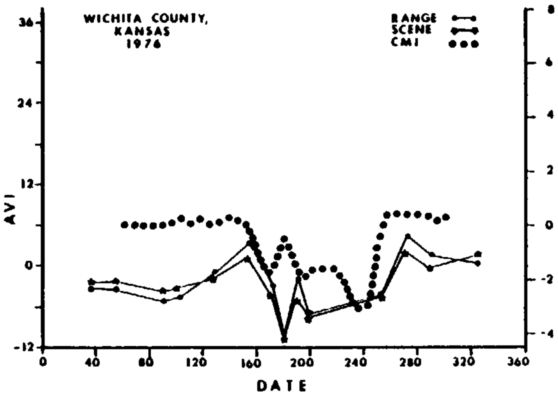


Figure 8.- Seasonal trajectories depicting rangeland and total scene vegetation indices (AVI) and the crop moisture index.

4.1.4 Crop/Spectral Research

Techniques are being developed and tested to incorporate spectral indicators of vegetation development and growing conditions into agrometeorological growth and yield models. For example, interrelations exist between leaf area index (LAI), intercepted photosynthetically active radiation (IPAR), yield, and spectral VI's derived from remote observations of plant canopies.

Spectrally derived VI's can be used to estimate LAI and IPAR for use in plant growth/yield model algorithms developed from experimental data. Relationships between yield and VI's can provide independent checks for agrometeorological growth and yield model outputs.

The reflectance of solar radiation by the soil background complicates the discrimination of vegetation by remote sensing. To study this effect, dry and wet reflectance data, for 20 soils covering a wide range in spectral properties, were obtained with a handheld radiometer. Principal components analysis was used to study the distribution of soil spectra in four-dimensional space and to define a mean soil line. Analysis of the mean soil line showed that it was not possible to discriminate bare soil from low vegetation densities. Greenness measurements were shown to be sensitive to both soil type and soil moisture condition. In contrast, the use of individual soil lines as a base to measure greenness minimized soil background influence and improved vegetation assessment, particularly in the case of low green plant canopy covers. These results show the importance of using specific soil spectra in vegetation discrimination.

In another study, spectral reflectance at two wavelengths (0.55 and 0.65 millimeters) was investigated using single leaves of fertilized and nonfertilized buffelgrass. Chlorophyll concentration and nitrogen content were less in nonfertilized leaves than in leaves receiving more than 112 kilograms of nitrogen per hectare. Significantly higher reflectance values, at the 0.55-millimeter wavelength, were measured from nonfertilized than from fertilized leaves.

Nonfertilized plots could also be distinguished from fertilized plots using color-infrared aerial photography. These results indicate that leaf reflectance measurements may be useful for estimating protein content and green biomass production of buffelgrass.

Reflectance measurements of Produra wheat fields were made at 13 different times of the day at Phoenix, Arizona, using a handheld radiometer with bandpass characteristics similar to those of the Landsat MSS. The major objective was to determine the effect of changing sun angles on the reflectance properties of canopies in various phenological stages and with different levels of green leaf area index (GLAI). Results indicated that diurnal changes in each of the four Landsat wavebands and several indices derived from them are related to canopy architecture, percentage of cover, and vertical distribution of green leaves within the canopy. Multispectral data acquired under differing sun altitude and azimuth angles contain important information regarding the three-dimensional distribution of plant material which can be extracted to determine phenological stage of growth or to estimate levels of stress. Additional analysis showed that substantial errors could be introduced into the estimate of GLAI from spectral observations if the diurnal patterns of reflectance caused by changing sun angles are not properly incorporated.

When plants are stressed because of insufficient water, both physiological and geometric changes occur, thereby increasing the complexity of the interpretation of spectral data. To study these effects, spectral responses in eight wavebands (three visible, two near-infrared, two mid-infrared, and one thermal-infrared) were measured by repetitively traversing a radiometer over several rows of cotton. After an initial measurement the stems of one row were cut at a point just above the soil. The subsequent dessication of plants within this row was followed by comparing reflectance and emittance of the row with that of a control row. Measurements in all wavebands reacted rapidly to stress, with the visible and thermal-infrared showing a larger change than the near-infrared. Reflectance changes caused by canopy geometry changes were apparently greater than those caused by leaf physiological and anatomical changes in all but the visible red band. The increase in red reflectance was attributed to a rapid decrease in absorptance by leaf chloroplasts. As expected, the radiometrically determined plant temperatures increased with time after the stress was imposed. These results demonstrate that canopy geometry changes caused by stress must be accounted for if plant water stress is to be quantified using reflectance measurements.

4.1.4 Aircraft and Satellite Investigations

Aircraft

Three black-and-white video cameras, each fitted with different narrowband filters, were used together in an aircraft to obtain information about agricultural crop and soil conditions. Inflight information was recorded on video equipment, and upon landing, the video tapes were ready for television (TV) displays and computer image analysis. Variations in reflective characteristics of landscape features were clearly evident between wavebands. False color composites, made using the computer image analysis system, were similar in appearance to color infrared photographs. These results suggest that a modified color video camera system and appropriate narrowband filters can enhance the information needs of agricultural managers in near real time. The TV formatted outputs of video systems make them a natural for transmission of images over electronic agricultural information networks of the future.

Combined Sensors

Linear combinations of spectral bands form physically significant VI's. Indices comprised of two and four bands have been used to discriminate vegetation from soil background. A procedure for calculating vegetation indices using any number of bands was evaluated. Reflectance values were obtained for each band for each sensor. VI's were calculated for various band combinations for the several sensors, and their dynamic ranges for a 0- to 100-percent change in vegetation were compared. A six-band VI calculated using six of the TM bands had the greatest dynamic range, followed closely by two five-band and one four-band index from the same sensor. The two-band index using bands 4 (near-infrared) and 7 (mid-infrared) of the TM had a greater dynamic range than any band combination of the other four satellite sensors. The four-band index of the Landsat-4 MSS and the three-band index of the French satellite SPOT were similar. The two-band indices from the AVHRR sensors on NOAA-6 and NOAA-7 changed less with vegetation changes than did the other three. This development means an improved ability to discriminate and evaluate vegetation from remote platforms.

NOAA Satellites

During the past year extensive work has been initiated on the use of the NOAA satellites for agricultural monitoring. Two locations have been principal contributors to this research.

Camp Springs, Maryland

Part of the AgRISTARS effort under way at the NOAA National Environmental Satellite, Data, and Information Service (NESDIS) is to develop products from operational meteorological satellite data that will supplement ground-based weather observations for agricultural monitoring. Meteorological quantities that are needed for crop models and that can be produced from satellite data include estimates of precipitation, daily temperature extremes, canopy temperatures, insolation, snowcover, and VI's.

The NOAA polar-orbiting satellites have AVHRR's onboard that make observations in the visible band (channel 1, 0.58 to 0.90 millimeters) and in the near-infrared band (channel 2, 0.73 to 1.10 millimeters). The spectral responses for these bands are similar to responses for bands 5 and 7 on the Landsat MSS.

The reflectance of green vegetation in the visible part of the spectrum is low (20 percent or less) but is much higher (50 to 60 percent) in the near-infrared. Other surfaces, such as water, bare ground, and clouds have reflectances that are nearly the same in the two bands. Thus, the difference between measurements in channels 1 and 2 is a sensitive indicator of vegetation. The differential reflectance of vegetation in the visible or near-infrared was used with MSS data to estimate crop acreage, to study the distribution and condition of vegetation, and to detect plant stress. The advantage of the NOAA satellites for monitoring vegetation is that they provide daily observations while Landsat has a repeat time of 16 days. Cloud obscuration of the areas of interest is much less of a problem with daily observations. The trade-off for daily coverage is resolution. Only a small part of the Earth can be observed daily at the full 1-kilometer AVHRR resolution; daily global coverage is obtained at 4-kilometer resolution.

Examples of an experimental VI product are shown in figures 9 and 10.

Figure 9.- Northern Hemisphere composite AVHRR image of the normalized difference vegetation index [(channel 2 - channel 1)/channel 2 + channel 1)] for August 23-29, 1982.

Figure 10.- Northern Hemisphere composite AVHRR image of the normalized difference vegetation index [(channel 2 - channel 1)/channel 2 + channel 1)] for March 21-27, 1983.

These are Northern Hemisphere, polar-stereographic mapped images of the normalized difference [(channel 2 - channel 1)/(channel 2 + channel 1)] vegetation index. The greener the scene, the darker the image and the higher the VI value, which ranges between 0.1 and 0.6 for most vegetation. The images were generated from 4-kilometer AVHRR observations made during the week of August 23-29, 1982, and March 21-27, 1983. The data were mapped each day into a 1024- x 1024-pixel polar stereographic array and composited over a 7-day period by saving the greenest observation for each array point. Atmospheric effects, such as Rayleigh and Mie scattering and subpixel clouds, reduce the radiance in channel 2 relative to channel 1 and reduce the value of the data. Saving the greenest observation over the 7-day period minimizes cloud and atmospheric effects and throws out high nadir-angle observations in favor of straight-down looks. The disadvantage of saving the greenest observation is that it can bias the sampling toward the greener vegetation (forest, irrigated land, etc.). The usefulness of this product for monitoring global agriculture is being evaluated by units of NOAA and USDA.

Insolation, the primary energy source for growing crops, is used in numerical models for estimating crop yield, potential evaporation, and soil moisture. The amount of solar radiation reaching the surface is determined by the transmittance. Under overcast conditions, up to 60 to 70 percent of incident solar radiation may be reflected to space and another 10 to 15 percent absorbed within the cloud. The satellite directly observes the reflected component of the incident radiation, so satellite measurements in the visible part of the spectrum are directly related to insolation at the surface. The NOAA Geostationary Operational Environmental Satellite (GOES) is the preferred data source for satellite estimates of insolation because its repeated observations throughout a day allow tracking of changing cloud conditions. Where geostationary data are not available, techniques using polar orbiter data have been developed.

An insolation method has been developed that uses hourly GOES visible data to estimate hourly insolation. The technique involves regression against observed target brightness as measured by GOES, and the known brightness of the target under clear conditions. The difference between these two quantities is a measure of cloudiness. Hourly estimates are summed to give a daily total insolation, which is the measure used in agricultural models. Figure 11 shows a comparison of satellite estimates of daily insolation against pyranometers. These data are for satellite estimates colocated with selected sites in the NOAA pyranometer network. Insolation estimates are currently being made and archived for all of the United States and for agriculturally important areas in Mexico and South America.

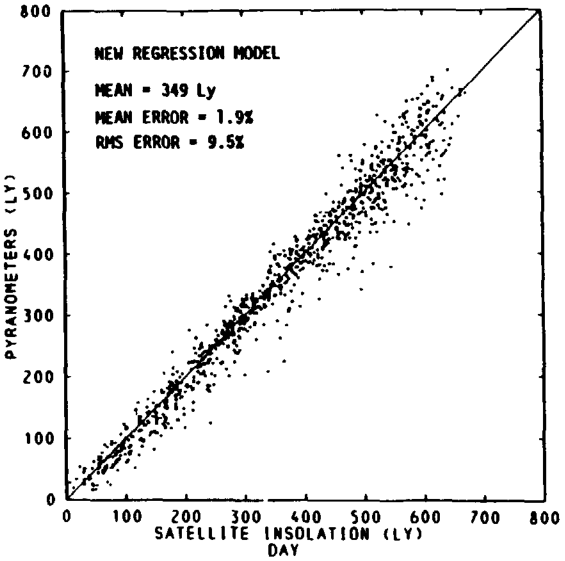


Figure 11.- Observed daily total insolation versus satellite estimates using hourly GOES data.

Canopy temperature, shelter temperature, dewpoint temperature, and daily maximum and minimum temperatures are all needed for use in crop and soil moisture models. Surface temperature has a high spatial variability which contributes to crop forecasting errors where observations are sparse and not representative of the whole region. Quantities derived from satellite data are area averages. For large agricultural areas a single satellite estimate may be more representative than two conventional observations within the area.

The approach chosen to obtain temperatures for agricultural monitoring is through the operational atmospheric soundings. The enhanced sounding processing provides temperature and moisture soundings for 3- by 3-pixel arrays of the high resolution infrared radiation sounder 2 (HIRS/2) instantaneous fields of view (IFOV's) giving a ground resolution of about 75 kilometers at nadir. Canopy temperature is simply the moisture corrected brightness temperature observed in an atmospheric window channel of the HIRS/2. If the radiating surface of the Earth is covered with vegetation, then the surface is a plant canopy. Of course, the IFOV for the HIRS/2 is so large that the radiance measured is from a mixture of surface types (water, bare soil, crops, and native vegetation).

Shelter and dewpoint temperatures are obtained by regression using the Television Infrared Observation Satellite (TIROS) operational vertical sounder (TOVS) data and sounding products as predictors in the equations. Figure 12 shows satellite estimates of shelter temperature compared with observed values from NOAA-6 soundings. The results shown are for clear and partly cloudy conditions during spring and summer. The error increases for cloudy retrievals (microwave) and during the winter.

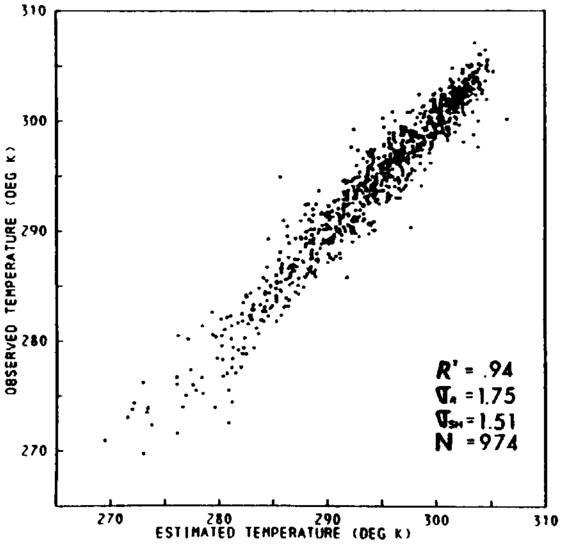


Figure 12.- Shelter temperature plotted against satellite estimates for clear and partly cloudy retrievals for April through July 1981.

Estimates of maximum and minimum temperatures are obtained by regression against shelter temperature, local solar zenith, and cloud cover. The overpass times of the daytime polar orbiter (NOAA-7) at 0230 and 1430 local time are near optimum for estimating the daily maximum and are good for estimating the minimum.

Since the maximum and minimum temperature estimates are liable to considerable error, the experimental temperature product being prepared for USDA is a blend of satellite and surface temperature observations, with greater weight given to the conventional measurements. The satellite values enter the field where conventional data are sparse.

As part of the agricultural monitoring program, interactive and fully automated techniques are being developed for analysis of precipitation over major crop growing regions. A manual method was developed into an interactive method which uses mapped NOAA AVHRR data, climatic rainfall analyses, and convectional cloud and rainfall observations from the global telecommunications system. The objective is to obtain a more accurate distribution of daily rainfall than was previously possible with convectional raingauge data. A meteorologist analyzes a cloud type field based on interpretation of the rain clouds observed in the visible and infrared satellite imagery. The computer uses the climatic rainfall analyses and global regression equations to estimate the rainfall between satellite passes. An example of a field of precipitation estimates superimposed on cloud imagery is shown in figure 13.

Figure 13.- A field of precipitation estimates superimposed on cloud imagery for a mapped AVHRR scene.

A second method uses similar input data on a more automatic approach where the AVHRR infrared temperatures are converted directly into precipitation estimates. In this method, the analyst edits the resulting precipitation field. In the two procedures discussed above, the most important responsibility of the meteorologist is to interpret and analyze for the development or dissipation of rain clouds during the 6- or 12-hour period between passes.

The third technique developed uses hourly GOES infrared images for automatically tracking and measuring the growth of convective cloud systems. The estimates are automatically generated for crop growing regions and are transferred for climatic adjustments and editing on interactive equipment.

Houston, Texas

Considerable effort has been made to develop a practical method of computer screening cloud-contaminated pixels from satellite data. A simple Fortran subroutine has been developed that can quickly and efficiently perform a hierarchical classification of NOAA-7 AVHRR data into clouds, haze, water, bare soil, and vegetation. The subroutine uses data from all five AVHRR bands in a hierarchical series to obtain the classification results. The approach allows the subroutine to adjust automatically for time of year and scene location. Bands 3 and 4 are used to detect the presence of haze. Bands 1 and 2 are used to detect clouds and to classify cloud-free data into water, bare soil, and vegetation. The approach developed for NOAA-7 AVHRR data should be amendable to other satellite-sensor systems.

The increase of atmospheric haze caused by volcanic eruptive products, as measured by the NOAA-7 AVHRR data, was demonstrated. Prevailing nadir atmospheric transmission, measured on the ground at Weslaco, Texas, before the El Chicon volcano eruption was 0.686, and afterward it was 0.611. This represents a decrease of 10.9 percent (fig. 14). The decrease of atmospheric transmission measured on the ground agreed with increases of NOAA-7 AVHRR digital count minimum (DCM) values in the visible and infrared bands obtained over the Gulf of Mexico. The DCM's ranged from 17 to 37 before, as compared to a range of 45 to 116 after, the eruption. These results demonstrate

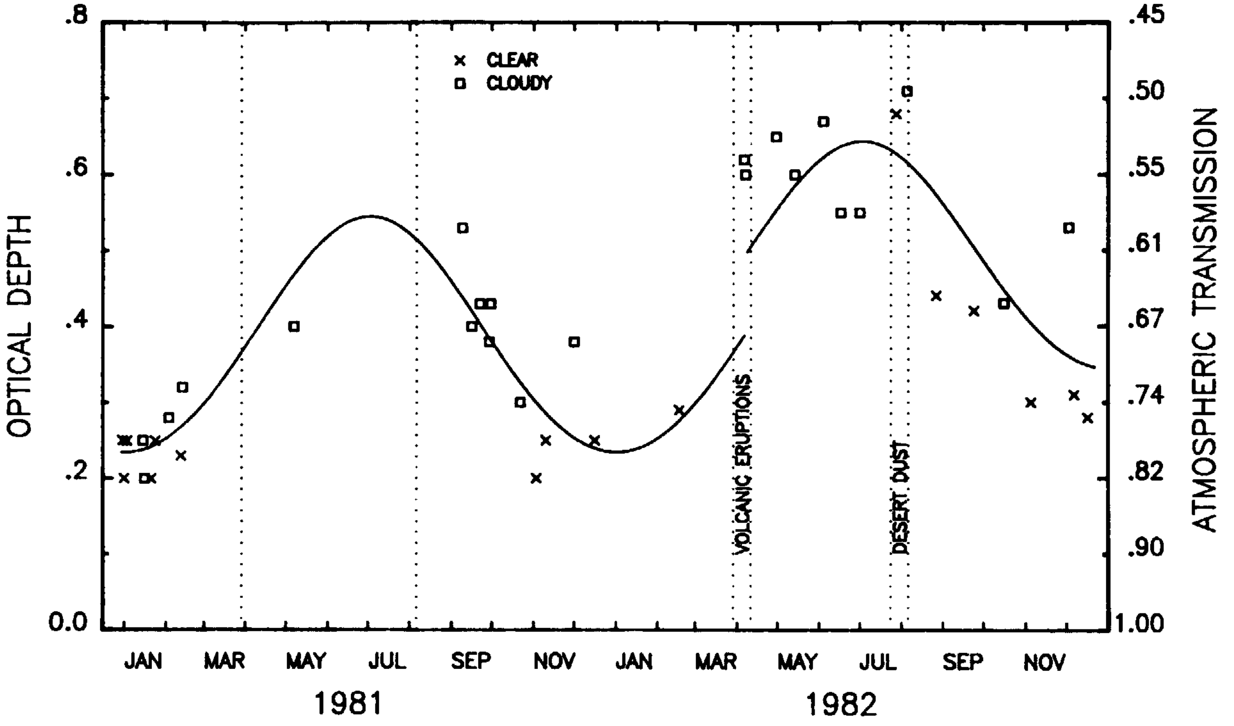
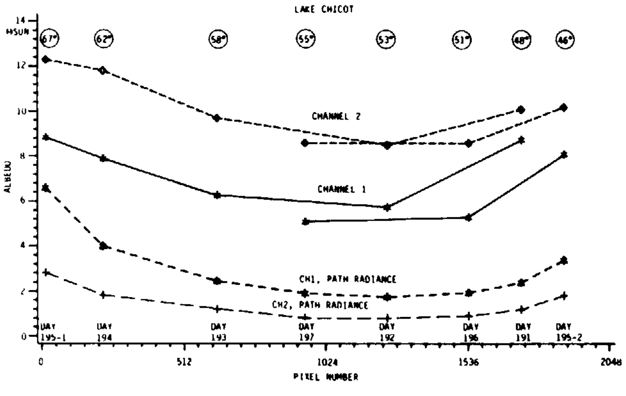


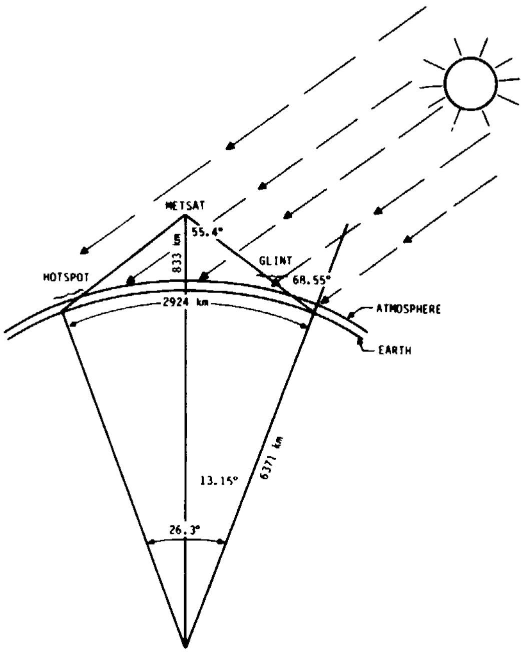
Figure 14.- Prevailing nadir atmospheric transmission, ground-measured, and NOAA AVHRR minimum digital counts before and after the El Chichon Volcano eruptions.

the importance of monitoring NOAA-7 AVHRR DCM's for transient atmospheric haze effects that could potentially interfere with early warning crop stress detection activities.

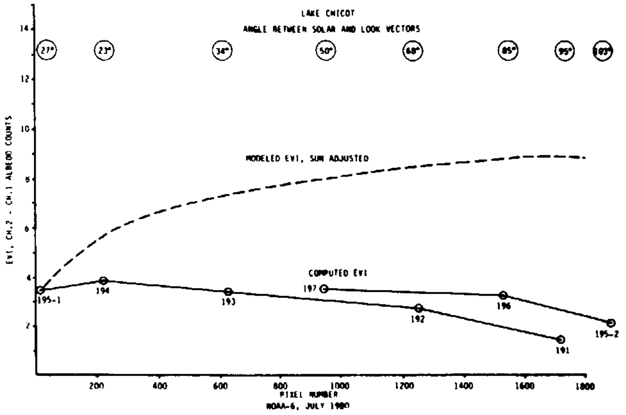
Another study researched the effects of solar illumination, view angle, and non-Lambertian surfaces on NOAA AVHRR sensor data. Figure 15 summarizes the results of applying geometric and solar corrections to the data. Results indicate that useful greenness information can be derived using data up to about 512 pixels either side of nadir. The effect of non-Lambertian surfaces becomes apparent when considering the angle differences between insolation and the satellite viewing vectors. It is suggested that the increased shadowing with increasing pixel numbers plays a significant role in the interpretation of data from non-Lambertian surfaces. The findings also show that solar zenith corrections (dividing AVHRR data by the cosine of the sun zenith angle) are not necessary when computing vegetation index numbers (VIN's).



