(NASA-CR-140674) THE APPLICATION OF REMOTE SENSING TECHNIQUES: TECHNICAL AND METHODOLOGICAL ISSUES (Environmental Research Inst. of Michigan) 72 p N75-10564
CSCL 14B G3/43 Unclas 52733

THE APPLICATION OF REMOTE SENSING TECHNIQUES: TECHNICAL AND METHODOLOGICAL ISSUES

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OCTOBER 1974

RESEARCH APPLIED TO NATIONAL NEEDS (RANN)
National Science Foundation
Washington, D.C. 20550
Grant No. GI-34809X1

ENVIRONMENTAL
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Sponsorship. The work reported herein was conducted by the Environmental Research Institute of Michigan with support from the Research Applied to National Needs (RANN) program of the National Science Foundation under Contract No. GI-34809X1. Dr. Larry Tombaugh is the sponsor's representative. Contracts and grants to the Institute for the support of sponsored research are administered through the Office of Contracts Administration.

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TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. 193500-5-X	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle APPLICATIONS OF REMOTE SENSING TECHNOLOGY: TECHNICAL AND METHODOLOGICAL ISSUES		5. Report Date October 1974
		6. Performing Organization Code
7. Author(s) F. C. Polcyn and T. W. Wagner		8. Performing Organization Report No. 193500-5-X
9. Performing Organization Name and Address Environmental Research Institute of Michigan Infrared and Optics Division P.O. Box 618 Ann Arbor, MI 48107		10. Work Unit No.
		11. Contract or Grant No. Grant No. GI-34809X1
		13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address RESEARCH APPLIED TO NATIONAL NEEDS (RANN) NATIONAL SCIENCE FOUNDATION Washington, D.C. 20550		
		14. Sponsoring Agency Code

15. Supplementary Notes

The ERIM Principal Investigator and NSF Sponsor Representative for this project are, respectively, Dr. R. Keith Raney and Dr. Larry W. Tombaugh.

16. Abstract

This report outlines capabilities and limitations of modern imaging electromagnetic sensor systems and compares the products of such systems with those of the traditional aerial photographic system. Focus is given to the interface between the rapidly developing remote sensing technology and the information needs of operational agencies. In particular, communication gaps are shown to retard early adoption of the technology by these agencies. An assessment is made of the current status of imaging remote sensors and their potential for the future. Public sources of remote sensor data and several cost comparisons are included.

17. Key Words Remote sensing, Electromagnetic sensors, Image processing, Multispectral scanners, Radar, Technology/user interface, Research needs, Resource inventory, Environmental monitoring	18. Distribution Statement Approved for public release; distribution unlimited.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED		

FOREWORD

This report is one of a series prepared under support from the Research Applied to National Needs (RANN) program of the National Science Foundation (NSF), Contract Number GI-34809X1. The project entitled "The Application of Remote Sensing Technology to Environmental Planning and Public Policy Formulation," has the objective of assisting in increasing the effectiveness of public planning agencies through innovative use of the technology of remote sensing information systems. Principal tasks include: (1) determination of the present sources, content, and flow of information within and between selected agencies, (2) introduction of remotely sensed information into these agencies, and (3) assessment of the actual and likely future import of such information on public decisions effected by the agencies.

This volume constitutes one of several reports to be published under the grant. Focusing on the technologist/user interface, it outlines the capability and limitations of remote sensors and discusses communication problems that can arise between the user and the technologist.

The authors wish to thank Dr. Larry W. Tombaugh, the Sponsor's Representative, and Dr. R. Keith Raney, ERIM's Principal Investigator, for their helpful suggestions and for recognizing the need for this report.

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APPLICATIONS OF REMOTE SENSING TECHNOLOGY: TECHNICAL AND METHODOLOGICAL ISSUES

1
INTRODUCTION AND SUMMARY

Since the 1940's, new techniques for generating imagery from aircraft and spacecraft have been developed which make possible the mapping and measurement of surface features any where on or near the surface of the earth. The new sensors span a large portion of the electromagnetic spectrum, from the ultraviolet through the visible and infrared into the micro-wave region. The development and application of these new sensor systems have come to be known as the technology of remote sensing.

While much effort has been spent to develop the different sensors, less has been spent on understanding the relationship of the outputs of the sensors to the various information needs of planners, decision makers, resource managers, administrators, ecologists, geologists, and environmentalists —in short, those who would apply these sensors to real world concerns. This report focuses on the technology/user interface but does not dwell on the sensors themselves.

Other publications provide the technical description of camera systems, multispectral scanners, radars, and satellite sensors. We believe that insufficient attention has been directed toward the user who should benefit from the output of the sensors. This report is prepared for the user who would like to consider the application of remote sensing for his needs. Included is a discussion of the mechanics of securing, planning for, and utilizing various sensor outputs.

Selected sensor systems must be understood in terms of their limitations and potentials as analytical tools. It is these constraints which form the heart of this report. Also is included a discussion of problem specification and the technology/user agency interface. We have attempted to outline the most promising remote sensing applications to date and to indicate those areas where further research should be emphasized. A brief consideration of technology costs completes our appraisal of what remote sensing is now and what it means for the future.

Most applications of remote sensing technology include subtle and complex issues. In many cases remote sensing may be the best potential technique to bring to bear on such issues. The purpose of this report is to provide a basis for constructive dialog between the user and technologist. It should serve to increase the awareness in each community of the other's problems. It may serve to increase the awareness in each community of its own problems.

2
REVIEW OF SENSORS AND TYPICAL PRODUCTS

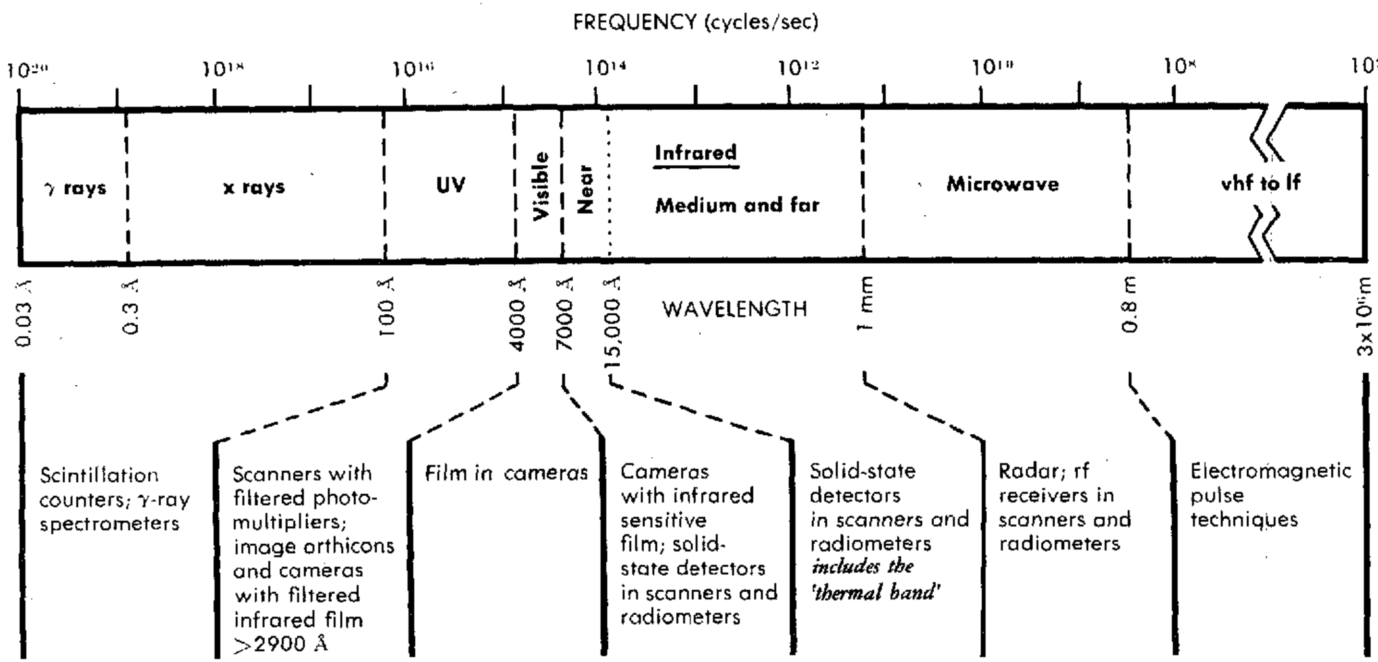
Much information from a scene can be extracted through visual observation. Aerial photography was originally designed to produce a permanent record of a scene in the visible and near-visible region for inspection and analysis at a later time in well equipped facilities. Through training and use of models, an expert can extract considerably more information from an image than an untrained observer. To obtain still more information about a scene, imaging sensors have been developed which operate in the nonvisible region [1]. The resulting imagery contains information about other properties of the elements in a scene, e.g., surface temperature of objects and "color" differences in invisible regions of the spectrum. Figure 1 indicates the conventional ranges of the electromagnetic spectrum and the sensors used to record energy in these ranges.

These "exotic" sensors usually do not directly provide the information which a user wants, but such information can often be derived from a series of inferences and deductions based on the remote sensing data and information from other sources. Figure 2 diagrams the steps for obtaining information by remote sensing. Remote sensors have been developed whose capability is generally set by technology state-of-the-art and operational requirements for collecting a given type of data. These sensors observe a scene and record the electromagnetic radiation reflected or emitted by elements within it. The output record may be in image format or stored on magnetic tape as electrical signals which can be used to produce an image directly to indirectly after being processed by a computer. To get the information the user desires, the imagery or video data must be analyzed with the aid of models which relate the observable with the information being sought. The resulting information usually can be translated into the format desired by the user.

For an example of this kind of technical inference chain, we might look at how measurement of surface temperature may be used to decide when an area should be irrigated. Infrared scanners exist which can measure temperature differences to a fraction of a degree centigrade. In actuality, the sensor measures energy from a scene, and its output signal is a set of voltages proportional to the energy the sensor receives. Thus one is able to derive temperature data from the set of voltages.

The temperature becomes a derivable physical variable deduced from the sensor output. Studies have shown that there is a relationship between surface temperature and the moisture or water present in the soil. During the day, cooler temperatures indicate the presence of relatively greater soil moisture than do warmer temperatures. At night this relationship

1. Holter, M. R., M. Bair, J. L. Beard, T. Limperis, 1970. Imaging With Non-Photographic Sensors, in Remote Sensing with Special Reference to Agriculture and Forestry, Nat. Acad. of Sciences, Washington.



THE ELECTROMAGNETIC SPECTRUM AND SOME SENSORS THAT USE IT. The infrared portion of the spectrum, though much wider than the band of visible radiation, is still a small part of the total. Recent research has focused on the integrated use of several sensors, each making use of a different portion of the spectrum.

FIGURE 1. REMOTE SENSORS FOR THE ELECTROMAGNETIC SPECTRUM

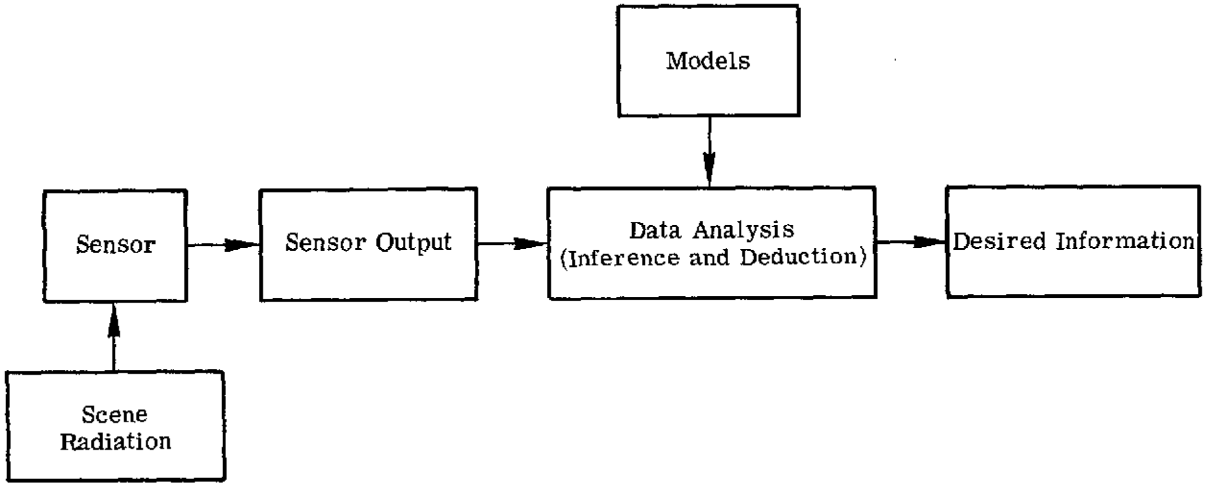


FIGURE 2. REMOTE SENSING DATA/INFORMATION CHAIN

between the water content and temperature of soils is reversed. Two factors contribute to this effect: Water evaporates when heated, and saturated materials have a relatively high heat capacity. Thus in daylight, part of the sun's energy absorbed by water goes into the vaporization of water and only part to aquatic heating. Therefore, water bodies tend to remain relatively stable in temperature, so that in general they are cooler than their surroundings in daytime, and warmer than their surroundings at night.

Physical parameters such as precipitation, wind, and soil properties and their vertical distribution also influence what the surface temperature will be. Only by accounting for all of these parameters can the expected temperature for different soil conditions be used to calculate the probable soil moisture present. Thus, for example, after a series of deductions drawing together theory and field measurements, the parameter of soil moisture content can be determined and used as an input to a decision model which decides whether additional irrigation water should be applied to a given agricultural area. While this example represents a complex situation, it nonetheless illustrates the chain of inference from a remotely sensed measurement to an environmental decision. Of course, in an operational mode, the complexities are automated, and soil moisture information may be brought quickly to the decision.

Another example is illustrated in Table 1, which diagrams a multispectral sensor user-chain designed to provide information on plant productivity. The left-hand column lists stages of increasing data collection capability. The other columns show the information to be derived as the data collection capability is thus increased. In this table, the simplest system uses a single-band sensor with no calibration or supporting ground observation. The next stages include multiband data capability with references, the addition of calibration sources, then the addition of ground references and, finally, observation. In each case a different sensor output is possible. The different sensor outputs provide a variety of potential derivables; through these additions, information is obtained from the expanded inferences or deductions [2]. The level of output desired by the user and the resulting system complexity and cost should be clearly explored between the user and the remote sensing technologist.

REVIEW OF SENSORS

Historically and for much of the work today, standard black and white photography is the main sensor for most aerial survey operations. If employed vertically, aerial cameras produce plan images of a scene. If in addition the camera is properly designed and operated, and the left-hand image corrected for residual distortions, quite precise images and mapping products are possible. Figure 3 shows the imaging geometry of aerial photography. Many aerial survey

2. Polcyn, F. C., N. A. Spansail, and W. A. Malila, 1973. How Remote Sensing Can Help the Ecologist, in The Surveillant Science, Remote Sensing of the Environment, (R. K. Holz, ed.). Houghton Miffin Co., Boston, pp. 349-359.

TABLE 1. SENSOR-USER CHAIN TO PROVIDE INFORMATION CONCERNING PLANT PRODUCTIVITY

SENSOR REQUIREMENTS		SENSOR OUTPUTS		POTENTIAL DERIVABLES		POSSIBLE INFERENCES OR DEDUCTIONS
				Spatial Pattern	→	Plant Community Structure and Stratification
			→	Time Variation of Relative Image Contrast	→	Maturation or Wilting
Single Channel Data	→	Voltage ↓		Relative Apparent Temperature (IR)	→	Effects Due to Change in Energy Balance
Synchronous Multi-channel Data and Reference, relatively calibrated		Raw Spectrum (voltage) ↓		Species Identification (if one has Training Set)	→	Distribution of Plant Species over a Scene
			→	Soil Type Identification (if one has Training Set)	→	Probable Soil Fertility Levels
				Enhanced Image Contrast	→	Change in Species: Maturity, Disease/ Nutrient Status, or Moisture Status
Absolute calibration	→	Spectral Radiance watt/cm^2/ster ↓				
			→	Outgoint Energy Over Large Areas	→	Energy Budget Calculations
Ground References and	→	Percent Reflectance or Emittance ↓		Spectral Shape, Day-to-Day Basis	→	Distribution of Plant Species or Soil Types
			→	Absolute Apparent Temperature (IR)	→	Quantitative Knowledge of Thermal Processes
Observations		Ground Truth		Moisture Content of Soil and Species Identification Using Signature Library	→	Possible Moisture Availability for Plant Growth
					→	Distribution of Plant Species or Soil Types over a Region Having Minimum Ground Truth.

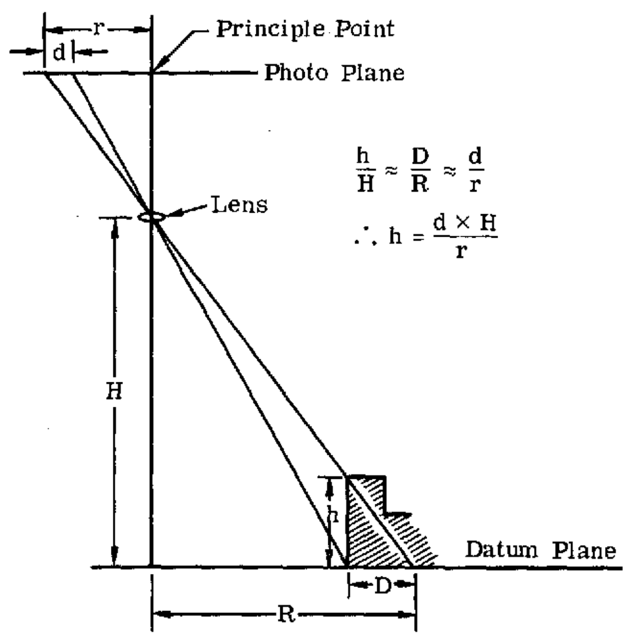


FIGURE 3. IMAGING GEOMETRY OF AERIAL PHOTOGRAPHS. This shows how the height of a building (h) may be determined from its relief displacement (D) on a single vertical photograph. The same phenomenon is used to create contour or topographic maps for stereoscopically viewed imagery pairs.

companies around the country maintain aircraft and camera systems to provide services as required. In addition to standard panchromatic film, black and white infrared* films operate in the spectral region where vegetation has a high reflectance. Such film, which is less affected by atmospheric transmission losses than films that rely entirely on the visible spectrum has taken an important place in many conventional camera missions, particularly those concerned with forestry inventorying.

Because of its increasing availability, high quality color aerial photography has begun to complement black and white photography as one of the standard data sources in aerial surveys. The use of color improves the recognition of patterns and even makes detection of anomalies easier. Color photography can be considered a three-channel multispectral system (the film uses red, green, and blue sensitive layers and dyes to produce an image with faithful color reproduction). The resulting image is readily interpreted by anyone who can visualize the earth's appearance from a high vantage point.

Quite recently, infrared Ektachrome films have come into use. In this film, one of the layers is sensitive to the invisible infrared. The three dyes create a false color presentation as the red dye depicts infrared exposure. Since healthy vegetation reflects highly in the near infrared, this film plays an important role in vegetation mapping. It is particularly useful in detecting vegetation stress or low vigor as will the presence of aquatic vegetation.

Based on the pioneering work of R. N. Colwell and others, operation in narrow bands using different film-filter combinations permits enhanced detection of particular features through good object/background contrast in narrow spectral bands. The contrast between objects will vary from band to band because of their spectral characteristics. Thus, in all these cases, a photointerpreter experienced in recognizing objects from a set of photographs having different tonal values is needed to make the final classification.

