APPLICATIONS OF SATELLITE REMOTE SENSING FOR U.S. CROP ACREAGE ESTIMATION, 1980-81 RESULTS*

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ABSTRACT

As part of the AgRISTARS (Agriculture and Resources Inventory Surveys through Aerospace Remote Sensing) DCLC (Domestic Crops and Land Cover) project, the Remote Sensing Branch (RSB) of the Statistical Reporting Service (SRS) is investigating the operational use of LANDSAT data in an applied research mode.

Currently, six States (Kansas, Missouri, Oklahoma, Illinois, Colorado and Iowa) are participating in the project. The primary objective is to provide timely, more precise crop area estimates for major crops in selected States. The SRS approach is to use ground gathered June Enumerative Survey (JES) data in conjunction with LANDSAT data to improve the precision of crop area estimates.

This paper presents an overview of SRS, the SRS Remote Sensing Environment, project implementation, costs, contributions and project results.

1. THE SRS STRUCTURE 5/

An agricultural producer today is a combination of highly skilled technician and executive who frequently must apply considerable expertise and make demanding decisions such as a manager of a factory or other business would have to do. To operate efficiently, effectively and profitably, farmers, ranchers, and others in agriculture require accurate and timely information, and reliable evaluations concerning production, supplies, prices, exports, weather and other inputs.

SRS provides the channel for the orderly flow of this intelligence about the agricultural economy of the United States of America (USA). This agency is responsible for the National and State crop area estimates and other agricultural statistics as well as the coordination and improvement of the United States Department of Agriculture's (USDA's) statistics program. SRS is also concerned with statistical research and methods to improve gathering, evaluating, and processing information.

The agency also performs technical assignments for other Federal and State agencies in addition to limited services for agriculturally related private firms on a reimbursable or advance payment basis. The services provided consist of surveys and data collection activities. SRS also participates in the Agency for International Development's (AID) foreign visitor training program and provides technical consultation and support to developing countries in implementing agricultural estimating programs.

SRS has served agriculture for over a century under various organizational titles. Tasks and procedures have changed continually over the years to accommodate changing needs. SRS is a broad-based non-policymaking organization headquartered in Washington, DC. The agency consists of a Crop Reporting

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Figure 1. U.S. DEPARTMENT OF AGRICU
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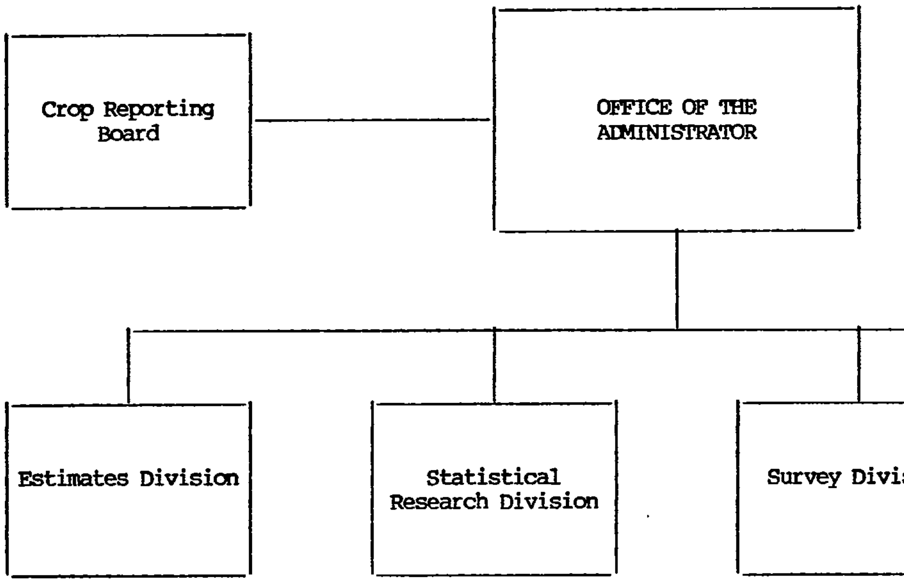

Board, State Statistical Division, Estimates Division, Survey Division, and Statistical Research Division. An organizational chart is shown in Figure 1.

