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LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)



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REVIEW OF LACIE METHODOLOGY (A PROJECT EVALUATION OF TECHNICAL ACCEPTABILITY)

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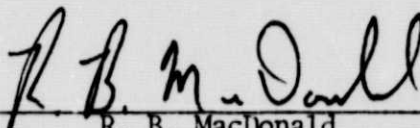


National Aeronautics and Space Administration
LYNDON B. JOHNSON SPACE CENTER

Houston, Texas
July 1976

LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)
REVIEW OF LACIE METHODOLOGY
(A PROJECT EVALUATION OF TECHNICAL ACCEPTABILITY)

Approved By:

A handwritten signature in cursive script, appearing to read "R. B. MacDonald", is written over a horizontal line.

R. B. MacDonald
Project Manager

July 1976

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REVIEW OF LACIE METHODOLOGY
(A PROJECT EVALUATION OF TECHNICAL ACCEPTABILITY)

LACIE Project Office
Lyndon B. Johnson Space Center

PURPOSE OF LACIE

LACIE is an experimental program designed to

1. Evaluate and demonstrate the capability of existing technology (remote sensing, data processing and analysis, and other associated technologies) to make improved world-wide crop production information available to decision makers in a cost-effective manner; this test of technology is to be conducted in a quasi-operational environment.
2. Research and develop alternate approaches and techniques which, upon evaluation, are qualified to be incorporated into the LACIE quasi-operational system where required to meet performance goals or to improve efficiency.

The experiment is structured to have three major elements to meet these objectives: a quasi-operational on-line activity to conduct the actual inventory, a research activity to explore alternate techniques, and a test and evaluation activity to examine such techniques prior to their incorporation into the on-line system.

A comprehensive experiment plan was developed to evaluate the acceptability of existing technology, to develop new technology as required, and to make an acceptable technological approach available for a future cost-effective operational system.

In recognition of the value of periodic technical reviews, LACIE schedules formal, in-depth technical reviews by selected technical personnel inside and outside LACIE having expertise relevant to LACIE technology. These reviews are scheduled at approximate 6-month intervals, and recommendations are tracked to a logical final disposition.

The primary objective of the LACIE experiment is to assemble, operate, and evaluate existing remote sensing technology to provide multicountry wheat production information cost effectively at the country level outside the United States.

Specific accuracy performance criteria¹ are stated for at-harvest estimates; however, an equally important goal of LACIE is to establish how accurately estimates can be made at very early and intermediate points in the crop year.

The three major points of justification for LACIE are the following:

- Current crop production reporting in foreign areas tends to be questionable from the standpoint of accuracy, timeliness (early season and at-harvest reports late), objectivity, and system reliability.
- Remote sensing technology, not heavily dependent on ground data acquisition, appears to offer a cost-effective approach to a global crop estimation system that could provide improved information to the USDA and to the administration.
- Previous investigations and analyses indicate the feasibility of using remote sensing technology and existing systems to support a quasi-operational experiment prior to the development of a cost-effective operational system.

Certain key technical issues require further examination in a quasi-operational environment in the course of the development of an operational system. These include the following:

1. Can the Land Satellite (Landsat) data and classification technology support estimates of wheat acreage in a sample segment accurately and reliably enough for useful large-area crop acreage surveys?
2. Are the four Landsat spectral bands adequate to identify wheat at appropriate stages of crop maturity?
3. Does the 0.44-hectare (1.1-acre) spatial resolution of Landsat cause excessive errors in estimating the acreage?
4. Can wheat be identified in the Landsat data without resorting to ground-verified field identification?
5. Can human intervention in the analysis process be made repeatable and objective?
6. Can a sample strategy for acquisition of Landsat data be designed to achieve the required accuracies with a manageable data load?

¹The performance goal for accuracy is to obtain 90-percent accuracy for at-harvest estimates 90 percent of the time, that is, 9 years out of 10. This is referred to as the 90/90 criterion and applies to production, at-harvest, at a country level.

7. How can the geographic wheat distribution best be determined to properly sample?
8. Does loss of the segment acquisition due to cloud cover cause excessive errors, such as bias?
9. Is the 18-day Landsat coverage frequent enough?
10. Are two satellites required?
11. Can yield models which depend on operationally available weather, historic yield, and ancillary data be used to estimate yields accurately enough for production estimation?
12. How early can reliable production estimates be made? How accurate are these estimates as the season progresses through harvest?
13. Can signature extension be made to work and increase system cost effectiveness?

RATIONALE FOR A THREE-PHASE EXPERIMENT

LACIE is the first attempt to survey an important crop on a large scale at repeated intervals over a wide range of conditions. Although the feasibility of the remote sensing technology had been established by experiments in confined geographic locales, it had not been demonstrated over large areas nor did any analysis system exist with the capacity to conduct a true large-area inventory. Accordingly, a phased approach with orderly steps was chosen. These steps involved expansion in two directions: in the technical complexity of the functions performed and in the geographic size and difficulty of the area being surveyed.

The choice of steps in terms of technical functions was dictated by the availability of components and the rate at which development of new components was anticipated. The choice of study area was based on moving from a known "yardstick" region to a global scale in several controlled steps. The phasing was also designed to provide some experience with the type of problems expected to be encountered in subsequent phases.