Increasing the number of film/filter combinations requires additional cameras to be flown simultaneously. The cost of accomplishing the mission then rises and eventually the magnitude of data overwhelms the photointerpreters.

OPTICAL MECHANICAL SCANNERS

Technical problems in data registration, lack of uniform exposure, and interpretation of many images force the multiband photographic approach to be somewhat limiting, especially for large-area surveys. The line scanner or optical mechanical scanner offers one type of solution to this data collection problem [3]. In its simplest form, the scanner uses a rotating mirror to scan a telescope normal to the aircraft's direction of flight. When mounted in an aircraft or a spacecraft, the scanner sweeps an area as illustrated in Figure 4, not

3. D. S. Lowe, 1968. Line Scan Devices and Why Use Them, in Proceedings of the 5th Symposium on Remote Sensing of Environment, Willow Run Laboratories, The University of Michigan, Ann Arbor, pp. 77-101.

*In the spectrum, the near-infrared, though invisible to human observers, is adjacent to the visible red band.

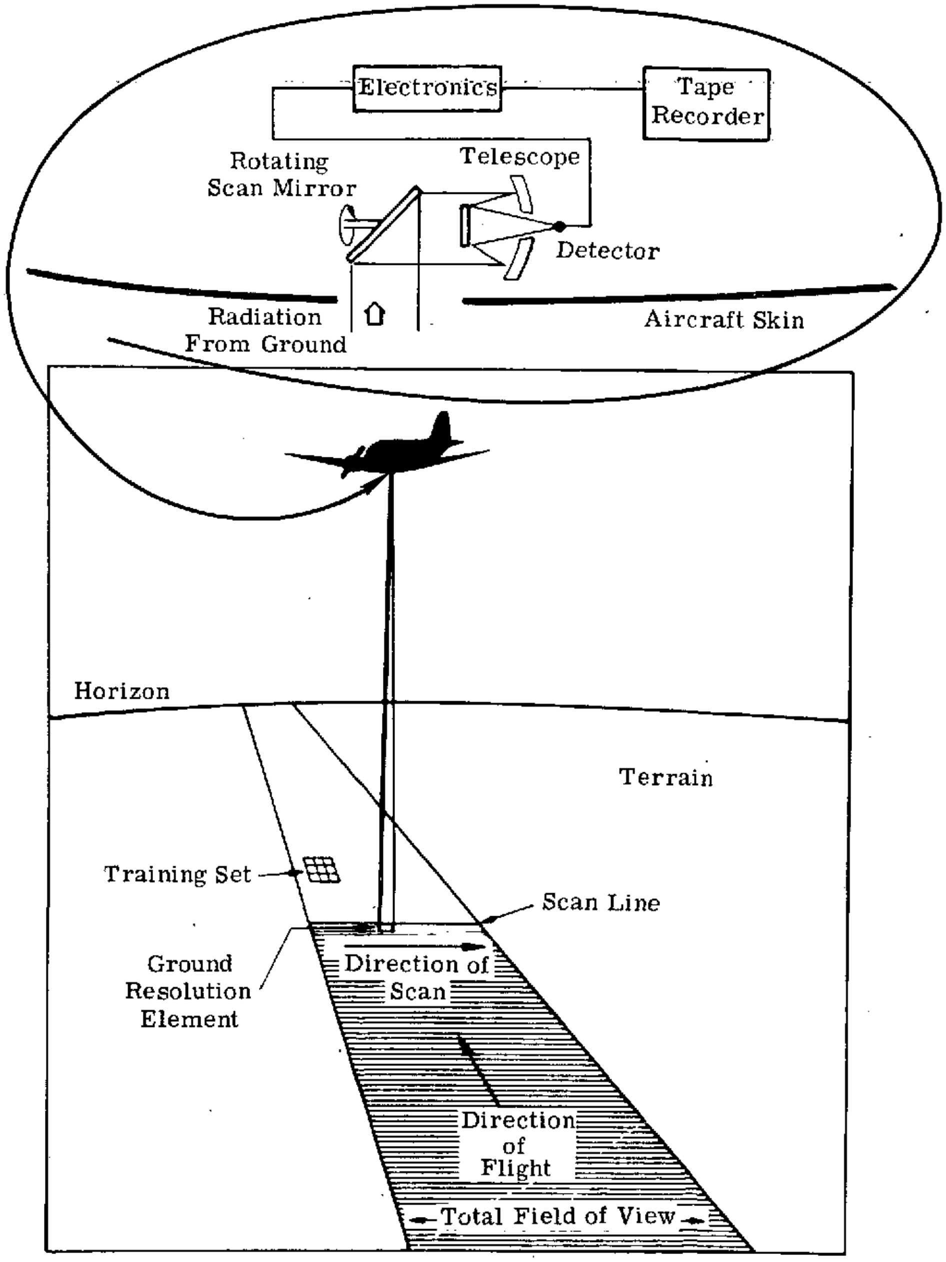


FIGURE 4. AIRBORNE MULTISPECTRAL SCANNER OPERATION

unlike an endless TV raster. The radiation collected by the rotating mirror is focused onto a solid-state detector which generates analogous electrical signals. The electrical signals either produce an image directly or are tape recorded magnetically and used for subsequent analysis in specialized equipment or in computers. The advantage of such a method is that the data are presented in a format that lends itself to machine-assisted interpretation. It eliminates the principal disadvantages of operating with multiple cameras. Another advantage of the line scanning instrument is that images may be produced from portions of the spectrum that cannot be photographed. Thermal infrared imagery is perhaps the best example, though both passive microwave and active radar systems also generate data in bands that cannot be photographed. Figure 5 presents images of the same area taken in both the visible and thermal infrared.

MULTISPECTRAL SCANNERS

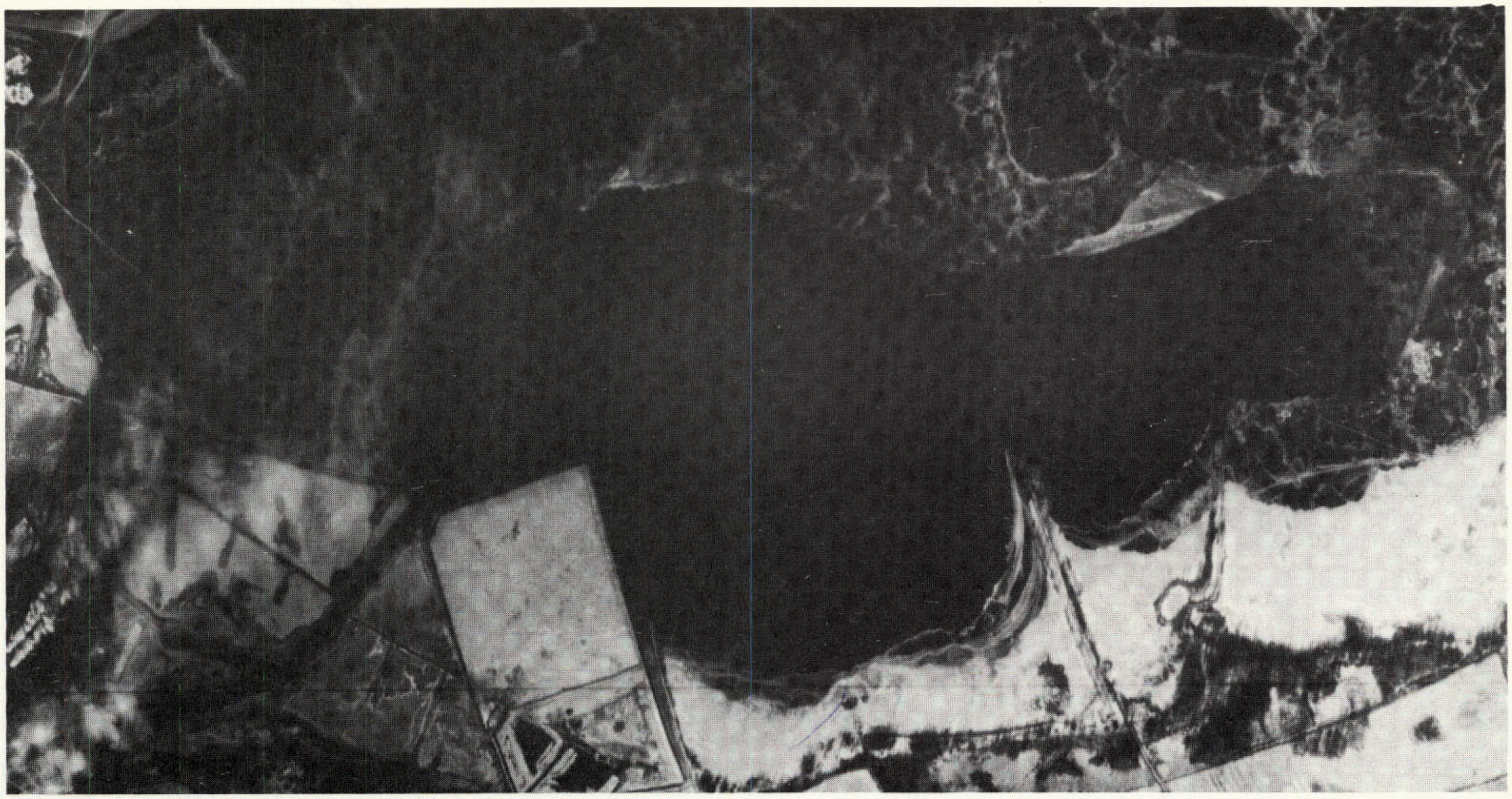
Early line scanning instruments, paralleling the idea of the multiband camera systems, used scanners with multiple detectors (and occasionally multiple aircraft) to generate data in more than one band at a time. This led to practical difficulties in data registration, i.e., in accurately superimposing the data from each scene element. A major innovation occurred in 1966 when the Environmental Research Institute of Michigan (then the Willow Run Laboratories of The University of Michigan)operated a multispectral scanner which overcame many of the deficiencies inherent in multiband cameras and in single-channel line scanning instruments [4].

At that time a spectrometer with the ability to operate simultaneously in 12 different spectral bands within the visible and infrared regions was installed in a line scanner in place of a single detector. By means of a prism, the light was divided into component spectral bands and fiber-optic bundles then carried each color to its own detector as illustrated in Figure 6.

The key feature of this innovation was the fact that all channels could observe the same point on the ground at the same time, thereby circumventing the problems of calibration and registration of former systems. This made possible computer processing of the spectral information from each scene element. The multispectral scanner provided a means whereby objects could be identified by machine and image-map outputs could be generated. The objects, in this case, would be distinguished from one another on the basis of their spectral signatures—viz., a set of voltages corresponding to the spectral reflectance or emission of a given object. Such recognition assumes that the set of spectral voltages is unique for a class of objects. This concept has been the subject of much research since 1966 and has led to the present ERTS-1* system. ERTS-1 has a four-channel multispectral scanner operating between 0.5 and 1.1 μm

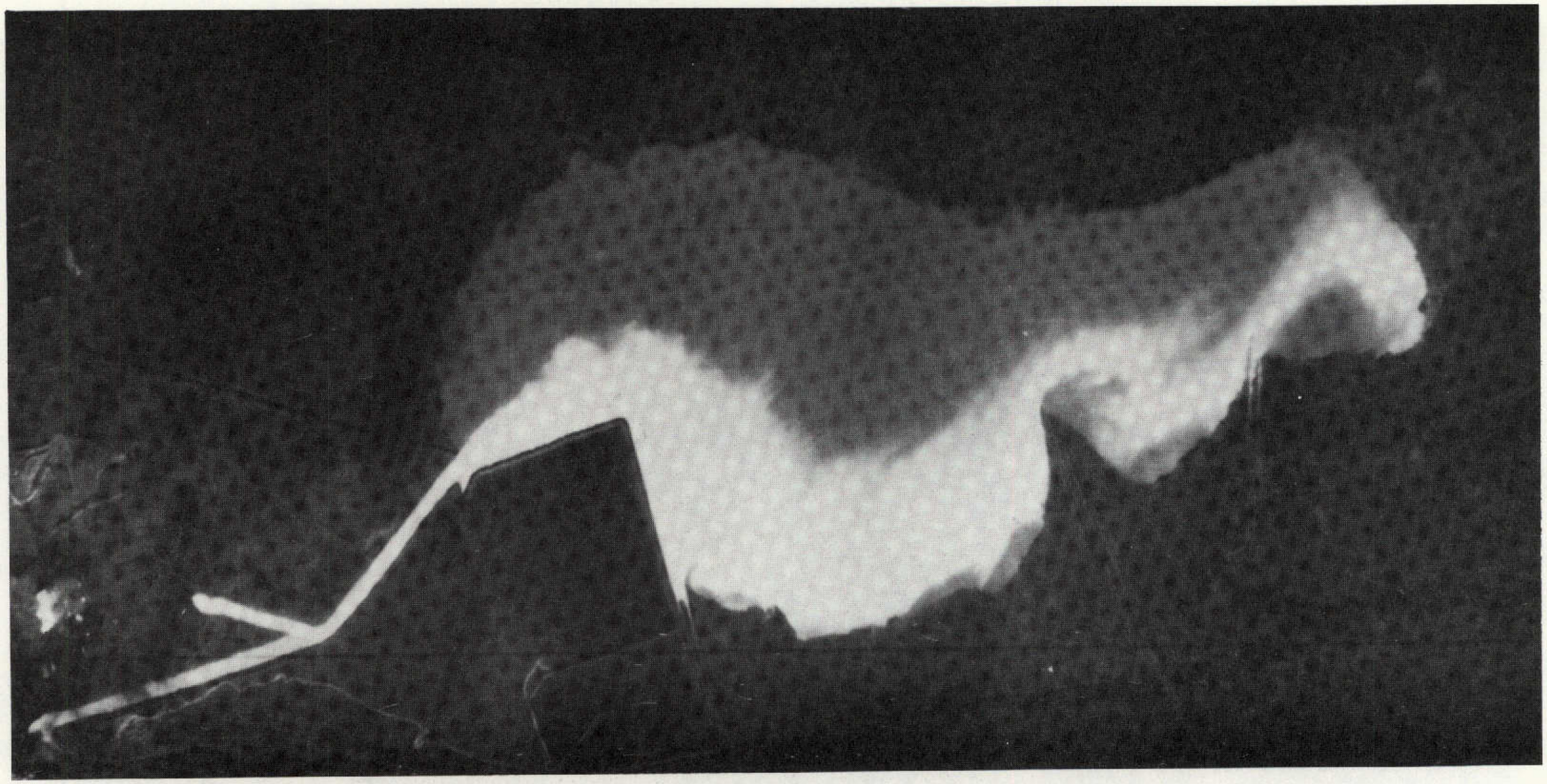
4. Lowe, D. S. and J. Braithwaite, 1966. A Spectrum Matching Technique for Enhancing Image Contrast, Applied Optics, Vol. 5, p. 893.

*Earth Resource Technology Satellite, and other such NASA-sponsored systems.



(a) J. C. Weadock and D. E. Karn, 12 January 1973, Saginaw Bay, 0.62 to 0.70 μm.
Shows the visible image in the red band.

FIGURE 5. COMPARISON OF VISIBLE AND THERMAL INFRARED IMAGES OF POWER PLANTS (Continued)



(b) J. C. Weadock and D. E. Karn, 12 January 1973, Saginaw Bay, 9.3 to 11.7 μm. Shows the thermal band, measuring relative surface temperature. (The whiter tones are warmer than the grey and black.) The plume of heated water is apparent; its temperature may be measured absolutely to 1^{o}F, and the volume of heated water may be estimated. (Note: only surface temperature is sensible.)

FIGURE 5. COMPARISON OF VISIBLE AND THERMAL INFRARED IMAGES OF POWER PLANTS (Concluded)

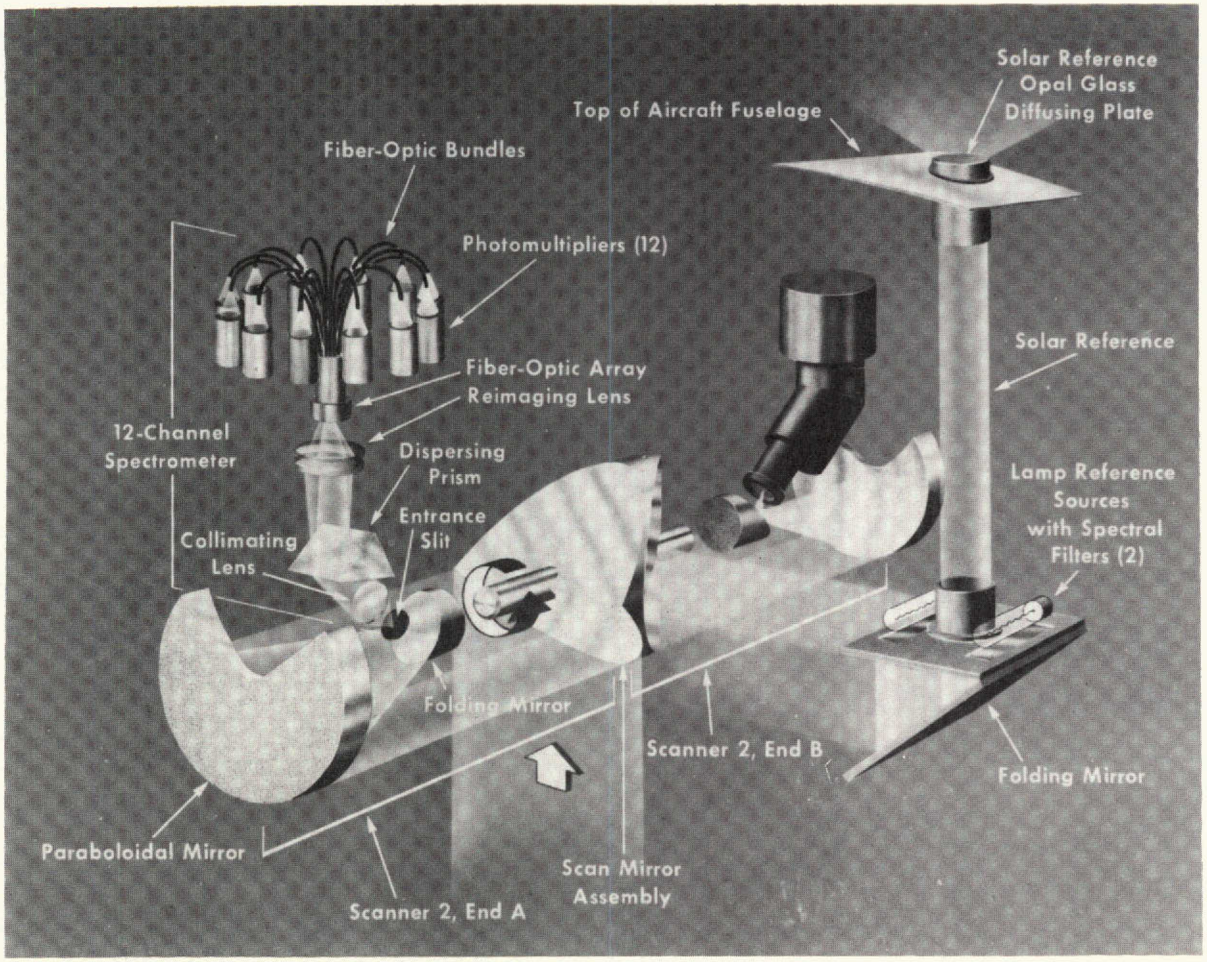


FIGURE 6. EXPLODED VIEW OF ERIM EXPERIMENTAL MULTISPECTRAL SCANNER

wavelength. Imagery produced by this satellite system has been widely distributed and its potential applications clearly demonstrated [5].