(a) Radiance values as influenced by scan angle (pixel number) for channels 1 and 2 of the NOAA-6 AVHRR sensor.



(b) Geometric relationship between the Sun and the AVHRR scanning limits with respect to the Earth.



(c) Modeled EVI's (Lambertian surface) and computed NOAA-6 derived EVI's illustrate the atmospheric and illumination geometry effects. Simulated data were derived using Dave's data set.

Figure 15.- Geometric and solar correction of NOAA AVHRR data.

4.2 INVENTORY TECHNOLOGY DEVELOPMENT/SUPPORTING RESEARCH

The general objectives of the ITD/SR projects during FY 1983 were to research, develop, and test space remote sensing technology in order to better understand the characteristics of vegetation-related features of the Earth's surface, and to develop methods for observing and analyzing these data and for extracting information about the Earth's surface, nature, and dynamics. The FY 1983 research was expanded from previous years' work on crop specific techniques to include research on all types of vegetation and global surveying applications. The ITD/SR projects are managed by NASA with participation by USDA and NOAA.

The ITD/SR research expands and improves upon the remote sensing technology developed in previous years, and beginning in FY 1983, it focused on corn/soybeans identification, vegetation mapping, TM, AVHRR, microwave and soils research, and estimation of biophysical characteristics.

4.2.1 Technical Objectives

The FY 1983 technical objectives were focused on the following:

- The testing of a crop temporal profile technique for corn/soybeans identification in Argentina.
- An evaluation of the use of TM data for corn/soybean identification.
- An evaluation of the use of TM data for land cover separability.
- An assessment of the capabilities of the AVHRR for vegetation monitoring.
- A determination of the spectral separability of forest species by different sensors.
- Continued research in the determination of quantitative relationships between soil properties and spectral response.
- Research and development on the estimation of biological productivity - especially forests, grasslands, and cultural vegetation - from remote sensing.

4.2.2 Corn/Soybean Identification

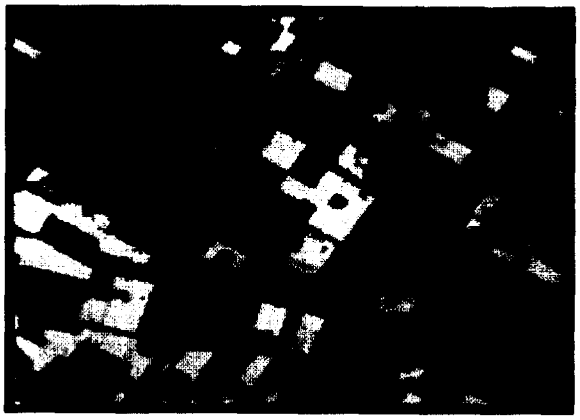
Argentina

A crop temporal profile technique was developed during 1982 to permit multidate Landsat spectral data to be interpreted in terms of key vegetation growth parameters. The resultant parameters, such as date of emergence, peak greenness, length of the growing season, and maturity stage, can be uniquely related to specific crop types.

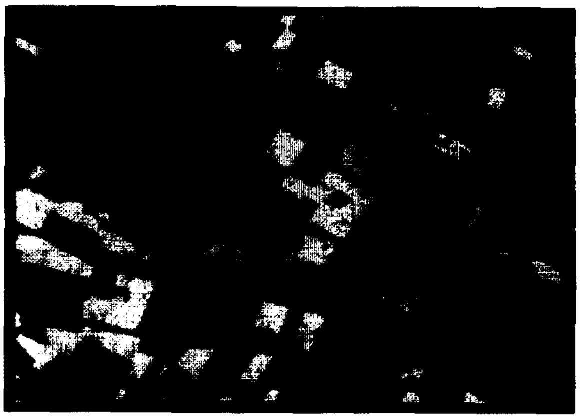
A typical crop temporal profile uses three features - the maximum value of greenness, the time distance between inflection points of the fitted profile, and the time of peak greenness - to automatically label and separate corn and soybeans using Landsat spectral data. As reported in the 1982 AgRISTARS Research Report, the relationship between these features and crop type was shown to be stable for corn and soybeans over large areas of the United States for 3 consecutive years. The higher accuracy for crop identification and proportion estimation obtained using this technique needed only to be tested in a foreign corn/soybeans region.

During FY 1983, this technique was applied to six segments in Argentina using Landsat-2 and Landsat-3 MSS data.

The same three profile features used in the U.S. study provided corn and soybean discrimination in Argentina. Results on Argentina segments using the automated profile technique gave a crop proportion estimate within 2 percent of those results using ground-truth labels (fig. 16).



(a) Results obtained by using ground-truth labels for corn, soybeans, and other crops to train the temporal profile classifier.



(b) Results obtained by automatically training the profile classifier using decision rules developed over only four segments within the United States.

Figure 16.- Classification results, segment 0682, Salto, Argentina.

Iowa

A multitemporal set of TM and TM simulator (TMS) data for Webster County, Iowa, was converted to TM greenness, and the multispectral profiles extracted were the same as those used with MSS data in the Argentina test. The profile features were found to be the same using MSS and TM data, and the performance accuracy was, on the average, 8 percent higher using TM data compared with MSS data. The increased accuracy was the result of a combination of better resolution, improved wavelength coverage, and a better S/N ratio.

Figure 17 shows the results of the TM classification: red is corn, blue is soybeans, and black is everything else. Figure 18 shows the areas of disagreement between ground survey data and classification results for soybeans. Red, pink, and green are the only areas of disagreement. The classification accuracy for corn is 96 percent and for soybeans is 90 percent.

It has been demonstrated that the same profile features apply in four years from 1978 to 1982 for two different sensor systems and two different countries.

Previous analyses of TMS data have shown that bands 1 through 4 of the TM are the optimum for the separability of corn and soybeans in Iowa in early August, but the mid-infrared bands provide additional separability during this period. An analysis of the three TMS scenes and three TM scenes acquired over central Iowa was undertaken to test the earlier findings and to determine both the additional amount of information provided by the mid-infrared spectral bands throughout the crop year and the effect of the increased TM quantization levels on corn/soybeans separability.

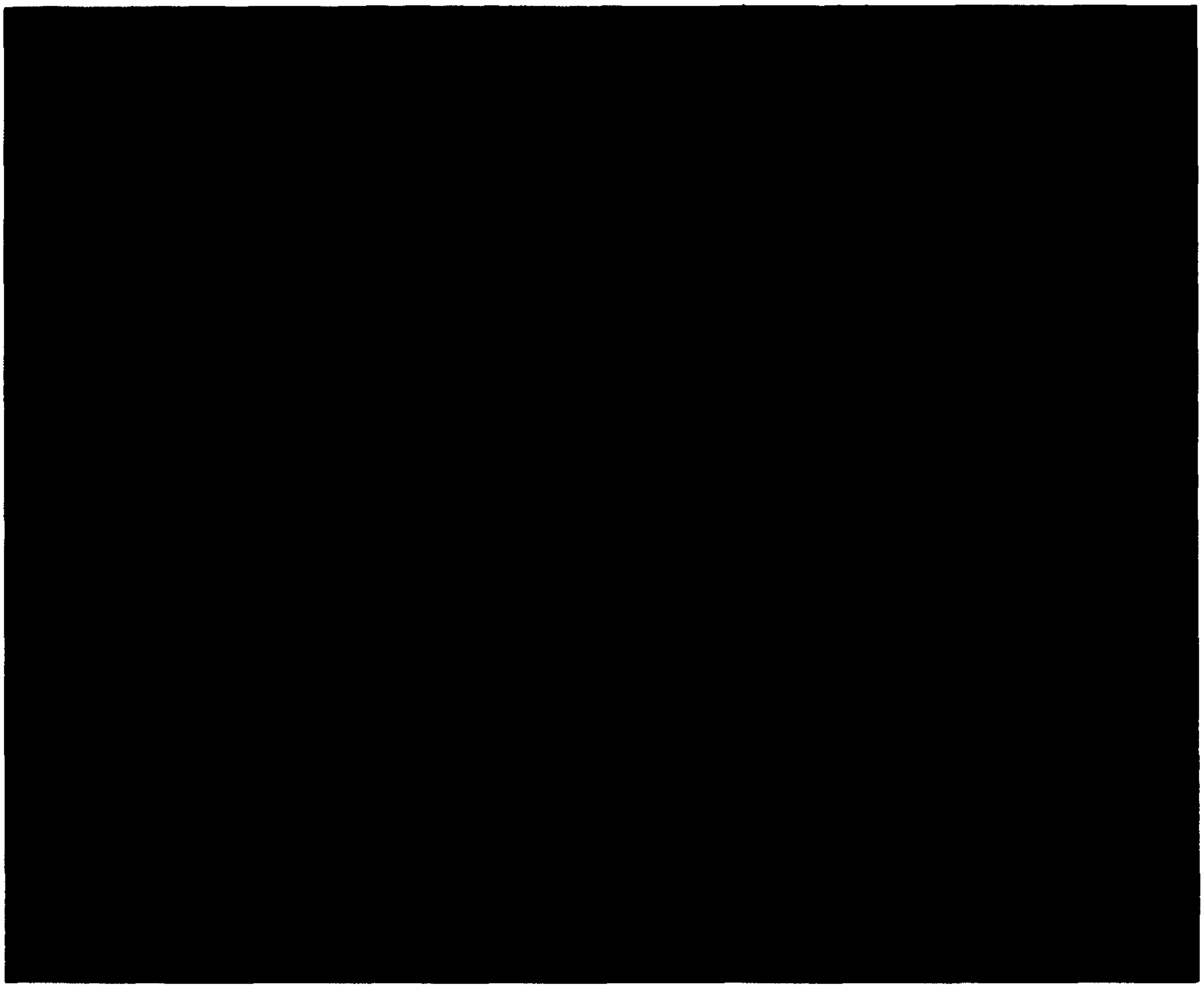


Figure 17.- A color-coded classification map of a TM scene. Red = corn; blue = soybeans; black = other.

Figure 18.- A color-coded misclassification map of a TM scene. Yellow = complete agreement between corn and soybeans; green = ground survey soybeans missed by classifier, blue = ground survey corn; pink = ground survey corn called soybeans; and red = classifier-called soybeans called other by ground survey.

The separability measure used in this study was the Fisher Information function. It was calculated using all seven spectral bands and the four visible and near-infrared bands. A value of 1.0 for this function indicates that two species are completely distinguishable and a value of 0 indicates that no separability exists. Figure 19 shows that September 3, 1983, was the best separability date using only the visible and near-infrared bands. The mid-infrared bands provided a separability on July 31, 1983, comparable to that on September 3, 1983. This result corroborates previous results using 1981 helicopter spectrometer data over this same sample segment. Early in the crop year (June 23), bands 1 and 3 (blue and red) were the best single bands. Later (August 2), bands 5 and 7 (mid-infrared) were best. In early September, both the mid-infrared and near-infrared (bands 4 and 5) were best. During harvest (October 21), the thermal (band 6) was the best single band.

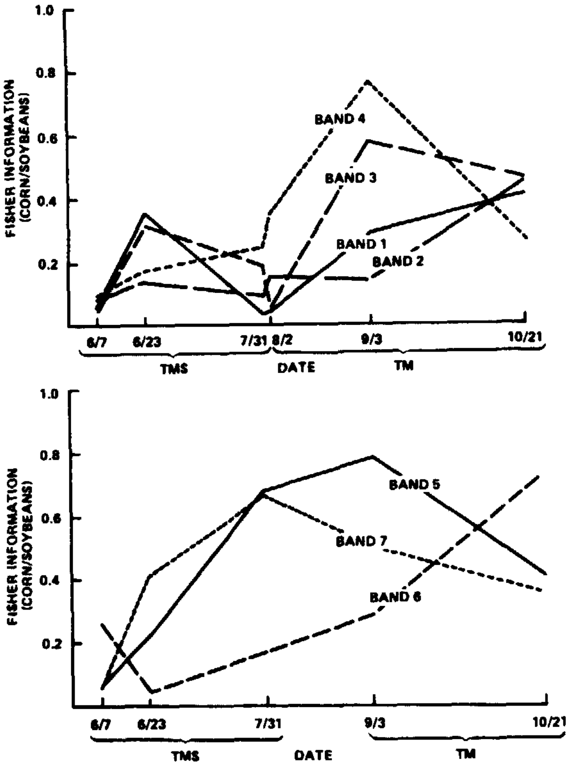


Figure 19.- Separability results for corn and soybeans using the Fisher information function on multi-temporal TM and TMS data over Webster County, Iowa, 1982.

4.2.3 Land Cover Separability

Planned research using TM data was impacted by the loss of the sensor acquisition capabilities. However, extensive single-date analysis in class separability was achieved from data acquired on August 22, 1982, over northeast Arkansas. An assessment of the relative contributions of the reflective bands (the TM thermal band was not included) to separabilities was completed. The basic data set consisted of four study sites which represented a wide variety of crops, land cover types, and range of conditions.

From these sites, approximately 1600 pixels that were ground verified were submitted to feature separability and subsequent classification algorithms. All possible band combinations were analyzed. Figure 20 represents the overall results achieved: (1) all bands; (2) the best three-band combination; and (3) the MSS "equivalent" bands for the 21 different categories. Figure 21 depicts the results from all three-band combinations. The primary result from these analyses revealed that performance was most sensitive to the inclusion or exclusion of bands 4 or 5.

The results of these experiments were achieved from a single data set, at a single acquisition period, and at conditions specific to that geographic region and time period. However, these caveats can also be viewed as components of a "worst case" situation, whereas a substantial number of classes (21) with

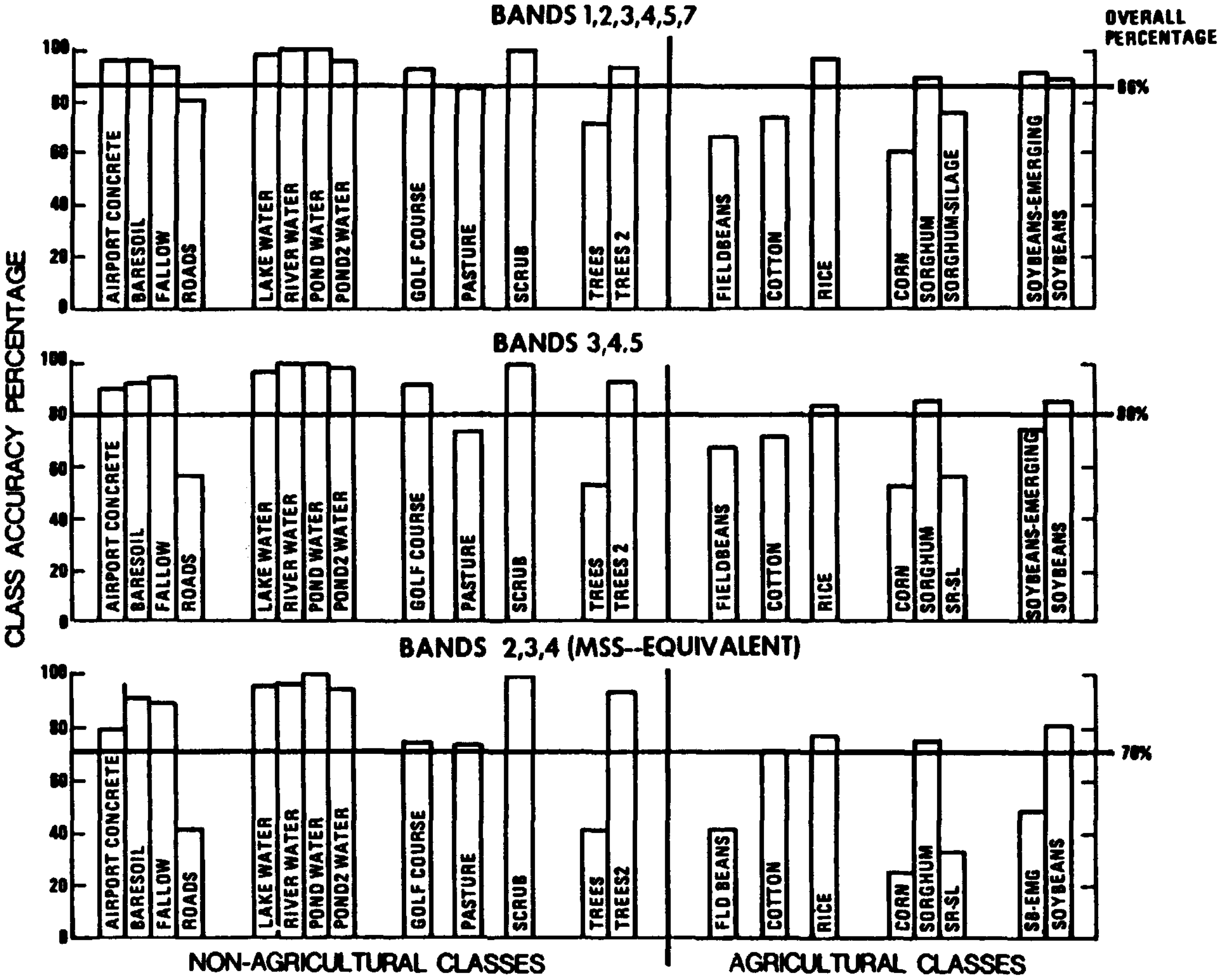


Figure 20.- Single-date TM analysis of Arkansas scene, August 22, 1982.

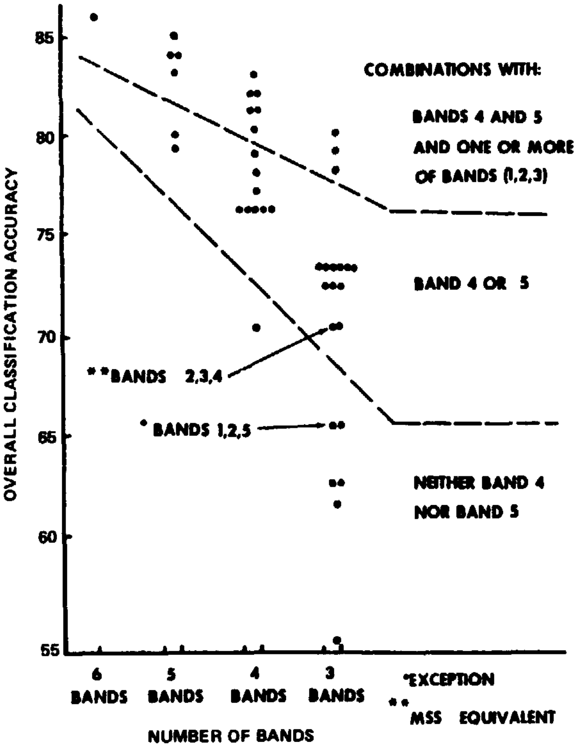


Figure 21.- Band combination analysis using single-date data, Arkansas scene, August 22, 1982.

single-date data achieved separability performances comparable to previous results with MSS over a smaller number of classes that required multitemporal data.

In another study in northeast Oklahoma, supervised, maximum-likelihood classifications of Seasat, Shuttle Imaging Radar A (SIR-A), and Landsat pixel data demonstrated that SIR-A data provided the most accurate discrimination (72 percent) between five land cover categories - cropland, pasture, forest, water, and urban. Furthermore, spatial averaging of the synthetic aperture radar (SAR) data significantly improved classification accuracy because of a reduction in the effects of both fading and natural, within-field variability. As expected, multisensor classifications of field-averaged data show that the addition of L-band radar to Landsat data significantly improves classification accuracy (figs. 22 and 23).

4.2.4 AVHRR Vegetation Monitoring

The investigation to assess the capabilities of the AVHRR for vegetation monitoring has focused on the development of technology as well as on an evaluation of the sensor's information content to provide a synoptic view that will permit the classification of the land surface into regional-level major ecosystem classes. Procedures that estimate or correct for the atmosphere have been evaluated. Thus, a good understanding of the conditions and limitations

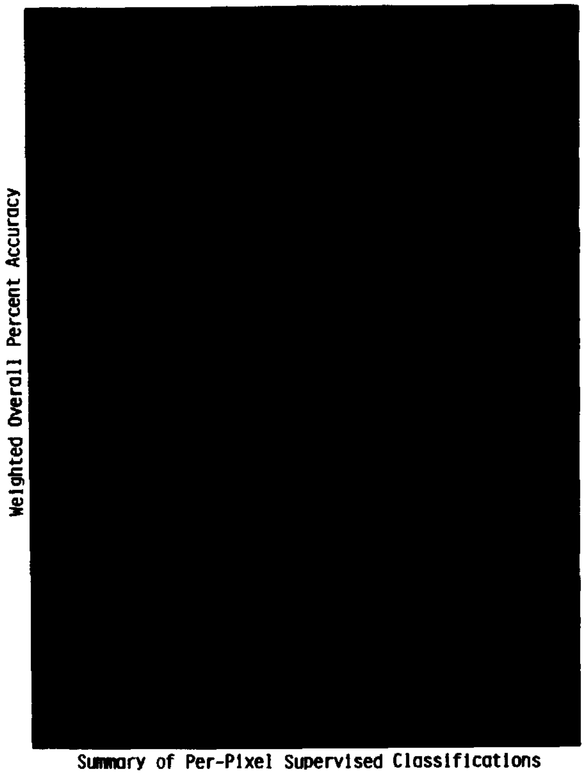


Figure 22.- Accuracy of per-pixel supervised land cover classifications of northeast Oklahoma.

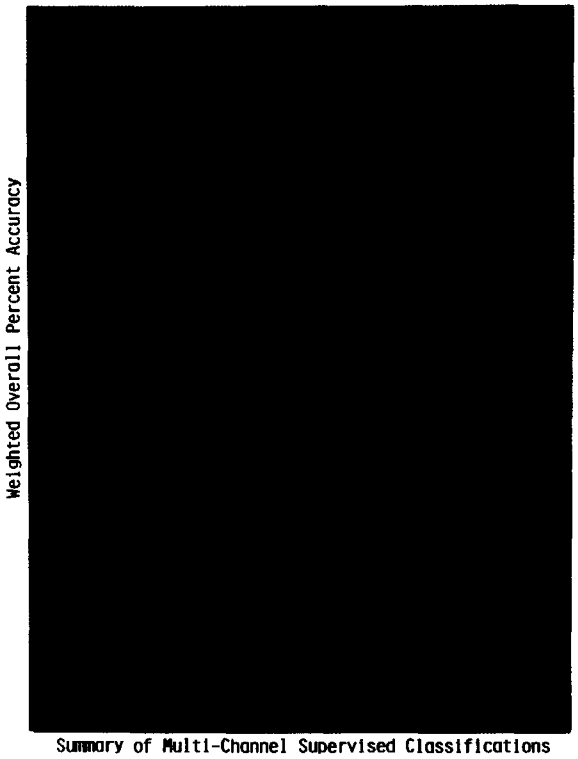


Figure 23.- Accuracy of field-based single and multichannel supervised land cover classification of northeast Oklahoma.

for use of the sensor has been attained (fig. 24). Preliminary analyses have also been performed to estimate the feasibility of using AVHRR data to distinguish land surface characteristics for use in a multistage sampling approach to land cover inventory and mapping. Results generally indicate that good separability exists between Level 1 Anderson land use classes.