Considering all of the foregoing along with a desire for a rapid advancement of the nation's international crop inventory capability and the need to utilize an available satellite, a three-phase experiment was planned as follows: Phase I was devoted to initial experiment design, selection and training of personnel, assembly of a quasi-operational analysis system, initial operation of the system to estimate crop area, development and preliminary testing of yield models, and an initial evaluation of key components of the approach. Phase II is designed to complete the initial system as defined prior to Phase I with the incorporation of

short-term changes based on Phase I results. In addition, Phase II is to expand the testing of the selected methodology to a broader geographic scope and for the first time, in addition to acreage estimates, to operate all parts of the system required to make yield and production estimates on a scheduled basis throughout the crop year. Phase III will permit additional improvements to the LACIE approach and includes extensive evaluation of the LACIE methodology in a quasi-operational environment over important wheat-producing regions of the world.

The research, test, and evaluation (RT&E) effort was also planned and phased so that improvements to the quasi-operational system could be made at an appropriate time and contribute to the development and preliminary evaluation of solutions to key technological problems uncovered.

A strong accuracy assessment effort is a major part of the experiment to evaluate the quasi-operational system in terms of established criteria and to uncover possible technological problems quickly. Accuracy assessment results guide both the quasi-operational activity and the RT&E in terms of delineating areas in which changes or improvements are needed.

SPECIFIC OBJECTIVES OF PHASE I

LACIE Phase I tasks were defined and scheduled to meet the following objectives:

1. Select the most promising technology components to (1) identify wheat and estimate its area, (2) estimate yield, and (3) estimate production.
2. Complete an overall experiment design (hardware, software, sample design) required to support all three phases.
3. Implement that part of the analysis system required to estimate wheat area over most of the hard red wheat region of the United States (the Great Plains).
4. Develop procedures for handling and analyzing large quantities of data required in LACIE to meet the planned expansion into foreign areas.
5. Select and train personnel from the three participating agencies to implement, operate, and evaluate the LACIE system.
6. Exercise the system in a quasi-operational manner and estimate wheat area over the U.S. hard red wheat region and evaluate the results, both against established performance criteria for at-harvest estimates and to determine how accurately early season estimates can be made.

7. Test selected methods for estimating wheat yield and production prior to implementation of this capability for Phase II.
8. Conduct parallel and supportive RT&E to investigate improved approaches.
9. Conduct initial analyses over selected foreign areas and areas in the United States outside the Great Plains yardstick area prior to expansion in Phase II.
10. Develop and implement evaluation plans for subsequent phases (II and III).
11. Implement the additional components of the system required to support making quasi-operational yield and production estimates in Phase II.

RATIONALE FOR AND DISCUSSION OF LACIE METHODOLOGY

Selection of technology.— Given the project objectives, with specific emphasis on large-area estimation and the relative importance of more timely and accurate estimates of foreign production, the LACIE design was restricted to use only data that were reliably available in foreign areas (e.g., Landsat imagery, data reported by meteorological stations, National Oceanic and Atmospheric Administration (NOAA) satellite data, and published historical data for the appropriate political subdivision in the selected countries). The LACIE system was designed within a framework of constraints originating from several sources. Examples of these constraints are the sample segment frequency constraints specified by the Goddard Space Flight Center (GSFC) and the use of readily available implemented classification technology validated by previous studies. The Crop Identification Technology Assessment for Remote Sensing (CITARS), the first such evaluation for LACIE (ref. 1), was a preliminary test of classification procedures proposed for LACIE. Additional considerations were costs, schedule milestones, available resources for system implementation, the specified performance criteria, the volume of Landsat data that could be stored and processed, and other similar factors.

Quasi-operational and research elements of LACIE.— The quasi-operational system designed was to have the following characteristics: (1) to be capable of handling large data loads; (2) to use the best available technology that meets the specified performance goals and would be cost effective in an operational follow-on as opposed to supporting a research and development objective; and (3) to produce current estimates of wheat area, yield, and production for selected major wheat-producing regions on a scheduled basis throughout the crop season. Changes in the technology utilized in the quasi-operational system are made only if the current technology does not satisfy the established performance

criteria or if an alternative technology is more cost effective. The implementation of an alternative technology would occur only after validation in an off-line test program.

A research program was established as a part of LACIE to make available alternative technology components in areas where the mainline technology was suspect.

Evaluation rationale.— A significant part of the evaluation of the statistical methodology and technical procedures being tested in LACIE is based on a quantitative evaluation of the LACIE survey estimates as compared to other reliable independent estimates such as SRS estimates for large areas; e.g., states and aggregates of states. The suitability of this technology is judged in terms of quantitative performance criteria.

Quantitative performance criteria for LACIE evaluation were chosen to represent improved information on world-wide wheat production at the country level outside the United States. These criteria were stated in terms of (1) accuracy (90/90 at harvest), (2) timeliness (acreage and yield estimates based on 14-day-old data), (3) continuity (regularly scheduled reporting from emergence through harvest), and (4) objectivity (quantification of confidence of estimates).

To develop and evaluate the LACIE survey system, the experiment was planned to first consider wheat-growing regions of the United States where reliable, independent survey estimates and ground truth would be available. Several study sites exist in Canada to augment the ground-truth data set.

LACIE survey estimate accuracy is quantified at national and, importantly, at subregion levels in the yardstick country. The subregional analysis is conducted to determine the country dependent survey performance in foreign areas with analogous agricultural/climatic conditions.

Crop survey estimates from established reporting agencies (the Bureau of Census and the SRS) in the yardstick country were assumed to be accurate enough for evaluation of LACIE estimates. Phase I experience indicates this to be a reasonable assumption at the national level. However, at the state level and below in the United States, SRS estimates were not sufficiently accurate for all purposes. Additional ground truth was acquired in Phase I, and the acquisition of more ground truth is planned in Phase II.

A statistical experimental design was developed to estimate the magnitudes of system subcomponent errors, such as classification and sample error (both bias and random components), analyst and machine error, yield estimation error, and production estimation error, so that the technology can be intelligently improved as required.

