Landsat, Computers, and Development Projects

Digital analysis of data from earth-orbiting satellites offers new perspectives on global development.

Pierre-Marie Adrien and Marion F. Baumgardner

The science of remote sensing, that is, the collection of physical information about the earth's surface from some distance away, such as from an aircraft or a satellite equipped with remote sensors, is of great importance for economic development.

At present, each of two U.S. satellites, Landsat 1 and Landsat 2, orbits the earth once every 103 minutes, scanning the same area on the earth's surface once every 18 days. The orbiting schedules are such that images are obtained from an altitude of approximately 920 kilometers over the same scenes at 6- and 12-day intervals. The satellites transmit the scanner data to receiving stations in Brazil, Canada, Italy, and the United States.

This data acquisition system can provide information at frequent intervals about the location, availability, and changing conditions of the natural resources of specific project areas. Such information is essential for establishing appropriate priorities and effective management plans in developed and developing countries. In considering the mapping and monitoring of earth resources on national, regional, and global bases, perhaps no better approach has yet been devised by man that the computer-implemented analysis of multispectral scanner (MSS) data acquired by earth-orbiting satellites.

Development of Remote Sensing Techniques

Remote sensing technology cuts across a broad range of scientific disciplines and requires close communications and cooperation among these disciplines for mapping and monitoring the land, vegetation, water, and mineral resources of our planet (*1*).

Aerial photography, one kind of remote sensing, has been used for decades (*2*) as a base for mapping soils, preparing land use inventories, identifying and measuring crop areas, delineating conditions of crop stress, and observing, in general, the surface of the earth (*2*).

Many new sensors have been developed since 1960 and great advances have been made in analysis and interpretation techniques. In the 1960's, for example, engineers at the Willow Run Laboratories of the University of Michigan [currently known as the Environmental Research Institute of Michigan (ERIM)] developed a multispectral scanner (MSS) for aerial remote sensing, and scientists and engineers at the Laboratory for Applications of Remote Sensing (LARS), Purdue University, developed computer-assisted pattern recognition techniques (*3*) for the quantitative analysis of multispectral data obtained from aircraft and satellite platforms. In 1967, a crop species, wheat, was identified by the analysis of multispectral data gathered over the Purdue Agronomy Farm, West Lafayette, Indiana. Now, the National Aeronautics and Space Administration (NASA) has developed specifications for the thematic mapper (TM) which will be mounted in Landsat D, scheduled to be launched in the early 1980's.

In July 1972, NASA launched Landsat 1, a satellite in sun-synchronous polar orbit designed to study earth resources from an altitude of more than 900 km. In January 1975, NASA placed in orbit Landsat 2, a duplicate of Landsat 1. Each of these satellites is equipped with an MSS that measures radiant energy reflected from the surface of the earth in four wavelength bands. These bands include a visible green band (0.5 to 0.6 μm), a visible red band (0.6 to 0.7 μm), and two reflective infrared bands (0.7 to 0.8 μm and 0.8 to 1.1 μm) (*4*). The radiation data from these different bands are transmitted to receiving stations on the ground (Table 1) and recorded on magnetic tape from which images can be produced (*5*). The smallest area which the Landsat scanners can resolve on the earth's surface is approximately 0.5 hectare. Each frame of imagery from Landsat covers an area 185 km by 185 km, that is, 34,000 km^2. Each revolution of the earth by the satellite requires 103 minutes, and the 30,000,000 data points (quantitative reflectance values) for each image of data are obtained in approximately 25 seconds (*6*). Therefore, more than a million data points per second, each representing a specific geographic address on the ground, are transmitted to the receiving stations (*7*).

Use of Landsat Data

During the past 3 years, the Large Area Crop Inventory Experiment (LACIE) has been conducted cooperatively by the U.S. Department of Agriculture (USDA), the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and several universities and research institutes (*8*). In this experiment, Landsat MSS, weather, and ground observation data are used to provide a model for wheat yield prediction in the Great Plains of North America.

