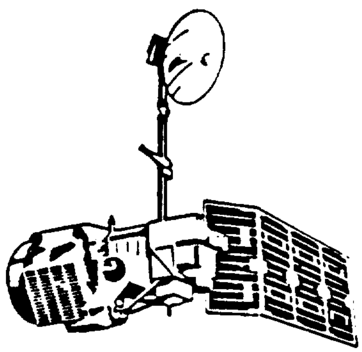
RSS * 86-05

APPLICATIONS OF REMOTE SENSING



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SUMMARY

The National Agricultural Statistics Service's strategy for using remote sensing for estimating crop areas is that remote sensing is another method of data collection that can supplement the existing data collection system, but not replace it. To improve crop acreage estimates, the goal is to integrate the two data collection systems through rigorous statistical methodology and by developing resource effective techniques.

This paper provides an overview of applications of remote sensing methodology and its strengths and weaknesses for measuring land cover.

INTRODUCTION

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 National Agricultural Statistics Service (NASS) is to provide accurate and timely estimates of crop areas under production. This information is used by farmers and agribusiness to make marketing and production decisions. This information is also required by policymakers when making decisions affecting the national economy.

The USDA, other Federal agencies, and State governments also have important responsibilities in 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 make information on global crop production necessary for marketing and policy decisions.

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 NASS approach to the use of remotely sensed data is to use it to supplement its basic sample survey program that currently provides estimates of crop acreages and other kinds of land use. Therefore, the following paragraphs will first provide an overview of procedures used in the operational sample surveys because these procedures are so closely linked to the use of satellite data. Then the use of satellite imagery to supplement this survey program will be discussed.

SAMPLE SURVEY ESTIMATES OF AREA HARVESTED AND LAND USE

The largest survey conducted by NASS to measure the area under cultivation for the different crops is the June Enumerative Survey conducted during late May and early June each year. The primary sampling frame is an area frame.

The basic procedures used by NASS to construct and maintain the area sample frame are documented by Fecso and Johnson (1981), and Houseman (1975). An area sampling frame is conceptually 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, agr.-urban, urban, and non-agricultural. 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 use 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 U.S. States as well as in several other countries including Morocco, Thailand, Sudan, Zaire. 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.

A random sample of about 16,000 segments of land across the United States is selected from the frame and their physical location is identified on county maps and on aerial photographs. 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. During the interview with each operator, the enumerator identifies each field within the segment by drawing the boundaries on the photograph. The interviewer also records information on a questionnaire which includes the size of each field, the land cover or crop planted, and the acres within each field actually planted. A field is defined as a continuous block of land containing the same crop or land cover. Figure 1 illustrates a sample segment.

Two estimates of the acres planted to each crop are obtained: a direct expansion estimate and a ratio estimate.

<u>Direct Expansion</u>. The acres planted to each crop are aggregated across fields to a segment total. The total acres of each crop in a segment are multiplied by the reciprocal of the probability of the segment being selected. The sum across all sample segments yields an unbiased estimate of the acres planted to each crop. The usual unbiased estimate of the sampling error is also determined as shown in Cochran (1977).

<u>Ratio Estimate</u>. One of the features of the overall area frame sample design is that a replicated sampling scheme is used. Replicates are rotated into and out of the sample so that 80 percent of the segments in the current sample were also in the previous year's survey. These matching segments provide an unbiased estimate of the acres planted to each crop each year. The ratio of the two estimates is multiplied by the previous year's direct expansion to obtain the ratio estimate of current year's planted acres.

The first official estimates of acres planted to each crop are published in late June each year. At this time, a forecast of the various crop acres to be harvested is also published. The acreage to be harvested is determined by using historic relationships between acres planted and acres harvested.

TECHNICAL DESCRIPTION OF SATELLITE DATA

This section describes 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. Figure 2 shows the launch history of the Landsat satellite. Table 1 briefly describes 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 with the 2600 km swath width of the sensor on the NOAA satellites. This means that the repeat time for the LANDSAT 5 satellite is 16 days. 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 shown later, our ability to use this data for agricultural purposes.

Hanuschak and others (1979) provide an excellent description of the term satellite data. 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 have a picture element size of 1.1 kilometers. The

Multispectral Scanner has four bands with light intensity readings for green light, red light and two infrared wave light intensity readings. 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 the pixel's radiometric data. The primary use of the Landsat data is to rely upon the radiometric data for each pixel to separate crops by type and to distinguish land uses. It is only to the degree that radiometric data for different crops and land uses can be separated that satellite data can be useful to NASS. Statistical analysis of the digital data can be used to estimate the area covered by different types of land use. Figure 5 shows a graphic representation of the Multispectral Scanner wave length measurements compared with those from the Thematic Mapper. Note that water provides a measurement only 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.

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 by land use.

USE OF REMOTELY SENSED DATA

This section describes how satellite data are 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, as described previously, 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 fields. 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. Effective use of satellite data for crop estimation purposes depends on the ability 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. The first phase is segment calibration anddigitization. Segment calibration involves a first-order linear transformation which links points on the segment photograph to a U.S. Geological Survey map base. Segment digitization is a computer aided process which records field boundaries indicated on the segment photograph into computer-compatible form. The calibration and digitization processes provide the ability of digitally locating every sample field relative to a map base.

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. The processes of segment calibration, digitization, and Landsat registration locates each sample segment in its corresponding Landsat scene to within five pixels of the correct location. This registration is adjusted to within 1/2 pixel of the correct location by overlaying line plots of segment field boundaries onto grayscale prints of Landsat images. This procedure allows accurate identification of all pixels associated with any 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. All pixels for each crop or type of land cover are processed through clustering algorithms. Each algorithm generates several spectral signatures for each land cover. Each spectral signature consists of a mean vector and a covariance matrix for that category's reflectance values. The sample of pixels linked to ground truth enables the use of discriminant analysis to differentiate between crops and land use 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 quadratic discriminant functions are used, 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 predicting what it contains.

