

LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)



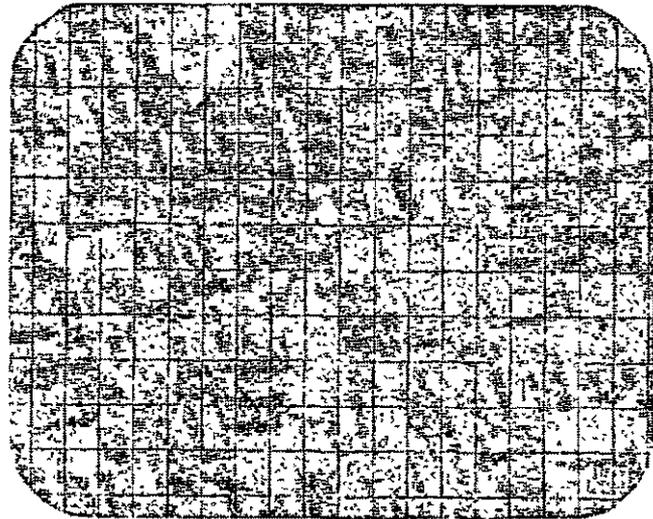
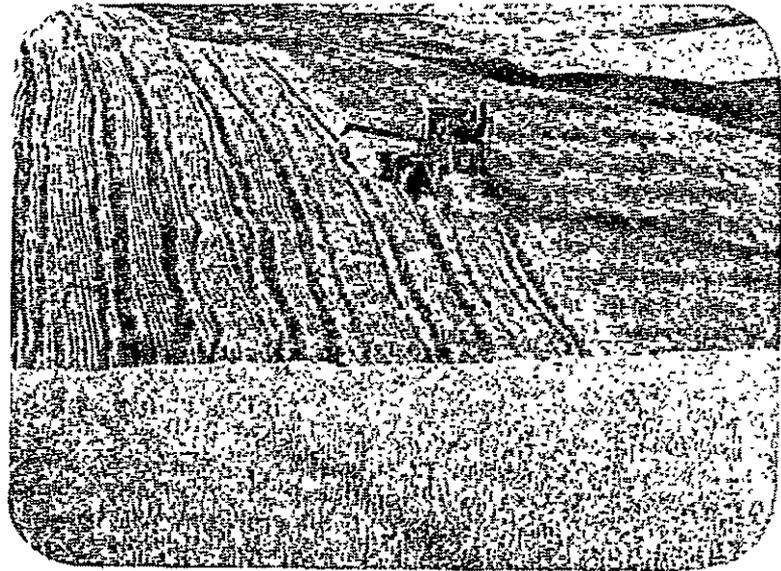
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EXECUTIVE SUMMARY

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National Aeronautics and Space Administration

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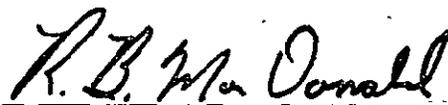
EXECUTIVE SUMMARY

Prepared by the LACIE Project Team:
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Original photography may be purchased from:
EROS Data Center

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Large Area Crop Inventory Experiment



NASA NOAA USDA

PREFACE

The purpose of this document is to describe the Large Area Crop Inventory Experiment - its background, technical approach, results and major conclusions.

*For a very abbreviated treatment
the reader is referred to the
Summary on page 1.*

The body of the document treats the major topics as follows:

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The Large Area Crop Inventory Experiment (LACIE), completed June 30, 1978, has met the USDA at harvest goals (90% accuracy with a 90% confidence level) in the U.S. Great Plains and U.S.S.R. for two consecutive years. In addition, in the U.S.S.R. LACIE indicated a shortfall in the 1976-77 wheat crop about two months prior to harvest thus demonstrating the capability of LACIE to make accurate pre-harvest estimates. This summary briefly documents these results and gives an assessment of the project.

LACIE was a tri-agency experiment carried out by the National Aeronautics and Space Administration (NASA), the U.S. Department of Agriculture (USDA), and the National Oceanic and Atmospheric Administration (NOAA). The goal of the experiment was to research, develop, apply and test the technology to estimate wheat production worldwide with improved accuracy and timeliness over current global estimates. The detailed objectives included the following:

- o To demonstrate an economically important application of repetitive multispectral remote sensing from space.
- o To test the capability of the Landsat, together with climatological, meteorological, and conventional data sources, to estimate the production of an important world crop.
- o Commencing in 1975, to validate technology which could provide timely estimates of crop production.

Beginning in 1974, available technology in aerospace remote sensing and in weather effects modeling, developed over the prior decade, was assembled in a research and development system. This system was applied on the task of estimating wheat production in important producing areas of the world. Many modifications were made to the initial approach, and both accuracy and efficiency improved steadily through the three years of the experiment which concluded in June 1978.

The basic technical approach of LACIE was to develop production estimates for wheat by combining separate area and yield estimates. Area was derived from Landsat data acquired over selected sample segments and yield was obtained using models which relied on weather data from the World Meteorological Organization Network. The experiment exploited high-speed digital computer processing of data and mathematical models to extract information in a timely and objective manner.

The LACIE technology worked very well in estimating wheat production in important geographic regions. Notably, LACIE produced in August 1977 what proved to be an accurate indication of the USSR spring wheat shortfall. This was well before more definitive information was released by the USSR. Additionally, two crop years of study in both spring and winter wheat regions of the Soviet Union resulted in estimates that support the experiment performance goals. Further, the confidence in this success was reinforced by the accuracy of the production estimates in the U.S. hard red winter wheat region for three crop years of study.

Application of the technology in Canada was less successful. However, the reasons for the shortcomings are reasonably well understood (field size is typically very close to the present satellite resolution limits and spring wheat is difficult to separate from some other crops). More recent work on spring wheat in the U.S. Great Plains indicates that these problems can be overcome. Exploratory investigations in other countries were made and the current technology is believed applicable to some countries (Australia, Argentina and possibly Brazil) and to require improvement in others (China and India).

The LACIE effort resulted in many technological improvements in the application of satellite and weather data: improvements in the field of global sampling using the Landsat data; a production estimation technology using area and yield components; a crop area estimation technology of acceptable accuracy accomplished without the use of ground data; and a crop yield estimation technology of acceptable accuracy.

While both the technology and understanding of the critical problems were significantly advanced through the experiment, they are still in the early stages of development and could easily be improved with continued effort. Refinements to the Landsat data analysis procedures can further improve wheat identification accuracies. Yield models may be improved by utilizing Landsat data together with weather measurements to better define the crop's response to growing conditions. Models which estimate the crop's stage of development can similarly be improved to provide important data to assist in making a more reliable separation of wheat from confusion crops (such as barley) and support improved early warning and yield forecasts.

The Department of Agriculture, beginning early in 1976, developed a data analysis system to transfer and exploit the emerging LACIE technology for USDA use. This prototype was approved in January of 1976 to serve as the vehicle for the transfer of technology from applied research to an application within USDA. The USDA system is now in initial operation with a team skilled in the analysis of remotely sensed data and other aspects of the LACIE technology.

LACIE was a timely response to an identified national need: it was broadly responsive to a specific user agency need; it built on more than a decade of research and development; it assembled a first-generation technology; and it was rigorously tested on a large scale for the world's most important crop in major producing regions of interest. An evaluation of the LACIE experience leads to the conclusion that it successfully:

- o Produced accurate results in important areas such as the USSR and the U.S. hard red winter wheat region.
- o Stimulated related research and technology development.
- o Produced more efficient and accurate procedures for analysis.
- o Provided a basis for a comprehensive research, development, and test program to extend the capability to other crops.

The encouraging results of LACIE have led to major planning efforts among the participating agencies to assess the information requirements of USDA (and possibly other users), and to define a follow-on activity for the early 1980's which will advance the capability developed in LACIE to other important global crops and agricultural problems. It is considered likely that, with suitable effort, this technology will advance rapidly and could be in widespread use in the 1980's.

The Large Area Crop Inventory Experiment (LACIE) has been a joint venture of the U.S. Department of Agriculture, the National Oceanic and Atmospheric Administration of the Department of Commerce, and the National Aeronautics and Space Administration.

LACIE was initiated in 1974 as a "proof of concept" experiment to assimilate remote sensing and associated technology into an experimental system and to apply that system to the task of producing production estimates for economically important agricultural commodities. Wheat, the most important internationally-traded crop, was selected as the test crop in the experiment both because of its economic importance and because its selection would fit well with the evolution of the technology. It is the crop that covers the largest total geographic area, and field sizes range from the very large fields of the United States and the Soviet Union to the small fields plots of India and China. Wheat is being either grown or harvested or sown in some part of the world almost every day of the year. Wheat is one of the least complex crops from an agricultural standpoint; is one of the best understood crops in regards to remote sensing; and was considered an excellent technological stepping stone because the technology developed should be adaptable to other crops.

The Agro-Economic Situation

Mankind is becoming increasingly aware of the need to manage better the utilization of the Earth's resources - its atmosphere, vegetation, oceans, fresh water, soils, minerals and petroleum supplies. As the world's population increases, and a higher standard of living is sought for all, more careful planning is required to make effective use of these resources to produce adequate food supplies. Agricultural production is highly dynamic in nature and dependent on complicated interactions of prices, weather, soils and technology. The outlook can and usually does change as these ingredients are altered either through natural changes

or as a result of man's decisions. Wheat, for example, is cultivated with a wide range of technology levels and much is grown in semi-arid regions with marginal weather. Thus its production is subject to extreme variations. The world's wheat supply has fluctuated from the oversupplies of the 50's and 60's to the critical deficiencies of the 1972 and 1974 crop years and back to the apparent oversupplies of the current period. These deviations have had severe economic impact.

Wheat is the most important of the world's grains, and grains as a class are the most significant commodities in terms of global agricultural economics. Figures 1 and 2 illustrate the magnitude and value of the international trade involved.

The great economic importance of agricultural products in terms of a positive contribution to the U.S. balance of trade, as shown in Figure 1, increases the need to obtain the best possible global agricultural information.

The increasing importance to other nations of the U.S. grain production and wheat production in particular, is illustrated in Figure 2.

U.S. TRADE BALANCE

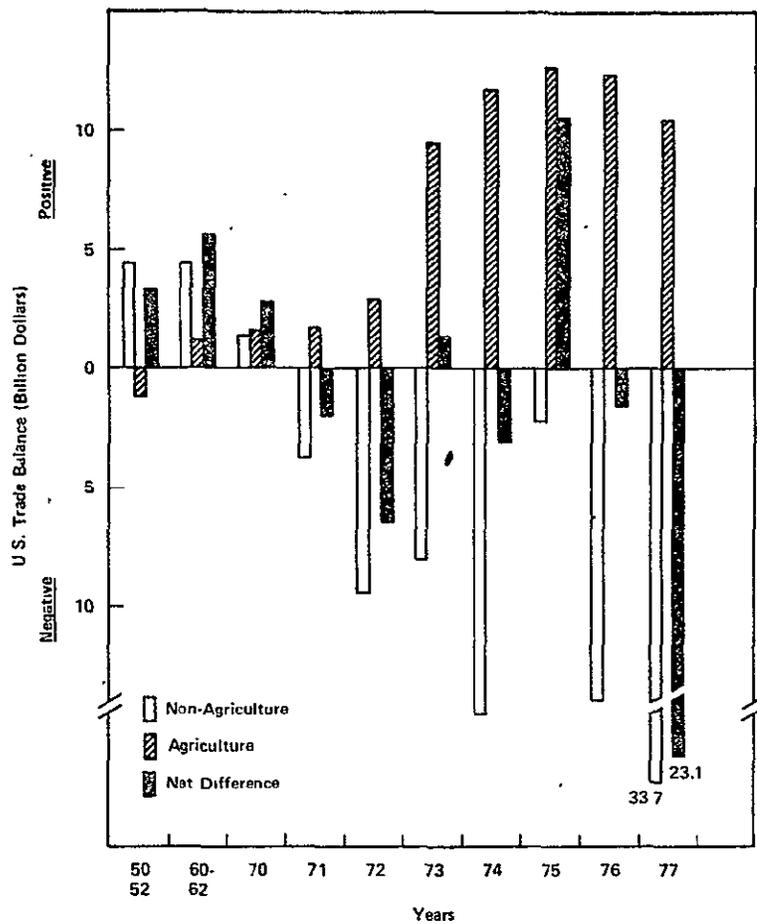
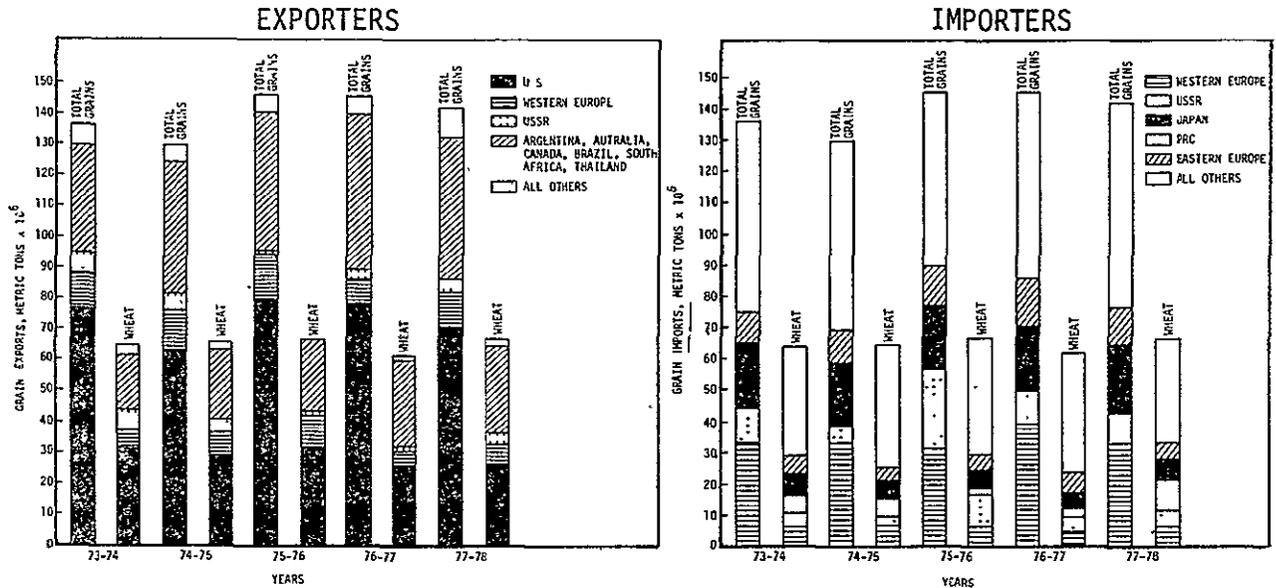


Figure 1. U.S. trade balance for net agriculture, nonagriculture, and the difference.