The ultimate objective of this type of research is to provide a continuous inventory of the world's food supply. If such research efforts are successful, the results will provide improved crop production estimates for the major food producing nations. An early evaluation of the results from LACIE suggests that the data from earth-orbiting satellites will provide invaluable information about areas and conditions of crops for agricultural information systems of the future.

Westin and Frazee (*9*) have used Landsat images for low intensity characterization and mapping of soils over large areas. They have also described analysis techniques that provide rapid and low-cost results that are useful for tax assessment of land and for extensive land use planning and management decisions.

Several developing countries, including Bolivia (*10*), Brazil, Chile (*11*), Costa Rica (*12*), Mexico (*13*), Sudan, Zaire, and others are using remote sensing from satellites in a number of projects. In Bolivia, for example, remote sensing, together with conventional aerial methods for photographing existing pipelines for

Mr. Adrien is a soil scientist with the Project Analysis Department, Inter-American Development Bank, Washington, D.C. 20577. Dr. Baumgardner is a professor of agronomy and is program leader of the Earth Sciences Research Programs, at the Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Indiana 47906.

Table 1. Landsat ground-receiving stations that are planned or in operation, and countries that have expressed interest in such projects. These ground stations, with their associated processing equipment, represent an investment that should reach $40 to 50 million by the end of 1977, much of it in the United States (5).

Country	Stations (No.)	Date operational	Likely prospects	Active interest	Comments
Argentina	0	1978 or 1979	Good		Agreement signed with NASA
Australia	0		Good		
Brazil	1	1974			
Canada	1	1972			A second station at St. John's, Newfoundland, is expected to begin operation in the first quarter of 1977
Chile	0			Yes	Agreement signed with NASA but construction not yet under way
India	0		Good		
Iran	1	Early 1978			Station site at Shahdasht, west of Tehran
Italy	1	1975			Data received since 1975; the ground station is operated by Italy for the European Space Agency as part of Earthnet*
Japan	0		Good		
Mexico	0			Yes	
Nigeria	0			Yes	
New Zealand	0			Yes	
Sweden	0		Good		To be part of Earthnet*
Thailand	0			Yes	
United States	3	1972			Station sites at Fairbanks, Alaska; Goldstone, Calif.; and Greenbelt, Md.
Upper Volta	0		Good		Proposed conversion of French tracking station
Zaire	0		Good		Agreement signed with NASA

*Earthnet is a program within the European Space Agency.

natural gas, is being used in the planning of four alternative routes for a pipeline to connect the Santa Cruz gas field with the Bolivian border and with a Brazilian pipeline that will route gas to markets in São Paulo 1800 km away. The maximum length of the Bolivian portion could be 550 km, more or less along the existing railroad bed. On the basis of Landsat data, however, an optimum route of 517 km was recommended. A saving of some 16 km, at current U.S. prices of about $150,000 per kilometer for a 68-centimeter line, could mean a total saving of $2.4 million (*14*).

At Purdue University, LARS recently completed a land use inventory of the U.S. portion of the Great Lakes drainage basin (340,000 km²). This project is an outgrowth of the 1972 agreement between Canada and the United States to reduce pollution in the waters lying between the two countries.

Computer-aided analysis of multispectral data from Landsat 1 were used to produce color-coded maps for each of the 191 counties in the eight states of the drainage basin. Four of the land uses that were spectrally identified and mapped included those classified as level 1, namely agriculture, forest, water, and urban. The land use classification system for levels 1 and 2 in this study were adapted from Anderson (*15*). Tabular statistics were provided by county with areas given in acres and hectares and as percentages of county area for land use levels 1 and 2. Statistics for a sample county are given in Table 2.