Figure 9 shows that the discrimination process does not correctly classify each pixel. A regression estimator is used to adjust for this misclassification. The use of Landsat data along with the ground data collected during the June Enumerative Survey to obtain improved estimates of planted acres is explained by Hanuschak, et al (1982) and Sigman, et al (1978). A regression estimator using 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:

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

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

$\bar{y}_h$ = 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.

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 with the satellite data and 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 the potential of Thematic Mapper data for crop yield estimation.

There are some limitations to the use of satellite data.

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, cloudless Landsat scene for a region. Landsat data cannot be used whenever there is cloud cover.

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 from the signature on July 8 or July 16. If there is cloud cover on the date the satellite passes over, another 16 days must elapse for a possibly usable scene. The discriminant functions will be different for the scene taken on July 1 than the scene taken 8 days later. The timing of the overpass of the Landsat satellite relative to the stage of crop growth of the different crops also affects the relative efficiency of the Landsat estimator as shown in figure 10. It is also difficult to use 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 subtly influence 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, supercomputers are very useful and cost effective (Ozga 1984). A supercomputer 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 large amount of data handled, large input/output transfer rates are necessary. The supercomputers used have been the CRAY series from the Cray Research Corporation. In addition, machines from the CYBER 200 series from the Control Data Corporation have been benchmarked for use in classifying Landsat data.

RESULTS

This section contains estimates of crop acreages and areas of different land covers as derived using the Landsat regression estimator.

Crop Acreage Estimates - State Level

Tables 3 and 4 compare winter wheat and corn planted acreage estimates based on the sample survey and Landsat regression estimates. Note that the improved precision of the Landsat regression estimator over the survey estimate results in relative efficiencies exceeding 2. This means survey sample sizes would have to be doubled to achieve the same precision without the use of Landsat data. On the other hand, one could argue that the relative efficiencies should be higher because an entire Landsat scene can be classified rather than only sample segments.

Some specific reasons for limited gains in precision are:

- The area frame sample is designed to be most efficient to produce estimates of crop acreage on a stand-alone basis. Table 5 shows a description of the land-use strata in Kansas and the allocation of the sample to those strata. Note that the sample size in several strata is too small to allow development of discriminant functions and regression estimates. Usual sample estimates are substituted for these strata when computing the State estimate.

- Because of cloud cover problems, data for some satellite scenes may not be available for an entire crop season. Sample survey estimates must then be substituted; this reduces the gains in efficiency of the regression estimator. In addition, the timing of the availability of the Landsat scene to the crop growth stage may not be optimum (see fig. 10). If the satellite scene is not obtained at the optimum crop stage of growth, the correlation between the actual and classified pixel content will be reduced.

Crop Acreage Estimates -- County Level

There is a tremendous demand for estimates of crop acreages at the county level. While the area frame sample can be efficient at the State level, sample sizes are totally inadequate to produce county-level estimates. Some work has been done to use the Landsat regression estimator to obtain county-level estimates (Battese and Fuller 1981).

Table 6 shows the sampling error for county estimates of winter wheat acreage in a Kansas crop reporting district. Results in terms of relative precision are very encouraging. Sampling errors in some counties are less than 10 percent and hover around 15 percent in several other counties.Winter wheat is a major crop in Kansas; the question is whether the satellite estimates would be as precise for specialty crops or minor crops with small acreages.

Land Cover Estimates

The methodology described above to obtain Landsat regression estimates of crop acreage can also be used to obtain estimates of acreages for different classes of land cover.

Table 7 shows acreage estimates for different classes of land cover in Missouri. The sampling errors and gains in efficiency were similar to those obtained for specific crop acreage estimates.

Several factors need to be considered when estimating types of land cover:

- The area sample frame and sample allocation to strata are designed to be optimum for crop acreages. Sixty-seven additional segments were selected from the less intensive agricultural strata and nonagricultural strata to obtain the estimates for Missouri.

- Data collection costs for the area frame sample survey increased about 11.5 percent because of the additional time spent by the interviewers to identify and delineate the different classes of land cover and define adequate boundaries on the sample segment aerial photograph (May, Jones, and Holko 1985).

- Care must be taken to carefully define land covers into classes that can be readily identified and distinguished by visual observation. In addition, the minimum mapping size is about 2 to 5 acres. This means that trees planted around the border of a field may not always be separated from the field.

Several benefits can be obtained from the land cover studies. The land cover classification can be used to evaluate land cover for any land area within the State whose boundaries are recorded in a computer readable format. Acreage estimates for different areas can be produced. In addition, map products can also be obtained. Photo products of the classification can be overlaid onto maps at specific scales. However, this approach depends upon the use of ground truth data for classification and estimation purposes.

<u>Crop Acreage Estimates</u> -- <u>Specialty and Minor Crops</u>

A recent study (Gordon, 1985) investigated the use of thematic mapper imagery to obtain an inventory of fruit trees in the State of New York. The basic findings reported in this study are:

(1) "As a single class, orchards in New York State (and possible elsewhere) can be identified using Landsat TM imagery."

(2) "Orchard type could not identified reliably due to the large contribution of the background to young as well as mature orchard reflectance."

(3) "Orchard age can be estimated from the normalized vegetative index (band 4-band 3)/(band 4+ band 3)."

The basic problem preventing more accurate classifications of orchards and by type of orchard was the confusion of tree reflectance with the background reflectance. Variations in types of ground cover and soil types confounded the spectral records between tree types.

Another area of confusion was between deciduous forests and orchards. A major recommendation to improve orchard classification was to do larger scale testing of the classifying procedure used. This means that more accurate ground truth information is needed and must include acreage measurements by type and estimates of canopy closure. Another recommendation was to use images from at least two different dates. Additional research is needed to determine the best combination of dates; different seasons vs. same season.

Since orchards represent a more permanent type of land cover compared with field crops, the use of satellite imagery does show considerable promise. The main benefit will occur if enough history of ground truth can be obtained to improve the classification procedure for larger and different areas.