SOURCE: FOREIGN AGRICULTURAL SERVICE, USDA

FIGURE 2. Major countries net exports and imports of grain and wheat.

Exporting and importing countries must maintain a delicate balance between supply and demand, anticipating the determining factors as far in advance of transactions as possible. The United States is the largest food exporter in the world and accounts for about one-half of the global grain trade and about 40% of the wheat trade*. Clearly, U.S. agricultural decisions have a far-reaching impact. While decisions have been and will continue to be based upon whatever information is available, there is a continuing need on the part of decision-makers, in both public and private sectors, for improved information. A key ingredient is the best possible estimates of national and global production.

* Trade in terms of tonnage

The Need for Improved Information

In recent years, various organizations formed to study the world food situation have recognized the strong need for a global food and fiber monitoring system. In one of these studies, the World Food and Nutrition Study, National Academy of Science, the following recommendation was made: "It is recommended that research be undertaken towards the development and implementation of a capability to repetitively monitor the status of the world's critical food producing regions and provide early warning of potential shortages in production. It is further recommended that a continuing supporting research and technology program be organized to develop future improvements for later incorporation into subsequent versions of an initial monitoring system." A similar resolution was made at the 1974 World Food Conference in Rome, Italy, in which an "urgent need for a worldwide food information system" was cited. It was recommended that such a system identify areas with imminent food problems and monitor world food supply and demand conditions.

Current world food supply estimates are a compilation of estimates generated for the most part by the various national agricultural information systems. The quality of world estimates, therefore, is a function of the quality of the information systems in the various countries. The estimates range from timely and reliable to almost nonexistent. Frequently estimates based on past trends, sometimes adjusted by subjective judgment, are given in lieu of objective and correct information.

A complicated but extremely important capability that must exist in any agricultural information system, if it is to be dependable, is the ability to assess both components which contribute to the variability of observed production - area and yield. Figure 3 shows variability in area, yield and production for the U.S. and in area and production for the USSR, two major wheat-producing nations. (USSR does not report yield. Whenever yield estimates are presented for Soviet wheat, those estimates are computed from estimates of production and the area involved

in that production). A comparison of the charts indicates that in the U.S., yield and area have fluctuated significantly from year to year, while in the USSR both area and production have similarly varied.

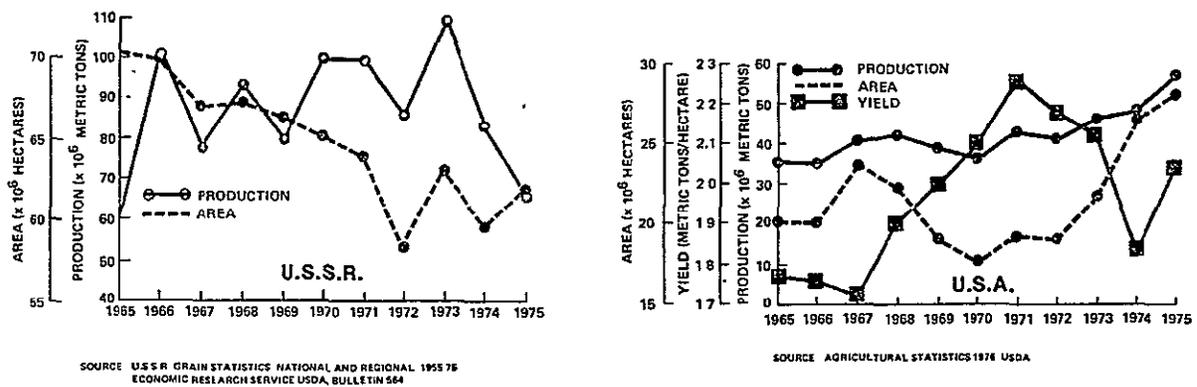


Figure 3. Wheat variability - USSR and US.

To forecast production accurately, it is critical to associate the correct weather with the actual area being affected. Where the effects are so severe as to remove area from production, this abandoned area must be correctly measured. Therefore, not only must an effective agricultural information system monitor the total area harvested, but it must also monitor the proportion of the area affected by weather extremes.

There is a manifest need to manage the planet's agricultural production, and improved information is critical to better management.

This need, brought into focus the feasibility of applying remote sensing, together with related technology, to the task of developing and evaluating technology that could serve an important role in providing the global agricultural information.

The Background of LACIE

The foundation for LACIE was established in 1960 when the Agricultural Board of the National Research Council recommended that a committee be formed to investigate the potential of aerial surveys to provide an increased capability in monitoring agricultural conditions over large geographic areas. An interdisciplinary group of scientists was selected to serve on the Committee on Remote Sensing for Agricultural Purposes, and by late 1962 the group had designed experiments to assess the feasibility of utilizing multispectral remote sensing to monitor crop production. This was followed in 1965 by the establishment of an organized research program, by the U.S. Department of Agriculture and the National Aeronautics and Space Administration, that led in an orderly fashion from the first successful computer recognition, in 1966, of wheat using multispectral measurements collected with aircraft to:

- (1) the identification of the spectral bands and other design characteristics of the first Earth Resources Technology Satellite (ERTS*) in 1967;
- (2) a simulation of ERTS data from the S-065 multispectral photographic system of Apollo IX in 1969;
- (3) the successful launch of ERTS in 1972;
- and (4) the conduct of feasibility investigations in 1972 and 1973 which demonstrated the potential utility of the ERTS system to monitor important crops.

Investigations into the relationships between weather and crop yield have been an agricultural research interest of long-standing. The availability of high-speed computers and worldwide weather data, in recent decades, allowed more extensive statistical analysis of the

*ERTS-1 was renamed Landsat 1. Although Landsat 1 is no longer functioning Landsats 2 and 3 are now in orbit and producing usable data.

relationships of yield and weather. Some researchers had studied individual plant response to weather factors while others had investigated the problem on a larger scale to determine the relationship between average yield and the departures from normal climatic conditions in a specific region. Several of these studies were undertaken at Iowa State University about 1970 to investigate key relationships between yield, technology, and climate in the major grain-producing areas of the United States. Based upon that work, NOAA initiated a study in 1973 to evaluate the likelihood of drought conditions reappearing in the U.S. and the possible effects of drought upon grain yield.

These efforts resulted in the development of an initial base of technology to support agricultural production monitoring. LACIE was a logical next step in the chain of research and development. This technology base consisted of earth observation satellites, environmental satellites, communications links, high-speed computer processing equipment, mathematical models, and an initial understanding of the use of these components in such an application. In LACIE these elements were, for the first time, assembled into a system capable of a large-scale application and evaluation, and the resulting system established the applicability of this technology to the monitoring of global wheat production.

LACIE Management

The LACIE experiment was guided by a tiered management structure which involved personnel from the USDA, NOAA, and NASA. Senior level personnel provided top level program objectives, and approved major changes in program direction, budgeting and schedules. A management team, with members from the three agencies, was responsible for reviewing the technical progress of the program and to insure that the program was accomplished on schedule, within allocated resources. A third level was the LACIE Project Manager who was responsible for project implementation and day-to-day operations. The major decisions

and directions for the LACIE experiment were made using this management structure to insure that user agencies' needs were being met and that all agencies were active participants in all phases of the project.

Roles of the Federal Agencies

Each of the three U.S. government agencies participating in LACIE brought specific expertise and experience to the planning and implementation of the experiment. Most of the individual LACIE tasks required the integrated efforts of at least two of the three agencies; however, various lead responsibilities were assigned. The USDA was responsible for: user requirements definition; collection of ground truth and historic data; compilation and release of production, yield and area estimates; cost-effectiveness analysis and reports and USDA prototype system design and test. NOAA was responsible for: the acquisition and processing of real time and historic worldwide meteorological data; the analysis of meteorological data to provide seasonally-adjusted crop calendars; the development and operation of models to estimate yield through the growing season; and the preparation of narrative assessments of crop growing conditions in regions of interest. NASA was assigned responsibility for: the project technical management; inventory system requirements definition; experiment design, implementation, operation, and system performance reporting; area classification and measurement technique development and implementation; and Landsat data acquisition and processing. Figure 4 illustrates the three agencies' participation.

Role of Universities and Industry

Researchers from universities and industry played a key role in supporting the experiment through the development of improved techniques that were evaluated in the later phases of LACIE, and through participation in technical review sessions held periodically throughout the experiment. In addition, key industries were, through contracts from the agencies, vital to the implementation and operation of the experiment.

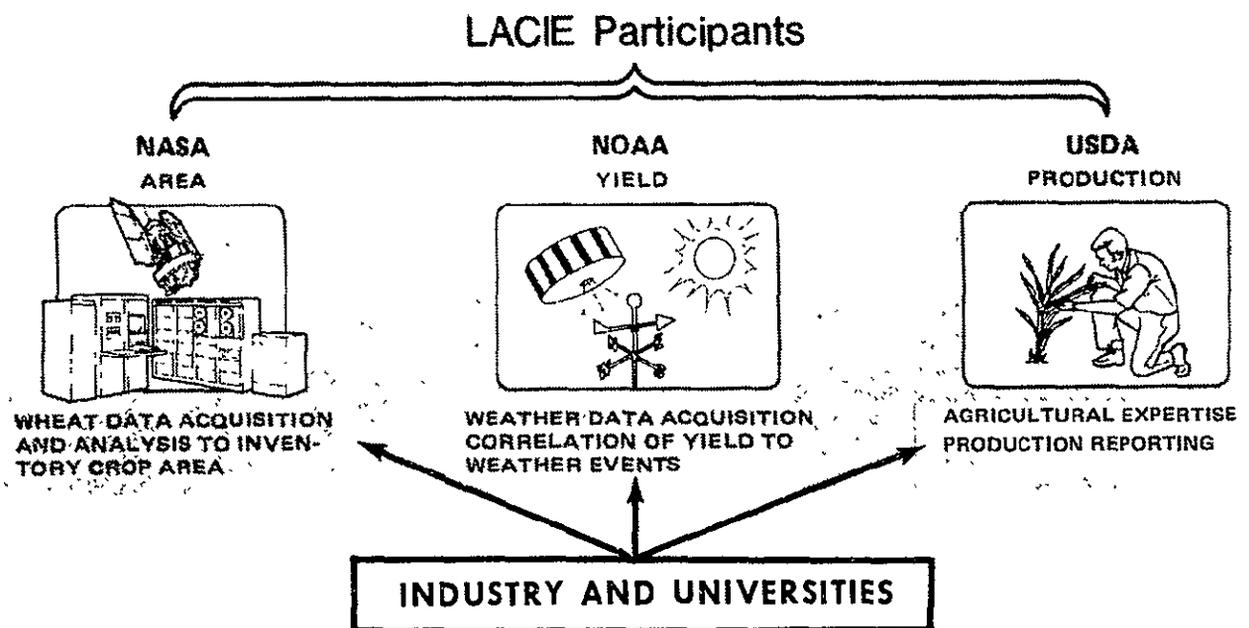


Figure 4. Each of the three agencies of the U.S. Government (USDA, NOAA, and NASA) that conducted LACIE brought particular expertise to the experiment and were supported by industry and universities.

EXPERIMENT OBJECTIVES, SCOPE AND TECHNICAL APPROACH

Experiment Objectives

The LACIE objectives as set forth in the Project Plan (LACIE-000605, JSC-09857) prepared in March of 1975 and officially approved in August of 1975 include the following:

- o To demonstrate an economically important application of repetitive multispectral remote sensing from space.
- o To test the capability of the Landsat, together with climatological, meteorological, and conventional data sources, to estimate the production of an important world crop.
- o Commencing in 1975, validate technology which could provide timely estimates of crop production.
- o To provide from an analysis of Landsat data acquired over a sample of the potential crop-producing area in major wheat-growing regions, estimates of the area planted to wheat; similarly, from an analysis of historical and real-time meteorological data over the same regions, provide estimates of wheat yield and combine these area and yield factors to estimate production.
- o To provide data processing and delivery techniques so that selected samples can be made available to the LACIE analyst teams for initiation of analysis no later than 14 days after acquisition of the data.
- o To provide a LACIE system design that will permit a minimum of re-design and conversion to implement an operational system within the USDA.
- o To monitor and assess crop progress (calendar) from a surface data base and evaluate the model potential for yield from surface data.

Ancillary goal-oriented activities included:

- o Periodic crop assessment during the growing season from planting through harvest.
- o Accuracy commensurate with USDA requirements.

- o Supporting Research and Development (R&D) program to improve methodology and performance.
- o Objective test and evaluation program to quantify results from R&D.

To maintain the experimental nature of LACIE, it was decided that the periodic crop assessment reports would be prepared on a monthly basis during the crop season, and mailed to the USDA LACIE Office the day before each corresponding official USDA report was released. The accuracy goal was set for production estimates at-harvest to be, within ± 10 percent of true country production 90 percent of the time (referred to as the 90/90 criterion). An additional goal was to establish the accuracy of these estimates from early in the season (the first quarter of the crop cycle) and through the harvest period. The three agencies agreed that achieving the 90/90 criterion would provide an improvement over information currently available at harvest utilizing conventional data sources in selected foreign countries. Also, an evaluation of the accuracy of the periodic assessments would establish the accuracy capability of the technology from early season through the crop year.

Scope and Schedule

The LACIE was focused on monitoring production in selected major wheat-producing regions of the world. The experiment extended over three global crop seasons, and was designed for expansion up to eight regions (Figure 5). All phases of the experiment utilized a "yardstick" wheat growing region of the U.S.; the nine-state, hard-red-wheat region in the U.S. Great Plains (USGP), where current information relative to wheat production and the components of production were available to permit quantitative evaluation of the technology in use within the LACIE. The experiment included exploratory studies for monitoring wheat production in five other major-producing regions (India, Peoples Republic of China, Australia, Argentina and Brazil) (Figure 5). As the experiment progressed, a combination of programmatic policy decisions, availability of resources, and the LACIE experimental design permitted an orderly expansion to include the monitoring of wheat production in two additional major-producing regions (Canada and the USSR).

