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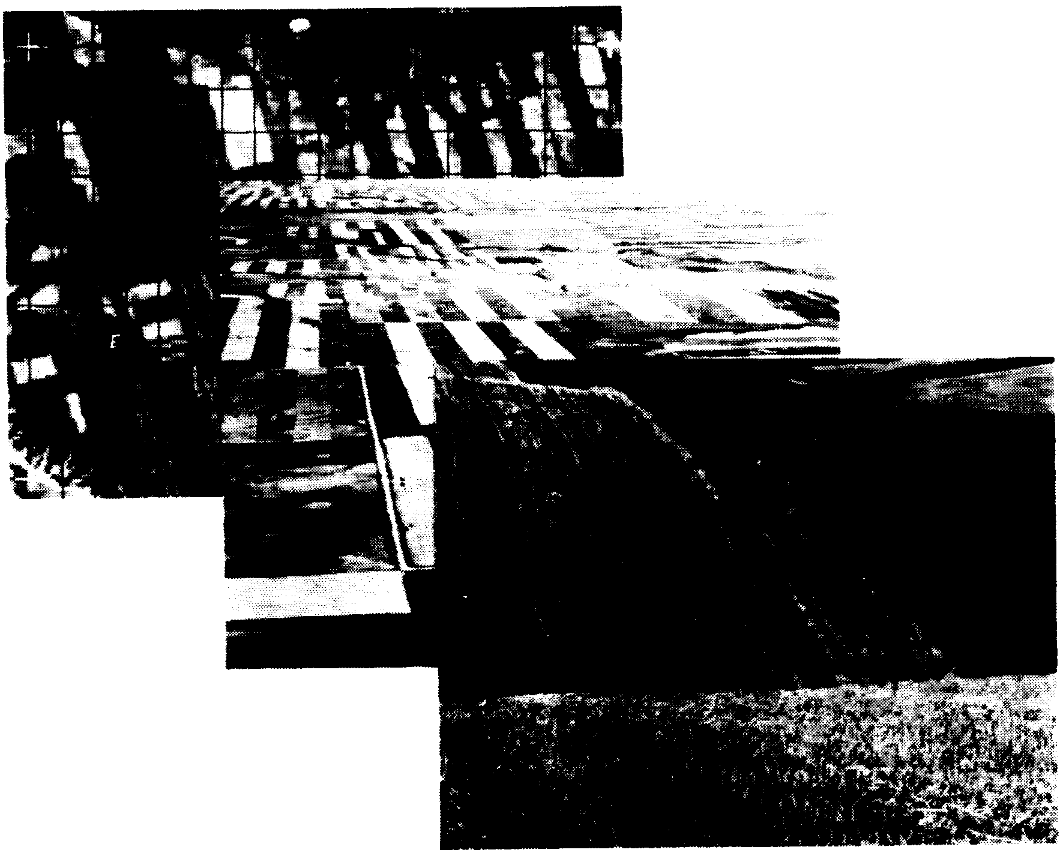
LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)

NASA NOAA USDA

# FINAL TECHNICAL EVALUATION SUMMARY REPORT




NASA
National Aeronautics and Space Administration
Lyndon B. Johnson Space Center


October 1, 1978

LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)

FINAL TECHNICAL EVALUATION SUMMARY REPORT

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NASA, USDA, NOAA

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Large Area Crop Inventory Experiment

# PREFACE

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

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## SUMMARY

The Large Area Crop Inventory Experiment (LACIE) was conducted over three crop seasons from 1974 through 1977 by the U.S. Department of Agriculture (USDA), the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and supporting industries and research institutions. The experiment was officially concluded in June 1978; the analysis and interpretation results and the final documentation are now in the final stages of completion. These results indicate the experiment met its primary objectives:

- Demonstrate an economically important application of repetitive multispectral remote sensing from space.
- Test the capability of the Landsat, together with climatological, meteorological, and conventional data sources, to estimate the production of wheat — an important world crop.
- Validate the technology and procedures for its use, which could provide improved agricultural information on a global basis.

Three years of intensive evaluation of the remote sensing technology in the U.S. and 2 years of Soviet wheat forecast experience indicate that, in important foreign wheat regions, the achievable forecast accuracies would support and possibly exceed USDA foreign production forecast performance goals. The USDA "90/90" accuracy goal at harvest of being within ±10 percent of the true production with a confidence level of 90 percent was supported and possibly exceeded by the LACIE Soviet forecast accuracies in both years of experimentation. In 1977, the LACIE winter and spring wheat forecasts released 2 months prior to the completion of harvesting accurately forecast a bumper winter wheat crop and a significant shortfall in the spring wheat crop. The LACIE August forecast for total wheat was within 6 percent of the final Soviet figure released 6 months later. The LACIE final estimate, which used data acquired through harvest, agreed with the Soviet figure to within 1 percent. The statistical precision of those forecasts was much better than required, thus achieving the repeatability necessary to support the "90/90" criterion. These results, which are further corroborated by more intensive U.S. testing, demonstrate the capability to make accurate preharvest and at-harvest forecasts under similar future circumstances. In view of the conventional forecast system's significant underestimates of the Soviet wheat crop in 1976 and the significant overestimates in 1977, it is clear that LACIE technology can make an immediate contribution to the accuracy and timeliness of existing commodity forecast information.

Experimentors began to assemble a research and development system in 1974 from the available technology base developed through research conducted over the prior decade. Emphasis was placed on utilizing automated information extraction techniques wherever possible in order to pursue the goals of producing timely information over large areas in a way that would prove cost effective for future operational systems.

This experimental system was then applied to the task of estimating wheat production in important wheat-producing areas of the world. Many modifications were made to the system. The procedures for its use, as well as the accuracy and efficiency, were steadily improved during the course of the experiment.

The basic technical approach of LACIE was to develop wheat production estimates by combining independent area and yield estimates. A production region was compartmented into agriculturally homogeneous subregions by using Landsat and historic data to define the uniform "strata." The area in wheat was then estimated from Landsat data acquired over statistically selected sample sites. Yields were forecast using models which relied on weather samples 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 well in estimating wheat production in important geographic regions, but tests of the technology in Canada proved to be more negative. However, the reasons for this were studied in considerable detail and are fairly well understood. A major factor was the inability of the current satellite sensor with its 80-meter resolution to distinguish agricultural fields that typically had dimensions of that size or smaller. Additionally, barley, a major confusion crop, was so similar to wheat that it could not be reliably differentiated. More recent research on this problem in the U.S. Great Plains (USGP) indicates that this latter problem can be overcome. Exploratory investigations in other wheat regions of the world were conducted, and the current acreage estimation technology is believed applicable to Australia, Argentina, and Brazil; because of small fields, improvement is required for China and India. Yield model tests in these countries indicate that models less dependent on historic data may be required for China, Argentina, and Brazil.

Major technological improvements were achieved in the application of satellite and weather data during the duration of the experiment. These included improvements in the field of global sampling utilizing Landsat data; a production estimation technology utilizing area and yield components; a crop area estimation technology that is *not dependent on the use of ground data;* and a crop yield estimation technology that is implementable on a global basis. While both the technology and understanding of the critical problems were significantly advanced through the experiment, in the opinion of the investigators, they are in an embryonic stage and could be greatly advanced with continued effort. Refinements to the Landsat data analysis techniques can further improve wheat identification accuracies. Yield models may be improved by utilizing Landsat data to estimate crop appearance together with weather measurements to better define a crop's response to growing conditions. Models which estimate a crop's stage of development may similarly be improved to provide important data to assist in making a more reliable separation of wheat from confusion crops, such as barley, as well as to support improved early warning and yield forecasts.

The USDA initiated an effort early in 1976 to develop a data analysis system to serve as a vehicle for the transfer of technology from applied research to an application within the USDA. The USDA system was put in initial operation with USDA personnel during 1978.

An evaluation of the LACIE experience leads to a conclusion that LACIE has proved to be a response to an identified national and world need. It built on more than a decade of prior research and development to assemble a first-generation technology into an experimental system that was in turn rigorously tested on a large scale to monitor the world's most important crop in major producing regions of interest. It stimulated related research and development very importantly, identified key problems requiring further attention in the future, and generally provided a basis for a comprehensive research and development 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.

# INTRODUCTION

The LACIE has been a joint venture of the USDA, NOAA of the Department of Commerce, and NASA.

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 field 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

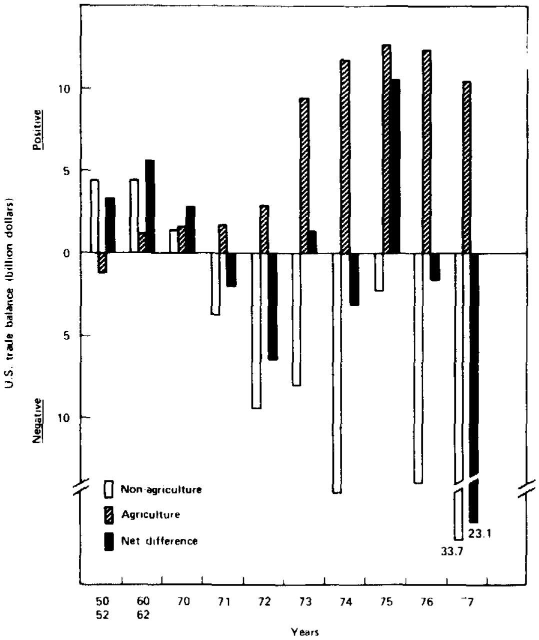
Mankind is becoming increasingly aware of the need to better manage the utilization of the Earth's resources — its atmosphere, vegetation, oceans, fresh water, soils, minerals, and petroleum supplies. As the world's population increases and a higher standard of living is sought for all, more careful 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 semiarid regions with marginal weather; thus, its production is subject to extreme variations. The world's wheat supply has fluctuated from the oversupplies of the 1950's and 1960'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 of wheat production in particular, is illustrated in figure 2.

Exporting and importing countries must maintain a delicate balance between supply and demand, anticipating the determining factors as far in



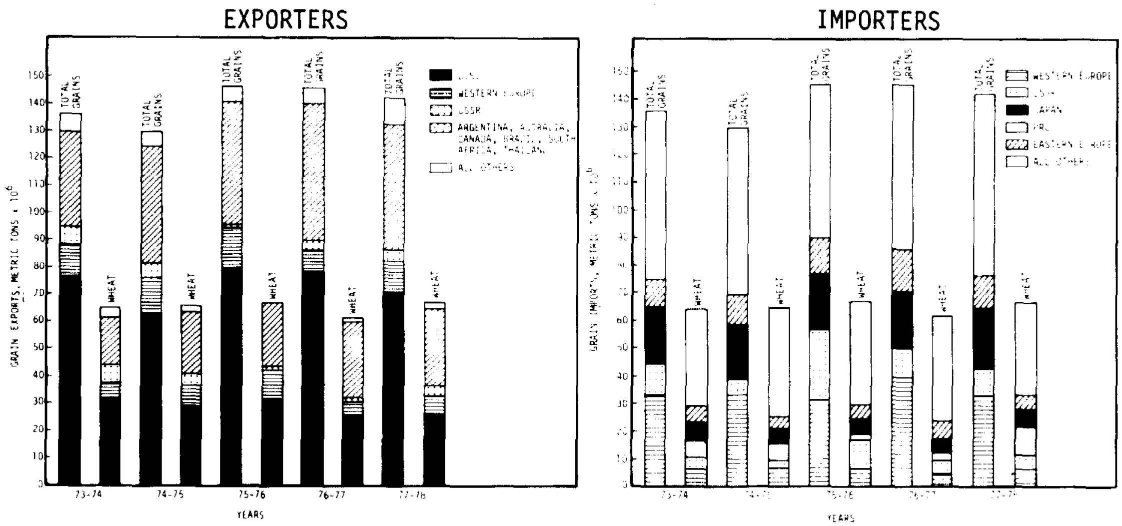

Source: Economic Research Service and Council on International Economic Policy

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

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 percent of the wheat trade in terms of tonnage. 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 decisionmakers, in both public and private sectors, for improved information. A key ingredient is the best possible estimates of national and global production.

## 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 the World Food and Nutrition Study by the National




Source: Foreign Agricultural Service, USDA

Figure 2.— Net exports and imports of grain and wheat for major countries.

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 U.S.S.R., two major wheat-producing nations. (The U.S.S.R. 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 U.S.S.R. both area and production have similarly varied.

