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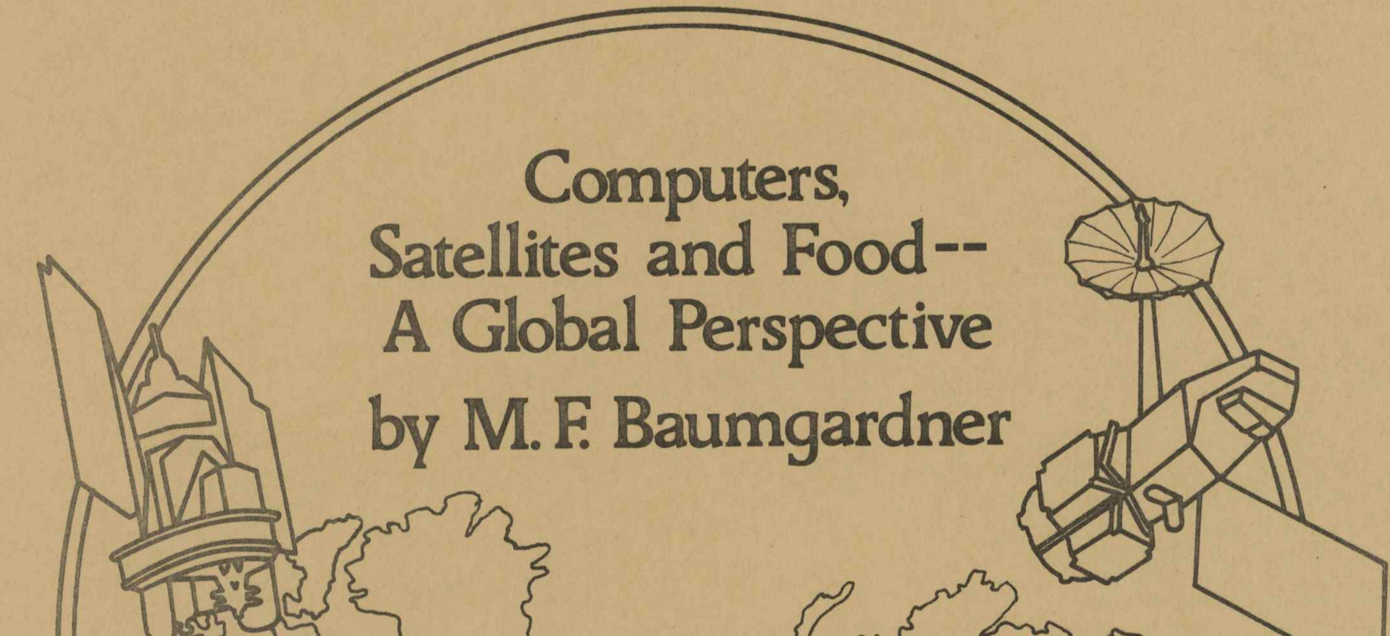

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COMPUTERS, SATELLITES, AND FOOD -- A GLOBAL PERSPECTIVE*

by

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The past two decades have witnessed dramatic advances in science and technology which already impact the daily lives of many hundreds of millions of people. Every morning millions of television viewers in North America see images of cloud formations and patterns over this continent, images generated from satellite sensor data only hours or even minutes prior to broadcast time. All of us are benefactors daily of satellite communication systems which provide the luxury of viewing events or political activities as they occur half a world away, or of dialing directly from our home or office telephones and within minutes or even seconds conversing with friends or colleagues in Bonn, Tehran or Hokkaido. Yet a new dimension of technology is coming into focus which may have an even greater impact on human life. The impact of this new technology will greatly be determined by the degree to which it can contribute to the solutions of three crucial dilemmas facing man--world hunger, environmental deterioration, and wasteful consumption of finite resources.

Mis-information or Missing Information

Each of these dilemmas shared by the entire human family is closely related to the manner in which we develop, exploit, manage, consume and/or

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conserve the resources of our environment. A system of management which provides for efficient utilization and conservation of natural resources should include methods for inventorying and for periodic monitoring of the supply and condition of the resources. When we consider the current utilization and management of natural resources on a global or even a national or regional scale, the list of development and management decisions based on erroneous or missing information is endless if not deplorable. Let me give one classic example. In a semi-desert rangeland area north of the equator in Africa one of the developed countries built a $20 million facility with stainless steel equipment to produce 50 tons of powdered milk per day. Apparently the decision-makers who determined to build this facility did not have access to basic data about the soils, climate, rangeland conditions, and cultural practices of the cattle-owning nomadic tribes. For several years this wonderful facility at the desert edge has been essentially useless because there is no supply of raw milk, and there is no reason to believe that there will ever be a supply of raw milk in that environment.