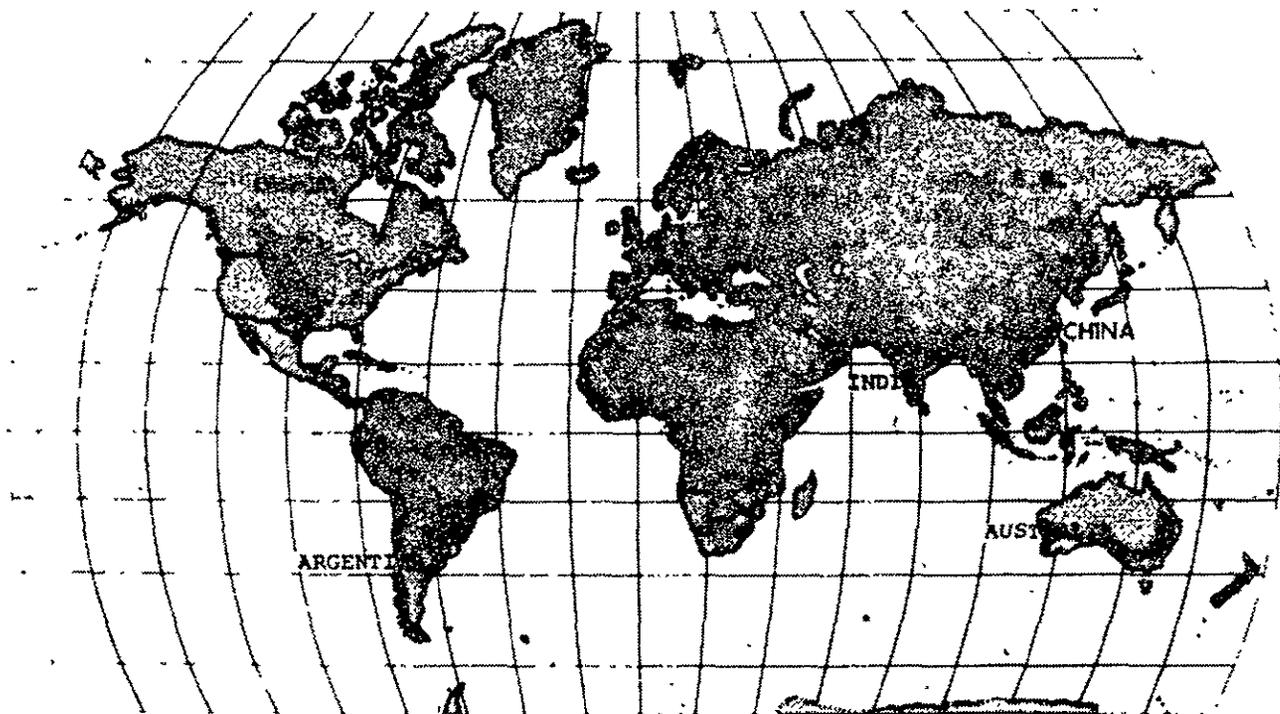
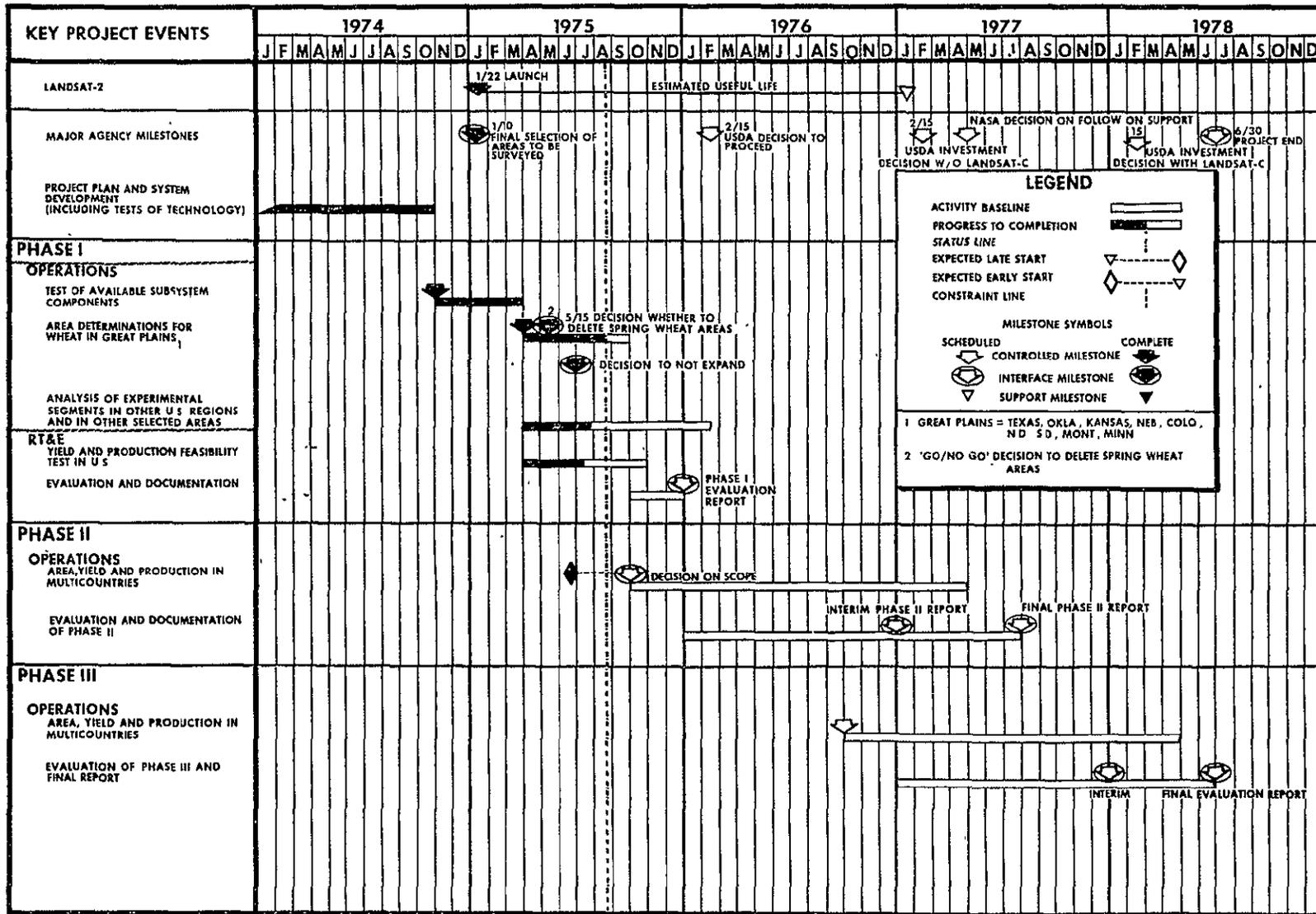


Figure 5. Major Wheat Producing Regions Considered in LACIE.



LEGEND

ACTIVITY BASELINE [Solid horizontal bar]

PROGRESS TO COMPLETION [Horizontal bar with diagonal lines]

STATUS LINE [Dashed horizontal line]

EXPECTED LATE START [Dashed line with diamond]

EXPECTED EARLY START [Dashed line with inverted diamond]

CONSTRAINT LINE [Dotted horizontal line]

MILESTONE SYMBOLS

SCHEDULED [Open diamond]

CONTROLLED MILESTONE [Diamond with horizontal line]

INTERFACE MILESTONE [Diamond with vertical line]

SUPPORT MILESTONE [Diamond with diagonal line]

COMPLETE [Filled diamond]

1 GREAT PLAINS = TEXAS, OKLA., KANSAS, NEB., COLO., N.D., S.D., MONT., MINN.

2 'GO/NO GO' DECISION TO DELETE SPRING WHEAT AREAS

ORIGINAL PAGE IS OF POOR QUALITY

Figure 6. ORIGINAL LACIE SCHEDULE

The LACIE extended over three overlapping global crop seasons, each of which was considered an experiment phase (Figures 6 and 7). Phase I of LACIE, global crop year 1974-75, focused on the integration and implementation of technology components into a system to estimate the proportion of the major producing regions planted in wheat, and the development and feasibility testing of yield and production estimation systems. An end-of-season report for area estimates of wheat/small grains in the U.S. Great Plains was generated. In addition, at the end of Phase I, key USDA management decisions resulted in the incorporation of a USDA-User System within the USDA-LACIE effort.

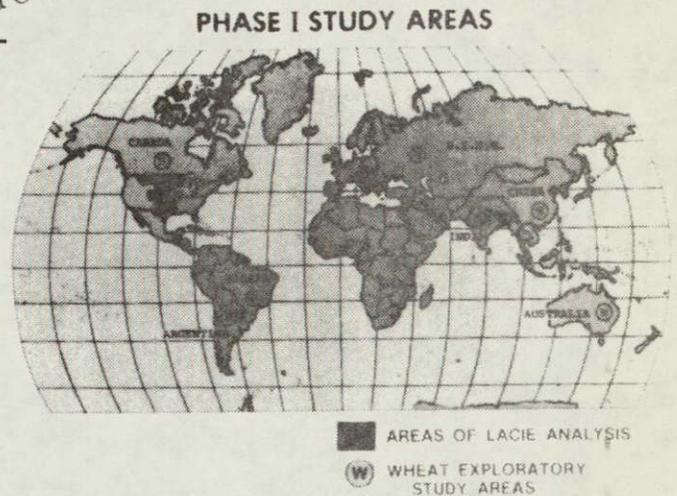
In Phase II, global crop year 1975-76, the technology, as modified during Phase I, was evaluated for monitoring wheat production for the U.S. Great Plains and Canada, and "indicator regions" in the USSR. Monthly reports of area, yield, and production of wheat for these three major-producing regions were generated. A substantial level of effort was expended to deal with significant problem areas and to incorporate solutions into the LACIE analysis systems for use during Phase III.

During Phase III, global crop year 1976-77, new technology, developed during Phase II, was implemented and evaluated for monitoring wheat production for the U.S. Great Plains and the USSR. Monthly reports of area, yield, and production estimates of wheat for these major producing regions were generated.

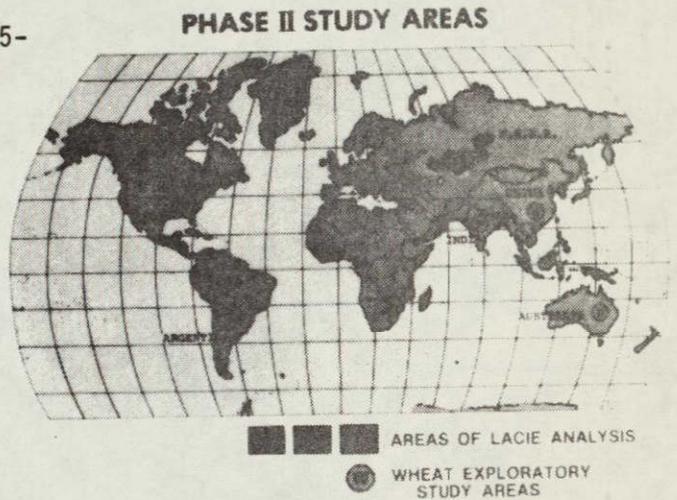
Technical Approach

The technical approach to LACIE (Fig. 8) was to estimate production of wheat on a region-by-region basis where production is the product of area and yield. Both of these components, area and yield, were estimated for local areas and aggregated to regional and country levels based upon a sample strategy over

(1) In Phase I, global crop year 1974-75, integration and implementation of technology components, developed within pre-LACIE research and development efforts, into a system to estimate the proportion of the major producing region planted to wheat the development and feasibility testing of yield and production estimation systems was accomplished. An end-of-season report for area estimates of wheat/small grains in the U.S. Great Plains was generated. Exploratory experiments were begun in wheat areas of interest.



(2) In Phase II, global crop year 1975-76, the technology, as modified during Phase I, was evaluated for monitoring wheat production for the U.S. Great Plains, Canada, and "indicator regions" in the USSR. Monthly reports of area, yield, and production of wheat for these three major-producing regions were generated. Exploratory experiments were conducted in the other five countries.



(3) In Phase III, global crop year 1976-77, new technology was implemented and evaluated for monitoring wheat production for the U.S. Great Plains and the USSR. Monthly reports of area, yield, and production estimation of wheat for these major-producing regions were generated. Additional tests of area technology over Canadian ground truth sites were conducted.

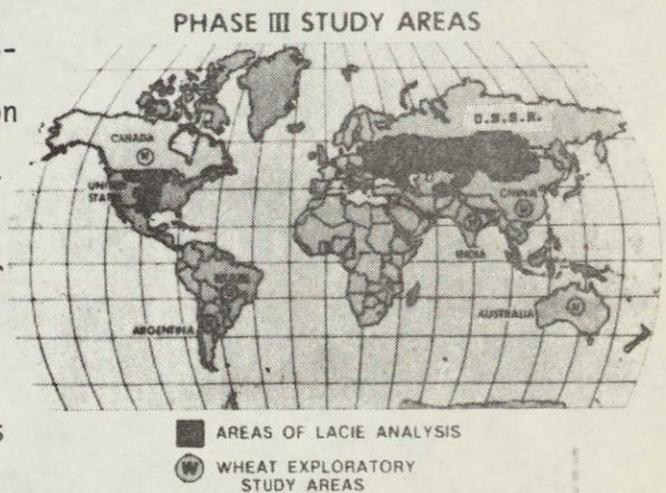


FIGURE 7: Major Wheat-Producing Regions Considered Within the Three Phases of LACIE.