RADAR SYSTEMS

In the microwave region, high-resolution sidelooking radars (SLAR) have been developed which transmit a high intensity pulse of energy that is reflected from the terrain. The timed return of the radar pulse is a measure of the distance to an object, while the beam width determines image resolution in the flight direction. The return signals produce an image in which the lightest tones represent objects from which a greater fraction of the energy is returned. The intensity of this returned energy is strongly affected by (1) surface orientation, or (2) surface roughness; dielectric properties of the surface also affect the return. Generally the greater the electrical conductivity and surface roughness of an object, the greater is the signal returned. Roughness, however, is a relative concept dependent on the wavelength of illumination and angle of view. By using different wavelengths, a multiband radar system becomes similar to a multispectral scanner system, and the possibility for measuring and differentiating materials on this basis becomes possible.

For example, a surface that appears smooth in the L-band (30 cm wavelength) can appear quite rough in X-band (3 cm wavelength). Multiband radar systems are just now becoming available for mapping, and the full capability of such systems has not yet been established.

Differences in soil and vegetation penetration by various radar wavelengths suggest useful applications. In addition, radar systems can be made to transmit and receive radiation at different polarizations, thereby allowing another attribute for recognition of objects. Thus operated, a two-wavelength radar system may generate four channels of information, that is, two bands with two polarizations each (viz., like polarization and cross polarization in the transmitted and received signals of each band). Since most objects partially depolarize the transmitted signal, the reflected signal will contain both horizontal and vertical components. Certain objects, depending on their local geometry and conductivity, will produce different amounts of depolarization. Most radars require large antennas and high power to get meaningful ground resolution at reasonable ranges. Coherent sidelooking radars permit the returned signals to be collected in a way that permits a small antenna together with a computer to function like a large antenna [6]. This system provides high spatial resolution independent of the altitude, but at a price of greater sensor complexity and a need for data processing.

5. Proceedings of Third Earth Resources Technology Satellite-1 Symposium, December 10-14, 1973. National Aeronautics and Space Administration, Washington.

6. Zelenka, J. S., 1971. Imaging Radar Techniques for Remote Sensing Applications, in Proceedings of 9th Annual Allerton Conference on Circuit Systems Theory, University of Illinois, Urbana.

The usefulness of radar imaging systems has well known examples in the mapping of the Darien Peninsula, Panama [7], and the Amazon Basin, Brazil [8]. Both areas are heavily covered with clouds that prevent conventional mapping by means of aerial cameras. In a series of parallel flights, radar image mosaics were collected and the terrain features of these areas were inventoried for the first time. An example of a radar image is shown in Figure 7. Radar data are available for about one-third of the United States, and may be obtained for special purposes through several agencies and commercial suppliers (see Appendix D).

LASER SCANNERS

Active sensor systems provide their own source of illumination. These systems, in which a laser beam scans in synchronization with a receiver, open up another dimension to remote sensing because of the new parameters that can be measured. For example, it is possible to induce fluorescence in materials, and one can process the laser pulse's time-of-return to provide height information analogous to the topographic information derived by stereo photography. This time-ranging ability also may be useful in measuring water depth, tree height and structure, crop structure, and topographic relief.

A wide variety of new sensors now available or soon to be developed evidence the growing role of remote sensing. Society's concerns with resource inventorying and management, environmental quality, coastal zone management, recreation and wetland inventorying, world food resources, and similar topics should all benefit from this new technology.

7. MacDonald, H. C., 1969. Geologic Evaluation of Radar Imagery from Darien Province, Panama, Modern Geology, Vol. 1, No. 1, pp. 1-63.

8. deMoura, J. M., 1972. Radam Project Summary in Proceedings of 8th Symposium on Remote Sensing of Environment, Willow Run Laboratories, The University of Michigan, Ann Arbor.

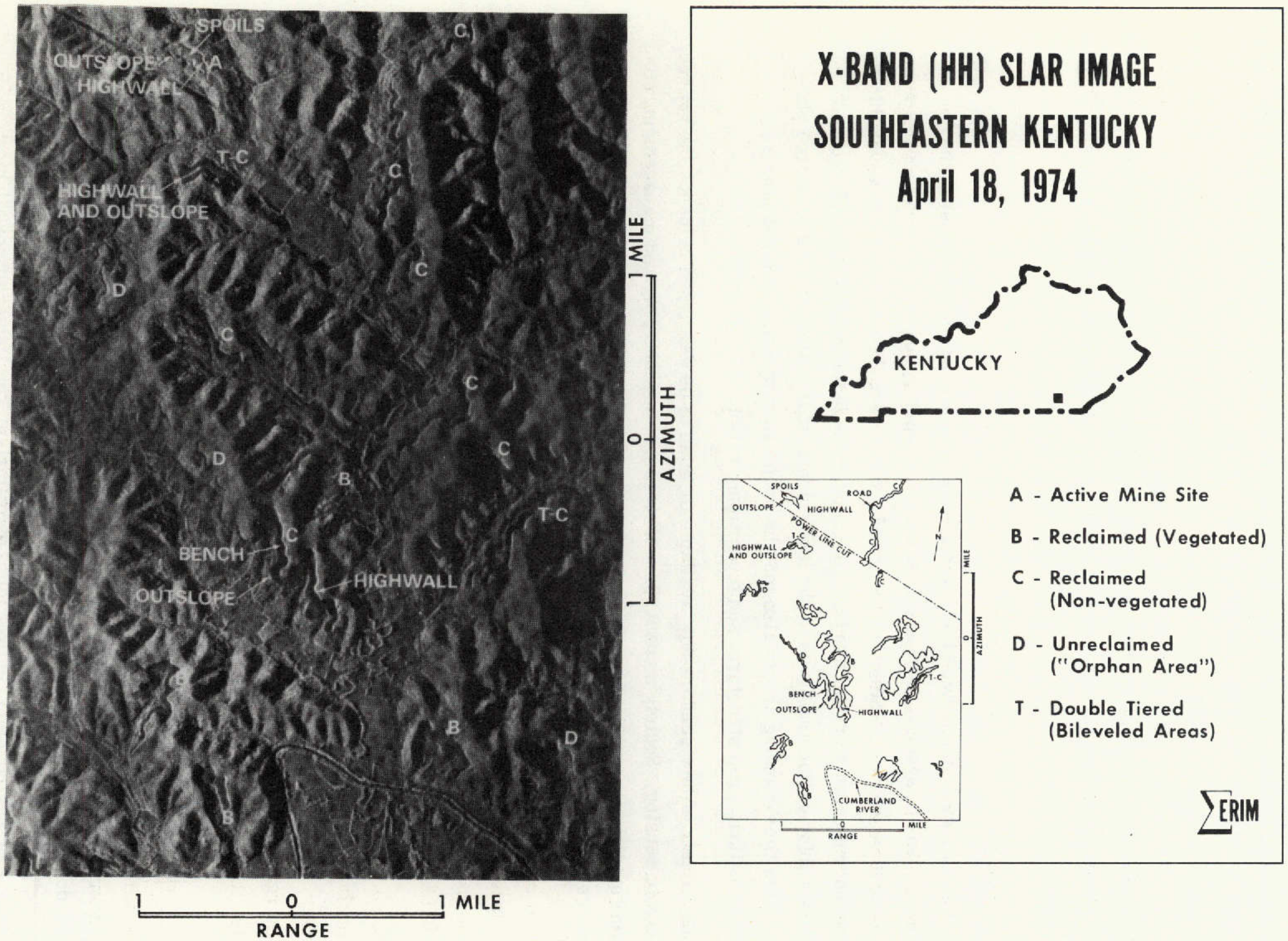


FIGURE 7. EXAMPLE OF A SIDELOOKING RADAR IMAGE

3
SENSOR OUTPUTS AS MAPS

From the earliest day of man's explorations, maps have been essential as a useful summary of spatial data. Early cartographers constructed their maps as best they could from a number of ship or field observations. These were taken by explorers who relied on crude instruments to measure sun or star positions and even poorer instruments to measure the passage of time. Eventually, as measurement accuracies improved, reconstruction of locational information in maps produced more reliable navigation aids, demarcation of transportation routes, and better defined boundaries for different governmental jurisdictions.

More recent developments to gain an overhead view of the earth through aircraft or space photography offers cartographers a new source of information not only for spotting changes in major terrain elements but also for taking inventories of land cover types and geological features in a way not considered feasible heretofore.

With the advent of ERTS-1, the ability that modern remote sensors possess for providing map-like imagery for large areas is just now being realized. Output data from ERTS-1 meet the location accuracies defined by USGS for 1:250,000 scale maps. One example of the value of ERTS has already been reported; it concerns the correct depiction of features in Eastern Massachusetts. Previous maps were found to be in error when compared to precision corrected data from ERTS-1 [9].

Modern, image-forming, remote sensors offer similar capability for producing map-like outputs. All of them, however, including photographic systems, have limits on the accuracies of feature location within the image. Achieving the removal of these inaccuracies to defined limits depends on the level of sophistication built into the data collection system and subsequently used image reproduction subsystems.

Section 3.1 discusses, for different sensors, the trade-offs in scale, resolution, and accuracy. Section 3.2 describes how area measurement statistics, derived from outputs of these modern sensor systems, are handled by special processing machines; a statement is included on recognition accuracies when objects fill the instantaneous field of view (IFOV) or are smaller than the IFOV. Computer graphics are taken up in Section 3.3.

3.1 SCALE, RESOLUTION, AND ACCURACY

The scale of any photomap depends on sensor altitude and camera lens focal length. The scale is the magnification ratio of the image to the real world and can be derived by dividing the

9. Williams, R. S., Jr., 1973. Coastal and Submarine Features on MSS Imagery of Southeastern Massachusetts: Comparison with Conventional Maps. Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1, Vol. I, NASA, pp. 1413-1421.

altitude into the camera focal length. Unless lenses are interchanged, the user has only the variable of altitude to select if he desires data of a given scale. (Scale can, of course, be adjusted through projection and enlargement techniques, but this is more expensive.)

One advantage of higher altitude is shown in Figure 8. If a large area is to be mapped, the need for mosaicking may be reduced by flying as high as possible consistent with requrements for resolving the smallest objects or features of interest and maintaining the required map accuracies. At high altitude the camera angle is smaller and therefore less distortion is introduced. Mapping the same large area from medium altitudes necessitates use of a wider angle lens, with consequent practical problems of uniform exposure and resolution over the entire film plane. Such a lens may also cause spatial distortions, as discussed below.

Low altitude flights tend to produce the best possible resolution but, by requiring multiple flight lines create problems in achieving proper coverage on adjacent lines and obtaining uniformly exposed film when a mosaic of many frames must be constructed.

One's ability to construct a large-area mosaic depends strongly on the nature of the distortions in each of the individual frames or strips of imagery collected. Where an image is formed on film without any use of scanning, as in camera systems, maintaining the film plane parallel to the ground and keeping the camera axis parallel to the aircraft heading will help insure distortionless imagery. Maintaining uniform exposure and relying on specialized viewers and plotters also help in making photomosaic construction practical.

When vertical features are imaged, however, cameras introduce errors (as do all sensors). At low altitude, the imaging of non-flat terrain emphasizes elevation-dependent errors; this effect is illustrated in Figure 9. Here a directionally straight mountain road (Fig. 9a) is imaged as a winding road when viewed off-axis (Fig. 9b) since its elements are at different elevations. Vertical features in camera outputs appear to lean away from the optical axis. (This may be put to advantage since viewing an object at slightly different angles makes stereo viewing possible.)

Optical-mechanical scanners and radars, unlike cameras, construct an image point-by-point because they use a scanning technique. This fact of scanning removes some sources of error, but introduces the potential for a variety of additional distortions. Planners or any other users who wish to use the output images of modern remote sensors as map-like products must be familiar with the various distortions that could be introduced and which, if not corrected, might lead to misrepresentations.

For example, a scanner mounted in an aircraft is susceptible to the roll, pitch, and yaw of the aircraft. In present-day scanners, a roll-corrected signal is automatically built into the electrical recording so that, in image reproduction, it may be used to adjust each scan line relative to the next and correct for the motions of the aircraft, at least in that one dimension. The other axes of possible motion (the pitch and yaw) do introduce smaller errors but

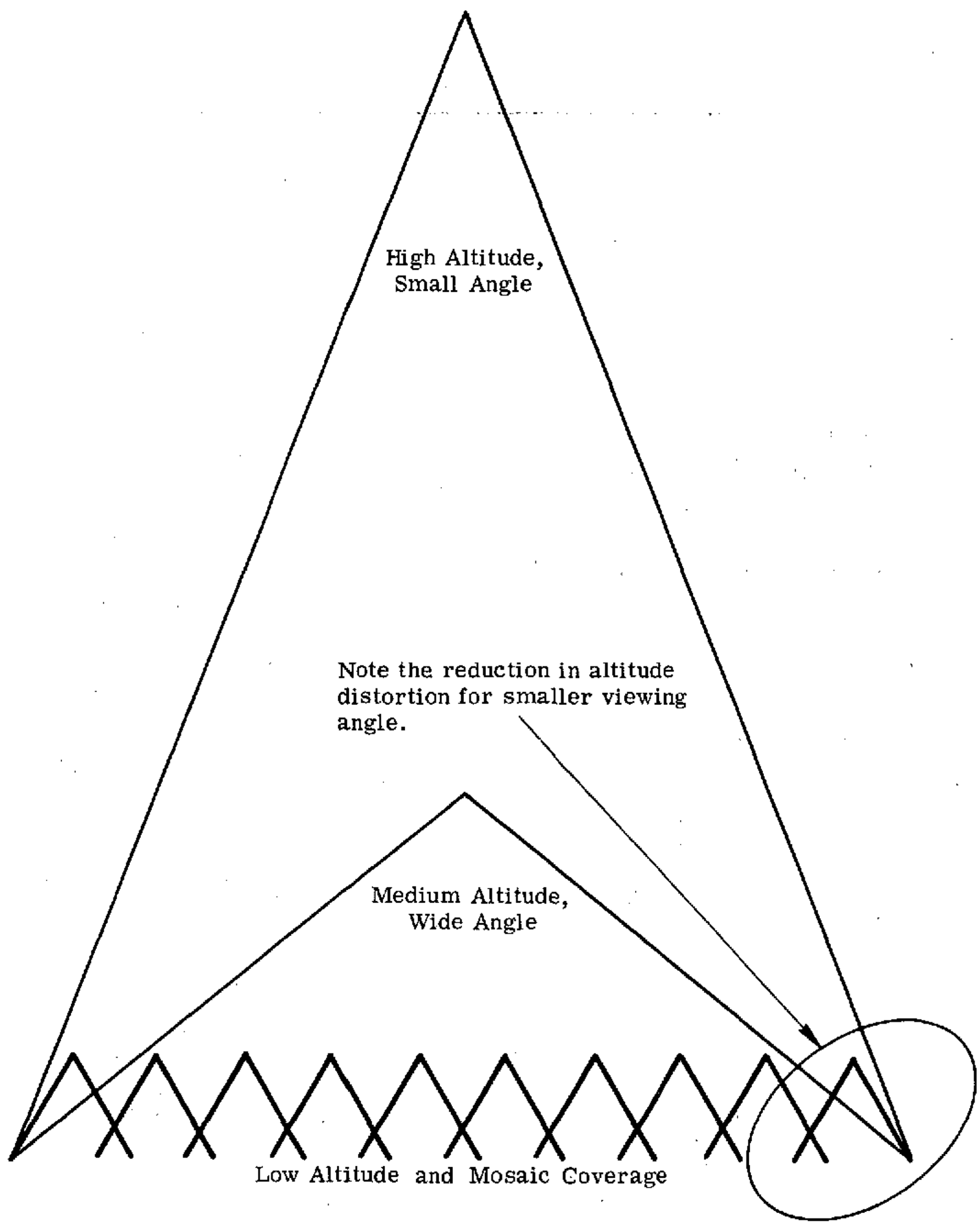
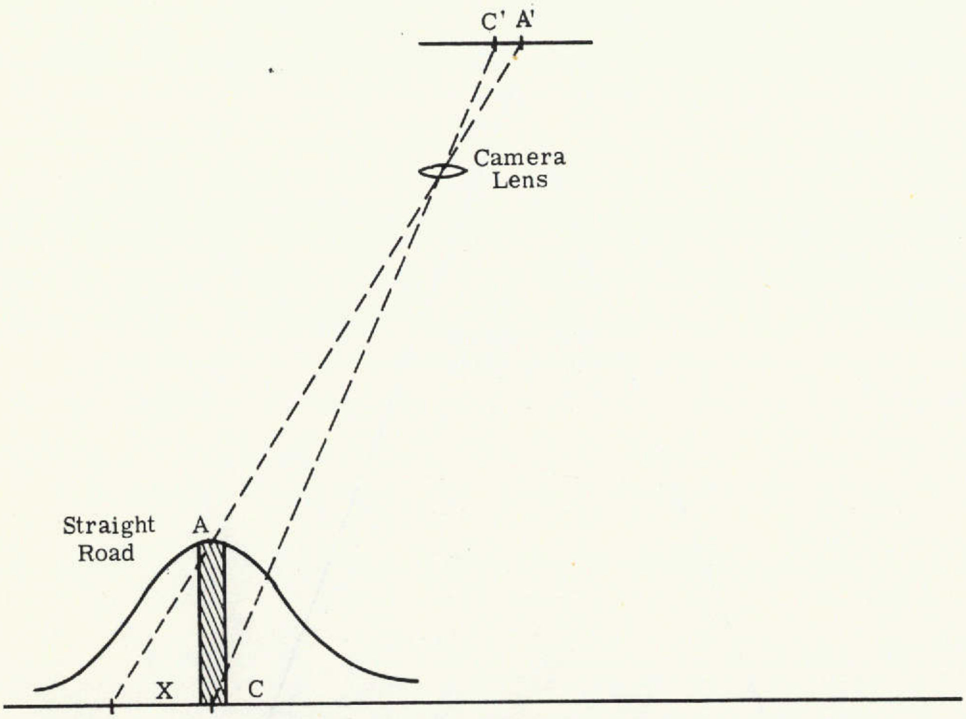
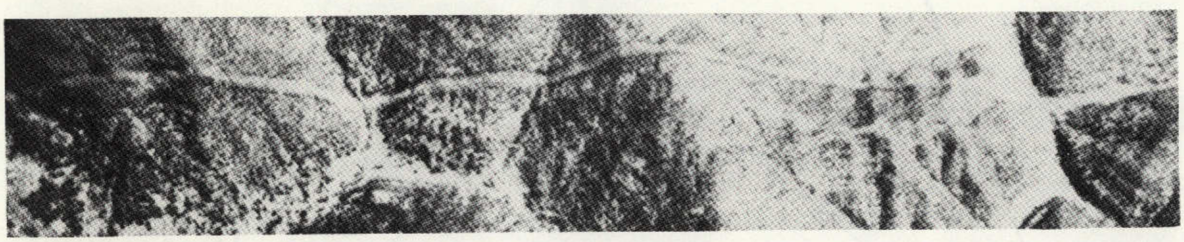


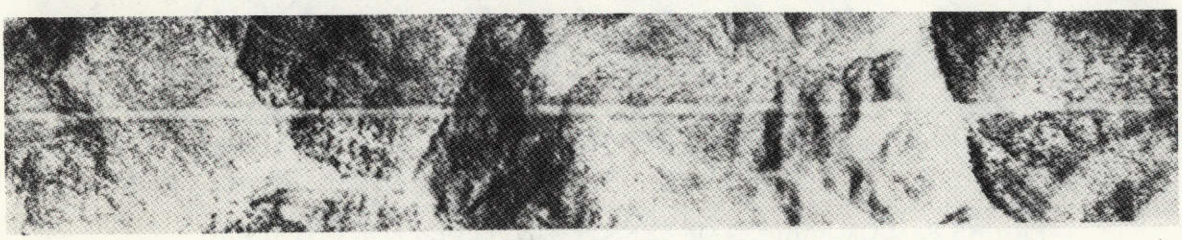
FIGURE 8. COMPARISON OF SENSOR ALTITUDES FOR OBTAINING LARGE-AREA COVERAGE



(a) Elevation Distortion in Photography.
Top (A) of mountain will image as if it were "leaning" away (X-distance) from its base as shown in (b) below.