If we can believe the experts, the world population will expand from the present 4 to 6 or 7 billion within the next 25 years. The growing affluence in some nations and the overall global increase in population suggest that world food production must double by the year 2000. Since most of the readily available arable land of the world is already being utilized, the required increase in food production must come from land already under cultivation and from potentially arable land. In the latter case, great expenditures of energy and capital will be required to prepare new land for cultivation by draining, irrigating, or leveling. At a time when the world is grappling with energy shortages, the development of new lands for agriculture is not an attractive solution.

As we ponder the hunger dilemma, we are forced to consider the problem of land deterioration on a national and global basis. Because of desertification, depletion, water-logging, salinization, wind erosion, water erosion, flooding, and urbanization litterally tens of millions of hectares of good agricultural lands are lost from production each year. In the United States alone more than a million hectares (2½ million acres) are removed from agricultural production each year through highway construction and urbanization. During the last 200 years at least a third of the topsoil on the U.S. croplands has been lost. During this same period more than 100 million hectares in the United States have been lost from crop production, more than half as much as the U.S. is now cultivating.

No one knows how many millions of hectares are being eliminated each year from food production by water-logging and salinization in the Ganges Plain, by desertification in the Sahel, by poor drainage in the Pampa, or by severe rainfall erosion in Bulgaria. But, the fact is, this is happening in all these locations and in many more.

Many organizations (national, international, government, private) give major attention to planning, funding and implementing solutions to the dilemmas which have been described--hunger and environmental deterioration. One of the fundamental hurdles to development and management of land, vegetation, and water resources is the lack of essential data or information for the decision-maker. What are the soil characteristics and potential productivity of the proposed project area of country X? How much has the soil loss and sedimentation hazard been accelerated in northwest Missouri since all government restrictions were removed and the farmers can plant all their land to corn and soybeans? In the Republic of Sudan with its very limited supply of development capital, agricultural management expertise, and lack of detailed inventories of its natural resources, how can a rational decision be made on the location and implementation of an agricultural development project? Can we develop a relatively accurate "early warning" system to alert the world to developing food deficit and food surplus areas so that rational decisions may be made for corrective action with a minimum of human suffering and social upheaval?

A global information system which will help to provide accurate, timely, repetitive data about agricultural resources is sorely needed.

The Data/Information Equation

The past decade has brought together expertise from a range of science and engineering disciplines, resulting in a new technology which employs computers and air- and spacecraft sensor systems to observe, measure, map and monitor the earth's surface. This complex technology, now commonly referred to as "remote sensing," has provided invaluable methods not previously available for viewing land, vegetation, water and mineral resources.

This new technology provides the basis for the design and development of a global information system for earth resources. It is useful to visualize the system as a triangle with three separate components:

Data
Acquisition

Data
Utilization

Data
Analysis

1. Data acquisition. After several years of experimentation with aircraft sensor systems and supporting computer technology, the National Aeronautics and Space Administration (NASA) launched its first earth resources technology

satellite, now called Landsat-1, on 23 July 1972. Landsat-2 was successfully placed in orbit on 22 January 1975. The continuously operating sensor on each satellite is a multispectral scanner which quantitatively measures the radiation of energy from the earth's surface in four wavelength segments or bands--visible green, visible red, and two reflective (or near) infrared bands. Landsat 1 and 2 are in circular, sun-synchronous polar orbits designed to provide scanning of the entire earth surface every 18 days by each satellite. Since the satellites are spaced nine days apart, each address (or point) on the earth is scanned every nine days. Data acquisition or scanning of the earth surface occurs at mid-morning local time. From an altitude of 920 kilometers (570 miles) the scanners can resolve (or "see") an area of 0.45 hectares on the ground.

Data obtained by the scanners are telemetered to receiving stations when the satellites are within transmission range. Stations currently receiving data include:

Brazil	- Cuiaba, Mato Grosso
Canada	- Prince Albert, Saskatchewan
Italy	- Rome
United States	- Fairbanks, Alaska
	Goldstone, California
	Goddard, Maryland

Agreements have been reached with NASA for receipt of Landsat data by four other stations under construction or to be constructed:

Canada - Maritimes
Chile
Iran
Zaire

When the satellites are out of range for effective transmission, scanner data must be temporarily stored by tape recording aboard the spacecraft for later transmission.

