Reprinted from

Eighth International Symposium

Machine Processing of

Remotely Sensed Data

with special emphasis on

Crop Inventory and Monitoring

July 7-9, 1982

Proceedings

Purdue University
The Laboratory for Applications of Remote Sensing
West Lafayette, Indiana 47907 USA

APPLICATION OF SATELLITE REMOTE SENSING IN USDA CROP INFORMATION SYSTEMS

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I. INTRODUCTION

The U. S. Department of Agriculture has long been interested in the application of remote sensing for improving its information on global crops. Through the Foreign Agricultural Service (FAS), which operates the Department's crop statistics program for foreign countries and through the Statistical Reporting Service (SRS), which operates the domestic crop statistics program, special efforts have been carried out during the past two decades to develop procedures for exploiting remote sensing technology for improving output of these two programs. Since these two programs are based on entirely different methodologies, the focus of development efforts has been quite different as has the actual applications of data from satellite remote sensing for improvement of the information output from them. Because of these differences this paper will discuss the current use of satellite remote sensing data in the system used for foreign countries separately from the approach used in the domestic system. Despite current differences based on realities of the diverse conditions for collecting agricultural data around the world, it is expected that, as the "state of the technology" changes, the two approaches will become increasingly less diverse. This is not to suggest that they will ever completely merge into one unique system for collecting all of the global data on agricultural crops required by the Department; however, it is hoped that improvements in one system will be useful in both. It should be noted, that the use of satellite remote sensing for estimating foreign crops where little or no ground data are available, and where even the accuracy of historical agricultural statistics may be suspect, presents somewhat different and more difficult problems than does its use for estimating U.S. crops. On the other hand, the potential payoff is far greater for improved foreign estimates than it is for U.S. estimates. The general consensus within the Department is that the cost of satellite remote sensing can only be justified in terms of its use to provide data for foreign areas.

II. FOREIGN APPLICATIONS

Operational satellite remote sensing programs covering foreign areas are administered by the Foreign Agricultural Service (FAS) and carried out by the Foreign Crop Condition Assessment Division (FCCAD) located near the Johnson Space Center (JSC) in Houston, Texas.

This Division was established officially in January 1978 to support the FAS with foreign crop production estimates. The Division has been operational since that date providing routine and ad hoc reports on such diverse commodities and agriculturally related subjects as food and coarse grains, oil seeds and other industrial crops, winterkill, deforestation, monitoring water impoundments, plant disease and moisture stress in plants. These analyses presently emphasize the USSR, Eastern Europe, Brazil, Argentina, Mexico, Australia, China and India. The Division utilizes three major data sets--remotely sensed satellite data (both LANDSAT and NOAA satellite series), meteorological data and ancillary data such as soils and historical agricultural statistical data (area, yield and production).

The automated data processing support consists of an ADP Support Branch and four minicomputers (three in Houston and one in Washington, D.C.). The computers consist of the Terminal Support System (TSS) in Washington, D.C., and in Houston the User Interface System (UIS) or data base computer, the Scene Processing Unit (SPU) or image extraction computer and the Analyst Terminal System (ATS).

The TSS is occupied principally with sending data to and receiving data from the Houston office and programming for the Houston office. It also provides statistical packages for analysts in Washington, D.C., and enables the analysts in Washington to query the Division's data base.

The UIS is dedicated to storage and retrieval of all ancillary data (soils, meteorological, historical statistical data, model results, etc.). The Division has adopted the U.S. Air Force I,J grid network (25X25 N.M. grid cell) to construct its global data base. All data are input at the cell or subcell level. For example, soil data are encoded at the quadrant level and WMO meteorological data are input at the cell coincident with the geographic location of the station. Whereas the gridded meteorological data are input for a selected sample of cells, historical agricultural statistical data are input only in cells that have traditionally been cropped. Greenness values and/or biomass are calculated for each cell (between 60 degrees north and south) and other model output or results are also stored at the cell level.

The FCCAD Data Base is the subject of a technical paper to be presented Thursday afternoon in the Applications of Georeference Information Systems Session. This presentation presents the application of "A Database to Support Crop Condition Assessment Based on Remote Sensing Technology."