(b) Off-Axis Perspective View



(c) Near-Axis Perspective View

FIGURE 9. IMAGE DISTORTIONS RESULTING FROM NONLEVEL TERRAIN

they are usually ignored except in the most demanding of applications. Depending on the accuracy for which the map is to be used, such errors in pitch and yaw may be neglected. The adjustment for those errors could be accounted for during the actual data collection if one employs a stable three-dimensional platform. User requirements should establish this need before the data are gathered and processed.

Scanners, unlike cameras, use different mechanisms for generating the two dimensions of the resulting data or image: the scanner speed, and the aircraft speed. Therefore the geometry is very susceptible to differential scale errors; that is, the magnification along the line of flight (LOF) will in general, differ from the magnification across the LOF. If this is important to the user, specifications should be placed on this differential error.

The fact of altitude discussed earlier also comes into play in the operation of optical-mechanical scanners. If a wide area is to be mapped, several lines must be flown in parallel, while holding the aircraft ground speed as constant as possible. In some cases all lines may have to be flown in the same direction to reduce the effect of cross-winds on aircraft heading; this can increase the cost of data collection but serves to reduce data interpretation, mosaicking, and formatting problems.

Another important consequence of the scanning motion is illustrated in Figure 10. Data are collected from a relatively level land, but during the reproduction of the image an angular compression is introduced. To the scanner, the world appears "cylindrical" as indicated by the image plane. The larger ground resolution toward the edge of the scan covers greater areas at coarser resolutions but is projected at a constant rate and size on the film during reproduction.

For scanners with large fields of view (greater than 90^o) the compression of the edges is significant (see Fig. 10b). Different image lengths represent the same object distance, depending on its relative location between the middle of the frame and the edges.

Technologically there are methods to correct for the angle distortion—for example, the cathode ray tube (one of the prime methods of reconstructing images) may be made to follow a nonlinear sweep, or digital rectification (requiring computer software) may be applied. Again, the constraints and remedies (if any are required) should be worked out between the user and technologist prior to data gathering and reduction.

The continuous strip capability for scanners is one advantage over mapping with frame-type cameras, because it reduces the need for constructing mosaics from individual frames. Depending on the area to be covered, a continuous strip map from a tape of 12-minute duration for an aircraft flying at 120 knots produces a continuous strip some 24 miles long. The swath width of the map, for a 90^o scanning system, would be approximately 1-1/2 times the altitude. The area covered then becomes a function of the speed of the aircraft, its altitude, and the scanner's total scan width. Map distortions can be introduced if the ground speed is not held constant. Cumulative error in compression or expansion of the flightline image can be proportional to $\Delta L = \Delta V \cdot t$, where ΔL is an error in true flightline lengths, ΔV is the error in velocity, and t is the time interval of the flightline.

By using the flexibility of the ground image reproduction station, many geometric and scale errors can be reduced or eliminated. The construction of maps to the accuracies called for at 1:12,500 scale is difficult to achieve in present state-of-the-art sensors. While photographs can be rectified by linear transformations on the entire image at once, this cannot be done easily for scanner images because of changes that can occur during the length of time it takes to construct the image. Only by using known ground control points and ancillary aircraft data, is it possible to associate each picture element to a ground location in terms of a set of grid coordinates. For many purposes, computer software now exists that reduces scale errors in scanner data to quite acceptable levels.

The location accuracy will ultimately be limited to within the area defined by the instantaneous field of view (IFOV) and the altitude. For airborne systems, typical IFOVs are on the order of 1 to 3 milliradians. This means that a 1000 ft altitude, a 3-mrad sensor would integrate energy across a 3 ft × 3 ft or approximately 9 sq ft area directly below the aircraft. In order to see an object smaller than 9 sq ft, a very sharp contrast in reflectivity or temperature would have to be present so that the amount of energy measured over 9 sq ft without the small object, would be different than the signal obtained from that resolution element which saw the background plus the small object. That energy difference would have to be greater than the system noise of the scanner in order to be detectable on an output image. These are fundamental limitations to sensor detection. They are not unlike considerations of blur circle, lens distortion, graininess of film, etc., in talking about camera systems.

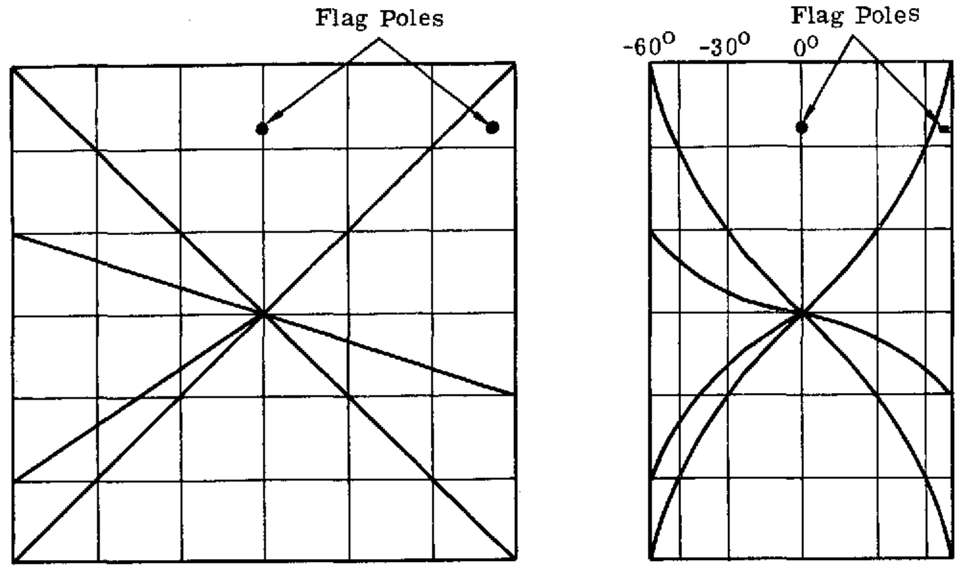
In summary, map accuracies at certain small scales can be met when using cameras, scanners or radars, but success ultimately depends on the total system design and proper operational procedures. For maps at larger scales, the costs of rectifying the sensor data may not be cost-effective since better ground control, more sophisticated navigation equipment, and higher precision sensors are expensive. Depending on user needs, the costs of collecting imagery, and the availability of supporting equipment, better sensor outputs can be achieved which will make comparisons with other information easier. However, the user should be forewarned that unless he specifies his needs regarding scale and accuracy, and also his tolerance on these numbers, he will receive mapping products with scale and accuracy determined by others that may not reflect his expectations.

3.2 RECOGNITION AND CLASSIFICATION

Computer-assisted measurements from sensor data give area counts of special features. The use of multispectral systems and computers can reduce the need for grid-counting of areas on photographs. For large-area surveys, this alternate method with machines can prove most cost-effective. A scanning system produces an electrical analog of the scene, picture element by picture element, during the data collection phase and the result is in a form quite amenable to computer calculations. This represents a more accurate measurement of the energy relationship between objects than that usually obtained by first securing a photograph of an area and then trying to quantitatively measure density or radiance differences from the film. A number of complicated events tend to degrade the quantitative values obtained from a film transparency. This section places main emphasis on the use of optical scanners and their ability to provide quantitative data.

Data collected by the scanner in each of several wavelengths constitute a nearly optimum way of recording the true energy regime coming from the terrain. This quantitative capability permits the use of a computer to do rapid counting. The multispectral aspect affords discrimination between objects on the basis of spectral signature, and the electral format enables counting the individual elements that make up a given object class. For land-use applications, among others, area statistics of various objects become a useful and feasible output. The area statistics are derived from resolution elements or picture elements (pixels). By counting these for a given class of objects and (depending on IFOV and altitude) equating the area represented by each picture element, the total area of that object class within a given scene is quite readily provided.

In calculating the area of various features that are classified by the multispectral technique, care must be taken in normalizing the number of pixels to the area actually existing. For example, the ground resolution is derived as the altitude times the instantaneous field of view. At nadir the ground resolution is its smallest [equal to $(h^2\omega^2)$]. As the scan angle moves off nadir, the ground resolution increases as a function of $(h^2\omega^2 \sec^3 \theta)$ where h is the altitude, ω is the instantaneous field of view, and θ is the angle away from the nadir (see Fig. 11). For small angles of θ, the cube of sec θ increases gradually. Therefore, not until $\theta = 30^\circ$ does the ground resolution area increase by 50%. The total scan angle in this case would be 60°. For this reason, in many cases only the middle portion of a total scan width is used for calculations. If the sampling rate is employed at 1 sample per resolution element then the digital count can easily be multiplied by the area of the average resolution element within the swath width chosen. If the digital sampling is done at too high a rate (oversampling) then an erroneous relationship will be introduced so the safest course of action is to make an independent area check of a known field size at the proper scale. Available ground measurements for typical distances can be used for calibrating the product of digital counts times instantaneous area observed.



(a) Original Scene (Ortho-Projection, 120° Coverage)

(b) Scanner Image of Scene

FIGURE 10. COMPARISON OF ORIGINAL SCENE GEOMETRY WITH SCANNER IMAGE GEOMETRY

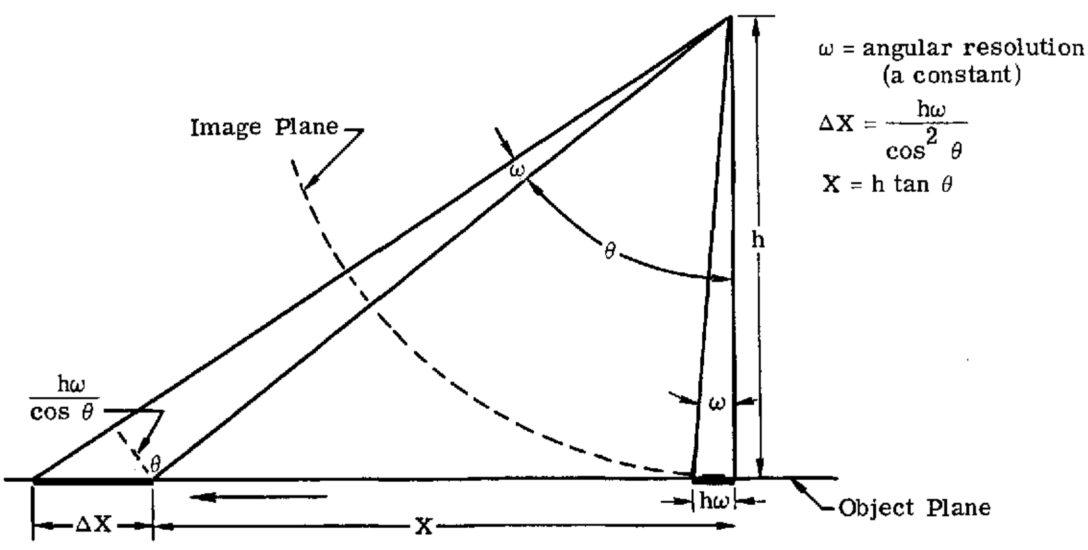


FIGURE 11. CYLINDRICAL DISTORTION OF SCANNER DATA

RECOGNITION ACCURACIES

The use of machine-assisted processing raises the question of recognition accuracy for the multispectral process. Various tests have been made to compute this accuracy. These tests involve a statistical sampling scheme in which the percentage of recognized counts is found by dividing the sample count by the total count within a given boundary. A percent probability of recognition is thus derived. This statistical model uses a number of similar objects throughout the scene so that the percent correct classification has a more accurate meaning. Typical recognition accuracies above 85% have been reported and, for special object classes and targets, 95% recognition probabilities can be achieved.

Two kinds of errors can occur: One can miss detection of objects A; or one can misclassify objects B as belonging to Class A. The level of tolerance on each of these types of error depends upon the cost of incurring each type of error and can only be judged relative to their importance to a particular user application of interest.

The reliability of the measurements depends on a variety of factors. Certain procedures have been invented which increase the reliability of recognition accuracy; collectively these procedures are known as preprocessing. A number of normalization techniques are employed such as removal of the effects of sun angle differences, sensor variations across the scan line, corrections for atmospheric transmissivity, and removal of noise interferences. These factors are estimated for a number of parameters, based on known methods and experience. In some cases these smoothing procedures eliminate noise variations, because the averaging takes place in a manner that degrades the resolution of the scene at the expense of improved signal quality. For applications involving large areas of counting, this may be the proper trade-off. In other applications that involve high resolution detection of fine detail—that is, the counting of objects a few pixel elements in size—this procedure will cause a loss in counts for small objects.*

In general, the overall accuracy of recognition depends on the definition of class and the size of the classes. Thus, it is sometimes easier to separate broad categories of land cover types than to distinguish between subclasses of a given type (that is, soil, vegetation, water, are readily separated). But for some classes like agriculture, it may be easier to distinguish each of several crop types than to measure collectively all areas as "active agriculture." As

*A specialized technique for estimating the percentage of a given object within a resolution element has been invented and promising results have been shown for counting small ponds and lakes from space using ERTS-1 data [10].

10. Horwitz, H. M., R. F. Nalepka, P. D. Hyde, and J. P. Morgenstern, 1971. Estimating the Proportions of Objects Within a Single Resolution Element of a Multispectral Scanner, Proceedings of 7th International Symposium on Remote Sensing of Environment, Willow Run Laboratories, The University of Michigan, Ann Arbor, pp. 1307-1320.

increased resolution is obtained, differentiation within a class may be possible depending on seasonal and temporal effects. (See Chapter 4.)

3.3 OUTPUT DISPLAYS

There are several different output formats obtainable from remote sensing systems. Grouped broadly, they are: (1) imagery, either produced directly from camera systems, or produced indirectly from scanner systems; (2) recognition maps, usually produced via intermediate computer processing of scanner data; and (3) special tabular data, usually summarizing features of interest represented in one of the above formats.

Imagery, the natural output of a camera, is a comfortable way to present some of the information inherent through scanners. The format is thus (i) a photograph, in black and white or color; (ii) a photo-like image created from one or more channels of a scanner, such as an image that depicts the location and extent of the hot spots of a forest fire, occasionally but erroneously called an infrared photograph; (iii) a color composite simulating a color or false color infrared photograph, such as many of the well known products from the ERTS-1 satellite; and (iv) a computer generated output that employs color and symbol variations to denote the color or gray scale intensities of the information. The common feature of all of these formats is that the information simply presents the relative presence or absence of color type information in a spatial image.

In contrast to imagery, the equipment can be programmed to recognize certain features of the information, and the output is known as a recognition map. Indeed, these recognitions may be independent of the visible color of the objects recognized, even though they are in one recognition class. For example, the location and area of roof tops may be required for an impervious materials study. For such recognition, the output display may be programmed to indicate selected categories by color, by computer printer symbol, or a combination of these. An example of a computer recognition map is shown in Fig. 12. The specific mode of display frequently becomes secondary to the problems of recognition (see below), but perhaps for that reason the display symbols are often more freely specifiable by the potential user.

There are other outputs that have value in application. Two of these are more commonly known by their technique of generation: ratio enhancement, and level slicing. They also are recognition displays. Ratio enhancement is used to provide visual emphasis to selected classes of objects, and to deemphasize the remainder. It is most frequently employed in relatively rapid and inexpensive analog devices. Slicing, on the other hand, is a non-linear decision rule applied to the intensity level of a single channel of data. The output that results shows those areas whose brightness falls within prescribed limits, and excludes all else. For example, a

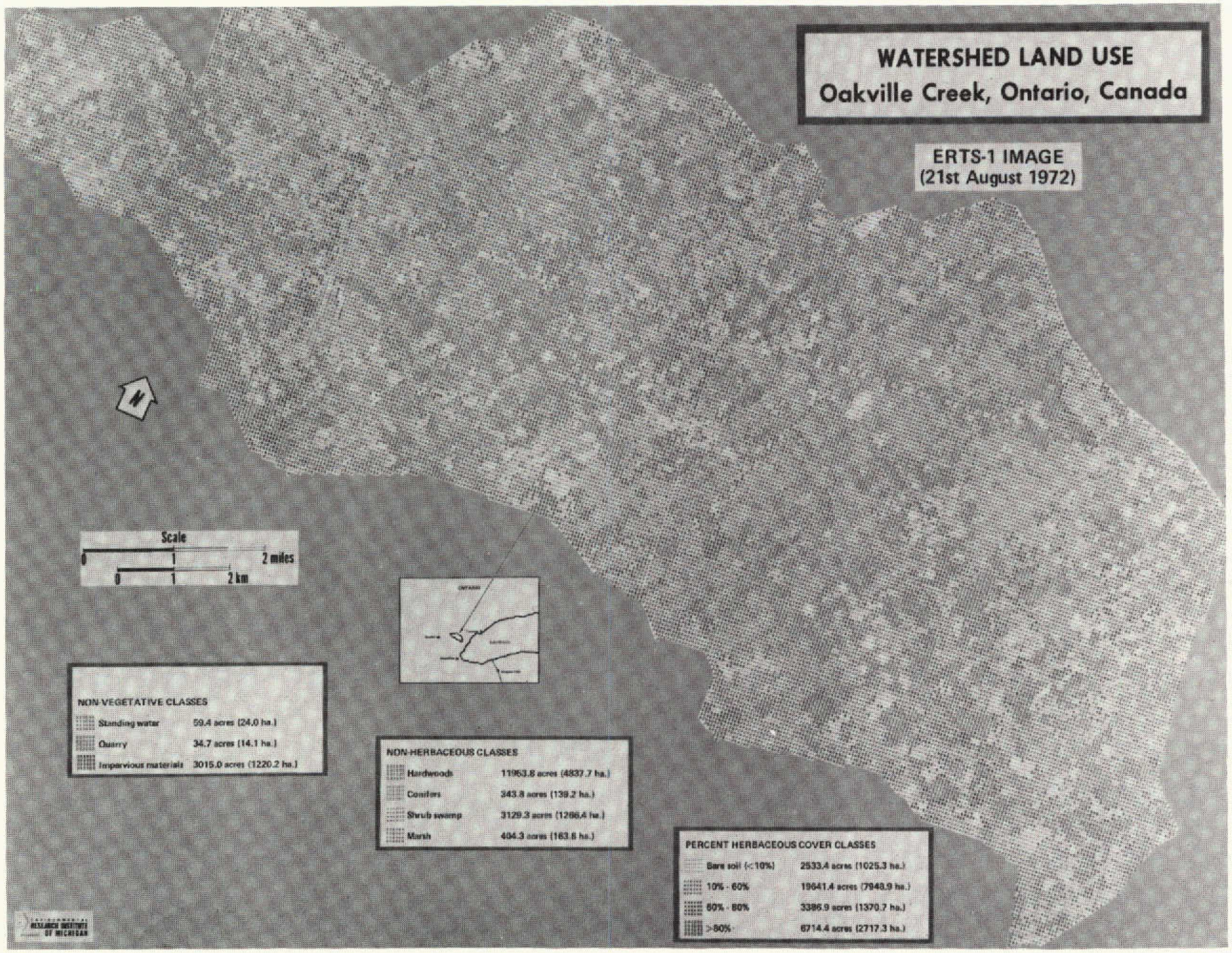


FIGURE 12. WATERSHED LAND USE FROM ERTS-1 DATA (original in color).
Oakville Creek, Ontario, Canada.

thermal sliced image might show all areas whose surface exceeds a given temperature. An example of these outputs is given in Figure 13.