<u>Cost Analysis</u>

Figure 11 shows the average cost of obtaining State-level acreage estimates by the following categories:

<u>Computing (33%)</u>. Tape reformats, data transmission, digitizing, registration, full-scene classification, etc. on DEC 10, IBM 3320, and CRAY-IS computers.

<u>Data (15%)</u>. Purchase cost of full-scene landsat data.

Salaries (43%). Data analysts (mathematical statisticians) and support staff.

Equipment (4%). Digitizer tablets, plotters.

Miscellaneous (6%). Maps, photos, paper.

This breakdown shows that 75 percent of the total cost is directly related to salaries and data processing. The greatest gains in cost efficiency will come from reducing the staff hours required to complete all phases of the estimation process. Similar gains may occur from more efficient use of the computer although a more efficient use of staff time may come from increased computer use.

FUTURE PROSPECTS

The primary goal will be to make improvements in uses now being made of satellite data. 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. The smaller resolution and increases in the number of spectral bands 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 NASS are monthly forecasts of crop production during the growing season. Research, we hope, will reveal how the daily AVHRR data from the weather satellites can be used with survey data to forecast crop yields.

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FIGURE 1 - AREA SEGMENT DIVIDED INTO TRACTS AND FIELDS

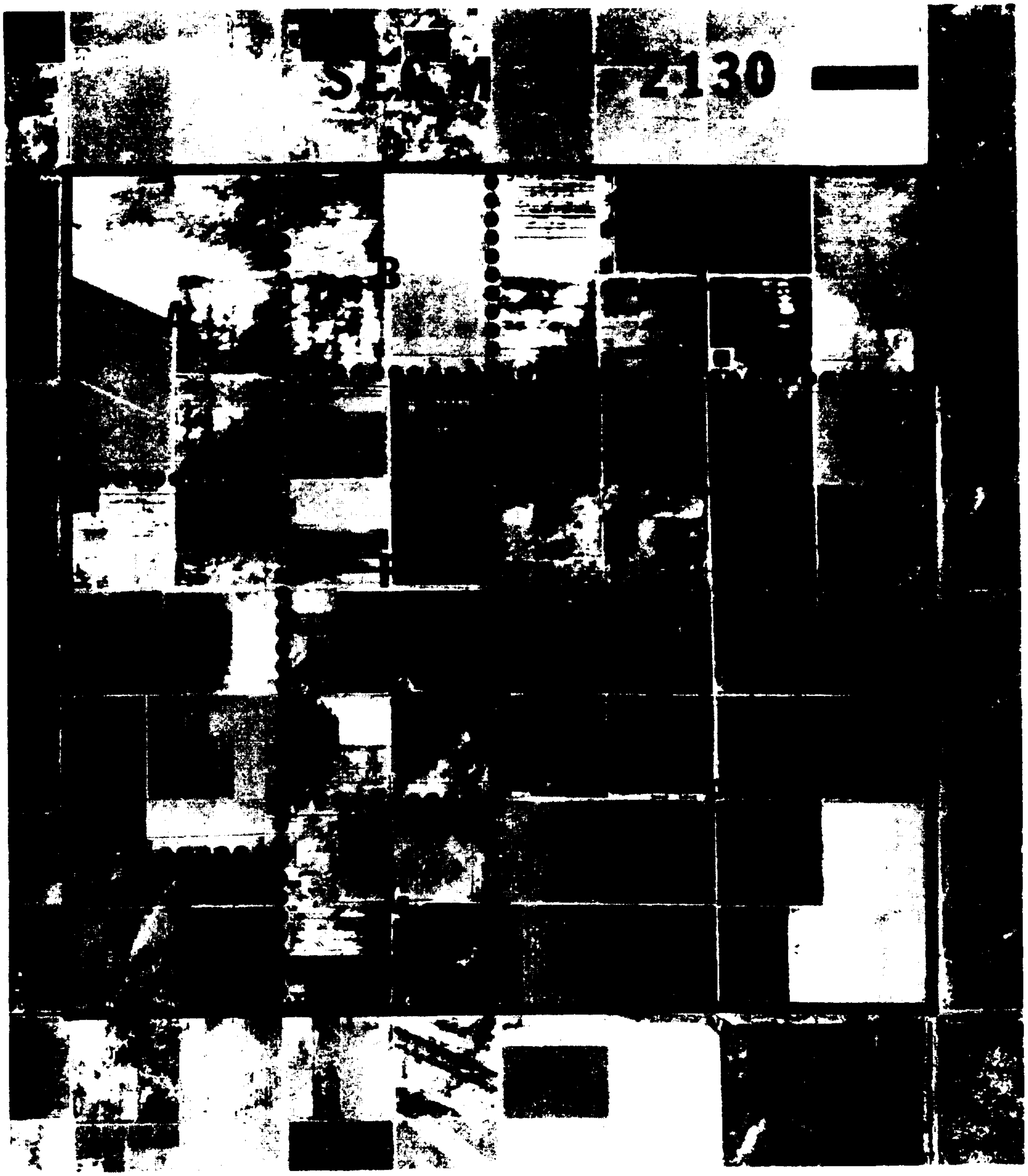


FIGURE 2 - **Launch History of Landsat Observatories**

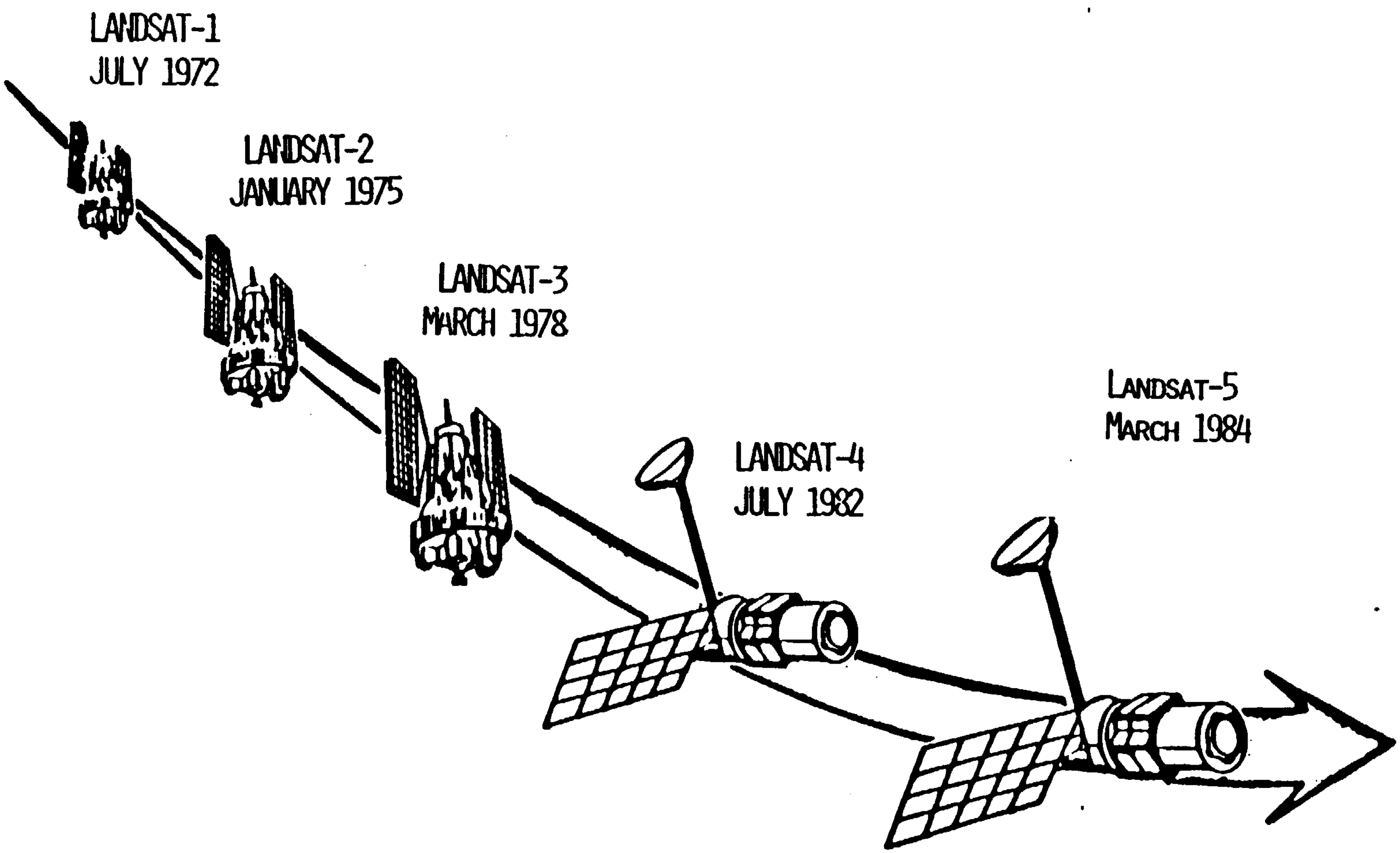


FIGURE 3 - TYPES OF SATELLITES

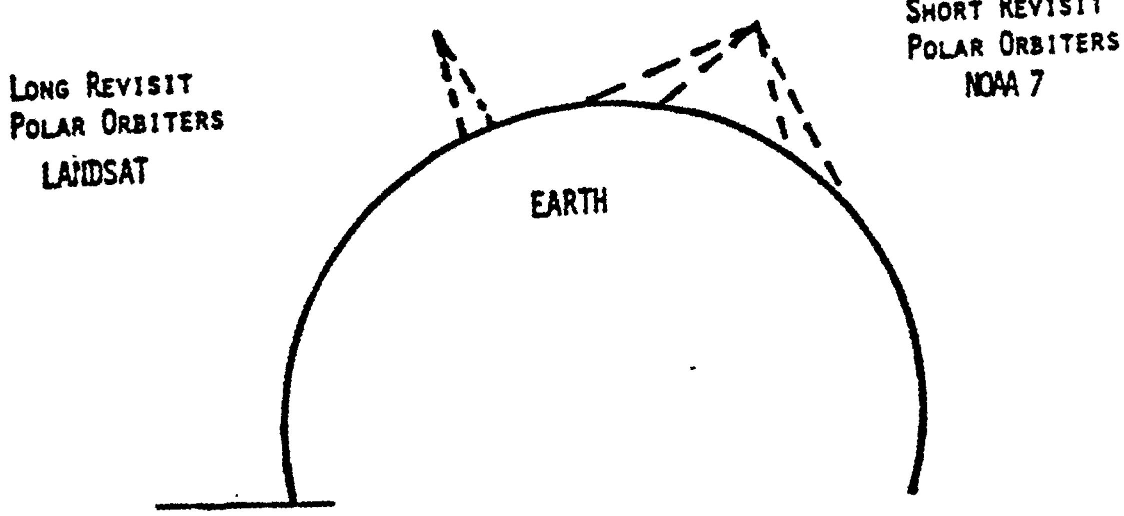


FIGURE 4 - REMOTE SENSING MODEL

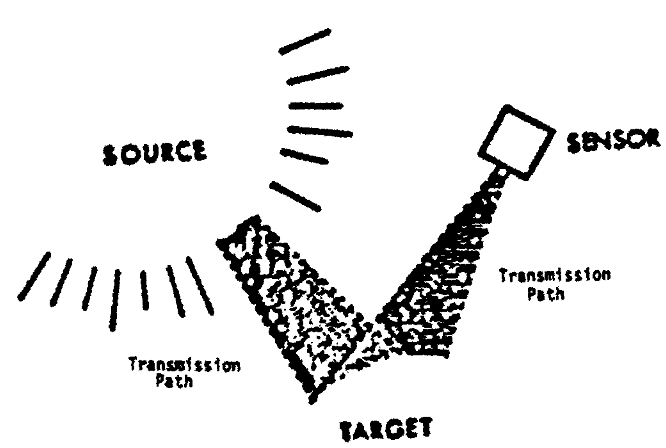


FIGURE 5 - SPECTRAL BANDS OF LANDSAT SENSORS

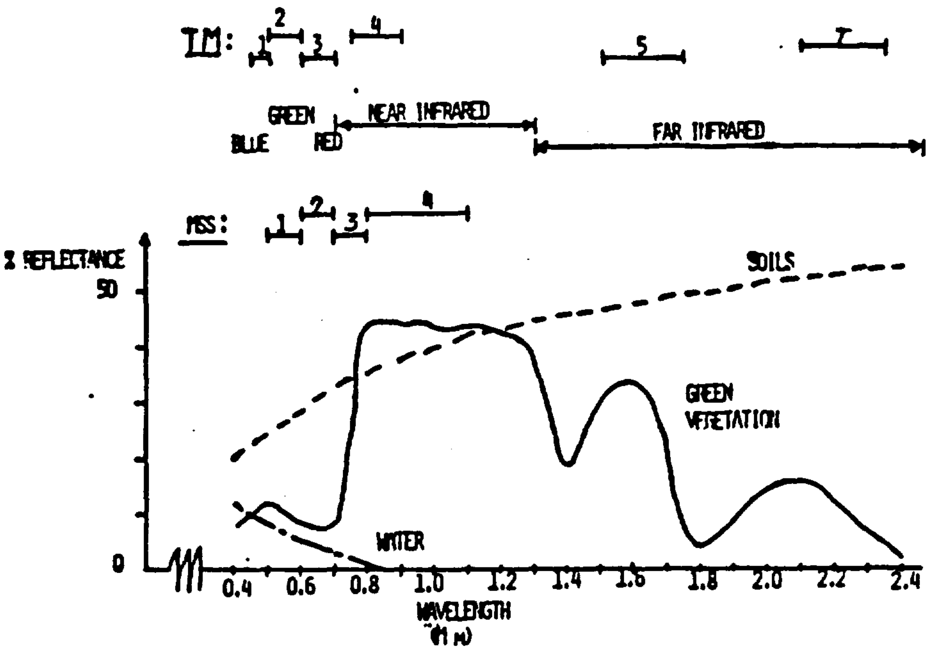


FIGURE 6 - REGISTRATION

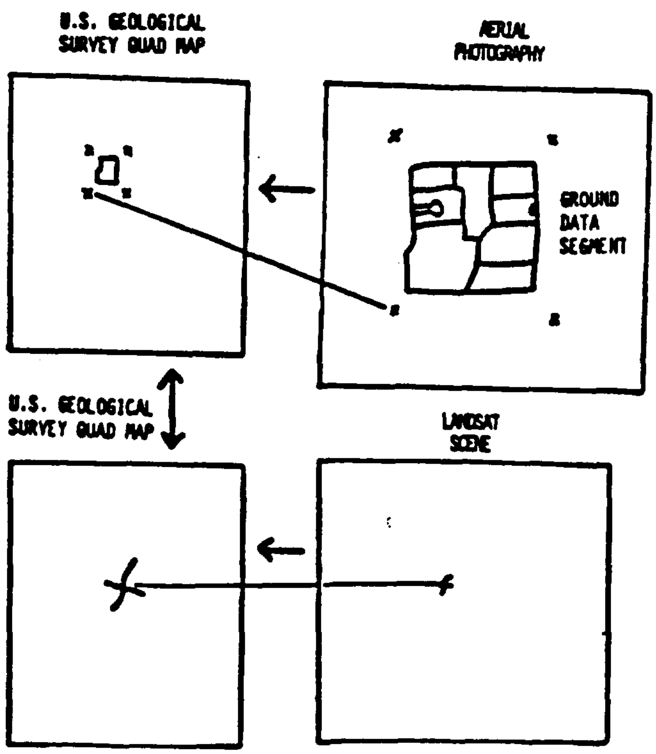


FIGURE 7 - DISCRIMINANT FUNCTIONS

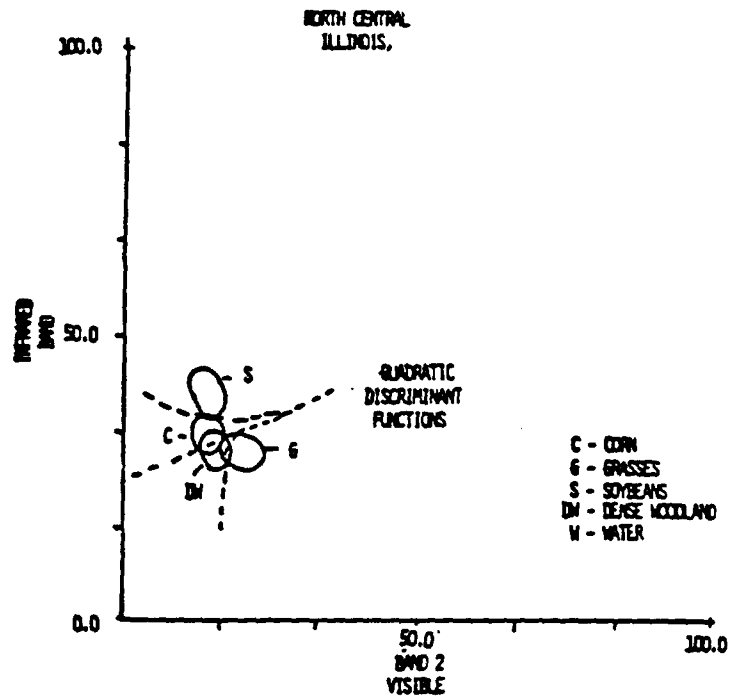
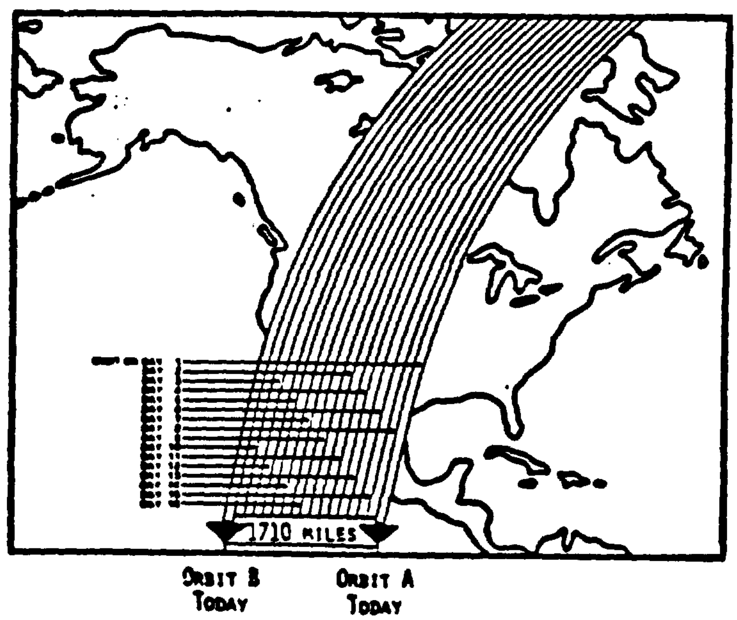