To forecast production accurately with remote sensing technology, it is critical to associate the correct weather with the actual area

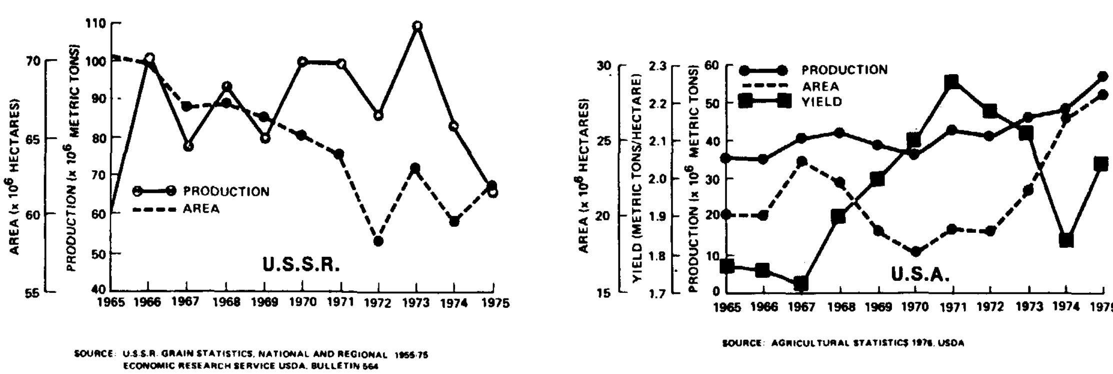



Figure 3.— Wheat variability — U.S.S.R. and U.S.

being affected. Where the effects are so severe as to remove area from production, this abandoned area must be correctly measured. Therefore, an effective agricultural information system must not only 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 USDA and the NASA, 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 in recent decades of high-speed computers and worldwide weather data allowed more extensive statistical analysis of the 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

*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.

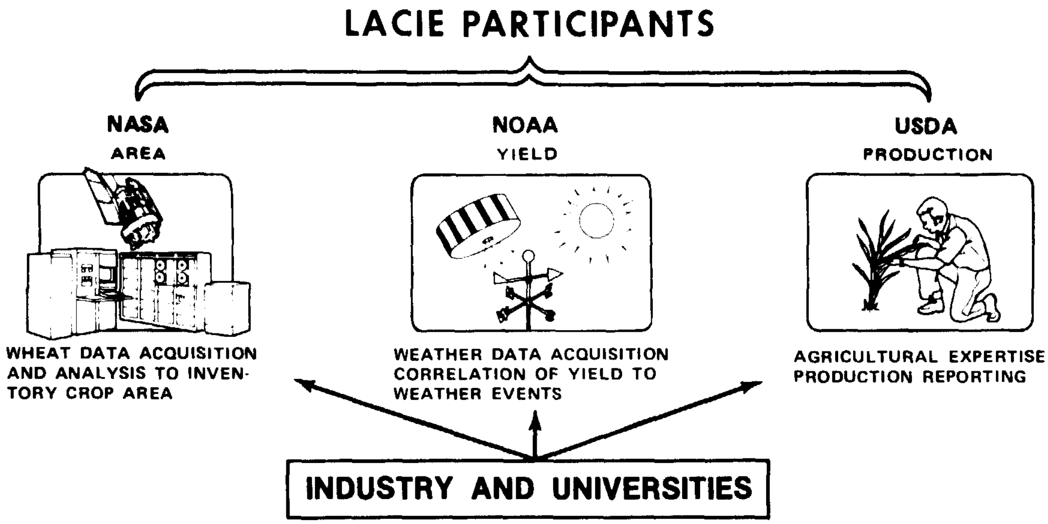
technology to support agricultural production monitoring. LACIE was a logical next step in the chain of research and development. This technology base consisted of earth observation satellites, environmental satellites, communications links, high-speed computer processing equipment, mathematical models, 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 ensuring 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 ensure 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.




[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.]

Figure 4.— Roles of LACIE participants.

## 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, through contracts from the agencies, key industries were vital to the implementation and operation of the experiment.

# EXPERIMENTAL OBJECTIVES, SCOPE, AND TECHNICAL APPROACH

## EXPERIMENTAL OBJECTIVES

The LACIE objectives as set forth in the Project Plan (ref. 1) prepared in March 1975 and officially approved in August 1975 include the following:

- To demonstrate an economically important application of repetitive multispectral remote sensing from space.
- To test the capability of the Landsat, together with climatological, meteorological, and conventional data sources, to estimate the production of an important world crop.
- Commencing in 1975, to validate technology which could provide timely estimates of crop production.
- To provide estimates of the area planted to wheat from an analysis of Landsat data acquired over a sample of the potential crop-producing area in major wheat-growing regions; similarly, from an analysis of historical and real-time meteorological data over the same regions, to provide estimates of wheat yield and combine these area and yield factors to estimate production.
- 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.
- To provide a LACIE system design that will permit a minimum of redesign and conversion to implement an operational system within the USDA.
- 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 include:

- Periodic crop assessment during the growing season from planting through harvest.
- Accuracy commensurate with USDA requirements.
- Supporting research and development program to improve methodology and performance.
- Objective test and evaluation program to quantify results from research and development.

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 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, People's 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 U.S.S.R.

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 USGP was generated.

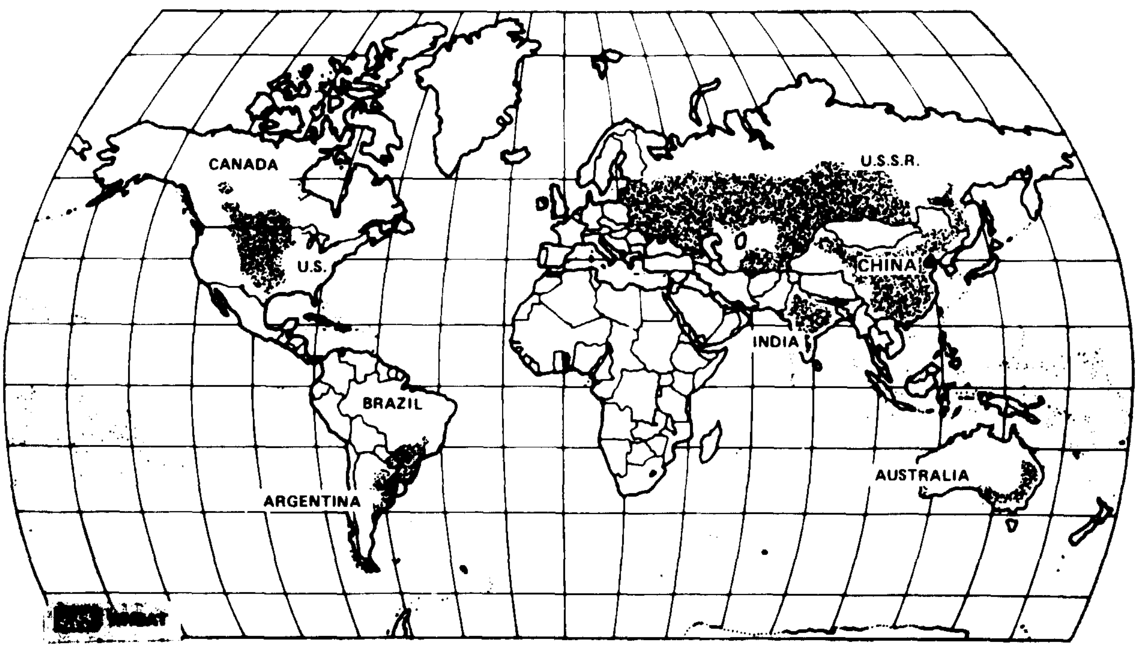



Figure 5.— Major wheat-producing regions considered in LACIE.

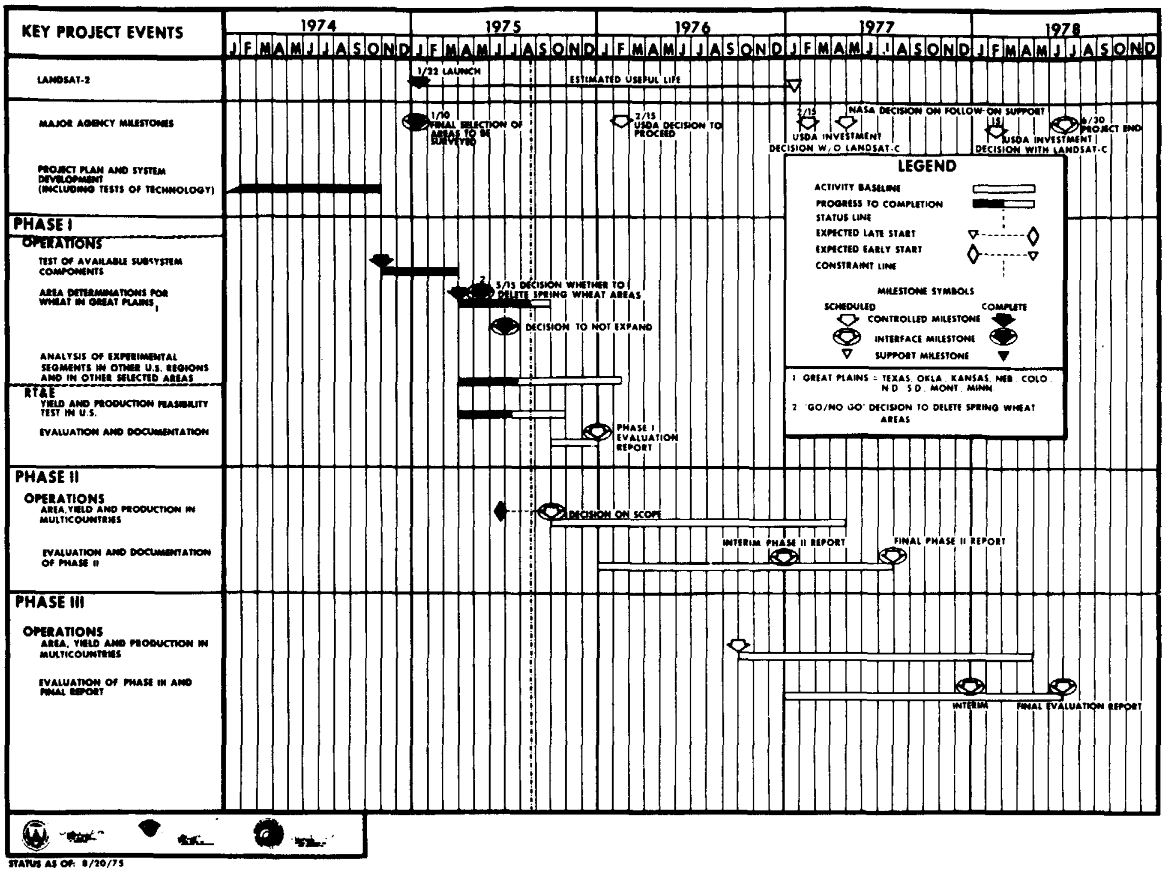


Figure 6.— Original LACIE schedule.

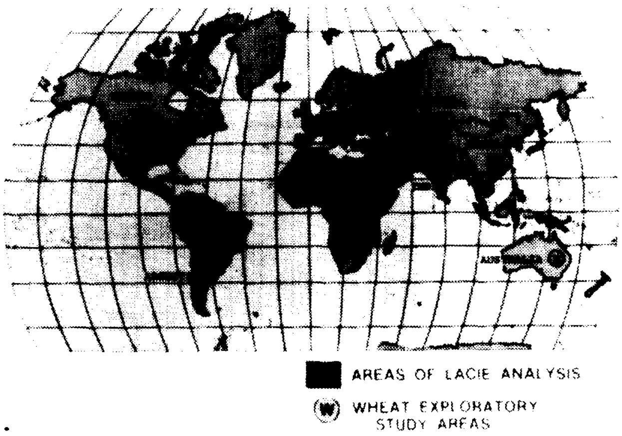
In addition, at the end of Phase I, key USDA management decisions resulted in the incorporation of a USDA-User System within the USDA-LACIE effort.

In Phase II, global crop year 1975-76, the technology, as modified during Phase I, was evaluated for monitoring wheat production for the USGP and Canada, and "indicator regions" in the U.S.S.R. 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 USGP and the U.S.S.R. Monthly reports of area, yield, and production estimates of wheat for these major producing regions were generated.

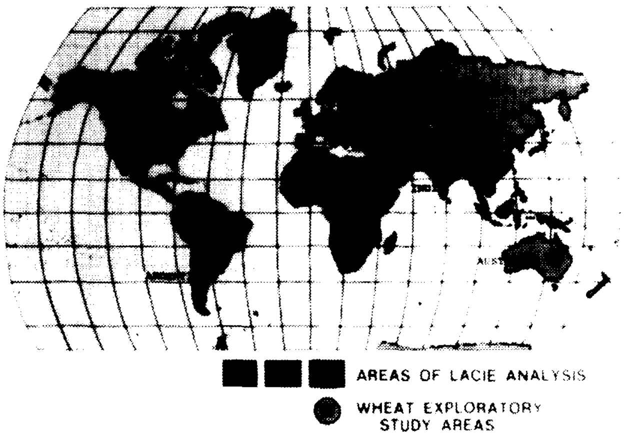
(a) Phase I study areas.

