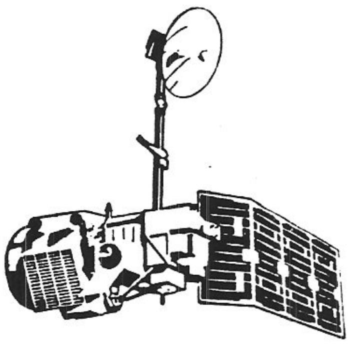
85-05

REMOTE SENSING

FOR

AGRICULTURE



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Remote Sensing for Agriculture

SUMMARY

The U.S. Department of Agriculture (USDA) has a long term program of research, development, testing, and evaluation of aerospace remote sensing to meet data and information needs about land use and crop production. An integral part of the USDA's statistical program as administered by the Statistical Reporting Service (SRS) is to provide accurate and timely estimates of crop areas under production. This information is used by farmers and agri-business to make marketing and production decisions. This information is also required by policy makers when making decisions affecting the national economy.

The USDA, other Federal agencies, and State governments also have important responsibilities in the areas of land and forestry management and land use planning. The loss of prime agricultural land, increased urbanization, deforestation, and environmental impacts of pollution are concerns facing the nation. In addition, the importance of agricultural exports to the U.S. economy are such that information on global crop production is necessary for marketing and policy decisions.

The USDA in cooperation with other Federal and State agencies uses information from different satellites. The primary source of such data has been from the Landsat satellite's multispectral scanner. These data are used to support programs to estimate areas planted to different crops and to develop land use inventories. Thematic Mapper data from the Landsat satellite is being evaluated for crop identification, land cover separability, and forest species discrimination. Other satellites such as the NOAA 6 and NOAA 7 obtain data from Advanced Very High Resolution Radiometers (AVHRR). The AVHRR data is being evaluated for its ability to monitor vegetative conditions and plant stress.

The use of the various satellite data first involves obtaining ground to pixel registration using third order linear transformations. Discriminant functions are developed from pixels matched to ground truth data. The discriminant functions are then used to classify all elements in a satellite scene. Regression estimators are used to estimate the population parameters. To support the use of satellite data, considerable research is underway to enhance the computer processing. Super computers such as the CRAY IS are being used and efforts are underway to obtain more efficient programs for the various stages of processing.

BACKGROUND

The United States Department of Agriculture has been an extensive user of remote sensing products since the early 1950's when it began using aerial photography. A primary use was to certify the amount of acreage planted to particular crops in order for farmers to qualify for farm subsidy programs. Other Agencies in the U.S. Department of Agriculture such as the Forest Service and Soil Conservation Service use aerial photography to monitor land use and to evaluate timber resources.

One of the primary needs of the U.S. Department of Agriculture is timely estimates of crop acreages. These estimates each year are based on a sample survey utilizing an area sampling frame. The area sampling frame is basically the land mass of the United States that has been stratified into different types of land use. Heavy reliance is placed on the use of aerial photography to delineate the land use boundaries. A random sample of about 16,000 segments of land is selected from the frame and their physical location is identified on county maps and aerial photographs. Figure 1 illustrates such an aerial photograph with a sample segment outlined. During the survey, interviewers who have received training on interviewing and map reading procedures locate the sample segments and personally interview each farm operator with land in the segment. Land operated by a single operator is called a tract. The interviewer identifies each field within the segment by drawing boundaries on the photograph. The interviewer also records the size of each field, the land cover or crop planted and the acres within each field. A field is defined as a continuous block of land containing the same crop or land cover. The sample frame construction and sample survey are time consuming and expensive processes; therefore, the survey is primarily designed to produce the most reliable estimates at the national level. One of the goals of the remote sensing program carried out by the Statistical Reporting Service is to use remotely sensed data to improve the state and local estimates without increasing the size of the sample survey. Related goals are to improve the design of the area frame sample and to improve land cover information needed by other units in the U.S. Department of Agriculture.

The first chance for the Statistical Reporting Service to gain experience with satellite digital data processing was when Landsat I was launched in 1972. Since that time the Statistical Reporting Service and other agencies in the U.S. Department of Agriculture have been deeply involved in learning how to use satellite information to improve crop acreage estimates and to evaluate the land uses and renewable resource inventories in the United States. Figure 2 displays the launch history of the Landsat series.

TECHNICAL OVERVIEW

The purpose of this section is to provide characteristics of the satellites used for agricultural purposes and how their data are used. The primary satellite used for agricultural purposes has been the Landsat series, but research is underway to evaluate data from the NOAA 6 and NOAA 7 satellites. Table 1 gives a brief description of the characteristics of these satellites. Both satellites are sun-synchronous, polar-oriented satellites. The primary difference between the satellites is in the scanners used. The Multispectral and Thematic Mapper Scanners have a swath width of 185 km, compared to the