The SPU has as peripherals a High Density Tape (HDDT) processor which includes a Serial Control Interface (SCI) and an Array Processor (AP-120B). These peripherals and specially developed software give the SPU the capability of extracting a full frame or any subset of LANDSAT data. The complete set of LANDSAT data acquisitions is transmitted from Goddard Space Flight Center (GSFC) each day via the Domestic Communications Satellite (DOMSAT) and recorded on digital tapes by NASA/JSC. These HDDT's are then brought to the Division facility and processed by the SPU which extracts any scenes or subsets thereof required by the remote sensing analyst. Customarily the analyst requests two products; i.e., sampled full frame[1] and full resolution subscenes. The sampled frame is every fifth pixel from every fifth scan line. These products are stored on the analyst disk packs on the CCA; they are never stored in the data base. This gives the analyst a synoptic overview of approximately 80x80 miles of the scene. The full resolution sizes are variable, dependent on the analyst's requirement and/or the task, ranging in size from 3-1/2 x 3-1/2 miles up to approximately 15x15 miles. The vegetative values[2] for each cell within the sampled full frame are calculated and stored in the appropriate cell in the data base.

The NOAA series satellite data AVHRR are extracted, framed and loaded directly to the analyst disk pack by any of the computers in this facility. This is accomplished by the use of a "METSAT Preprocessor" software package[3] designed and programmed specifically for this purpose on this system. These data are highly complementary to the LANDSAT data even though the resolution is considerably worse. However, the advantages are more frequent coverage, every four to nine days, as opposed to every 18 days for LANDSAT; and each scene the Division extracts enables the analyst to examine imagery which is 600 miles east to west and 300 miles north to south. To avoid distorting vegetative values, only grid cells which fall within the center 300-mile section are used for calculation. These values are then stored in appropriate cells in the data base. This capability enables the analyst to rapidly review satellite data covering his/her entire area of responsibility every four to nine days assuming good acquisitions.

Some of the major capabilities and functions on the CCA system are as follows:

o Vegetative Index Processor[4] to calculate the intensity and dispersion of green vegetation. These data are then stored in the UIS data base for later recall and analysis.

o Image Transfer System (TIX)[5] to reformat and transmit color infrared images to FAS in Washington, D. C. These images are restructured for ease of transmission through the telephone system and are used for joint analysis with analysts in Washington.

o Rapid Image Correlation[6] to select an identifiable area within a larger search area and delete the remainder of the data leaving only the selected area. Assuming decent landmarks within a search area, the same area (within two-three pixel tolerance) can be selected on succeeding passes, giving the analyst a very cost-effective, usable multitemporal analysis capability for some applications.

o Grid Cell Overlay[7] to superimpose the I,J grid over an image with the I,J identification annotated at selected junctures.

o Classification and clustering[8] to group crops and calculate hectarage and/or areal extent.

The color graphics terminal interface to the data base allows the analyst to display any of the data elements in the UIS data base for which retrieval and display programs have been written.[9] These programs are menu driven and are executed as follows: (1) The analyst selects the area of interest from a world map by using a light pen; (2) as the area is activated, an enlarged window of that part of the world is displayed on the top half of the screen with program menus on the bottom half; (3) the analyst has the option of calling for a greater enlargement; and (4) lastly, data elements can be selected from vegetative indices, crop calendars for selected crops, soils, and meteorological data.

For example, if meteorological stations are selected, they appear on the map plotted geographically. The analyst can select a station and specify a ten-day date range, the station I.D. and associated met data elements (temperature, precipitation, etc.) to be displayed graphically on the lower half of the screen. This ten-day window can be moved forward or backward in ten-day increments.

While the FCCAD analyst selection and training criteria are probably not unique, they should be discussed at this point. The backgrounds of the Commodity Analysis Branch personnel are multidisciplinary consisting of formal education in economics, soil science and geography at this time. There is one common element in all of their backgrounds--having been brought up in a rural setting and/or farming background. Once selected, the analyst enters an intensive study of remote sensing and of his country(ies) with periodic familiarization trips to his/her country(ies). The intent, of course, is to make the analyst a country expert in all countries of his/her responsibility in all aspects of agriculture and remote sensing. This includes, but is not limited to, cultural practices, cropping areas, agricultural trends, government agricultural policy, transportation networks, export/import facilities and capabilities, and the interrelationships of the agricultural economy as it relates to the overall economy.