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




(b) Phase II study areas.

In global crop year 1975-76, the technology, as modified during Phase I, was evaluated for monitoring wheat production for the USGP, Canada, and "indicator regions" in the U.S.S.R. 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.




(c) Phase III study areas.

In global crop year 1976-77, new technology was implemented and evaluated for monitoring wheat production for the USGP and the U.S.S.R. 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.

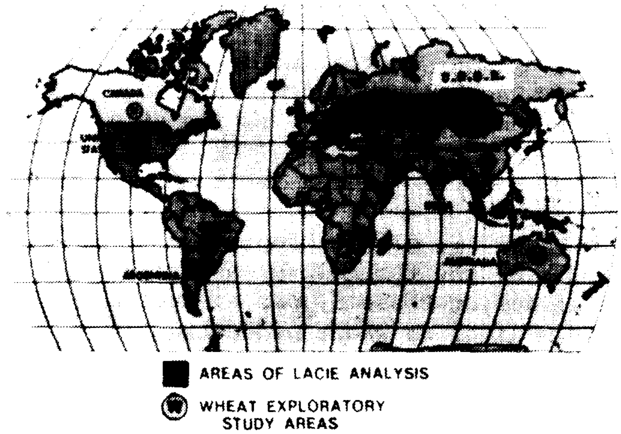



Figure 7.— Major wheat-producing regions considered within the three phases of LACIE.

## TECHNICAL APPROACH

The technical approach to LACIE (figure 8) was to estimate production of wheat on a region-by-region basis where production is the product of area and yield. Both area and yield were estimated for local areas and aggregated to regional and country levels based upon a sample strategy over the regions in which wheat was a major crop. Maximum use was made of computer-aided analysis in order

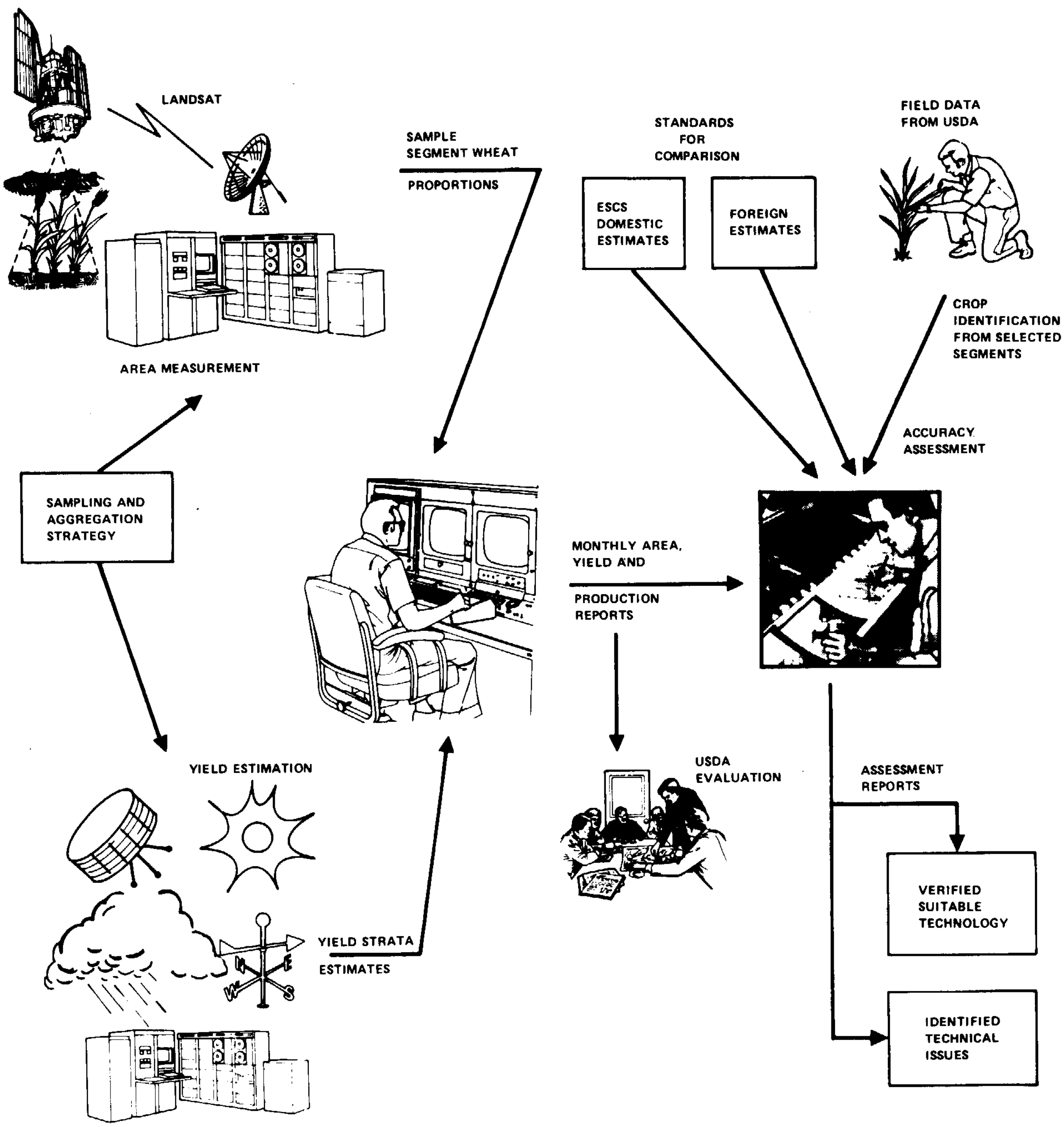



Figure 8.— LACIE technical approach.

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- by 6-nautical-mile sample segments. Utilization of Landsat full-frame imagery allowed samples to be drawn only from agricultural areas and required only 2 percent of the area to be analyzed with the contribution of sampling error to the area estimate being less than 2 percent. 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 were 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 percent) of each sample segment as either wheat or nonwheat.* 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.

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 USGP 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

*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.

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. Assessments of potential yield thus could 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 wheat 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 wheat crop in the U.S.S.R.

## PHASE III U.S.S.R. RESULTS

In 1977, the LACIE experimental commodity production forecast system was utilized to monitor the U.S.S.R. total country wheat production from early season through harvest. Commodity production forecasts for winter wheat were generated and released to the LACIE project office of the USDA in Washington, D.C., the day prior to the corresponding public release by the USDA's Foreign Agricultural Service (FAS). LACIE initiated forecasts for U.S.S.R. winter wheat production on April 1, 1977; the initial LACIE forecast for spring and total wheat was released on August 8, 1977. Shown in figure 9 are the LACIE in-season forecasts for Soviet total wheat, the FAS forecasts, and the LACIE recomputed estimates generated postharvest prior to the U.S.S.R. wheat release. The recomputed estimates are the seasonal forecasts obtained from the LACIE system after correction of two Landsat data problems encountered during the Phase III operation: a 45- to 60-day processing backlog and missing data resulting from an inadvertent omission in a Landsat data order.

The initial 1977 LACIE in-season forecast of total U.S.S.R. wheat production, released on August 8, 1977, was 97.6 million metric tons (MMT), over 11 percent below the most recent FAS July projection but only 6 percent above the final U.S.S.R. wheat figure of 92.0 MMT. The final LACIE estimate of 91.4 MMT differed from the U.S.S.R. final figure by about 1 percent. The wheat production forecasts released by the FAS are shown as the dashed line in figure 9.

In comparison to the accuracy and timeliness of U.S.S.R. information currently available without LACIE technology, LACIE forecast accuracies demonstrate 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 forecast techniques must rely heavily on statistics and reports released by the countries themselves. Disregarding questions as

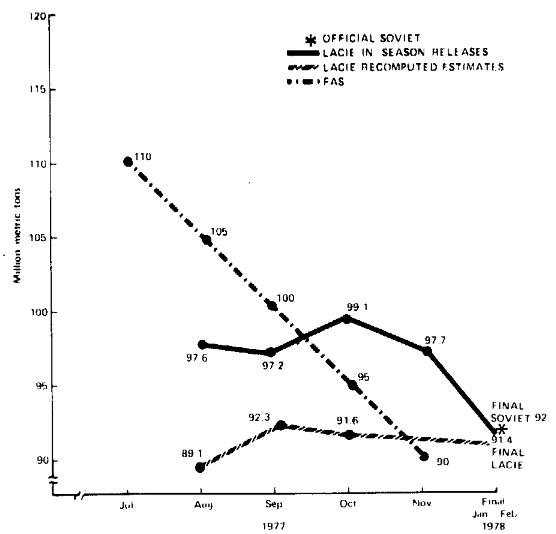



Figure 9.— LACIE estimates of 1977 Soviet wheat production.

to the reliability of such information, perhaps the major problem is its timeliness. The U.S.S.R. releases only a planning figure for total grain production early in the year and a postharvest estimate of total grain production in early November; wheat statistics are not released until January or February after harvest.

In January 1977, the U.S.S.R. released a 213.3-MMT planning figure for total grains, about 13 percent above the 1971-74 average shown in table 1 (ref. 2). Since wheat had historically comprised 48 percent of the total grains, the original U.S.S.R. goal would have contained about 102 MMT of wheat. FAS estimates of total wheat began at about 97 MMT in February 1977 (ref. 3). The FAS carried a total-grain forecast of 224 MMT, which was significantly above the Soviet figure of 213.3 MMT. The FAS steadily increased its wheat forecasts to a high of 110 MMT in the July 8 report (ref. 4), primarily in response to its assessment of a much better than average U.S.S.R. winter wheat crop and a forecast of an average to above-average spring wheat crop. As can be seen in figure 9, the FAS decreased the Soviet forecast from the July figure of 110 MMT by about 5 MMT per month thereafter; the reduction on August 10 (ref. 5) was primarily in response to June and July drought conditions in the spring wheat regions. The 5-MMT reduction in September was primarily in response to a mid- to late-August official Soviet release of winter wheat acreage information (ref. 6). The data compiled about June 1 by the U.S.S.R. indicated a loss of winter wheat acreage due to winterkill during the harsh Soviet winter. The final FAS release on October 20, 1977 (ref. 7) carried a wheat estimate of 95 MMT and an estimate of total grains at 215 MMT.

On November 2, 1977, Chairman Brezhnev announced that U.S.S.R. total grains production was expected to be only 194 MMT. The U.S.S.R.

TABLE 1.— SOVIET WHEAT AND TOTAL GRAINS PRODUCTION FOR THE YEARS 1971 THROUGH 1976

| Year | Wheat production (MMT) | | | Grains[a] production (MMT) | Ratio wheat to grain production (%) |
|---|---|---|---|---|---|
| | Winter | Spring | Total | | |
| 1971 | 47 787 | 50 973 | 98 790 | 181 175 | 54.5 |
| 1972 | 29 380 | 56 613 | 85 993 | 168 238 | 51.1 |
| 1973 | 49 435 | 60 349 | 109 784 | 222 530 | 49.3 |
| 1974 | 44 698 | 39 215 | 83 913 | 195 708 | 42.9 |
| 1975 | 36 651 | 29 573 | 66 224 | 140 118 | 47.2 |
| 1976 | 44 594 | 52 288 | 96 882 | 223 755 | 43.3 |
| Avg. | 42 091 | 48 166 | 90 264 | 188 587 | 47.9 |

[a]Includes wheat, rye, barley, oats, corn, and miscellaneous other grains.

had missed its target figure by 19 MMT; the FAS estimate of 2 weeks prior exceeded the figure by 21 MMT. In late January 1978, the U.S.S.R. announced its 1977 wheat production at 92 MMT: winter wheat at 51.9 MMT (9.8 MMT above average, as shown in table 1) and spring wheat at 40.1 MMT (8.1 MMT below average).

A review of the FAS reports seems to indicate that unanticipated loss of winter wheat acreage to winterkill and a misreading of the poor Soviet harvesting conditions were the primary causes of the FAS winter wheat overestimate. The spring wheat overestimate seems to have been a result of misreading the impact and extent of the drought which affected a majority of the spring wheat region in the U.S.S.R.

The early-season May and June LACIE forecasts for Soviet winter wheat ranging from 51 to 55 MMT were indicating a near-record winter wheat crop (see figure 10). The LACIE winter wheat estimate of 21 million hectares indicated a 15-percent increase in U.S.S.R. plantings above average (ref. 8) and a 22-percent increase over the 1976 figure. In addition, LACIE yield forecasts stood at 25.5 quintals per hectare, 11 percent above the U.S.S.R. average. Given that the U.S.S.R. could produce a spring wheat crop near its 48-MMT average, its 1977 total wheat production would achieve near-record proportions of 100 to 105 MMT. The LACIE system was then focused on the U.S.S.R. spring wheat crop. The early-season August estimate of 39 million hectares indicated an almost 9-percent decrease from average in the U.S.S.R.'s spring wheat planting. Combined with the LACIE yield model forecasts of a surprising 20.5-percent decline in yield from average, this indicated that the U.S.S.R. spring wheat crop would fall a disastrous 30 percent below average. If these trends held, the U.S.S.R. would achieve only an average total wheat crop.