The third form of output, tabular or summary data, is obvious but for that reason should not be overlooked by the user. Modern computer processing is fully capable of counting perimeters, areas, or numbers of identified objects in a class; this summary data may be of more immediate value to a user than the imagery or scanner products on which it is based.

With future computer processing systems, interactive displays on a TV-like monitor will be available so that classification results can be observed, new variables introduced, and immediate consequences or correlations noted. The remote sensor products as seen on the computer display or produced in hard copy are one translation of sensor data.

The user is urged to share in specifying the precise symbolic language of the translation—namely, colors, symbols, scales, accuracy, and choice of content most consistent with his needs. The technologist will respond to user needs within the range of technical feasibility and available resources.

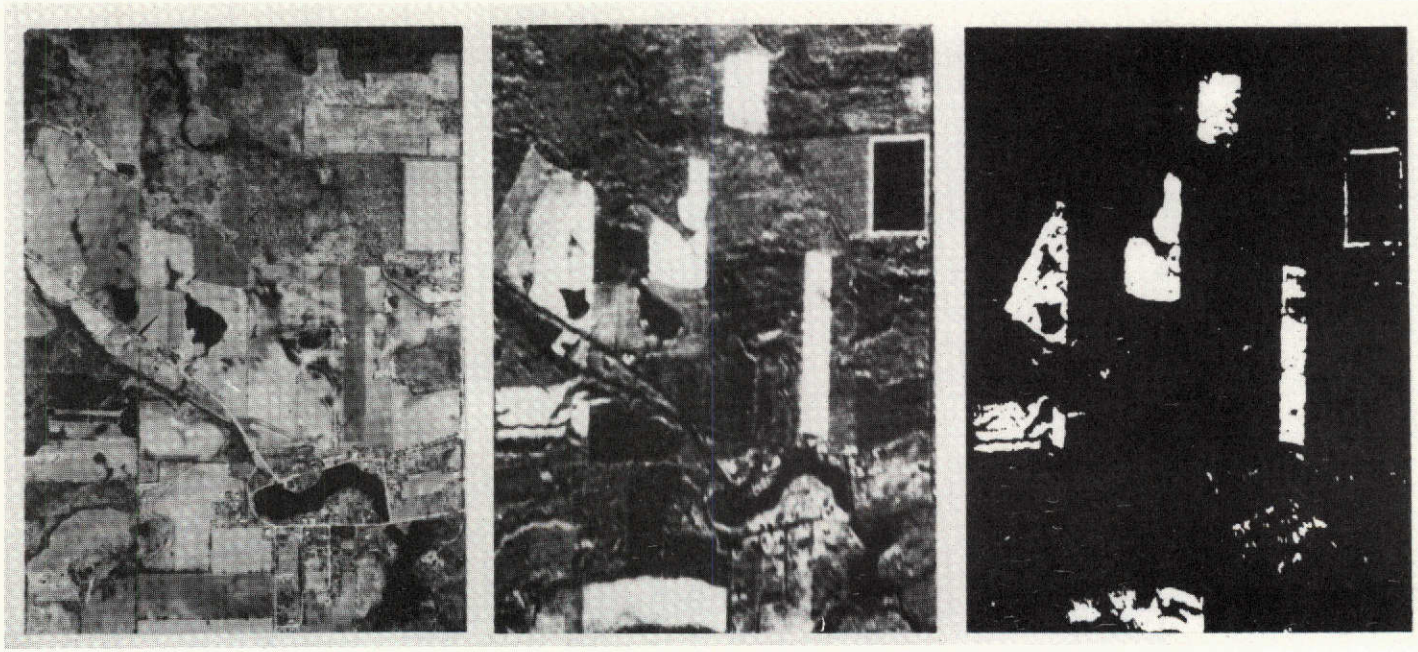


Photo | Ratio Image | Level Slice

FIGURE 13. COMPARISON OF A PHOTO-IMAGE, ENHANCED IMAGE, AND THEMATIC IMAGE OF THE SAME AREA

4
SENSOR OUTPUTS AS AN ANALYTICAL TOOL

The remote sensing systems considered in this report are imaging sensors which depend on the electromagnetic radiation reflected or emitted by objects in a scene. Other sensor systems concerned with detection and measurement of natural radioactivity, magnetism, and gravity are also under development, but these are non-imaging devices primarily for special geologic purposes and are not considered here.

The physical basis of imaging electromagnetic sensors is straightforward. The reflectance and emittance of radiant energy by an object is wavelength dependent and is relatively specific for the materials and conditions of that object [11]. In other words, different objects have different reflectance and emittance characteristics which vary uniquely over the range of the electromagnetic spectrum. By collecting reflected or emitted energy in one or more discrete portions of the spectrum, it is possible to identify scene objects or conditions and distinguish one from another. Since the quality and quantity of radiant energy is a function of certain physical properties of the object, many objects can be objectively classified on the basis of their interaction with natural or man-generated electromagnetic radiation.

The attributes of electromagnetic radiation which can be detected and measured are limited. They include intensity (flux density), frequency, and polarization. Intensity refers to the energy of the radiation, frequency determines its wavelength or mundanely, its "color," and polarization refers to the relative orientation of the radiation's electric vector to some coordinate system. Using these attributes of radiation, spatial and temporal variations are recorded to provide scene information. The spatial variations are optimally displayed in an image format, where the image shows differences in either tone (grayscale) or visible color. An image is a reduced scale map-like analog of the original scene. From this graphic representation of the energy radiating from a scene, objects and features are recognized on the basis of their relative shape, size, and tone or color. This is the basis of conventional photo-interpretation.

Temporal variations refer to time-dependent radiation changes which occur from the same object space. For example, in time-lapse photography of a growing crop, one records changing radiation attributes as the crop changes physical condition during its growth cycle. For object identification purposes, two aspects of this temporal or time-dependent phenomena are important: (1) the optimum time or season for distinguishing an object of interest from all possible background objects not of interest, and (2) appearance comparisons of the same objects at two or more different times. These dual aspects are discussed later in this section as temporal effects and change detection, respectively.

Currently, polarization differences of radiation emanating from a scene are not well known and little utilized, except with radar sensors where polarized radiation is both transmitted and received. Future research will provide better insights into the information content of polarized radiation.

It is important to recognize that electromagnetic remote sensing devices are designed to detect and record surface or near surface phenomena "seen" through the atmosphere. In certain portions of the spectrum, the atmosphere is opaque to some sensors and they cannot be used. Also, a device's ability to "see" anything other than a solid or liquid surface is extremely limited. Long wavelength radar sensors can penetrate dry unconsolidated material to some extent, and photographic and other optical sensors can penetrate clear water to up to 30 meters, but these are exceptions to the general rule that the electromagnetic sensors record only surface phenomena. Subsurface conditions may or may not be related to the surface phenomena. For example, a green leaf and a green painted vehicle may have an identical green "color," but their emitted radiation in the thermal infrared wavelengths depends greatly on their subsurface thermal properties.

Without concern for specific sensors, this section deals with their outputs as an analytic tool—in other words, how the record of scene radiation is transformed into real information or, more particularly, what quantitative scene information is obtainable and what are its limitations. This discussion concerns the production of thematic maps, the use of temporal and change detection information, and the need for ancillary ground observations.

4.1 THEMATIC MAPS

Remote sensor data can be processed to provide information which is complementary to standard cartographic maps. These data may be in the form of analog images that provide a graphic display of relative radiation differences for selected wavebands, such as aerial photographs for the visible wavelengths, or in the form of enhanced or classified images. Single waveband analog images are illustrated in Figure 4. Enhanced and classified images are the products of efforts to obtain predetermined scene (thematic) information not readily available from photographic or other sensor outputs. The thematic images clearly designate, by distinctive tone, color, or symbol, the location and distribution of selected scene elements. The thematic images may provide no specific information concerning the scene radiation characteristics upon which they are based. For example in Figure 13 are three images of the same scene. The first image simply shows the appearance of the scene in single waveband (the photographic visible) where lighter tones, or grayscales, correspond to greater radiant energy than do the darker areas within the same image. The middle image shows enhancement of certain portions of the scene and suppression of others. This enhanced image is semi-thematic in that it is still necessary for the human observer to make a decision on the exact delineation of the features. The right-hand thematic image provides exact delineation of a single terrain feature—green vegetation. If desired, other scene features can be identified, coded differently, and overlaid to produce a single composite thematic image. These images represent the most sophisticated and, for many purposes, the most useful remote sensing products; however, there are important questions concerning their variable accuracy and reproducibility. In general the thematic image-maps are as useful and accurate as the knowledge of scene radiation and data processing characteristics on which they are based.

The technology of multispectral remote sensing provides a number of examples of thematic images produced for a variety of purposes. Table 2 lists a number of examples and gives their literature references.

4.2 TEMPORAL EFFECTS

The radiation environment that the remote sensor records is constantly changing. These changes result from the diurnal cycles of sunlight and darkness, the seasonal cycles of temperature and moisture, and the episodic cycles of changing weather patterns. Resulting from these cycles are periods of time when natural events are more readily recorded by remote sensors than at other times. The selection of time-of-day or season and the prevailing weather conditions can make significant differences in the quality and nature of the data. For example, surface temperature is greatly affected by the diurnal heating of absorbed sunlight during the day and re-radiation at night. Normal surface temperature ranges are large during the day and relatively small at night. Therefore, if subtle temperature differences associated with geothermal heating are of interest, thermal infrared data should be collected at night; solar heating during the day would mask the slight temperature effects. Likewise, if crop inventory is the objective, remote sensor data should be collected during the season that the particular crop is most easily distinguished from all other scene features. For winter wheat this may mean early spring; for corn, early fall; and for conifers, perhaps the winter. The mapping of urbanization growth is enhanced by scheduling data collection missions during the early spring or late fall to make it easier to observe structures in the absence of foliage. If soil information is sought from agricultural areas, early summer is the time for the greatest number of bare fields.

Another application requiring timely observation is the detection and prevention of spruce beetle infestations in the Black Hills of South Dakota. By judicious selection of the time of overflight, previsual detection of the loss of tree vigor is possible. Early detection leads to practical prevention of the spread of the infestation. In water resources activities, both seasonal and diurnal observations may be important. Tidal changes have strong influences on estuary vegetation cycles and salt intrusions, and these effects are often dependent upon the magnitude of the river discharge which varies seasonally. In the Great Lakes, spring seasonal warming cycles affect nearshore thermal currents which in turn limit the mixing zone for pollutants of water run-off and industrial outfalls. In addition, strong winds can produce nearshore currents that restrict river discharges from interacting with deeper lake waters.

TABLE 2. PARTIAL LIST OF REFERENCES ILLUSTRATING THE PRODUCTION OF THEMATIC IMAGES FROM REMOTE SENSOR DATA

I - VEGETATION AND LAND USE

Marshall, R. E., et al., 1969. Use of Multispectral Recognition Techniques for Conducting Rapid Wide-Area Wheat Surveys. Proceedings of the 6th International Symposium on Remote Sensing of Environment, Vol. 1, pp. 3-20.

Kolipinski, M. C., and A. L. Higer, 1969. Inventory of Hydrobiological Features Using Automatically Processed Multispectral Data. Proceedings of 6th International Symposium on Remote Sensing of Environment, Vol. 1, pp. 79-94.

Miller, L. D., and R. L. Pearson, 1971. Aerial Mapping Program of the IBP Grassland Biome: Remote Sensing of the Productivity of the Shortgrass Prairie as Input into Biosystem Models. Proceedings of the 7th International Symposium on Remote Sensing of Environment, Vol. 1, pp. 165-206.

Weber, F. P., et al., 1972. Computer-Generated Land Use Maps of a South-Eastern Forest Region. Proceedings of 8th International Symposium on Remote Sensing of Environment.

Thomson, F. J., 1972. ERTS-A Terrain Feature Maps of Yellowstone National Park. Proceedings of 8th International Symposium on Remote Sensing of Environment.

Driscoll, R. S., and M. M. Spencer, 1972. Multispectral Scanner Data for Plant Community Classification. Proceedings of 8th International Symposium on Remote Sensing of Environment, Vol. p. 1.

II - WATER AND MARINE RESOURCES

Malila, W. A., and T. W. Wagner, 1972. Multispectral Remote Sensing of Elements of Water and Radiation Balances. Proceedings of 8th International Symposium on Remote Sensing of Environment, Vol. 1.

Polcyn, F. C., et al., 1972. Multispectral Survey of Power Plant Thermal Effluents in Lake Michigan. Proceedings of 8th International Symposium on Remote Sensing of Environment, Vol. 1.

Wiesnet, D. R., et al., 1974. Flood Mapping of the 1973 Mississippi River Floods by the NOAA-2 Satellite. Proceedings of 9th International Symposium on Remote Sensing of Environment.

Wezernak, C. T., 1974. The Use of Remote Sensing in Limnological Studies. 9th International Symposium on Remote Sensing of Environment.

III - GEOLOGY AND SOILS

Tanguay, M. C., et al., 1969. Multispectral Imagery and Automatic Classification of Spectral Response for Detailed Engineering Soils Mapping. Proceedings of 6th International Symposium on Remote Sensing of Environment, Vol. 1, pp. 33-64.

Vincent, R. K., and F. J. Thomson, 1971. Discrimination of Basic Silicate Rocks by Recognition Maps Processed from Aerial Infrared Data. Proceedings of 7th International Symposium on Remote Sensing of Environment, Vol. 1, pp. 247-52.

Kristof, S. J., and A. L. Zachary, 1971. Mapping Soil Types from Multispectral Scanner Data, Proceedings of the 7th International Symposium on Remote Sensing of Environment, Vol. III, pp. 2095-2108.

The impact of any information, whether derived through remote sensing or other sources, on phenomena with temporal dynamics and complexity, is only as effective as the underlying descriptive model will allow. Such models are evasive and therefore poorly understood in most cases: they are the subject of much current environmental research.

4.3 ANCILLARY GROUND OBSERVATIONS

Remote sensing by its very nature attempts to measure from a distance some parameter wanted by a user. Sensors measure radiation reflected or emitted from a material but the user of the data desires other information. Of necessity, then, the electromagnetic radiation properties are used to form judgements concerning the nature of the useful parameter. In many cases the variations in the spectral properties of the radiation can lead to an unambiguous definition of an object, particularly when the object radiation is distinct from background radiation. This is usually true for major classification categories such as forest, water, and certain agricultural crops. While the remote sensor imagery can be used to correctly identify these objects, it is often difficult to selectively subdivide and identify subcategories. Analogously, in recognizing different people one uses stored spatial and color information on face, hair, body outline, carriage, and manner of walking to identify a distant individual as a stranger or acquaintance. In much the same way, recognition of objects in remote sensing imagery requires a knowledge of a number of characteristics and often data not directly observable. To get the maximum information from photography, interpreters must be trained to identify surface features from a vertical view of them. For this purpose special keys and signatures are generated that illustrate features the interpreter must identify. Identification involves observation of the tone and texture of the object, its shape, its location, and its environmental context. Automatic classifiers (computers) must be similarly trained to recognize features. The computer's ability to make a correct classification is no better than the decision rule and training sample upon which the classification is based. To be sure, the computer can far out-perform man in its capacity to make quantitative comparisons and computations rapidly, but it must be correctly programmed. Thus at this research stage, one must make a series of ground observations in support of remote sensing data collection. These ground observations, called "ground-truth," are used in training the computer to recognize features and subsequently to evaluate the thematic classification results. So, if we want a computer to recognize a wheat field, it is necessary to identify a sample wheat field for the computer. Once one has trained the computer, other known wheat fields are required in order to evaluate the accuracy of the classification. While ground measurements before, during, or after the remote sensing flight are currently necessary for many applications, the objective is to perform scene classification without need for extensive ground truth.

In addition to these ground observations for training and evaluation, ground observations are sometimes required as inputs to models which translate the remote sensing observable into user information. For example, subsurface water temperature may be an objective though the remote sensor only maps surface temperature. From vertical temperature observations and/or plume discharge velocities, one can model and calculate subsurface temperatures for large areas surveyed with a thermal infrared scanner. Subsurface properties can be measured with special probes and thus provide needed data impossible to obtain in any other way.

Ground instruments are a focal point for measuring time-dependent variables as opposed to the remote sensor which measures spatial variables. From one point of view, ground measurements frequently record time-dependent phenomena at a few sample points, whereas remote sensing is geared to measure spatial properties over a large area but in a very short time interval and with less frequent reobservation. These spatial measurements, taken together and coupled with time-dependent parameters, constitute a more complete description or more thorough monitoring of the environment. When combined in a single program, the two types of measurements can provide an optimum mix of complementary information.

This is particularly true for dynamic situations involving large areas. Aircraft remote sensors can synoptically view areas having an extent measured in tens of square miles, whereas a satellite sensor (such as ERTS-1) maps 10,000 mi^2 in 25 seconds. This ability to observe large areas almost instantaneously permits one to "freeze" dynamic events such as water circulation patterns. Thus, in a study of the effects of power plant discharges on water quality, repetitive remote sensing coverage provides data on the extent of the mixing zone for varying discharge and environmental parameters as well as documentation of natural environmental activity. The value of this information is increased when used in conjunction with point-sampled data, and indeed it can be used to direct the placement of ground sensors for the collection of meaningful data.

In choosing and making ground observations and measurements, the remote sensing technologists must work closely with the user who knows what information is ultimately required. This problem of user/technologist interface is discussed in Chapter 5. Suffice it to say, a good line of communication is essential. The ground measurements can be made by either party or both, depending upon the use of the data and the expertise required in the observations. If ground data were required to calibrate the remote measurements for atmospheric effects, the technologist may be best equipped to make these measurements. If the ground observations include vegetation species identification, a botanist should be included in the field party.

Therefore, in any <u>projected</u> data collection mission, considerable time and effort <u>must</u> be devoted to working out with the user the kinds and details of ground truth collection that are required. Ground truth may be roughly categorized as follows:

a. General Background Information - This type of ground truth embraces available reports and maps dealing with the data collection sites, the nature of the user problem, and instrumentation parameters (both airborne and ground-based). It includes soil, vegetation, and geological surveys of the site, aerial photos, topographic and land use maps, and references to specific user problems in books, journals, and correspondence.

b. Local Identification - Once the objects or conditions of interest have been selected, these should be located on aerial photos, maps, or imagery. Landforms, vegetation, drainage patterns, etc., should be noted and recorded with ground photography. Radiometers and other instruments should be used to monitor as much of the flight-recorded scene as possible (often auxiliary environmental conditions affect the data collected). These data are vital for analysis and interpretation of processed imagery.

c. Training Set Selection - If computer processing of the data is to be performed, it is wise to select suitable training sets prior to the data collection flights and to record in detail their conditions prior to and during the flights. The validity of the training sets may determine processing success, or lack of it. The size and homogeneity of the training sets in relation to the sensor altitude is important. Optimal training set size is 25 resolution elements (5×5 pixels) or greater.

4.4 CHANGE DETECTION

One of the more promising aspects of remote sensing is that information is recorded in an image format which facilitates comparison of data taken at different times. By overlaying two or more images, one can readily observe changes. A satellite with its repetitive orbit constitutes a unique method for observing the same area on a periodic basis. Recently, orbital data in computer-tape format has been geographically referenced so that local sample points can be easily identified by line and point numbers.