In addition, a system simulation/error model has been developed to estimate the effects on accuracy of various sample designs,

cloud cover effects, and different agricultural/climatic conditions. This simulator is being used to investigate the accuracies obtainable with the LACIE technology in various regions and with various proposed changes to the technology.

In Phase I, major emphasis was devoted to identifying significant problem areas and incorporating necessary changes into the on-line system. A final evaluation of these improvements was made late in Phase I on the basis of a final at-harvest analysis of all data. The evaluation of the early season estimates for Phase I could not have been completed much before an assessment of the accuracy of the early season Phase II estimates. Therefore, a decision was made to concentrate the LACIE efforts at that time on the real-time evaluation of Phase II early season estimates. Thus, major attention is being given to establishing the accuracy with which early season estimates can be made in Phase II.

REVIEW OF LACIE ACREAGE ESTIMATING METHODOLOGY

Sampling frame and sampling design.— Based on known constraints, a total allocation of 4800 sample segments was divided among the selected countries using the criteria and procedures in reference 2. (Sample segment location constraints are also specified in this document.) The sampling strategy selected for use in the United States was designed to utilize county-level statistics for segment allocation. This strategy was implemented based on the following rationale.

1. Such a sample design would provide the most accurate estimate in the United States, the selected "yardstick" area, for which historic statistics were available down to the county level to support missing data resulting from cloud cover. By utilizing the most accurate available sampling strategy in the United States, the impact of having less accurate data in foreign countries could be determined through use of a "degraded" data set obtained by employing various subsets of the U.S. data.
2. Statistics normally produced by the USDA would be adequate to evaluate sampling error without the need for extensive ground truth.
3. The methodology for using Landsat imagery and agrophysical data was not sufficiently developed at the start of Phase I to select strata along natural boundaries; hence, strata would need to be defined by political boundaries.
4. The implemented strategy would provide data of sufficient quantity and quality to meet required performance levels and also satisfy the existing constraints.

Throughout the life of the experiment, attention will be devoted to other key sampling-related issues such as optimal sample segment size, the optimal number of sample segments, and potential

relaxation of engineering constraints on sample segment location. The exact formulations used in the sample design, expansion (or aggregation) process are shown in reference 2.

In the LACIE framework, the substrata are identified as Group I, Group II, or Group III (county-level designations in the United States). These designations are made on the basis of a threshold value defined in reference 2. However, the qualitative definitions are as follows:

- Group I substrata - intensive wheat-producing areas which are allocated one or more sample segments.
- Group II substrata - areas which produce some wheat; sample segments allocated based on PPS; a sample segment represents more than one substrata.
- Group III substrata - areas historically having very little wheat; thus, no sample segments are allocated.

The basic rationale underlying this scheme is that such an allocation scheme appeared to produce the most efficient utilization of the data available for stratification and would give better segment coverage to major producing areas and would thus improve the probability of an accurate estimate.

Although certain engineering constraints were considered in the implementation of this general approach, the evidence examined in Phase I indicated that these factors did not significantly impact accuracy. A majority of these constraints are no longer inherent in the system, and an improved Phase III sample design will not be limited by such constraints.

Phase I experience indicated that the design discussed above had two main disadvantages: (1) the approach may not be optimum to indicate the expected performance levels in foreign regions; that is, the U.S. county is a substrata of much smaller size than the areas for which data were available in most foreign regions, and (2) sophisticated methodologies are necessary to evaluate the precision of area, yield, and production estimates. Although the methodology utilized is correct, considerable effort is required to establish the degree to which all assumptions are sufficiently satisfied; and extensive data are required to conduct the evaluation of precision.

Although the LACIE selected sample segments are probably larger in size than might be optimum for a future operational system, the planned analysis of within-segment and between-segment variation in LACIE Phases I and II will permit selection of a more optimum segment size and total segment number for Phase III in LACIE.

CROP CLASSIFICATION AND AREA ESTIMATION METHODOLOGY

The rationale on which the choice of the classification and per-segment area estimation technology was based was to select (1) the best available tested and implemented technology; (2) technology to identify wheat in the Landsat data without the use of ground truth; (3) the most efficient repeatable analyst procedures to process the large data quantities; (4) procedures to satisfy a need for timely estimates and the resultant requirement for rapid analysis of a segment; and (5) procedures to minimize human intervention required to assure cost effectiveness.

Much work had been done to establish a remote sensing technology base extending from 1966 when computerized pattern recognition analysis techniques had been coupled with electromagnetic energy measurements to classify major agricultural crops, through 1973 using Landsat-1. These results provided the basis on which to select the LACIE crop classification and estimation technology and were promising enough to have established the feasibility of conducting gross inventories of the areal extent of agricultural crops.

As pointed out in "Purpose of LACIE," certain key technical issues required further examination in a quasi-operational environment. These issues motivated the design and activation of an extensive accuracy assessment effort, specifying ground-truth data collection and comparative analysis techniques to aid in the resolution of these issues.

Classification and proportion estimation.— A source of major concern in any estimation problem is bias. Many factors in the LACIE area estimation system are known to result in underestimates or overestimates of the area.

Any estimation system must make provisions to establish the degree to which the system estimates are biased and to determine whether or not the magnitude of the bias is acceptable in terms of some success criterion. The coefficient of variation (c.v.) is used in LACIE as conventionally defined and includes variation due to classification and sample random errors. LACIE also includes an estimate of the bias to account for total mean-square error.

In addition, the LACIE experiment design includes methods for indicating the magnitudes of the sources of the bias and variance of the area estimates, such as the training set size, the time of year or the growth stage at which wheat area was estimated, the effect of the analyst, the effect of the classifier, the effect of Landsat spatial resolution, and other possible error sources.