The following three scenarios are fairly representative of the operational capabilities of this Division. Completeness of the data base for any given country is dependent upon the length of time the Division has been working that country. Therefore, the data elements used for discussion in these scenarios are not available on a worldwide basis. The total data base will be completed as time and resources permit.

Scenario 1

The analyst follows the crop throughout the year as different groups of crops are planted, mature and are harvested. He continually reviews the different model outputs against a base year; i.e., vegetative indices at the cell level, soil moisture calculations,[10] crop calendars,[11-12] stress model results,[13-14] winterkill model results, [15-16] precipitation and temperature against norms, in addition to a visual analysis of the imagery itself. From these tools, the analyst can make certain conclusions--the crop is better or worse than the base year, and the area devoted to a group of crops appears to be larger than or smaller than the base year. Depending on the experience of the analyst and length of time he/she has worked a given country, it is possible to estimate a percentage range for the increase or decrease with a fair degree of accuracy. Quantifiable estimates for area and yield are pending development of an acceptable yield model and area change sampling scheme.

Scenario 2

Through routine viewing of imagery or notification from other sources, the analyst is aware of a change in agriculture. In this case, areas of native vegetation being brought into cultivation. The analyst will calculate the area change (using classification or clustering routines) then begin accessing the data base for input to the impact analysis. The grid cell overlay would be superimposed on the image to determine the cells involved in the change. Once cells are identified, the analyst will query the data base for the following information:[17]

(1) Type of soil in the cell.

(2) Crop mix customarily found on this soil and climatic regime.

(3) Maximum yield of these crops under these conditions.

The analyst must then relate these yields through his knowledge of the country's cultural practices opposed to optimum practices. Again, through his/her knowledge of the country, the analyst determines the most probable candidate(s) among the potential crops. At this point, the analyst is prepared to issue a report on the potential increase in production for this area. The final product may be somewhat subjective, but it is based on an objective analysis.

Scenario 3

An anomaly occurs in the high density agricultural area. A significant deviation is noted in the vegetative indices from the normal or expected value. The analyst can identify the area using cell vegetative indices and visual examination of the image. If it is decided that the vegetation is undergoing significant change, the analyst can query the affected cells for the agricultural statistics to determine the crops historically grown in the area. Stress model output, calculated growth stage for the crops, soil type and soil moisture can then be reviewed. If none of these elements is reflective of the observed stress, the Division contacts the Counselor for Agricultural Affairs at the American Embassy via the FAS/Department of State telecommunication network for assistance. The areal extent and geographic location of the anomaly, as well as the Division's analysis, are related to the Counselor. If the Counselor or his staff has no current knowledge of conditions in the specified area, his office can include the area in its travel itinerary. Once the area has been observed first hand, information on the cause and associated impact can be relayed back to the Division by phone or the telecommunication network.

The remote sensing capabilities discussed in the foregoing and other techniques/capabilities being currently utilized by the Division fall short of FAS goals. Future availability of models, techniques, etc., developed by the research and development community which are applicable to FAS requirements will be implemented on the Division's present or future system to reach our goal of a complete system for global crop production estimation.