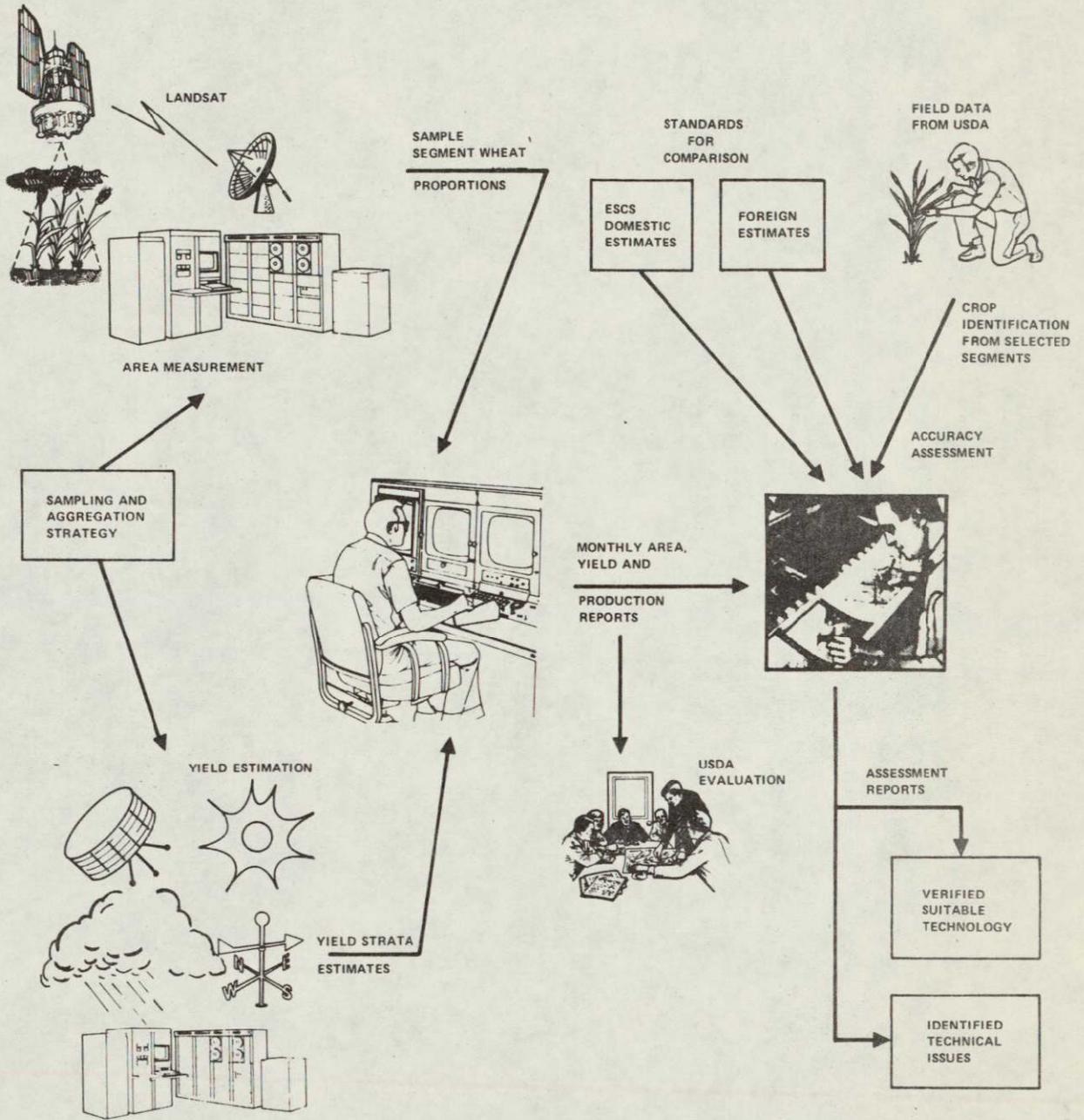


Figure 8. LACIE Technical Approach.

the regions in which wheat was a major crop. Maximum use was made of computer-aided analysis in order to provide the most timely estimates possible. Estimates of production, area, and yield were made throughout the crop season and evaluations conducted to verify the LACIE technology and to isolate and identify key technical issues.

Area was derived by analyst/computer crop identification and measurement from Landsat 2 multispectral scanner (MSS) data acquired over 5 x 6 nautical mile sample segments. Utilization of Landsat full-frame imagery allowed samples to be drawn only from agricultural areas and required only 2% of the area to be analyzed with the contribution of sampling error to the area estimate being less than 2%. The digital, computer-aided statistical pattern recognition techniques employed in LACIE were designed to take advantage of the changing spectral response of crop types over time in order to maximize the accuracy of the area measurement. Thus, Landsat data was acquired throughout the crop season, screened for cloud cover, registered to previous acquisitions, and the sample segments extracted in digital format. Since in-situ ground truth was not to be used, training of the pattern recognition algorithms was performed by trained analyst interpreters who labeled a small amount (less than 1%) of each sample segment as either wheat or non-wheat.* This labeling was based on the appearance of wheat as observed over time on digital, film imagery of each segment and on graphical plots indicating the response in each of the spectral channels. Because the spectral appearance of the crop is a strong function of growth stage, models were implemented which estimated the growth stage of wheat based on local weather data. Analysts were also provided with ancillary information for each region which summarized seasonal weather and local cropping practices.

*In general, analysts were not able to reliably discriminate wheat from other small grains during LACIE. Therefore, labeling was generally performed for small grains and historically derived ratios were applied to small grains estimates to estimate wheat. A procedure for direct discrimination of spring wheat from other small grains based on subtle differences in crop stages and appearances was tested late in LACIE Phase III over North Dakota.

Yield was estimated using statistical regression models based upon recorded historical wheat yields and weather in each region. These regression models forecast yield for fairly broad geographic regions (yield strata) using calendar-monthly values of average air temperature and cumulative precipitation over the stratum. Meteorological data for input to these yield models (and, in addition, the growth stage models and weather summaries) in the U.S. Great Plains were obtained primarily from the surface observation stations of the National Weather Service, Federal Aviation Agency, and military services. In foreign areas, the data were collected by each country's weather service and were available via the global telecommunications network of the World Meteorological Organization. Over both the foreign and domestic areas, environmental satellite imagery was used to refine the precipitation analyses based upon cloud patterns. Yield models were developed in order to make estimates early in the season, throughout the growing season, and at harvest. For winter wheat in the northern hemisphere, these estimates began in December and were updated until harvest in June or July. Spring wheat yield estimates began as early as March and were revised monthly through August or September. This allowed assessments of potential yield to begin almost at the time the plant emerged from the ground.

RESULTS

Of all the LACIE results and accomplishments, perhaps the most important was the demonstration that LACIE technology can provide improved production information in important global regions and can respond in a timely manner to large weather-induced changes in production. The most graphic example of this capability occurred in the 1977 LACIE inventory of the Soviet wheat crop and will be described first.

Phase III Soviet Union Results

As shown in Figure 9, the Soviet's early estimates for their wheat crop was 110 million metric tons (MMT). The initial 1977

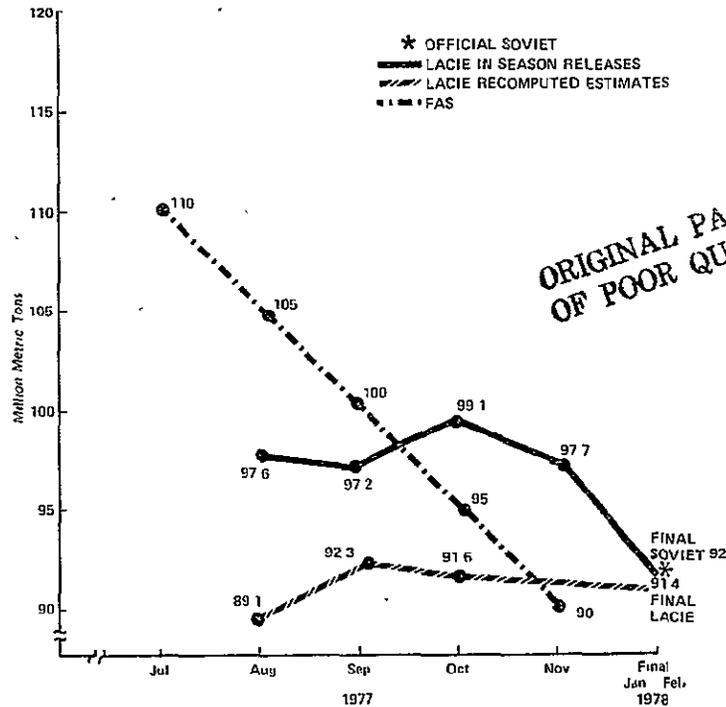


Figure 9. LACIE Phase III USSR total wheat production results compared to USDA/Foreign Agricultural Service (FAS) and official Soviet (USSR) reports.

LACIE forecast of total Soviet wheat production in August was 97.6 MMT, 20 percent below Soviet January expectations, 7 percent below FAS August projections, but only 6 percent above the final Soviet wheat figure of 92.0 MMT. The final LACIE estimate of 91.4 MMT differed from the Soviet final figure by about 1 percent.

In comparison to the accuracy and timeliness of Soviet information currently available without LACIE technology, these results represent an important advance in the problem of global commodity production forecasting. Without the reliable data sources and repeatable analysis techniques tested in LACIE, commodity production forecasts must rely heavily on statistics and reports released by the countries themselves. Disregarding questions as to the reliability of such information, perhaps the major problem is its timeliness. The Soviets release only a planning figure for Soviet production early in the year and a post-harvest estimate of total production in early November -- wheat statistics are not released until January or February following harvest. The wheat production forecasts released by the Foreign Agricultural Service (FAS) of the USDA, shown as the dashed line in Figure 9, are based to a large extent on Soviet reports and to a lesser extent on reports from foreign agriculture attaches. The LACIE-recomputed estimates in Figure 9 resulted from the simulation of an operational system which could produce wheat production estimates 30 days following Landsat data acquisition.

Figure 10 traces the contributions of winter and spring wheat production estimates to the totals in Figure 9. The May and June winter wheat forecasts were for a normal to above normal crop. The increase from May

to June was known, on the basis of LACIE forecast experience in the U.S., to be a result of a steadily increasing visibility to Landsat of the wheat crop as it completed its early spring development*. However, the continued increase in the July and August winter wheat forecasts were not justified as real increases, either on the basis of improving detectability or improving weather. Thus, LACIE analysts alerted to technical problems, initiated efforts to isolate the source of this apparent increase. The spring wheat estimates seemed to be unaffected by the problem and stabilized as expected following the August forecast. LACIE in-season forecasts were continued as usual

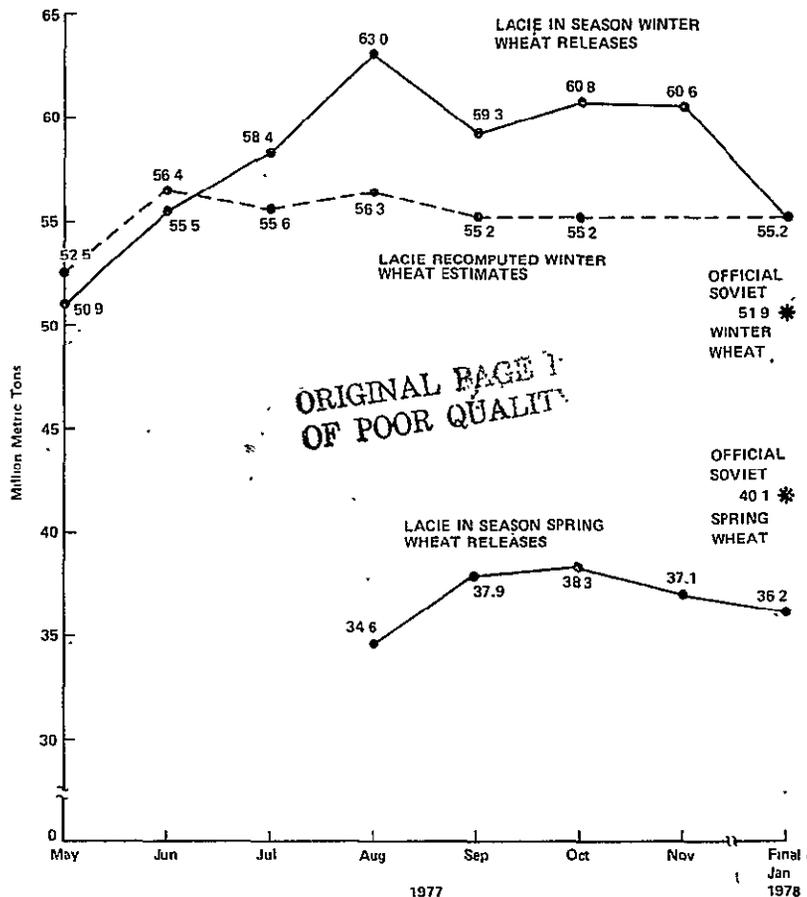


Figure 10. The contributions of LACIE Soviet winter and spring wheat production estimates to the LACIE total productions shown in Figure 9.

* Landsat data utilized in the LACIE in-season releases often lagged 45-60 days behind the release date because of processing backlogs.

through November with the problem in the winter wheat forecasts. By November the winter wheat problem was isolated to be the result of an incomplete Landsat data acquisition order from the Johnson Space Center to the Goddard Space Flight Center, which led to the loss of key early season Landsat acquisitions for about 20% of the Soviet winter wheat sample segments. In these segments, where only spring acquisitions were available, the Landsat analysts could not differentiate between winter wheat and spring grains, such as barley, which had already emerged to the point of detectability. Even though the LACIE forecasts with the implementation problems were already quite accurate, the curve in Figure 10 labeled "recomputed estimates" were generated in December of 1977 to simulate the performance of an operational system without the winter wheat data order problem. To generate the recomputed estimates, winter wheat areas for those segments affected by the incomplete data orders were computed utilizing the original area estimate as an estimate of the total small grains which was then reduced to a winter wheat figure using historic ratios of winter wheat to total small grains area. Additionally, the problem arising from the 45 to 60 days backlog was removed by utilizing Landsat data acquired up to 30 days prior to the reporting date. No such acquisition problems existed for the spring wheat forecasts and the in-season LACIE results indicated a severe shortfall in the Soviet spring wheat crop as early as August.

The clues to the potential production shortfall in the Soviet spring wheat region came early in the season when weather conditions started on an unfavorable note. The average air temperature for the two month period of May and June was up to 55% ($^{\circ}\text{C}$) above normal throughout the spring wheat growing area. This resulted in an unusually high demand for moisture. In Figure 11 it is evident that the abnormally high temperatures were widespread.