To obtain known land use categories for specific points in the Landsat data, aerial photographs had to be taken over sample areas of all the representative land use categories to be mapped. Color and infrared photographs (70 mm) were taken over less than 4 percent of the watershed. Locations and land use categories were identified by examining the aerial photographs, and definitions were processed by the computer for use in identifying and mapping the desired land use classes over the entire watershed by computer-aided analysis. This inventory was completed in approximately 1 year (*16*).

Relevancy to Development Projects

In terms of cost and labor consumption, clear-cut advantages have already been established over conventional methods of natural resources inventory (*17*). For example, the cost of Westin and Frazee's low intensity mapping of soils with Landsat images was a fraction of what conventional mapping costs would have been (*9*).

Landsat data hold great promise for the Sudan, the largest country in Africa. The northern third of the Sudan's 2.5 million km² is desert. Much of the rest is semiarid and, without careful planning and management, of only marginal agricultural use. Freed from colonial rule less than two decades ago, the Sudan is struggling to develop its resources. However, there are few surveys of the land, or vegetation, water, and mineral resources of most of the country at scales greater than 1:1,000,000 or 1:500,000.

Table 2. Land-use classes for Sheboygan County, Wisconsin, derived from computer-aided analysis of data from Landsat (*16*).

Land uses	Acres	Hectares	County area (%)
Urban			
Residential	38,600	15,620	11.9
Commercial	4,680	1,890	1.4
Total	43,280	17,520	13.3
Agriculture			
Row crop	30,590	12,380	9.5
Close-grown crop	35,700	14,450	11.0
Pasture	123,820	50,120	38.0
Total	190,120	76,970	58.5
Forest	84,840	34,340	26.1
No major use			
Water	6,350	2,570	2.0
Wetland	540	210	0.1
Total	6,890	2,780	2.1
Grand total	325,130	131,610	100.0

Between July 1972 and August 1973, more than 750 frames of data from Landsat 1 were obtained over the Sudan. If one discounts overlap between scenes, there were enough data to provide coverage of the entire country ten times over. At the request of the Food and Agriculture Organization (FAO) and the Government of Sudan, scientists at LARS analyzed data obtained by Landsat 1 on two different dates (7 November 1972 and 9 February 1973) over the El Fula region in the provinces of Northern Kordofan and Southern Kordofan, southwest of Khartoum.

The objective of the study was to assess the usefulness of computer-aided analysis of Landsat data in preparing an inventory of the land, vegetation, and water resources in the tropical savannah. Results indicate that these techniques can quickly and efficiently provide maps at scales as large as 1:24,000 delineating important soil differences, vegetation complexes, surface drainage patterns, erosion hazards, and land use (*18*). One of the most difficult aspects of the Sudan project was that of obtaining sufficient ground (or aerial photographic) observations to provide spectral definitions for computer analysis and for evaluation and classification of the results. This is a common difficulty in many land areas of the world where little or no survey information is available.

Figure 1 shows the classification of one small area near the village of El Fula. The original computer printout was at a scale of 1:24,000 and each data point (printer symbol) represents an area of 0.5 hectare. On the basis of the study the government of Sudan has allocated funds and assigned high priority to the development of facilities for utilizing remote sensing technology in surveying and monitoring the country's natural resources.

An integrated model capable of predicting crop growth response and progress in situ in relation to fertilizer applications, weather variability, soil moisture-holding capacity, irrigation frequency, and other factors that affect yields would be of considerable importance to the producer or farmer. Data from Landsat could help to identify and measure fluctuations in such environmental factors through sequential monitoring of the agricultural scene. Eventually, it may be possible to store such data in a data bank in a processed format useful to researchers, project specialists, food growers, and other potential users.

Global remote sensing information systems also hold great promise for monitoring the conditions of rangelands, locating and quantitatively estimating timber stands, monitoring and measuring areas of soil deterioration, developing land use capability and soil productivity maps, and monitoring crop conditions under both rain-fed and irrigation agriculture.