This testing indicated that classification procedures employed *initially* in the quasi-operational system did indeed have a significant source of bias. However, these test results allowed the source of the bias to be isolated and at least partially

corrected in Phase I. The bias resulting from current procedures appears to be acceptably small for both Group I and Group II segment area estimates.

In order to improve the cost effectiveness of the LACIE system, signature extension techniques are being evaluated in Phase II and will be incorporated if found effective.

The effect of the human analyst on the system will be continually monitored although tests to date indicate that documented data analysis procedures, developed to reduce analyst subjectivity, have been effective in addressing this potential problem.

Finally, an expanded probability ground data set will be collected in Phase II to evaluate potential error sources discussed above.

As problems are uncovered by these assessments of the quasi-operational system, requirements for alternate technology are being defined for the LACIE RT&E program whose effort is focused on developing and evaluating solutions to key technological problems. The products of this effort, if validated by the LACIE test and evaluation program, will either be incorporated into the quasi-operational system or stand alone as potential solutions at the end of Phase III.

Nonresponse due to cloud cover.— LACIE does not get coverage over every segment on every pass because of atmospheric effects, such as haze and cloud cover. To counteract this problem, a sample strategy was designed that, in principle, will minimize the effect of such loss. However, the magnitude of this effect is being monitored in the accuracy assessment program, and it is planned to continue to look for significant effects due to missing data over the full range of geographic conditions in which a future operational system needs to perform.

TIMELINESS

The timeliness goal established for the LACIE area estimation system is to process the Landsat data within 14 days after acquisition when projected into an operational environment. Since LACIE is basically a one-shift, 5-day-a-week operation, the processing time goal is 29 days, allowing for queuing times in the one-shift operation. However, this time could be reasonably expected to reach the 14-day goal in the anticipated operational environment of three shifts, 7 days per week.

Yield estimates are based on monthly averages and are generated about 4 days after the end of the month. Production estimates are made about 10 days after the end of the month.

LACIE is faced with a data timing difference in estimates which complicates accurate comparisons. For example, LACIE area is based on emerged wheat which should, through the growing season,

converge to area available for harvest. The SRS area estimates are based primarily on planted area until June.

REVIEW OF YIELD FORECAST METHODOLOGY, INCLUDING MODELING, INPUT DATA, AND FORECAST PRECISION

Yield model.— LACIE initially selected a regression model developed by NOAA to test and evaluate in Phase I prior to quasi-operational testing in Phase II.

These models were run over different size geographic regions to determine the proper size of regions such that when yield is merged with area to estimate production and aggregated to the country level, LACIE accuracy performance criteria would be met.

The Phase I analyses of the model incorporated into the quasi-operation in Phase II indicated that at-harvest estimates of yield could be expected to meet the LACIE 90/90 accuracy criterion. Early season estimates also appeared to be quite good over the 1974-1975 season. The Phase I tests consisted of running the models in real time during the 1974-1975 crop year and with historical data each year for a 10-year period prior to that.

It is recognized, however, that the models may not perform as well in foreign areas where historical record data are lacking or nonexistent. For this reason, LACIE is expending considerable effort in the RT&E program to develop improved yield estimation models. These efforts are concentrating on approaches that model yield in terms of variables that are closely related to the plant growth processes and that are significant determinants of yield.

Research tasks have also been initiated to develop improved methodology for estimating the trend factor(s) for the LACIE yield models. Sensitivity analyses in Phase I clearly indicated the importance of properly estimating trend.

In Phase I, LACIE evaluated the best candidate models developed by the Earth Satellite Corporation (Earthsat) and initiated development of yet another model at Kansas State University (KSU). The LACIE project made the results of the Earthsat model runs available to the SRS, which is currently evaluating the approach for applicability.

Use of variables (input data).— The input variables used in the LACIE model were selected on the basis of statistical analyses which established a significantly strong correlation between average monthly values of the variable and final yield. Specifically, it was found that the major factors or variables are temperature and precipitation. LACIE is currently evaluating yield models that make use of weekly or daily averages of these variables. In addition, the LACIE is researching improved approaches to estimating variables found to be important indicators of yield.

SIGNIFICANT RESULTS OF PHASE I

Quasi-operational acreage test.— After correction of significant implementation problems in the initial quasi-operational area estimation system, the resulting wheat area estimation at harvest, based on its performance quantified over the U.S. Great Plains, was deemed marginally satisfactory in consideration of the 90/90 at-harvest criterion for wheat production estimation. The criterion can be met by a reasonable increase in the number of sample segments acquired and/or with improved stratification of agricultural and nonagricultural areas in selected regions. The area estimation system shows a tendency to underestimate when compared to the SRS estimates; that is, statistical analyses show a statistically significant difference between the two estimates. A significant contribution to this is believed to be a sampling problem in North Dakota.

The LACIE Great Plains area estimate was approximately 18 million hectares (46 million acres) compared to the SRS estimate of approximately 20 million hectares (51 million acres), or about 10 percent below the SRS figure. This represents a statistically significant difference from the official USDA December 1975 year-end estimate of acreage for the yardstick region. The major source of this bias is due to the sample allocation in North Dakota. An improved allocation of samples on the basis of a better partitioning of agricultural lands into more homogeneous strata is expected to reduce any bias to a tolerable level. The use of full-frame Landsat imagery is critical to defining adequate strata to avoid such sampling error; this improved sample allocation is currently planned to be tested in Phase III. The c.v. computed for the LACIE acreage estimator, when projected to the U.S. national level, is about 4.5 percent, a fraction of a percentage point above the 4.25 percent required if production estimates are to meet the 90/90 criterion. Since data loss due to cloud cover and early implementation problems resulted in a reduction in the number of LACIE sample segments used (of 411 allocated, 272 were satisfactorily acquired, processed, and aggregated), this random error component can very likely be reduced to its acceptable limit of 4.25 percent or below by the improvements implemented and planned for Phases II and III.