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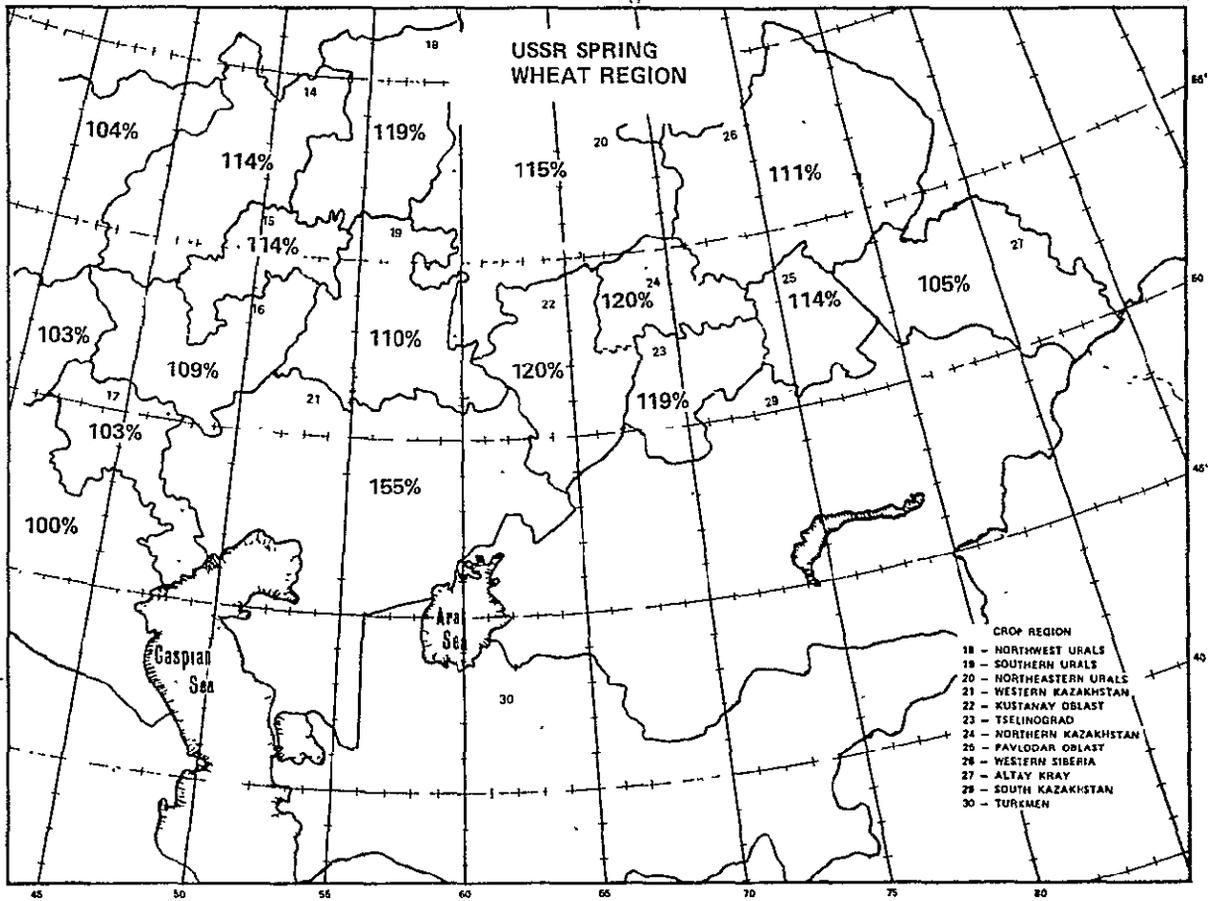


Figure 11. Percent of normal for May-June air temperature (monthly average °C) in Soviet Spring wheat regions. The figures are 1977 May and June average ÷ May-June long term average (expressed as percent).

During the same period of May-June, rainfall was below normal in many of the crop regions noted in Figure 12. The above normal demand for moisture combined with the below normal supply clearly indicated a serious problem was developing early in the season. Figure 13 highlights where the difference deviated most from the normal supply-demand relationship. The differences between precipitation and potential evapotranspiration are used in the LACIE yield models to represent relative soil moisture available to the crop and one would expect a significant detrimental effect in the eastern and southern crop regions. An investigation of the Landsat data and the yield model response at subregional levels indicated the drought conditions were clearly observable in the Landsat data and that the yield models accurately responded by reducing yield estimates in the

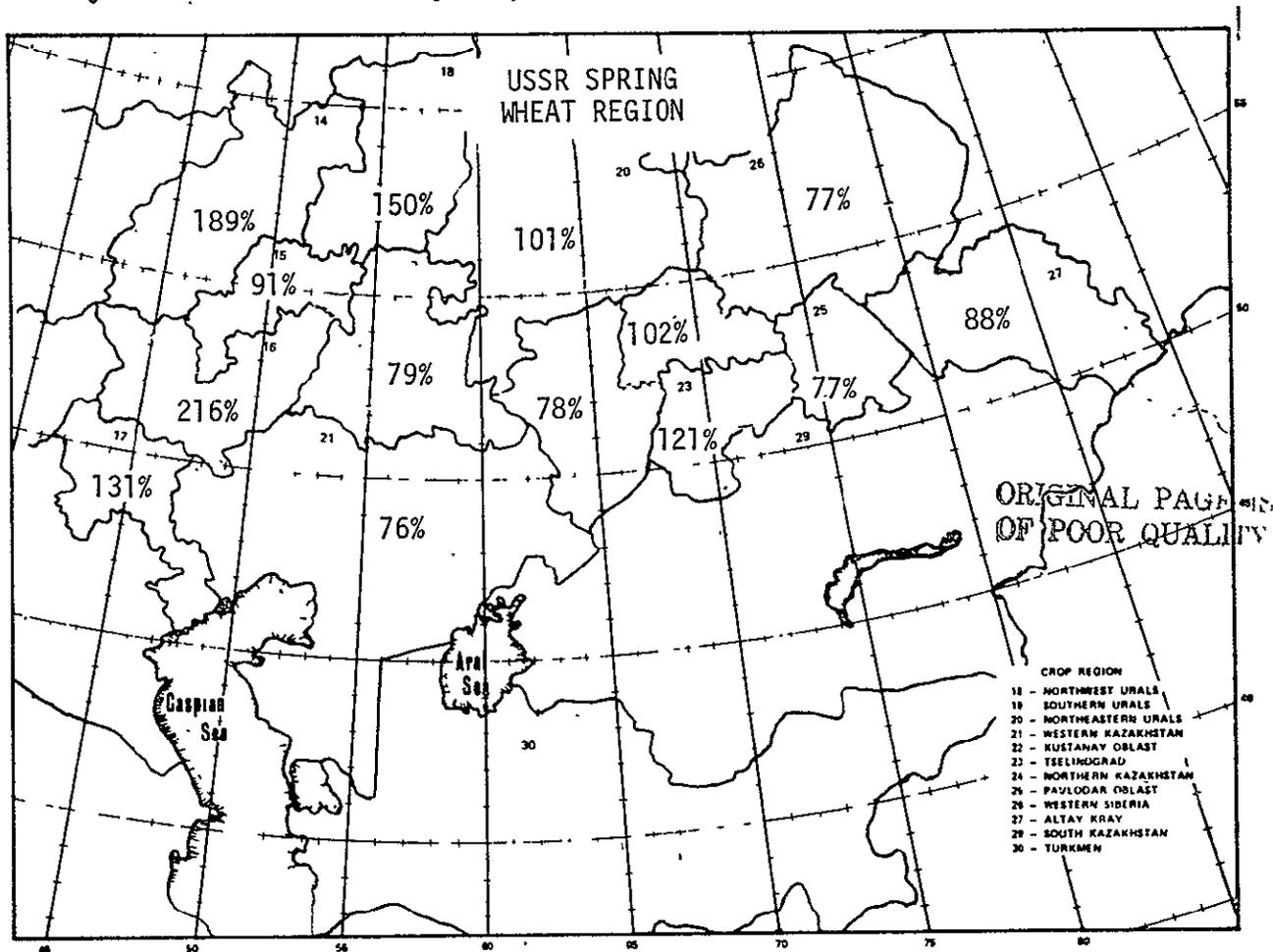


Figure 12. Percent of normal for May-June monthly precipitation (millimeters) in Soviet spring wheat regions.

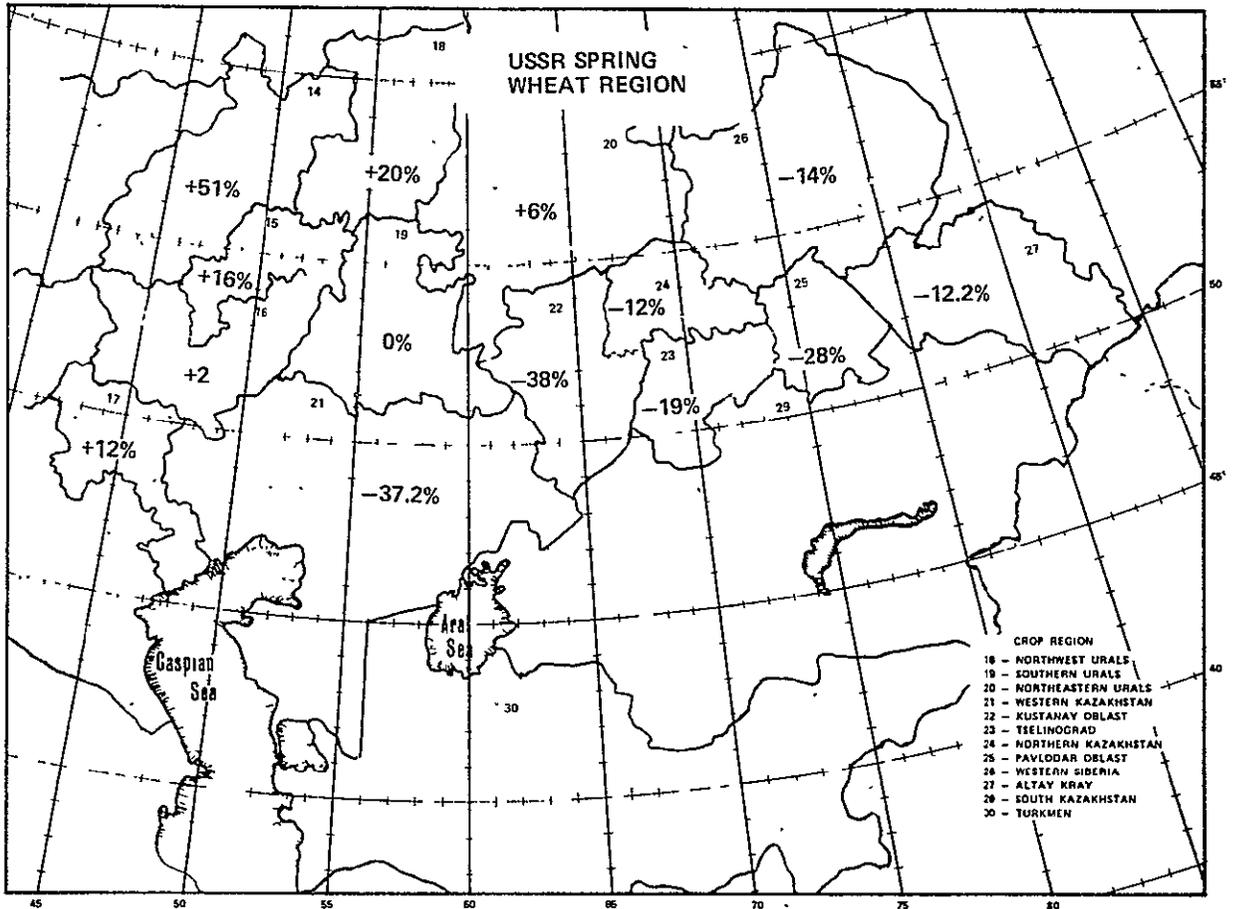


Figure 13. Percent deviations from normal May-June monthly precipitation minus Potential Evapotranspiration* (PET)(millimeters). PET computed by Thornthwaite method

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* Potential Evapotranspiration computed by the Thornthwaite Method.

affected regions. Note on Figure 14, the severe reductions in yield in the affected regions - in many cases, 50% below normal. LACIE yield models reduced the yield prospects nearly 2 quintals per hectare in response to the high April temperatures before the spring wheat growing season had commenced. The continuing drought reduced the yield nearly 2 more quintals per hectare below the 11.5 quintal per hectare normal. In Figure 15, it can be seen that these drought conditions were also quite evident in the Landsat data. In this figure, radiometric measurements from Landsat which are known to be related to crop canopy condition substantiated that the crop in the shaded areas was under severe drought conditions. Note, however, that in the northern regions the LACIE was forecasting above normal yields.

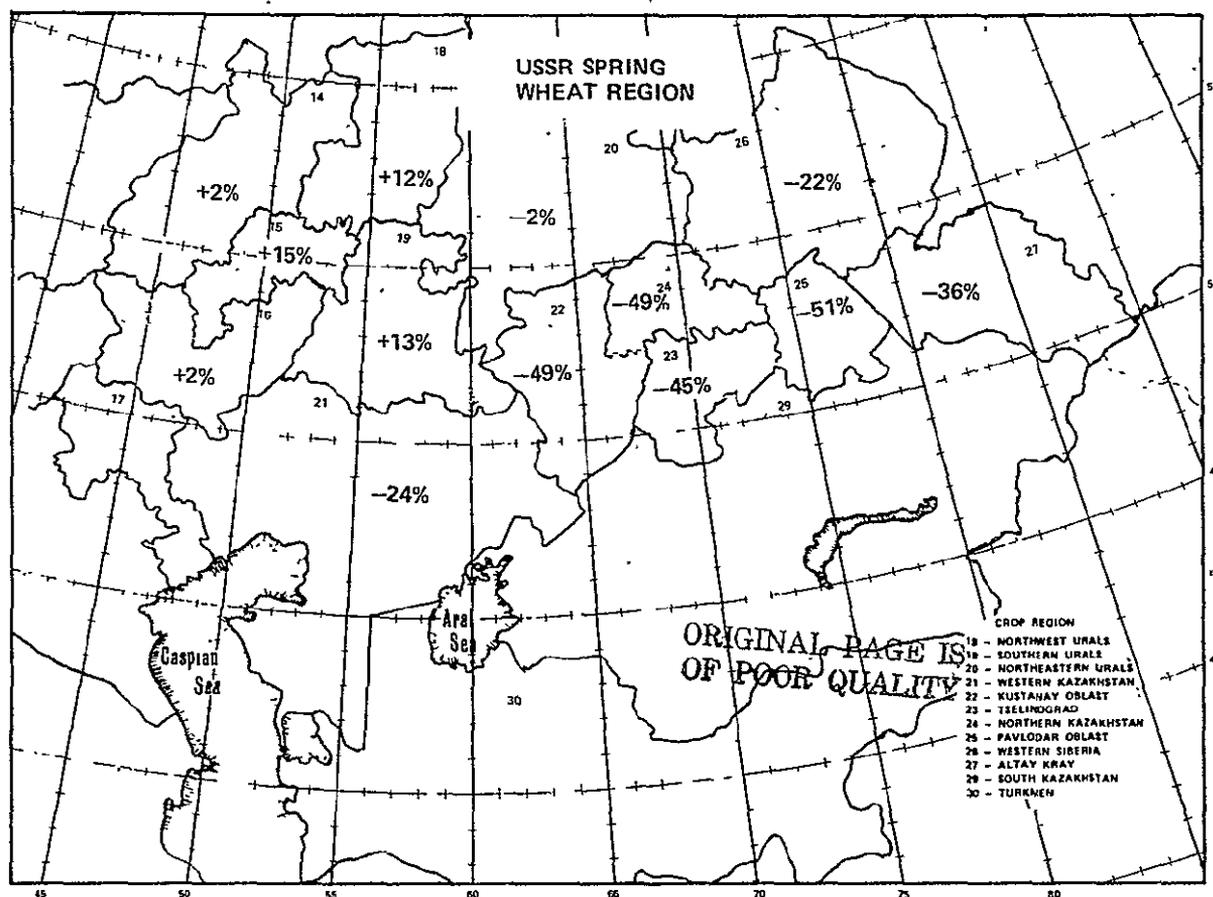


Figure 14. Percent deviations from trend yields (quintals per hectare) given normal May-June weather and adjusted for trend as forecast by the LACIE Soviet spring wheat models.