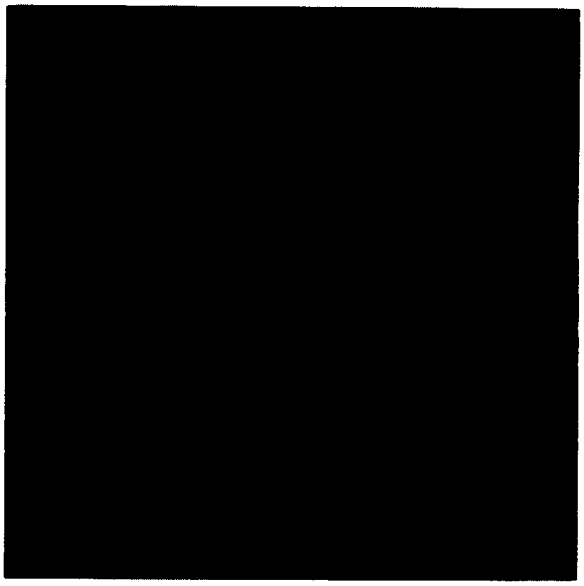
The AVHRR ground track progresses from west to east, so that with daily acquisitions, multiple viewing angle data may be obtained. Because of the non-Lambertian nature of the surface, different amounts of shadow are viewed at different angles, providing either a source of noise, if it is desirable that the scene appearance be independent of view, or a source of information, if the desire is to determine characteristics of canopy structure from these data. Figure 25 shows the pattern of change in the Gray-McCrary Index (GMI), AVHRR channel 2 - channel 1, for five scenes as the NOAA-6 AVHRR moved across the scene over 6 consecutive days, July 9-15, 1980. In this figure the sun is to the right, and pixels numbered near zero are to the far west end of the scan. Differences in the patterns of pine, hardwood, and crops indicate there is information concerning the nature of the canopy in multiple viewing angle data. In this figure the dashed curve represents the effect of viewing angle on a Lambertian model, with a light haze atmosphere indicating how poorly the Lambertian assumption simulates the radiative properties of these vegetative surfaces.

4.2.5 Forest Species Separability

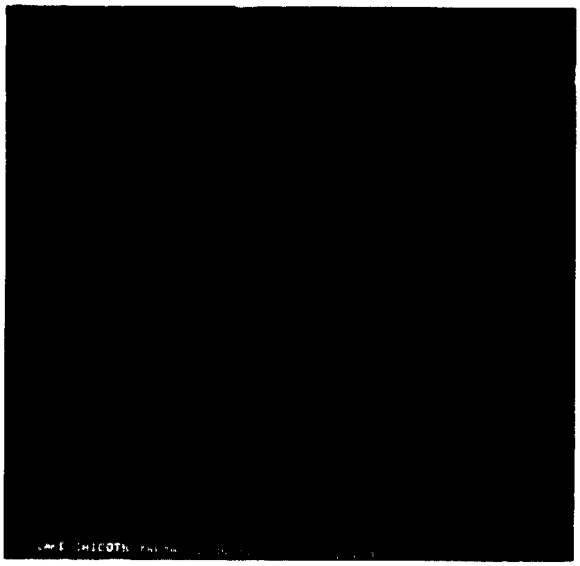
Remote sensing data can be used to stratify a scene into its various structurally distinct categories prior to estimating LAI or other biophysical characteristics. In anticipation that the relationships between LAI and reflectance might be species dependent, a number of studies were conducted to determine which species might be spectrally distinct.

Landsat MSS data and aircraft TMS data acquired over test sites within the Superior National Forest of Minnesota were analyzed using a clustering algorithm, CLASSY. CLASSY was specifically designed to determine the spectrally distinct components of spectral reflectance data.

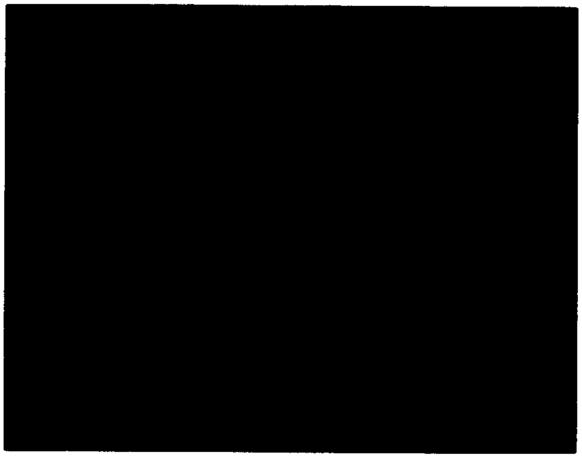
Five distinct classes appeared in the MSS data and fifteen distinct classes appeared in the TMS data. Higher spatial resolution and a larger number of spectral bands account for the increase



(a) AVHRR.



(c) TM.



(b) MSS.

Figure 24.- A three-sensor view of Lake Chicot, Arkansas, September 23, 1982.

in the number of distinct classes appearing in the TMS data. In the MSS data black spruce was confused with jack pine, but it was separable from aspen. In the TMS data, all classes observed in the MSS data were distinguishable. In addition, classes not distinguishable in the MSS data, such as brush areas, bogs, aspen-pine mixes, and burn areas, were distinguished in the TMS data.

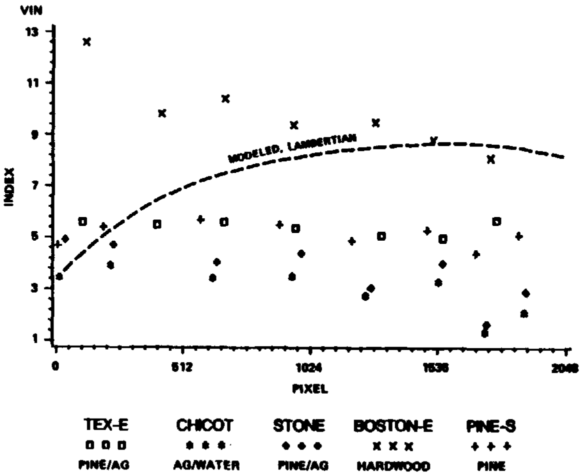


Figure 25.- AVHRR view-angle effect on vegetative index (channel 2 - channel 1).

The Fisher Information function was used to quantify the spectral separability of the various boreal forest species. This function is a measure of the overlap in spectral space between the spectral reflectance distribution functions found by CLASSY for the various species in the scene. In general, the conifers (black spruce and jack pine) are very distinct from the deciduous trees (birch and aspen). However, species within the conifer and deciduous categories are not very separable. Hence, other dates, bands, and multitemporal data will be explored to ascertain the separability that may be achieved.

Another study was conducted using TMS for assessing northern forest cover types. The objectives were to determine those TM wavebands most useful for differentiating northern forest cover types, and to obtain a baseline assessment of classification accuracy due to waveband combination (fig. 26). TMS data and coincident aerial photography were collected over a 23,200-hectare forested area near Baxter State Park in north central Maine. The results of the discriminant analyses suggest that useful waveband combinations include at least one band from the visible (0.4 to 0.7 millimeter), and one band from the mid-infrared (1.3 to 3.0 millimeter) spectral regions. The blue band proved most useful for discriminating coniferous defoliation categories, especially in differentiating healthy conifer stands from those damaged by the spruce budworm. An analysis of the classification accuracies indicated that most of the useful spectral information was contained in the first three bands. The two mid-infrared bands provided significant spectral information for differentiating all cover type groups considered. The second mid-infrared band proved most useful for coniferous defoliation assessment, while the first proved most useful for differentiating all cover types.

Three of the four most useful wavebands for discriminating northern forest cover types (bands 1, 5, and 6) are not available on the Landsat-1 through

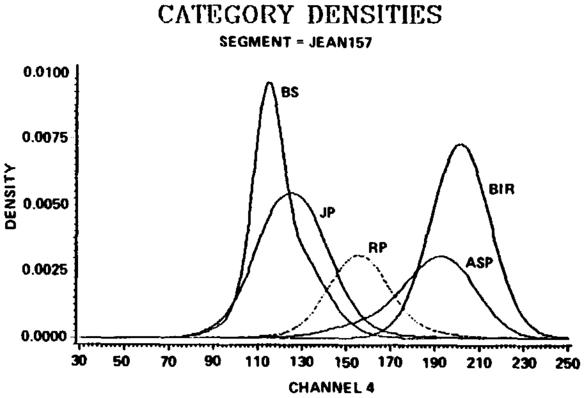


Figure 26.- Spectral separability results for tree species within the boreal forest of Minnesota, using the Fisher information function on channel 4. BS = black spruce, JP = jack pine, RP = red pine, BIR = birch, ASP = aspen.

Landsat-4 MSS's. Hence, significant improvements may be expected in the ability to spectrally differentiate the more detailed land cover categories using TM data.

Another study was designed to determine the information content of the TMS data acquired over the Clearwater National Forest, Idaho. Supervised and unsupervised classifications were performed on the TMS data to evaluate the use of conventional, 'on-the-shelf' techniques for extracting land cover resource information.

Results from the TMS analysis revealed that the use of conventional digital image processing, incorporating maximum likelihood classification, provides a readily available technology for TM data analysis. In addition, it was found that the increased number of spectral channels on TM were of significant value in improving classification accuracy. Additional findings from this analysis were: (1) TMS 7-channel, 30-meter, 8-bit radiometry yielded a higher classification performance than did 3-channel, 60-meter, 6-bit MSS-like data; (2) optimal channels for forest structure discrimination are from a wide range of the electromagnetic spectrum (visible, near-infrared, mid-infrared and thermal); (3) manually interpreted color composites of channels 7 (thermal), 4 (green) and 2 (blue) provided the best results for forest structure discrimination; and (4) the increased level of scene noise due to the increased spatial resolution of TM data may degrade per-pixel classification performance; therefore, techniques such as contextual classifiers, spatial data aggregation, and logic models should be evaluated as methods to more fully utilize TM data.

The East Texas Radar Experiment has a long-term objective, the goal of determining how well various classes of vegetation can be separated in a southern temperature forest. Classes of forest characterized by species, age, and stand density were selected as a test bed for this research. The short-term objective is to use scatterometers (nonimaging radars) for selection and design of imaging radars. Aircraft flights in September 1981 provided data from multiparameter scatterometers; multimode, X-band SAR; TMS; and color infrared photographs. Landsat MSS data were obtained earlier. The multiparameter scatterometer data have been analyzed using a simple single-feature, two-class separability measure. L-band (20-centimeter) cross-polarized data, horizontally acquired/vertically transmitted (HV), are useful for separating trees from other features and for discriminating between individual tree classes and non-tree classes, such as clearcut and grassland. Separability between various tree classes is best demonstrated by C-band (6-centimeter), cross polarization (HV). Figure 27 shows radar backscatter in decibels plotted against the number of readings for pine and hardwood classes. The classification error rate for these two classes is above 14 percent.

The multiparameter scatterometer data have also been analyzed using linear

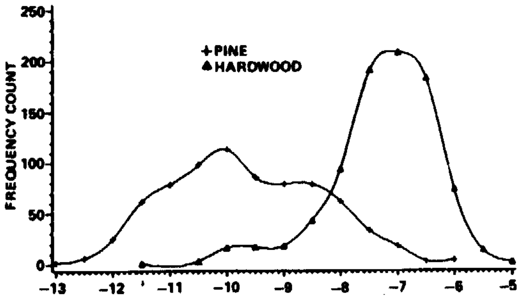


Figure 27.- Radar backscatter histogram: pine versus hardwood.

discriminant analysis, which is a multiclass, multifeature classifier. Higher frequency (C-band and Ku-band) gives the best overall classification accuracy, on the order of 50 percent; the addition of another frequency or polarization increases the classification accuracy to about 64 percent, while use of multiple angles further improves the accuracy to about 72 percent. The vertical transmit polarization seems to be very important in achieving good overall classification accuracy.

The X-band SAR data require digital preprocessing to obtain better quality images. In addition, the airborne TMS measurements must be preprocessed to conduct a synergistic study of optical and microwave data for forest classification.

4.2.6 Soils Research

The soils research effort is directed toward developing quantitative relationships between soil properties and spectral response to estimate specific soil physical, chemical, and interpreted properties related to biological productivity, biogeochemical cycles, and hydrological cycles.

Within the past year significant progress was made in the soils area. Laboratory soil reflectance measurements were used to simulate Landsat MSS digital counts for clear and turbid atmospheres and were found to be within the range of values for soils seen in Landsat data (fig. 28). Reflectance curve forms representing genetically homogeneous soil properties were found to be separable in greenness and brightness vector space. Organic matter content could be stratified into 0- to 2-percent and greater than 2 percent, with 80 percent accuracy. This technique of converting reflectance data from controlled experiments to simulated Landsat digital counts will enable researchers to account for the effect of soil on vegetation-spectral relationships, to conduct sensitivity analyses of the effect of soils on spectral models, and to develop a better understanding of the relationships of spectral and physical-chemical properties of soils.

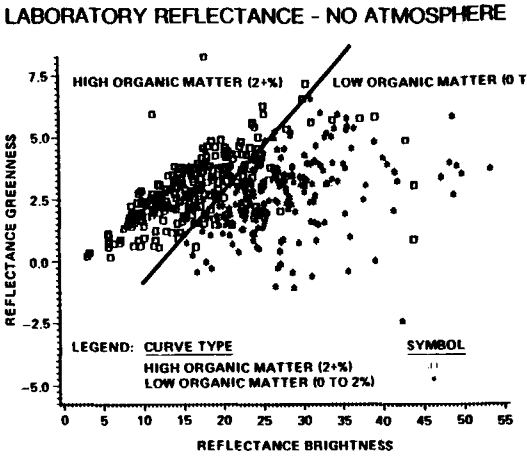
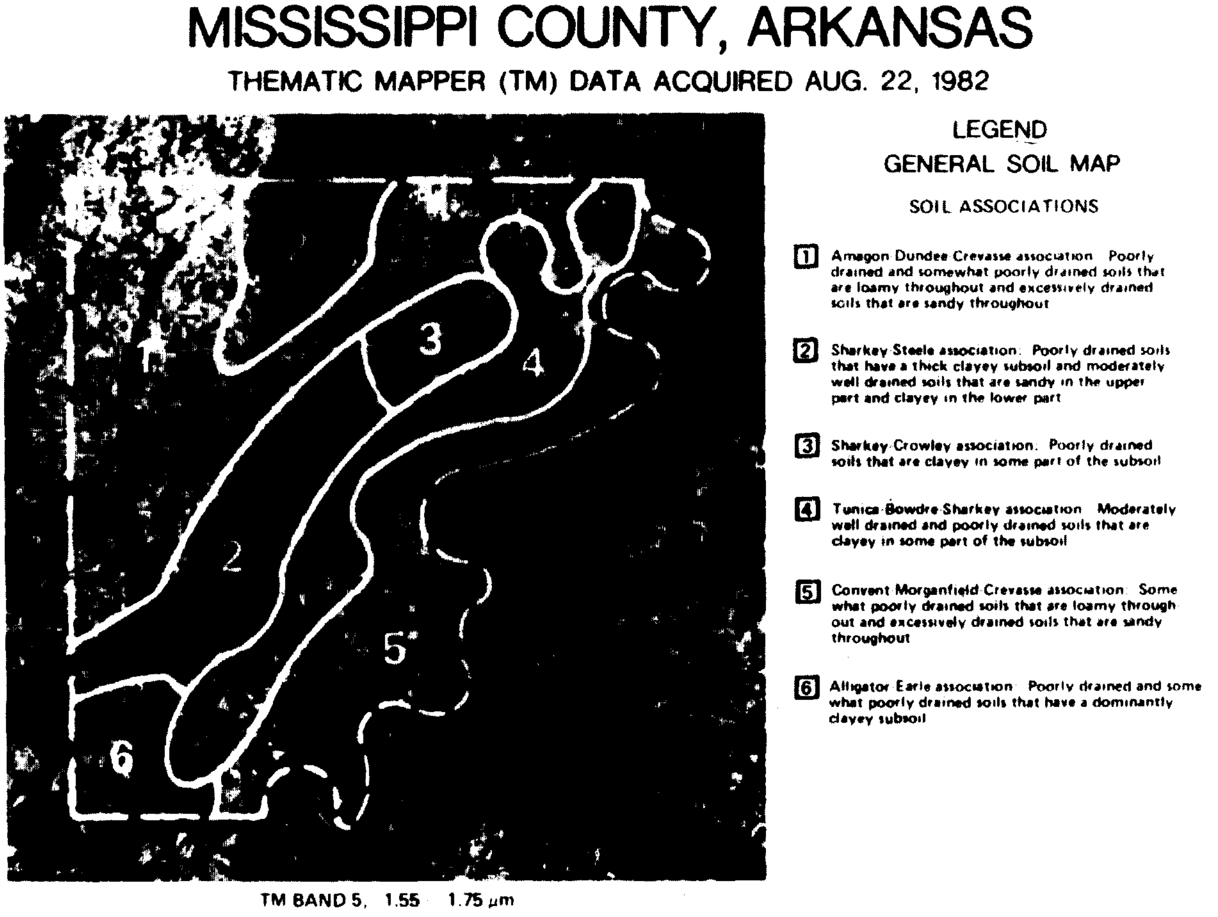


Figure 28.- Location of reflectance spectra curve types of high and low organic matter in greenness and brightness vector space.

Landsat TM data acquired over two different regions (Mississippi River alluvium and glacial till in Webster, Iowa) were evaluated to assess field soil effects on vegetated landscapes and to determine whether TM spectral bands provide information for soil association maps. Results from these studies indicate that the TM provides information which is related to the soil properties. Within the alluvium, the most useful bands for identifying soil association boundaries located by USDA's general soil maps (see fig. 29) were the 0.76 to 0.90 millimeter, the 1.55 to 1.75 millimeter, and the 10.4 to 12.5 millimeter. Within the glacial till region, aircraft TMS and Landsat-4 TM data acquired over soils ranging from bare to fully vegetated cover indicated that key soil properties (i.e., soil moisture regime) could be separated throughout the growing season. The September 3, 1983 TM data, even with a vegetated cover of greater than 90 percent, separated the soil moisture regimes with 72.5 percent accuracy for soils covered by corn and 68 percent accuracy for soils covered by soybeans. These results indicated that the improved spectral and spatial resolution of TM offers the potential to separate important soil properties, even in regions with similar soils and under a dense vegetation canopy.



MISSISSIPPI COUNTY, ARKANSAS

THEMATIC MAPPER (TM) DATA ACQUIRED AUG. 22, 1982

LEGEND

GENERAL SOIL MAP

SOIL ASSOCIATIONS

1 Amagon Dundee Crevasse association Poorly drained and somewhat poorly drained soils that are loamy throughout and excessively drained soils that are sandy throughout

2 Sharkey Steele association: Poorly drained soils that have a thick clayey subsoil and moderately well drained soils that are sandy in the upper part and clayey in the lower part

3 Sharkey Crowley association: Poorly drained soils that are clayey in some part of the subsoil

4 Tunica Bowdre Sharkey association Moderately well drained and poorly drained soils that are clayey in some part of the subsoil

5 Convent Morganfield Crevasse association: Some what poorly drained soils that are loamy through out and excessively drained soils that are sandy throughout

6 Alligator Earle association Poorly drained and some what poorly drained soils that have a dominantly clayey subsoil

Figure 29.- TM band 5 overlaid on Mississippi County, Arkansas, general soils map.

4.2.7 Biophysical Characteristics Estimation

The distribution, dynamics, and composition of vegetative land cover are prime factors in the global energy balance. Vegetative evapotranspiration affects global circulation and patterns of precipitation and temperature. Biological productivity of land-related vegetation plays a key role in determining the amount of carbon dioxide in the atmosphere. Vegetation structure determines the ratio of runoff to storage and evaporation in the hydrologic cycle. Existing process models require a knowledge of the global distribution and dynamics of the attributes of land-related vegetation. Currently, this information is not very accurate or complete. Improvements in the estimation of vegetation characteristics, temporal changes, and distribution patterns are needed to provide an understanding of global processes. Remote sensing can provide critical inputs to process models which predict biological productivity and biomass based upon known physical and biological principles and remotely sensed parameters such as LAI, canopy temperature, and soil moisture.

The current research in biophysical characteristics has concentrated on the remote estimation of the biological productivity of forests, grasslands, and cultural vegetation, especially the relationships between plant structure and biophysical properties (LAI and biomass) and between radiometric and biophysical properties of vegetated canopies.

Three study sites were selected to represent each of the major biomes. The Superior National Forest near Ely, Minnesota, was chosen because it contained important species found in boreal forests - black spruce, aspen, and birch. The Konza Prairie near Manhattan, Kansas, is a tall grassland research area which supports long-term ecological studies by the National Science Foundation. The Purdue University Agronomy Farm in Indiana was selected because of its capability for measuring biophysical properties and environmental factors affecting biological productivity under controlled conditions.

Although ground estimates of LAI are not currently available for the boreal forest site, theoretical studies indicate that canopy reflectance is strongly related to LAI, leaf optical properties, canopy structure, and background or understory. These studies suggest that LAI can be estimated from remotely sensed data and that:

1. The ratios of TM bands 4:3 and 4:5 are superior to greenness for the estimation of LAI because both are less sensitive to leaf angle distribution, understory reflectance, and sun zenith angle.
2. Multiple view angles should greatly improve the accuracy of estimation of LAI.
3. If only nadir view reflectance data are available, the LAI-reflectance relationships will be canopy structure dependent, so that the scene would need to be stratified into groups with similar structure prior to estimation of LAI. This might require classification of the scene into structurally similar classes (e.g., species) prior to biophysical characteristics estimation.

Use of the ratio of TMS counts in band 4 to counts in band 3 (4:3 ratio) to map vegetation density in a gross way was qualitatively evaluated over a portion of the Superior National Forest test area. A simple level slicing was applied to the 4:3 ratio values over this area. The result is shown in figure 30.

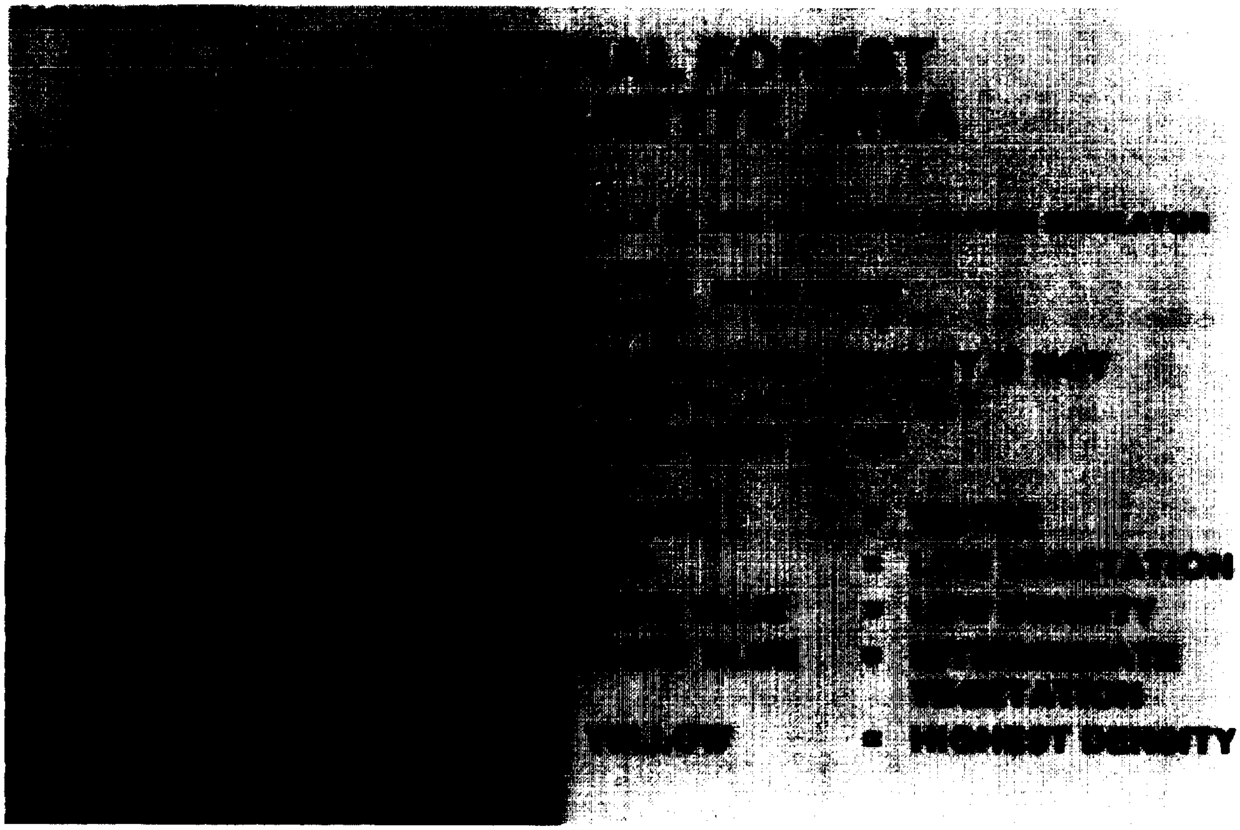


Figure 30.- Band 4:3 ratio image of a TMS scene showing variation in vegetation density over a portion of the Superior National Forest. Lake Jeanette is in the center of the image.