The results of this quasi-operational test for area were further examined in the Phase I production feasibility test in which the LACIE area estimates were combined with LACIE yield estimates and the resulting production estimates were evaluated. This production estimate satisfied the 90/90 criterion and indicated the basic compatibility of the LACIE area and yield estimators.

Much of the accuracy assessment² for area estimation technology in Phase I was focused on the fundamental technical issues discussed in the section of this report entitled "Purpose of LACIE."

²LACIE accuracy assessment methodology will be summarized in the final LACIE Phase I Evaluation Report to be released shortly.

Results indicated that the Landsat data and the classification technology can estimate the small grains (i.e., wheat and closely associated small grains) area within a sample segment accurately and reliably enough to meet the LACIE goals. Overall, the LACIE estimates in a 9- by 11-kilometer (5- by 6- nautical-mile) segment agree well with ground and aircraft determined area within these segments. In North Dakota where 20 such sites were examined, no significant difference was detected between the LACIE and ground-truth estimates over the 9- by 11-kilometer (5- by 6-nautical-mile) segments. The estimated c.v. of the random classification error was "acceptably" small. These analyses confirmed that bias introduced by various factors, such as Landsat spatial resolution, lack of spectral resolution, classifier (analyst-interpreter) bias and repeatability, is not *excessive* in terms of the required performance criterion.

Results of these tests did indicate a difficulty in differentiating wheat from other closely related small grains. However, satisfactory wheat area estimates were obtained through the reduction of the small-grain area estimates in accordance with relative amounts of these crops as determined from historic data; and these procedures are being refined.

The accuracy assessment program also indicated that an incorrect classification procedure *initially* implemented in the quasi-operational system did introduce a significant bias into the area estimate; however, these test results allowed the source of this bias to be isolated and corrected.

Other detailed tests indicated that small-grains identification can be adequately established, through the use of human analysts, directly from the Landsat data without ground truth. The repeatability of the analyst performance was also verified in duplicate analyses of a common set of segments by several analyst teams.

There are some indications that in regions with marginal wheat production with small fields or large amounts of confusion crops, wheat identification may be more difficult than in more intense producing areas. LACIE plans to monitor these situations closely during Phases II and III.

Fundamental issues involving sample design were also partially answered by the Phase I accuracy assessment. The several approaches taken to estimate sample error indicate that for the U.S. Great Plains, except North Dakota, it is acceptably small given all the allocated segments. Loss of acquisitions from cloud cover was a problem in Phase I; however, tests conducted to date indicate that error arising from this loss is probably random in nature with no significant bias being introduced.

In North Dakota, a significant underestimate of the wheat area was observed. Further analyses indicate the major problem is with the sample placement as opposed to the classification analysis. Indicated solutions are the allocation of additional samples or improved stratification to reduce agricultural area variability, or both.

Yield feasibility.— The Phase I analyses of the model to be incorporated into the LACIE quasi-operational system in Phase II indicated that the Phase II model can be expected to support the 90/90 criterion in regions having characteristics similar to the geography and agriculture represented by each of a majority of the states in the yardstick region. It is recognized, however, that the models may not perform as well in foreign areas where historical record data are lacking or nonexistent.

In a test of the yield models over the years 1965 to 1975, the c.v. of the yield estimates was on the order of 2 percent at the national level, lower than the 4.25 percent required. However, it was noticed that in 5 of the individual years, the difference in the average yield predicted by LACIE and the SRS was large enough to indicate a statistically significant difference for those years, even though over all test years the LACIE overestimated about as frequently as it underestimated SRS. A more conservative test was devised in which, for these same test years, the LACIE at-harvest yield estimates for each year were combined with the SRS area estimates for that year to produce production estimates referred to as LACIE test production estimates (TPE). The difference between the LACIE TPE and the SRS production estimates were then computed for each test year. Since for each year SRS area and SRS yield figures combine to precisely the SRS production estimate, the differences between the LACIE TPE and the SRS production estimates could be attributed solely to the area-weighted differences between the SRS and LACIE yield estimates. A hypothesis test was developed which showed that in case the differences between the LACIE Great Plains TPE and the SRS Great Plains production estimates were within ± 9.5 percent of the SRS estimate in 8 of 10 years, then the LACIE yield estimator could be expected to meet the at-harvest country level 90/90 criterion. This criterion would be met when the yield estimate is combined operationally with an unbiased area estimator in which the errors are uncorrelated with the yield estimator errors and for which the random error component is equal to the random error component of the yield estimator. This test indicated that the LACIE yield estimator would meet only about an 88/90 criterion. However, this test and others indicated that one source of error in the yield models was the form of the models which resulted in unrealistically high or low yields for extremely high or low values of the temperature or precipitation. An improved model has been developed. Tests of this improved model indicate that it will significantly improve estimates.

Production feasibility test.— When the LACIE area estimates and the LACIE yield estimates are combined, the resulting production estimates satisfy the 90/90 criterion. In the Great Plains, the LACIE production estimate was 8.8 percent below the SRS final estimate for the same region. The c.v. of the LACIE production estimate was 5.3 percent at the Great Plains level and 4.2 percent when projected to the national level. This is within the acceptable tolerance of 6 percent for an unbiased estimator. Since the difference between the SRS and LACIE estimate at the Great Plains level is not significant (i.e., could likely be a random

fluctuation in this statistical quantity), the estimator can be judged to satisfy the 90/90 criterion since the c.v. is less than the 6 percent required. The largest regional problem observed is once again in North Dakota where production is significantly underestimated because of the area underestimate discussed earlier.