As figure 10 shows, the LACIE winter wheat forecasts had increased from the May to June reports. On the basis of LACIE forecast experience in the U.S., the increase was a result of steadily increasing visibility to Landsat of the wheat crop as it completed its early spring development. Since the continued increase in the winter wheat hectarage forecasts through July and August had no known physical basis, it resulted from a system problem. The LACIE analysts, thus alerted to technical problems, initiated efforts to isolate the source of

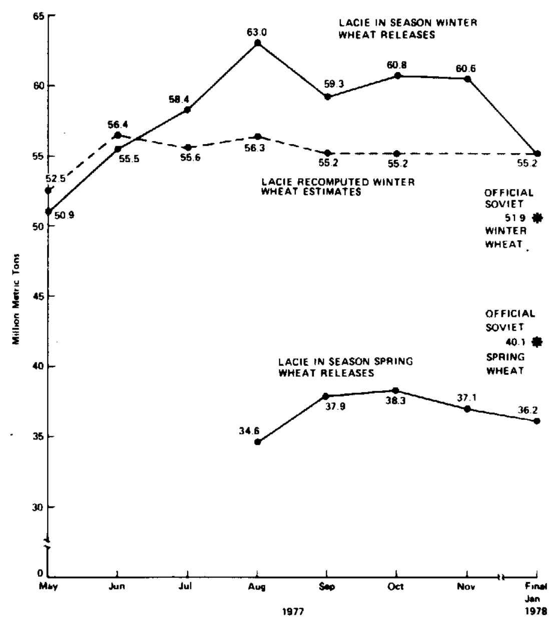



Figure 10.— The contributions of LACIE Soviet winter and spring wheat production estimates to the LACIE total productions shown in figure 9.

this apparent increase. The spring wheat estimates seemed to be unaffected by the problem; they stabilized after the August forecast, as expected. LACIE in-season forecasts were continued as usual even though the winter wheat forecasts were believed to be inflated by a few percent.

The winter wheat problem was quickly isolated as being the result of an inadvertent omission in the Landsat data acquisition order from the Johnson Space Center (JSC) to the Goddard Space Flight Center (GSFC) for the Soviet wheat region above the 48th parallel. The failure to order these acquisitions affected accuracies in about 20 percent of the U.S.S.R. winter wheat sample segments. In these segments, Landsat data were not acquired during March and April, the winter wheat greening and recovery period following dormancy. As a result, the Landsat analysts could not differentiate between winter grains and spring grains, which had emerged sufficiently by May to be confused with winter grains. Fortunately, the effect on the LACIE forecasts was only a few percent and the real-time in-season forecasts for winter wheat remained reasonably accurate. To evaluate the effect of the data order error, "recomputed estimates" were generated in December 1977 to obtain the seasonal estimates which would have resulted from the LACIE system if planned Landsat data orders for winter wheat had been correctly placed. To generate the recomputed estimates, winter wheat areas for those segments affected by the faulty data orders were computed, using the original segment area estimates as estimates of the total small grains. The total grains estimates were then reduced to winter wheat figures, using historic ratios of winter wheat to total small grains area. Additionally, a problem arising from the 45- to 60-day Landsat data processing backlog observed in Phase III was removed by using Landsat data acquired up to 30 days before the reporting date for each report. No Landsat data order problem existed for the spring wheat forecasts. Recomputed estimates for spring wheat are not significantly different from the in-season forecasts.

Tables 2, 3, and 4 tabulate the relative difference (RD) and coefficient of variation (CV) in percent. The Soviet final yield is derived from ratio of production to area, as no Soviet figures are available. Area is given in millions of hectares (Mha); yield is given in quintals per hectare (q/ha), and production is given in MMT.

The recomputed LACIE winter wheat area, yield, and production estimates are in very good agreement with the U.S.S.R. figures, as shown in table 2. Early, mid-season, and at-harvest forecasts of area, yield, and production differ from the U.S.S.R.'s forecasts by less than a few percent. Table 3 shows similar good agreement with the LACIE spring wheat forecasts released during the season. The August-through-final LACIE forecasts of U.S.S.R. total wheat were also in good agreement (table 4) and support the 90/90 accuracy criterion. It should be emphasized that the total wheat forecasts given in table 4 use recomputed winter wheat estimates and real-time in-season releases for spring wheat. Total wheat estimates were also generated, using recomputed estimates for both spring and winter wheat. These will not be treated here because the spring wheat recomputed estimates do

TABLE 2.— LACIE 1977 RECOMPUTED ESTIMATES AND RD'S WITH SOVIET 1977 WINTER WHEAT FINAL FIGURES

[Released February 1978]

| | Area (Mha) | Yield (q/ha) | Production (MMT) |
|---|---|---|---|
| Soviet final | 20.7 | 25.1 | 51.9 |
| Early season (April)[a] | | | |
| LACIE | 21.3 | 24.3 | 51.7 |
| RD(%) | 2.8 | -3.3 | -0.4 |
| CV(%) | 6.3 | 4.4 | 7.0 |
| Mid-season (June)[a] | | | |
| LACIE | 22.1 | 25.6 | 56.4 |
| RD(%) | 6.3 | 2.0 | 8.0 |
| CV(%) | 4.5 | 4.2 | 5.7 |
| At harvest (October)[a] | | | |
| LACIE | 21.6 | 25.6 | 55.2 |
| RD(%) | 4.2 | 2.0 | 6.0 |
| CV(%) | 2.5 | 3.6 | 4.2 |
| Final | | | |
| LACIE | 21.5 | 25.6 | 55.2 |
| RD(%) | 3.7 | 2.0 | 6.0 |
| CV(%) | 2.5 | 3.6 | 4.2 |

[a]Based on Landsat data acquired through the first day of the previous month.

TABLE 3.— LACIE 1977 IN-SEASON RELEASES, CV'S, AND RD'S WITH SOVIET SPRING WHEAT FINAL FIGURES

[Released February 1978]

| | Area (Mha) | Yield (q/ha) | Production (MMT) |
|---|---|---|---|
| Soviet final | 41.3 | 9.7 | 40.1 |
| Early season (August) | | | |
| LACIE | 38.9 | 8.9 | 34.6 |
| RD(%) | -6.2 | -9.0 | -15.9 |
| CV(%) | 3.5 | 8.7 | 9.2 |
| Mid-season (September) | | | |
| LACIE | 41.0 | 9.3 | 37.9 |
| RD(%) | 0.7 | -4.3 | -5.8 |
| CV(%) | 2.9 | 7.1 | 7.2 |
| At harvest (October) | | | |
| LACIE | 42.6 | 9.0 | 38.3 |
| RD(%) | 3.1 | -7.8 | -4.7 |
| CV(%) | 2.6 | 6.9 | 7.0 |
| Final | | | |
| LACIE | 41.4 | 8.8 | 36.3 |
| RD(%) | 0.0 | -10.2 | -10.5 |
| CV(%) | 2.3 | 7.0 | 7.2 |

not differ significantly from the real-time in-season releases. These estimates are treated in full in various LACIE accuracy assessment documents.

A more detailed examination of the response of the LACIE wheat yield models to the 1977 meteorological conditions in the U.S.S.R. indicates that these models responded to both significantly above and below average growing conditions in U.S.S.R. wheat regions. The Soviet 1977 winter wheat production of 51.9 MMT was 23 percent above

TABLE 4.— LACIE 1977 SOVIET TOTAL RECOMPUTED WINTER WHEAT AND IN-SEASON SPRING WHEAT FORECASTS, CV'S, AND RD'S WITH SOVIET FINAL FIGURES

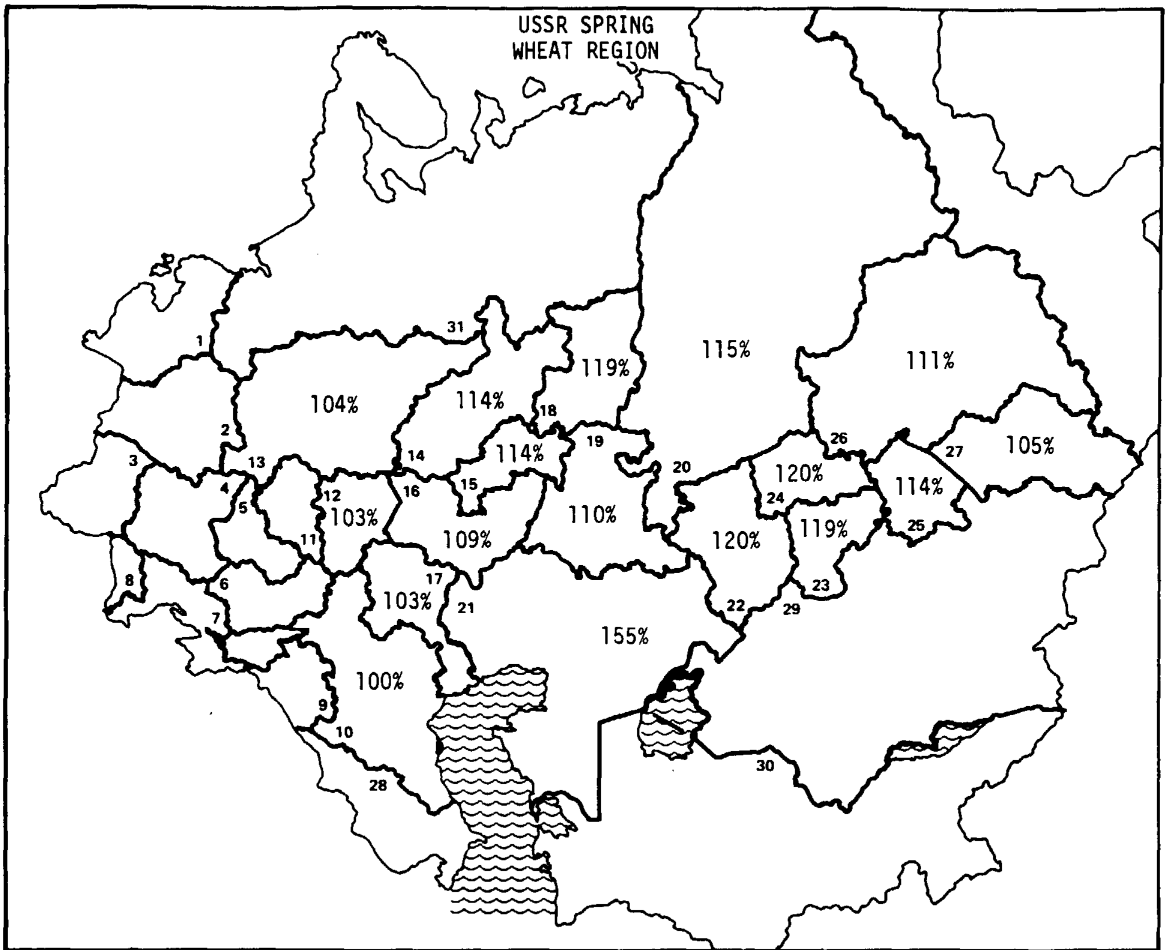
[Released February 1978]

| | Area (Mha) | Yield (q/ha) | Production (MMT) |
|---|---|---|---|
| Soviet final | 62.0 | 14.8 | 92.0 |
| August[a] | | | |
| LACIE | 61.0 | 14.9 | 90.9 |
| RD(%) | -1.6 | 0.7 | -1.2 |
| CV(%) | ~2.6 | - | ~4.3 |
| September[a] | | | |
| LACIE | 62.6 | 14.9 | 93.1 |
| RD(%) | 1.0 | 0.0 | 1.2 |
| CV(%) | 1.9 | - | 3.9 |
| October[a] | | | |
| LACIE | 64.2 | 14.6 | 93.5 |
| RD(%) | 3.4 | -2.1 | 1.6 |
| CV(%) | 1.8 | - | 3.8 |
| Final | | | |
| LACIE | 62.9 | 14.5 | 91.4 |
| RD(%) | 1.4 | -2.1 | -0.7 |
| CV(%) | 1.8 | - | 3.8 |

[a]Based on Landsat data acquired through the first day of the previous month.

average. The Soviet spring wheat production of 40.1 MMT was 17 percent below average.