FIGURE 1 - AREA SEGMENT DIVIDED INTO TRACTS AND FIELDS

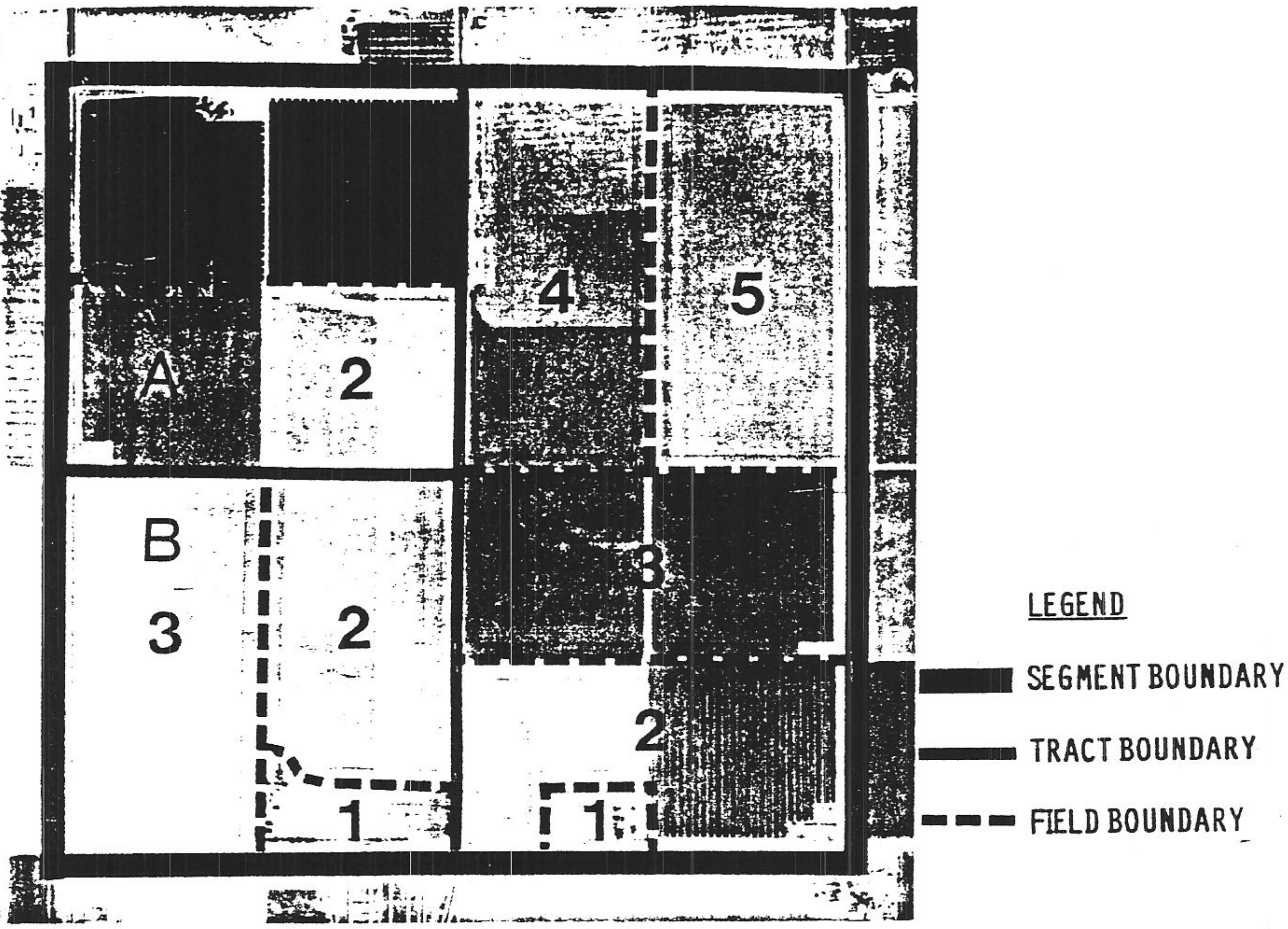


FIGURE 2 - **Launch History of Landsat Observatories**

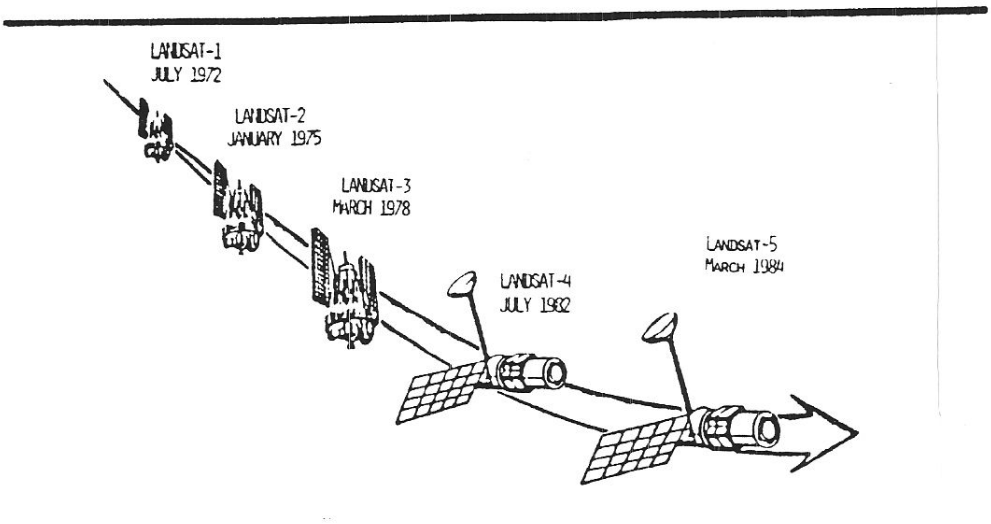


TABLE 1. CHARACTERISTICS OF U.S. SATELLITES USED FOR AGRICULTURAL PURPOSES

ORBITAL PARAMETER	LANDSAT 5 *	NOAA 6-7 **
ALTITUDE	705 KM (438 MI)	810 AND 850 KM
PERIOD (REVOLUTION TIME)	99 MIN 14¼ REVS PER DAY	103 MIN 14 REVS PER DAY
TIME OF EQUATORIAL CROSSING (DESCENDING AND LOCAL TIME)	9:45 AM	7:30 AM AND 2:30 PM
ORBIT	SUN-SYNCHRONOUS/POLAR	SUN-SYNCHRONOUS/POLAR
COVERAGE DURATION	16 DAYS (233 REVS)	12 HOURS
SENSORS	MULTI-SPECTRAL SCANNER THEMATIC MAPPER	ADVANCED VERY HIGH RESOLUTION RADIOMETER(AVHRR) AUTOMATIC PICTURE TRANSIMISSION (APT) HIGH RESOLUTION PICTURE TRANSMISSION
SWATH WIDTH OF SENSORS	185 KM (115 MI)	2600 KM

*LANDSAT 4 DATA USER'S HANDBOOK
**BACKGROUND INFORMATION FOR CIVIL SPACE REMOTE SENSING, U.S. DEPT. OF COMMERCE

TABLE 2. CHARACTERISTICS OF U.S. REMOTE SENSING SENSORS

WAVE LENGTH IN ELECTROMAGNETIC SPECTRUM (MICRO METERS)				SENSITIVE TO
BAND	MSS	TM	AVHRR	
BLUE		.45-.52		CHLOROPHYLL
GREEN	.50-.60	.52-.60		CHLOROPHYLL
RED	.60-.70	.63-.69	.58-.68	CHLOROPHYLL
REFLECTIVE INFRARED	.70-.80 .80-1.1	.76-.90	.72-1.10	VEG. DENSITY
		1.55-1.75 2.08-2.35		WATER IN LEAVES
			3.55-3.93	
THERMAL INFRARED		10.4-12.5	10.3-11.3 11.5-12.5	PLANT HEAT STRESS
RESOLUTION (PIXEL)	80 M	30 M (120 M FOR THERMAL)	1.1 KM	

MSS-MULTI-SPECTRAL SCANNER
TM-THEMATIC MAPPER
AVHRR-ADVANCED VERY HIGH RESOLUTION RADIOMETER

2600 km to swath width of the sensor on the NOAA satellites. This means that the repeat time for the LANDSAT 5 satellite is 16 days. In other words, it takes 16 days for the satellite to repeat itself over the same area, while each NOAA satellite makes two complete coverages of the earth every day. Figure 3 displays this in the form of a picture. The LANDSAT scene is very narrow compared to the scene measured by the NOAA satellite. This also affects, as will be shown later, the ability to use this data for agricultural purposes.

At this point it may be helpful to define the term satellite data. A report by Hanuschak and others (1979) provides an excellent description. The scanners measure energy reflected and emitted from the earth's surface. Figure 4 depicts a remote sensing model. The energy from the sun is either reflected back into space or is first absorbed by an object and then emitted back to space. The combination of the two sources of reflected and emitted energy represent the total spectral response of an object that can be measured by the scanners in the different bands