FIGURE 8 - LANDSAT ORBITAL PATHS



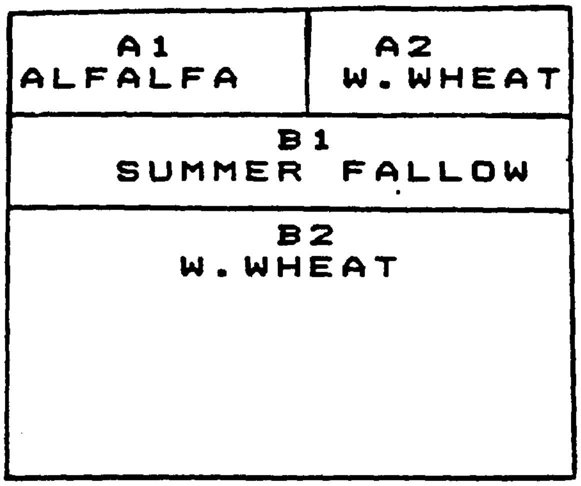
- SUNSYNCHRONOUS NEAR POLAR ORBIT CROSSES EQUATOR 9:45 A.M.
- ORBIT PERIOD 98.9 MIN.
- 14 ORBITS/DAY
- 16 DAYS BETWEEN REPEAT COVERAGE
- 107 MILES BETWEEN ADJACENT PATHS
- 1710 MILES BETWEEN EACH ORBIT

FIGURE 9

CROP ACREAGE ESTIMATION USING AREA FRAME AND LANDSAT DATA

LABEL PIXELS BY COVER TYPE

DEVELOP CROP SIGNATURES AND CLASSIFY LANDSAT DATA IN AREA SEGMENTS.



SRS SEGMENT DATA

47	42	40	35	37	32	32
42	45	43	40	39	37	35
34	37	50	29	34	36	32
~~10~~	~~15~~	~~20~~	~~17~~	~~21~~	~~21~~	~~25~~
9	10	14	15	14	11	10
~~17~~	~~14~~	~~22~~	~~26~~	~~23~~	~~17~~	~~22~~
37	21	39	32	36	23	24
43	40	42	39	40	39	26
46	42	44	41	42	37	23
39	37	41	39	41	32	44