Clues to the potential shortfall in the U.S.S.R. spring wheat region came early in the season when unfavorable weather conditions began. The average air temperature for the 2-month period of May and June was considerably above normal throughout the spring wheat area, as shown in figure 11. During the same period of May and June, rainfall was below average in many of the crop regions noted in figure 12. The above-average demand for moisture, combined with the below-average supply, indicated a potential shortfall early in the season. Figure 13 highlights the instances in which the supply-demand difference deviated most from average. The differences between precipitation and potential evapotranspiration are used in the LACIE yield models to represent relative soil moisture available to the crop. As figure 13 indicates, significant drought effects were forecast in the eastern and southern crop regions. An investigation of the Landsat data at subregional levels indicated that the drought conditions were clearly observable in the Landsat data. An examination of the yield model responses indicated that the LACIE yield models responded by reducing yield estimates in the affected regions. Figure 14 displays the model yield reductions by crop region in response to the weather conditions preseason through harvest. Note the severe reductions in yield in the affected regions, in many cases 50 percent below normal. These drought conditions were also quite evident in the Landsat data (figure 15). In this figure, radiometric measurements from Landsat which are known to be related to the crop canopy condition indicated that the shaded areas, which contained a significant share of the wheat acreage in regions 21, 22, 23, 24, 25, 27, and 29, were under severe drought conditions. In these regions, LACIE yield models were forecasting below-average yields. Note, however, that in the northern regions LACIE was forecasting above-average yields.

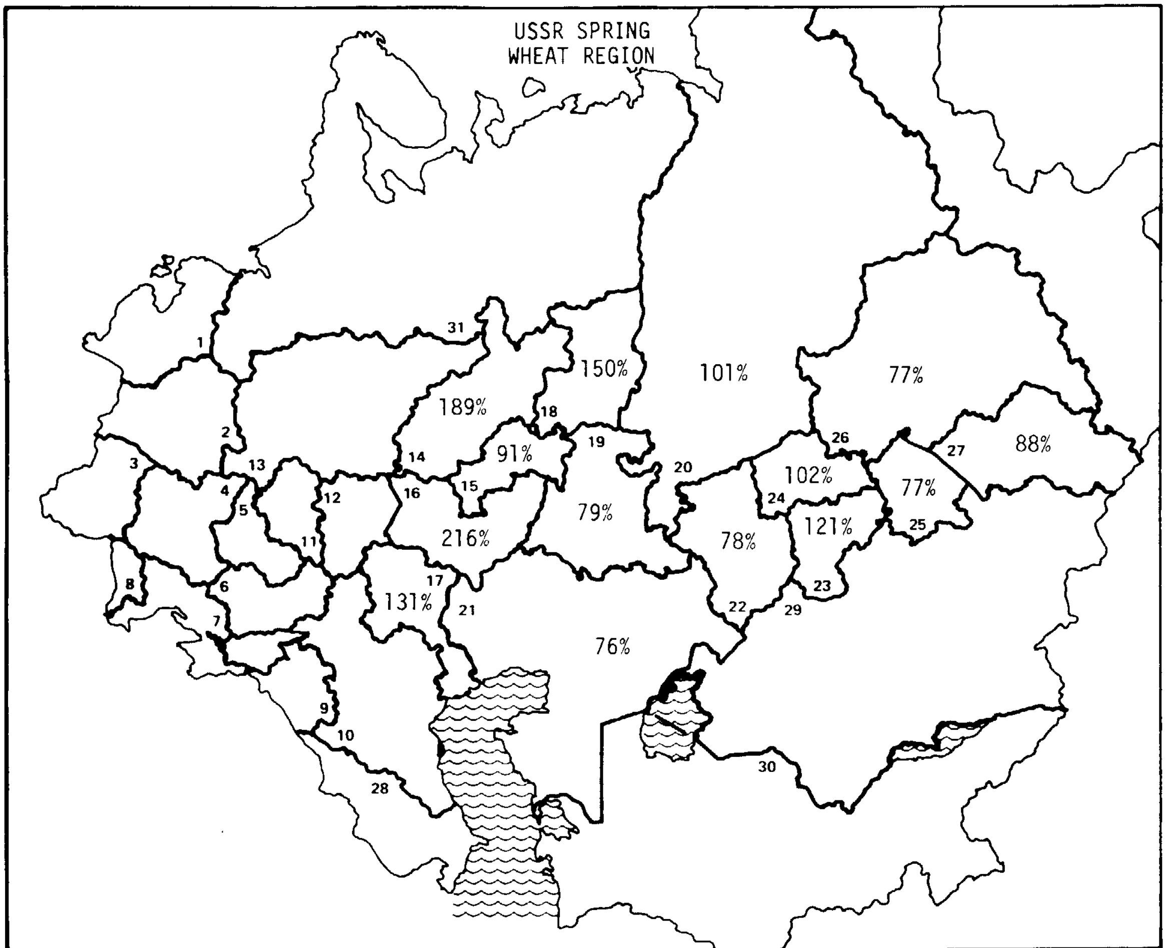



**CROP REGION YIELD STRATA LEGEND**

1. BALTICS (W)
2. BELORUSSIA (W)
3. WESTERN UKRAINE (W)
4. NORTHCENTRAL UKRAINE (W)
5. NORTHEASTERN UKRAINE (W)
6. EASTERN UKRAINE (W)
7. SOUTHERN UKRAINE (W)
8. MOLDAVIA (W)
9. KRASNODAR KRAY (W)
10. NORTHEASTERN CAUCASUS (M)
11. WESTERN BLACK SOIL (M)
12. EASTERN BLACK SOIL (M)
13. CENTRAL REGION (M)
14. VOLGA VYATSK (M)
15. UPPER VOLGA (M)
16. MIDDLE VOLGA (M)
17. LOWER VOLGA (M)
18. NORTHWESTERN URALS (S)
19. SOUTHERN URALS (S)
20. NORTHEASTERN URALS (S)
21. WESTERN KAZAKHSTAN (S)
22. KUSTANAY OBLAST (S)
23. TSELINOGRAD OBLAST (S)
24. NORTHERN KAZAKHSTAN (S)
25. PAVLODAR OBLAST (S)
26. WESTERN SIBERIA (S)
27. ALTAI KRAY (S)
28. TRANS CAUCASUS (S)
29. SOUTH KAZAKHSTAN (S)
30. CENTRAL ASIA (S)
31. NORTHWEST REGION (S)

W – WINTER WHEAT
S – SPRING WHEAT
M – MIXED SPRING AND WINTER WHEAT

Figure 11.— Percent of normal for May-June temperature in Soviet spring wheat regions.

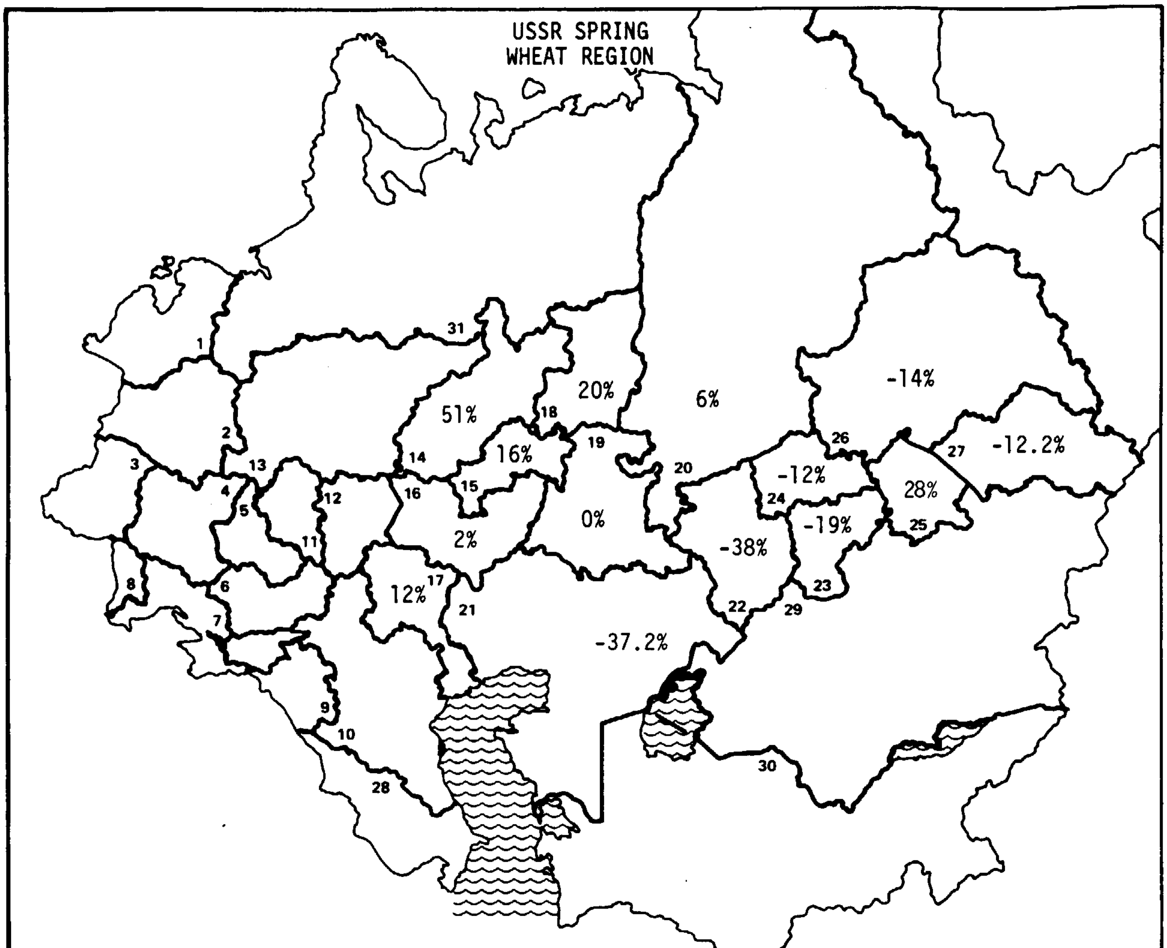



**CROP REGION YIELD STRATA LEGEND**

1. BALTICS (W)
2. BELORUSSIA (W)
3. WESTERN UKRAINE (W)
4. NORTHCENTRAL UKRAINE (W)
5. NORTHEASTERN UKRAINE (W)
6. EASTERN UKRAINE (W)
7. SOUTHERN UKRAINE (W)
8. MOLDAVIA (W)
9. KRASNODAR KRAY (W)
10. NORTHEASTERN CAUCASUS (M)
11. WESTERN BLACK SOIL (M)
12. EASTERN BLACK SOIL (M)
13. CENTRAL REGION (M)
14. VOLGA VYATSK (M)
15. UPPER VOLGA (M)
16. MIDDLE VOLGA (M)
17. LOWER VOLGA (M)
18. NORTHWESTERN URALS (S)
19. SOUTHERN URALS (S)
20. NORTHEASTERN URALS (S)
21. WESTERN KAZAKHSTAN (S)
22. KUSTANAY OBLAST (S)
23. TSELINOGRAD OBLAST (S)
24. NORTHERN KAZAKHSTAN (S)
25. PAVLODAR OBLAST (S)
26. WESTERN SIBERIA (S)
27. ALTAI KRAY (S)
28. TRANS CAUCASUS (S)
29. SOUTH KAZAKHSTAN (S)
30. CENTRAL ASIA (S)
31. NORTHWEST REGION (S)

W – WINTER WHEAT
S – SPRING WHEAT
M – MIXED SPRING AND WINTER WHEAT

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




**CROP REGION YIELD STRATA LEGEND**

1. BALTICS (W)
2. BELORUSSIA (W)
3. WESTERN UKRAINE (W)
4. NORTHCENTRAL UKRAINE (W)
5. NORTHEASTERN UKRAINE (W)
6. EASTERN UKRAINE (W)
7. SOUTHERN UKRAINE (W)
8. MOLDAVIA (W)
9. KRASNODAR KRAY (W)
10. NORTHEASTERN CAUCASUS (M)
11. WESTERN BLACK SOIL (M)
12. EASTERN BLACK SOIL (M)
13. CENTRAL REGION (M)
14. VOLGA VYATSK (M)
15. UPPER VOLGA (M)
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27. ALTAI KRAY (S)
28. TRANS CAUCASUS (S)
29. SOUTH KAZAKHSTAN (S)
30. CENTRAL ASIA (S)
31. NORTHWEST REGION (S)