The State Statistical Division consists of 44 State Statistical Offices (SSO's); one office serves the six New England States (Maine, New Hampshire, Vermont, Massachusetts, Connecticut, and Rhode Island) and the Maryland Office also serves Delaware. This decentralized approach for making estimates is based on the assumption that statisticians located in the SSO's can best adapt general procedures to the varied local circumstances and have a far better grasp of regional conditions affecting agriculture.

The SSO's are the primary data collecting, processing, evaluating, estimating, and publishing units of SRS. Following prescribed procedures, they conduct surveys and recommend statistical estimates for their States and counties to the Crop Reporting Board. These estimates are published after Board review and adoption. Other major responsibilities of the SSO's include liaison with the State agricultural sector and maintenance of a corps of voluntary reporters for surveys and a part-time staff of enumerators.

The Crop Reporting Board reviews and adopts official State and national estimates for crops and livestock as required by USDA regulations. The Board includes a Chairman, the SRS Deputy Administrator, a Vice Chairman, the Estimates Division Director, a Secretary, and the Chief of Data Services Branch, Survey Division. In addition to the six permanent members, five or six commodity specialists are selected by the Chairman from the Estimates Division and the SSO's to participate in determining the estimates.

The Estimates Division is the primary source in SRS for agricultural statistics. They analyze and interpret the various sources of data. Their analysis and interpretations are used by the Crop Reporting Board in making estimates and forecasts of the Nation's agriculture. The Division evaluates commodity statistics, determines needs, and implements proper statistical plans in support of the crop and livestock reporting program. Estimates Division also ensures that appropriate methods and procedures are used in all phases of the program.

The Survey Division is responsible for preparing and establishing procedures used by the SSO's in collecting data by mail and enumerative surveys, and for carrying out the objective yield measurement program. The Division designs and tests survey techniques including forms and questionnaires, writes data collection instructions, and conducts training schools for enumerators. The Division processes the data and produces summaries for use by the SSO's and the Crop Reporting Board in setting official estimates. The Division also conducts data collection activities for other USDA and Federal or State Agencies on a reimbursable basis.

The primary functions of the Statistical Research Division are to develop new and improved collecting, estimating, and forecasting methods for Agricultural Statistics and to encourage the use of sound statistical techniques throughout USDA. The Division devises improved sampling techniques and methods of controlling sampling errors, constructs area and list sampling frames, and researches nonsampling errors stemming from questionnaire wording, enumerator's interviews, or other causes. New models for assessing the yield of field and fruit crops are investigated. The potential of remotely sensed data in contributing to the SRS program is also studied quite extensively. The Applications Section of the RSB is currently investigating the operational implementation of remote sensing technology as part of the AgRISTARS DCLC project which is the focus of this paper.

2. THE SRS REMOTE SENSING ENVIRONMENT

AgRISTARS is a joint research program between USDA, the National Aeronautics and Space Administration (NASA), the U.S. Department of Commerce (USDC), the U.S. Department of Interior (USDI), and AID. AgRISTARS was established to investigate the use of remote sensing in agriculture. The Remote Sensing Branch of SRS has assumed the responsibility for implementing the DCLC project.

The DCLC project started in 1980. LANDSAT data are combined with conventional ground gathered data to provide timely, more precise, year-end major crop area estimates in selected States. Kansas and Iowa were chosen as the first two States in 1980. Missouri and Oklahoma were added in 1981. Colorado and Illinois are the new additions for 1982. The primary objective is to obtain major crop area estimates with reduced sampling errors. Major crops to be estimated in each State are shown in Table 1.