Registration or merging of two sets of data in time is not necessarily a trivial problem, particularly for two sets of aircraft data. Difficulties arise from parallax distortion and aircraft positional errors in navigation and attitude (roll, pitch, and yaw). These problems are discussed in Chapter 2.

Once practical problems of merging two data sets taken at different times over the same terrain have been successfully resolved, spectral differentiation procedures can be used to provide precise measures of change. In some cases the need for merging data can be eliminated by computing the percentages of the various objects within a scene. By using percentages, a normalization is introduced for the various classes. The use of average statistics for the two sets makes change detection schemes more practical. Another aspect of change detection is the use of seasonal changes to improve the feature identification accuracy. For example, ERTS data obtained in June pose a difficult situation for separating certain crop areas from forested areas. By taking data at a later time, perhaps September, significant changes in the cropped area from harvesting, plowing, or change in vigor alter the scene enough to make forested areas and agricultural areas readily separable. This then improves the accuracy of classification. Temporal changes in a variety of situations constitute useful information, whether in studies of urban growth, decreasing agricultural lands, encroachment of urbanization, reduction of forested areas, changes in timber harvesting practices, or changes in shore lines because of erosion. A variety of dynamic events such as sand movement, currents, tides, boundaries of nutrients, and ocean outfalls require repetitive observation.

5
TECHNOLOGY/AGENCY INTERFACE

A critical issue for application of remote sensing technology concerns the nature of the interface between the technology and the agencies that would use it. This interface determines whether remote sensing technology can be and will be applied to real world information needs. This interface must provide the technology with its raison d'être and direction for research and development. The interface must provide the user-agency with those new remote sensing tools which allow it to perform a better job in a more cost-effective manner. If remote sensing can provide useful information in an economic fashion and it does not, then a communication failure has occurred at some opportunity cost. Likewise, if a user agency fails to make its information requirements known to the technology which may be adapted to supply them, we have a similar interface gap. What is the nature of the technology/agency interface and why are there gaps?

The technology/agency interface has a number of aspects which must be examined. Details will vary with the specific agency and remote sensing organization involved, but certain generalizations can be explored (see Figure 14). Principal concerns of an agency/technology interface include points of contact, communication, requirements and products, evaluation, and follow-up. Such mechanics of the interface are individually discussed below. However, it must be borne in mind that the nature of the interface depends on the objectives of the user agencies and remote sensing organizations. These objectives are related to the mission and other characteristics of the agency or organization. For example, both the amenability of the user-agency leadership and the staff to innovative activities will determine whether or not an agency will even consider the potential applications of modern remote sensing technology. If research is not part of the charter of an agency, it is not likely that untried remote sensing techniques will be utilized. Other organizational characteristics relate to funding levels and the equipment capabilities of the agency to support remote sensing efforts. On the remote sensing side, leadership as well as staff orientations determine the extent to which technological applications are emphasized and a market sought. Because remote sensing is a hardware-dependent technology, equipment capabilities greatly influence the direction of development and applications.

A user agency is frequently mission-oriented and would like to apply remote sensing as a tool to obtain data concerning a specific project or problem area. The agency is primarily concerned with the format, accuracy, and cost of the final product. That product may be a single input to a larger data gathering effort, or it may represent a single input to a decision process.

The remote sensing technologist, on the other hand, is usually a research scientist or engineer within an organization whose objective is the continued development of technology and the continuity and growth of funding which orderly and expanding development implies. He sees the technology less as a tool than a vehicle for research. Any data produced for an agency are

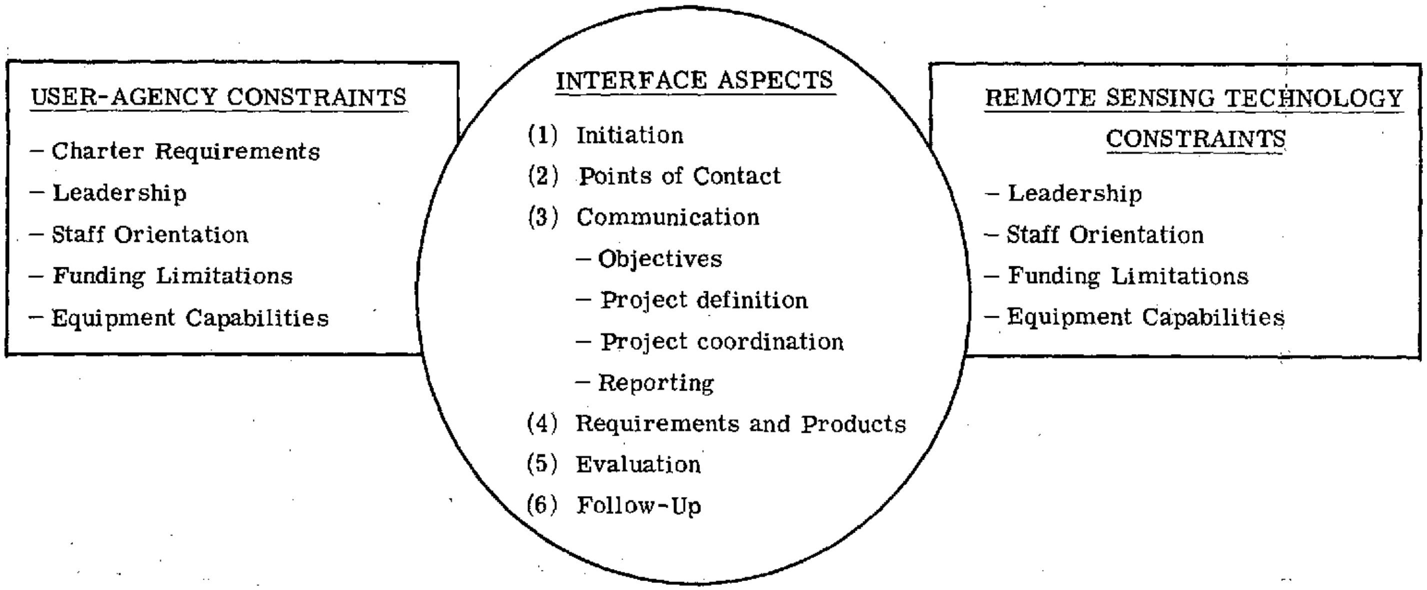


FIGURE 14. ASPECTS OF THE INTERFACE BETWEEN USER AGENCIES AND REMOTE SENSOR TECHNOLOGY

perceived as an interim step in a continuing development effort. New techniques or the elucidation of the physical basis for new techniques are his milestones. Thus the basis for initiating and maintaining an interface differ markedly for the technologist and the agency. These differences are seen in the various aspects and relative success of the interface.

5.1 INTERFACE INITIATION

Initiation of an interface between remote sensing technology and user agencies may occur from either side. An agency representative may identify a data need that he has and to which he thinks that remote sensing may contribute. To initiate an interface, however, he has several obstacles: administrative reluctance, lack of demonstrated utility, lack of knowledge of the remote sensing facilities, and insufficient or inflexible use of funds to support new innovative activities. For these reasons, initiation of an interface usually occurs from the technology side.

The remote sensing technologist needs a sponsor for his research or buyer for his new product. He is happiest when an agency provides either sufficient research funding or a dependable market for new techniques. When that funding or market declines or imposes a direction in which he is not equipped to go, he seeks support eleswhere. He approaches agencies which may be able to use previously developed techniques or support development of new techniques. He prefers to sell research and development, but if need be he will sell data products. Declining funding for research in technology development per se has resulted in increasing initiation of contacts with potential user agencies by competing remote sensing organizations.

Technologists publish widely in the discipline-oriented or profession-oriented press in order to attract new sponsors or markets. Most meetings and conferences concerning the environmental sciences are not complete without their session on applications of remote sensing. Increasingly, within remote sensing organizations, one finds individuals whose backgrounds are selected for the purpose of developing and maintaining contacts with specific agencies or technology application areas. Agriculturalists, geologists, foresters, and oceanographers working for remote sensing organizations attempt to translate the technology into salable terms. Their job is two-fold; to interpret the user needs into the terms of the engineers, physicists, and computer scientists; and to initiate contact with potential agencies. As a group, these user-oriented technologists have not been entirely effective due, in part, to their submersion in the sophisticated technology and loss of contact with their discipline or professional fields.

Initial contact may occur accidentally at a professional meeting or symposium, but most frequently it is planned in advance, either by the agency or by the technologist. If the contact is initiated by the agency, then the potential scope and financial constraints of a remote sensing effort are probably set and it remains for the agency to select the most promising organization with which to work. Frequently a remote sensing organization is approached not on the basis of its technical merits or reputation, but on the basis of its publicity and proximity to the agency.

Not generally understood by agencies is the fact that remote sensing is not a single technology, but rather a series of technologies spanning a wide range of scientific disciplines from radiation physics to computer processing to ecology. Some of these technologies, either singly or in combination, may meet the agency requirements while others will not. Any given remote sensing organization specializes in one or a limited number of these technologies. Rarely is a potential sponsor directed to some other remote sensing organization which may be better equipped to deal with his potential project.

In the case of initial contact of an agency by a remote sensing technologist, some conception of the data needs of the agency are assumed and the technologist attempts to further define those needs in order to suggest a remote sensing project. In this case the agency is limited in choice to working with the technologist and the organization he represents. Generally, however, the technologist is probably pursuing applications to which his particular remote sensing techniques are most suited. Therefore, the technologist is often in a better position to select an agency which may profit from new remote sensing inputs than vice versa.

5.2 POINTS OF CONTACT

After initiation of an interface between an agency and a remote sensing organization, several points of contact must be developed. Two points of contact are essential: on the administrative level, and on the technical level. Frequently many different people are involved directly or indirectly. For example, contacts may include agency administrators, agency workers, technologists, research administrators, and contracts personnel. Ultimately the success of the project under consideration requires that each of those involved understand and implement their respective roles. While the administrators must reach an agreement concerning the scope and direction of a project, frequently an agency worker, who is concerned with the actual application of the remote sensing results, should get together with the technologist who is charged with producing those results. Also, since a remote sensing project usually comprises a series of techniques applied in succession (airborne sensor operation, data playback and reproduction, computer processing, and data analysis, and interpretation), a number of individuals, each playing a key role for a certain stage, should be in contact with one another and be aware of the ultimate objectives of the project. Many others may be involved, depending on the nature and scope of the proposed project. One recent project in which aircraft and surface data were collected from three widely separated and populated sites in the middle of the night called for coordination of individuals from a remote sensing laboratory, a federal agency, two state agencies, and numerous county and local law enforcement agencies—75 people in all.

5.3 COMMUNICATION

Communication refers to the process of information exchange after contacts have been made at the appropriate levels. Communication is the key to the maintenance of a productive interface between an agency and a technology. At its best, it means a significant transfer of knowledge which has long-term usefulness to the agency and to the remote sensing organization. At its all too frequent worst, communication is marked by the lack of meaningful information exchange and a blurring of distinctions between concepts of useful information required by the agency and data produced by a remote sensor system. Various factors restrict or reduce communication, from personnel inertia to barriers of terminology. The process of information exchange occurs in three or four sequential but poorly defined phases. The first phase of information exchange is concerned with the joint determination of whether remote sensor technology may indeed supply useful data to the agency.

In this phase the agency must clearly make known to the remote sensing organization its data needs and how that data is intended to be used. There is a need to communicate the agency objectives in looking to the remote sensing technology-research, demonstration project, operational data requirements, etc. Frequently an agency is looking for a simple approach to a data collection task which has not been entirely satisfactory in the past. For example, many agencies which deal with subsurface conditions eagerly look to remote sensing for some easy way to sample below the surface. A technologist must be careful not to encourage these hopes when existing or near-future capabilities do not justify them. The technologist should describe to the agency the nature of the data the technology produces and the limitations of that data. For example, in providing soil moisture data, the technologist must forewarn the agency that sensor data is applicable only to the surface or very near surface. Also the technologist must make known some of the variables associated with data collection and processing—from the effects of weather conditions to alternatives in computer analysis. Frequently it is the cost effects and information potentials of these variables which are not clearly made known to the agencies at this stage.

The second phase occurs with project definition and mission planning. In this phase specific sensor and sensor combinations must be agreed upon, sites selected, and costs negotiated. Also the date and time horizons associated with a proposed project should be realistically determined. In a project involving the use of remote sensor data, the agency may not see any results for six months to a year after data collection unless shorter turnaround times are specifically requested and required. If extensive ancillary data is required in support of the sensor data, these must be identified and planned for. Often the agency can provide useful background and map information at this stage.

The third stage is the coordination of data collection operations and the subsequent reporting of mission success. If a large number of people are involved from several organizations, extensive logistical coordination should be worked out. For those agency personnel concerned with the data collection, this is a critical period. Generally their enthusiasm for remote sensing peaks with their active planning and participation in the project and a letdown often occurs if the technologist does not maintain communication with them. The sensor-recorded data may not be processed for months and the agency personnel may be disappointed in the apparent low level of interest in the ground observation data at that point and the lack of any further defined role for them during the remainder of the project. Unfortunately the technologist may view further communication with agency representatives after data collection or during data processing as an undesirable distraction from the pursuit of his research activities.

The fourth communication stage concerns discussion and evaluation of project results. Enthusiasm for this stage usually depends on the level of success in meeting the objectives of the project and the anticipation for continuing work. Seldom does a written report to an agency completely document the objectives, approach, data collection, processing, and results of a project. If the risks were clearly defined early in the communication process, the technologist will not hesitate to describe negative results; however, positive aspects such as the development of new techniques, are likely to be emphasized when the actual results fall short of the agency objectives. Such other aspects of the evaluation and follow-up stage are described in subsequent sections.

5.4 REQUIREMENTS AND PRODUCTS

Always an issue in the agency/technology interface is what are the real agency requirements and what are the actual products generated by remote sensing technology. Not surprisingly, the agency often defines a data requirement on the basis of existing instrumentation or traditional methods which may be unnecessarily restrictive. For example, an agency specifies a need for vegetation species identification when in fact it may be concerned with the distribution of ecological communities or measurement of vegetative cover. The agency may ultimately be concerned with the determination of social and economic parameters which remote sensing cannot supply directly. However, remote sensing can supply useful data if a correlation exists or can be developed between the economic or social parameters and the physical features recorded by the sensor. An agency may specify "land-use" information as a requirement, however, land use is a flexible term which becomes clear only in the context of the purposes of the information. Land use classification is different for the hydrologist, the regional planner, and the tax assessor. To the technologist, land use data usually means an inventory of the physical surface of the terrain—rather than the economic or social criteria sought by an agency. Where an agency sees a high-income, low-density residential area, the remote sensor may see only trees, and classifies the area as forest vegetation. On the other hand, where the remote sensor objectively classifies bare fields, corn, wheat, and pastureland, the agency may see only agricultural land use. Such limitation of remote sensor data to a record of existing physical conditions (without economic, social, or political context) is often a source of misunderstanding as to the nature of the remote sensing products but one which may be mitigated by more complete communication.

Agencies whose operational responsibilities include regulation or managing of the environment make decisions on the basis of measurements of mass, space, and time. Remote sensing technology is a tool for measuring space, usually at the expense of time (repeated or continuous measurement) and volume. The value of the tool depends on its reliability, accuracy, timeliness, cost-effectiveness, and the degree to which the data can be organized and combined with data from other sources. The spatial information requires the format of a map or areal statistics. The map-format requirement usually insures that data from other sources or collected at different times may be overlaid, combined, or compared with a minimum of difficulty. The fact that image products of most remote sensors do not have sufficient geometric control to produce a map-quality display is a serious current limitation of the technology and a source of irritation to many agencies who would otherwise readily use the data. Again this limitation is not endemic and may be mitigated in the future.

Currently all survey and reporting techniques have inherent limitations. An agency which has a survey or inventory task knows and accepts the limitations of its traditional techniques and equipment. Indeed, any survey system has a certain trade-off between its limitations and the cost of reducing those limitations. In introducing a new technology, such as remote sensing, a whole new set of unknown limitations is encountered. These must be made known before the data obtained from the new technology can be applied with any confidence. For example, remote sensing technology is designed to provide large amounts of accurate spatial data at the expense of time (continuous) or volume-related measurements. It is difficult for a hydrologist to incorporate extensive spatial data into a data-gathering system that has always relied on intensive time-dependent volumetric sampling from a few selected sites (rain gauges, stream gauges, evaporation pans, etc.). The application of extensive, quantitative spatial data to hydrology requires new studies of the correlation between spatial aspects of a drainage basin and the run-off, infiltration, or evaporation characteristics. Unless the agency is willing to consider revisions of their data collection and processing procedures, and support investigations of the optimal combination of new and old data for their requirements, remote sensing technology may not make a significant contribution to the agency.

5.5 EVALUATION

How do you evaluate an image or determine the accuracy of statistics for a large area? This is a serious problem both for the technologist, who wants to determine the effectiveness of his techniques, and the agency, which wants to determine whether a given data product is useful. When establishment of evaluation criteria is left to the waning stages of a remote sensing project, criteria usually becomes biased in favor of the product results. The criteria can be concerned with: (1) the relative advance over previous efforts, (2) the value of the product to a user or scientific community, (3) the value of the product (alone) to the agency, (4) the value of the product, in combination with other data, to the agnecy, or (5) the cost-effectiveness of the product. The technologist prefers the first two sets of criteria, while the agency looks at the latter three criteria. Without specific agreement on the evaluation criteria, the agency and the technologist can arrive at vary great differences concerning the results of a given project. A reluctance to include agency personnel as authors of reports or published papers concerning the research performedmay stem, in part, from these differences in evaluation criteria rather than a desire by the technologist to be recognized as the sole author of the project. An encouraging trend is the publication of project reports, prepared by the technologist and approved by the user agency. This trend helps ensure some feedback from the agency to the technologist and makes the conclusions less self-serving to remote sensing than they would be if published by the remote sensing organization.

5.6 FOLLOW-UP

Several things may occur upon completion of a remote sensing project sponsored by mission-oriented agency. (1) agency may conclude that the new technology has nothing to offer, and terminate the interface. The agency may conclude that the technology is not sufficiently advanced to be practical for its purposes, but may decide to (2) support further development or (3) await further progress. The agency may conclude that the technology is operational or nearly operational and take steps to (4) strengthen ties with remote sensing organizations through further contracts or (5) build an in-house capability. The first and last occurrences are the least desirable to the technologist for in both cases he has lost a sponsor for continuing his research. If the research support is continued, then the interface will broaden as the agency and the technologist become increasingly familiar with each other's requirements, capabilities and limitations. Even if the agency chooses not to continue support, the conscientious technologist will continue to maintain contact with the agency. In doing so, he can alert the agency to recent innovations which may improve the prospects of applying remote sensing technology to agency problems and concerns.

6
TECHNOLOGICAL CONSIDERATIONS

Remote sensor systems are designed to provide accurate and detailed spatial sampling of large areas—with the chief data-products in statistical or image formats. This chapter attempts to summarize the current state of the art with regard to the application of remote sensing technology. The various applications are roughly divided into three stages of development (operational, feasible, or possible) to indicate their current status. The last stage is for those application areas which have promise but will require considerable additional development. This discussion includes recommendations for continued research in (1) application of existing technology and (2) development of new sensor and data handling techniques. Also, availability and access to existing and new data are discussed along with some indications of data collection and processing costs.