W – WINTER WHEAT
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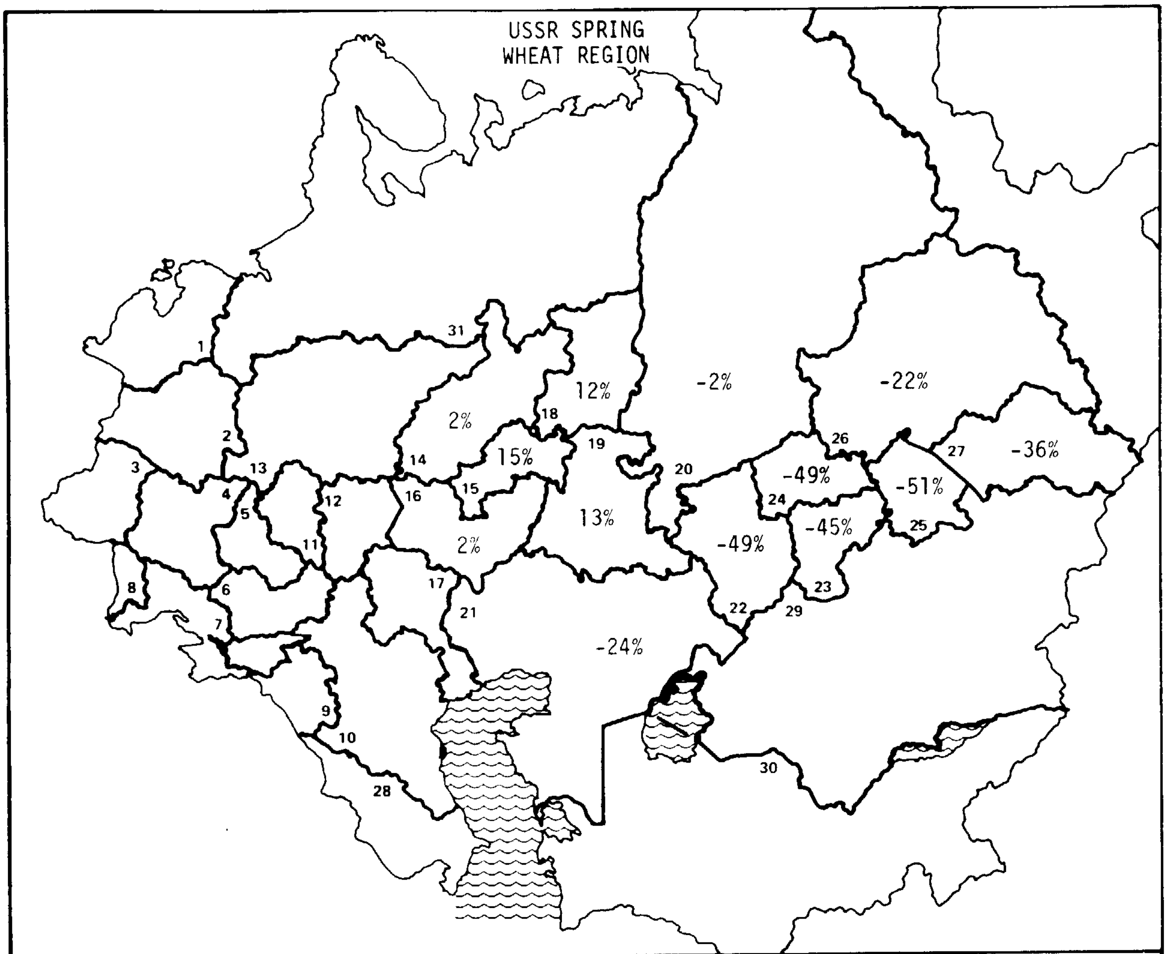
M – MIXED SPRING AND WINTER WHEAT

Figure 13.— Percent deviation from normal in moisture supply in Soviet spring wheat regions.




**CROP REGION YIELD STRATA LEGEND**

1. BALTICS (W)
2. BELORUSSIA (W)
3. WESTERN UKRAINE (W)
4. NORTHCENTRAL UKRAINE (W)
5. NORTHEASTERN UKRAINE (W)
6. EASTERN UKRAINE (W)
7. SOUTHERN UKRAINE (W)
8. MOLDAVIA (W)
9. KRASNODAR KRAY (W)
10. NORTHEASTERN CAUCASUS (M)
11. WESTERN BLACK SOIL (M)
12. EASTERN BLACK SOIL (M)
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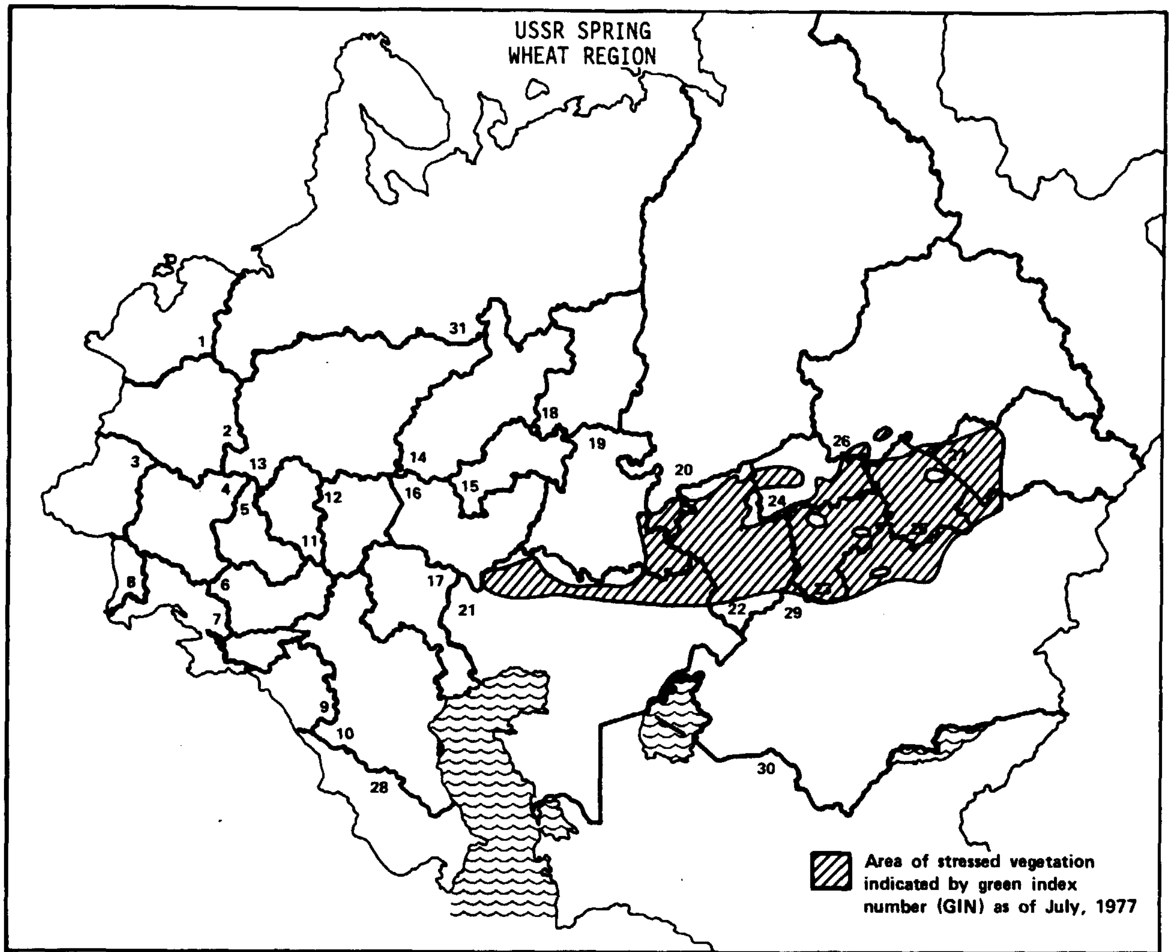
23. TSELINOGRAD OBLAST (S)
24. NORTHERN KAZAKHSTAN (S)
25. PAVLODAR OBLAST (S)
26. WESTERN SIBERIA (S)
27. ALTAI KRAY (S)
28. TRANS CAUCASUS (S)
29. SOUTH KAZAKHSTAN (S)
30. CENTRAL ASIA (S)
31. NORTHWEST REGION (S)

W – WINTER WHEAT
S – SPRING WHEAT
M – MIXED SPRING AND WINTER WHEAT

Figure 14.– Percent deviation from trend yields forecast by LACIE Soviet spring wheat models.




## CROP REGION YIELD STRATA LEGEND

| | | |
|---|---|---|
| 1. BALTICS (W) | 12. EASTERN BLACK SOIL (M) | 23. TSELINOGRAD OBLAST (S) |
| 2. BELORUSSIA (W) | 13. CENTRAL REGION (M) | 24. NORTHERN KAZAKHSTAN (S) |
| 3. WESTERN UKRAINE (W) | 14. VOLGA VYATSK (M) | 25. PAVLODAR OBLAST (S) |
| 4. NORTHCENTRAL UKRAINE (W) | 15. UPPER VOLGA (M) | 26. WESTERN SIBERIA (S) |
| 5. NORTHEASTERN UKRAINE (W) | 16. MIDDLE VOLGA (M) | 27. ALTAI KRAY (S) |
| 6. EASTERN UKRAINE (W) | 17. LOWER VOLGA (M) | 28. TRANS CAUCASUS (S) |
| 7. SOUTHERN UKRAINE (W) | 18. NORTHWESTERN URALS (S) | 29. SOUTH KAZAKHSTAN (S) |
| 8. MOLDAVIA (W) | 19. SOUTHERN URALS (S) | 30. CENTRAL ASIA (S) |
| 9. KRASNODAR KRAY (W) | 20. NORTHEASTERN URALS (S) | 31. NORTHWEST REGION (S) |
| 10. NORTHEASTERN CAUCASUS (M) | 21. WESTERN KAZAKHSTAN (S) | |
| 11. WESTERN BLACK SOIL (M) | 22. KUSTANAY OBLAST (S) | |

W – WINTER WHEAT
S – SPRING WHEAT
M – MIXED SPRING AND WINTER WHEAT

Figure 15.– Landsat monitoring of drought – 1977 U.S.S.R. spring wheat.

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 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 in the previous year for the Kokchetav segment, by comparison shows a dramatic decrease in crop vigor in 1977.

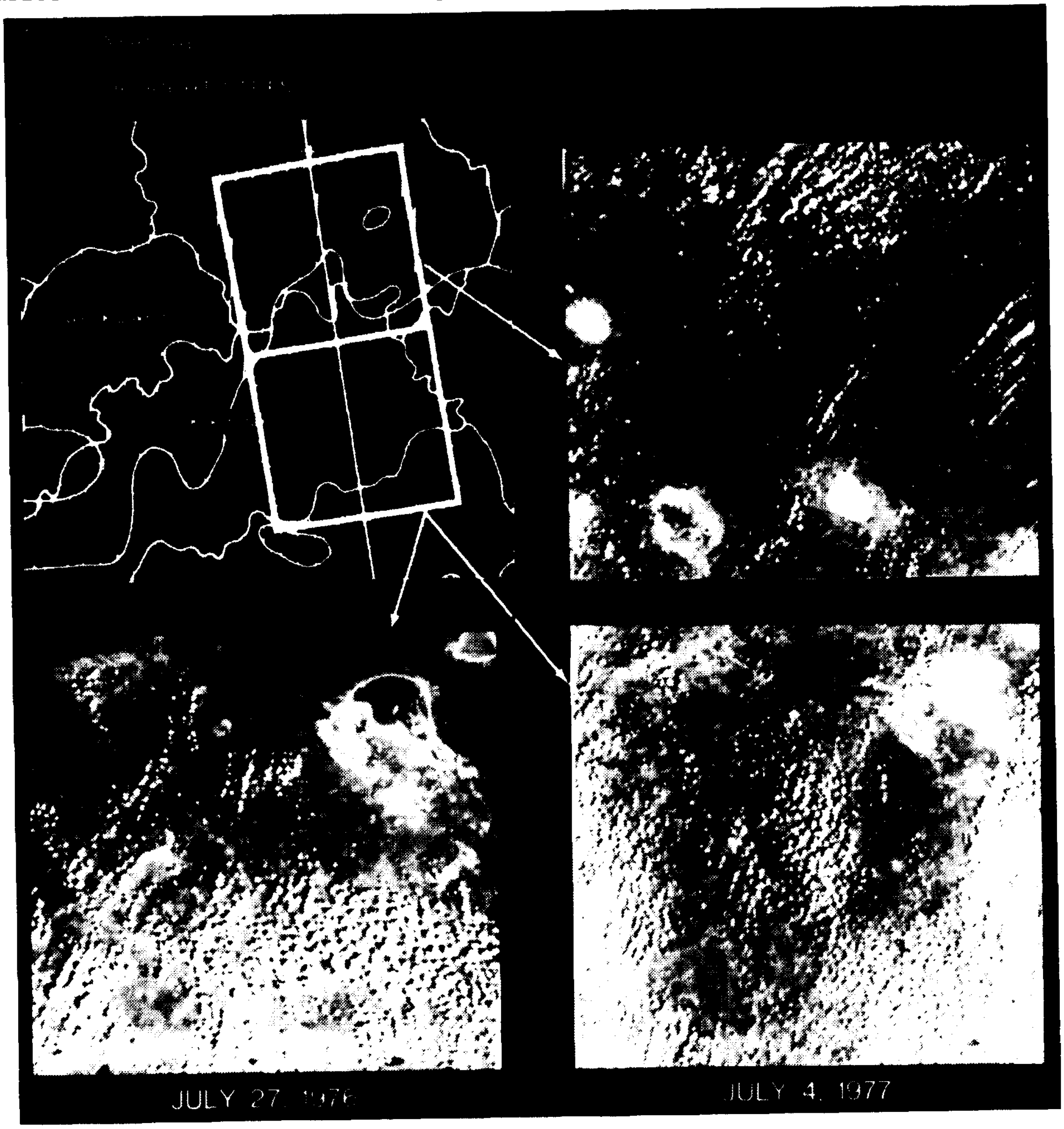



Figure 16.— Landsat imagery from Omsk and Kokchetav, illustrating drought effects.