of the electromagnetic spectrum. Table 2 shows the different characteristics of the remote sensing scanners. Landsat 5 contains the Multispectral Scanner and a Thematic Mapper Scanner. The smallest area for which a spectral response can be recorded is called a pixel. The size of the picture element or pixel for the Multispectral Scanner is 60 meters, while the size for the Thematic Mapper is 30 meters, except for the thermal infrared band which has a pixel size of 120 meters. The Advanced Very High Resolution Radiometers (AVHRR) in the NOAA satellites has a picture element size of 1.1 kilometer. The Multispectral Scanner has four bands with light intensity readings for green light, red light and two infrared wave lengths. The Thematic Mapper has seven different bands covering a wider range of the electromagnetic spectrum. The AVHRR scanner covers an area of the electro-magnetic spectrum that overlaps that of the Multispectral and Thematic Mapper Scanners. The primary difference is that the size of the picture element is much larger.

The total spectral response for every pixel on the earth's surface can be represented by four measurements using the Multispectral Scanner and seven measurements using the Thematic Mapper. The set of measurements for each pixel is called a signature. The primary use of the satellite data is to rely upon the spectral signature of each pixel to separate crops by type and distinguish land uses. It is only to the degree that the spectral signatures for different crops and land uses can be separated that satellite data can be useful. Statistical analysis of the digital data can be used to estimate the the area covered by different types of land use. Figure 5 shows a graphical representation of the Multispectral Scanner wave length measurements compared to those from the Thematic Mapper. Note that water only provides a measurement in the low end of the electro-magnetic spectrum, while soil and vegetation can be measured across the entire range of the spectrum. The reflectance intensity for soils and green vegetation show considerable variability across the electro-magnetic spectrum. Green vegetation reflectance intensities vary considerably in band 3 from the Multispectral Scanner. This graph also shows there are portions of the electro-magnetic spectrum where it is difficult to separate soils from green vegetation. In the near infrared portion of the spectrum, soils and green vegetation have reflectance intensities that are very close to each other. This points out the need to have scanners that cover a wide range of the electro-magnetic spectrum.