Black corresponds to water. The lowest values of the 4:3 ratio are coded red, the next highest dark blue, then light blue, and finally yellow. Qualitative evaluation of this density map from aerial photography and helicopter surveillance indicates that red pixels generally correspond to bare ground or roads, as can be seen from Echo Trail outlined in red, winding across the center of the image and touching the tip of Lake Jeanette in the image center. Yellow generally corresponds to very dense stands (e.g., dense aspen). However, the intermediate level 4:3 ratio correspondence to vegetation density was species dependent. In some cases, what appeared to be very dense black spruce stands had lower 4:3 ratios (dark blue) than did less dense aspen stands (light blue). It is likely that a scene will require stratification into structurally similar strata prior to application of the 4:3 ratio for vegetation density estimation.

In the Konza Prairie experiment, LAI measurements are already available, and as figure 31 shows, the bands 4:3 ratio tracks LAI throughout the season. Burned and unburned treatments were monitored in this experiment, and the two treatments can clearly be distinguished by the 4:3 reflectance ratio.

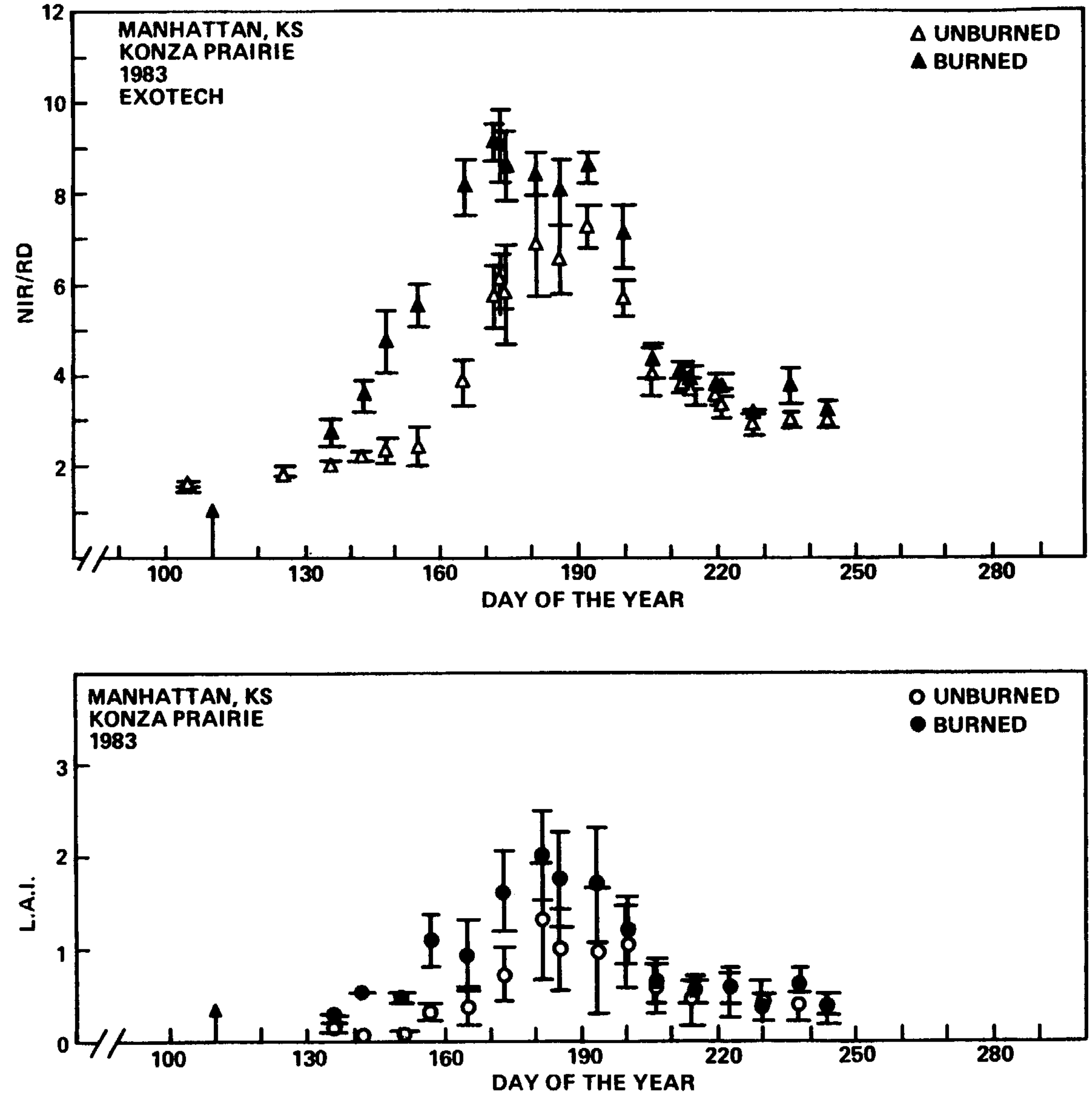


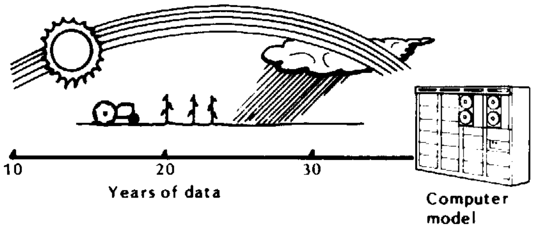
Figure 31.- Variation of the NIR/RD (band 4:3) ratio and leaf area index (LAI) during the growing season for unburned and burned control areas within the Konza Prairie.

4.3 YIELD MODEL DEVELOPMENT

YMD research utilizes the measurement of environmental and plant characteristics to project crop yield potential within a region. This effort is a key component of any commodity production forecasting methodology and, as such, contributes to both the domestic and foreign crop estimation processes. Research is jointly supported by NOAA/NESDIS, USDA/ARS, USDA/SRS, and staff support from NASA.

YIELD MODEL DEVELOPMENT

This is research to determine how various crops will respond to weather conditions, agricultural practices, and other factors. Many years of data are taken into account.



4.3.1 Technical Objectives

The FY 1983 objectives were:

- To test and evaluate candidate crop yield models.
- To develop new and improved crop yield models.
- To acquire, process, and store meteorological and satellite data appropriate for model development and testing.
- To conduct research on and to evaluate the use of satellite spectral inputs to yield models.

4.3.2 Yield Model Test and Evaluation

The initial phase of applying a set of test criteria to evaluate existing models is nearing completion. The models tested were of the type relating meteorological data to published yield series. These models, represented by the Center for Environmental Assessment Services (CEAS) and Thompson-type models, cover the crops of soybeans, corn, wheat, and barley. The evaluation consisted of internal model evaluation and comparative evaluation of the performance between models. In general, these models tend not to be sensitive to either extremely high or low yields. However, with the evaluation and documentation, they may be appropriate for a user's needs, provided the user is aware of the model limitations. Thus far in the AgRISTARS program, 47 reports have been issued concerning model comparisons and evaluations.

CERES-wheat is a wheat production simulation model developed for use in farm management, large area yield estimation, farm policy analysis, and identification of research needs. It was designed to account for the major factors influencing wheat yield, including weather, genetics, soil water, and sowing (time, depth, and rate), but excluding pests. The model runs with daily time steps and requires inputs of daily temperature, precipitation, and radiation. Genetic inputs are duration of growth stages, grain number, and grain weight. Soil inputs consist of water content at critical limits and factors influencing root growth. Stresses considered include plant water deficit and cold damage as they influence tillering, leaf and stem extension, assimilation rate, senescence, grain growth rate, and grain nitrogen.

To test the capability of the CERES-wheat model, 280 different data sets on wheat growth and yield were collected from 25 sites throughout the world between 36°S and 50°N latitude. Published and unpublished data from agricultural experiments where weather, soils, management, and genetic data were available allowed testing the validity of the model for estimating phasic development, biomass production, LAI, soil water, yield, and yield components. Yield in the data set (given in kilograms per hectare) ranged from 380 at Bushland, Texas, to 9520 at Greoux, France (fig. 32). The correlation coefficient for estimated versus observed yields for the data set was 0.89.

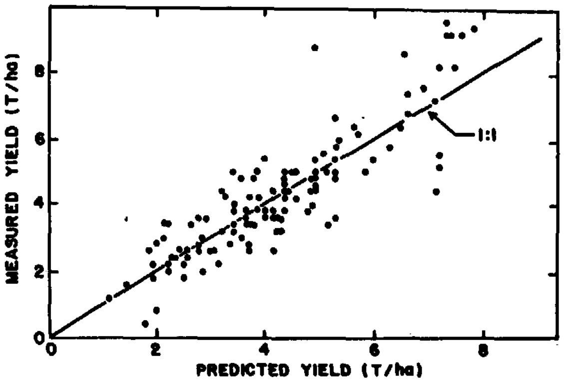


Figure 32.– A comparison of measured wheat yields with estimated yield using the CERES-wheat model for a diversity of environments.

The CERES winter wheat model was modified to produce operational yield estimates in the USSR throughout the growing season. The gridded meteorological data were provided to the NOAA/USDA Joint Modeling Center by USDA. The resulting yield estimates were returned for use in assessments. Ancillary data were also generated by the model, including stage of development (fig. 33).

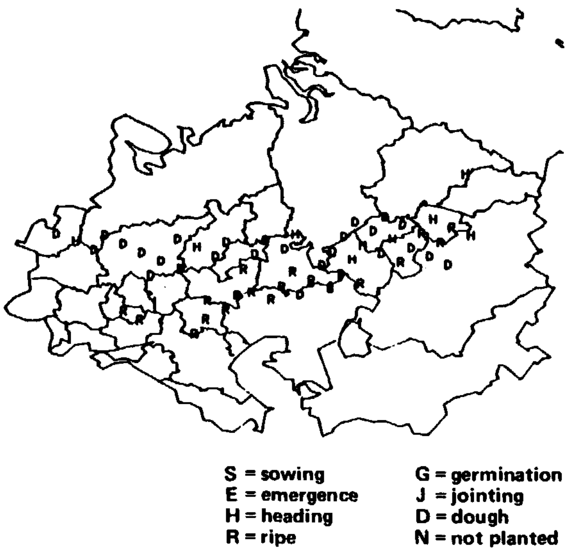


Figure 33.– CERES winter wheat model estimates of USSR spring wheat growth stages, July 31, 1983.

The model output was useful in assessing the wheat crop during the 1983 growing season as reported by FAS:

"The operation run of this model using weather data from 1981, 1982 and 1983 over the Soviet Union provided some very positive results that correlate well with information from the USSR and with other systems commonly used to produce yield estimates of winter wheat in the USSR . . . .

. . . The results of the model can only be described as good. This analysis is based on a set of circumstantial evidence and a very meager set of reported information from radio broadcasts or from newspaper articles. Most specific is the information from weather reports that place the crop calendar stages. This information generally placed the crop stage within a few days of those reported in the model. This became very satisfactory and in no area was the crop stage found to be more than five days off. This was true for both the winter wheat and spring wheat models. The other piece of information deals with yield. A Rayon level yield of almost 30 C/ha was reported for Novomokiro Rayon in Denepropetropovlovsk Oblast. The model yield for this area is 29.7 C/ha. This is the only 'ground truth' information on yield that could be used for a grid cell comparison. Although little ground truth information is available, yields calculated by the model were nowhere more than 1.5 C/ha different than those estimated by the analyst or those measured by the Vegetative Index Numbers.'

The CERES-maize model was tested and also became quasi-operational. The model was used in real time to evaluate the U.S. corn crop and the impact of the drought on corn yield. These indications were based on the weather data from 34 stations: observed data to date; forecast daily maximum and minimum temperatures for days of the coming week; and average temperature and precipitation beyond that point in time. The results of this effort and the comparison with the USDA within-season estimate indicate the model provided an early estimate of the low corn production (fig. 34).

The 1983 season was unusual. It started with a wet spring which delayed planting but which in some areas mitigated the effects of hot, dry July and August periods. The model forecasted 1983 yield reductions from 1982 levels of 31 percent to 55 percent in Illinois, Indiana, Iowa, Ohio, and South Dakota where very little corn acreage was irrigated. However, in Kansas and Nebraska where most acreage was irrigated, yield estimates indicated only slight reductions, if any, on irrigated acreage, but severe reductions on nonirrigated acreage.

The Texas A&M wheat model (TAMW) was also operational and available to provide real-time assessments. These, however, were not run on an operational basis.

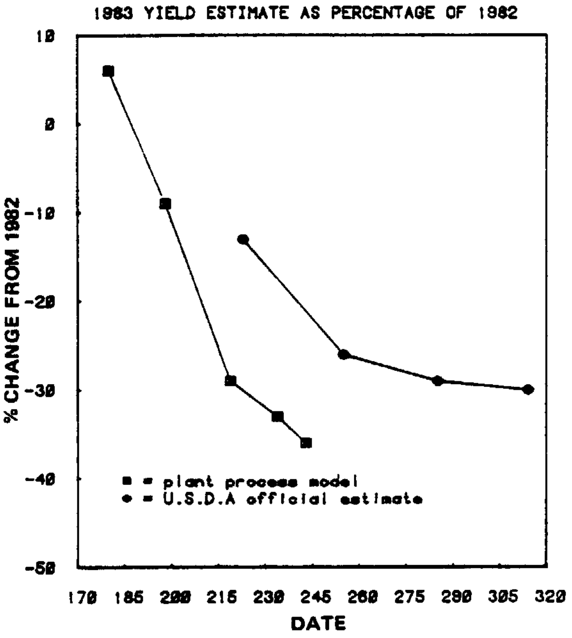


Figure 34.- Comparison of CERES-maize model yield estimates with USDA official estimates.

Phenology Models

Phenology models which estimate the stage of crop development are a vital component of plant process models. Because weather has a different effect on yield depending upon the developmental stage of the plant, the ability of a model to correctly identify the stage is critical. Three winter wheat plant process models were compared as to the accuracy of their estimated stage date predictions for large areas.

The models compared were CERES-wheat, TAMW, and A. M. Feyerherm's modification of the Baier-Robertson model. Each model was used to predict phenological stage dates for Kansas crop reporting districts (CRD's). The predicted dates were compared to observed dates which were collected by USDA/SRS for use in the agency's *Weekly Weather and Crop Report* for the years 1952 through 1980. The predicted stages included jointing, heading, dough, and ripe. Final yield estimates were also compared.

Results indicate that CERES-wheat is slightly superior in its predictions. The Baier-Robertson model is about 23 days early in predicting jointing. TAMW is consistently about 10 days early on all observed stages. Each of the models would be useful in predicting phenological stage dates and yields accurately, but the CERES-wheat model is recommended for predicting winter wheat growth stages at the CRD level.

A phenology model for soybeans was not available for application, so one was developed. Much is known about the sensitivity of soybean development to meteorological conditions. The soybean plant responds strongly to daylength and temperature in its phasic development. Daylength responses, especially, vary greatly among varieties. Under very dry conditions, water stress may also affect development. Attempts to develop physiologically-based large area yield models for soybeans have been hampered by the lack of a growth stage model which incorporates these responses and is also applicable to a wide range of geographic and climatic settings.

A phenology model was developed and tested for soybean maturity groups I to V. The model is based on temperature, daylength, and water availability. The model coefficients were tested on data taken at the same time at Spickard and Mt. Vernon, Missouri, and on data for the 1981 season from 22 international sites. The test results indicate that the model will generate reliable estimates of soybean growth stages over a wide range of climatic conditions.

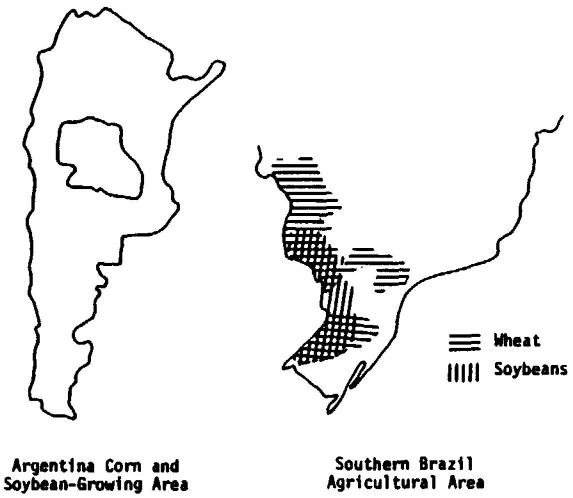
The model is suitable for incorporation into a soybean growth simulation model or for running as an independent crop calendar model. It requires only daily maximum and minimum temperatures and rainfall.

Regression Models

Following the techniques used to develop the Argentina wheat models in FY 1982, additional yield models for Argentina and Brazil were developed during FY 1983. Two models were derived for Argentina's yields of corn and soybeans. These models are at the country level and are based on monthly average temperature and monthly total precipitation at stations in the crop area. The corn and soybean areas, both very similar, are located in a small part of central Argentina's humid Pampas.

Covariance models were derived for Brazil's wheat and corn yields. These models may be used to provide estimates for the states in Brazil. For wheat, five states were included in the model, and for soybeans, seven states were included (fig. 35).

For the past two growing season, models have been developed, improved, and operated for production in the three principal USSR grain producing areas (the Ukraine, Kazakh, and Belorussia). Grain models have been developed and preliminary results are being evaluated. These models are of the correlation or regression type, using several years of meteorological data and a published series of production estimates. The models indicate a sensitivity to weather variables as indicated by the changes that occur between using preliminary and final World Meteorological Organization (WMO) data. Model output generated on a current basis has been provided to



Argentina Corn and Soybean-Growing Area

Southern Brazil Agricultural Area

Figure 35.- Regression yield models developed for corn and soybeans in Argentina and for wheat and corn in Brazil.

those in USDA responsible for foreign estimates.

Other Model Evaluation

Sponsored research continued with development of a wheat model that is based on relationships observed from experimental plots, but designed to operate on aggregated data. Evaluation of this model was conducted for spring wheat in Minnesota and North Dakota, and for winter wheat in Indiana, Kansas, Montana, and Ohio. Results indicate that the model, as compared with CEAS or Thompson-type models, may have a higher degree of response to unusual conditions, without the requirement for site specific input data.

4.3.3 Yield Model Research and Development

The USDA/SRS has cooperated with scientists at the University of Florida to build a plant process model for soybeans, which can be used to predict yields at various stages of plant growth. In fact, the model has much broader application. It is part of a University project to develop models to aid in the farm management decision-making process. The structure of the model consists of leaf, stem (including petioles), shell, seed, and root tissue components.

In the model, the plant components are described as biomass per square meter of ground area. The structure of the model has been developed to describe the rates of change of component biomass resulting from changes in photosynthesis, respiration, tissue synthesis, and senescence processes. The model is interactive and contains menus displaying selected weather, management strategy, insect propagation, and production practice options.

Operation of the model, from a user's point of view, has three phases. In the first phase, the user selects the scenario and strategy. The second phase consists of a simulation of the entire soybean season for the conditions selected. In the third phase, the user selects the variables for graphing and obtains within-season plots of variables such as LAI index, insect population density, seed weight, and percentage of defoliation. Also produced during this phase are season-end results of yield, net profit, pesticide applications, and irrigation applied. The season-end values are provided for comparisons of strategies from run to run, whereas within-season values are displayed for evaluation of model behavior relative to expected or previously observed behavior. The user may then make another run, changing as few or as many menu selections as desired, or he may end the simulation session.

When the model is used for prediction purposes, plant part data collected in sample fields can be fed back into the model at the appropriate date(s) so that various predetermined parameter values can be modified to provide a description of simulated plant growth which is 'closer' to observed plant growth.

Other historical weather data for the general field site or simulated weather with location parameters is used as the weather for the remainder of the growing season to provide stochastic results for yield.

4.3.4 Satellite Spectral Inputs for Crop Yield Models

NOAA-7 Thermal Infrared Evapotranspiration Study

Data were acquired this year to investigate NOAA-7 thermal-infrared sensing related to plant evapotranspiration (ET). Exploratory research was conducted in this area because of the difficulty in obtaining ET information through other means; ET is important in modeling plant processes for yield determination. Input to ground measurement models generally involves a water balance model approach with an initial soil moisture determination and fairly precise 'continuous' precipitation measurement over the growing season at or near a point for which the model is to be operated (plot level).

The intended use of the data is to determine if, over a growing season, there is a relationship between daily polar orbiter satellite observations and crop ET as determined by ground measurement input models. The logic for investigation is that canopy air temperature differs from air temperature above the canopy and that the difference is related to ET.

If satellite thermal measurement at resolution level (1 kilometer) has a sufficiently strong relationship to the evapotranspirative condition over a site, satellite measurements can be used as direct input, or as a supplement to ground measurement input, to plant process simulation models.

The recalibrated model is obtained by minimizing a weighted error function, which is constructed by the user with specific plant part variables and corresponding weights for each data collection date.

Vegetative Information From NOAA-7 Data

A specialized data set providing global coverage from channels 1 and 2 from the NOAA-7 polar orbiter was made operational. Data begin in April 1982 and are available within a week after acquisition. Several products are available from these data for assessing global crop conditions.

Time series of the GMI (GMI = channel 2 - channel 1) for specified areas compare conditions the current year with conditions the previous year.

Maps of channel 1 and channel 2 displayed in the Ambroziak Color Coordinate System (ACCS) indicate areas where vegetation is stressed. The time series of these images, as well as a year-to-year interpretation, were prepared for selected areas of the world.

Progress maps display the condition of vegetative reflectance (GMI) in a season. For example, the advancement of vegetation to the north, which follows the movement of precipitation in North Africa, can be monitored throughout the season (fig. 36). This vegetative reflectance can also be used to compare conditions this year to those last year, or conditions this week to those last week.

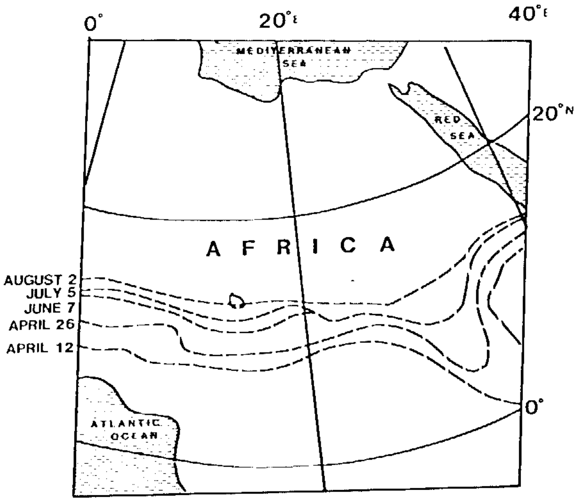


Figure 36.- A vegetation progress map of Northern Africa derived from AVHRR vegetation indices.

The GMI is differenced at each pixel; this difference is then displayed on a map (fig. 37).