CHANGES IMPLEMENTED AND PLANNED FOR PHASES II AND III ON THE
BASIS OF LACIE EVALUATION OF PHASE I
TECHNOLOGY AND APPROACH

Early in LACIE, areas of technical risk were identified, and research and development efforts were initiated to provide for future system upgrades. The results of Phase I were also tracked, and in August and September 1975 project reviews were held with technical personnel inside and outside LACIE with expertise relevant to LACIE. These reviews aided in solidifying areas of needed improvement, and these improvements were made to the analysis system. In March 1976, a further project review was held to review the implemented and planned improvements, and additional recommendations were formulated for system improvements. On the basis of this review and as improvements are formulated and implemented into the system, additional reviews will be held. The most significant technology changes resulting from these project actions are the following.

Technology Changes Implemented for Phase II

Team approach.— Early design consideration involving signature extension and limitation on the time available to hire and train analysts resulted in an approach of having separate image interpreters and data processing specialists sequentially involved in the analysis of a single segment. This approach did not allow the analysts sufficient visibility and understanding of cause-and-effect relationships to establish quality control over results. As a result, for Phase II, analysts were provided additional training and now work in teams. The approach has demonstrated benefits in accuracy, efficiency, and reduced cost overhead.

Improved acquisition plan and analysis concept.— At the beginning of Phase I, the LACIE fall estimates of winter wheat were significantly higher than the SRS estimates. LACIE correctly classified bare soil from the Landsat data but improperly summed these with the proportion estimates. This problem was compounded by the facts that early biowindow Landsat data were acquired too early and that in many fields wheat which had been planted had not yet sprouted. Since then, crop growth stage models have been incorporated in the LACIE operation, and Landsat data can be selected at the proper time.

Crop calendar starter models.— The LACIE analyst requires crop calendars which define the stage of growth of the plant in order to discriminate wheat (or small grains) from other ground cover. Adjustment of the normal crop calendar is required to account for the current year change due to climatic variation. During Phase I of LACIE, the adjusted crop calendar model, based on Robertson's biometeorological time scale, performed satisfactorily in the Great Plains when the model was initiated with actual planting dates for spring wheat and jointing dates for winter wheat. Realizing that actual dates will not be available for foreign regions, concentrated efforts were undertaken to develop both winter and spring wheat starter models. This resulted in a winter wheat end-of-dormancy restart model and a spring wheat planting date starter model being implemented for LACIE in the spring of 1976.

Accuracy assessment.— The LACIE Phase I Accuracy Assessment activity in the United States concentrated on the analysis of the intensive test site (ITS) data. In order to cover wider geographic areas and better assess the LACIE operations, some regular LACIE segments in Montana and North Dakota, the so-called "blind sites," were ground truthed late in the Phase I operation. These were so successful at giving rapid and accurate feedback into the system that the number of such segments in the U.S. Great Plains has been increased for Phase II, and this effort is now oriented to provide data for early season as well as at-harvest evaluations of LACIE performance.

These data are to be used to evaluate classification error, not sampling error; and in order to be cost effective, it is necessary to randomly select the segment after a large number of acquisitions have occurred. This selection process will tend to weight selection toward regions which have lower cloud cover probabilities. However, for this procedure not to be biased, it is only required that the cloud cover probability be uniform over a county. In order to augment the sampling accuracy, critical data from the SRS 1.6- by 1.6-kilometer (1- by 1-mile) segments are being provided for the 1973-1974 and 1974-1975 crop years.

In Canada, for Phase II, the accuracy assessment activity will focus on 10 ITS's. Data from these sites will support investigations into yield, crop calendar accuracy, and an effort similar to the one carried out in the United States to assess classification accuracy with respect to training set size, biostage, and analyst teams.

In the U.S.S.R., previous years' Landsat data will be ordered and analyzed by LACIE for several key indicator oblasts. Classification accuracies from ITS's in Canada and the United States will be projected in the U.S.S.R. country aggregation by use of the LACIE simulation models.

Sampling accuracy will be determined by image interpretation of full-frame imagery in the United States and in foreign areas.

Monitoring "standard statistics" based on the LACIE estimates will also be used to infer how overall accuracy changes from planting to harvest in the United States and foreign areas alike.

Foreign exploratory segments.— Exploratory segments in foreign areas and in regions of the United States outside the Great Plains were defined to gain early indications of technical feasibility before expansion in foreign regions. A review of Phase I results produced new recommendations for Phase II exploratory segments. Segments were reselected in several countries to make the exploratory analyses more meaningful, either through inclusion of total political subdivisions or through better representation of the agriculture. Secondly, new analysis techniques are being evaluated for the small field problem identified in China and India.

Technology Changes Planned for Phase III

Upgraded yield models.— In addition to providing acceptable yield estimates, the Phase I test of yield models and the parallel supporting research emphasized the need for the planned specific model changes needed for a more responsive system. Key limitations to existing models are failure to account to a sufficient degree for climatic effects on yield as a function of crop development stage, refinement of model meteorological input to a daily basis, and dependence on historical data records of varying quality which may not be consistent with homogeneous yield strata. Two improved model forms are under development, one of which will be selected for implementation in the yardstick region and in the U.S.S.R. spring wheat indicator region early in Phase III.