FIGURE 3 - TYPES OF SATELLITES

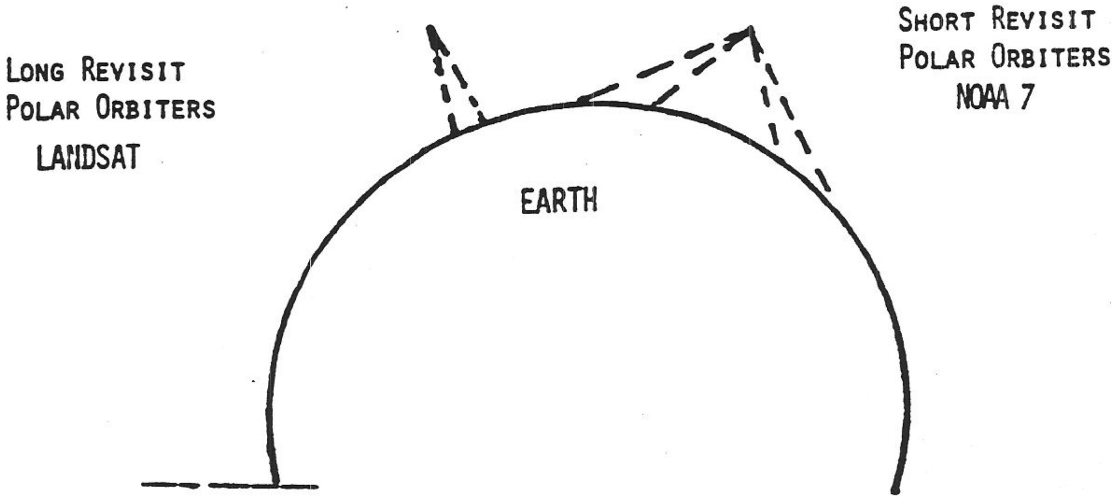


FIGURE 4 - REMOTE SENSING MODEL

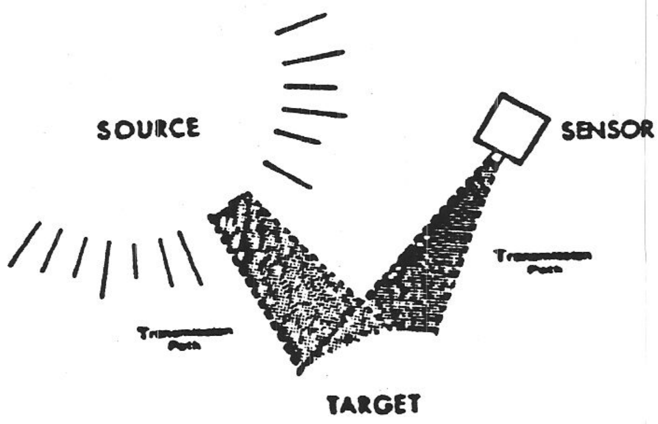


FIGURE 5 - SPECTRAL BANDS OF LANDSAT SENSORS

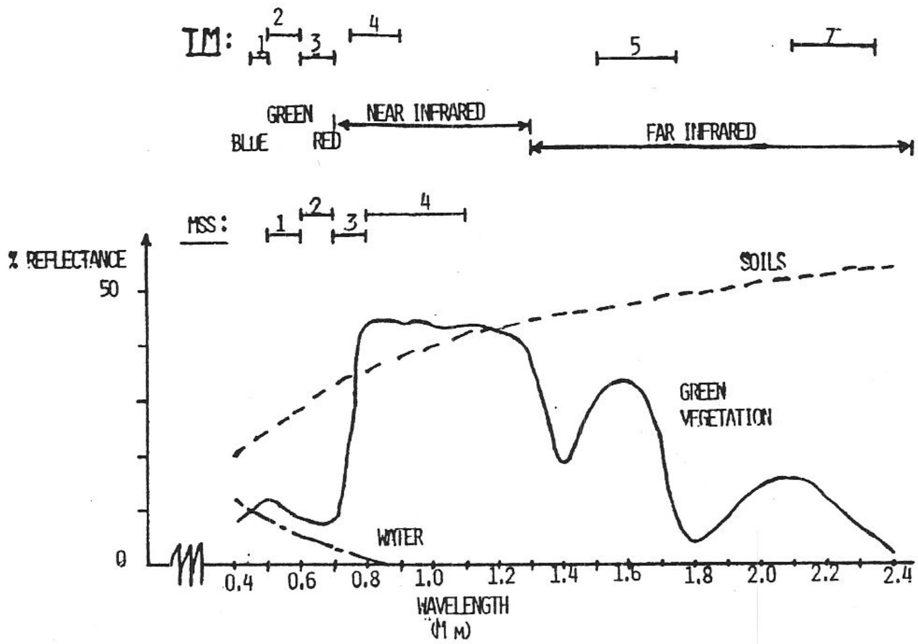
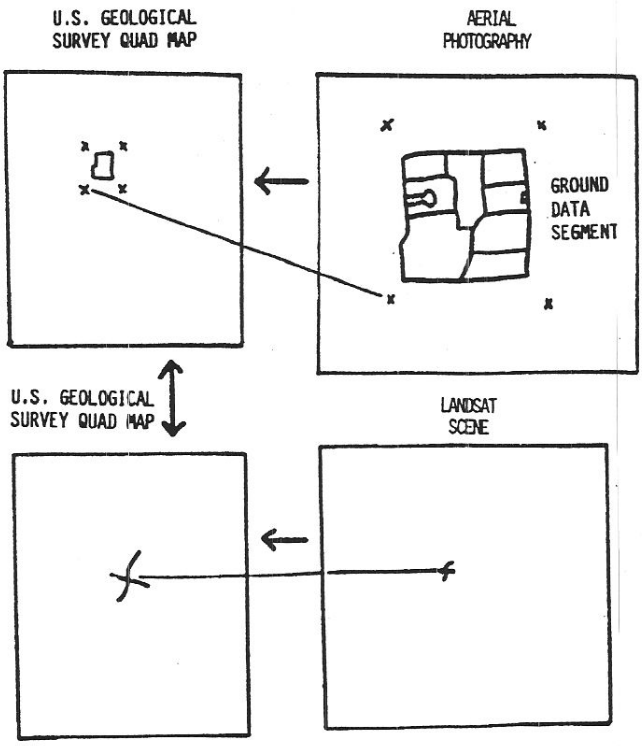