Figure 37.- Comparison of changed vegetation conditions between 1982 and 1983 in the Central United States, derived from AVHRR vegetation indices (day 122).

Yield indications based on the GMI are available for areas around the world. This work was started in FY 1982 and was extended geographically to corn in FY 1983. The yield indication was for the 1983 U.S. corn crop (fig. 38). The limiting factor is the requirement for the yield estimates of the previous year.

Efforts in FY 1984 will attempt to improve the quality of the global coverage data for channels 1 and 2.

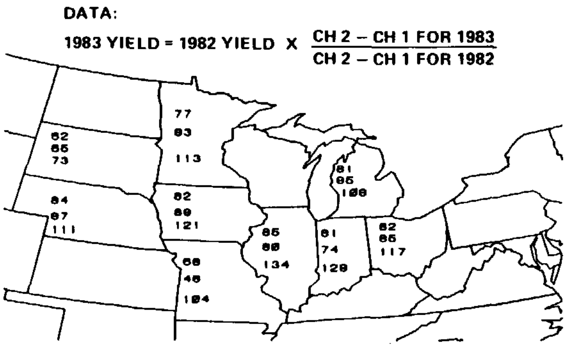


Figure 38.- Predictions of 1983 U.S. corn yields (in bushels per acre) from AVHRR. The upper number represents the 1983 yield as estimated from AVHRR data; the middle number the 1983 yield as estimated by USDA, October 1983; and the lower number the 1982 USDA final yield.

Satellite derived information on vegetative conditions will be evaluated along with information from crop simulations, i.e., plant process models, to determine their joint contribution to assessing crop conditions.

4.3.5 Data Acquisition, Processing, and Storage

Area Specific Reference Handbooks

Agroclimatic information for selected geographic areas was required to support many of the AgRISTARS tasks. Some of these activities include building yield models; developing training sets for satellite assessments; and extending plant process models to new areas. Therefore, handbooks were prepared with divisions in the text for geography, soils and vegetation, climate, and agriculture. Each handbook contains crop calendars for the major crops in all the agricultural regions within the country. Also, maps of the crop-growing areas of the countries are featured. The handbooks provide a quick and easily understood reference for assessment of the climate/agriculture for these countries. Development of additional handbooks in FY 1985 is planned.

The handbooks currently available are:

#1 Agroclimatic Handbook - Argentina

#2 Agroclimatic Handbook - Brazil

#3 Agroclimatic Handbook - Australia

Daily Meteorological Data for Argentina and Brazil

Historic daily temperature and precipitation data are needed to evaluate the plant process models in Argentina and Brazil. Data were developed during FY 1982 at the National Climatic Data Center. The synoptic reports transmitted on the Global Telecommunication System were used to produce daily estimates of daily maximum and minimum temperature and daily precipitation amounts. These data were incomplete; the plant process models need complete data throughout the growing season as well as prior to that time. This requirement for prior data is necessary to establish the soil moisture. It was necessary to use spatial and temporal objective analysis both for quality control and for providing missing data. The quality control was done in FY 1983; controlled and complete data sets were provided to allow some testing to begin in FY 1984.

Micro-Computer Applications

Several AgRISTARS data sets and tasks are on Apple microcomputers. NOAA-7 data from channels 1 and 2 have been displayed in color on the Apple computer but not in the ACCS. Real-time data can be acquired by dial-up from the U.S. National Weather Service (NWS) IBM 360/195 mainframe computer. Regression models can be developed on the Apple microcomputers. These models can then be used to provide real-time yield estimates using data retrieved from the NWS real-time data sets. Communication with Apple computers at other locations was also accomplished, and data were successfully transmitted.

Corn/Soybeans Data Base

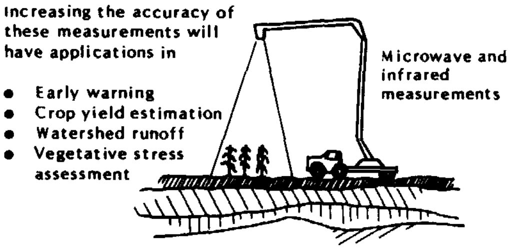
A data base was developed of production input variables and yield performance trials for corn and soybeans in the U.S. Corn Belt region. Progress was also made in developing procedures for converting soybean performance trials data into a genetic index which will help explain the gradual long-term increase in soybean yield. In addition, a survey was completed for corn and soybean production inputs and cropping practices for sample fields in Illinois, Iowa, and Missouri. This data will be used to help track the effect of changes in cultural practices, input combinations, and technology on corn and soybean yields. Inclusion of these factors as input variables for large area crop yield models will be explored.

4.4 SOIL MOISTURE

The objective of the SM project is to develop and evaluate the technology needed for remote and ground measurements of soil moisture. Development of the technology is an intermediate step in applying the techniques to agricultural information needs. A knowledge of soil moisture is important as input to models for predicting crop yield, plant stress, and watershed runoff. This work will provide knowledge about a key variable needed in several other AgRISTARS projects.

The SM project is managed by the USDA/SCS, working closely with the USDA/ARS and NASA. The scope of the work includes the improvement of in situ soil moisture measurement techniques; the development and evaluation of remote sensing approaches; and through mathematical modeling efforts, relating the in situ and remote sensing measurements to moisture storage over large areas. Applications of the results will be applied to various agricultural and hydrological problems over broad regions.

SOIL MOISTURE STUDIES



4.4.1 Technical Objectives

Specific FY 1983 technical objectives included the following:

- Continue basic research on microwave sensor development and evaluation with particular reference to measurement of dielectric properties and the study of roughness and vegetation effects.
- Conduct an aircraft experiment involving repetitive flights of a dedicated sensor package in order to develop algorithms for estimating surface soil moisture over large areas under diverse conditions.
- Continue to study methods for estimating profile moisture content and ET fluxes from remotely sensed surface measurements.
- Evaluate the use of geographic information systems (GIS's) to support SCS program responsibilities.

4.4.2 Microwave Sensor Development and Evaluation

In order to extract soil moisture information from remotely sensed observations of a vegetation-soil complex, the effects of vegetation on the microwave response must be well understood. A series of vegetation experiments, conducted during the summer of 1982 with truck-mounted microwave radiometers, indicated that certain crops (such as mature corn) have both biomass and structural properties that influence the microwave sensitivity to soil moisture. In particular, the orientation of stalks and the presence of vertical structure in the crop canopy can greatly affect the measured microwave response (fig. 39). The magnitude of this effect varies with the amount of water in the plant, disappearing at low levels of vegetation water content.

Analyses of model simulations and microwave data obtained from truck-mounted radiometers have verified the concept of using time series microwave measurements to distinguish between soil types based on their hydraulic properties (such as ponded infiltration rates, water

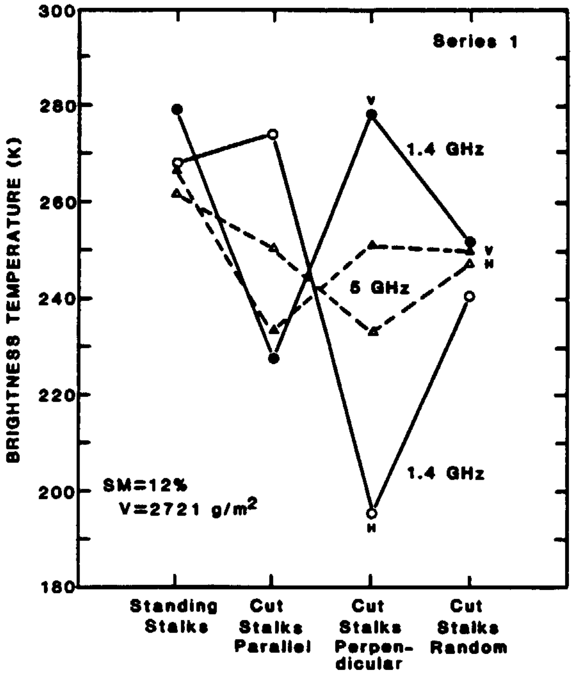


Figure 39.- Effect of corn stalk orientation on measured brightness temperature with vegetation biomass held constant. SM is volumetric soil moisture in the 0- to 5-centimeter layer; V is vegetation water content.

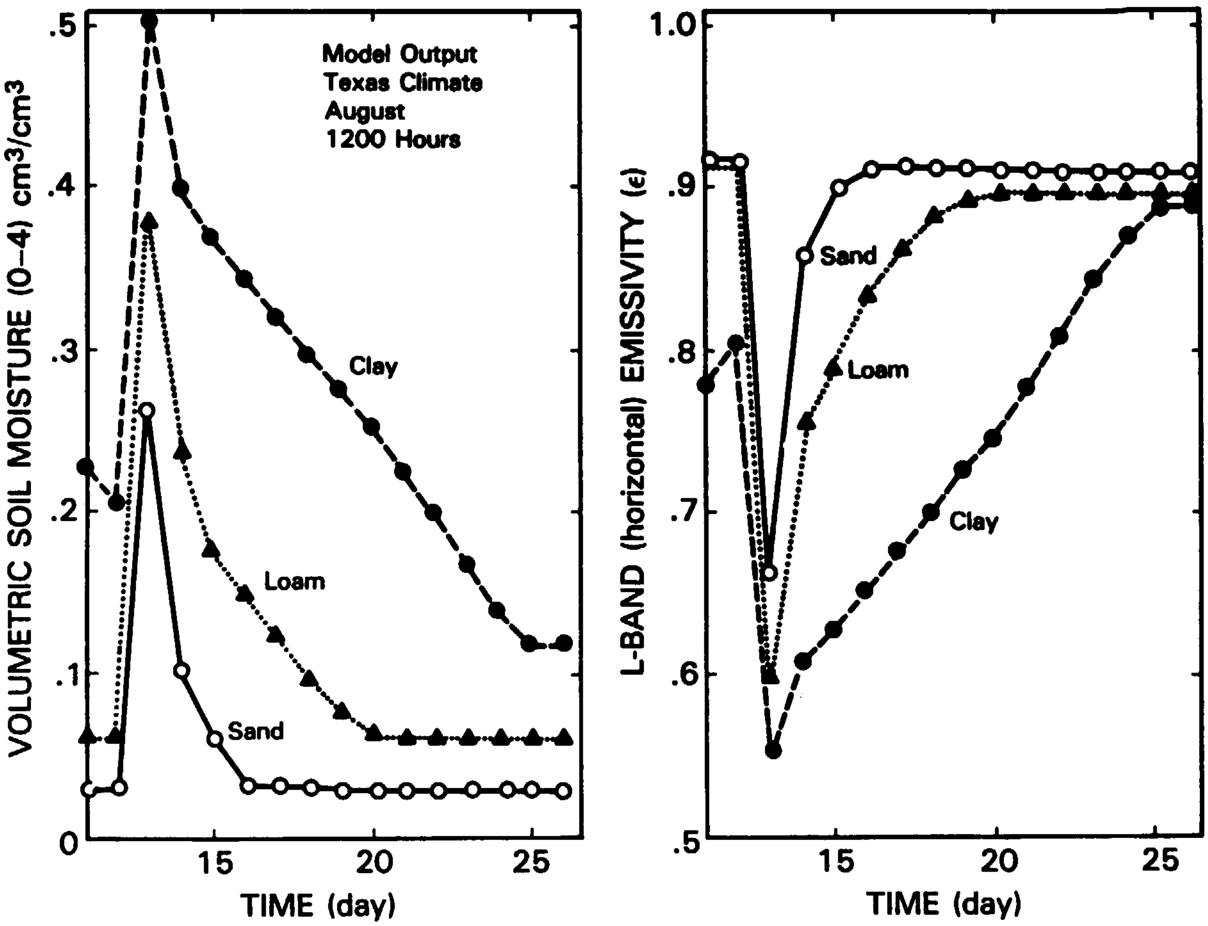
holding capacities, etc.). Results indicate that a relative classification of the hydrologic soil type can be accomplished with a one-time microwave measurement if it is known that the surface soils were subjected to significant rainfall from 1/2 to 2 days prior to measurement. A more quantitative classification can be made if a long-term time series of microwave data can be collected over large areas where some ground verification of soil properties is available.

A comparison of the soil moisture response of three 1.4-gigahertz radiometers from truck and aircraft platforms at a variety of test sites indicates that microwave remote sensing of bare soil produces repeatable and quantifiable results regardless of geographic location and sensor system used. The combined microwave sensitivity of these data sets appears to be on the order of 3.4° K per 1 percent change in volumetric soil moisture for the L-band wavelengths (2.7° K/percent soil moisture if watersheds characterized by some vegetation and surface roughness are included). Detailed examination of data from aircraft flights over agricultural fields in South Dakota suggests that when the data are partitioned according to the level of roughness a direct relationship can be found between the degree of roughness and the microwave response. With the addition of appropriate algorithms to handle the effects of roughness and vegetation, all of these results demonstrate the potential of microwave remote sensing for estimating soil moisture over large areas (fig. 40).

4.4.3 Microwave Radiometer Aircraft Experiments

In late 1982 a series of six microwave data collection flights for measuring soil moisture was made over a small watershed measuring 7.8 square kilometers in southwestern Minnesota. These flights provided 100-percent coverage of the basin at a 400-meter resolution. In addition, three data collection lines were flown at lower elevations to provide a sample of higher-resolution (60-meter) data. The low level flights provide considerably more information on soil moisture variability. General moisture change trends were detectable with the measurements. Surface changes, however, such as crop harvesting and tillage appear to have a major effect on measurements at any one point. Future measurements over a time series will have to account for these changes on the surface.

In 1983 a new aircraft-sensor system was assembled for soil moisture research. This system consists of a



(a) Data from soils physics model.

(b) Data from radiative transfer model.

Figure 40.- Time series microwave emissivity values expected from three different soils during a simulated soil moisture dry-down. Soil moisture profile data from a soils physics model (a) were used as input to a radiative transfer model (b).

three-beam L-band passive microwave radiometer, a thermal-infrared scanner, and an MSS and video camera onboard a NASA Skyvan aircraft.

This system was used in a series of eleven flights between mid-May and late June over sites on the eastern Maryland portion of the Delmarva Peninsula. The primary purpose of these experiments was to verify system performance. Figure 41 illustrates typical results for a field with a corn crop during this period. Analysis of the results to date indicates that the system is extremely reliable and should require only minimal day-to-day ground-truth verification in large area studies.

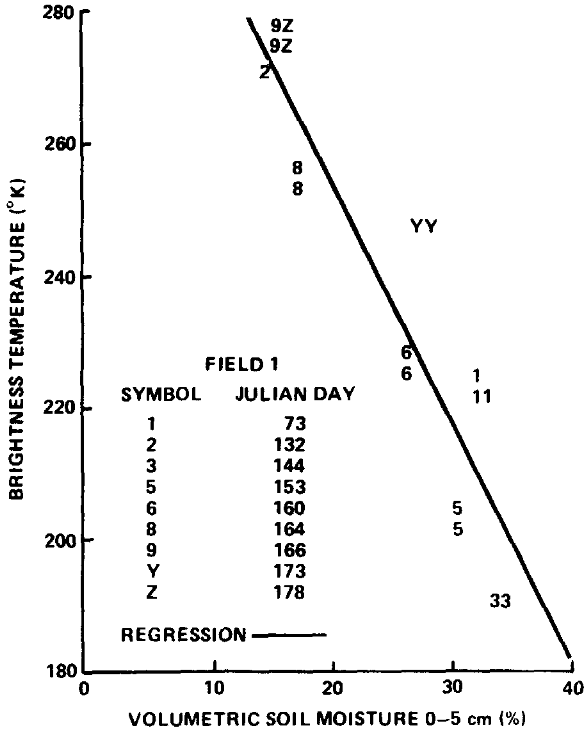


Figure 41.- Maryland cornfield soil moisture versus brightness temperature, 1983.

A second objective of this series of flights was to explore the use of temporal variations in brightness temperature as a source of information on soil moisture and evaporation. Preliminary analyses indicate that cumulative water balance and brightness temperature are highly correlated.

4.4.4 In Situ Sensor Development

A prototype instrument for measuring surface soil water content has been fabricated and is currently undergoing testing and calibration. The instrument uses nuclear magnetic resonance (NMR) techniques to nondestructively and nonintrusively measure volumetric soil water content at depths of 1.5, 2.0, and 2.5 inches below the soil surface. The instrument is mounted on a small farm tractor and is capable of making continuous measurements at speeds in excess of 10 miles per hour.

4.4.5 Evapotranspiration Studies

Thermal-infrared data acquired by the AVHRR on NOAA satellites were evaluated in conjunction with the visible through the near-infrared reflectances, meteorological data, and land use maps. A quantitative analysis of infrared data for surface energy balance yields reasonable results, consistent with earlier work by a number of authors. In particular, surface evaporation results were consistent with the Penman equation in vegetated areas, while vegetation-free areas had lower evaporation values. Examination of Landsat data and conventional maps of land use shows that the major variability apparent in the NOAA image data, i.e., areas on the order of hundreds of kilometers, is associated with topography, differences in soil characteristics and farming practices, cities and residential areas, and other similar factors.

Inclusion of these factors in the analysis procedure will require a more sophisticated approach involving extraction of map-type data from large-scale, centralized data bases.

4.4.6 Soil Moisture Sensing

The soil moisture sensing program combines theory with laboratory and field experimentation as supported by simulation studies to examine problems with sensor implementation and application.

The dielectric properties of a medium largely determine its microwave scattering and emission characteristics. During FY 1983, several dielectric measurement programs made notable progress.

An ongoing program to measure the dielectric properties of soils as a function of moisture content was expanded to cover the frequency range of 1.4 to 18 gigahertz using free-space and guided-wave transmission techniques. Measurements from a variety of field soils and texturally distinct laboratory soils were fitted with empirical expressions dependent upon frequency, soil texture, and volumetric moisture. In addition, a physically based model, previously found useful at frequencies of 1.4 and 5.0 gigahertz, adequately described the dielectric behavior of moist soil at higher frequencies.

An understanding of the dielectric properties of plant canopy components is fundamental to quantitative description of microwave scattering, emission, and attenuation by vegetation. A variety of canopy components (leaf, stalk, and fruit) was measured by guided-wave transmission techniques to examine the dielectric dependence on plant moisture content. Samples of these data are shown in figure 42 for wheat at 8 gigahertz.

Under field conditions of variable plant geometry and water content, a vegetation canopy both scatters and attenuates incident microwave radiation. Depending upon frequency and angle of incidence, these effects tend to limit a microwave sensor's sensitivity to soil moisture and enhance its sensitivity to canopy properties such as biomass and geometry. A series of field investigations in FY 1983 sought to further our understanding of the influence of crop canopies on scattering and emission. One-way and two-way canopy attenuation experiments were conducted at several points in crop development for wheat (fig. 43), soybeans (fig. 44), and corn. Repeated sampling allows for a description of the statistical distribution of net canopy attentuation for selected

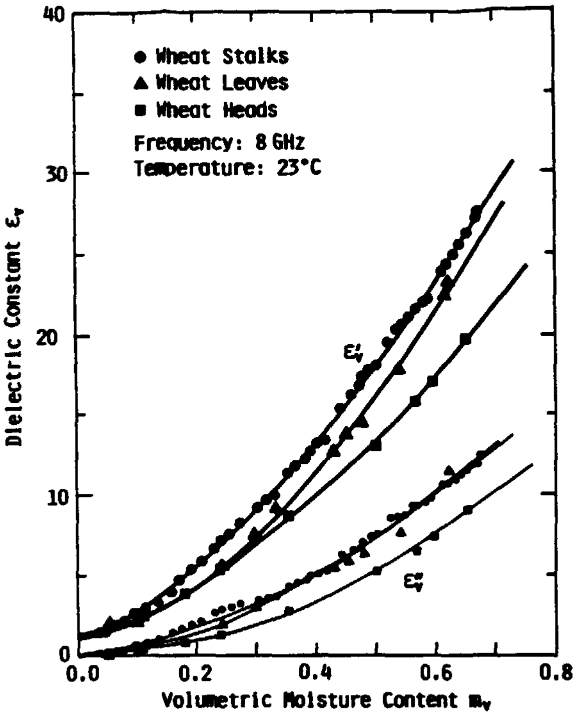


Figure 42.- Dielectric dependence of plant canopy components on plant moisture content.

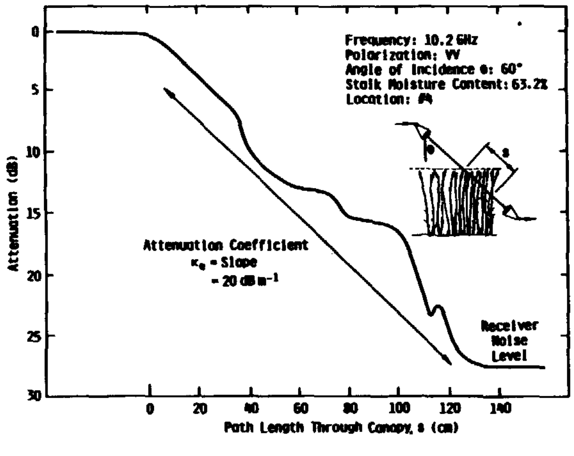
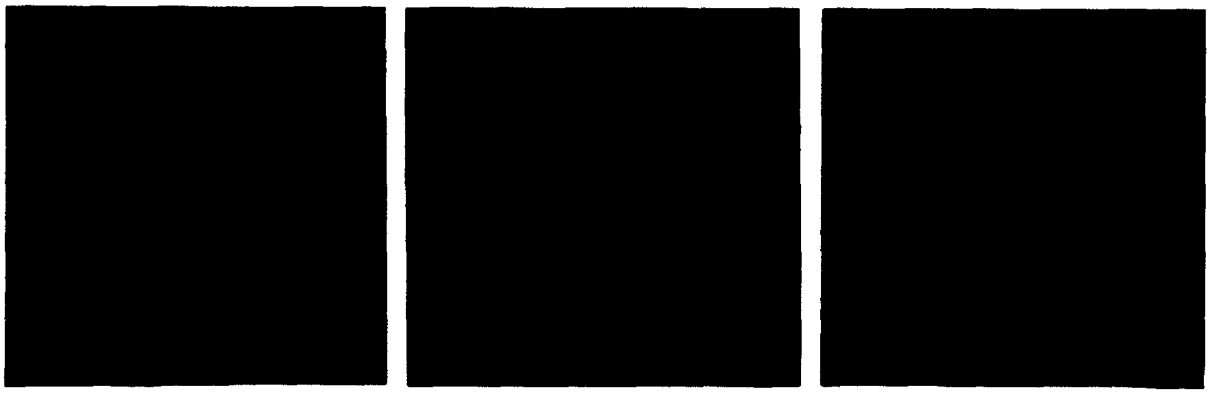
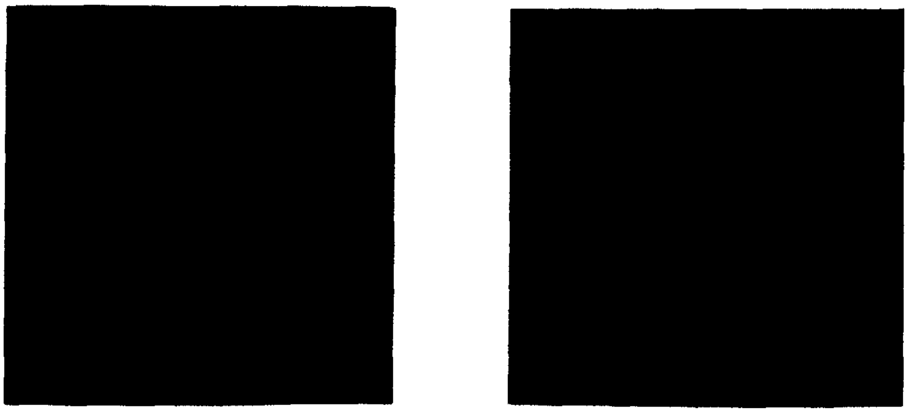


Figure 43.- Microwave measurements of canopy attenuation in crop development for wheat.