The modeling approach at KSU is to derive yield response to the environment from historical plot data, determining partial derivatives that describe the reduction from an area yield potential caused by environmental effects. This form provides a great deal of flexibility of choice in the input weather-related variables as might be required in data sparse regions. It is very adaptable to stratification of areas of homogeneous yield potential and provides a definite step toward a general model. This model form is expected to be an improvement over existing models in areas with little or no historical data. Further, it can emphasize and place reliance on additional point meteorological data. This model can also accommodate remotely acquired data.

The improved NOAA/Center for Climatic Environmental Assessment (CCEA) model form is more area-specific in the applicability of its coefficients than is the KSU model; however, it is anticipated that it will account for seasonal weather anomalies (by incorporation of crop calendar into yield model). A soil moisture budget will replace precipitation as an input to account for run-off, and an improved definition will be made of regions where plant response to weather is uniform (stratification). These models are to be available for quasi-operational testing by April 1977.

Revised sampling in key areas.— A methodology has been developed to define sample strata along meaningful boundaries of homogeneous agricultural areas defined by contours of equal agricultural density and variability as determined from Landsat imagery and by soil and climatic relationships. Activities are under way to implement this early in Phase II for the yardstick region in the United States and the U.S.S.R. spring wheat indicator region. In addition, it is believed that this change will provide a sampling plan that offers more insight into the performance to be expected in foreign areas.

Signature extension.— The objective of signature extension is to allow an increase in sample segments analyzed without substantially increasing analysis costs in an operation. This was documented as an area of high technical risk in the initial days of LACIE. The first attempts in Phase I were, for the most part, costly and unsuccessful. The supporting research and development element of LACIE indicated that improved technology is available in the areas of stratification to define segments of similar spectral characteristics and in the area of algorithms for correction of atmospheric variations. This technology is being evaluated under test conditions and, if successful, can be transferred to a quasi-operational test in late Phase II. The quasi-operational test will provide the basis for a decision to implement signature extension into the operation in Phase III. There is no technical reason to believe that signature extension capability cannot be developed.

Clustering.— Clustering is a technique that has been widely used for the analysis of multispectral data. It was strongly recommended as a tool for the analyst to use in defining the spectral structure in a scene. The results of Phase I indicate that it would be especially valuable to the analyst in attempting to perform multitemporal analysis when the analyst has several images to contend with. Implementation in Phase III is contingent on successful development and test efforts now under way.

Revised thresholding.— Thresholding is used in segment analyses to extract extraneous picture elements (pixels) from the proportion estimate; that is, pixels which contain little or no information related to wheat (e.g., data dropouts, clouds, and shadows). In addition, it is useful as a diagnostic tool in the evaluation process; for example, in the detection of missing training signatures. In Phase I, the threshold model resulted in undesirable levels of thresholding, and the thresholded pixels were not being treated correctly in the proportion estimate. Improvements are being incorporated in the threshold model for Phase III. Test show that this will yield improved estimates relative to the former model, specifically when multitemporal classification is utilized.

Analyst-interpreter keys.— During LACIE Phase III, the analysis of Landsat data will employ newly developed analyst-interpreter keys which group spectrally similar segments and provide in a

single document the ancillary data and decision logic for determining crop identification within each group of segments. The keys will provide interpretative methodology and analytical tools for improved wheat and/or small grains identification from the earliest crop development period.

GENERAL OBSERVATION OF EARLY SEASON PHASE II RESULTS

Evaluations of the LACIE U.S. Great Plains area, yield, and production estimates in Phase II by the LACIE accuracy assessment and Information Evaluation staff (USDA LACIE staff in Washington) have found that the LACIE estimates agree well with the SRS estimates. Comparisons of LACIE area estimates to the Phase II blind site estimates indicate that the LACIE estimate of standing and vigorous wheat area is also in good agreement with actual ground conditions as determined from aircraft color infrared (CIR) imagery and ground observations and thus reflect wheat area available for harvest quite accurately. In the current crop year, late planting, drought conditions, green bug infestation, late grazing, and winter kill are affecting significant amounts of wheat, causing stands which are not recognizable from Landsat or aircraft CIR imagery.

To date, LACIE has released for the U.S. Great Plains five monthly reports on wheat area, yield, and production. These reports are delivered to the USDA LACIE staff in Washington, D.C., prior to the release of the SRS reports. The Information Evaluation staff in Washington compares the LACIE estimates to the SRS estimates after the latter are published.

A problem exists in evaluating the LACIE early season yield and production estimates in that no technique other than the LACIE type yield models exists for making objective early season yield estimates. In the yardstick region, the SRS does not normally make early season wheat production estimates before May, other than by trend. In April 1976, the SRS resorted to a weather model very similar to that used by LACIE to make early estimates of wheat yield in April. The April SRS estimate was made as the result of a special request from the U.S. Secretary of Agriculture because of drought conditions.

For the 2 months thus far in Phase II (April and May), when side-by-side comparisons are possible, LACIE yield results appear to be tracking reasonably well with the official SRS estimates. In April, the LACIE yield estimate in the Great Plains was slightly higher than the SRS estimate. In May, the SRS yield estimate increased and the LACIE yield estimates for the same period decreased and both estimates now agree well.

The first LACIE estimate of area, yield, and production in a foreign country was accomplished in Phase II using fall collected data over an important winter wheat (indicator) region of the U.S.S.R. The LACIE estimates are lower than those for a normal year, but the trend of this reduction is in line with the current weather situation in that region.