III. DOMESTIC APPLICATIONS

A. CURRENT OPERATIONS

Because of its extensive use of probability sampling for collection of comprehensive ground data on crops (area planted, area harvested and quantities produced), the SRS has approached the use of satellite remote sensing with the objective of providing cost-effective improvement in the estimates already provided by the ground samples. Even before the first LANDSAT (then called Earth Resources Technology Satellite) was launched in 1972, SRS had been using remote sensing in the form of aerial photography for constructing its Land Area Sampling Frame.[18] This frame is the foundation of all the advances the SRS has made since 1960 to employ modern probability sampling for producing current agricultural statistics for the United States. Use of LANDSAT imagery for frame construction and maintenance was explored in 1977.[19] Results of this research demonstrated the contribution of LANDSAT image products in area sampling frame construction. The LANDSAT image products are current and have a considerable advantage over available aerial photography, much of which may be eight to ten years old, in determining broad land use strata. Thus the LANDSAT image products were rapidly integrated into the ongoing program of area frame construction and maintenance. Use of LANDSAT MSS and RBV image products has proved to be extremely cost-effective in reflecting actual land use changes. This means that when a new frame is constructed, it is truly up-to-date and provides for significant increases in sampling efficiency. California was the first entire state for which LANDSAT imagery was used for constructing a new frame. The new sample from this frame for the June Enumerative Survey (JES)[20] resulted in a reduction in data collection costs of about 30 percent, with essentially no loss in precision of the estimates. Conversely, precision of the state level estimates could have been significantly improved had the amount of funds for data collection for the sample from the old frame been used for increasing the sample size from the new frame.[21]

LANDSAT image products have now been fully integrated into all SRS frame development activities. In addition to California, new frames using these products have been constructed for Oregon, Washington, Idaho and Texas. Frames in all other states utilizing satellite imagery will be rebuilt as rapidly as resources permit. This use of LANDSAT has been relatively easy to implement, since it clearly provides improved information on land use (more up-to-date) and because the timeliness (age of product after data acquisition) requirement is not nearly as critical as for other SRS requirements for directly improving crop area estimates.

The SRS strategy for directly using satellite remote sensing for crop and livestock estimates has been based on the following premises:

(1) Remote sensing is simply another method of data collection,

(2) Remote sensing can be used to supplement the existing data collection system, but never completely replace it,

(3) The two data collection systems must be integrated through rigorous statistical methodology, and

(4) Resource-effective techniques must be developed for successful integration.

As a method of data collection, satellite remote sensing is certainly a powerful one when viewed in terms of the vast amounts of data that can be collected on a routine repeatable schedule (except for certain limitations such as cloud cover). The sheer amount of data collected can become a limitation on its use unless the collection system is combined with a highly sophisticated data processing system for rapidly and efficiently reducing the data to a form that can be used for making inferences about the population actually measured. In the case of SRS, that population is usually the area devoted to agricultural crops, or to a specific crop. The dynamics of U.S. agriculture require that any data collection system used must provide for rapid collection, processing and release of the resulting information. The current ground system used by SRS for crop area estimates typically provides for all of these to be completed within about one month from the start of data collection. Data collection for the JES normally begins the last week in May and the resulting estimates of area planted, by crop, are published during the last week of June. One limitation on the current experimental LANDSAT system has been its inability to provide timely turn-around of the data once it has been acquired.[22] This has limited SRS operational use of LANDSAT data for estimating crop area to the annual end of season estimates. For example, with the optimum acquisition period of late July to early September for differentiation between corn and soybeans in the U.S. Corn Belt, and the present schedule of several weeks to several months for satellite data delivery, it has not been possible to process the data and integrate the results into the existing system until the final end of season estimates are being prepared in late November and December.

With the large number of agricultural characteristics collected simultaneously in SRS ground surveys, and the present limits on satellite remote sensing to primarily collecting data on condition and extent of vegetation, the second premise for integrating remote sensing into the existing system is rather self-evident. As long as data on crop varieties, fertilizer inputs, livestock, grain stocks, and numerous other economic data on agriculture are required by the Department's agricultural statistics program, potential improvements through satellite remote sensing are quite limited in terms of the total program.

Given the existing SRS system of area frame sampling which includes field-by-field enumeration within some 15,700 randomly selected land area segments for the 48 conterminous states, it was logical to approach the integration of satellite remote sensing data as a conventional double-sampling problem.[23] Using a subsample of the ground collected data for classifier training, and another subsample (or the entire ground data set)[24] for adjusting resulting classification results to provide unbiased estimates of areas devoted to different crops and/or land use seemed to be a reasonable approach for making direct crop acreage estimates from satellite data. Consequently, this is the approach SRS chose for extensive research beginning shortly after LANDSAT I was launched in 1972. This approach exploits the complementarity of the synoptic coverage of the satellite remotely sensed data and the inference and "truth" aspects of the ground sample data.