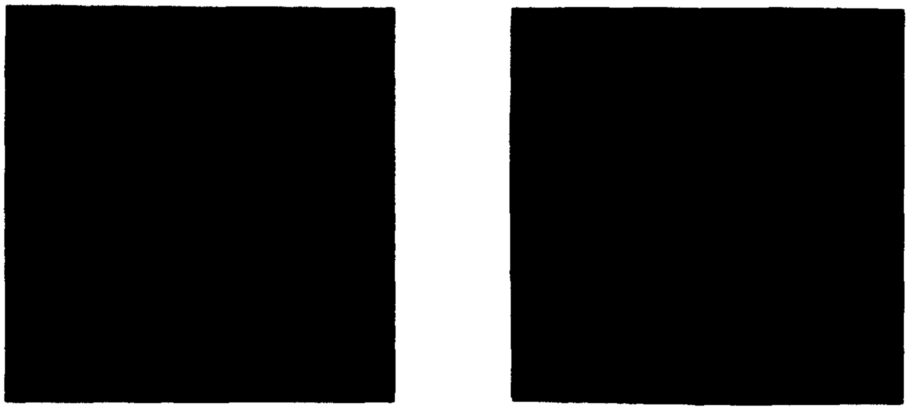
DAY 141 DAY 150 DAY 160

Figure 48.- *Simulated C-band orbital radar imagery.*



ACTUAL MOISTURE
(100 m RESOLUTION)

PREDICTED MOISTURE
(100 m RESOLUTION)



PREDICTED MOISTURE
(1 km RESOLUTION)

PREDICTED MOISTURE
(3 km RESOLUTION)

Figure 49.- Actual and predicted soil moisture distribution for day 141.

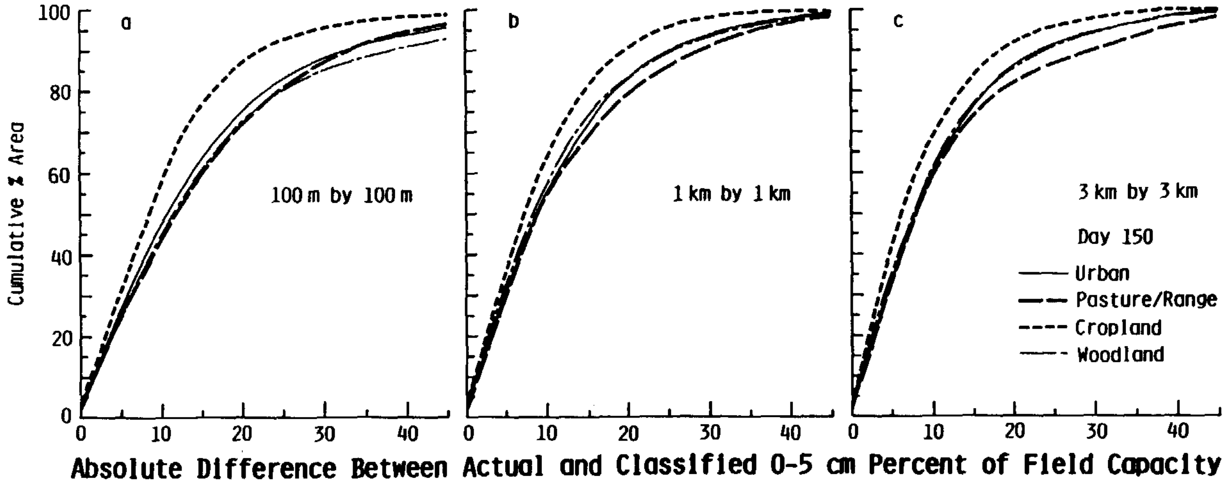
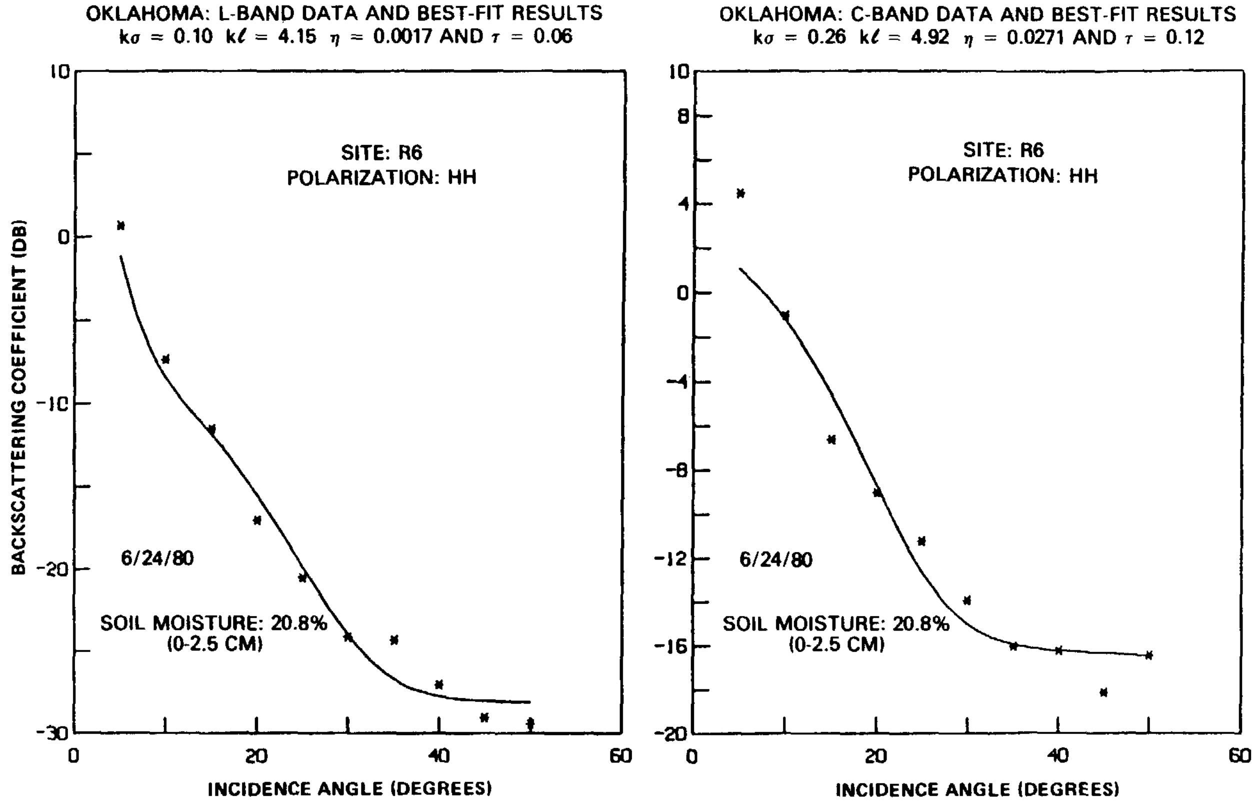


Figure 50.- Effects of geographic size on moisture classification accuracy.

4.4.7 Model Research

In related modeling research, investigators have developed an electromagnetic wave scattering model to simulate the measured angular distribution of radar backscatter from vegetation-covered soil surfaces using a least-squares fit method. The model takes into consideration coherent and incoherent scattering from a rough soil surface, which is characterized by two parameters, the surface height standard deviation and the surface correlation length. The effects of vegetation canopy scattering and attenuation are also included in the model. The model results agree well with data obtained at both L-band (1.6 gigahertz) and C-band (4.75 gigahertz) frequencies (fig. 51). Inversion of model fits to a large collection of scatterometer data can provide reliable estimates of the surface roughness characteristics, particularly the standard deviation of surface height variations.

To describe the thermal microwave emission from a vegetation canopy, the vegetation can be modeled as a homogeneous medium containing discrete scatterers specified by their size, permittivity, and fractional volume. The discrete scatterers in this case consist of cylinders oriented vertically that model the stalks of vegetation and are specified by their radius and length, and ellipsoidal scatterers of a specified size that represent the leaves of the vegetation. A probability density function specifies the orientation of the ellipsoids. The purpose of developing this model was to quantify the effects of the vegetation canopy on thermal microwave emission from a soil volume. Simulations utilizing this model were compared to experimental measurements acquired over sorghum fields at Texas A&M University. The model simulation compared extremely well with the experimental measurements. The overall results show that the cylindrical scatterers or the stalks of the vegetation have the dominant effect on the thermal microwave emissions from the vegetation volume. Using somewhat different modeling approaches, researchers at Massachussets Institute of Technology and George Washington University are also making progress toward describing microwave interactions within a crop canopy.


OKLAHOMA: L-BAND DATA AND BEST-FIT RESULTS
kσ = 0.10 kℓ = 4.15 η = 0.0017 AND τ = 0.06

OKLAHOMA: C-BAND DATA AND BEST-FIT RESULTS
kσ = 0.26 kℓ = 4.92 η = 0.0271 AND τ = 0.12

Figure 51.- Comparison of model calculations and scatterometer data for a grassland watershed in Oklahoma.

Theoretical modeling can help to improve our understanding of the fundamental physical processes at work within a vegetation-soil complex. Canopy temperature represents the integrated response of a crop to prevailing weather and soil water conditions. If changes in canopy temperature due to weather can be quantified and accounted for, then it should be possible to infer the soil water status from the canopy temperature. A steady-state model of transpiration has been developed which solves the water balance equation for a plant by explicit accounting of plant physiologic control of water loss from leaf stomata. Once transpiration is known, the canopy temperature is obtained from the energy balance equation. For well-watered corn, soybean, and sunflower crops, the canopy temperature during the significant portion of the daylight period is determined largely by air and dewpoint temperatures; wind speed and solar radiation have very little effect on the canopy temperature. As root-zone soil water decreases, the canopy temperature increases; this increase is predictable in terms of crop physiology and soil water potential.

A model of the energy and moisture fluxes in the soil and atmospheric boundary layer has been applied successfully to estimate daily evaporation over wheat and barley fields in Germany using thermal-infrared remotely sensed data. A sensitivity analysis of the model showed that for bare soil net radiation was the most important independent variable required, while for wheat and barley the air temperature and vapor pressure were as important as the net radiation. Thus, ground data requirements do not appear to be excessive when used with remotely sensed data to calculate evaporation with the physically based model. Overall, surface temperature was the most critical remotely sensed parameter, although soil moisture could be an important model input under nonpotential evaporation conditions.

Assuming the capability of remote sensing to measure the net surface soil moisture fluxes, a model was developed to monitor net rainfall and evaporation as well as soil water content over the entire profile for bare soil conditions. Verification of the model simulations with measured field data produced good results.

The ability of a water uptake model for sorghum to predict root zone water content and canopy temperatures was examined with a view toward potential application in remote sensing determination of canopy water stress and crop yield reduction. Total ET simulated over a 50-day period using the model was found to be in good agreement with the experimental values. Soil water content profiles calculated with the model showed some systematic deviation from the measured values, possibly because the physical nature of the profile was assumed to be homogeneous. The spread of the simulated results, however, reflects the variation of hydraulic soil properties. A sensitivity analysis showed minor sensitivity to rooting depth and distribution, and moderate sensitivity to the excretion of water by the roots into dry soil layers.

4.4.8 Geographic Information System

In cooperation with USDA/SCS, NASA Ames Research Center conducted several studies in the uses of GIS's for support of SCS program responsibilities, including the application of remote sensing technology.

Interagency planning led to the definition of multiple task areas:

- GIS Implementation
- Land Resources Modeling
- Direct Assistance/Remote Sensing

The approach used to study GIS Implementation was to develop analysis scenarios of SCS operational requirements and to relate these scenarios to a comprehensive review of GIS capabilities. A representative set of SCS programs was selected and reviewed, noting the organizational setting of each program and current technology implemented. The individual programs were then translated into the GIS domain and examined for implications to an overall SCS system design. The program translation was simplified by first compiling and documenting generic GIS functional capabilities, and then describing how these capabilities would be implemented within existing SCS programs.

This application of GIS technology to existing SCS programs could be implemented in several ways, including internal SCS implementation, cooperation with state-operated GIS's, and use of Federal data bases. Although the main thrust of the research concerned studies examinimg the internal implementation of GIS technology, the latter two options were also examined. Through separate studies of existing state and Federal data bases, an inventory was completed, identifying hardware and software in use as well as data types and formats found within each data base. This inventory not only identified potential data sources for SCS, but also provided an insight into GIS implementation.

The internal implementation study was completed by reviewing eight candidate GIS software packages available commercially. The packages were compared to existing SCS processing requirements and the list of generic GIS functional capabilities. An inventory of hardware (including peripherals) capable of supporting the candidate systems was also completed in support of the implementation study. This resulted in a potential system design that would function agency-wide.

For the Land Resources Modeling task, a test was developed to determine the usefulness of an existing data base to address SCS resource issues. The universal soil loss equation (USLE) was implemented and models run to determine severity of erosion problems in Santa Cruz County, California. Results of this test have shown that an existing data base can be used as an automated soil loss information system and that large areas can be inventoried for predicted soil loss with savings in both time and money over conventional ground sampling methodologies.

As part of the Direct Assistance/Remote Sensing task, a study was initiated to evaluate the near-term opportunities remote sensing offers to USDA/SCS. Research was initiated to evaluate remote sensing within the context of the National Resource Inventory (NRI) currently underway within the SCS. An analysis of change detection techniques using Landsat data was completed in Santa Cruz County, California, identifying those techniques valuable in supporting the SCS's national inventory. Results of this study have shown that remotely sensed change detection techniques, when properly applied, can: (1) greatly improve the ability to update and optimize the sampling design of the NRI; (2) provide a 'quick-look' data layer to help the resource manager characterize sample plots before field reconnaissance; and (3) reduce field costs by intensively ground checking only those areas identified by remote sensing techniques as having changed through time.

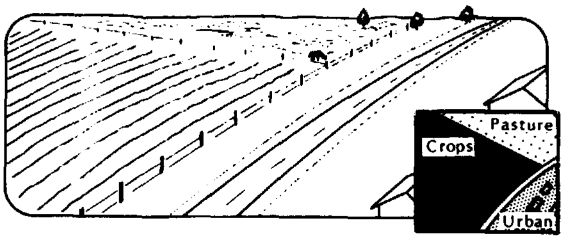
4.5 DOMESTIC CROPS AND LAND COVER

The DC/LC crop acreage objectives are to improve state and substate crop acreage estimates by integrating Landsat data with ground data from the existing USDA program and to evaluate the effectiveness of alternative procedures. The land cover objectives are to explore methods for meeting USDA needs for land cover inventories, land-use change estimates, and mapping products of land cover.

This project is managed by the USDA/SRS with support from NASA. Major crop estimates in the United States are being addressed first in the U.S. Great Plains for wheat and in the Corn Belt for corn and soybeans.

DOMESTIC CROPS AND LAND COVER

Directed at automatic classification and estimation of land cover with emphasis on major crops, this project uses Landsat and advanced sensor data to improve accuracy of data classification on the local level.



4.5.1 Technical Objectives

Technical objectives during FY 1983 focused on the following:

- Developing, testing, and evaluating operational procedures for estimating the acreages of major crops over large areas, such as a state, in a timely fashion.
- Continuing studies to evaluate SRS methodology for estimating land use/land cover.
- Cooperating with various research and government organizations in California for purposes of developing remote sensing procedures applicable to both agricultural surveys and irrigation inventories.
- Evaluating Landsat TM data for their ability to distinguish crop and land cover classes.
- Continuing data processing enhancements.

4.5.2 Timely Crop Acreage Estimation Over Large Areas

For the 1983 crop year, acreage estimates of major crops for seven states were calculated by combining Landsat-4 MSS data with ground data. The seven states were Arkansas, Colorado, Illinois, Iowa, Kansas, Missouri, and Oklahoma (fig. 52). Crops included were winter wheat, corn, soybeans, rice, and cotton. The ground data consisted of information on crop field locations and acreages obtained from the USDA/SRS June Enumerative Survey (JES). The estimates that used both Landsat and JES data averaged about twice as efficient as those based on the JES data alone. SRS has reduced the project cost per state associated with using Landsat data from $305,000 in 1978 to $120,000 in 1983.

4.5.3 Land Use/Land Cover Estimation

During FY 1983 a state-level land cover study was conducted in Missouri in addition to the production of timely estimates of crop acreages. For the land cover study, additional items were added to the JES questionnaire used in Missouri. These additional items recorded acreages for 21 nonagricultural ground covers.

Available spring Landsat data were combined with ground data to produce timely crop-acreage estimates for

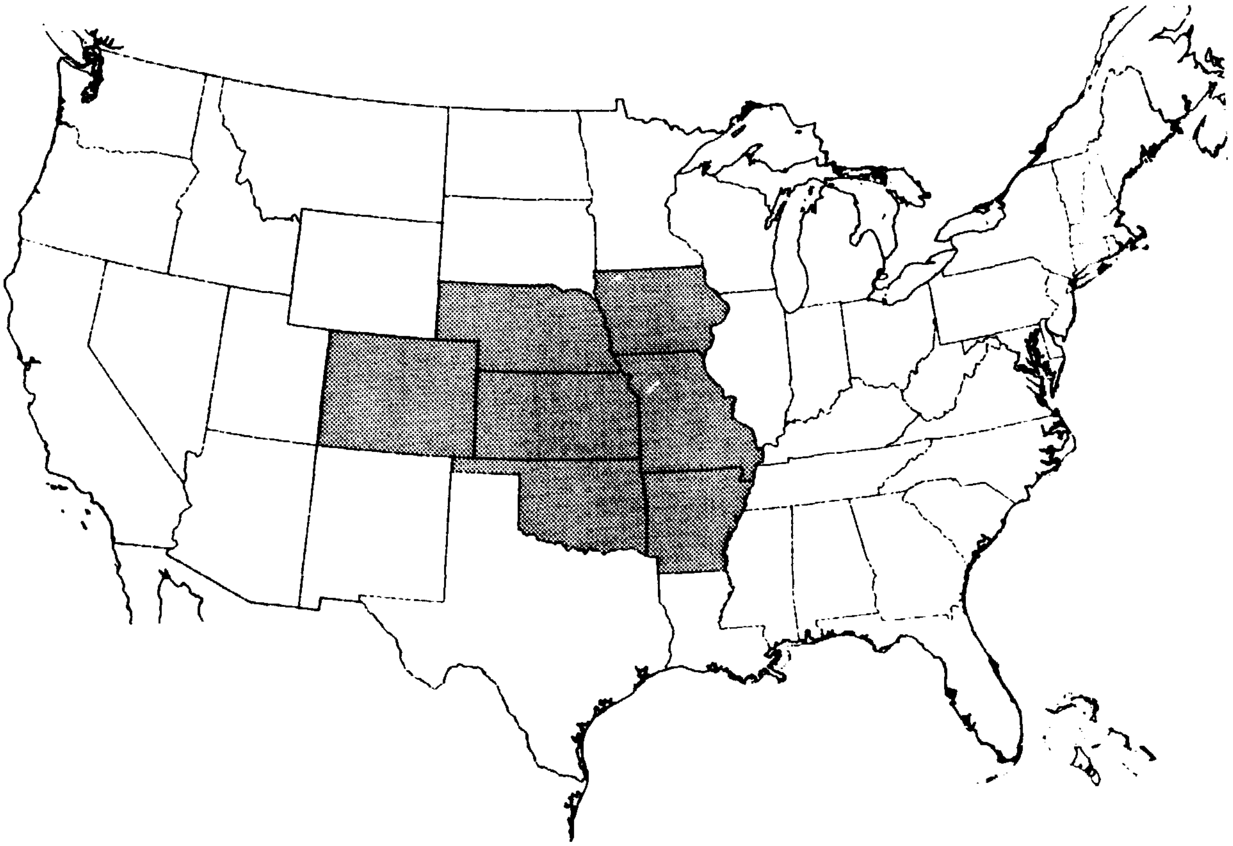


Figure 52.- Seven-state area for which MSS and ground data were combined to produce crop acreage estimates for the 1983 crop year.

planted and harvested winter wheat. Spring-plus-summer Landsat data were combined with ground data to produce estimates for cotton, rice, corn, and soybeans. In early 1984, the classification of the spring-plus-summer Landsat data will be used to calculate state-level estimates for the 21 nonagricultural ground covers.

Also in FY 1983 a study was completed that analyzed the results of using single-date versus multidate Landsat MSS data, plus the results of stratifying by soils. This study was conducted in Robeson County, North Carolina, for the land covers of forest, soybeans, corn, and tobacco. The study findings were that the stratified, multitemporal procedure had the highest overall accuracy. The addition of a June Landsat MSS data set to an August data set had about the same effect on overall classification accuracy as the stratification of the August data set by soils. However, the unstratified, multidate approach was clearly better for crop discrimination.

4.5.4 California Cooperative Project

Research on remote sensing for application to irrigated agriculture was initiated in California in FY 1982. This work continued in 1983. In addition to SRS and NASA, cooperators in the project included the California Departments of Agriculture and Water Resources and the University of California at Berkeley. This project was designed to develop remote sensing procedures applicable to both agricultural surveys and irrigation inventories.

California has a large number of minor crops rather than a small number of major crops. This distinguishes it from Midwestern states, where most of the DC/LC work in crop-acreage estimation has been performed. The applicability of the DC/LC crop-acreage estimation procedure (described in section 4.5.2) to California was studied in FY 1983. The study findings show that with minor modifications the DC/LC procedure is applicable to California agriculture.

The FY 1983 study also produced county estimates of crop acreages and produced resource maps based on calculated values called crop odds. A crop odd is the probability that a Landsat pixel is a particular crop. Figure 53 illustrates a map based on crop odds.

4.5.5 Landsat TM Evaluation

In FY 1983, classification accuracies were compared for Landsat MSS and TM data simultaneously acquired over the Albemarle Sound region of North Carolina. This comparison assessed the effects of sensor attributes that differ between the two sensors, i.e., spectral, spatial, and radiometric resolutions.

Three data sets were computer classified: six- and three-band TM data sets and a three-band MSS data set. The study concluded that the improved classification accuracy for TM data resulted primarily from improved radiometric resolution and additional spectral bands. The increased spatial resolution of TM data played only a minor role in increasing classification accuracy because of the large fields in the study area.

4.5.6 Data Processing Enhancements

In late FY 1982, NASA Ames Research Center replaced their ILLIAC IV computer with a Cray 1S computer. Several processing steps in the DC/LC crop-acreage estimation procedure were programmed on the Cray 1S during FY 1983. The cost of classifying an entire MSS scene (four channels) into twelve categories was reduced from over $1000 on the ILLIAC IV to $35 on the Cray 1S.

Processing steps not performed on the Cray 1S are performed on a commercially time-shared DEC-10 computer. In FY 1983, work was initiated to rewrite the computer programs for these processing steps. The rewritten programs will be able to execute on a microcomputer-based system or on mainframe computers other than the DEC-10.

One of the processing steps of the DC/LC crop-acreage estimation work is the digitization of ground-data photographs. Prior to FY 1983 this was done with a digitizing tablet connected by telephone line to the DEC-10. In FY 1983 two alternative digitizing procedures were evaluated. In four states a digitizing tablet connected locally to a microcomputer was used. This resulted in considerable savings in telecommunication costs. The ground data for three other states were digitized with video digitizing equipment located in Washington, D.C. Consisting of a television camera, an image processing system, and a minicomputer, this equipment makes possible high throughput digitizing of ground data.