2. Data analysis. The enormity of the task of handling, storing, retrieving, analyzing and interpreting data from Landsat becomes apparent when we examine the data flow from each of the current Landsat scanners. As each satellite moves in polar orbit, its multispectral sensor scans a path or swath 185 kilometers (115 miles) wide along the earth's surface. Each image or data tape prepared from scanner observations contains data representing an area of 185 by 185 kilometers, i.e., 34,000 square kilometers, or 13,000 square miles. Since each revolution of the earth by the satellite requires only 103 minutes, the 30,000,000 data points (quantitative reflectance values) for each image of data are obtained in approximately 25 seconds. Therefore, more than a million data points per second, each representing a specific geographic address on the ground, are being transmitted to receiving stations.

How can this quantity of data be used effectively? How can we prepare to derive maximum benefit from the earth-orbitting scanners of the 1980's which will transmit 15 million data points per second from a broader range of the visible and infrared spectrum and with a spatial resolution of 1/10 hectare instead of the present ½ hectare?

Obviously, such massive quantities of data call for machine processing. During the past decade dramatic advances have been made in the design, development and implementation of both hardware (computer) and software (computer programs) for processing and analyzing multispectral data from air- and space-borne scanners. Several software systems based on classical pattern recognition theory have been developed and implemented.

Perhaps it is appropriate to separate the use of the computer for analyzing satellite data into two basic tasks. First, the computer can be programmed to examine the quantitative reflectance values obtained by the Landsat scanners and to produce high quality black and white and/or color composite images which may then be analyzed and interpreted visually. This procedure may be used effectively with single bands (green, red, near infrared) of spectral data or with two or more bands.

The second basic task which may be performed by the computer is that of classification. During the performance of this task the computer examines the spectral data (single or multiple bands) obtained by the satellite scanner for a specific scene or area and then assigns every data point to a specific class. A classification may be performed by one of two methods--supervised or non-supervised. In the first instance the analyst must provide the computer with a spectral definition (training set) of the features to be identified and classified by the computer. That is, the analyst provides a statistical sampling of addresses (data points in the scanner data) where the feature or class of interest is known. For example, the analyst may wish to identify and map all the wheat fields in Western Kansas during late May. By inputting into the computer the addresses of several known wheat fields, the computer can then examine Landsat scanner data obtained in late May and identify all wheat fields in the region. The classification should be very accurate if wheat is spectrally different from all other features in the scene and if the "training" or "spectral definition" samples are valid.

Non-superivised classification simply takes advantage of the fact that the landscape generally shows wide variations in reflectance. In this type of classification no ground observation data are used to train the computer. The analyst simply instructs the computer to examine the spectral characteristics of the data points for a given scene or area and to assign each data point to a cluster or group of other data points having similar spectral properties. The analyst may request a simple clustering into 3 classes or a complex clustering into 31 classes or some other number. The number is determined by the objective of the analyst.

In both supervised and non-supervised classification a broad range of options are available. Data from a Landsat pass in March may be overlaid onto data obtained in September, or data from 1972 onto data from 1976 in order to detect and monitor changes in the scene. Data from other sources or of other types such as population density, topography maps, soil drainage properties, or land ownership may be digitized, adjusted to the same scale as the Landsat data and used for data bases and correlation studies.

3. Data utilization. Any system of data acquisition and analysis assumes that the data are useful to someone. Since the launch of Landsat-1 in July 1972 an increasing number of scientists and organizations in many nations have examined the utlity of Landsat data and found the data to be useful in many applications. The areas of greatest utility may be separated as follows:

Land resources
Mineral resources
Vegetation resources
Water resources

a. Land resources.

Land is one of the finite resources of the world. Since most of the arable and potentially arable land of the world is already being exploited, the doubling of food production in the world must come primarily from the land already under cultivation. When the increasing population places more and more stress on the land and exceeds the carrying capacity of the land under a given cultural or management system, land deterioration sets in. In many areas of the world land is deteriorating very rapidly.

It has been demonstrated in many areas that Landsat data can be effectively used for mapping soils, inventorying land use, and identifying and monitoring such land degradation phenomena as desertification, overgrazing, salinity, erosion and water-logging. These kinds of information are needed before effective corrective measures can be defined and improved management systems implemented.

b. Mineral resources.

Geologists have found the synoptic view provided by Landsat to be most valuable. They have observed earth surface anomalies and features not previously identifiable in aircraft-acquired images. Many important lineaments in the earth's crust have been mapped for the first time with Landsat images. Landsat data have been used in many countries to correct and update existing geologic maps and in other countries to produce geologic maps for the first time.

As geologists have worked with the Landsat data, they have found that many subsurface features or phenomena are related in some way to surface features observable by Landsat. Although much is yet to be perceived and learned about the geologic applications of Landsat data, many valuable geologic applications have been made.

c. Vegetation resources.