LANDSAT ENERGY READINGS

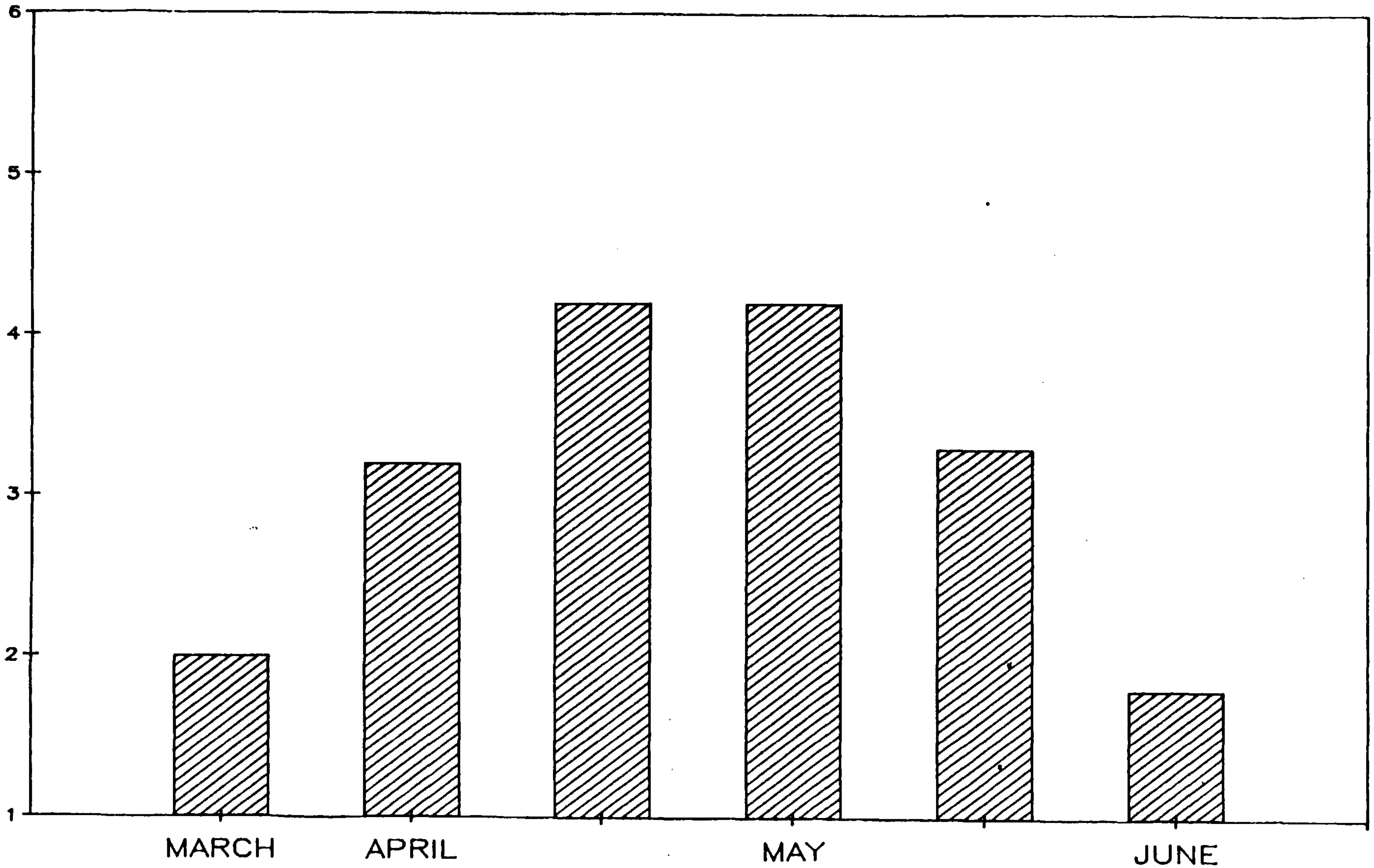
A	A	A	W	W	W	A
A	A	A	A	W	W	W
W	A	A	T	W	W	W
~~S~~	~~S~~	~~T~~	~~S~~	~~T~~	~~T~~	~~W~~
S	S	S	S	S	S	S
~~T~~	~~T~~	~~T~~	~~T~~	~~T~~	~~T~~	~~T~~
W	W	W	W	W	T	T
W	W	W	W	W	W	W
A	W	A	W	W	W	T
W	W	W	W	W	W	A

CLASSIFIED LANDSAT DATA

A – ALFALFA
W – W.WHEAT
T – TREES
S – SUMMER FALLOW

FIGUR

Relative Efficiency of the Landsat Regression Estimator During Crop Season by date of Landsat Overpass



Optimal Dates vary according to year's weather and stage of crop development.
Relative efficiencies are greatest when winter wheat is in Boot to Heading Stage

(April and May have two values)