Over the past decade, research and development activities both within SRS and by other organizations have solved most of the operational problems for using LANDSAT MSS data as a direct input to U.S. crop area estimation. Registration problems have increasingly been reduced to the point where only minimal analyst time is required for locating MSS pixel data corresponding to the available ground data. Clustering and classification algorithms have been improved and adopted for use in the EDITOR[25] software system by SRS.

The EDITOR software integrates a distributed data processing system, which employs micro-computers, mini-computers, standard large main-frame computers with very large and fast parallel processors. Micro and Mini computers are used for data-entry (digitizing ground data) and for small scale processing. Standard large main frames (IBM/370 and 3400 Series) are used for ground data editing, MSS data reformatting, etc., and the large parallel processor (CRAY-IS) is used for classification of all LANDSAT data for complete scenes. This system has been continuously modified and improved, so that in its present state, even though operated as a research system, it could very well be deemed operational. In fact, based on results of processing all useable growing season MSS data for Iowa and Kansas in 1980,[26] and for Iowa, Kansas, Oklahoma and Missouri in 1981[27] it is apparent that the use of satellite remote sensing is very close to being resource effective, which is the last premise upon which SRS use of satellite remote sensing is based.

The SRS definition of "resource-effective," is that not only are total monetary costs equal to or less than other alternatives for achieving the precision improvements available through processing the satellite data but also that analyst and/or staff time is less than for other alternatives. This is the primary concern, that has directed the technology development away from photo-interpretative or other analyst intensive methodologies toward maximum use of large-scale computers to exploit the MSS digital data format. Current procedures demonstrated for four states in 1981 and planned for six states in 1982 are very close to being what SRS would define as "resource effective." Not only has total staff time for processing satellite data been dramatically reduced through extensive research by SRS, NASA and many other institutions, hardware and software improvements have occurred which makes the technology even more promising for operational implementation in states covering most of the U.S. production of wheat, corn, soybeans and several other major food and feed grain crops. The most serious questions concerning eventual operational use of satellite remote sensing for monitoring and estimating U.S. crops are: (1) the question of data continuity, i.e., will there be future satellites beyond D-Prime, (2) the policy of requiring data users to pay for costs of the total system through increased prices for data, and (3) the critical need for delivery of digital data to SRS ten to fourteen days after acquisition. SRS has shown that costs of improved estimates through remote sensing have decreased over the past decade (based on data provided through the EROS Data Center at a price that only covers costs of reproduction) to a point where the technology is cost-effective when compared with other alternatives.[28] Also documented is the fact that costs of the other alternatives are increasing. This advantage for using satellite remote sensing data may be in jeopardy because of already announced data price increases and the possible implications for future increases.

For the domestic crop statistics program, SRS has in place a quasi-operational capability for using LANDSAT MSS data for improving the existing system based on ground surveys. MSS data processed for Iowa in 1978, for Iowa and Kansas in 1980, and for Iowa, Kansas, Oklahoma and Missouri in 1981 were used by the Crop Reporting Board in preparing the final end-of-season acreage and production estimates for major crops in these states. This capability will be extended to cover two additional states, Illinois and Colorado in 1982.

B. FUTURE OPERATIONS

Perhaps of even more significance for U.S. crop statistics is the potential for using satellite remote sensing data for small area (county, multi-county, crop reporting district) crop estimates. As ground data collection becomes more expensive, and the problem of respondent burden is addressed, data collection by satellite remote sensing will be even more attractive for the future than it is at present. Statistical research to develop appropriate methodology for producing small area estimates is being pursued by SRS and other institutions.[29] Progress suggests that very useable small area estimates for major crops can now be produced almost as a byproduct of processing the LANDSAT MSS data for State-level estimates.

If questions of data continuity, delivery and costs can be successfully resolved future use of satellite remote sensing in the domestic crop statistics system is relatively certain, especially in view of prospects for improved data from new sensors (TM, SPOT, MLA, etc.).

A rather complete history of SRS research and development for using satellite remote sensing in crop area estimation is the subject of an invited papers session this afternoon. Those interested in technical details of the present SRS capability should attend that session or refer to the research reports listed as references to this paper.

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V. AUTHOR BIOGRAPHICAL DATA

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