Figure 2. AgRISTARS DCLC REMOTE SENSING ENVIRONMENT

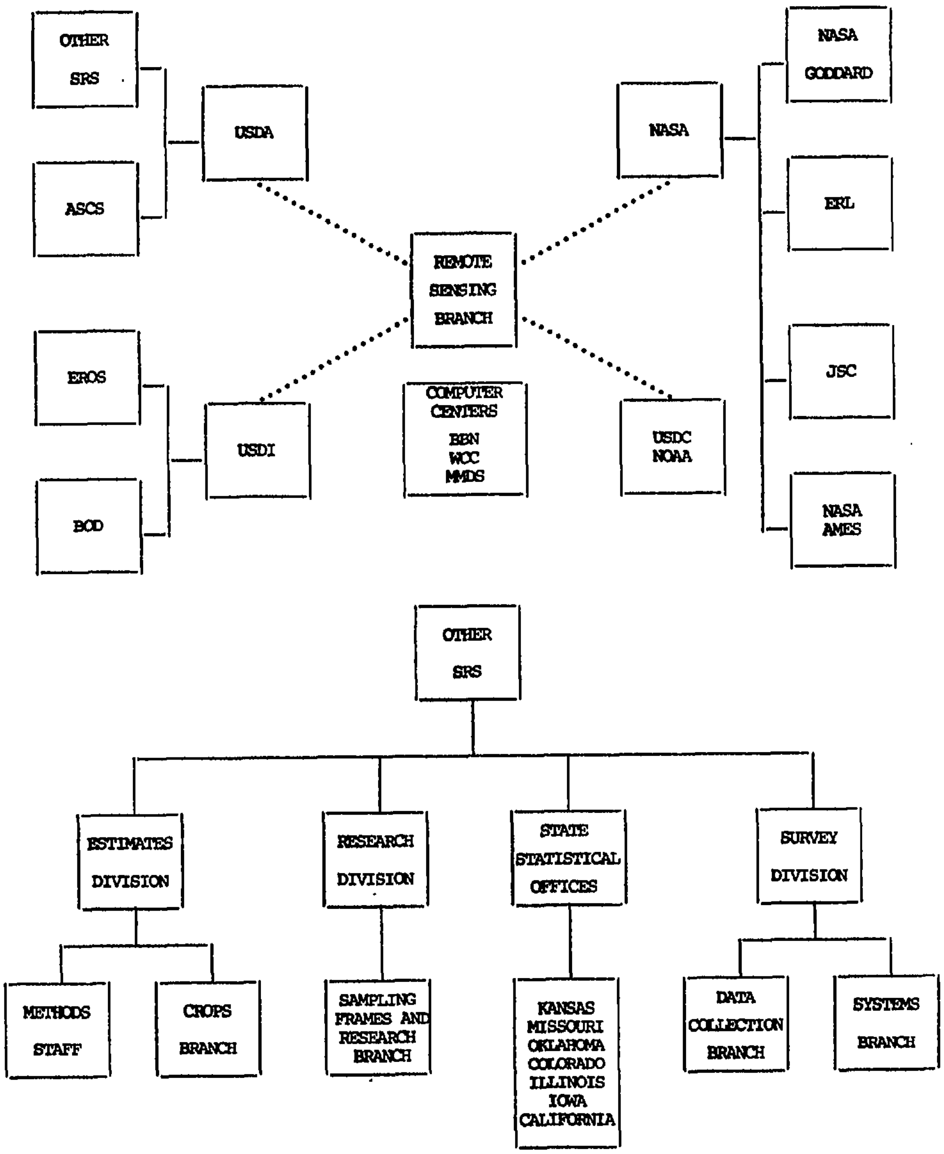

Table 1. Major Crops By State

STATE	MAJOR CROPS
Kansas	Winter Wheat
Oklahoma	Winter Wheat
Colorado	Winter Wheat
Missouri	Corn and Soybeans
Illinois	Corn and Soybeans
Iowa	Corn and Soybeans

Successful completion of the DCLC project requires the cooperation of several U.S. Government agencies as well as input from a number of divisions within USDA's SRS. The SRS Remote Sensing environment is illustrated in figure 2. Although the contributions of each Agency are varied, each serves a vital function in determining the final outcome of each year's project. Besides USDA, the departments represented are the following; NASA, USDC and USDI. There are also two commercial computer centers which are used in processing both the ground data and the LANDSAT data. The following will present in capsule form tasks which each of these governmental and commercial entities perform in providing support to the DCLC project.

NASA launched the LANDSAT series of satellites and has four groups which have continued to support the DCLC project in utilizing the LANDSAT digital data. NASA's Goddard Space Flight Center (GSFC), located in Greenbelt, Maryland, processes the LANDSAT data after it is beamed to Earth. Earth Resource's Laboratory (ERL), located in Bay St. Louis, Mississippi, has assisted with scene registration algorithms and has developed an automated method for shifting segments using computerized routines. Johnson Space Center (JSC), located near Houston, Texas, has provided research support on clustering, classification and estimation procedures. The NASA Ames research complex, located in California, has provided substantial computer facilities for full scene classification. Prior to 1981, the ILLIAC-IV was the main computer, however, it was replaced by a CDC 7600 during 1981. A CRAY-1S computer, provided by NASA Ames, will be used for full scene classification in 1982.

