In the late 1960's, work began on aircraft and space remote multispectral sensing systems for agricultural applications. The Laboratory for Application of Remote Sensing (LARS) at Purdue University did much of this initial work and showed how to use data from multispectral sensors to classify major agricultural crops.

The corn blight watch experiment in 1971 demonstrated that a single crop —i. e., corn—could be identified by multispectral techniques and that variations in crop health —e. g., blight infection—could be mapped with multispectral data. The corn blight program showed the validity of the concept using aircraft, but it took experiments on Apollo 9 to demonstrate[3] that crops could be recognized and mapped from space.

Early experiments conducted with Landsat over a series of test sites—e, g., the joint U.S. Department of Agriculture (USDA) /Canada spring wheat program[4]—showed clearly that Landsat data could provide useful information, though their ability to separate similar crops like spring barley and wheat was limited.

The National Aeronautics and Space Administration's (NASA) LACIE (Large Area Crop Inventory Experiment)[5] was designed to extend the early wheat test results to other wheat areas of the world. While success was claimed for the LACIE program, it is clear that major questions remained about the ability of Landsat data to discriminate between crops and about the negative effects of extensive cloud **cover. These** problems: 1) reduced the effectiveness of the system to assess crop area, a major objective of LACIE; and 2) severely limited the ability to use satellite data during the growing season.

The results of the U.S. /Canadian spring wheat experiment led to two conclusions, that: 1) Landsat data are at their best when used to assess the stress conditions of the agricultural system, and 2) a system was needed to allow daily computer simulation of the agricultural scene using basic modeling of soils, precipitation, solar radiations, and plants.

These conclusions implied that it was possible to develop a cost-effective crop assessment system. Such a system should reduce concentration on crop area mapping during the year in question from Landsat, and emphasize instead crop yield relationships inherent in the crop stress information available from the Landsat spectral data. A crop simulation system (conclusion 2) would provide the framework in which to use the Landsat crop stress information as well as provide useful crop assessments when clouds obscured the field of view.

Development of the crop simulation system, initiated in 1973,[6] concentrated on the use of the meteorological satellite data to overcome the limitations of ground meteorological reporting stations. This approach had the distinct advantage of offering the potential of a near continuum of the meteorological data needed to run plant simulation models. The system was first tested in Iran; [7] later tests were made in the United States under the NASA LACIE programs. The results showed the metsat-based simulation system to be sound, but in need of further development.

In **"1976,** another test of the system was run to test the ability of the system to assimilate Landsat crop condition information and thereby improve yield estimates; it showed that Landsat crop condition data did improve when yield estimates made by meteorologically derived yield simulation models were added,

In 1977, Earth Satellite Corp., a value-added company, placed the Landsat/metsat conjoint simulation system in commercial operation over various areas of the world. This value-added system, called CROP-**CAST™** now covers over 12 "different crops in 12 countries.

## Landsat Data Uses

Landsat data today offer opportunities to provide the following useful data to agricultural assessments:

- spatial distribution of potential crop yield classes in three to six unique categories;
- spatial location of winter kill in winter wheat areas of the world;
- area of irrigation in a crop area;

[1] "Remote Multispectral Sensing in Agriculture, " Bulletin 844, Laboratory for Application of Remote Sensing (LARS), Purdue University, vol. 3, Annual Report, September 1968.

[2] "Corn Blight Watch Experiment Final Report, Experimental Results, " NASA S['-353, 1974

[3] 'Crop Surveys From Multiband Satellite Photography Using Digital Techniques," LARS Information Note 032371, Purdue University, 1971

[4] An Investigation of the Feasibility of Developing a Semi-Automated System for Monitoring Spring Wheat Production, " prepared for the USDA (A. CS), contract No 123341024, May 1974, by Earth Satellite Corp, Washington, D.C

[5] 'The Large Area Crop Inventory Experiment (LACIE), ' in Proceedings of the NASA Earth Resource Survey TM X-58168 JSC 09930, June 1975, Houston, Tex

[6] "Iran Agriculture Program Evaluation of Techniques and Procedures, " prepared for the Ministry of Agriculture Iran, Interim Report lune-October 1974 Earth Satellite Corp., Washington, D C

[7] "CROPCAST Crop Reports, " vol 5, issue 15, Aug 15, 1982, continuing series of CROP Reports, prepared by Earth Satellite Corp

- areas of abandonment —i. e., planted fields that are not harvested because of low yield or other reasons;
- replanting areas—i .e., areas where another crop is sown in the spring following losses to a winter crop;
- soil moisture distributions at planting times;
- snow cover and perhaps depth assessments;
- winter wheat crop area at spring green-up; and
- flood area mapping and crop damage assessment.

USDA started using some of these Landsat-derived data on a routine basis in 1980. CROPCAST™ introduced some of the Landsat data in 1977 and expanded their use in 1983, after negotiating a program with the Swedish Space Corp. in Stockholm to provide near-real-time Landsat analyses directly from the Swedish Landsat station at Kiruna. The Swedish analyses provide Landsat data to CROPCAST™ in 4 to 5 days after acquisition. This compares favorably with the scales of 4 to 5 weeks for the USDA Foreign Agriculture Service operation in Houston.