Perhaps the most dramatic application of remote sensing technology to date is the identification, mapping and areal measurements of agricultural crops. Researchers in the United States and several other countries have demonstrated that Landsat data obtained on appropriate dates can be analyzed rapidly by computer to identify wheat, corn, soybeans, sugarcane, cotton, rice, and other crops. An important current research project in the United States involves the U.S. Department of Agriculture, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the Laboratory for Applications of Remote Sensing at Purdue University, and a few other laboratories. Known as the Large Area Crop Inventory Experiment or LACIE, the objective is to develop a more accurate and timely wheat yield prediction equation using data from ground sampling, aircraft observations, Landsat data, and weather satellite data. It is theorized that Landsat can provide in real time valuable measurements on area planted, conditions of crops during growth, harvest conditions, and area harvested. If an improved yield prediction model can be developed for wheat in North America, its application on a global basis should be possible. If it works for wheat, a similar equation or technique should work for rice, corn, soybeans, sunflowers, and other crops important in world trade.

Landsat data have been used by several scientists and organizations in a wide range of soils and climatic regions to study the conditions of forests and rangelands. Satellite imagery has been found especially useful to detect dramatic differences in range conditions and to detect changes in forests caused by clear cutting, forest fires and disease.

d. Water resources.

Landsat digital data are particularly valuable for studying the quantity, quality, and periodic changes of surface water. Several states in the United States have used computer analysis of Landsat data to produce state maps showing all the lakes, ponds, and reservoirs larger than 5 to 10 hectares in size. Others have used multispectral analysis to separate surface water bodies into several categories related to the content and type of suspended matter in the water and to depth. Such studies are valuable in determination of sedimentation rates in reservoirs, of sources of pollutants, and for planning corrective action.

Thinking Small on a Global Scale

A decade from now we will look back to the results from our analysis of multispectral data from Landsats 1 and 2 and consider those systems quite primitive. For, if the planned development schedule can be realized, a global information system of the mid-1980's will provide a great improvement, both in quantity and quality, of data about the earth's surface.

Not only will we be able to obtain a rapid synoptic view of the U.S. Corn Belt, the Mekong Delta, the Argentine Pampa, the Danube Plain, or an entire nation, but we will be able to identify and characterize many features of soils, crop conditions, and water resources in areas as small as one tenth hectare, that is, 1/5 the area of a soccer or football field. This system will be designed to provide complete global coverage every 7 to 9 days and to distribute data to the user within a period not to exceed 4 to 5 days after data acquisition. A global information system of the future optimized for acquisition of earth resources data will provide simultaneously an overview of the global and national scenes as well as a detailed look at the local scene.

During the next two decades many nations, if resources become available, will be able for the first time ever to identify and map to a high degree of accuracy their land, vegetation and water resources and to monitor crop conditions and land use changes. With the use of satellite scanner data these tasks may be done at scales as small as 1:1,000,000 or as large as 1:10,000 or larger.

Tasks which have never before been possible or feasible may at last be accomplished. Some of these tasks which may contribute to the solutions of the problems of hunger and environmental deterioration include:

Global and national crop surveys
Global survey of land deterioration

- Overgrazing
- Wind erosion
- Water erosion
- Salinization
- Desertification
- Flooding
- Water-logging
- Clear cutting of forests

Assessment of natural disasters

- Drought
- Flooding
- Earthquake
- Crop destruction by insects, diseases

<u>Political/Social/Economic Resolution</u>

I have addressed you as a scientist, as a technician. I have made several references to spatial resolution of the satellite sensors. That is, what is the smallest area identifiable on the ground? In my research we refer often to temporal resolution, i.e., what is the frequency of repetitive scanning of an area? We also speak of spectral resolution, i.e., the number and width of spectral bands measured by the scanners.

What I have not addressed may be clustered into a broad but very important category--political/social/economic resolution. I have attempted to stretch your imagination and to introduce you, if you have not been exposed before, to the exciting potential benefits to the human family of a global information system. The technology is with us and continues to develop at an accelerated rate. But perhaps the most important questions have yet to be resolved. What is the resolution of our political, social and our economic scanners as we attempt to design a global information system which will optimize the benefits to the citizens of all nations? How do we internationalize such a system so that all nations may participate and reap the benefits? How do we transfer the technology effectively so that all nations may be equipped to use the system? Can we have a global information system which does not erode the sovereignty or invade the privacy of nations? These and many more questions are yet to be resolved.

I hope and trust that we may have both the will and the wisdom to solve them. There is so little time and we have so much to do!