Landsat Improvements

Although many different sensing devices and techniques are being studied, it seems certain that the principal remote sensing instrument on board orbiting satellites within the next decade will be the MSS. However, with the experience gained from the Landsat experiment, it is now possible to predict some of the improvements that may be incorporated into a global remote sensing information system in the early 1980's.

Spatial resolution. One of the limitations of the Landsat scanners for certain uses in many areas of the world is the spatial resolution of only 0.5 hectare. It is technically feasible to build a scanner with greater resolution, and serious consideration is being given to the design of a scanner with a resolution of 30 meters, or less than one-tenth of a hectare. Such a scanner could facilitate the identification of more detailed ground features.

Spectral range. Whereas present Landsat scanners are limited to measuring radiation within only a portion of the visible and the near infrared spectrum, it is proposed that radiation measurements in the middle and thermal infrared be added to the capabilities of satellite scanners in the 1980's. The thermal band will be particularly useful for studying the behavior of hot springs and volcanoes in areas such as Central America where they are found in unusually high concentration.

Scanning frequency. Studies are under way to determine the optimum frequency of satellite coverage for a wide range of applications. Observing or monitoring certain scenes more frequently than at 18-day intervals would be desirable for many users. This is particularly critical in areas where cloud cover is a problem. More frequent satellite coverage will increase the probability of obtaining cloud-free observations. Future systems may provide coverage as