In addition to the highly dynamic, real-time applications discussed above, Landsat data are used in various other ways to assist with agricultural problems:

- soil maps are prepared over areas that have limited conventional soils data,
- Landsat data are used in the design of a crop area sample survey design, and
- irrigation potential can be mapped using Landsat data.

## Specific Examples of Key Landsat Information Applications

Operational use of Landsat data in agriculture centers primarily on the delineation of stress and irrigation potential. Some recent examples drawn from CROPCAST™ operations include:

- The 1983 delineation of drought stress in the Odessa region of the U.S.S.R. The meteorological models indicated dry conditions and stressed plants, but Landsat provided positive evidence that this was true.
- The 1983 confirmation of drought stress in Rumania and other Eastern Europe areas.
- The 1980 delineation of the drought stress in soybean areas on the west side of the Mississippi in Arkansas. The meteorological system had indicated general problems, but Landsat data provided a detailed inventory of the stressed fields.
- In 1981, China was undergoing drought in the Bejing area, The meteorological models and ground reports of drought conflicted because of the extensive use of irrigation in the area. Landsat data ordered from the Japanese ground station provided verification of a serious decline in the irrigation reservoirs and the existence of some crop stress.

These few examples show the value of Landsat data to confirm, and thus to add confidence to, agricultural assessment worldwide.

## Meteorological Satellite Data Uses

Meteorological satellite data from both geosynchronous and polar orbiters are used routinely in the CROPCAST™ Agricultural Simulation System. The AgRISTARS program also includes plans to use them on a routine basis because they provide a quantitative source of precipitation estimates for many value-added meteorological services in the United States and overseas.

In the current CROPCAST™ system and in the planned AgRISTAR in 1986, the data from the geosynchronous meteorological satellite from the United States, the European Space Agency, and the Japanese provide a primary input to a global analysis of rainfall and solar radiation—key factors in plant simulation models.

The manipulation and analysis of metsat data by Earth Satellite Corp. provides a useful example of how value is added to primary satellite data. Data from the U. S., Japanese, and European metsats are delivered to Earth Satellite's offices via the National Oceanic and Atmospheric Administration (NOAA) and NASA facilities. Earth Satellite takes facsimile photographs received over this system, converts them to digital form and enters them into a common grid system with various other kinds of data. After processing by computer models, analyses of soil moisture, plant growth, stress, yield, etc., are produced. The spatial resolution of these analyses, obtained with the use of the satellite data, is unobtainable in any other way.

Data from the polar-orbiting NOAA satellites* are used in the CROPCAST™ (and will be used in future AgRISTARS programs) in two ways; one is to supplement the geosynchronous data at latitudes above about 50° N and S, the other is to make use of the resolution (1 km) and spectral capabilities of the polar orbiters to map vegetation, flooded lands, and snow cover.

The ability to map vegetation is made possible by sensors operating at wavelengths of 500 to 700 nanometers and 800 to 1,200 nanometers. These spectral bands measure the level of plant reflectance in the red and infrared parts of the spectrum in the same way

* From the automatic very high-resolution radiometer (AVHRR)

that the Landsat multispectral data are used. The l-km resolution will only resolve large fields, but the spectral capability provides excellent delineations of vegetation stress over large areas.

The low-resolution, low-cost data from the polar orbiters have many advantages in comparison with higher resolution Landsat data; among them are daily coverage and broad area vegetation condition mapping. These attributes make the data very attractive to customers of value-added services, to the future USDA AgRISTARS program, and to the U.N, Locust Program. The following examples illustrate some actual uses of these data by CROPCAST™ since 1980.

- The U.S.S.R. coverage by Landsat is limited to the western half. In 1982, polar-orbiter data were used to map crop stress in the U.S.S.R. spring wheat belt, and thereby accurately to assess yield.
- In 1973, drought and fires dotted the cacoa areas of west Africa. CROPCAST™ used these data to delineate the drought area and to estimate the location and extent of the damaging fires.
- In 1980, polar-orbiter vegetation analyses were used to map the extent of the drought in the United States.
- In 1981, 1982, and 1983, polar-orbiter vegetation analyses were used to assist in assessing sugar beet yields in the European Community and the U.S.S.R.

In the foregoing examples, the use of only polar-orbiter data was discussed; however, conjoining data from the metsat and Landsat systems leads to cost-effective ways to use these data in agricultural assessments.

## Conjoint Applications of Landsat and AVHRR Meteorological Satellite Data

Landsat data by themselves have some significant limitations—e.g., the satellite views the same point on the ground at intervals of only **16** days, thereby reducing the data's potential to monitor short-term changes in crop condition and other factors. On the other hand, Landsat data offer higher resolution. Although polar-orbiter data possess lower resolution (1 km at best) the satellite views the same area once per day, in daylight, and once per night.

Conjoining data from both the Landsat system and AVHRR offers improved confidence in delineating vegetation stress because Landsat data provide calibration samples on which to "tune" the AVHRR data. Tests conducted by Earth Satellite Corp. indicate that AVHRR data used in this way over the U.S.S.R. can provide accurate crop stress information at a cost significantly less than that obtained from Landsat alone. The data are also available more reliably because the daily passes allow cloud screening not possible with Landsat.

NOAA polar-orbiter data will be used more and more in agriculture as users learn how to acquire and process the data. Data from Landsat, SPOT, or other higher resolution satellite systems will continue to be important for calibrating these data.