FIGURE 6 - REGISTRATION



Another use of the digital data is to use image processing as described by Star (1985) to convert the digital recordings into images. These images can be printed in photo form which are used for visual photo interpretation purposes to identify different categories of land use.

The next part of this section will describe how satellite data are actually used. First, it is necessary to classify the digital recordings from each of the sensors. One of the early findings was that it is necessary to accurately identify the content of a sample of pixels so that statistical procedures can be used to classify the entire set of pixels in a satellite scene.

The area frame sample survey conducted each year is used to provide a sample of "ground truth" data. The actual content of fields in sample segments can be linked with the spectral signatures of the pixels in the sample field. In other words, the pixels in sampled corn fields also have spectral signatures. The statistical relationship between spectral signatures for known crop types or land uses can be used to classify an entire Landsat scene.

The first step is to obtain accurate ground to pixel registration. To effectively use satellite data for crop estimation purposes, it is essential to be able to accurately locate each pixel in a Landsat scene, so that these pixels can be correctly linked to sample fields. Figure 6 shows a diagram of the procedure involved. Cook (1982) described a third-order linear transformation that maps each Landsat pixel to a map base. The process of relating the Landsat row-column coordinates with map latitude-longitude coordinates using a mathematical process is called registration. The process begins by linking each, pixel in the Landsat scene to a map base using a coordinate digitizing process. A coordinate digitizing process is also used to link each field in the sample segment to the same map base. In other words, the coordinates of the boundaries of each sample field must be translated to the map base. This process assumes that the field interviewers were able to accurately delineate the boundaries for each sample field.

The four spectral responses from the Multispectral Scanner or the seven spectral responses for a pixel from the Thematic Mapper for a pixel are recorded in a vector format. Then it is possible to compute a mean vector and a covariance matrix for all pixels linked to sampled corn fields and similar mean vectors and covariance matrices for other crops and land uses of interest. The sample of pixels linked to ground truth enables the use of discriminant analysis to differentiate between crops and land uses in the entire population.

Figure 7 shows discriminant functions based upon two bands. All pixels with data falling in the ellipse labeled S will be called soybeans. This shows that the spectral signatures for some kinds of land cover cannot be easily separated into specific categories. For example, the mean and covariance matrix for all pixels in the ground truth segments that contain corn do not overlap with the mean and covariance matrix for pixels in the ground truth segments that contain grasses. However, the mean and covariance matrix representing pixels containing dense woodland shows that some of the pixels have spectral signatures that fall into the same range as the spectral signatures recorded for corn or grasses. This means that when using the quadratic discriminant functions, some of the corn pixels will be incorrectly identified as dense woodland, and some of the dense woodland pixels will be incorrectly classified as corn. The quadratic discriminant functions are based upon analysis of the pixels matched to the ground truth data and are supplemented with prior probabilities. For example, one can determine a prior probability that the land in a certain portion of a state is more likely to contain corn than dense woodland.

Once the discriminant functions have been developed, every pixel in a satellite scene can be classified into a land use or crop type. In other words, every single pixel in the satellite scene can be given a label identifying what it contains. The classified pixels can be used to obtain estimates of the area covered by different land uses by developing a regression estimate based upon the relationship between the satellite data and the ground truth data .

Some of the limitations of the use of satellite imagery are as follows:

Cloud Cover. Each Landsat satellite passes over a given area only once every 16 days. It is possible for an entire crop season to pass and not obtain a single good Landsat scene for a region without cloud cover. Whenever there is cloud cover, the Landsat data cannot be used.