6.1 OPERATIONAL APPLICATIONS

In the past half century there has been built up a large body of literature concerned with photographic sensor applications. Topographic maps depend on the cartographic and spatial displacement accuracy of paired photographs, and many types of land use or surface cover maps are based on the contrasts inherent in black and white photos. Panchromatic photos are extensively used for agricultural crop inventory (ASCS), timber volume assessment (Forest Service and timber companies), soil surveys (SCS), and hydrographic and geologic maps (USGS) [12]. For most types of large area planning or construction activities, such as urban planning or highway construction, acquisition of aerial photographs at the appropriate scales is one of the first orders of business. Despite the widespread use of panchromatic photography for numerous applications, newer types of color and false-color photography have not enjoyed universal acceptance—despite extensive coverage from NASA high-altitude aircraft and the earth resources satellite (ERTS-1) in this format. The color and false-color images, while providing significantly more information for certain purposes, have higher processing and reproduction costs which limit their use to relatively high-value detailed studies. For large-area surveys very high altitude photography (>30,000 ft) eliminates much of the task of photomosaicking and is coming into increasing favor.

The low-resolution global coverage of a series of NOAA satellites has demonstrated the value of timeliness in utilization of remote sensor data. These satellites provide meteorologists and television viewers alike with images of major cloud patterns of their region which are less than six hours old.

12. American Society of Photogrammetry, 1969. Manual of Photographic Interpretation.

The only imaging remote sensor system, other than the camera, which has gained commercial acceptance is the thermal infrared scanner. A number of aerial survey firms possess or have access to thermal infrared scanners and use them to measure and map thermal patterns of outfalls of power plants, water circulation patterns, geothermal activity, forest fires, oil spills, and lake and sea ice.

Although not of specific concern for this report, which deals with imaging electromagnetic sensors, several nonimaging airborne sensor systems are operational but with their utility currently limited to high-value surveys such as mineral or oil prospecting. These include airborne magnetometers and electromagnetic sounders. Gamma-ray surveys for soil moisture and snow pack information have been conducted for a number of years in the Soviet Union. Promising results in Canada and the U.S. are making these gamma-ray sensors operational for hydrologic and natural radioactivity (geologic) surveys.

6.2 FEASIBLE APPLICATIONS

A number of sensor applications have shown remarkable feasibility but are not as yet operational. They are not operational because either they have not been accepted by a user-agency as being cost-effective in comparison to traditional data collection systems or there is as yet no market for the new information available. In this category are included most applications of multispectral scanner systems and several applications of the imaging radar systems. In some cases these feasible applications represent substantial complements to operational systems now in use, such as for soil survey; in other cases they represent entirely new capabilities made possible by the new technology. Examples of the latter include energy balance mapping, and water chlorophyll and transparency (Secchi Disk) mapping. The several applications discussed as being feasible are vegetation and land-use oriented, water and marine-oriented, and geologic-oriented. Space does not permit a discussion, in detail, of all feasible applications.

6.2.1 VEGETATION AND LAND-USE ORIENTED APPLICATIONS

Wherever the climate is favorable the terrestrial surface is covered by vegetation, both natural and cultivated. The nature, location, and physical condition of this vegetation greatly affects man's welfare and is a suitable subject for a number of feasible remote sensing applications:

(1) Automatic crop inventory. As mentioned above, aerial photography is currently used for crop inventory purposes. This crop identification and areal tabulation process can be accomplished by automated processing systems which improve the accuracy and speed of survey results.

(2) Early detection and assessment of vegetation stress. Stress in forests and crops may be caused by disease, insect damage, drought, or other factors. The earliest

manifestations of stress may be in relation to plant temperature or energy balance. Temperature and energy balance measurements can be recorded by multispectral sensors tuned to the appropriate wavelength ranges. If the stress is caused by lack of water, this may be used to signal the need for irrigation water.

(3) Assessment of rangelands. Recent techniques show an ability to measure cover and assess above-ground biomass of herbaceous vegetation. If applied to large areas of rangeland, these techniques are capable of providing extensive and quantitative information on range condition and grazing pressure.

(4) Detection of barren or denuded areas. The nature and extent of areas lacking vegetation are often indicative of man- or nature-induced disturbances to the environment. These disturbances may be from strip-mining operations, rapid urbanization, forest clear-cutting, or floods. While conventional aerial photography is useful for detecting these areas, modern sensor developments can furnish accurate detailed information about barren areas for large regions. These capabilities make feasible a number of regulatory and environmental monitoring capabilities which are not currently utilized.

(5) Early disaster assessment. Several remote sensor systems provide opportunities for obtaining images of disaster areas under conditions such that the camera system would be of little use. Every major disaster is characterized by significant surface disturbances, often to both vegetation and man-made structures. The night-time capabilities of infrared scanner systems and the all-weather capabilities of radar systems are well known but under-employed.

6.2.2 WATER- AND MARINE-ORIENTED APPLICATIONS

The biosphere of the earth is first and foremost a water environment. Life is even more closely tied to its water resources than to its food (energy) resources. The remarkable properties and extensive nature of water resources make it a natural subject for a variety of remote sensing applications.

(1) Wetlands, mapping. The identification and delineation of fast decreasing wetlands can have an important role for maintaining environmental diversity and habitats for wildlife, including economically important waterfowl. Several new sensors are superior to the camera for delineation and statistical tabulation of wetlands.

(2) Locating of pelagic fish resources. Marine environments vary in their suitability for fish. Current remote sensing techniques can be used to locate areas of appropriate surface water temperature and chlorophyll content (a measure of primary productivity). Turbid water areas may also serve as a refuge from predators for economically

valuable species. Other fish may be detected through the distinctive appearance of large schools or fish oil on the surface.

(3) Recording of currents and other water movement dynamics. New remote sensing techniques make it possible to enhance slight differences in color or temperature associated with water bodies. These slight differences may be used to record water movements, particularly currents over large areas. The mixing and movement patterns of water have a major effect on weather, navigation, and the ability of such waters to assimilate waste materials.

(4) Recording snow and ice accumulation and movement. The extent of snow cover and the water-equivalent of snow represents important hydrologic information for those areas dependent on spring snowmelt for fresh water supplies. Ice accumulation and movement within water bodies can affect navigation. Glacier changes are sensitive indicators of climatic change. Remote sensing techniques are feasible for recording these spatial conditions.

(5) Detection of suspended materials and pollution. The optical properties of materials suspended in water can be used to identify them. For example, chlorophyll concentration mapping of lakes using spectral ratio techniques has been demonstrated as feasible. The mapping of suspended materials can be used to pinpoint the location of pollution sources or events.

(6) Water-depth mapping. The depth of shoal areas in relatively clear water can be automatically mapped using known principles of light attenuation for different spectral wavebands. This technique may be very useful for tropical areas of poorly known or constantly changing bathymetry.

6.2.3 GEOLOGIC-ORIENTED APPLICATIONS

Photo-geology as a discipline has developed a large literature which relates the surficial appearance of earth to economically important subsurface conditions. Exploration for ores, ground water, and construction materials can benefit from new forms of aerial orbital imagery.

(1) Lithologic surveys. Geologic information is available to the extent that surface conditions are identifiable and the extent to which these conditions are indicative of the subsurface. Several minerals have uniquely identifiable spectral characteristics which may be detected by modern remote sensors. These minerals include oxides of iron and silicon. Large structural elements, such as faults and fissures, not evident on large-scale photographs or mosaics become evident in satellite images.

(2) Survey of regional geomorphology. New types of imagery covering regional areas can be used to obtain and update geomorphological and physiographic knowledge. Terrain shadow effects and image enhancement techniques can be used to emphasize subtle landform and drainage differences. Other imagery may show the thermal effects of soil moisture or aquifer recharge areas.

6.3 APPLICATIONS REQUIRING FURTHER DEVELOPMENT

The applications listed above are feasible; but if they are to become operational, additional research and demonstration is necessary. Note that these applications are similar in several respects. Spatial data is required from large areas and the actual information sought from these data frequently represents but a small portion of that collected. In monitoring pollution events, for example, only a small portion of a water body may be effected. In other cases, perhaps only a single waveband recorded by a multiband system provides the required information. The challenge for further development is to provide systems which can collect the large amounts of data and filter that data for useful information in a timely and cost-effective manner. Also, research into the linkages between remote sensor data and user information is clearly necessary and must be carried out on a discipline-by-discipline basis in cooperation with the users.

If we assume that necessary research is supported and that data collection and processing costs become economic, a large number of potential technology applications emerge. In large part these application areas will benefit from remote sensing as one type of input to a much larger data collection, information integration, and decision-making process. It is assumed that users will accept current "exotic" remote sensor products as readily as aerial photographs are accepted today, and that increasing economies of scale will result in a growing demand for extensive spatial information.

6.3.1 NATURAL RESOURCE DEVELOPMENT

Further development of renewable and nonrenewable resources will increasingly require synoptic and timely information of large areas. Whether one talks about the mineral exploration of the Antarctic continent, the agricultural development of the Amazon basin, the transport of Arctic oil and gas to the Midwest, or the management of the remaining marine mammals, aerial and orbital imagery has an increasingly important role to play. With a clear knowledge of the trade-offs between detail and resolution on the one hand and spatial coverage on the other, combinations of complementary sensor systems can be designed to provide levels of stratified sampling which help determine the levels of accuracy of the data. For example, the recording of successively larger watershed systems within a major drainage basin, such as the Great Lakes, will provide energy and water balance information useful to comprehensive hydrologic models. From the models, in turn, will come data on how the basin and component watersheds can be managed to improve the quality and flow of the water resources. Decisions on food trade may be based on the synoptic monitoring of both domestic and foreign crop production and anticipated yeilds.

6.3.2 ENVIRONMENTAL MONITORING

With the seemingly inevitable increasing scales of resource development come increasing dangers of adverse environmental impact. Remote sensing technology can provide the earliest possible warning of environmental stress, from the vast areas of the ocean surface to the heat islands generated by urbanization. Geostationary satellites can act as continuous sentinels to alert of oil spills, forest fires, or flood stages on major rivers. Increasing experimentation with weather modification will require an ability to assess largely spatial effects of the techniques employed—beneficial as well as adverse—for both researchers and environmental monitors alike.

The current archive of ERTS-1 data of the entire United States and much of the rest of the land portion of the earth will make the 1972-73 period a benchmark with which to objectively establish environmental change from comparisons of similar orbital data in the years ahead. Accurate registration of orbital data at different times makes physical change-detection images highly feasible.

6.4 RECOMMEND RESEARCH AREAS

If the remote sensing applications listed above are to be implemented then research is required in developing them. This research may be in establishing the reliability of detection under a variety of observation conditions. In most applications, remote sensing cannot perform the task without ancillary data. Research is needed to define the optimal mix of remote sensing data and non-remote sensing data, and the processing techniques suited for obtaining the desired information.

In addition to studies involving the use of current, off-the-shelf technology, consideration must be given to the uses of new sensor technology. In particular, lasers and the unique properties of laser radiation provide a new dimension to multispectral sensing in the optical wavelengths. In addition, fluorometry has shown promise for detecting and quantitatively measuring pollutants and aquatic vegetation. Fluorescence is being or can be used to identify oils and oil spills, to measure chlorophyll in both water and terrestrial vegetation. In addition to being able to collect imagery day or night time, the laser will permit collection of vertical profile information by precise measurement of the time for reflection of radiation from the surface.

While sensor development has progressed rapidly over the last decade, major challenges confront us in the data processing field. Massive amounts of useful remote sensor data exist on miles of unanalyzed computer compatible magnetic tapes. Current computer processing techniques are simply too slow and therefore too costly, to keep up with the current data collection rates. Part of the problem has been the need to explore and develop data processing techniques which are applicable to the needs of a variety of potential users. These techniques are usually developed using the flexible programming capabilities of large general-purpose digital computers. While ideal as a research tool, these computers are simply too slow to handle the large amounts of remote sensor data in an economical way. As we learn which processing techniques will provide useful information, we need to implement these techniques on different types of hardware. Clearly, a new breed of computer facility is required. Relatively small-size, very fast special-purpose computers provide the data processing potential required. One such prototype is the Multivariate Interactive Digital Analysis System (MIDAS) described later in Section 6.6 of this chapter. Coupled with the continued development of fast special-purpose processing systems must come the understanding of processing trade-offs in terms of both time and information. For example, a number of relatively simple processing techniques (ratioing, level slicing) can be used to obtain certain types of information; but other information needs require use of sophisticated (maximum likelihood ratio) decision algorithms which are several times more costly to implement.

6.5 SOURCES OF REMOTE SENSING DATA AND INFORMATION

A potential user of remote sensing has many options concerning the nature of the product which he procures. He may wish to procure raw data or processed information. In either case he must specify a number of parameters to assure that he has a useful scale, resolution, coverage, and format. In addition to these, timeliness of the data may be a key factor. The first step is to determine whether or not data exist which can serve the purpose. Data collection is currently a major expense in remote sensing programs and any savings in this area should be considered.

6.5.1 SOURCES OF EXISTING REMOTE SENSING DATA

Two national organizations exist to store and sell remote sensing data collected at a national level. These are the Department of Agriculture's ASCS, and the Department of Interior's Earth Resources Observation System, EROS.

ASCS photographs most of the United States every five years in black and white photography at scales of 1:20,000 and 1:40,000. Price details and instructions on how to procure this photography are given in Appendix A.

The EROS Data Center at Sioux Falls, South Dakota is the outlet for ERTS and SKYLAB imagery and computer-compatible tapes. In addition, EROS sells all the aerial imagery taken by NASA in support of its earth observation program (largely high-altitude color and color infrared photography taken at a scale of 1:60,000 and 1:120,000) and likewise aerial imagery produced by USGS in its mapping program. A price list for support of Data Center Products is given in Appendix B.

The Cartographic Division of the Soil Conservation Service has made available ERTS mosaics that collectively cover the entire continental United States. Appendix C details the subregions these photographs cover, includes a price list, and tells how to order.

Additional sources of remote sensing data include: aerial survey firms, state highway departments, public utilities commissions, and local and regional planning commissions.

6.5.2 SOURCES OF NEW REMOTE SENSOR DATA

When suitable data are not available, then one must procure them. Aerial photography and thermal imagery can be purchased from the many aerial survey firms throughout the country. Multispectral data and radar imagery are, in general, more specialized and costly and only limited facilities are available. Appendix D lists the commercial organizations known to provide these services. In procuring such data, one should specify the format and conditions required, as discussed in Chapters 3, 4, and 5. The inexperienced user would do well to discuss his application and requirements with the data collection organization to assure that the resulting product will meet his needs.

Having obtained the necessary data base, the user will undoubtedly need to process the data into the required information. Depending upon the requirements, he may need an assistance from contractors, particularly if the data reduction requires special skills or facilities. When the use of such a contractor is anticipated, he should be involved in specifying the data-collection parameters.

Most aerial survey organizations offer photo-interpretation and stereo-plotting services. Universities have staffs in urban planning, civil engineering, geology, geography, natural resources, and/or forestry who are intimately familiar with photo-interpretation and photogrammetric techniques. These staffs are often available on a consulting basis. For multispectral data processing and interpretation of radar imagery, the number of facilities capable in the area is more limited; these are given in Appendix C.

6.6 TECHNOLOGY COSTS

Important questions in the application of a new technology are "how much does it cost?" and "how do the costs compare with existing operational techniques?" The answers to these questions largely determine whether the new technology will be accepted after technical feasibility has been demonstrated. Unfortunately the answers are poorly known and difficult to calculate. Different answers seem reasonable for different purposes.

Actual costs associated with developing and demonstrating feasibility are high, resulting from the construction and use of advanced one-of-a-kind equipment. Mistakes and inefficient procedures used in exploring and revising processing schemes are also expensive, as is the time of skilled scientists to document both negative and positive results. Few research efforts in the high-technology remote sensing field can be undertaken for less than ten thousand dollars and many comprehensive efforts require support which is an order of magnitude greater.

Once feasibility has been demonstrated, the costs may be reduced greatly. Usually two types of costs are quoted, depending on the time horizon of the prospective application. To duplicate particular processing results with other data-sets usually requires less than half the initial feasibility costs. This assumes that no new hardware or software costs are incurred, but that the personnel and facilities are still research-oriented rather than operationally oriented. Finally, one can project an "operational cost" either inclusive or exclusive of hardware and software overhead. This operational cost assumes the availability of routinely collected data and operational processing facilities. It is this cost which, while poorly known, should be compared with alternative information sources.

For example, the costs of collecting multispectral data are greater than those of collecting conventional aerial photography. However, a close comparison suggests the following points.

Costs associated with conventional aerial photography usually include only that for data collection. Costs of collecting multispectral scanner data, while a little greater than for the photography, result in a vastly greater amount of quantitative data. The labor costs and the aircraft costs are equivalent, and material cost differences are insignificant.

In the data manipulation and data extraction phase, photography must be interpreted; therefore, the costs of trained labor to deduce information from photographs should be included and could be expensive. One should also realize that specialized optical instrumentation equipments have been built to aid a photointerpreter, namely stereo plotters, image manipulators, densitometers, magnifiers, zoom transfer scopes, etc., which may be part of the data reduction phase. The costs of these must be included for remote sensor comparisons. The multispectral data collection system provides the data processor with data that eliminate the densitometric step because the data are in electrical analog form. Because of the format of newer remote sensor data and because of the development of machine-assisted processing, larger areas can be rapidly surveyed. For example, in a recent project the watershed of Lake Ontario was mapped and a number of land categories were measured by machine for some 32,000 square miles using three consecutive days of ERTS data (Figure 15). Portions of nine ERTS frames each recording over

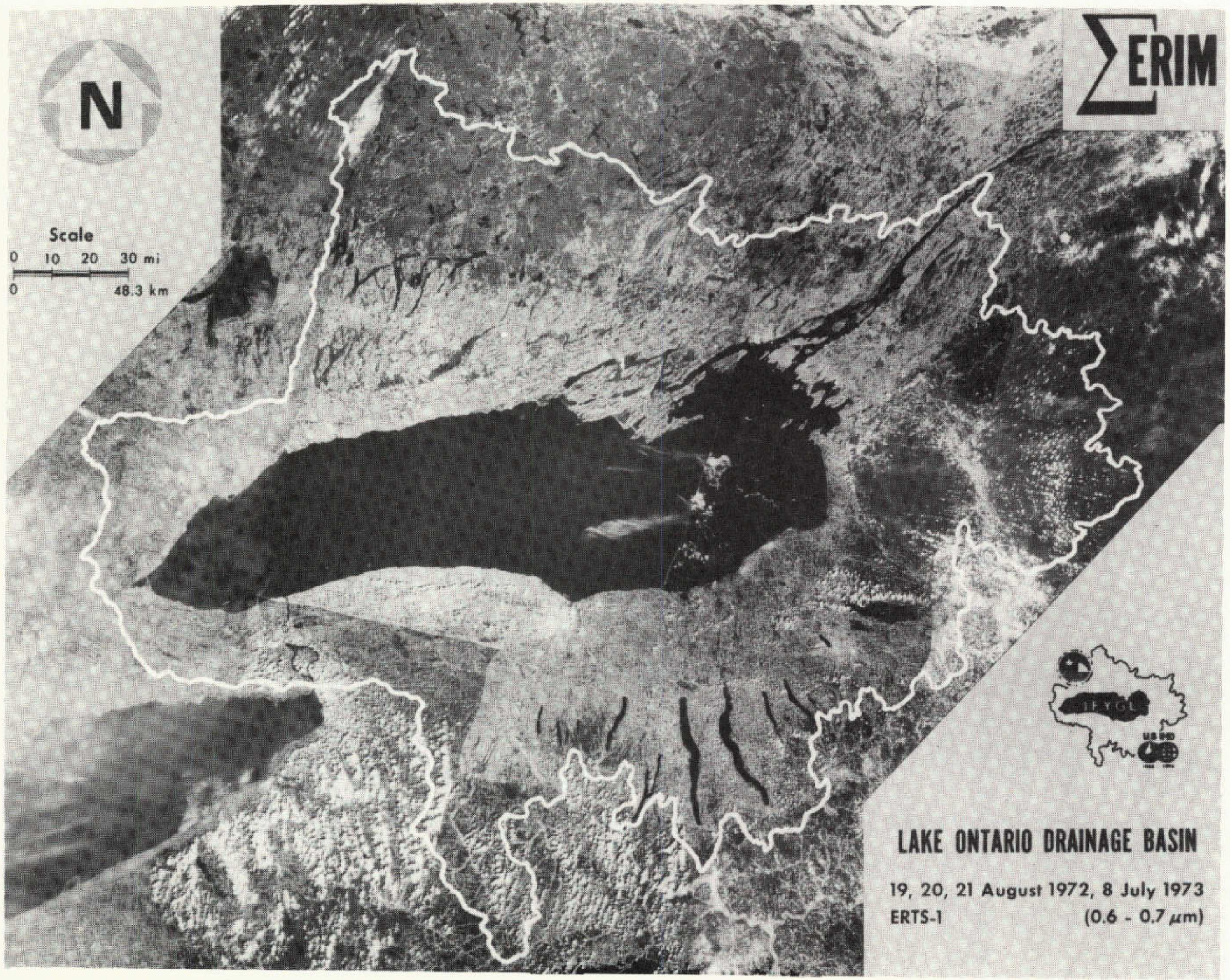


FIGURE 15. ERTS IMAGE MOSAIC OF THE 34,000-SQUARE MILE LAKE ONTARIO DRAINAGE BASIN

15,000 sq. miles, were used. Over 200 frames would have been required to construct a mosaic over this same area using high altitude RB-57 imagery. The photographic data format would require manual grid counting for extracting land use classes. Aircraft logistics would have required controlled flightlines and clear weather lasting many days. For a lower altitude photographic coverage (at 10,000 ft), 1700 frames would be necessary for the Lake Ontario Basin mosaic and time needed to collect the data would be even longer. Substantial savings for a large-area inventory are possible through the use of modern orbital remote sensor systems coupled with special computers.