ECONOMIC EVALUATION AND TRANSFERABILITY APPROACH

The plan for economic evaluation of LACIE is comprised of two parts, (1) the cost of an operational wheat estimation system within the USDA and (2) the value of foreign wheat production estimation to USDA and Administration decision-makers. This cost is expressed in terms of men, monies, and materials as projected into an operational environment as opposed to NASA, NOAA, and USDA resources required in the LACIE environment, including RT&E and the experimental quasi-operational system. The planning guidelines and facts that underlie the project approach are based on experience gained in LACIE and in addition draw heavily upon operations research techniques. The following characteristics of LACIE need to be understood.

1. The physical system (hardware, software, and procedures) supporting LACIE at JSC, GSFC, and CCEA is comprised of diverse pieces of existing systems, originally designed for somewhat different applications than LACIE. Thus, they are experimental in nature and are not representative of a facility designed specifically for a production-oriented wheat inventory task.
2. LACIE is an experiment being supported by activities over and above the quasi-operation. Only about one-third of the assigned personnel are dedicated to the operations portion of the experiment, the majority being applied to general experimental support tasks.

A USDA operational wheat estimation system is being cost-simulated on the basis of task specific, state-of-the-art hardware, software, and procedures. This cost factor will be evaluated in a manner similar to that used by private industry and the U.S. Department of Defense; for example, an acceptable cost for the production system would be a cost range that falls within the ratio of 5 to 1, where 5 equals system development cost and 1 equals any 1 year's production cost.

The benefits accrued from a production system are derived from the impact of geographically broader, more timely, accurate, and objective wheat information available to the decision-makers. Benefit areas are to be identified through a plan to interview decision-makers at various levels throughout USDA to assess worth in terms of (1) the types of decisions made; (2) the use of crop information and its value to respondents; and (3) the potential effect on USDA's responsibilities including USDA policy decisions, program actions, publication of reports to the agricultural community, ability to analyze and respond to changes in policy, and improvement in forecasts having economic consequences. In addition, modeling techniques will be used to assess the impact of improved wheat information on commodity price forecasting efforts, farm income, target price and load levels, government costs under alternative programs and decisions, and consumer food decisions.

An integral part of the project plan, the output of this review will be applied, together with the technology and procedures that are being developed within the experiment, to the design of a system that could be placed directly into production at a USDA facility.

REFERENCES

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GLOSSARY

CITARS - Crop Identification Technology Assessment for Remote Sensing; a project to evaluate the effectiveness of various methods of analyzing remotely sensed agricultural data (considering various crops, atmospheric and seasonal factors, and sensors) conducted by NASA/JSC in cooperation with supporting universities and federal agencies.

classification - as applied to remote sensing, a semiautomated, computer-implemented process in which subsets of measured values of electromagnetic energy reflected from ground cover types within a geographic area (training area) are uniquely associated with the prevailing cover types in that area. Measurement values similarly obtained from cover types outside the training area are then labeled or classified according to the associations developed within the training area.

clustering - mathematical procedure for organizing multispectral data into spectrally homogeneous groups.

crop calendar - calendar depicting the period of growth, development, or biological stages of the major crop types within a specified region during a calendar year.

data processing - application of procedures (mechanical, electrical, computational) by which data are changed from one form to another.

ground truth - all the information known about a selected location resulting from records, in-situ measurements, and field observations.

ITS - intensive test site; area selected as a calibration standard for remote sensing operations. Ground truth information is collected in conjunction with each set of remotely sensed data acquired.

LACIE - Large Area Crop Inventory Experiment; joint experiment of the U.S. Department of Agriculture, the National Oceanic and Atmospheric Administration, and the National Aeronautics and Space Administration to prove out an economically important application of remote sensing from space. A series of experimental investigations utilizing multispectral and meteorological data to identify and measure the real extent of major crop types and to estimate their yields.

Landsat - Land Satellite; designation for two NASA earth resources remote sensing satellites equipped with multispectral scanners and return beam vidicons, the first (Landsat-1) of which was launched 1972 and the second (Landsat-2) in January 1975.

pixel - picture element; dual record of a single data-take during the scan of an electro-optical scanning sensor and referenced by scan line and column.

PPS - probability proportional to size; one-stage variable probability sampling applied in many types of surveys (agriculture, forest, and census). The probabilities of selection are defined as

$$P_i = \frac{C_i}{\sum C_i} c_i ,$$

in which C_i is a prediction, obtained by remote sensing of the resource quantity in the i th population unit.

real time - term used in electronic data processing to describe operations conducted at the same time as, or concurrently with, the collection of input data.

remote sensing - discipline concerned with conducting aerial or space surveys of the earth's surface using all types of sensing devices; space, airborne, or other data collection platforms; manual and automated data processing equipment; information theory and processing methodology; information theory and devices; and large-systems theory.

remote sensing technology - technology based on measurements of electromagnetic energy reflected or emitted from scenes or objects. The five elements of remote sensing technology are data acquisition, data correction, data analysis, information management, and applications.

sampling - statistical procedure using portions of a subject of interest to represent the properties of that subject.

signature - color, tone, brightness, texture, and pattern of a scene or object; the overall visual characteristics of a crop as it appears on multispectral imagery.

signature extension - extrapolation of a known set of remotely sensed data to classify other remotely sensed data.

signature extension accuracy - measure of the accuracy with which known spectral signatures can be used to classify features in remotely sensed data acquired from areas other than from which the signatures were developed.

spatial resolution - the smallest size of a uniformly gray object that can be recorded by a given sensor on an image that can be distinguished from a uniformly gray background at a given contrast ratio.

spectral band - discrete segment of the electromagnetic spectrum that a sensor is capable of recording.

threshold - mathematical barrier beyond which a data point (pixel) will be excluded from a given class of features. The threshold values are controlled by the characteristics of the automated classification program employed.