Timeliness. Due to delays in receiving data because of cloud cover and the time required for processing, estimates of acres planted and land use based on satellite data are not received until late November. By that time their primary use is to improve the estimates of acres planted obtained using only survey data.

Need for Current Ground Data. Figure 8 shows the path of the satellite orbits as they cross the United States. As a satellite passes in a southward direction, it covers a swath of about 115 miles. It will be 8 days before the adjacent 115 miles is covered by the satellite. The spectral signatures emitted by different types of land use and crops change as the crop season progresses. In other words, the spectral signature of corn fields on July 1 is considerably different than on July 8 or July 16. If there is cloud cover on the date the satellite passes over, it is necessary to wait 16 more days to hopefully obtain a usable scene. The development of the discriminant functions is very sensitive to the particular growth stage and conditions at the time the satellite passes over the scene. The discriminant functions will be different for the scene taken on July 1 than the scene taken 8 days later. It is also difficult to utilize discriminant functions for relationships determined in one year for the next year. This is because of the differences in planting dates and crop progress from year to year. Atmospheric conditions such as haze can also have subtle influences on the spectral signatures recorded for each pixel.

Computing Needs. Another limiting factor to wide use of this methodology is the requirement to process massive amounts of data. Landsat scenes that cover entire states are completely classified. In some cases more than one scene for the same area will be used. For this heavy concentrated processing, super computers have been found to be very useful and cost effective (Ozga 1984). A super computer is a Single Instruction Multiple Data (SIMD) machine characterized by very fast processing in a vector or parallel mode in which several items of data are being operated on simultaneously. The items of data in Landsat processing are the reflectance values for the pixels. Due to the

FIGURE 7 - DISCRIMINANT FUNCTIONS

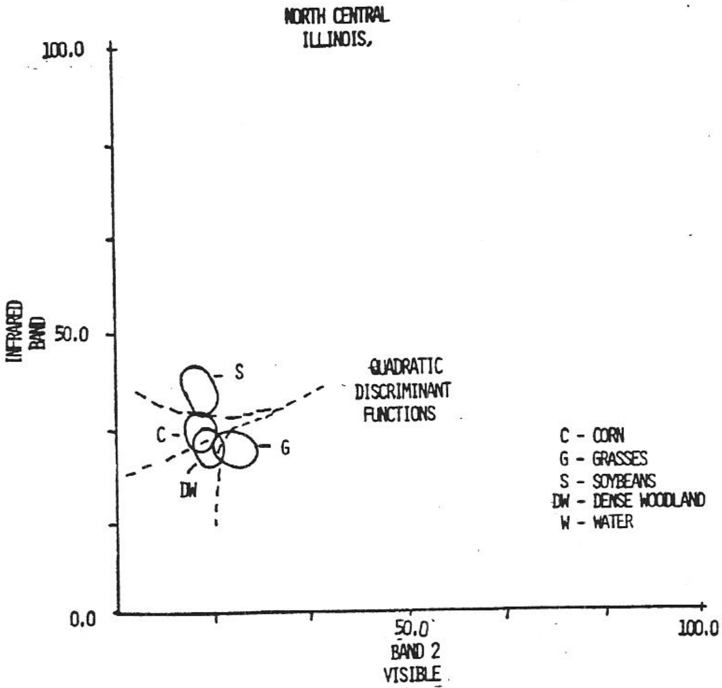
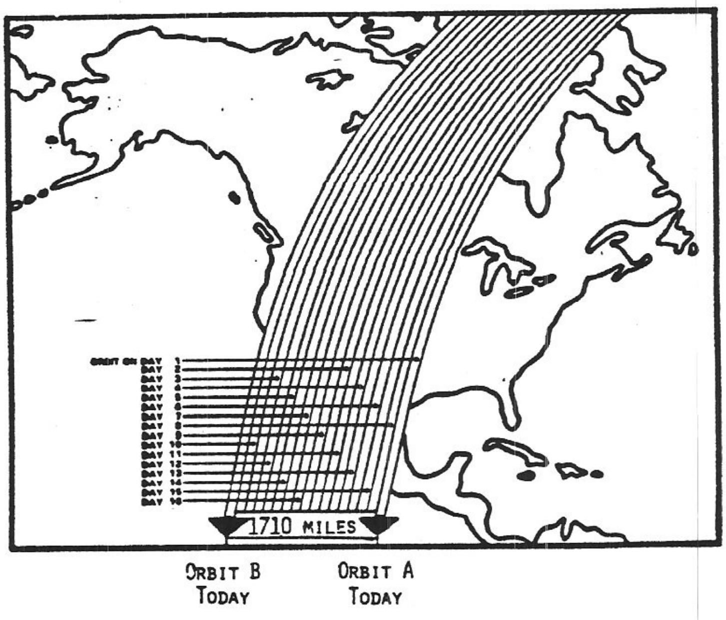


FIGURE 8 - LANDSAT ORBITAL PATHS



- SUNSYNCHRONOUS NEAR POLAR ORBIT CROSSES EQUATOR 9:45 A.M.
- ORBIT PERIOD 98.9 MIN.
- 14 ORBITS/DAY
- 16 DAYS BETWEEN REPEAT COVERAGE
- 107 MILES BETWEEN ADJACENT PATHS
- 1710 MILES BETWEEN EACH ORBIT

large amount of data handled, large input/output transfer rates are necessary. The two series of super computers used are the CRAY series from the Cray Research Incorporation and the CYBER 200 series from the Control Data Corporation.