NOAA of the USDC provides satellite imagery from weather satellites. These images aid DCLC investigators in determining cloud-free dates of imagery within a day of acquisition. This permits early identification of potentially useable LANDSAT scenes which are sufficiently cloud-free for use in analysis.

Three computer centers are used in the data processing effort. Two centers are commercial facilities. One center is operated by Bolt, Beranek, and Newman (BBN) in Boston, Massachusetts. Most of the computing is performed at BBN. The other commercial center is Martin Marietta Data Services (MMDS) located in Orlando, Florida. All the ground data update functions are performed on this system and clean data tapes for use at BBN are produced. USDA's Washington Computer Center (WCC), located in Washington, D.C., provides support for reformating LANDSAT computer compatible tapes (CCTs).

USDI provides assistance both through its Earth Resources Observation Service (EROS), located in Sioux Falls, South Dakota, and through its Branch of Distribution (BOD). EROS provides both hard copy photographic copies of the LANDSAT MSS data in transparency and photo format as well as the digital data in the form of CCTs.

A number of divisions within USDA participate in providing support services to the RSB. Within the Statistical Research Division, the Sampling Frames and Survey Research Branch updates county maps with segments rotated into the sample each year and provides framework maps for digitizing strata boundaries on BBN so that estimates can be made for each land use stratum. The Data Collection Branch and Systems Branch of the Survey Division provide JES support for the ground data collection effort. Systems Branch provides programming support by creating computer generated questionnaires for an intentions follow-up survey. The SSO's collect the JES ground data, perform a field level edit and also digitize the segment level field boundaries. The Estimates Division is represented by both Methods Staff and the Crops Branch. The Methods Staff establishes specifications for the JES design and ensures that special requirements for remote sensing use are met. Finally, the Crops Branch accepts DCLC input in establishing estimates for the Annual Crops Summary.

3. BACKGROUND AND OBJECTIVES

LANDSAT data are combined with ground-gathered survey data to provide timely, year-end major crop area estimates in selected states. A regression estimator as described in Cochran (Section 17.1-7, third edition) [1] was used. The regression estimator as used by the RSB has been previously described by Hanuschak and others [2].

In 1980, clustering was performed using the LARSYS [6] clustering algorithm. In 1981 the CLASSY[4] clustering algorithm was used. Clustering is a data analysis technique by which one attempts to determine the natural or inherent relationships in a set of observations or data points.

A Gaussian Maximum likelihood classifier was used in both years. Classification is based on discriminant analysis [2]. Discriminant analysis is a process used in attempting to differentiate between two or more populations of interest based on multiviariate measurements.

The SRS objective of providing timely, year-end state and sub-state crop area estimates with reduced sampling errors by using ground gathered data in combination with LANDSAT data, was accomplished in 1981.

In 1981, winter wheat harvested area estimates for Kansas and Oklahoma were provided to the SRS Crops Branch and the SRS SSO's on October 30, 1981. Corn and soybeans planted area estimates were provided to the Crops Branch and the SSO's on December 16, 1981, for Iowa and Missouri. For Missouri, rice and sorghum planted area estimates were also provided to the SSO and the Crops Branch. The data were reviewed by the Crops Branch and SSO's in their final end of season annual Crops Summary.

During 1980, acquisition of quality and timely LANDSAT data was severely impaired. Satellite and LANDSAT preprocessing problems lowered the digital data quality and increased the delivery time necessary for receiving LANDSAT data products. Many of the LANDSAT data quality and timeliness problems encountered during 1980 were due to ground handling complexities at NASA Goddard which were fixed prior to the 1981 DCLC project.

4. STATE STATISTICAL OFFICE CONTRIBUTION

The SSO's played an integral part in the outcome of the DCLC project. Part of their role was to be the primary ground data collectors. In this role the SSO's provided field boundary, acreage, crop and land cover type data for the randomly selected SRS area segments. These data were collected during the June Enumerative Survey (JES) and special follow-up surveys in Iowa and Missouri. The data were used to establish training fields for computer classification of LANDSAT digital data and again for estimation. After collecting the ground data, an intensive field level edit was made by each state followed by digitization and plotting of the segment data.

Prior to FY80 these functions were performed by the RSB staff in Washington, D.C. In view of an expanding program, it was apparent due to efficiency considerations that some tasks would have to be performed in a decentralized fashion. Thus, the field level edit, digitization and plotting functions were successfully transferred to each of the four SSO's.