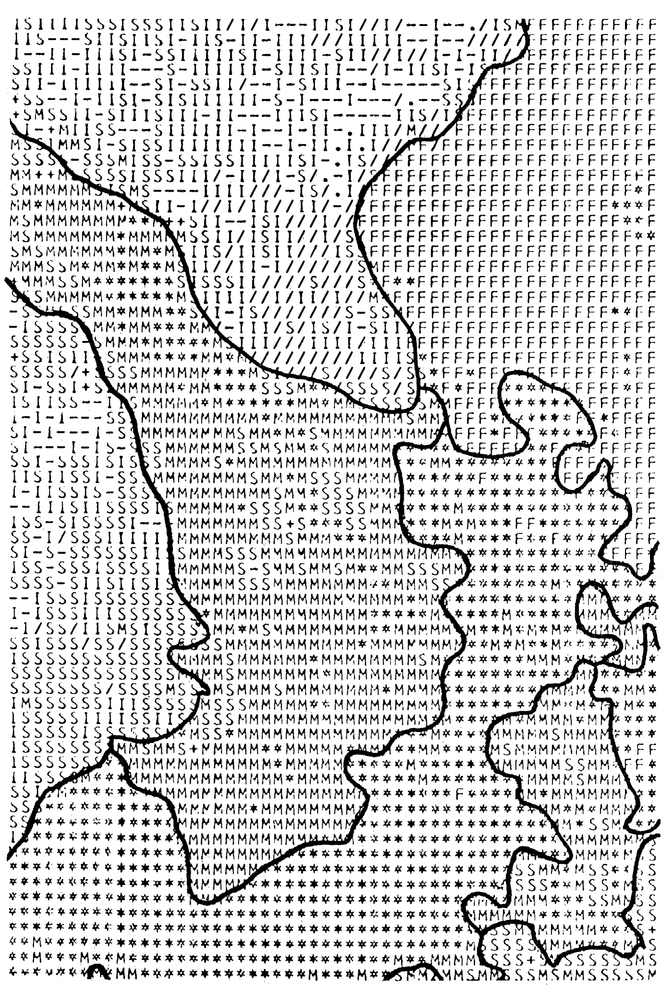

Fig. 1. Annotated supervised classification of Wadi El Ghalla, southwest of El Fula in the Sudan; data obtained on 9 November 1972 from Landsat MSS. Approximate area, 25 km^2. Symbols: *F*, Alluvial floodplain of Wadi El Ghalla, vertisols (dark swelling clay soils), poor drainage; no trees or brush, tall grass following rains; cultivated (for vegetables) during dry season. *, Alluvial floodplain of Wadi El Ghalla, vertisols (dark swelling clay soils), moderate cover of riparian forest (*Acacia seyal, Tamarindus indica, Acacia nilotica complex*), coarse grass undercover. *M*, Alluvial floodplain and fan of tributary emptying into Wadi El Ghalla; light-colored, light-textured soils; mixed acacia species, shrubs, and sparse grass undercover. *S*, Sandy, light-colored upland soils; savanna woodland complex. *I*, Sandy, light-colored upland soils; scattered trees and thornbushes: eroded. /, Sandy, light-colored upland soils, essentially without vegetative cover, severely eroded.

frequently as every 7 to 9 days. At present, Landsat 1 and Landsat 2 are used in tandem and they provide coverage at intervals of 6 and 12 days.

Analytical capabilities. Multispectral data received from Landsat are recorded in digital form. That is, for each resolution element (or 0.5 hectare) scanned by the satellite, four quantitative values are recorded on magnetic tape. There is one value representing the intensity of reflectance from the earth's surface for each of the four wavelength bands. Every half minute more than 7.5 million quantitative observations per band are recorded.

Since Landsat 1 was launched, great progress has been made in computer technology and in imaging devices and other equipment for analyzing and interpreting masses of data from satellites (*19*). Rapid progress in the development of computer hardware (equipment) and software (computer programs) is expected to continue (*20*). Analytical capabilities in the 1980's will be far superior to our present capabilities in speed, range, and low cost per unit of data analyzed (*21*).

Dissemination of data. Landsat 1 and Landsat 2 were designed for research work. One of the consequences of this design is a built-in delay in distributing satellite data to users. Many scientists and representatives of the user community have expressed concern that an operational information system for global monitoring of earth resources must provide for rapid dissemination of data. Future systems should provide great improvement in this respect over the present experimental Landsat system.

Landsat Follow-On Program

As the Landsat program progresses into the 1980's, a broad range of technical modifications are being planned to bring about significant changes in both the data and distribution systems. In order to obtain data over lands beyond the transmission limits of ground-receiving stations, Landsats 1 and 2 are equipped with magnetic tape recorders. Recorded data from distant areas are transmitted when the satellite is within range of one of the U.S. receiving stations. The limited useful life of the recording tapes and the recorders on Landsats 1 and 2 have emphasized the need for elimination of recorders on future earth resources satellites.

Future Landsat satellites will collect data at an altitude of 705 km by means of the MSS and the thematic mapper, a scanner that is being designed for six spectral bands (Table 3) and that will have a 30-m resolution element (*22*). The thematic mapper will have a relatively greater capability than the MSS to resolve small crop-growing areas. As described in Fig. 2, the thematic mapper will resolve 80 percent of these areas which will correspond to 99 percent of the total area under cultivation.

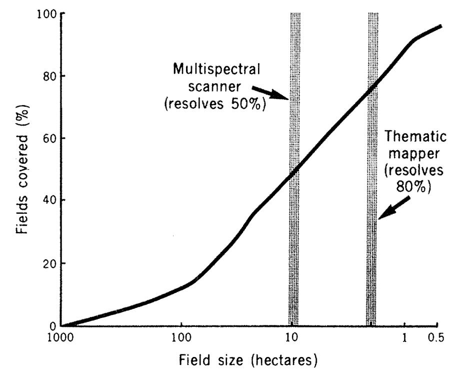

Fig. 2. Comparative analysis of the worldwide estimated field-size distribution viewed by the multispectral scanner and the thematic mapper (*22*).