USE OF SATELLITE DATA

The purpose of this section is to discuss some of the uses made of satellite data by the U.S. Department of Agriculture. The primary use of the Landsat data has been to improve the crop estimation program. The estimates of crop production are based upon two components - the area planted and to be harvested, and the yield per acre. The satellite imagery has been most useful to improve estimates of acres planted. The following paragraphs will describe how the satellite data are used in the basic area frame construction and how the satellite imagery is used to improve estimates from the sample survey.

Area Frame Construction - The basic procedure used to construct and maintain the area sample frame is documented by Fecso and Johnson (1981), and Houseman (1975). Conceptually, an area sampling frame is the total land mass of a state or region divided into sampling units (segments). Then the sampling process is a matter of selecting a sample of (n) segments out of the (N) total segments. In a practical sense, statistical and cost efficiencies are obtained through the use of stratification and two-stage sampling.

The first step in constructing an area frame is to identify categories of land use that will improve sampling efficiency. Some typical land use strata are intensive cultivation, extensive cultivation, rangeland, ag-urban and non-agricultural. Historically, the stratification has been done on a county by county basis using everything from aerial photographs and soil maps to general knowledge. Work as shown by Hanuschak and Morrissey (1977) has been underway to utilize Landsat materials to improve the stratification process. The general procedure is to overlay county maps onto color Landsat imagery. The Landsat imagery is photo interpreted to determine land use while the county maps provide physical features to use as stratum boundaries. In recent years this procedure has been used to construct new area frames in many states in the U.S. as well as in several other countries (Morocco, Thailand, Sudan, Zaire, etc.). The use of the satellite imagery can yield significant improvements in sampling efficiency when it aids in defining "crop specific" strata. Examples are the separation of dryland from irrigated areas, and the identification of areas with a concentration of a specific crop.

Within each land use stratum, a two stage procedure is used to select the sample of segments. First, the land mass within a stratum is divided into primary sampling units (PSU), each of sufficient size to contain 5 to 10 final sample units. The PSU's are digitized to obtain the land area. A replicated sampling scheme is used within each stratum to select PSU's with probabilities proportional to size. The selected PSU's are then subdivided into the number of actual final sampling units assigned to them and one is selected at random.

To date, satellite imagery has not been used for this stage of sample selection. However, there is considerable potential. First, satellite imagery could be used to help identify the boundaries of PSU's so that the area within each is more homogeneous. After PSU's have been delineated, they could also be grouped into substrata so that "similar" PSU's are grouped together. This may lengthen the "life" of an area frame if the basic stratification is enhanced by re-arranging PSU's into different substrata over time as land uses change.

Estimation - Another use of the Landsat data has been to use it along with the ground data collected during the June Enumerative Survey to obtain improved estimates of planted acres as shown Hanuschak, et al. (1982) and Sigman, et al. (1978). A regression estimator as described by Cochran (1977) utilizing both ground data from the area frame sample survey and classified Landsat pixels is used. The regression estimates of total acres in corn for example, can be described as:

$$\hat{Y}_R = \sum_{h=1}^{L} N_h \ \bar{y}_h \text{(reg) where}$$

$$\bar{y}_h\text{(reg)} = \bar{y}_h + \hat{b}_h (\bar{X}_h - \bar{x}_h)$$

$\bar{y}_h$ = The average acres of corn per sample segment in the h^{th} stratum.

$\bar{x}_h$ = The average number of corn pixels per sample segment as classified by the discriminant functions.

$\bar{X}_h$ = The average number of corn pixels per population segment as classified by the discriminant functions. This is based on the entire population of pixels in the h^{th} stratum.

$\hat{b}_h$ = The estimated regression coefficient between the number of acres (y_{hi}) and the number of classified corn pixels (x_{hi}) for the segments in the h^{th} stratum.

N_h = The population number of segments in the h^{th} stratum.

The variance of the regression estimator can be considerably less than that from the estimator based only on the sampled segments if there is a good correlation between satellite data and ground data. This procedure assumes that ground data are available to do the initial development of discriminant functions. The SRS experience indicates that the use of Landsat data without ground cover information is of limited value for estimation purposes. The use of Landsat data without corresponding ground cover data is of value for general land use stratification purposes; however, there are other limitations to the use of the Landsat data which require additional research for improvements. Images acquired by the Thematic Mapper sensor on the Landsat satellite are being evaluated for determining or monitoring the planted areas of different vegetables and fruit trees in New York State. Some work is also being done to determine to potential of Thematic Mapper data for crop yield estimation.

Forest Monitoring - The Forest Service in the U.S. Department of Agriculture uses satellite imagery in a variety of ways (AgRISTARS 1983). It is also used to evaluate and conduct a forest management program and to identify pest infested areas in national forests. It is used to conduct timber inventories for fire management purposes and to do research on environmental problems involving acid deposition. Some work is underway is to determine wave bands most useful for differentiating forest cover types. One situation was to develop a procedure useful for discriminating healthy conifer stands from those damaged by the Spruce Bug Worm. Work is also underway to evaluate the spectral separability for tree species such as Black Spruce, Jack Pine, Red Pine, Birch and Aspen. The Forest Service also uses image processing and the Geographic Information System to give fire fighters detailed information about any part of the forest including vegetation and elevations for fire fighting purposes.