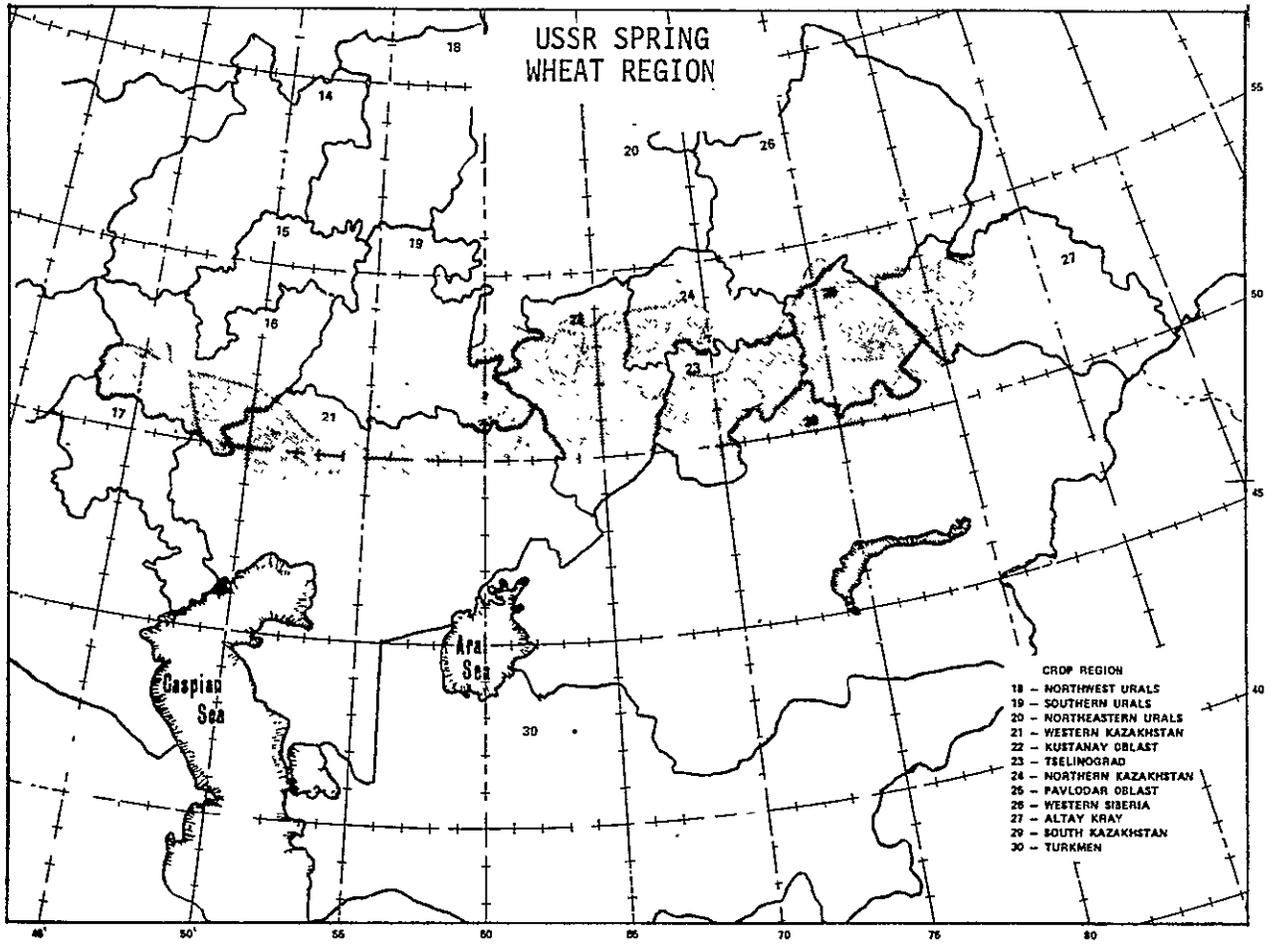


Figure 15. Shaded areas indicate stress vegetation mapped from Landsat radiometric measurements as of July 1977

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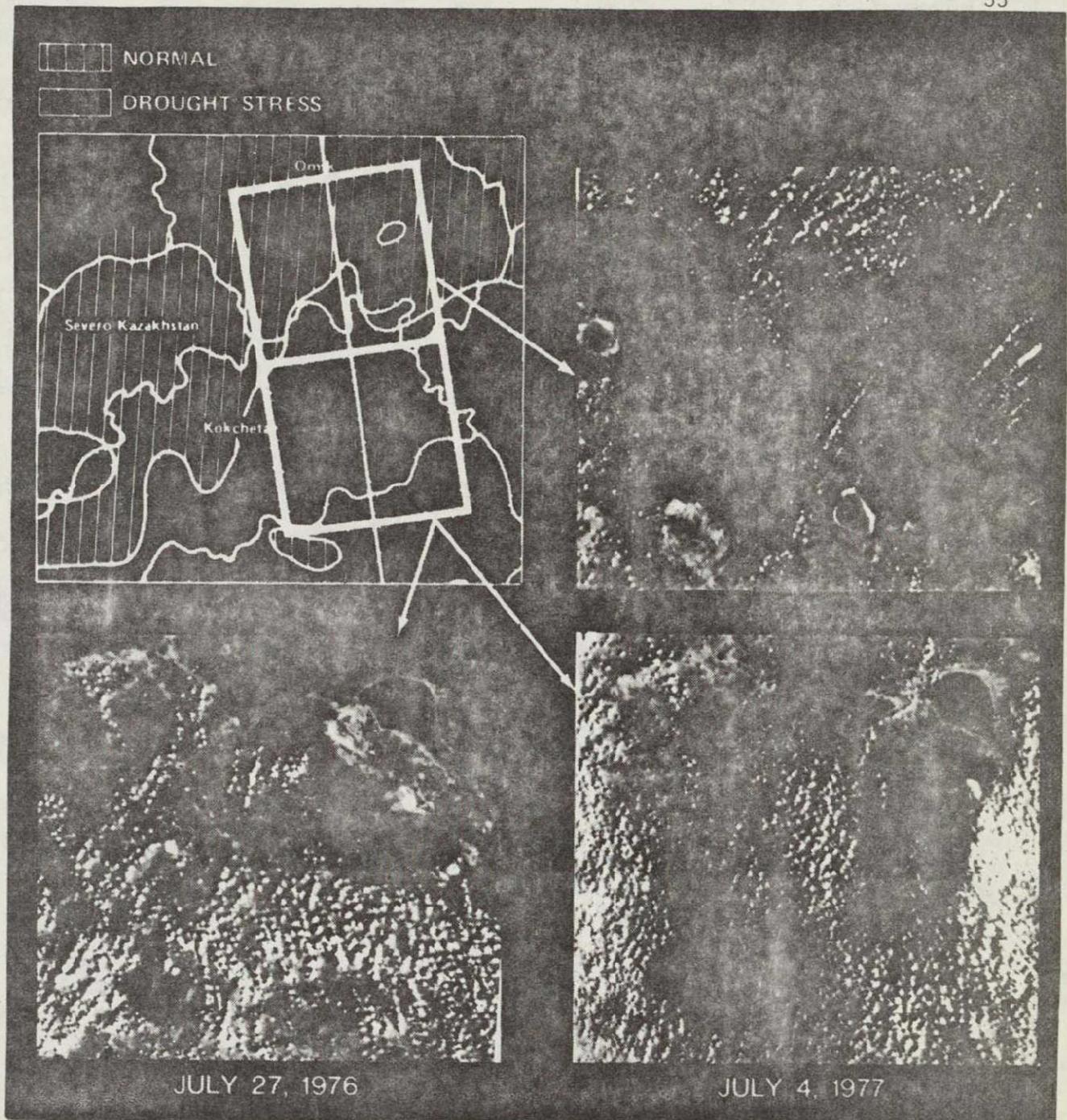


Figure 16. Drought conditions were evident in Landsat data.

Figure 16 illustrates the drought effects visible on Landsat imagery of the affected area. The two-segment images on the right, collected on July 4, 1977, were from a normal moisture area (Omsk Oblast at the

top) and from moisture stressed areas (Kokchetav Oblast, bottom). The effects of moisture stress are detectable by the lack of darkness (redness) in the image, an indicator of crop canopy condition. The image on the left collected the previous year for the Kokchetav segment, when compared to the 1977 image, shows a dramatic decrease in crop vigor in 1977.

To quantitatively assess the impact of reduced spring wheat yield, the total wheat area growing in each of these crop regions had to be estimated. The LACIE wheat area estimates for each region were multiplied by the forecasted yield per hectare to obtain production estimates for each region. When these individual production figures were summed, the overall estimate of spring wheat production was 36.3 million metric tons, a deviation of about 21% below normal.

The performance of the LACIE yield and acreage estimates has been empirically estimated by a fairly large number of "performance experiments." The LACIE, Landsat-derived, acreage estimates have been evaluated through comparisons with independent ground truth and USDA estimates for the U.S., and foreign country estimates and USDA estimates in Canada and the USSR. From such experiments, it is known where the technology tends to work and where it needs specific improvement. The LACIE yield models, whose performance is much more sensitive to weather than is the acreage technology, have been evaluated over the same regions described above, and in addition, over 10 years of historic data. While these years and regions are quite different from each other and represent a reasonable sample of potential conditions to be encountered in a global survey, empirical estimates of the various performance quantities can be viewed with increasing confidence with additional replications over a number of years. In discussions of the LACIE results which follow, statements are made that in some cases, the LACIE technology did support 90/90, and in some cases, it did not. These statements represent inferences

drawn from the performance experiments described above. A quite legitimate question is, how much confidence can be placed in these statements? LACIE has taken a standard, statistical approach to examining the experimental data. Using this approach, available experimental data have not contradicted the 90/90 hypothesis except for the cases noted. An examination of the experimental data does not contradict the 90/90 for U.S. winter and USSR total wheat. While a lack of contradiction of this hypothesis implies that the LACIE technology may be satisfying 90/90 in a region, increased confidence can only be gained through additional replications over a number of years.

Phase III U.S. Results

In addition to the Phase III Soviet performance, Phase III results in the U.S. further substantiated the conclusion that the technical modifications incorporated into the experiment during Phase II worked exceedingly well. Overall, the Phase III U.S. results (Figure 17) showed significant improvement over those of Phase II. The LACIE winter wheat estimates in the U.S. and USSR, as in Phase II, were indicative of 90/90 accuracies, as was the Soviet spring wheat estimate. Additionally, there was a significant Phase III improvement in the ability to estimate spring wheat area which reduced the difference between the LACIE and Economics, Statistics, and Cooperative Services (ESCS) estimates of wheat area to less than one percent in comparison to a Phase II difference of -13 percent. In contrast to the LACIE Phase I and II results, the LACIE Phase III estimates of yield were significantly under those of the ESCS and were not supportive of the 90/90 criterion. However, the yield estimates combined with the improved Phase III area estimates resulted in production estimates which differed from ESCS by less than 10 percent. Statistical tests indicated that the Phase III U.S. production estimates could be of 90/90 accuracy. Thus, the Phase III U.S. results were judged to be marginally indicative of 90/90

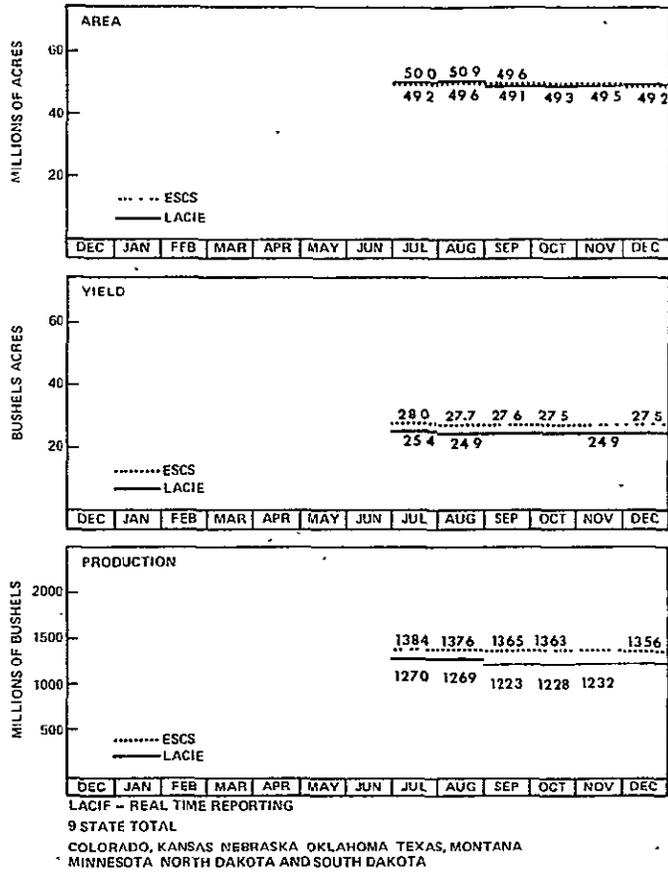


Figure 17. Phase III U.S. Nine-State Region Estimates

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performance. The Phase III area, yield, and production estimates for the U.S. nine-state region are shown in Figure 17. The yield estimates shown in Figure 17 are not the individual yield model results, but are derived for the total nine-state region by dividing total production by total acreage. Even though the final yield estimate was prepared in September, the derived value changed slightly as later Landsat data was used to refine area estimates.