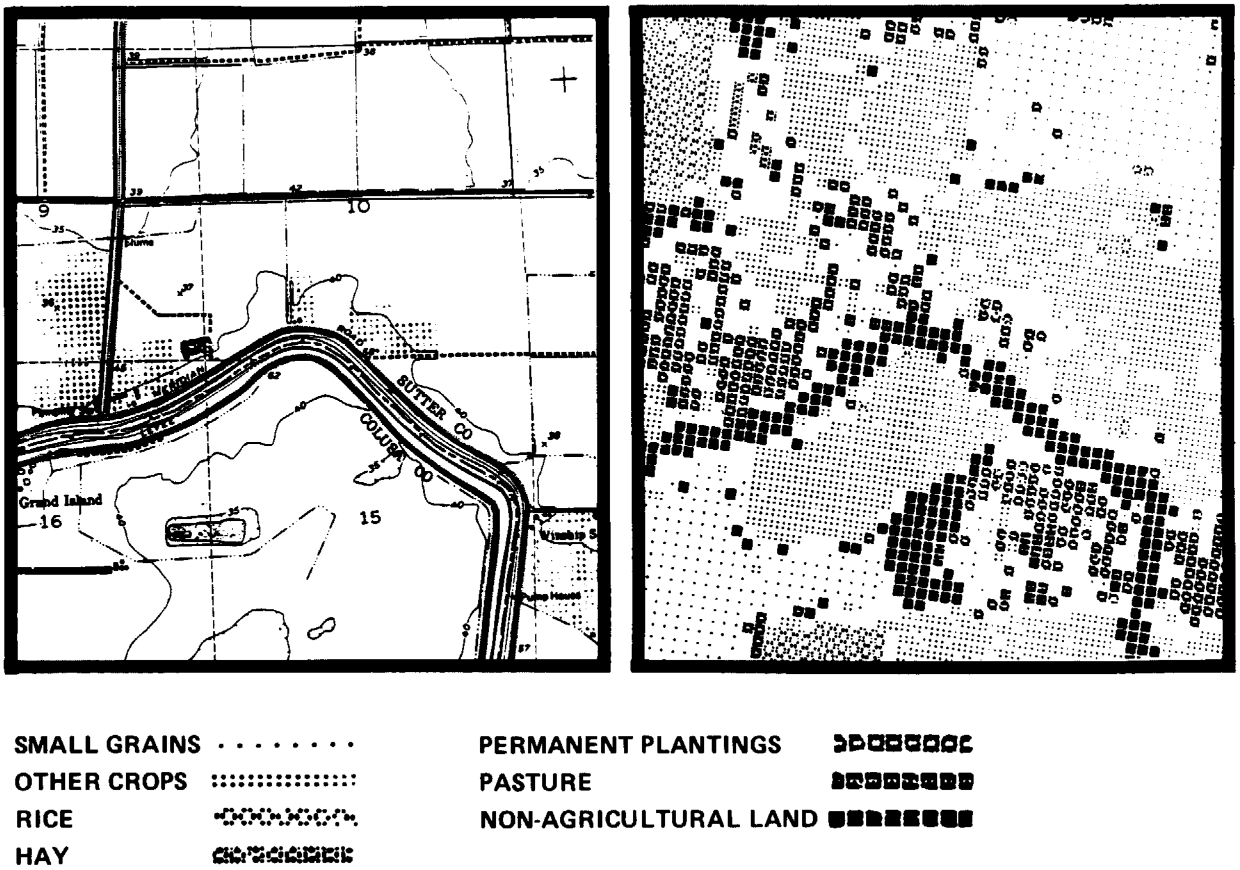


Figure 53.- Comparison of USGS topographic map and crop-odds map. The mapped area is a portion of the USGS Tisdale Weir quadrangle in California. In the shaded portions of the crop-odds map, the indicated crop odd exceeds 0.75. In the unshaded areas, all crop odds are less than 0.75.

4.6 RENEWABLE RESOURCES INVENTORY

The objectives of the RRI project are the development and implementation, in the USDA Forest Service, of new remote sensing technology which will offer capabilities in support of the national renewable resource assessment process. The USDA Forest Service is the management agency in the RRI project, and will be the user of the technologies developed.

Four main categories are being addressed:

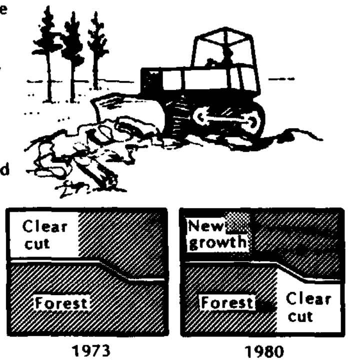
- National Inventory
- Stress/Damage Assessment
- Timberland Classification
- Environmental/Land Use

RENEWABLE RESOURCES INVENTORY

Four main categories are being addressed:

(1) National inventory
(2) Stress/damage assessment
(3) Timberland classification
(4) Environmental/iand use

Use of data from the Landsat multispectral scanner and the more detailed data from the improved sensors is planned.



Use of data from the Landsat MSS and the more detailed data from the improved sensors is planned.

4.6.1 Technical Objectives

The particular objectives in FY 1983 were focused on:

- Improving methods for collection, display, and use of resource information for more efficient forest management.
- Completion of the Multiresource Inventory Methods Pilot Test (MIMPT) and publication of the final report.
- Transfer of remote sensing technology to field users.

4.6.2 Forest Management and Remote Sensing Activity

Sixteen missions were flown using the NASA U-2 aircraft with advanced camera systems to obtain resource data to support developmental projects. The San Juan National Forest, Colorado, continues to be a prime area for the testing and evaluation of remote sensing techniques. Other areas of data acquisition include the Hill Country in central Texas, east Texas Pineywoods, and the Northeastern United States. The Texas data were used to evaluate the extent of infestation of oak wilt in central Texas and the extent of the southern pine beetle outbreak in east Texas. The data acquired over the Northeastern United States were used to determine the extent of hardwood defoliation caused by the gypsy moth. Improvements were made on equipment used to laminate positive transparency film. Lightweight portable light tables were designed, constructed, and tested for use with positive transparency film. Testing was done on part of the 1983 demonstration of optical bar panoramic aerial mapping of hardwood defoliation (caused by the gypsy moth) over a multistate area of the Northeastern United States.

4.6.3 Multiresource Inventory Methods Pilot Test

The MIM PT was concluded and a final report was written. The MIM PT demonstrated the potential use of Landsat satellite technology for conducting recurrent inventories over large land areas. Driven by USDA Forest Service requirements, the pilot test provided information to support resource planning activities as well as forest inventory and assessment activities at national, state, and multicounty levels.

4.6.4 Technology Transfer

Considerable emphasis was placed on transferring remote sensing techniques to the field users in the Forest Service as well as to other state and Federal agencies. Several advanced remote sensing and photointerpretation workshops were conducted at the field office level. Support was provided to several field units to carry out local remote sensing projects.

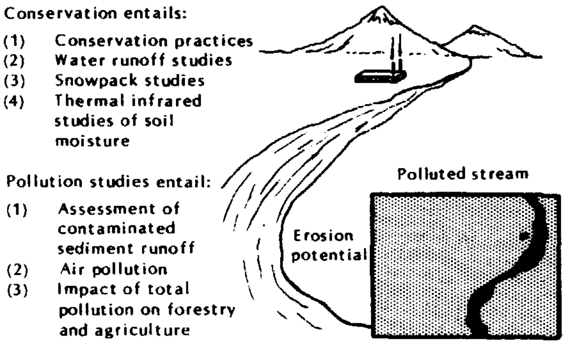
4.7 CONSERVATION AND POLLUTION

The conservation assessment portion of the C/P project addresses applications in three areas: inventory of conservation practices, estimation of water runoff using hydrologic models, and determination of the physical characteristics of snowpacks.

The pollution portion of the C/P project provides an assessment of conservation practices through the use of remote sensing techniques to assess quantitatively such factors as sediment runoff, gaseous and particulate air pollutants, and the impacts of these factors on agricultural and forestry resources.

The USDA/ARS manages the C/P project with support from NASA and NOAA.

CONSERVATION AND POLLUTION



4.7.1 Technical Objectives

Specific FY 1983 technical objectives focused on the following:

- Determining the utility of remotely sensed data for the identification and inventory of existing soil conservation practices and for input to erosion models.
- Determining the suitability of present and planned remote sensing data for use in existing hydrologic models and developing new models or components to incorporate remotely sensed data for water resources management.
- Using available visible, near-infrared, and microwave satellite data in conjunction with radiometric measurements from ground-based and aircraft systems to analyze the physical properties of snow and the effects of changes in snowpack conditions.
- Studying the potential use of Landsat MSS data as input to pollution models and evaluating methods of remotely measuring atmospheric oxidants in areas where impact on vegetation is suspected.

4.7.2 Conservation Practices Inventory

Preliminary data analysis during FY 1983 indicated that some conservation practices can be successfully detected in Landsat-4 TM data. However, a number of existing practices are of such size and definition that present sensors and standard techniques cannot detect them with great accuracy.

High-resolution photography at two different scales has been evaluated for the Kansas, Mississippi, and Oklahoma test sites. A matrix has been developed from the results of that interpretation which indicates the requirements for identifying a number of different practices.

4.7.3 Soil Erosion Modeling

The goal of this task is to survey the feasibility of using remote sensing techniques for providing various inputs to an erosion model using the USLE. Four areas experiencing large soil loss rates have been chosen as study sites in Alabama, Kansas, Mississippi, and

Oklahoma. Remotely sensed data from the Landsat MSS and the TM are being integrated with digitized soils and topographic data bases as input for determining the values of the various factors that make up the USLE.

All remotely sensed data have been acquired, and construction of digitized soils and topographic data bases has been completed in FY 1983.

Preliminary use of the USLE model with Landsat MSS data in Alabama and Mississippi has been reviewed with the USDA/SCS personnel of these states, and results indicate great promise.

4.7.4 Water Resources Management

The SRM has been tested on a variety of basins worldwide, with tests recently completed on the largest basin studied so far, the Kings River Basin (4000 square kilometers) in California. Results from the model applications consistently indicate that satellite snow-cover extent is the most important variable for SRM. Figure 54 shows the results from 4 years of simulations of runoff using SRM throughout the snowmelt-runoff season, with snow-cover extent information being obtained from both NOAA and Landsat. Results from 14 international basins indicate that the model accuracy for simulation of seasonal water yield (volume) is 97 percent and of daily flows is 85 percent. The SRM User Manual has been been published (NASA RP-1100), and SRM is ready for conversion to operational forecasting.

The U.S. NWS River Forecasting System (NWSRFS) model is being modified to accept remote sensing data. One aspect of the modification involves restructuring of procedures in the model to permit remote sensing updates of model states and forecasts. The other important aspect is the development of a method to areally average data acquired over a basin by both conventional and remote sensing means for input to models. Such a method has been developed and is called the correlation area method (CAM). This method takes into account that there are certain basic differences in spatial and temporal coverage of various types of data. The CAM can apportion and weight conventional point data, aircraft flight line data, and spaceborne large-area coverage observations over the same basin. Different combinations of data will be available at different times, and CAM will allow basin-wide parameter estimates based only on the data available at a given time. Thus, data emission from certain sensors at any time will not prevent operation of the model.

A more long-range approach to utilizing this new technology is to design a family of hydrologic models to be compatible with remote sensing capabilities. The overall framework (fig. 55) for this model has been assembled. The model is designed to use: general hydrologic land cover categories available from satellites; snow-covered area for driving a snowmelt-runoff algorithm; surface soil moisture available from microwave data for soil moisture accounting and linkage to a soil moisture profile model; vegetative indices, biomass estimates, and surface temperature for ET and interception calculations; and high-resolution data for channel network and overland flow considerations. In addition to making optimum use of the spatial and temporal characteristics of the remote sensing data, the new model employs a GIS as an integral feature for overlaying data, merging data of different characteristics, and performing hypothetical basin treatments for design studies. The digital format of the remote sensing data and the large volume of data that can be collected with remote sensing make the use of the GIS madatory. The new model is now ready for field testing.

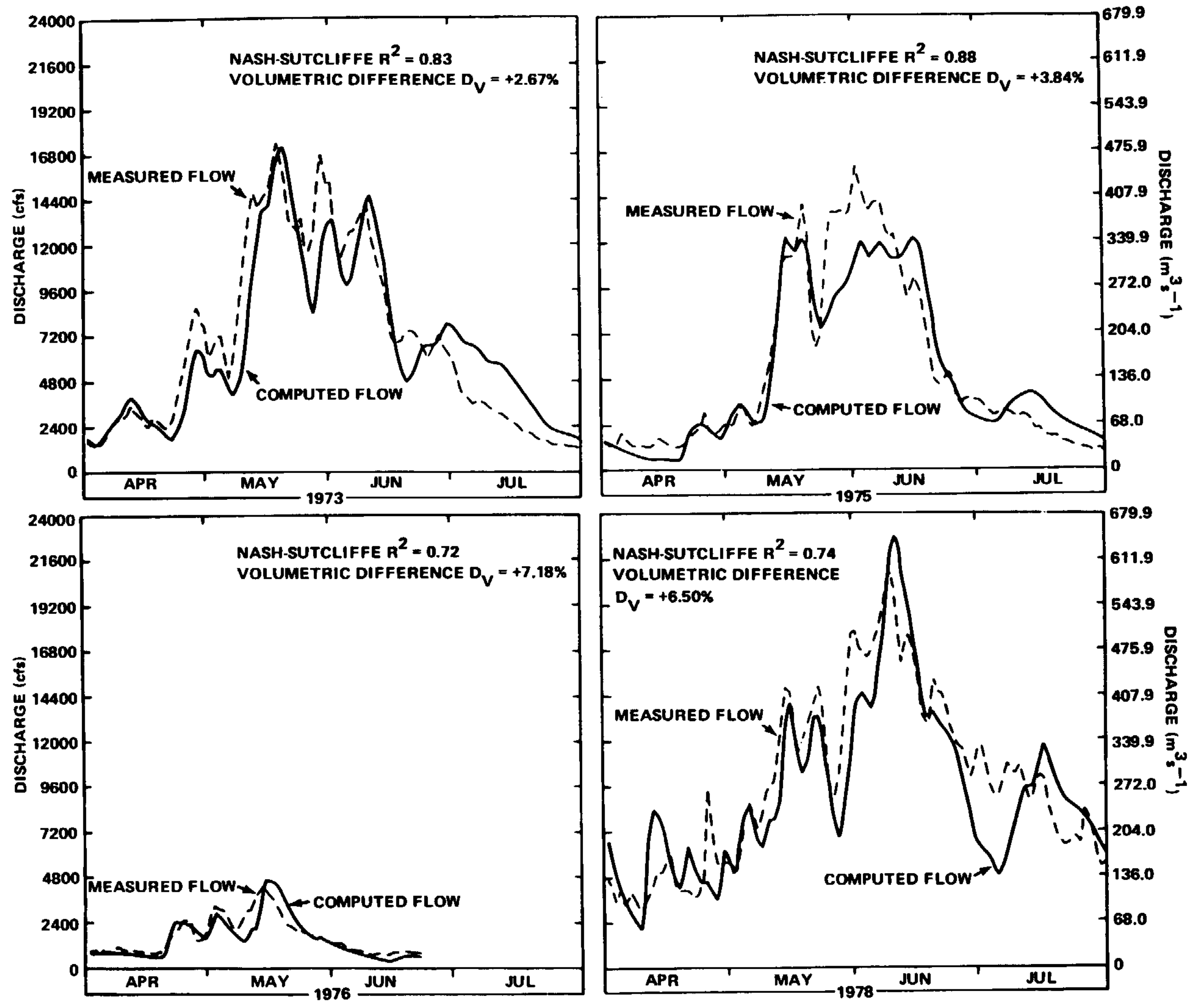


Figure 54.- Discharge simulation for the Kings River Basin, California, using the snowmelt-runoff model.

4.7.5 Snowpack Studies

A field and aircraft experiment was conducted in the Sierra Nevadas in California in February 1983. Snow pit data were collected by investigators from the University of California at Santa Barbara during an overflight by a NASA CV-990 aircraft equipped with the airborne multichannel microwave radiometer (AMMR). The objective of this experiment was to determine the microwave signatures of deep (less than 2 meters) snow. Data are under analysis.

Using scanning multichannel microwave radiometer (SMMR) satellite data, investigators found that a comparison of the horizontal and vertical polarizations can be useful for analyzing the structure of a snowpack. Analysis of data from 10 satellite overpasses of the Midwestern

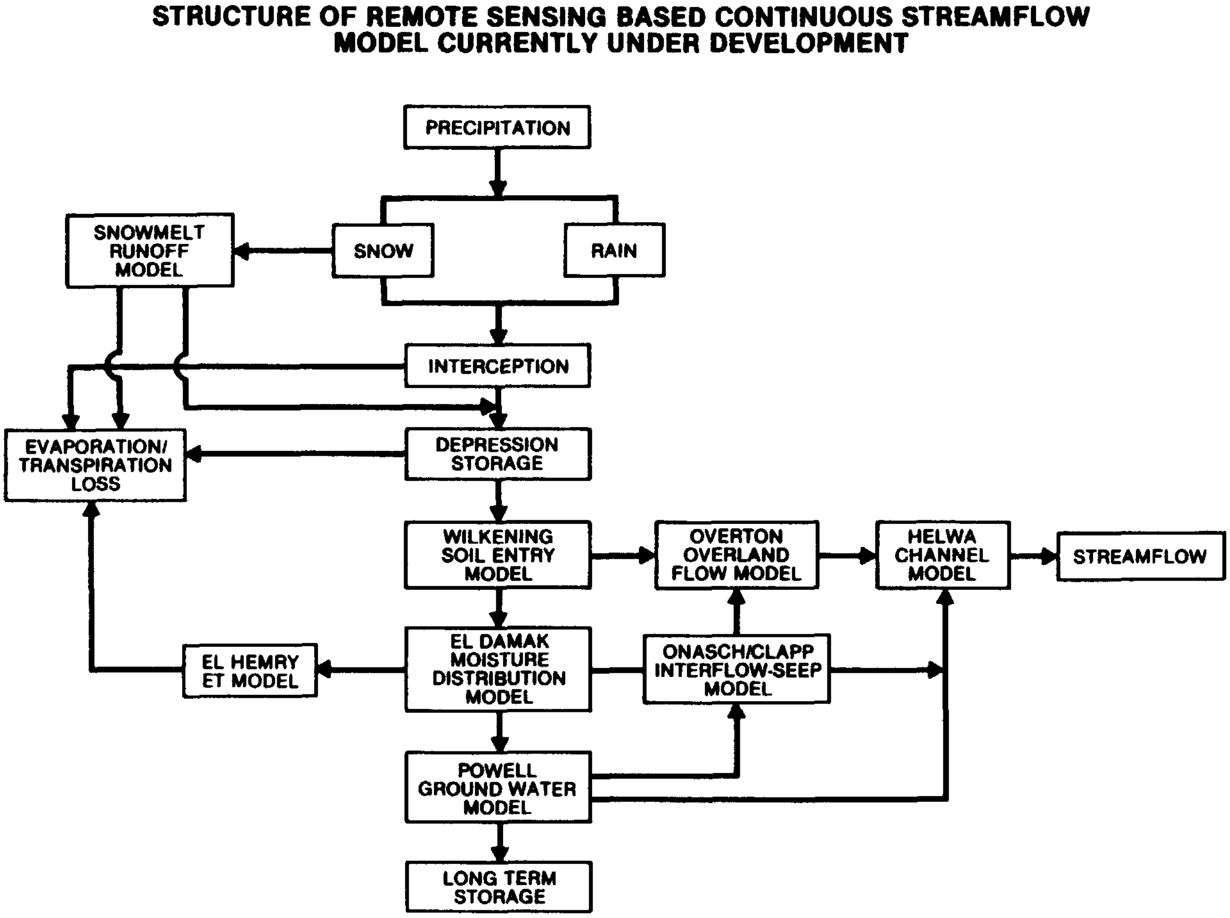


Figure 55.- Structure of remote-sensing-based continuous streamflow model currently under development.

United States has revealed that horizontally polarized T_B (radiation temperature) data correlate better, in general, with snow depth than do vertically polarized data. In addition, when large discrepancies were found in the response of the horizontally and vertically polarized data to snow depth (fig. 56), snowpack melting and/or metamorphism was apparently occurring.

4.7.6 Agricultural Water Quality Studies

A comparison was made between ground data collected from Lake Chicot, Arkansas, and Landsat TM data collected on September 23, 1983. A preliminary analysis of limited data indicates that TM data may be useful in monitoring suspended sediment and chlorophyll in a lake with high suspended sediment loads. Total suspended loads ranged from 168 to 508 parts per million (ppm). TM band 3 appears to be most useful, with bands 1, 2, and 4 also containing useful information relative to suspended sediments. Considering water data only, bands 1, 2, and 3 appear to provide similar information. Bands 3 and 4 are also significantly related. Bands 5 and 7 appear to have independent information content relative to the presence or absence of water.

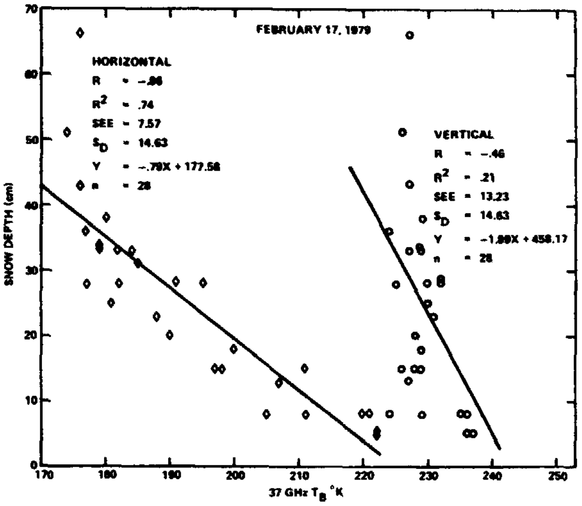


Figure 56.- A comparison of the horizontal and vertical polarizations of snow depth.

Insufficient range of water temperature ground-truth data made an evaluation of TM band 6 difficult.

TM and MSS bands 1, 2, 3, and 4 all appear to respond to changes in water quality. TM bands 1, 2, 3, and 4 appear to have overlapping information content for water sites, while TM bands 5, 6,and 7 probably provide independent, though similar, information about water sites. MSS and TM bands 1, 2, 3, and 4 were strongly correlated with each other for water sites. Thus, the main benefits of TM data, as compared to MSS data, for water sites would be gained mainly from their better ground resolution and higher quantification rather than from their separation of the spectral signal.

4.7.7 Air Pollution and Vegetation Impact

A scanning spectroradiometer specially designed for work in open-top field exposure chambers was constructed and tested late in the 1982 growing season. The laboratory-type instrument, located in a small camper-style trailer near the field site, uses 50-meter lengths of optical fibers to reach the chambers in the field and is capable of measuring light intensities from 400 to 1100 nanometers at a 20-nanometer band width. The first reflectance spectra were obtained from soybean plants growing in open-top chambers in the field and being exposed to different low concentrations of ozone throughout the growing season. An analysis of these spectra is complete and suggest the following:

- Ozone effects on the reflectance from the soybean plants were most obvious at wavelengths between 560 and 620 nanometers (fig. 57).