Crop Condition Assessment - The Foreign Agricultural Service in the U.S. Department of Agriculture uses remotely sensed data to assess crop conditions for selected crops in some areas of the world. Reports of crop conditions are used as additional information when production estimates are made. Not much has been said about the use of the AVHRR scanner in the NOAA satellites. The advantage of the NOAA satellites for monitoring purposes is that they provide daily observations, while Landsat has a repeat time of 16 days. The trade off for daily coverage is resolution. The resolution of the AVHRR is in the one kilometer range. The primary use of the AVHRR data is in crop condition assessment. The data can be used to compute vegetative index numbers. The vegetative index numbers computed for all pixels may provide drought stress information that can be used to monitor crop moisture stress in the U.S. Great Plains or in other semi-arid regions of the world. Linear combinations of spectral bands that form physically different vegetative indexes have also been used to make quantitative estimates of leaf area index, percent ground cover, plant height, biomass, and plant population. Additional details about this procedure are provided by Perry and Lautenschlager (1982).

Land Use - Ground gathered data and Landsat Multispectral Scanner digital data are also analyzed to produce a classification of land areas into specific types called land covers (AgRISTARS 1983). The land covers include rangeland, cropland, forest, residential, commercial, industrial and various types of water. The analysis produces two kinds of output. First, acreage estimates with measures of precision, and second, photo products of the classification which can be overlaid onto maps at specific scales. State level acreage estimates are obtained and sub-state level land cover classification overlays and estimates are generated for selected geographic areas. These products are used in managing land and water resources. The Department of Water Resources in the State of California (Wall, et al., 1984) has long recognized the need for specific land use data as an input to state water planning. Over 9.9 million acres of land are irrigated in California. Since the late 1940's, the Department of Water Resources has been performing a continuing survey to monitor land use changes over the state. The land use survey system has limitations for making current statewide estimates of irrigated land. For example, only one-seventh of the state is surveyed in any given year. The photography can also only be taken once a year which greatly limits the ability to detect the cultivation of small grains which are double cropped in a multiple cropping scheme along with other crops. The Department of Water Resources has been cooperating with the National Aeronautics and Space Administration, the University of California and the Statistical Reporting Service in addressing the use of Landsat imagery and digital data to aid in the water management decision making. The purpose is to determine the proportion of the total area of the state that is irrigated in a given year and the distribution and area of specific crop types. The development has included testing both visual analysis of Landsat color composite imagery and computer assisted analysis of Landsat digital data.

Conservation and Pollution - Work in this area (AgRISTARS 1983) is largely still in a research mode. Some analysis has been done to determine if some conservation practices can be successfully detected in Landsat Thematic Mapper data. Present sensors cannot detect them with great accuracy. Thematic Mapper data are also being evaluated with ground truth data to monitor suspended sediment in lakes or rivers to measure water quality. Thematic Mapper and Multispectral Scanner bands 1-4 all appear to respond to changes in water quality.

FUTURE OF REMOTE SENSING

Figure 9 shows an overview of future satellites to be launched by the U.S. and other countries. The use of remotely sensed data has proven to be both practical and useful.

The primary goal in the future will be to make improvements in uses now being made of satellite data. The future sensors will provide improved resolution over more bands in the spectrum. This will improve the ability to discriminate between different crops and land covers. It will also improve the ability to monitor land use and crops for smaller areas than is now feasible. This will greatly improve estimates of crop acres planted in local areas such as counties (Battese and Fuller 1981). The smaller resolution and increases in the number of spectral bonds will provide additional challenges for computer processing, however.

Another gain will be to use the land use classifications to improve the stratification of the area sample frame used for agricultural surveys. It will be possible to develop crop specific stratification procedures.

Satellite data will be used more to monitor crop conditions. Some of the most important statistics published by the Statistical Reporting Service are monthly forecasts of crop production during the growing season. Hopefully, research will reveal how the daily AVHRR data from the weather satellites can be used to forecast crop yields.

In closing, it is probably safe to say that uses not even thought of today will be practical in the future.

FIGURE 9

FUTURE SENSORS

U.S. COMMERCIALIZATION (?)

- EOSAT- EARTHSAT, HUGHES, RCA
- LANDSAT 6 - 1989 LAUNCH
- LANDSAT 7 - 1991 LAUNCH

  SIMILAR TO LANDSAT 5, MSS EMULATOR, TM
  - 60 METER MSS, 4 BANDS
  - 30 METER TM, 7 BANDS (120 METER THERMAL)

FRENCH

- SPOT 1- LAUNCH FALL 1985
- SPOT 2, 3, 4
  - PUSH-BROOM, SOLID STATE
  - 10 METER PANCHROMATIC, 20 METER MULTISPECTRAL

JAPAN

- MOS 1, MARINE OBSERVATION, 1986 LAUNCH
- ERS 1, EARTH RESOURCES, 1987 LAUNCH
  - SOLID STATE, 50 METER RESOLUTION

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