The field level edit is a labor intensive effort that was performed during a two week period following the JES. Recorded information on photographs, questionnaires and computer records were verified.

Segment digitization is the process of converting segments from fields drawn on aerial photographs or topographic maps to a computer file of coordinates in a geographic coordinate system. This task was performed using a tablet digitizer, in conjunction with an interactive software sub-system (EDITOR). After the segments were digitized, they were plotted and checked for accuracy. In 1981, a much greater amount of time was required for digitization than in previous years. This was due both to problems with a sudden change in the Bolt, Beranek and Newman (BBN) data processing facility operating system as requested by the General Accounting Office (GAO) and to equipment breakdowns in the SSO's and RSB.

The other major role of the SSO's was interpretation of the final state and sub-state level estimates generated at the end of the project.

5. LANDSAT DATA ACQUISITION

The following LANDSAT products were used: 1:1,000,000 scale positive black and white transparencies (bands 5 and 7), 1:250,000 scale paper products (bands 5 and 7) and computer compatible tapes (CCTs). Delivery of these products involved two phases. The data were first transmitted from satellite to NASA Goddard where it was processed and sent via DOMSAT to the EROS Data Center (EDC). EDC in turn processed the data, filled the data order, and shipped the products to SRS.

In 1981, while data delivery was improved, the 10-14 day requirement for delivery after acquisition was not met. Delivery times ranged from about 1 week to 20 weeks with an average time of 3 to 4 weeks. As a result of not obtaining some data in a timely manner, a considerable amount of overtime work had to be performed to meet timeliness deadlines. This turnaround time must be improved for the continued expansion of the DCLC program.

6. DATA PROCESSING

Prior to processing the LANDSAT data, analysis districts were determined. Analysis districts consisted of counties partially or completely contained in one or more scenes of the same LANDSAT pass. Areas overlapping two scenes were assigned to a specific scene by looking at cloud cover, data quality, imagery dates, and each scene's containment relative to the other.

Several data processing centers were used in processing the JES and LANDSAT data to calculate regression estimates. The Martin Marrietta Data System (MMDS), Bolt Beranek and Newman (BBN), Washington Computer Center (WCC), and the CDC 7600 computer at NASA Ames were used. The major software package used was EDITOR[3]. EDITOR is a comprehensive interactive data analysis system for processing LANDSAT and JES data. EDITOR runs on a modified DEC System-10 computer and is available at BBN in Cambridge, Massachusetts. Some EDITOR programs are also implemented on CDC 7600 and CRAY-1S computers at NASA Ames. EDITOR was used for digitization, registration and analysis of the JES and LANDSAT data.

A data set containing ground data from the JES was created and edited using a set of SAS programs on the MMDS. The final edited data set was then transferred to BBN. Boundary information for each field of crop data was digitized on BBN and converted to a geographic coordinate system by calibrating the segment photo to U.S. Geological Survey (USGS) maps. The calibration process consisted of locating corresponding points on both the aerial photograph and the USGS map on which the segment could be located. A regression routine then converted the digitizer coordinates to map coordinates by using coefficients calculated from the corresponding points data.

LANDSAT computer compatible data tapes were reformated at WCC and copies of the tapes containing the reformated data were mailed to BBN and to NASA Ames for processing.

Each selected scene was registered to USGS maps in Washington, DC. This process called registration relates LANDSAT row-column coordinates with USGS map latitude-longitude coordinates by means of third order bivariate polynomial equations.

A second step of registration followed the initial scene registration. This step consisted of using grey-scale print-outs and segment plots to shift each segment to a more accurate location based on interpretation of lightness-darkness regions within the print-out.

An EDITOR operation termed "masking" was next used to establish the location of the LANDSAT pixels for each field. The locations were stored in "segment mask" files which were then used to extract LANDSAT pixels corresponding to specific crop types or land uses. Criteria that could also be used in selecting pixels were field boundary information (that is, to include or exclude field boundary pixels), crop conditions, field codes and field size. This extracting process is known as packing and the files are termed "packed" files.

Packed files containing no field boundary pixels were clustered by crop type and land cover. Files containing more than 5000 pixels were sampled before clustering to save computer costs and reduce turnaround time. The statistics describing the clusters generated were saved in "statistics" files which were combined to form a "combined statistics" file which represented all sampled crop and land covers for the segments represented.