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 forecast 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 MMT, a deviation of about 20 percent below normal.

While the LACIE models responded realistically to the 1977 departure in the U.S.S.R. spring wheat yields, there is some evidence to suggest that these models tend to underestimate the yield. For the period from 1955 to 1976, U.S.S.R. country-level spring wheat yield data seem to have a moderately strong trend component, as shown by the linear best fit trend line of figure 17. The LACIE U.S.S.R. yield models were developed at the crop region level using 1973 data, the most recent available. These models show a trend to level off after 1973 and as a result project a trend value of 1.2 quintals per hectare below the linear trend projection. Thus, it would appear that if a larger trend value had been used the LACIE final spring wheat yield estimate would have been in closer agreement with the U.S.S.R. estimate. Note (figure 17) that the LACIE yield models did respond to the adverse weather with

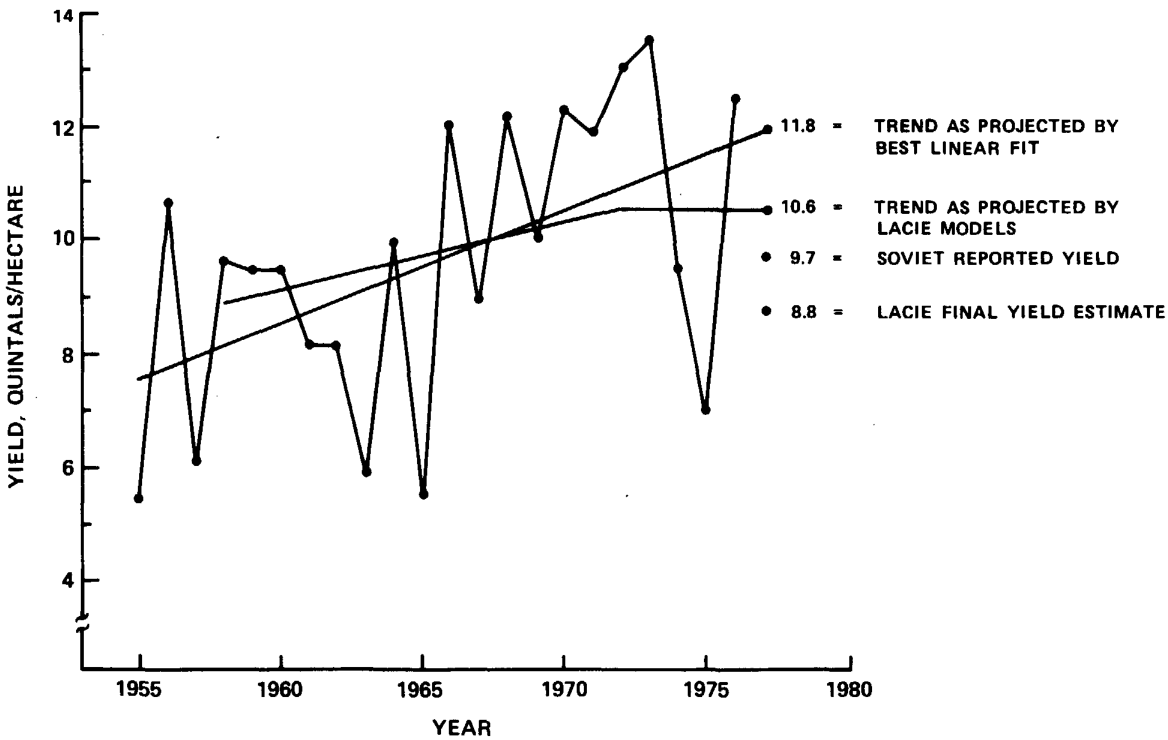



Figure 17.— Time series of historical Soviet spring wheat yields showing trends as computed from best linear fit and as projected by LACIE yield models.

forecasts 1.8 quintals per hectare below the LACIE trend projections. This response is due primarily to above-average temperatures and below-average precipitation in April and below-average available soil moisture in June. The above-average April temperature could not have directly affected the mid-May planted spring wheat crop; the yield forecast reduction due to April temperature may be unwarranted unless it can be explained as a statistical result of induced model correlations between April temperature and future seasonal conditions which reduce wheat yields (for example, a warmer-than-average May and June with a correspondingly shorter wheat development cycle).

## U.S., U.S.S.R., AND CANADIAN RESULTS – PHASE I THROUGH PHASE III

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 U.S.S.R. 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 supported 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 U.S.S.R. 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 18) showed significant improvement over those of Phase II. The LACIE winter wheat estimates in the U.S. and U.S.S.R., 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

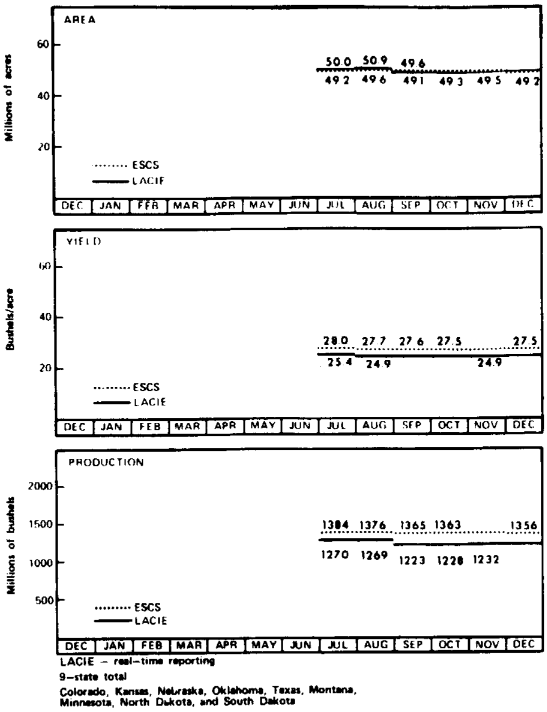



Figure 18.— Phase III, U.S. nine-state region estimates.

wheat area which reduced the difference between the LACIE and Economics, Statistics, and Cooperative Service (ESCS) estimates of wheat area to less than 1 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 supportive of 90/90 performance. The Phase III area, yield, and production estimates for the U.S. nine-state region are shown in figure 18. The final yield estimate was prepared in September; however, the derived value changed slightly as later Landsat data were used to refine area estimates at the yield strata level.

More extensive evaluations of the U.S. yield models over a 10-year period indicated a performance consistent with 90/90 except for years with extreme agricultural or meteorological conditions. Table 5 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 nonparametric statistical test employed to analyze these 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,

TABLE 5.— RESULTS OF AN EVALUATION OF THE LACIE PHASE III U.S. YIELD MODELS ON 10 YEARS OF INDEPENDENT TEST DATA

| Year | ESCS, bu/acre | LACIE estimate, bu/acre | Error | Within tolerance? |
|---|---|---|---|---|
| 1967 | 21.6 | 22.5 | +0.9 | Yes |
| 1968 | 26.0 | 24.6 | -1.4 | Yes |
| 1969 | 28.4 | 29.4 | +1.0 | Yes |
| 1970 | 28.2 | 26.6 | -1.6 | Yes |
| 1971 | 30.8 | 27.9 | -2.9 | No |
| 1972 | 29.3 | 29.1 | -0.2 | Yes |
| 1973 | 30.8 | 30.6 | -0.2 | Yes |
| 1974 | 23.8 | 28.4 | +4.6 | No |
| 1975 | 26.8 | 27.3 | +0.5 | Yes |
| 1976 | 26.4 | 27.1 | +0.7 | Yes |
| 1977[a] | 27.5 | 24.9 | -2.6 | |

Mean error = -0.1 bu/acre
RMSE = 1.90 bu/acre
Accept 90/90
[a]For comparison only, LACIE 1977 estimates.

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 that 1974 was a very dry year in the USGP, 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. It thus 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 the 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 minimum daily air temperatures. Generally, the Phase III evaluations of these models indicated that model improvements are required, particularly the development of a planting date prediction model. The models seemed to perform adequately when given accurate planting date data. 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 U.S.S.R. 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 19 displays the experimental estimates as compared to the ESCS estimates for the region. Figure 20 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.

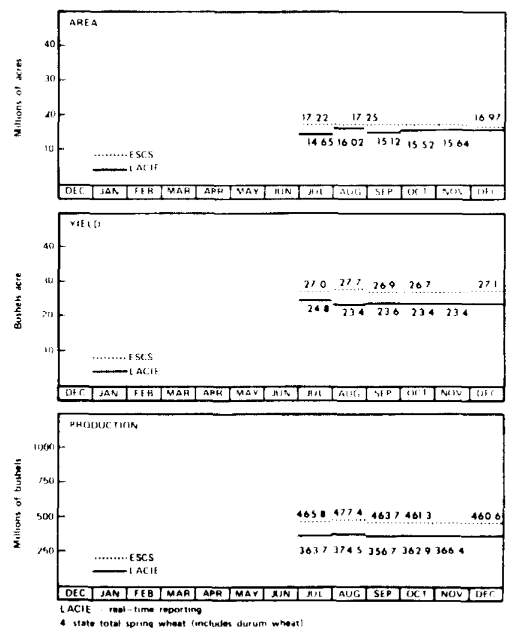
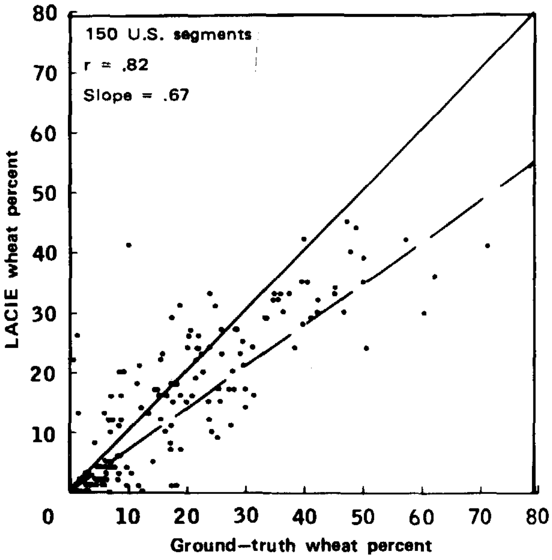
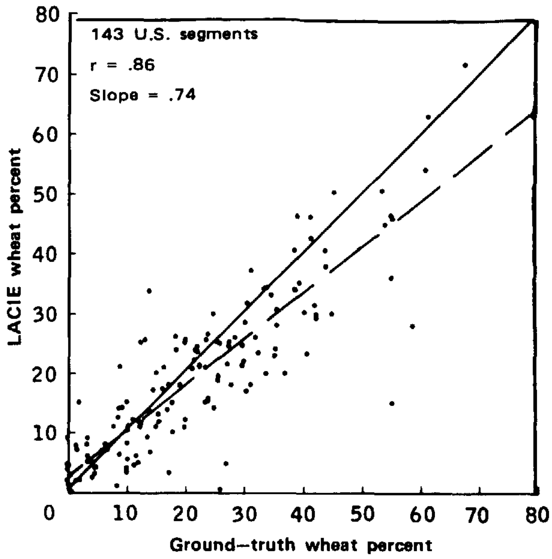



Figure 19.— Phase III, LACIE estimates for U.S. spring wheat.



Phase II



Phase III

Figure 20.— Comparison of LACIE segments estimates and ground observed estimates of wheat area proportions — U.S. yardstick test sites.

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. However, the actual time during which a segment is undergoing active processing is within the revised goal of 14 days from acquisition to availability for aggregation, distributed as follows:

- Data acquisition, transmittal to GSFC, segment extraction and registration, quality screening, and transmittal to JSC required 7-1/3 days.
- JSC LACIE data base update, segment film image production, analysis packet preparation, review, and assignment to analyst required 2-1/3 days.
- 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 to 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., U.S.S.R., 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 3 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 U.S.S.R. Difficulty was encountered in the U.S. and 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 21 shows typical field sizes in the northern U.S., the U.S.S.R., and China, illustrating how field size and shape are problems in some areas. On the left portion of figure 21 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.