Through continuous communication between Landsat D and either of two stationary communications satellites, known as the Tracking and Data Relay Satellite System (TDRSS), data from the thematic mapper will be transmitted in real time, that is, as it is collected, to TDRSS and retransmitted to a single global receiving station at White Sands, New Mexico. Foreign stations will have to be upgraded if they wish to take full advantage of the TM capabilities. A data processing facility is being designed at the Earth Resources Observation Systems (EROS) Data Center, Sioux Falls, South Dakota, to assure that there will be no backlog in processing and archiving of data in the United States. This center is currently developing the EROS Digital Image Processing System (EDIPS) which is expected to start operating in June 1978. It will give EROS the capability of processing 340 scenes per day in two shifts.

The specific objectives of the Landsat follow-on programs as defined by NASA are:

1) To implement an operational demonstration of a prototype second generation Landsat system and validate operational uses in agriculture, land inventory, water, petroleum, and mineral resources.

2) To provide a commitment of sufficient duration to encourage user investment and allow user operational needs and benefits to develop and be tested (including industrial support base).

3) To provide a complete satellite and data distribution system to meet operational requirements (timeliness and throughput).

4) To provide a real test of institutional arrangement.

Preparing for the Future

The potential applications of this technology made possible by recent developments in data acquisition, data analysis, and communications have been dramatically demonstrated across a wide array of disciplines. One of the great challenges that looms before the developing world is that of transferring this technology to those who can most benefit from its use.

One approach for leaders of any country wishing to obtain, analyze, and interpret data from earth resources satellites is to determine who the potential users of such information would be. A national coordinating committee or government agency could be established in these countries to provide a focus on the applications of remote sensing and to coordinate remote sensing activities. Many countries lack trained scientists and engineers who can provide technical leadership, but there are a number of centers in the United States and other countries

Table 3. Sensor parameters proposed by Thematic Mapper Working Group for Landsat D spacecraft (*22*).

Spectral bands	Wavelength* (μm)	Objectives	Resolution (m)
Blue	0.45 to 0.52	Water depth, land use, soil, and vegetation	30
Green	0.52 to 0.60	Vegetation vigor	30
Red	0.63 to 0.69	Chlorophyll absorption	30 to 40
Near infrared	0.76 to 0.90	Stress and biomass	30
Near infrared			
Mid-infrared	1.55 to 1.75	Vegetation moisture	30
Thermal infrared	10.4 to 12.5	Temperature variation	90 to 120

*The number of detectable gray levels or relative reflectance values per Landsat D thematic mapper band will increase to 256 from the current values of 127 for MSS bands 4, 5, and 6, and 63 for band 7. By comparison, the human eye can detect approximately 16 gray levels.

Table 4. International participation in NASA's earth resources investigation programs (*25*).

Africa	*Europe*	*Asia*	*Central and South America*
Botswana*†	Belgium*	Bangladesh*†	Argentina*†
Egypt†	Federal Republic of Germany*†‡	India*	Bolivia*†‡
Kenya*†	Finland*†	Indonesia*	Brazil*†‡
Lesotho*	France*†‡	Iran*†‡	Chile*†
Libya†	Greece*	Israel*‡	Colombia*
Mali*‡	Italy*†‡	Japan*†‡	Ecuador*
South Africa*†	Netherlands*‡	Korea*†	Guatemala*
FAO*†‡¶	Norway*†	Malaysia*†	Peru*†
	Romania†	Pakistan†	Venezuela*
Oceania	Spain*†	Philippines*†	
Australia*†‡	Sweden*†	Sri Lanka†	*North America*
New Zealand†	Switzerland*†‡	Thailand*†‡	Canada*†‡
	United Kingdom*†‡	Turkey†	Mexico*†‡
	Organization of European Communities†	Central Treaty Organization†	
		Mekong Commission*†	

*Landsat investigations. †Landsat follow-on investigations. ‡Earth resources experiment package (EREP/Skylab) investigations. ¶FAO is also active in Asia and Central and South America in the earth resources investigation programs.

where training in aerospace remote sensing technology is available (*23*). During the decade ahead a concerted effort must be made to provide the opportunities for a wide range of resource scientists and managers in the developing countries to receive in-depth training in the analysis and interpretation of Landsat data. The international development organizations can play a key role in allocating funds to support these educational opportunities.