The combined statistics file was then used to classify pixels into a cover type. Counts of the classified pixels were made by cover types within a segment. The classified pixel counts along with the corresponding JES data were then used in making sample level estimates. Full frame classification, aggregation of pixels by stratum and large scale estimation were then performed for each analysis district. Full frame classifications were performed on a CDC 7600 computer at the NASA Ames Research Center in 1981 and on the ILLIAC-IV in 1980. After the data for each states analysis districts were processed, a state level estimate for each crop of interest was obtained using an accumulation program. The accumulation program aggregates all substate estimates to a state total. Area estimates for which LANDSAT data are or aren't available are included in the state total. Direct expansion estimates using only JES segment data were provided for areas where LANDSAT data were unavailable.

In 1981 much work had to be performed outside of regular working hours due to problems associated with the BBN computer system. BBN was forced by an external group to modify their system. This modification placed severe limits on the percentage of the machine's capacity that we could utilize. This problem has been corrected.

7. ESTIMATION RESULTS

LANDSAT regression estimates for 1980 and 1981 are in Table 2. State level relative efficiencies ranged from 1.3 to 1.9 in 1980 and from 1.3 to 2.3 in 1981. Relatives efficiencies at the substate levels ranged from 1.2 to 6.4 in 1980 and from 1.2 to 15.8 in 1981. Relative efficiency measures the degree of improved precision obtained from using the LANDSAT data in addition to the ground data. The figure obtained indicates the factor by which the sample size would have to be increased to equal the precision obtained using LANDSAT data in addition to the randomly selected JES segment data. The 1980 and 1981 results were negatively impacted due to missing data in some areas due to clouds, data quality, and failure to achieve 10 to 14 day delivery of LANDSAT data to SRS from time of acquisition.

Table 2. 1980 and 1981 State Level Estimates

Year	State	Crop	Estimate (Ha)	R.E.
1980	Kansas	Winter Wheat	5,052,500	1.3
1980	Iowa	Corn	5,803,200	1.9
1980	Iowa	Soybeans	3,291,350	1.5
1981	Kansas	Winter Wheat	5,297,900	2.3
1981	Oklahoma	Winter Wheat	2,519,600	1.3
1981	Missouri	Corn	774,600	2.2
1981	Missouri	Soybeans	1,963,700	2.1
1981	Iowa	Corn	5,820,200	1.6
1981	Iowa	Soybeans	3,275,150	1.6

8. PROGRAM COSTS AND CONTRIBUTIONS

Since the AgRISTARS DCLC program has now expanded to six States, there is a renewed interest in the relationship between program costs and contributions. Some historical perspective provides insight into the cost trend associated with SRS's use of LANDSAT data in conjunction with the ground data from the JES.

The first entire State project was conducted from 1975 to 1977 using 1975 data. The study area was Illinois. The cost associated with this project included all research and development efforts including a comprehensive software system (EDITOR). The total project cost was approximately $750,000. The first timely project for an entire State was conducted in 1978 using 1978 data from Iowa. Since most of the methodology and software had already been implemented, the cost decreased to about $300,000. In 1980, the AgRISTARS DCLC project costs for Iowa and Kansas were approximately $200,000 per State. In 1981, the project costs for Iowa, Kansas, Oklahoma, and Missouri were approximately $180,000 per State. There is an obvious downward trend in the LANDSAT project costs that is expected to continue as the move from research and development to applications continues.

The cost of the JES for the 1981 four State project was approximately $64,000 per State. The estimated overall cost per State associated with estimates from the JES ground data only, and the JES plus LANDSAT regression estimates is shown in Table 3. The cost can be ratioed for various relative efficiencies to determine if the improvement in statistical precision is cost effective relative to the alternative of increasing the JES sample size.

The use of LANDSAT data in conjunction with JES data is cost effective for all relative efficiencies with a corresponding cost ratio less than or equal to one. Using this criterion a relative efficiency of about 2.5 would be the break even point. In future years it is expected that the break even point will be lower. The reason for this expectation is that JES costs per unit probably will rise and JES plus LANDSAT costs per unit will probably decrease. The JES costs per unit will probably increase due to increases in travel and interview costs. More efficient computer data processing and proration of labor costs over large geographic areas should result in lower JES plus LANDSAT costs per State.