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 U.S.S.R. 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 U.S.S.R. winter and spring wheat, the results indicated that similar accuracies were achieved with Landsat and weather data acquired 1-1/2 months prior to harvest.

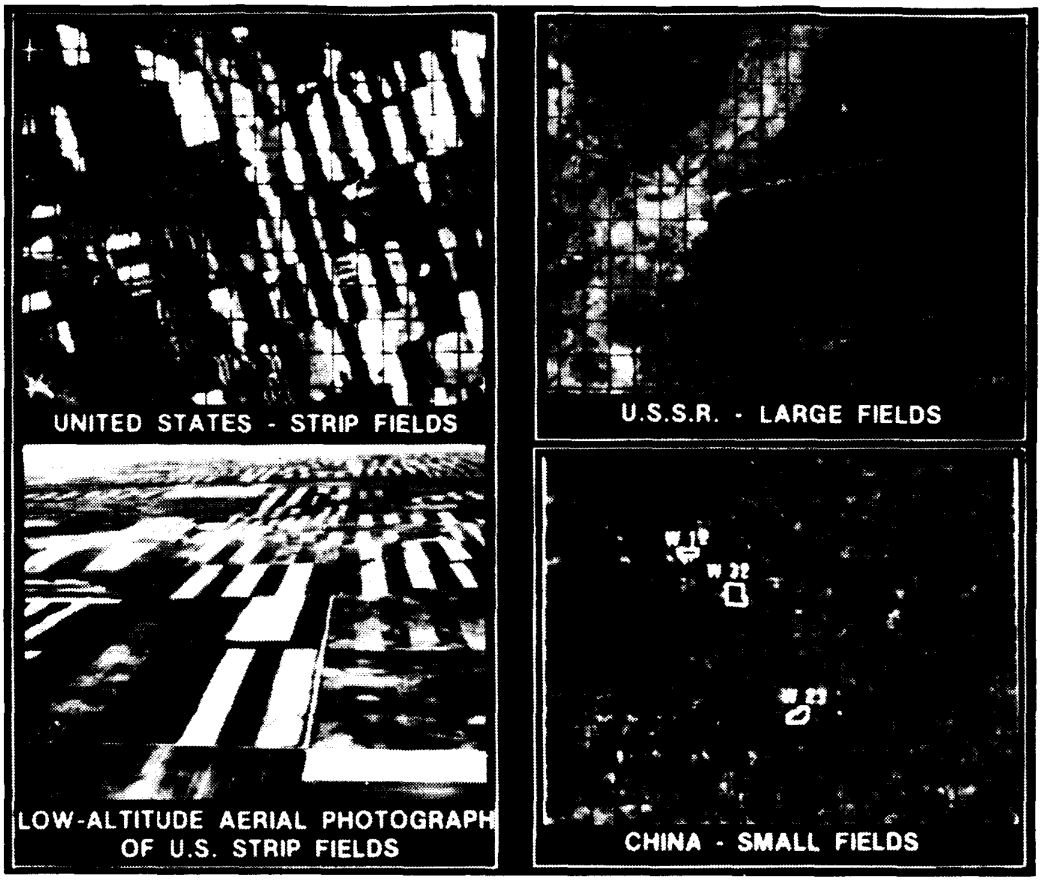



Figure 21.— Landsat segment images in the U.S., U.S.S.R., and China illustrating strip fields, large fields, and small fields.

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 U.S.S.R. would be expanded to include the region producing more than 90 percent of the U.S.S.R. total wheat production. The decision to expand the region to be inventoried in the U.S.S.R. was prompted by the lack of true production information for the Phase II U.S.S.R. indicator regions and thus the unavailability of a reliable estimate of the bias of the LACIE estimates for the U.S.S.R.

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 2 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 U.S.S.R.

## FOREIGN EXPLORATORY INVESTIGATIONS

Exploratory investigations in Argentina, Australia, Brazil, India, and People's Republic of China 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.

- Australia — Landsat data collected over Australia indicates field sizes and multitemporal signatures similar to those of the USGP and the U.S.S.R. Yield models have been developed for five states in Australia. A test of these models on 10 years of independent test data indicates they will support the 90/90 criterion. Crop growth stage prediction models developed in the U.S. have been implemented in Australia; but difficulties have been encountered in their use because of varietal differences from the U.S.; the model was designed for winter wheat with a dormancy period, but the Australian wheat does not go into dormancy.
- 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, two 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; this can again be largely attributed to differences in U.S. and Indian wheat. Indian wheat does not go into dormancy and has a shorter growth cycle.
- 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 field sizes in less populated frontier areas are similar to those in the U.S.S.R. In both of these countries, ancillary data are 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.
- 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 U.S. 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:

- Improved computer-aided Landsat data processing procedures
- Development of regression models for estimating wheat yield
- Development of growth stage models for wheat
- Improved sampling efficiency through stratification based on Landsat data
- 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:

- 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.
- Analysis techniques to deal more effectively 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.
- The possible need for Landsat coverage at intervals more frequent 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.
- Crops in tropical regions with their distinctly different characteristics. Crop varieties and the remote sensing conditions tend to be significantly different in a region such as India.
- 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. Corn Belt.

- 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.
- 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.

## USDA USER SYSTEM

A decision was made by the 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 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:

- To have a USDA facility (equipment, personnel, procedures) capable of performance testing and evaluating remote sensing technology against USDA requirements.
- 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

The many results and achievements from the 3 years of LACIE experimentation can be usefully summarized in the context of the originally stated experiment objectives as set forth in reference 1.

"Demonstrate an economically important application of repetitive multispectral remote sensing from space." The results of LACIE have confirmed the utility of remote sensing technology, in its current state, to provide improved commodity production forecast information. Repetitive multispectral remote sensing data played a vital role in identification, mensuration, and condition assessment of the wheat crop. The periodic spectral data from Landsat permitted the identification and mensuration of the growing wheat crop, without the use of ground-observed crop identity data. This latter capability is key to crop forecasts in inaccessible foreign regions. The periodically acquired Landsat data was also successfully used to monitor the condition of the wheat canopy, which provided important corroborative data for confirming forecasts from the agrometeorological yield models. Experiment results defined a need for a periodicity even more frequent than the 18 days provided by Landsat in order to distinguish between crops with growth cycle differences of less than 14 days and to reduce the impact of data loss to cloud cover.

"Test the capability of the Landsat, together with climatological, meteorological and conventional data sources, to estimate the production of an important world crop." Wheat, the most important internationally traded crop, was selected as the test crop in LACIE not only because of its economic importance, but also because it is grown around the globe under a wide range of conditions. Therefore, the LACIE achievements provide a stepping stone from which to adapt remote sensing technology to other crops.

LACIE developed, engineered, and demonstrated solutions to the major problems associated with the acquisition and analysis of the Landsat, climatological, meteorological, and conventional data required for a global crop inventory. Landsat images from the LACIE test countries were successfully used to locate and delineate wheat-growing regions in each country. These regions were further stratified into uniform subregions using information derived from an analysis of the Landsat images. This stratification permitted the development of an efficient sample design and reduced the potentially immense data volume to a manageable load: for example, only 2 percent of the Landsat data was required to achieve accurate estimates of crop area within the survey region. Interactive computer procedures were developed for rapid and reliable analysis of the Landsat data to determine crop acreage and condition. Yield models were developed and successfully applied. These models use only those climatological, meteorological data available on a routine basis from the important global agricultural regions.

"Commencing in 1975, validate technology which can provide timely estimates of crop production." 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 available on Landsat-D 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, was demonstrated. The LACIE forecast accuracies for the Soviet indicator regions in 1976 indicated that accuracies achieved 1 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 was adequate to support the 90/90 criterion, and the at-harvest LACIE estimate was to within 1 percent of the Soviet estimate.

In the third year, U.S. results were significantly improved as a result of prior year modifications in the acreage estimation technology. The USGP production forecasts were to within 10 percent of the ESCS. Indications were that 90/90 estimates could be achieved for years in which crop conditions are not extreme in comparison to years on which the yield models were developed. The U.S.S.R. forecasts correctly predicted a spring wheat shortfall in August 1977 well before the November 1977 announcement of a shortfall in total grain and a February 1978 Soviet confirmation of a shortfall in the Soviet spring wheat crop. Additionally, LACIE met or exceeded its performance goal in the U.S.S.R. winter wheat area in 1977, correctly predicting a winter wheat bumper crop several months preharvest.

Exploratory investigations conducted in Australia, Argentina, Brazil, India, and the People's Republic of China provided valuable insight as to the similarities and differences among those regions and the areas studied more intensely in Canada, the U.S., and the U.S.S.R. These investigations indicate that LACIE acreage estimation technology will be applicable to Australia, Argentina, and Brazil, but may require improvements in the small-field regions within India and China. Yield model tests in these countries indicate that models less dependent on historic data may be required for China, Argentina, and Brazil.

"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." A data acquisition, storage, and analysis system, incorporating the state-of-the-art remote-sensing technology, was assembled and successfully operated in the U.S., Canada, and the U.S.S.R. Reports of acreage, yield, and production were produced according to a fixed reporting schedule. A large data base of Landsat, climatological, agronomic, and field research data was assembled for future technology development and assessment. This data base includes data from the U.S., Canada, U.S.S.R., Australia, India, Brazil, Argentina, and China.

"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." The analyst contact time required to analyze Landsat data, acquired at multiple dates over a 5- by 6-nautical-mile agricultural site (approximately 23,000 acres), was reduced from 10 to 12 hours in the first year of LACIE to 2 to 4 hours by the end of the experiment. The LACIE results further indicated that Landsat data could be acquired and analyzed within a 14-day period in an operational system.

"Provide a LACIE system design that will permit a minimum of redesign and conversion to implement an operational system within the USDA." The USDA designed and is in the process of completing the implementation of an application test system for further evaluation of the LACIE technology. All elements of the LACIE technology have been transferred to the USDA system. As a result of a realignment in Department priorities toward the end of LACIE, this technology is currently being utilized for crop condition assessment as opposed to the commodity production forecasting application evaluated in LACIE.

"Monitor and assess crop progress (calendar) from a surface data base and evaluate the model potential for yield from surface data." 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. The growth stage models are of key importance to the analysis of Landsat data and will also play an important role in advanced yield models. Phase III evaluations of these models indicated that improvements are required, particularly the development of a planting date prediction model. Extensive evaluations of the various yield models using 10 years of historic data indicated that the models worked well in forecasting yield near harvest. Exceptions were years where deviations in weather were extreme or regions where rapid changes in technology were not detected by the crude trend analysis methods used in the modeling effort.

"Conduct a supporting research and development program to improve methodology and performance." At the outset of LACIE, needs for technology improvements were recognized and a research and development program involving the university and industrial research communities was organized. This effort has successfully contributed new technology developments in the following major areas:

- *Improved machine processing procedures* for Landsat data analyses that reduced analyst contact time by a factor of 3 during LACIE and permitted the first capability to reliably process multiple Landsat acquisitions acquired at several dates (multitemporal data).
- *Improved sampling strategies* that utilize Landsat imagery, agricultural, and climatological data to stratify the survey region into homogenous subregions to reduce sampling variance and increase efficiency. The improved sample strategy for the U.S.S.R. permits a reduction in the data processing load by 20 percent through increased sampling efficiency.
- *Development of "signature extension" methodology* that will

potentially result in further significant reductions in Landsat data analyses costs. The "signature extension" methodology will permit the definition of "signature strata" and a technique for efficient sampling of the signature "population" for manual identification. Using these techniques, manual identification of the crop signatures can be rapidly and inexpensively extended through computer analyses to identify and measure the crops of interest.

- *Development of potentially improved yield models* that require less historic data and thus may show improved performance in foreign regions with little or no reliable historic data, such as China, Brazil, and Argentina.
- *Development of improved crop development stage prediction models* is necessary to both Landsat data analyses and yield model improvement. The construction of a comprehensive research data base from an ongoing field measurements program was accomplished.

"Establish an objective test and evaluation program to quantify the results from the research and development activities." A test and evaluation effort was designed and successfully conducted throughout the three phases of LACIE. This effort was extremely important in that it permitted a relatively inexpensive and informed selection of a particular technology configuration from among many alternatives prior to evaluation on a global scale. The test and evaluation effort was successful in evaluating all major components of the technology produced by the research and development program.

# 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 multiagency 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. Conversion practices assessment
7. Pollution detection and impact evaluation

While all seven requirements are of major importance to the USDA, 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.

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