It will be difficult for any country to chart a rational course for its development in remote sensing technology until a broad array of potential users of the technology are familiar with current and projected capabilities and can participate actively in designing a program that can best meet their country's needs (*24*).

Several nations in Latin America, Africa, and Asia are participating in the Landsat experiment (Table 4) (*25*). The analyses of Landsat data in many developing countries have shown great promise in providing useful inventories and information about natural resources which never before were available.

Summary

Data provided by earth-orbiting satellites and analyzed through specific computer techniques are rapidly providing policy-makers around the world with new information on the location and extent of their countries' renewable and nonrenewable resources. Development projects utilizing remote sensing technology are being supported, for example, by the Inter-American Development Bank, the World Bank, and other international funding agencies. The Inter-American Development Bank is financing a natural resources inventory of five countries in Central America, and this will require the application of remote sensing in the analysis of 33 Landsat images covering the area. Although the Landsat program remains experimental in nature, studies pertaining to its follow-on aspects will ensure continuation of the program so that developed and developing countries will be able to maintain better control of the management of their natural resources.

Note added in proof: Landsat 1 went partially out of commission in August 1977.

References and Notes

1. M. E. Bauer, *Adv. Agron.* **27**, 291 (1975); J. B. Peterson, F. E. Goodrick, W. N. Melhorn, *Delineation of the Boundaries of a Buried Pre-Glacial Valley with Landsat-1 Data*, LARS Information Note 100175 (Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Ind., 1975), pp. 5–6; R. S. Williams, Jr., and W. C. Carter, Ed., *A New Window on Our Planet*, Geological Survey Professional Paper 929 (Government Printing Office, Washington, D.C., 1976).
2. *Manual of Remote Sensing* (American Society of Photogrammetry, Falls Church, Va., 1975), pp. 27–35.
3. P. H. Swain, *Pattern Recognition: A Basis for Remote Sensing Data Analysis*, LARS Information Note 111572 (Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Ind., 1972), pp. 1–4.
4. *Data Users Handbook*, Document No. 76SDS4258 (NASA, Houston, Tex., rev. ed., 1976), pp. 2–3.
5. The data were gathered from various sources within the Office of International Affairs at NASA headquarters, Washington D.C. 20546.
6. Approximately 7.5 million data points (pixels) are recorded for each of the four spectral bands; consequently, approximately 30,000,000 data points are obtained per image.
7. M. F. Baumgardner, *Computers, Satellites and Food—A Global Perspective* (abbreviated text of an illustrated lecture prepared for presentation to the North Atlantic Assembly, Williamsburg, Va., 1976).
8. R. B. MacDonald, F. G. Hall, R. B. Erb, *The Use of Landsat Data in a Large Area Crop Inventory Experiment* (Institute of Electrical and Electronics Engineers, New York, 1975).
9. F. C. Westin and C. J. Frazee, *Soil Sci. Soc. Am. J.* **40** (No. 1), 81 (1976).
10. C. E. Brockmann, *Earth Resources Technology Satellite Data Collection Project ERTS-1*, Report Type III (Servicio Geologico de Bolivia, La Paz, Bolivia, 1974); ______ and G. W. Brooner, in *Proceedings of NASA Earth Resources Survey Symposium* (Johnson Space Center, NASA, Houston, Tex., 1975).
11. G. Delannais, *Evaluacion Multidisciplinaria de Imágenes del Satélite ERTS, Zona de Malleco, Cautin* (Instituto de Investigacion de Recursos Naturales, Corporacion de Fomento de la Producción, Santiago, Chile, 1974).