More extensive evaluations of the U.S. yield models over a ten-year period indicated a performance consistent with 90/90 except for years with extreme agricultural or meteorological conditions. Table 1 lists the results of a test of the Phase III yield models with historic data for the years 1967 to 1976. The models were developed with data for the 45 years prior to each of the test years. A non-parametric statistical test employed to analyze this data did not reject the 90/90 hypothesis; however, had the models exceeded the tolerance bounds in at least one more year as it appears to have done in 1977, the 90/90 hypothesis could have been rejected. Additionally, the root mean square error (RMSE) of 1.9 bushels per acre is larger than desirable for a 90/90 estimator. It should be noted, however, that 1974 was a very dry year in the U.S. Great Plains, and wheat yields were very poor. The LACIE yield models failed to respond to this deviation and overestimated the yield by 4.6 bushels per acre. Without 1974, the RSME would drop from 1.9 bushels per acre to 1.3 bushels per acre, which is not significantly different than that required for a 90/90 estimator. Thus, it appears that the yield models may satisfy the 90/90 criterion in years without extreme departures in yield. As reported earlier, the LACIE yield models were responsive to the departure in the 1977 Soviet spring wheat crop which was not extreme, but of great economic importance to U.S. and other countries.

In Phase III, the LACIE wheat growth stage models were also evaluated. These models, which are of key importance to the analysis of the Landsat data, predict the growth stage of wheat given maximum and

<u>YEAR</u>	<u>SRS, BU/ACRE</u>	<u>LACIE ESTIMATE, BU/ACRE</u>	<u>ERROR</u>	<u>WITHIN TOLERANCE?</u>
1967	21.6	22.5	+0.9	1 YES
1968	26.0	24.6	-1.4	1 YES
1969	28.4	29.4	+1.0	1 YES
1970	28.2	26.6	-1.6	1 YES
1971	30.8	27.9	-2.9	0 NO
1972	29.3	29.1	-0.2	1 YES
1973	30.8	30.6	-0.2	1 YES
1974	23.8	28.4	+4.6	0 NO
1975	26.8	27.3	+0.5	1 YES
1976	26.4	27.1	+0.7	1 YES
1977*	27.5	24.9	-2.6	

MEAN ERROR = -0.1 BU/A

RMSE = 1.90 BU/A

* Phase III Results

Table 1. Results of an evaluation of the LACIE Phase III U.S. yield models on 10 years of independent test data.

minimum daily air temperatures. Generally, the Phase III evaluations of these models indicated model improvements are required, particularly the development of a planting date prediction model. Given accurate planting date data, however, the models seemed to perform adequately. Improved crop growth stage prediction models are also key to improved yield models.

Phase III testing of improved sampling strategies in the U.S. and USSR indicated that substantial cost savings can be realized through improved sampling efficiency. These improved strategies will permit accurate estimates with significantly reduced data loads.

The results in the strip fallow (small fields) areas of the hard red spring wheat regions of the U.S. showed significant improvement, but still exhibited a tendency to underestimate the area of spring small grains. Figure 18 displays the experimental estimates as compared to the ESCS estimates for the region. Figure 19 compares the LACIE estimates of wheat area percentages, at the segment level, with ground truth. These ground truth data were prepared independent of and after the Landsat Phase III proportion estimates were produced. This comparison for both Phases II and III provides an indication of the level of improvement in Phase III results obtained in the U.S.

The actual analyst contact time required to analyze a Landsat segment, manually select training fields, compute training statistics, and computer process the nearly 23,000 elements of a LACIE segment was reduced from 10 to 12 hours in Phase I, to 6 to 8 hours in Phase II, and to 2 to 4 hours in Phase III. It was also concluded that the LACIE experiment demonstrated that the timeliness goal of 14 days could be realized in a future operational system.

The dispersed nature of the LACIE data processing system has led to long "in-work" times (from 30 to 50 days) for segments of Landsat data due to many manual steps in the logistics and the fact that the experiment has been run, for the most part, on a one-shift, 5-day-a-week basis. The actual time during which a segment is undergoing active processing is, however, within the revised goal of 14 days from acquisition to availability for aggregation, distributed as follows:

- o Data acquisition, transmittal to GSFC, segment extraction and registration, quality screening and transmittal to JSC required 7 1/3 days.

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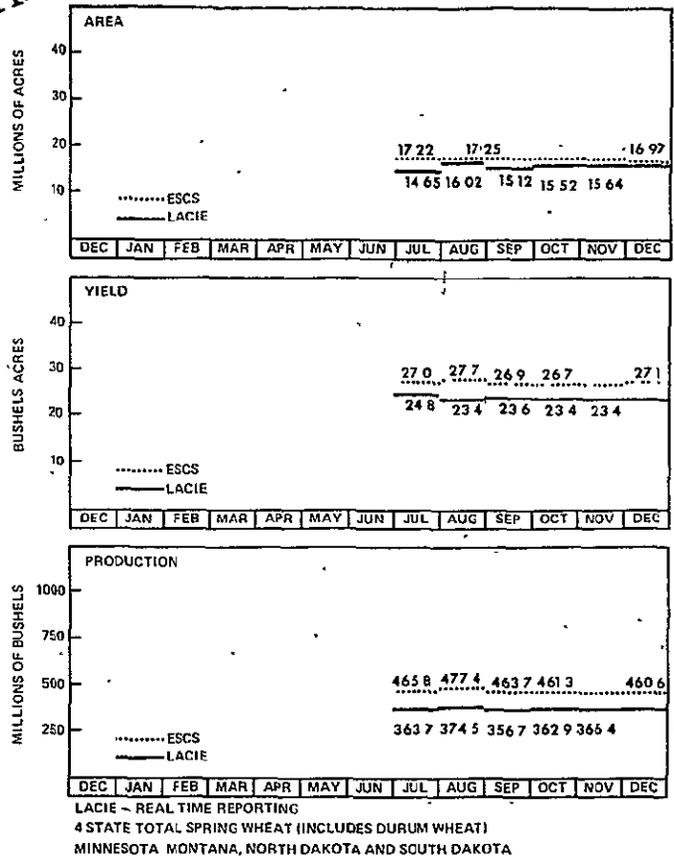


Figure 18. Phase III LACIE estimates for U.S. spring wheat.

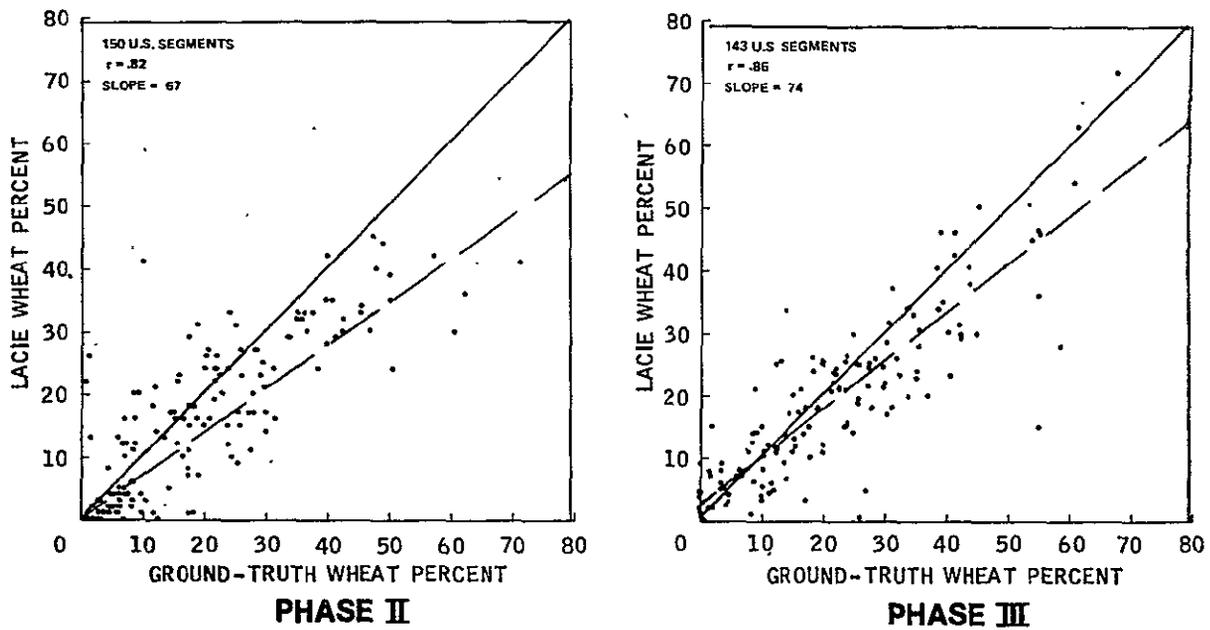


Figure 19. Comparison of LACIE segments estimates and ground observed estimates of wheat area proportions - U.S. yardstick test sites.

- o JSC LACIE data base update, segment film image production, analysis packet preparation, review and assignment to analyst required 2 1/3 days.

- o Study of analysis packet data, labeling, batch processing, analyst evaluation of results, quality check and release for production aggregation required 3 days.

LACIE has provided the experience which would allow design of a system utilizing LACIE technology to support a sample segment turn-around time of 14 days.

Considering that the actual analyst "contact time" is 2-4 hours per segment, that the computer processing time expended is around 5 to 8 minutes per segment, and that the LACIE data processing system is, as has been noted, an assembly of components originally designed for other purposes, a production system can almost certainly be engineered that would require a substantially shorter time than 14 days from data acquisition through segment analysis.

Phase II Results in U.S., USSR, and Canada

While the 1977 Phase III results are very encouraging, they are by no means the complete story. Results in the U.S., during the three years of LACIE, and in the Soviet Union in Phase II, also substantiate the Phase III Soviet results. Results for the U.S. and Canadian spring wheat have also defined crop regions for which the remote sensing technology needs improvement.

An evaluation of Phase II results indicated that the production estimation approach worked well for winter wheat in the U.S. and for both winter and spring wheat in the USSR. Difficulty was encountered in the U.S./Canadian spring wheat regions in reliably differentiating spring wheat from other spring small grains, primarily spring barley. An

additional complicating factor in these same regions was the strip fallow fields with widths very close to current Landsat resolution limits. Figure 20 shows typical field sizes in the northern U.S., the USSR, and China, illustrating how field size and shape are problems in some areas. On the left portion of Figure 20 is an aerial photograph and segment of the strip/fallow region of the U.S. Note the prevalence of very long and narrow fields - a result of moisture conserving strip/fallow practices. Similar practices are also common in Canadian spring wheat areas.

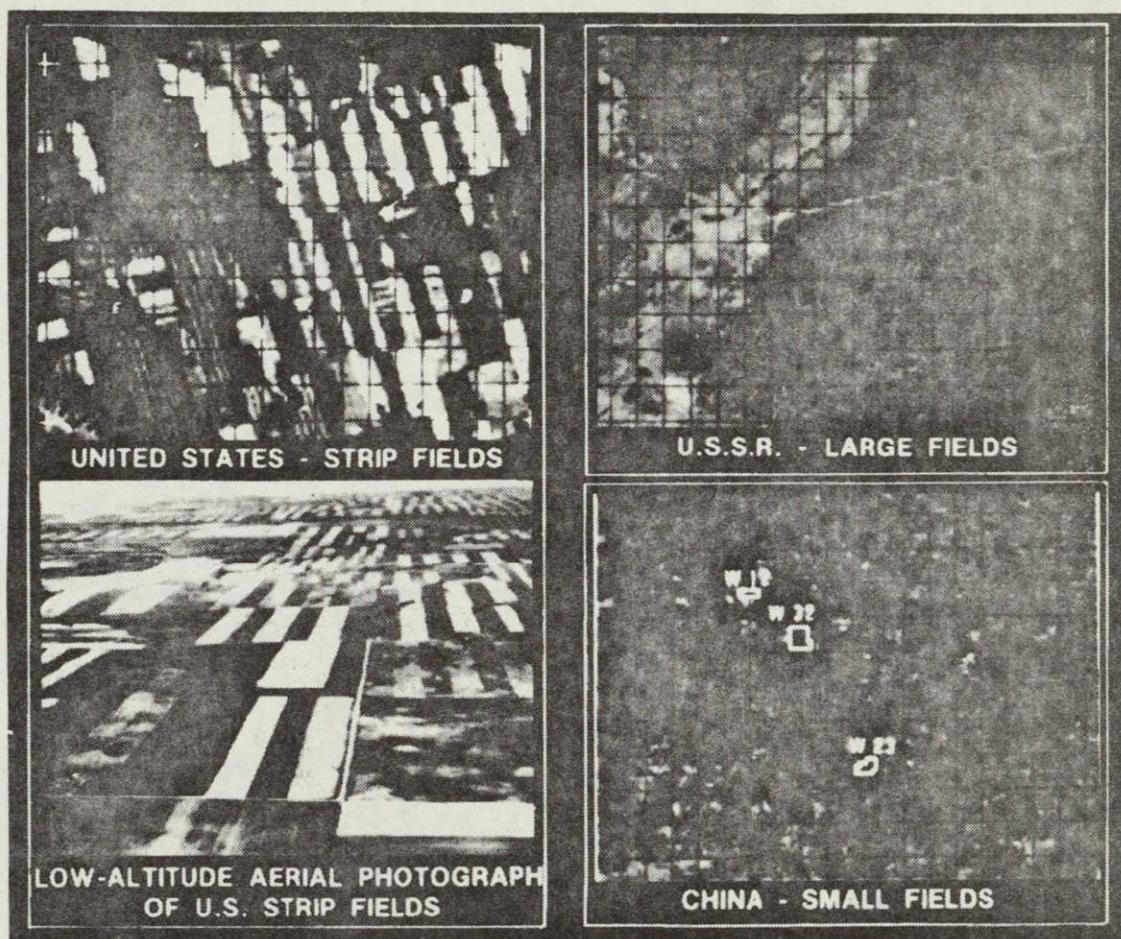


Figure 20. Landsat segment images in the U.S., USSR, and China illustrating strip fields, large fields and small fields.

These factors led to a significant Phase II underestimate of the U.S. and Canada spring wheat areas of 29 and 26 percent, respectively. In the USSR spring wheat regions, where field sizes are considerably larger and the ratios of spring wheat to spring small grains are more stable than in the U.S. and Canadian regions, the Phase II Soviet wheat area estimates were in reasonable agreement with "ball park" estimates based on official Soviet statistics. Available indications of 1977 implied that the LACIE at-harvest estimates of Soviet production did not differ significantly from the Soviet figures and other indications such as estimates of the coefficient of variation of the LACIE estimates also indicated the LACIE estimates were of 90/90 quality. Again, additional replications are required to verify the 90/90 hypothesis. The final at-harvest LACIE estimate was to within 1 percent of the Soviet figure. Most encouraging was the accuracy of the estimates made early in the growing season. In both the U.S. winter wheat and the USSR winter and spring wheat, the results indicated that similar accuracies were achieved with Landsat and weather data acquired one and one-half months prior to harvest.