- Ozone promotes early senescence. Injury is not obvious until later in the growing season. Visible injury occurs

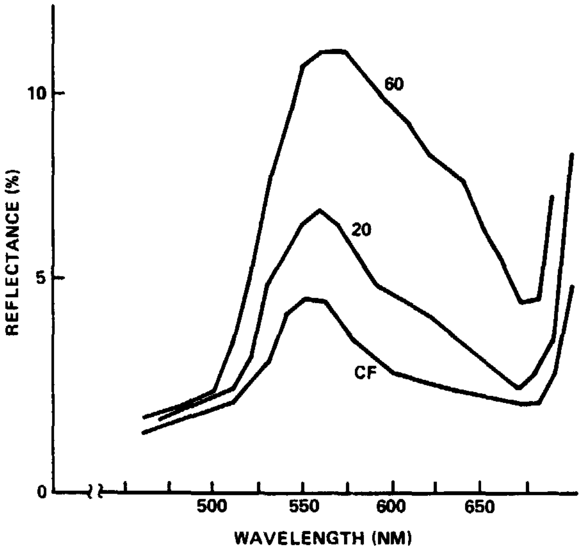


Figure 57.- Reflectance of soybeans in the visible portion of the spectrum. Plants were exposed for 7 hours per day throughout the growing season either to 20 or 60 ppb ozone or to charcoal filtered air.

earlier in the growing season, but it is generally limited to the lower leaves and is therefore not as apparent to the overhead sensor of the spectroradiometer.

- In contrast to results of earlier work with snap bean plants exposed to high ozone concentrations for short time periods in growth chamber experiments, no differences in reflectance were observed in the near-infrared (700- to 1100-nanometer) part of the spectrum of soybean plants exposed to much lower ozone concentrations for much longer times.

APPENDIX A

AgRISTARS MANAGEMENT AND ORGANIZATION

1. INTRODUCTION

The program scope of AgRISTARS specifically addresses the seven information requirements identified by the Secretary of Agriculture.[2] It is structured into projects designed to conduct research, develop, test, and evaluate the various applications of aerospace technology. These projects are designed to support a decision regarding the routine use of remote sensing technology by USDA.

2. RESPONSIBILITIES

The organization and management philosophy recognizes that each involved Government agency enters into an agreement to support remote sensing research which will address the information requirements defined by the USDA. Each Government agency budgets, manages, and maintains control of the resources necessary to meet its own responsibilities as jointly agreed upon (see fig. A-1).

3. JOINT MANAGEMENT STRUCTURE/ORGANIZATION

The program utilizes the matrix management system. There are eight major projects, each having a number of tasks assigned to various line organizations of the participating agencies. Each of the eight projects has a project manager who reports to a Program Management Group (PMG). The PMG, in turn, takes its direction and guidance from the Interagency Coordinating Committee (ICC). As viewed in figure A-2, the functional relationships are structured into a three-level management system, each having distinct responsibilities.

3.1 INTERAGENCY COORDINATING COMMITTEE

The ICC is comprised of membership from USDA, NASA, USDC, UDSI, and AID. It is chaired by the USDA and is responsible for approving AgRISTARS program objectives and establishing priorities; approving the AgRISTARS Program Plan; assessing progress, identifying problems, and developing corrective actions; and coordinating the use of resourses assigned to the program.

3.2 PROGRAM MANAGEMENT GROUP

The PMG represents a joint approach to management which provides participation, project integration, and needed visibility by all participants and assures full responsiveness to USDA information requirements.

The PMG is a full-time management/coordination group responsible for a wide range of management and support activities for both the ICC and the research projects. Included are tasks related to the following areas:

- Program/Project Plans
- Change Control Function
- Project Support
- Data Requirements Consolidation
- Resources Planning and Monitoring
- Review and Reporting

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[2] Joint Program of Research and Development of Uses of Aerospace Technology for Agricultural Programs, February 1978.

USDA

- DEFINITION OF USDA INFORMATION REQUIREMENTS.
- YIELD MODEL RESEARCH, DEVELOPMENT, AND TESTING (RD&T) AND APPLICATIONS.
- RD&T – APPLICATIONS ANALYSIS FOR AREA, YIELD, AND PRODUCTION ESTIMATION.
- DEVELOPMENT OF AGRONOMIC/ANCILLARY DATA BASE.
- USER EVALUATION.
- GROUND DATA COLLECTION.
- RD&T AND APPLICATIONS FOR CROP WEATHER ASSESSMENTS.[1]
- RD&T AND APPLICATIONS FOR EW/CCA ANALYSIS.
- RD&T AND APPLICATIONS FOR RRI ANALYSIS.
- RD&T AND APPLICATIONS FOR LAND USE, PRODUCTIVITY AND C/P ANALYSIS.
- RD&T FOR SOIL MOISTURE MEASURING TECHNIQUES.

NASA

- RD&T FOR FOREIGN CROP AREA ESTIMATION.
- RD&T FOR COMBINING AREA AND YIELD ESTIMATES FOR FOREIGN CROP PRODUCTION.
- FIELD RESEARCH.
- LANDSAT DATA ACQUISITION.
- RD&T – SPECTRAL INPUTS TO YIELD MODELS.
- RD&T – SPECTRAL INPUTS TO QUANTITATIVE EW/CCA.
- RD&T FOR SPECTRAL ANALYSIS RELATED TO INVENTORY AND CONDITION ASSESSMENT TECHNIQUES FOR RRI.
- RD&T INVENTORY AND MONITORING TECHNIQUES FOR LAND USE AND C/P.
- RD&T FOR REMOTELY SENSED SOIL MOISTURE MEASURING TECHNIQUES.
- DEFINITION OF REQUIREMENTS FOR FUTURE SENSORS (INCLUDING IN-SITU).

USDC

- METEOROLOGICAL DATA BASE.
- RD&T AND APPLICATIONS OF ENVIRONMENTAL SATELLITE DATA.
- RD&T METEOROLOGICAL YIELD MODELS.
- RD&T WEATHER/CROP ASSESSMENTS.[2]
- RD&T ON USE OF CONVENTIONAL AND SATELLITE-DERIVED METEOROLOGICAL DATA APPLIED TO RRI AND C/P.
- RD&T ON TECHNIQUES FOR DETERMINING SOIL MOISTURE.

USDI

- LANDSAT DATA STORAGE, RETRIEVAL, AND DISSEMINATION.

AID

- EVALUATION OF UTILITY OF RD&T RESULTS FOR APPLICATIONS IN DEVELOPING COUNTRIES.

[1] Primary emphasis is on assessment of crop conditions (e.g., yield, production) using meteorological data as an input to develop needed information.

[2] Primary emphasis is on acquisition and evaluation of meteorological data in terms of its utility for crop condition assessment.

Figure A-1.- AgRISTARS responsibilities of five Government agencies.

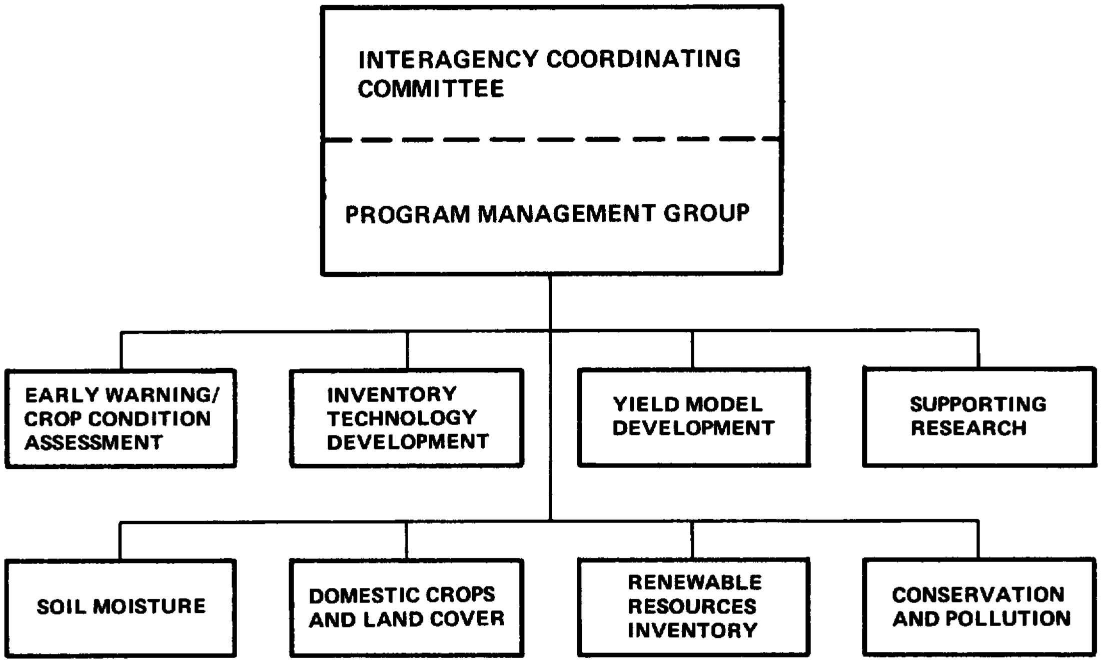

Figure A-2.- Joint agency program management and functional relationships.

4. PROJECT MANAGERS

Each of the projects is headed by a project manager whose selection from a participating agency is based principally upon considerations of technical expertise and expected levels of agency involvement. The project managers are responsible to the PMG for planning and managing activities within their projects. This includes defining project content, identifying expected projects and schedules, assessing status and progress, identifying problems, making change recommendations, planning and defining tasks, and participating with other project managers in the integration of the various projects.

5. REVIEW AND REPORTING

A review and reporting plan has been established to support major program planning and budgetary events.

Each year in the August through September period, the PMG, project managers, and task managers update the project implementation plans to reflect current budgets and the results and recommendations resulting from the various reviews.

Internal reviews are held at the various levels of management as required.

6. DOCUMENTATION

All aspects of the program are being documented in full by reports; technical memoranda and journal articles, as appropriate; press releases; and program progress reports.

7. PARTICIPATING ORGANIZATIONS

Many elements of Government, industry, and the university community are participants in AgRISTARS.

APPENDIX B

AgRISTARS PROGRAM AND PROGRAM-RELATED DOCUMENTATION

1. GENERAL

This appendix contains a by-project listing of all AgRISTARS program and program-related documentation from program inception through documentation of tasks completed in FY 1983. The listing provided has been further subdivided within each project into areas of plans, reports, procedures, etc., to facilitate easy retrieval of desired documentation.

2. REQUESTING DOCUMENTS

2.1 AgRISTARS DOCUMENTS WITH NTIS NUMBERS

Reproduction of all AgRISTARS documents with NTIS numbers should be available by writing:

National Technical Information Services
5285 Port Royal Road
Springfield, Virginia 22161

Otherwise, request documents according to instructions in sections 2.2 and 2.3.

2.2 CONTROLLED DOCUMENTS

Documents which carry an AgRISTARS control number may be obtained from NASA/JSC by either telephone or mail request. Address requests to:

Lyndon B. Johnson Space Center
SC - Documentation Manager
Houston, Texas 77058
Telephone 713-483-4776

2.3 UNNUMBERED DOCUMENTS (00900 SERIES AND PRESENTATIONS)

Requests for material within this area will be honored based upon availability of data. Requests should be made to:

Lyndon B. Johnson Space Center
(Appropriate Project)
SC - Program Management Group
Houston, Texas 77058
Telephone 713-483-2548

0. AgRISTARS PROGRAM DOCUMENTATION (AP)

Reports

0-01. AgRISTARS Annual Report. AP-J0-04111, 1980. NTIS: 82N23609.

0-02. AgRISTARS Documents Tracking List Report. AP-L1-04116, First Edition, Feb. 1981.

0-03. AgRISTARS Documents Tracking List Report. AP-L1-04116, Second Edition (February, March, April, May 1981), June 1981.

0-04. AgRISTARS Documents Tracking List Report. AP-L1-04116, Third Edition (Through September 1981).

0-05. AgRISTARS Documents Tracking List Report. AP-L2-04116, Fourth Edition (Through March 1982).

0-06. AgRISTARS Documents Tracking List Report. AP-L2-04116, Fifth Edition (Through June 1982).

0-07. AgRISTARS Documents Tracking List Report. AP-L2-04116, Sixth Edition (Through December 1982).

0-08. Data Directory Report, AP-J1-04137, JSC-17415.

0-09. AgRISTARS Annual Report - Fiscal Year 1981. AP-J2-04225, Jan. 1982.

0-10. AgRISTARS Research Report - Fiscal Year 1982. AP-12-0393, Jan. 1983.

0-11. AgRISTARS Documents Tracking List Report. Seventh Edition, AP-L3-04116, JSC-18887, LEMSCO-19557, Seventh Edition (Through June 1983).

Plans

0-12. AgRISTARS Technical Program Plan. AP-J0-00628, JSC-17153, Jan. 15, 1980.

0-13. AgRISTARS Technical Program Plan - Appendix B - Data Management Plan - Volume I. AP-J0-00628-1, JSC-17153, April 11, 1980.

0-14. AgRISTARS Data Management Plan. AP-L1-00630, JSC-17158, May 1981.

0-15. AgRISTARS, First Year Achievements. MU-J1-00629, JSC-17156, June 1981.

0-16. AgRISTARS Program Directive (ADP), AgRISTARS Program Relationship to Foreign Countries. ADP 80-1, Dec. 4, 1979.

0-17. AgRISTARS Program Directive (ADP), AgRISTARS Technical Approach Definitions, ADP 80-2, Mar. 5, 1980.

0-18. AgRISTARS Program Directive (ADP), AgRISTARS Large Scale Applications Tests (LSAT's). ADP 80-4, Apr. 24, 1980.

0-19. AgRISTARS Management/Organization Plan. AP-J0-00632, JSC-17396, Jan. 15, 1980.

0-20. AgRISTARS Program Documentation, Management/Organization Plan, April 19, 1982. AP-J1-C0637, JSC-17419, Apr. 1982.

0-21. AgRISTARS Program Documentation, Program Plan, April 19, 1982. AP-J2-C0651, JSC-18224, Apr. 1982.

0-22. AgRISTARS Revised Program Plan. AP-J0-C0659, JSC-18578, Sept. 1982.

0-23. AgRISTARS Program Documentation, 1984 Program Plan. AP-J3-C0662, JSC-18898, Dec. 1983.

0-24. AgRISTARS Resources Plan. Nov. 5, 1980.

0-25. AgRISTARS Technical Program Plan. AP-J9-00631, JSC-17395, Apr. 20, 1979.

1. EW/CCA

Instructions

1-01. Soil Moisture/Early Warning and Crop Condition Assessment Interface Control Document. MU-J0-00101, JSC-16842, Nov. 1980. NTIS: 82N19628.

1-02. Yield Model Development/Early Warning and Crop Condition Assessment Interface Control Document. MU-J0-00102, JSC-16843, Nov. 1980.

1-03. Crop Condition Query Software Documentation. EW-L2-00103, JSC-18271, LEMSCO-18618, Sept. 1982.

Reports

1-04. Meteorological Satellite Data - A Tool to Describe the Health of the World's Agriculture. EW-N1-04042, JSC-17112, Feb. 1981. NTIS: 81N31596.

1-05. Hand-Held Radiometry - A Set of Notes Developed for Use at the Workshop on Hand-Held Radiometry. EW-U1-04052, JSC-17118, Oct. 1980. NTIS: 81N28496.

1-06. Soil Moisture Inferences From Thermal Infrared Measurements of Vegetation Temperatures. EW-U1-04068, JSC-17125, Mar. 1981. NTIS: 81N29500.

1-07. Large Area Application of a Corn Hazard Model. EW-U1-04074, JSC-17130, Mar. 1981. NTIS: 81N28497.

1-08. The Characteristics of TIROS, GOES, DMSP, and Landsat Systems. EW-N1-04075, JSC-17131, Mar. 1981. NTIS: 81N29506.

1-09. The Environmental Vegetative Index - A Tool Potentially Useful for Arid Land Management. EW-N1-04076, JSC-17132, Mar. 1981. NTIS: 81N29505.

1-10. Canopy Temperature as a Crop Water Stress Indicator. EW-U1-04077, JSC-17133, Mar. 1981. NTIS: 81N33566.

1-11. Registration Verification of SEA/AR Fields. EW-L1-04101, JSC-17251, LEMSCO-16204, May 1981. NTIS: 82N21635.

1-12. Plant Cover, Soil Temperature, Freeze, Water Stress, and Evapotranspiration Conditions. EW-U1-04103, JSC-17143, Aug. 1981.

1-13. Utilization of Meteorological Satellite Imagery for Worldwide Environmental Monitoring: The Lower Mississippi River Flood of 1979. EW-N1-04104, JSC-17144, Mar. 1981. NTIS: 82N22588.

1-14. Techniques in the Use of NOAA 6-N Data for Crop Condition Evaluation. EW-N1-04105, JSC-17145, Apr. 1981.

1-15. Two Layer Soil Water Budget Model - A Tool for Large Area Soil Moisture Estimates. EW-U1-04106, JSC-17146, Apr. 1981.

1-16. Comparison of Landsat-2 and Field Spectrometer Reflectance Signatures of South Texas Rangeland Plant Communities. EW-U1-04107, JSC-17147, Apr. 1981.

1-17. Environmental Factors During Seed Development and Their Influence on Pre-Harvest Sprouting in Wheat. EW-U1-04115, JSC-17157, May 1981. NTIS: 82N22589.

1-18. A Meteorological Driven Maize Stress Indicator Model. EW-U1-04119, JSC-17399, Apr. 1981. NTIS: 82N23564.

1-19. Review of Literature Relating to the Modeling of Soil Temperature Based on Meteorological Factors. EW-21-04124, NAS-916007, July 1981. NTIS: 82N22544.

1-20. Airborne Observed Solar Elevation and Row Direction Effects on the Near-IR/Red Ratio of Cotton. EW-U1-04144, JSC-17420, Aug. 1981. NTIS: 82N23593.

1-21. Agricultural Research Service Research Highlights in Remote Sensing for Calendar Year 1980. EW-R1-04147, July 1981. NTIS: 82N23601.

1-22. A Look At the Commonly Used Landsat Vegetation Indices. EW-L1-04134, JSC-17413, LEMSCO-16844, Oct. 1981. NTIS: 82N21657.

1-23. An Empirical, Graphical, and Analytical Study of the Relationships Between Vegetative Indices. EW-J1-04150, JSC-17424, Oct. 1981. NTIS: 82N22592.

1-24. Predicting the Timing and Potential of the Spring Emergence of Overwintered Populations of Heliothis Spp. EW-U1-04185, T-4629H, Apr. 1981.

1-25. Area Estimation of Environmental Phenomena from NOAA-n Satellite Data. EW-L1-04190, JSC-17437, LEMSCO-17312, Feb. 1982. NTIS: 82N24553.

1-26. A Meteorologically Driven Grain Sorghum Stress Indicator Model. EW-U1-04208, JSC-17797, Nov. 1981. NTIS: 82N23591.

1-27. Evaluation of the Doraiswamy-Thompson Winter Wheat Crop Calendar Model Incorporating a Modified Spring Restart Sequence. EW-U1-04212, JSC-17801, Nov. 1981. NTIS: 82N23580.

1-28. Two-Channel Metsat to Universal Format Conversion Program (MET2CH2UF) User's Guide. EW-L1-04215, JSC-17803, LEMSCO-17262, Dec. 1981.

1-29. Program RAWPLT User Guide: Plotting of Landsat, Sun-angle, and Atmospheric - Corrected Data Versus Acquisition Date. EW-L1-04216, JSC-17804, LEMSCO-17331, Apr. 1982.

1-30. A Review of Remote Sensing and Grasslands Literature. EW-L2-04223, JSC-17809, LEMSCO-17644, Feb. 1982. NTIS: 82N24555.

1-31. Increase of Cold Tolerance in Cotton Plant (Gossypium Hirsutum L.) by Mepiquat Chloride. EW-U2-04243, JSC-17817, Feb. 1982.

1-32. Reflectance Measurements of Cotton Leaf Senescence Altered by Mepiquat Chloride. EW-U2-04244, JSC-17818, Feb. 1982.

1-33. Preliminary Study for Correlation of Meteorological Satellite Opening (METSAT) Data With Landsat Data. EW-L2-04248, JSC-17821, LEMSCO-17307, Mar. 1982.

1-34. Reflectance Differences Between Target and Torch Rape Cultivars. EW-U2-04250, JSC-17823, Mar. 1982. NTIS: 82N24544.

1-35. Leaf Reflectance - Nitrogen - Chlorophyll Relations Among Three So. Texas Woody Rangeland Plant Species. EW-U2-04251, JSC-17824, Feb. 1982. NTIS: 82N24545.

1-36. Reflectance of Litter Accumulation Levels at 5 Wavelengths Within 0.5 to 2.5um Waveband. EW-U2-04252, JSC-17825, Mar. 1982. NTIS: 82N24542.

1-37. Optical Parameters of Leaves of Weed Species. EW-U2-04253, JSC-17826, Mar. 1982. NTIS: 82N24546.

1-38. Use of Landsat 2 Data Technique to Estimate Silverleaf Sunflower Infestation. EW-U2-04254, JSC-17827, Feb. 1982. NTIS: 82N24547.

1-39. Semi-Annual Program Review Presentation to Level 1, Interagency Coordination Committee. EW-J2-04276, JSC-17822, Apr. 19, 1982.

1-40. Determination of Growth and Water Stress in Wheat by Various Vegetation Indices Through a Clear and a Turbid Atmosphere. EW-U2-04298, JSC-18241, May 1982.

1-41. Advanced Very High Resolution Radiometer (AVHRR) Data Evaluation for Use in Monitoring Vegetation Volume I - Channels 1 and 2. EW-L2-04303, JSC-18243, LEMSCO-17383, May 1982.

1-42. Computer Program Documentation for the Flood Damage Assessment Processors. EW-L2-04312, JSC-18246, LEMSCO-18237, June 1982.

1-43. Influence of Environmental Factors During Seed Development and After Full-Ripeness on Pre-Harvest Sprouting in Wheat. EW-U2-04319, JSC-18254, June 1982.

1-44. Estimating Total Standing Herbaceous Biomass Production with Landsat MSS Digital Data. EW-U2-04320, JSC-18255, June 1982.

1-45. Winter Wheat Stand Density Determination and Yield Estimates from Handheld and Airborne Scanners. EW-U2-04327, JSC-18258, June 1982.

1-46. Optical Parameters of Leaves of Seven Weed Species. EW-U2-04328, JSC-18259, June 1982.

1-47. Semi-Annual Progress Report Development of An Early Warning System of Crop Moisture Conditions Using Passive Microwave. EW-T2-04329, NAS9-16556, Apr. 1982.

1-48. Adjusting the Tasseled Cap Brightness and Greenness Factors for Atmospheric Path Radiance and Absorption on a Pixel by Pixel Basis. EW-U2-04334, JSC-18260, July 1982.

1-49. Comparison of Landsat-2 and Field Spectrometer Reflectance Signature of South Texas Rangeland Plant Communities. EW-U2-04335, JSC-18261, July 1982.

1-50. Computer Program Documentation for the Pasture/Range Condition Assessment Processor. EW-L2-04340, JSC-18265, LEMSCO-18627, July 1982.

1-51. Annual Report: Agricultural Research Service - Research Highlights in Remote Sensing for Calendar Year 1981. EW-R2-04345, JSC-18268.

1-52. SMDATA Program Documentation. EW-L2-04346, JSC-18269, LEMSCO-18646, Sept. 1982.

1-53. Diurnal Patterns of Wheat Spectral Reflectance and Their Importance in the Assessment of Canopy Parameters From Remotely Sensed Observations. EW-U2-04349, JSC-18561, Sept. 1982.

1-54. Comparisons Among a New Soil Index and Other Two-And-Four-Dimensional Vegetation Indices. EW-U2-04350, JSC-18562, Sept. 1982.

1-55. Use of a Near-Infrared Video Recording System for the Detection of Freeze-Damaged Citrus Leaves. EW-U2-04351, JSC-18563, Sept. 1982.

1-56. Computer Program Documentation for the Option Processor. EW-L2-04357, JSC-18571, LEMSCO-18761, Sept. 1982.

1-57. Semi-Annual Program Review Presentation to Level 1, Interagency Coordination Committee. EW-U2-04379, JSC-18582, Nov. 1982.

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