12. M. F. Baumgardner, E. Horvath, P. M. Adrien, M. A. Vasquez, C. L. Elizondo, *Using Satellites and Computers to Inventory the Natural Resources of the Tempisque Valley, Costa Rica*, a report to the Inter-American Development Bank and the Government of Costa Rica (Laboratory for Applications of Remote Sensing, Purdue Univesity, West Lafayette, Ind., 1976).
13. H. Gardunõ, R. Garcia Lagos, F. Garcia Simo, in *Proceedings of NASA Earth Resources Survey Symposium* (Johnson Space Center, NASA, Houston, Tex., 1975).
14. C. E. Brockman, personal communication.
15. J. R. Anderson, E. E. Hardy, J. T. Roach, *U.S. Geol. Surv. Circ. No. 671* (1972).
16. Office of the Great Lakes Basin Commission, *Inventory of Land Use and Land Use Practices in the United States Great Lakes Basin* (Ann Arbor, Mich., 1976).
17. L. W. Morley, *Third Earth Resources Technology Satellite Symposium* (Goddard Space Flight Center, Greenbelt, Md., 1974), vol. 11, pp. 7–11.
18. M. F. Baumgardner, *Evaluation of Satellite Data for Use in Natural Resource Surveys in Sudan*, final report submitted to the Food and Agriculture Organization, Via delle Terme di Caracalla, Rome, Italy (1974).
19. C. T. Wezernack and F. C. Polcyn, in *Proceedings of the Eighth International Symposium on Remote Sensing* (University of Michigan, Ann Arbor, 1972), vol. 1, pp. 541–551; D. M. Carneggie and S. D. Degloria, "Determining range condition and forage production potential in California from ERTS-1 imagery," in *Proceedings of the Eighth International Symposium on Remote Sensing* (University of Michigan, Ann Arbor, 1972), vol. 1, pp. 1471–1476; S. D. Titus, M. Gialdini, J. Nichols, in *Proceedings of the Tenth International Symposium on Remote Sensing of Environment* (Environmental Research Institute of Michigan, Ann Arbor, 1975), vol. 1, pp. 1093–1099; R. M. Hoffer, *Techniques and Applications for Computer-Aided Analysis of Multispectral Scanner Data*, LARS Information Note 062276 (Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Ind., 1976); P. H. Swain, *Advancements in Machine- Assisted Analysis of Multispectral Data for Land Use Applications* (Institute of Electrical and Electronics Engineers, New York, 1977), pp. 336–343.
20. T. L. Phillips, Ed., *LARSYS User's Manual* (Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Ind., 1974).
21. National Academy of Sciences, *Resource and Environmental Surveys from Space with the Thematic Mapper in the 1980's*, a report prepared by the Committee on Remote Sensing Programs for Earth Resources Survey (National Research Council, Washington, D.C., 1976).
22. Minutes of the Landsat Ground Stations Operations Working Group Meeting held on 12 April 1977 at the Instituto de Pesquisas Espaciais (INPE), São Jose dos Campos, Brazil.
23. *Photogrammetric Engineering and Remote Sensing* (American Society of Photogrammetry, Falls Church, Va., 1977), vol. 43, No. 3, pp. 257–302.
24. Ad Hoc Committee on Remote Sensing for Development, *Resource Sensing from Space-Prospects for Developing Countries* (National Academy of Sciences, Washington, D.C., 1977).
25. The information in Table 4 was obtained from the Office of International Affairs at NASA headquarters, Washington, D.C. It is relevant to point out that most of these countries have used visual interpretation techniques for Landsat data rather than digital methods. Some examples of developing countries that do have digital processing capabilities are: (i) Brazil, which processes its own data and produced approximately 10,000 Landsat images in 1976 and expects to produce about 30,000 in 1977. (ii) Bolivia, which is currently implementing appropriate software systems on a DEC 10 computer in order to have in-house capabilities to process Landsat computer compatible tapes (CCT's). (iii) India, which recently strengthened its digital processing facilities by purchasing sophisticated U.S. built hardware. (iv) Peru, which has been processing CCT's on a computer HP 2100 obtained through a cooperative program with Stanford Research Institute.