Near the end of Phase II, it was decided that the evaluation in the U.S. yardstick region would be repeated and the region to be inventoried in the USSR would be expanded to include the region producing more than 90 percent of the USSR total wheat production. The decision to expand the region to be inventoried in the USSR was prompted by the lack of true production information for the Phase II USSR indicator regions and thus the unavailability of a reliable estimate of the bias of the LACIE estimates for the USSR. Also, the coverage in Canada would be reduced to 30 segments, where Canadian investigators could collect ground truth to be used in an intensified evaluation of the small fields and small grains confusion problems. As noted earlier, changes made prior to the 1976-1977

crop year (Phase III of LACIE) were thought to comprise significant improvements. These improvements included an improved stratification of the region and relocation of selected samples using past Landsat imagery and development of Landsat analysis procedures to differentiate spring wheat from spring barley. In order to extend the life of the on-board Landsat II tape recorder, a decision was made not to acquire data over the southern hemisphere regions and to concentrate Phase III investigations in the U.S., Canada, and the USSR.

Foreign Exploratory Investigations

Exploratory investigations in Argentina, Australia, Brazil, India, and Peoples Republic of China (PRC) conducted throughout LACIE provided initial insight into the technical issues associated with other countries. These investigations included yield model development, analysis of exploratory sample segments, and collection of Landsat, meteorological, and agronomic data. Aggregated estimates of area, yield, and production were not attempted.

o Australia

Landsat data collected over Australia indicates field sizes and multitemporal signatures similar to those of the U.S. Great Plains and the USSR. Yield models have been developed for five states in Australia. A test of these models on 10 years independent test data indicates they will support the 90/90 criterion. Crop growth stage prediction models have been implemented in Australia; however, difficulties have been encountered in using them because of varietal differences from the U.S. where these models were developed. Whereas the model used was designed for winter wheat with a dormancy period, the Australian wheat does not go into dormancy.

- o India

The average field in India is smaller than the current Landsat resolution element; however, fields tend to be adjacent and may be less of a problem than those associated with small strip fields in the U.S. and Canada. In India, yield models have been developed for 15 states and exploratory segments analyzed. Although not evaluated operationally, 2 of the models tested on independent historic data indicate they will support the 90/90 criterion. Crop growth stage models were evaluated in India and showed very poor results. Much of this can again be attributed to differences in U.S. and Indian wheat. Indian wheat does not go into dormancy and has a shorter growth cycle.

- o Argentina and Brazil

Analysis of the Landsat data indicates that Argentina field sizes in the older, more populated areas of Argentina are similar to those in Kansas, and in less populated frontier areas, are similar to those in the USSR. In both these countries, ancillary data is extremely limited and thus affects both interpretive analysis and yield models. Yield regression models have been developed for five provinces in Argentina and one state in Brazil; however, the quality of data for building these foreign models is lower than for equivalent U.S. areas. Tests of the Argentina and Brazilian yield models over 10 years of independent test data indicate that the models for these countries will not support the 90/90 criterion. In general, crop signatures were typical of those encountered in the U.S. Based on limited experience, Landsat acquisition over the Brazilian wheat growing regions indicate more frequent cloud cover than was experienced in the U.S.

- o China

China, like India, has extremely small fields in the more densely populated areas, but in the newly developed spring wheat region, field

sizes are comparable to those in the United States. Historical data have not been found upon which to develop the ancillary data equivalent to other countries. This deficiency could result in a lower confidence level in the results of China segment analysis than for the U.S., due to lack of adequate crop growth stage and confusion crop information.

Technological Achievements and Problems Requiring Further Attention

Within the LACIE, several significant technological achievements were realized, some of which resulted in significant improvements in area, yield, and production estimation. Others were evaluated in parallel to the main efforts in the experiment and represent potential future improvements. The major achievements are as follows:

- o Improved computer-aided Landsat data processing procedures.
- o Development of regression models for estimating wheat yield.
- o Development of growth stage models for wheat.
- o Improved sampling efficiency through stratification based on Landsat data.
- o Development of improved statistical methods for accuracy assessment.

LACIE has also crystallized and prioritized problems that continue to exist in the technology and shortcomings in an understanding of certain aspects of underlying phenomena. Problems in need of special attention in the future include the following:

- o Yield models based on daily, or weekly, rather than monthly averages of temperature and precipitation, that more closely simulate critical biological functions of the plant and their interactions with the external environment and thus have response characteristics with more fidelity to a wider range of conditions.

o Analysis techniques to more effectively deal with the spatial information in Landsat data and to improve area estimation accuracies in regions having a high percentage of fields with sizes near the resolution limit of Landsat. Additionally, the anticipated improvements in area estimation as a result of the increased resolution of Landsat-D must be investigated, as well as spatial resolution requirements for future Landsat satellites.

o The possible need for Landsat coverage at more frequent intervals than 18 days and the addition of spectral channels to more reliably identify vegetation stress and to more reliably differentiate crops of interest from confusion vegetation. Also, the additional spectral channels of Landsat-D must be evaluated along with definition of recommended spectral channels for future Landsat satellites.

o Crops in tropical regions with their distinctly different characteristics. Crop varieties tend to be significantly different as are the remote sensing conditions. India is a region that is representative of these types of conditions.

o The effects of cloud cover as it prevents the acquisition of usable Landsat data at critical periods in the crop season need to be better quantified, particularly in more humid environments, such as the U.S. cornbelt.

o The trade-offs between the need to shorten the time between data acquisition, analysis and reporting and the costs of obtaining such shortened response. While considerable improvements can be made, considerable costs may be required to obtain them.

o Effective transfer of technology to significantly complement capabilities of existing systems is deserving of further attention. This must be important to technology developers and users alike.

A decision was made by USDA early in 1976 to initiate an additional activity to develop a data analysis system to transfer and exploit the emerging LACIE technology for USDA use. This prototype was approved in January of 1976 to serve as the vehicle for the transfer of technology from applied research to an application test within USDA.

The initial goal of this activity was to develop the basic analytical capabilities, hardware and software to support the testing and evaluation for USDA use of the technology developed during LACIE. Toward the end of LACIE, the effort was realigned in response to changing Departmental priorities to concentrate on utilizing the capabilities of the technology for early warning and change detection, and to consider the potential for application to other crops. The current objectives are:

- o To have a USDA facility (equipment, personnel, procedures) capable of performance testing and evaluating remote sensing technology against USDA requirements.
- o To develop, test, and implement a data management system for agricultural analyses which include geographically-oriented data (soils, climate, agricultural statistics, etc.) of a scope necessary to support a test of early warning techniques and regional crop condition assessment capabilities.

The USDA-led effort within the LACIE involved the active participation by NASA and NOAA in providing assistance in the transfer of technology from LACIE to the USDA user system.

CONCLUSIONS

LACIE was an experiment designed to research, develop, apply, and evaluate a technology to monitor wheat production in important regions throughout the world. LACIE utilized quantitative multispectral data collected by Landsat in concert with current weather data and historical information. The experiment exploited high-speed digital computer processing of data and mathematical models to extract information in a timely and objective manner.

The results from the three crop years of focused experimentation strongly indicated that:

- o The current technology can successfully monitor wheat production in regions having similar characteristics to those of the USSR wheat areas and the U.S. hard red winter wheat area.

- o With additional applied research, significant improvements in capabilities to monitor wheat in these and other important production regions can be expected in the near future.

- o The remote sensing and weather effects modeling approach followed in LACIE may be applicable to other major crops and producing regions of the world.

The major conclusions pertain to how well LACIE met its objectives, goals, and planned scope. The following points synopsise the most important findings:

- o The LACIE results in the second year of the experiment for the U.S. hard red winter wheat region were indicative of 90/90 accuracies in this region as early as 1-1/2 months preharvest. Experiment results in the U.S. and Canadian spring wheat regions indicated that technology improvements were needed to estimate acreage in regions where typical field sizes were close to the Landsat resolution limits. Additionally,

the need to improve the reliability of discriminating between spring wheat and its look-alike, spring barley, were demonstrated. The LACIE forecast accuracies for the Soviet indicator regions in 1976 indicated that accuracies achieved one month prior to harvest and at harvest for both winter and spring wheat were supportive of the 90/90 criterion. The precision of the LACIE forecasts were adequate to support the 90/90 criterion and the at-harvest LACIE estimate was to within one percent of the Soviet estimate.

o In the third year, U.S. results were significantly improved as a result of improvements in acreage estimation technology for the small fields regions. U.S. Great Plains production forecasts were to within 10 percent of the ESCS. Indications were that 90/90 estimates may be achieved for years in which crop conditions are not extreme in comparison to years on which the yield models were developed. The USSR results indicated a spring wheat shortfall in August 1977 well before an announcement of total grain shortfall was made by the USSR in November 1977 and before definitive information was released in February 1978. Additionally, LACIE met or exceeded its performance goal in the USSR winter wheat area in 1977.

o Exploratory investigations conducted in Australia, Argentina, Brazil, India, and the People's Republic of China provided valuable insight as to the similarities and differences between those regions and the areas studied in Canada, the U.S., and the USSR.

o Yield forecasting techniques as well as models estimating crop phenological stage were developed, exercised, and evaluated over the U.S., U.S.S.R., Canada, and five other foreign exploratory regions.

- o Yield models responded to important weather-induced deviations such as those observed in U.S.S.R. in the 1976-77 crop year. However, tests over ten years of historic data show that the models should be improved to respond completely to yield fluctuations in years with extreme deviations in weather.

- o Crop forecasts were produced periodically according to a pre-established schedule and prior (day before) to the release of official estimates from other sources. These were important in identifying the accuracy of early-season forecasts using this technology.

- o The LACIE was able to provide data processing and delivery techniques so that selected samples could be made available to analyst teams for initiation of analysis no later than 14 days after the acquisition of the data. In fact, during the experiment the goal was adjusted to learn how to acquire and complete analysis all within a 14-day period to facilitate still more timely reporting. Analysis indicates that the time between acquisition and completion of Landsat data analysis could be equal to or less than the 14-day goal in a future state-of-the-art system. The LACIE system design was not an optimum state-of-the-art system but rather was assembled for the most part from components already existing within the agencies. However, the design philosophy followed was one that permits the technology to be incorporated into a future state-of-the-art system without significant problems.

Several significant lessons were learned about the planning, management, and implementation of crop monitoring technology development programs:

- o Research, development, and evaluation requires several years of testing with large data sets over extensive geographic regions to verify technological issues due to the wide range of variability of the contributory factors.

- o A comprehensive accuracy assessment effort is vital. Considerable ground truth data from domestic "yardstick" or test regions is essential to the understanding of the accomplishment as well as to identify and correct deficiencies in the technology. Such an accuracy assessment program was conducted as a part of LACIE to evaluate the technology as a whole as well as its component parts in the 9-state "yardstick region" of the U.S.

- o A research and development program involving diverse scientific disciplines focused on technical issues that arise from a project similar to LACIE stimulate a more applied research activity and provide an improved and common understanding in the supporting research and industrial community.

- o The periodic use of a Peer Review in which critical issues on methodology and results are subjected to the scrutiny of reviewers largely from university, government, and industry, both scientists and managers, provided essential feedback.

- o Much was learned about the capabilities of the Landsat together with other data sources to estimate wheat production. The need for higher spatial resolution, additional spectral bands and increased temporal coverage to observe smaller fields and to separate wheat from certain confusion crops were identified. Landsat-D will provide a data source to support solution of technical problems related to these needs.

OUTLOOK

As a result of: (1) the continued interest of the USDA in exploiting this technology to provide improved world crop production information; (2) the success that has been achieved thus far with wheat, and (3) the understanding of technical issues identified in LACIE as requiring further investigation, the Secretary of Agriculture announced the need for a new initiative. The Secretary's Initiative is for a joint multi-agency program to develop improved uses of aerospace technology for agricultural purposes. The focus for the program is provided by the following broad information requirements in priority order:

- (1) Early warning of changes affecting production and quality of renewable resources.
- (2) Commodity production forecasts.
- (3) Land use classification and measurement.
- (4) Renewable resources inventory and assessment.
- (5) Land productivity estimates.
- (6) Conservation practices assessment.
- (7) Pollution detection and impact evaluation.

While all seven requirements are of major importance to the U.S. Department of Agriculture, the first two requirements essentially capture the Department's most urgent need for better, more timely, objective information on world crop conditions and expected production. The agencies that participated in LACIE are planning a follow-on activity for the early 1980's that will build on the LACIE experience and address the broader needs of the USDA.

EXECUTIVE SUMMARY

BIBLIOGRAPHY

Document of Plenary Papers, LACIE Symposium, Houston, TX, October 1978

Proceedings of the LACIE Symposium, Houston, TX, October 1978

Memorandum of Understanding Among the U.S. Department of Agriculture, The National Aeronautics and Space Administration and the National Oceanic and Atmospheric Administration for the Experimental Large Scale Crop Inventory Demonstration, LACIE files, Washington, DC, October 10, 1974

LACIE Project Plan - Baseline Document, (LACIE-C00605, JSC-09857), Houston, TX, August 1975

LACIE Management Plan - Baseline Document, (LACIE C00617, JSC-11334), Houston, TX, September 1976

LACIE Phase I Evaluation Report, (LACIE-00418, JSC-11663), Houston, TX, May 1976

LACIE Phase II Evaluation Report, (LACIE-00453, JSC-11694), Houston, TX, July 1977

Proceedings of the 1974 Lyndon B. Johnson Space Center Wheat-Yield Conference (LACIE-T00407), Houston, TX, April 1975

R. B. MacDonald, F. G. Hall, and R. B. Erb, in Proceedings of Second Symposium on Machine Processing of Remotely Sensed Data (pp 1B-1--1B-23), C. D. McGillem, Ed., Institute of Electrical and Electronics Engineers, Inc., New York, 1975

R. B. MacDonald, F. G. Hall, and R. B. Erb, in Proceedings of 10th International Symposium on Remote Sensing of Environment (Vol. 1, pp 17-37) Environmental Research Institute of Michigan, Ann Arbor, MI 1975

R. B. MacDonald, F. G. Hall, and R. B. Erb, LACIE: A Proof of Concept Experiment in Global Crop Monitoring, Midcon/77 Electronic Show and Convention, Chicago, IL 1977

R. B. MacDonald, F. G. Hall and R. B. Erb, LACIE: An Assessment After One Year of Operation, ERIM Symposium, Ann Arbor, MI 1976.

World Food and Nutrition Study: The Potential Contributions of Research Steering Committee NRD Study on World Food and Nutrition of the Commission on International Relations, National Research Council National Academy of Sciences, Washington, DC 1977