FIGURE 11

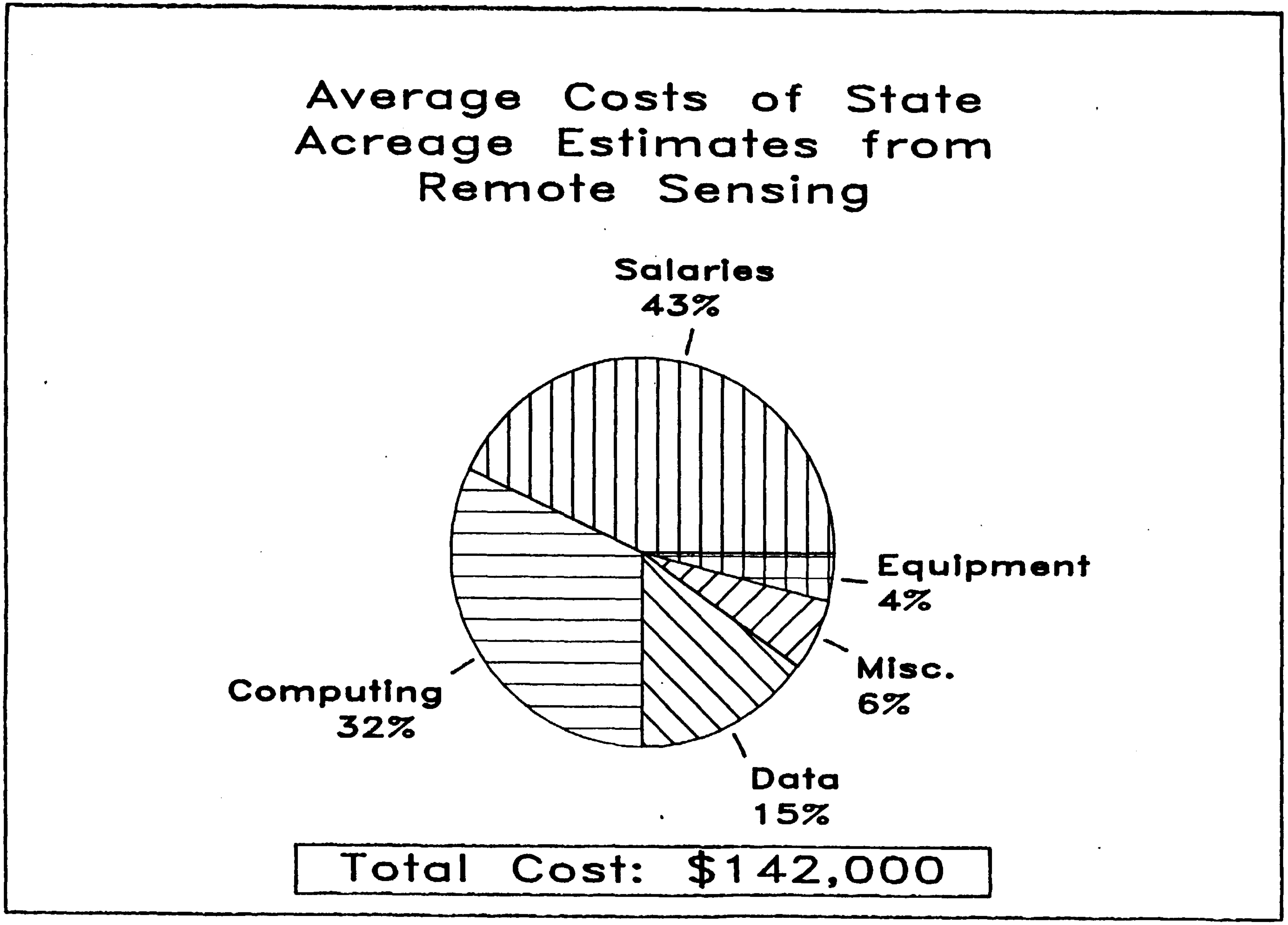

Average Costs of State Acreage Estimates from Remote Sensing
Salaries 43%
Equipment 4%
Misc. 6%
Data 15%
Computing 32%
Total Cost: $142,000

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 14½ 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	SENSITIVE TO
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

TABLE 3. A COMPARISON OF WINTER WHEAT PLANTED ACREAGE ESTIMATES FOR SELECTED STATES, 1984

STATE	SAMPLE SURVEY ESTIMATE	SAMPLE SURVEY STD ERROR	CVC(%)	LANDSAT REGRESSION ESTIMATE	LANDSAT REGRESSION STD ERROR	CVC(%)	RELATIVE EFFICIENCY 1
	(1,000 Acres)			(1,000 Acres)			
Colorado	3,408	216	6.3	3,409	147	4.3	2.2
Kansas	12,686	376	3.0	12,528	258	2.1	2.1
Missouri	2,403	172	7.2	2,137	129	6.0	1.8
Oklahoma	7,813	295	3.8	7,493	236	3.1	1.6

1/ Indicates increase in sample size needed in sample survey to achieve some precision obtained with use of satellite data.

TABLE 4. A COMPARISON OF CORN PLANTED ACREAGE ESTIMATES FOR SELECTED STATES, 1984

STATE	SAMPLE SURVEY ESTIMATE	SAMPLE SURVEY STD ERROR	CVC(%)	LANDSAT REGRESSION ESTIMATE	LANDSAT REGRESSION STD ERROR	CVC(%)	RELATIVE EFFICIENCY 1/
(1,000 Acres)			(1,000 Acres)				
Illinois	10,946	273	2.5	10,565	200	1.9	1.9
Iowa	13,441	302	2.2	13,331	197	1.5	2.3
Missouri	2,107	183	8.7	2,019	110	5.5	2.8

1/ Indicates increase in sample size needed in sample survey to achieve some precision obtained with use of satellite data.

TABLE 5: A DESCRIPTION OF THE KANSAS AREA FRAME LAND USE STRATIFICATION AND LANDSAT EFFICIENCY FOR WINTER WHEAT BY STRATUM, 1984.

STRATUM DESCRIPTION	POPULATION NUMBER OF SEGMENTS	NUMBER IN SAMPLE	LANDSAT EFFICIENCY
80% Cultivation	25,028	170	2.6
50-80% Cultivated	21,704	120	2.0
15-49% Cultivated	21,286	100	2.7
Agr-Urban	2,774	12	1/
City	2,841	12	1/
Resort	247	2	1/
Rangeland	3,147	15	1/
Nonagricultural	294	2	1/
Potential Water	29	2	1/
Water	231	0	1/
	77,681	435	2.1

1/ Regression estimates were not computed for these strata because the area frame sample size was too small to develop discriminate functions and regression relationships.

TABLE 6. RELATIVE SAMPLING ERRORS FOR WINTER WHEAT PLANTED ACREAGE ESTIMATES FOR COUNTIES IN DISTRICT 10, KANSAS, 1984

COUNTY	SAMPLING ERROR %
CHEYENNE	12.8
DECATUR	16.5
GRAHAM	11.5
NORTON	17.5
RAWLINS	8.3
SHERIDAN	10.9
SHERMAN	4.0
THOMAS	6.0
DISTRICT TOTAL	3.7

TABLE 7. Land Cover Direct Expansion and Regression Estimates for Missouri.*

	DIRECT EXPANSION		REGRESSION		
	Estimate	Standard Error	Estimate	Standard Error	Relative Efficiency
	(Acres)		(Acres)		
Hardwood	10,499,754	529,061	11,139,532	443,461	1.4
Conifer	181,568	43,325	187,650	21,782	4.0
Conifer-Hardwood	1,149,738	247,934	1,148,447	245,461	1.0
Grazed Forest	2,884,732	297,743	2,705,512	299,958	1.0
Brushland	1,286,435	143,382	1,318,875	138,723	1.1
Row Crops	8,539,851	361,734	7,742,383	246,344	2.2
Sown Crops	2,391,119	175,337	2,547,815	127,349	1.9
Idle/Cropland	2,100,277	163,574	2,015,582	139,389	1.4
Hay	3,110,286	197,393	2,980,606	171,303	1.3
Cropland/Pasture	1,434,850	234,325	1,245,797	149,895	2.4
Other Pasture	7,698,684	423,699	7,624,049	380,381	1.2
Idle Grassland	1,403,300	140,411	1,331,205	133,127	1.1
Farmsteads	385,091	23,474	387,434	23,515	1.0
Residential	962,910	105,045	823,018	95,629	1.2
Commercial	328,253	81,590	305,556	41,463	3.9
Other Urban	140,229	39,114	122,873	30,365	1.7
Transportation	296,577	53,422	288,724	53,398	1.0
Lakes	307,755	118,936	265,246	108,556	1.2
Ponds	84,270	17,563	84,438	13,130	1.8
Rivers	129,922	43,887	103,729	23,368	3.5
Disturbed Land	44,223	17,741	42,455	16,020	1.2
Transitional	183,379	137,668	-	-	-
Wetlands	106,830	87,386	-	-	-

*Fields that are double cropped are included in the estimates for each crop.