Including all full State projects since the first full State project in Illinois in 1975, the majority of relative efficiencies at the sub-state level have easily passed the cost ratio criterion but results have been considerably more mixed at the State level. State level relative efficiencies vary according to the number of satellites available, the amount of cloud cover during the optimum window, and the timeliness and quality of LANDSAT data delivered to SRS.

However, there are several problems associated with the 1981 cost ratio criterion. One problem is that it does not reflect the benefits associated with keeping a staff trained in the technical knowledge of new and vastly improving satellite sensors. Another problem is that it doesn't reflect the benefits to SRS of the improved precision of major items (other than crop area) on the JES questionnaires that would occur if the sample size were increased. This second problem is somewhat diminished in that there exists some serious questions about whether or not it would be feasible to increase the JES sample size by a factor of 2-1/2 or more. With current budget restraints and limitations on both full and part-time staff, and the additional recruitment and training of JES enumerators required to increase the JES sample size, use of LANDSAT data becomes perhaps the only feasible alternative for future expansion of data collection for domestic crop area estimation.

9. SUMMARY

The cooperation of several U.S. government agencies (USDA/SRS, USDA/ASCS, NASA/GODDARD, NASA/ERL, NASA/JSC, NASA/AMES, USDI/BOD, USDI/EROS, and USDC/NOAA) was required to implement the 1980, 1981 and 1982 AgRISTARS DCLC Program. In 1980, more precise crop area estimates were provided using LANDSAT data in conjunction with ground gathered data for two states. Winter wheat harvested area estimates were provided for Kansas. Corn and soybeans planted area estimates were provided for Iowa. In 1981, more precise and timely crop area estimates were provided using LANDSAT data in conjunction with ground gathered data for four States. Winter Wheat harvested area estimates for Kansas and Oklahoma were provided to the SRS Crops Branch and the SSO's on October 30, 1981. Corn and Soybeans planted area estimates were provided to the Crops Branch and the SSO's on December 16, 1981, for Iowa and Missouri.

The SSO's played a key role in both projects. They performed field level edits, digitization, plotting, and both state and substate evaluation of the regression estimates.

Both projects were hampered due to problems in acquiring quality and timely LANDSAT data. In 1981, the project was hampered due to problems with the BBN computer system due to changes in their operating system as requested by the General Accounting Office (GAO).

10. ACKNOWLEDGMENTS

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TABLE 3. Cost of JES and JES + LANDSAT Comparisons 1/ (Dollars)

Relative Efficiency	1. Cost of JES 2/	2. Cost of JES Plus LANDSAT 3/	Cost Ratio (2 ÷ 1)
1.0	64,000	180,000	2.81
2.0	146,000	180,000	1.23
2.5	187,000	180,000	0.96
3.0	228,000	180,000	0.79
4.0	320,000	180,000	0.58
5.0	392,000	180,000	0.46

TABLE 4. Major Item Costs JES and JES + LANDSAT 1/ (Dollars)

JES Cost/State		JES + LANDSAT Cost (4 States) 3/	
SSO	55,000	SSO	50,000
DC Staff	7,000	DC Staff	210,000
MMDS	2,000	BBN	355,000
Total	64,000	EROS	25,000
		NASA (Ames)	25,000
		Travel	25,000
		Equipment	10,000
		Materials	20,000
		Total	720,000
		Cost/State	180,000

1/ Cost of initial area frame development and current sample size JES drawing is not included. This cost is approximately $80,000/state (1983 Nebraska cost projection).

2/ The cost of additional sampling and materials for relative efficiencies greater than 1.0 is included.

3/ Cost figures represent additional costs.

TABLE 5. JES and JES + LANDSAT Benefits

JES Costs	JES + LANDSAT Costs
$64,000/State and Increasing	$180,000 Additional/State and Decreasing
<u>Benefits</u>	<u>Benefits</u>
Objective Method	Objective Method
National and State Estimates (Multiple items)	Improved National, State and Sub-state Estimates (Major crops only)
Potential to do Land Cover area estimates (State Level)	No Additional Respondent Burden
	Research and Development and Utilization of an Improving Technology (Next Generation of Satellites)
	Public Relations Benefit
	Potential to do Land Cover Estimates (State and Sub-State)
	Procedure Uses <u>ALL</u> Crop Area Information in the JES