Consider the current development of a special-purpose computer called MIDAS [13]. MIDAS, the Multivariate Interactive Digital Analysis System, represents a breakthrough in the field of image analysis. It will provide a low-cost capability for user-oriented, interactive, near-real-time, digital analysis to produce enhanced or thematic maps. MIDAS accepts data from multispectral scanners in the form of high-density digital tape, standard computer-compatible tape, or analog tape, and makes use of multispectral processing techniques within an innovative hardware approach. Its hardware and software are intended to require a minimum amount of instructional training for successful operation. MIDAS is intended to provide multispectral analysis for applications in disciplines such as agriculture, urban planning, forestry, geology, pollution detection, hydrology, and others. Features may be extracted that are spectral, spatial, temporal, and (possibly) polarization-dependent, thus providing a generally applicable and powerful capability.

The objective of providing greater processing speed includes much lower operating cost per project for operational needs and for research and development. It has been estimated that processing costs in the MIDAS system can be reduced by about a factor of 20 or more as compared to processing costs based on current processing feasibilities. For example, an aircraft data set of some 24 miles × 3 miles could be processed at a cost of less than $400 instead of present-day typical costs of about $8000. Comparisons in processing time are given in Table 3 for MIDAS and present computer systems. In this case, the times shown are for the five major steps in the processing of data to process an ERTS frame into 12 categories. Such high speed special-purpose computers, when linked with the optimum multispectral sensors which can be orbited, are the developments that will make satellite remote sensing cost-effective.

13. Kriegler, F. J. et al., 1974. MIDAS: Prototype Multivariate Interactive Digital Analysis System, ERIM Report 195800-25-F, (in 3 vols.).

TABLE 3. COMPARISON OF PROCESSING TIMES FOR VARIOUS SYSTEMS

PROBLEM: CLASSIFY 12 CATEGORIES OVER AN ERTS FRAME (4 TAPES CCT)
(Times in Hours)

Computer	Initial Map	Field Location	Signature Calculation	Classification	Map	Total (Less Location)
7094	2.0	40.0	2.0	8.0	2.5	14.5
MIDAS (CCT)	2.0	40.0	2.0	0.3	2.5	6.8
MIDAS (HDT)	0.1	40.0-4.0	0.3	40 sec	0.1	~0.5
360/57 (Est)	1.0	40.0	1.0	4.0	1.25	7.25

REFERENCES

1. Holter, M. R., M. Bair, J. L. Beard, T. Limperis, 1970. Imaging with Non-photographic Sensors, in Remote Sensing with Special Reference to Agriculture and Forestry, Nat. Acad. of Sciences, Washington.
2. Polcyn, F. C., N. A. Spansail, and W. A. Malila, 1973. How Remote Sensing Can Help the Ecologist, in The Surveillant Science, Remote Sensing of the Environment, (R. K. Holz, ed.). Houghton Miffin Co., Boston, pp. 349-59.
3. D. S. Lowe, 1968. Line Scan Devices and Why Use Them, in Proceedings of the 5th Symposium on Remote Sensing of Environment, Willow Run Laboratories, The University of Michigan, Ann Arbor, pp. 77-101.
4. Lowe, D. S. and J. Braithwaite, 1966. A Spectrum Matching Technique for Enhancing Image Contrast, Applied Optics, Vol. 5, p. 893.
5. Proceedings of Third Earth Resources Technology Satellite-1 Symposium, December 10-14, 1973. National Aeronautics and Space Administration, Washington.
6. Zelenka, J. S., 1971. Imaging Radar Techniques for Remote Sensing Applications, in Proceedings of 9th Annual Allerton Conference on Circuit Systems Theory, University of Illinois, Urbana.
7. MacDonald, H. C., 1969. Geologic Evaluation of Radar Imagery from Darien Province, Panama, Modern Geology, Vol. 1, No. 1, pp. 1-63.
8. deMoura, J. M., 1972. Radam Project Summary Proceedings of 8th Symposium on Remote Sensing of Environment, Willow Run Laboratories, The University of Michigan, Ann Arbor.
9. Williams, R. S., Jr., 1973. Coastal and Submarine Features on MSS Imagery of Southeastern Massachusetts: Comparison with Conventional Maps. Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1, Vol. I., NASA, pp. 1413-21.
10. Horwitz, H. M., R. F. Nalepka, P. D. Hyde, and J. P. Morgenstern, 1971. Estimating the Proportions of Objects Within a Single Resolution Element of a Multispectral Scanner, Proceedings of 7th International Symposium on Remote Sensing of Environment, Willow Run Laboratories, The University of Michigan, Ann Arbor, pp. 1307-20.
11. Colwell, R.N. et al., 1963. Basic Matter and Energy Relationships Involved in Remote Reconnaissance, Photogrammetric Engineering, Vol. 29(5), pp. 761-99.
12. American Society of Photogrammetry, 1969. Manual of Photographic Interpretation.
13. Kriegler, F. J. et al., 1974. MIDAS: Prototype Multivariate Interactive Digital Analysis System, ERIM Report 195800-25-F, (in 3 vols.).

Appendix A

HOW TO ORDER ASCS PHOTOGRAPHY

INSTRUCTIONS

IMPORTANT – On LABEL on face of order print or type items 1 thru 3 only.

IDENTIFICATION OF PHOTOGRAPHY

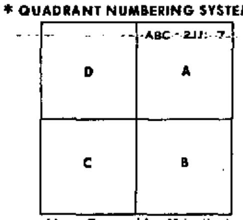
PAPER SIZE	QUANTITY	SYMBOL	ROLL NO.	EXPOSURE NO.
1	2	3	4	5
24" x 24"	1	D J D	3 A	96

Column 1. Enter paper size 9½" x 9½", 24" x 24" etc., When ordering indexes enter "Photo Index" and list sheet numbers and year of photography.

Column 2. Enter number of prints wanted from each exposure number.

Column 3, 4 and 5. Enter the symbol, roll number, and the exposure number of the negative. Exposure numbers may be listed in inclusive sequences. This information is in the upper right corner of each photograph and may be obtained from photo-index sheets or from the Agricultural Stabilization and Conservation Office in the county where the farm or area photographed is located.

*** QUADRANT NUMBERING SYSTEM**



(Area Covered by Negative)

Example: Your area of interest lies wholly within lower left quadrant, you should order ABC-2JJ: 7C. When more than one quadrant from the same negative is ordered, image overlap will be furnished.

If you do not know your area of interest as related to the negative, we suggest a visit to the ASCS office for assistance.

PRICES *(Quoted prices are based on paper size)*

Remittance is required before prints will be made, and must be by check, money order, or draft payable to ASCS. Stamps will not be accepted.

TYPE OF REPRODUCTION	SIZE	** APPROX. SCALE FROM 1:20,000 PHOTOGRAPHY	** APPROX. SCALE FROM 1:40,000 PHOTOGRAPHY	COST (per print) 1 - 25 2/	EXCESS OVER 25 3/
Contact Print 1/	9½" x 9½"	1" = 1667'	1" = 3334'	$1.75	$1.25
Enlargement	13" x 13"	1" = 1320'	1" = 2640'	3.00	2.50
Enlargement	17" x 17"	1" = 1000'	1" = 2000'	3.50	3.00
Enlargement	24" x 24"	1" = 660'	1" = 1320'	4.50	3.50
Enlargement	24" x 24"	1" = 330' * (Quadrant)	1" = 660' * (Quadrant)	4.50	3.50
Enlargement	38" x 38"	1" = 400'	1" = 800'	9.00	8.00
Photo Index (No. of sheets per county depends on size of county)	20" x 24"			3.00	3.00

*****All enlargements are made at diameters to fit paper size unless scale accuracy is requested. For "scale accuracy" add $0.50 per print.***

1/ For polyester base paper (9½" x 9½" only) add $0.75 per contact print.
2/ Applies to first 25 prints ordered regardless of size of order.
3/ Applies to each print in excess of 25. Quantity prices apply only when order is shipped to one address.

ADDRESS ORDERS FOR PHOTOGRAPHS OF THESE STATES

Western Aerial Photography Laboratory
Program Performance Division
ASCS-USDA
2505 Parley's Way, Salt Lake City, Utah 84109
Tel. Area Code 801, 524-5856

Arizona	Nevada
Arkansas	New Mexico
California	North Dakota
Colorado	Oklahoma
Hawaii	Oregon
Idaho	Texas
Kansas	Utah
Louisiana	Washington
Montana	Wyoming
Nebraska	

ADDRESS ORDERS FOR PHOTOGRAPHS OF THESE STATES TO:

Eastern Aerial Photography Laboratory
Program Performance Division
ASCS-USDA
45 South French Broad Avenue, Asheville, N.C. 28801
Tel. Area Code 704, 254-0961 Extension 610

Alabama	Michigan	South Dakota
Connecticut	Minnesota	Tennessee
Delaware	Mississippi	Virginia
Florida	Missouri	West Virginia
Georgia	New Hampshire	Wisconsin
Illinois	New Jersey	
Indiana	New York	
Iowa	North Carolina	
Kentucky	Ohio	
Maine	Pennsylvania	
Maryland	Rhode Island	
Massachusetts	South Carolina	

Orders for photography not held by Agricultural Stabilization and Conservation Service should be forwarded to the holding agency; if address is not known forward to the Coordinator of Aerial Photographic Work of the Department, ASCS, U. S. Department of Agriculture, Washington, D. C. 20250.

Appendix B
HOW TO ORDER EROS DATA CENTER PRODUCTS
EROS DATA CENTER STANDARD PRODUCTS
SATELLITE PRODUCTS

Sept. 1, 1974

ERTS DATA

Image Size	Scale	Format	Black & White Unit Price	Color Composite Unit Price
2.2 inch.	1:3369000	Film Positive	$ 2.00	N.A.
2.2 inch.	1:3369000	Film Negative	2.00	N.A.
7.3 inch.	1:1000000	Film Positive	3.00	12.00
7.3 inch.	1:1000000	Film Negative	3.00	N.A.
7.3 inch.	1:1000000	Paper	2.00	7.00
14.6 inch.	1:500000	Paper	5.00	15.00
29.2 inch.	1:250000	Paper	12.00	30.00

COLOR COMPOSITE GENERATION *(When not already available)

Image Size	Scale	Format	Unit Price
7.3 inch.	1:1000000	Printing Master **	$ 50.00

* Color composites are portrayed in false color (infrared) and not true color.
** Cost of product from this composite must be added to total cost.

COMPUTER COMPATIBLE TAPES

Tracks	b.p.i.	Format	Set Price
7	800	4-tape set	$ 200.00
9	800	4-tape set	200.00
9	1600	4-tape set	200.00

NASA ERTS CATALOGS

Title	Cost Per Volume
U.S. Standard Catalog - Monthly	$ 1.25 each
Non - U.S. Standard Catalog - Monthly	1.25 each
Cumulative U.S. Standard Catalog - 1972/1973 Volume 1 Observation ID Listing Volume 2, Coordinate Listing	1.25 each
Cumulative Non - U.S. Standard Catalog - 1972/1973 Volume 1 Observation ID Listing Volume 2 Observation ID Listing Volume 3 Coordinate Listing	1.25 each

SKYLAB PHOTOGRAPHY

S190A

Image Size	Scale	Format	Black & White Unit Price	Color Unit Price
2.2 inch.	1:2850000	Film Positive	$ 2.00	$ 5.00
2.2 inch.	1:2850000	Film Negative	4.00	N.A.
6.4 inch.	1:1000000	Paper	2.00	7.00
12.8 inch.	1:500000	Paper	5.00	15.00
25.6 inch.	1:250000	Paper	12.00	30.00

S190B

Image Size	Scale	Format	Black & White Unit Price	Color Unit Price
4.5 inch.	1:950000	Film Positive	$ 2.00	$ 6.00
4.5 inch.	1:950000	Film Negative	4.00	N.A.
4.5 inch.	1:950000	Paper	2.00	6.00
8.6 inch.	1:500000	Paper	2.00	7.00
17.2 inch.	1:250000	Paper	5.00	15.00
34.4 inch.	1:125000	Paper	12.00	30.00

See Reverse

EROS DATA CENTER STANDARD PRODUCTS

AIRCRAFT PRODUCTS

Sept. 1, 1974

AERIAL MAPPING PHOTOGRAPHY

Image Size	Format	Black & White Unit Price
9 inch.	Film Positive	$ 3.00
9 inch.	Film Negative	6.00
9 inch.	Paper	2.00
18 inch.	Paper	5.00
27 inch.	Paper	6.00
36 inch.	Paper	12.00
Photo Index	Paper	3.00

NASA RESEARCH AIRCRAFT PHOTOGRAPHY

Image Size	Format	Black & White Unit Price	Color Unit Price
2.2 inch.	Film Positive	$ 2.00	$ 5.00
2.2 inch.	Film Negative	4.00	N.A.
4.5 inch.	Film Positive	2.00	6.00
4.5 inch.	Film Negative	4.00	N.A.
4.5 inch.	Paper	2.00	6.00
9.0 inch.	Film Positive	3.00	12.00
9.0 inch.	Film Negative	6.00	N.A.
9.0 inch.	Paper	2.00	7.00
9 X18 inch.	Film Positive	6.00	24.00
9 X18 inch.	Film Negative	12.00	N.A.
9 X18 inch.	Paper	4.00	14.00
18.0 inch.	Paper	5.00	15.00
27.0 inch.	Paper	6.00	20.00
36.0 inch.	Paper	12.00	30.00

MISCELLANEOUS

MICROFILM

	Black & White Roll Price	Color Roll Price
16 mm (100 foot roll)	$ 15.00	$ 35.00
35 mm (100 foot roll)	20.00	40.00

KELSH PLATES

	Black & White
Contact Prints on Glass Specify thickness (0.25 or 0.06 inch) and method of printing (emulsion to emulsion or through film base).	$ 10.00

TRANSFORMED PRINTS

	Black & White
From convergent or transverse low oblique photographs.	$ 7.00

35 mm MOUNTED SLIDE

35 mm mounted duplicate slide where available $ .60

ROLL TO ROLL

Roll to Roll reproductions delivered in roll carries a 50% reduction in price.

See Reverse

Appendix C
ERTS-1 IMAGERY MOSAICS OF CONTERMINOUS UNITED STATES AND ALASKA

November 15, 1973

MOSAIC OF ERTS-1 IMAGERY OF CONTERMINOUS UNITED STATES AND ALASKA

The Cartographic Division of the Soil Conservation Service, U. S. Department of Agriculture, is compiling mosaics composed of imagery obtained by NASA's Earth Resources Technology Satellite (ERTS-1) and covering the conterminous United States and Alaska. The mosaic of conterminous United States is being compiled under contract for the National Aeronautics and Space Administration. The mosaic of Alaska, which has been completed using the best available imagery obtained through November of 1972, was compiled in cooperation with the Resource Planning Team of the Joint Federal-State Land Use Planning Commission for Alaska. All mosaic construction was performed on an Albers Equal Area Projection base.

The mosaic of conterminous United States is being compiled four times with the following combinations of imagery:

Season	Band, Spectral Region
July 23 to October 31, 1972	5, 0.6 to 0.7 micrometers
July 23 to October 31, 1972	7, 0.8 to 1.1 micrometers
January 1 to March 15, 1973	5, 0.6 to 0.7 micrometers
January 1 to March 15, 1973	7, 0.8 to 1.1 micrometers

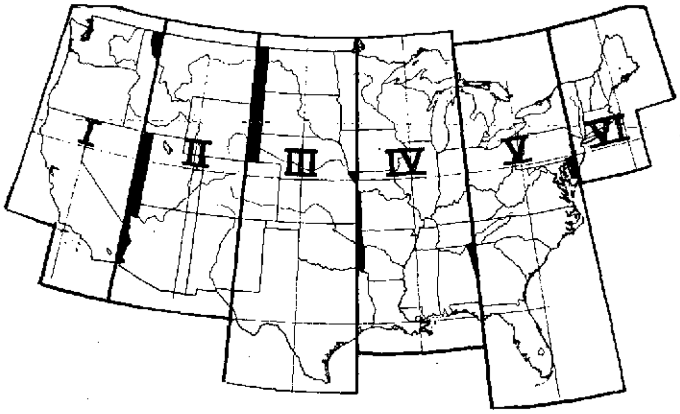
The mosaic of Alaska was compiled with the following combination of imagery only:

Season	Band, Spectral Region
July 23 to November 3, 1972	7, 0.8 to 1.1 micrometers

Due to the limited season for this Alaskan imagery, several small areas of the mosaic reflect some cloud cover. Also, in several areas of excessive cloud cover, planimetric map detail (which was used as a control base for compilation) will be seen in those spots of the reproduction.

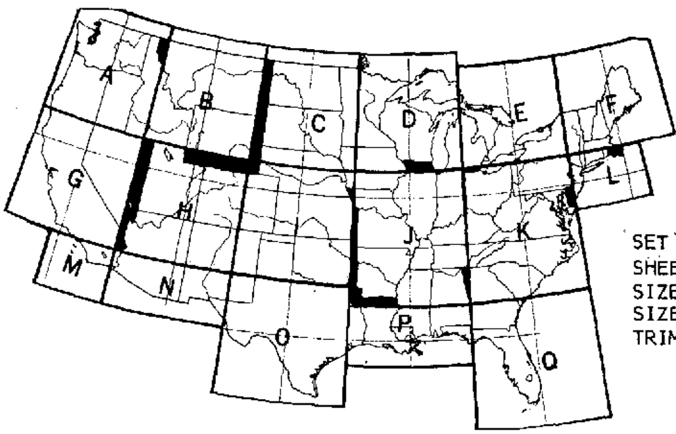
Reproductions of conterminous United States will be available in sheets covering areas defined on page 2. Sheets I, II and III of the set of six negatives; sheets A, B, C, G, H, I, M, N and O of the set of 17 negatives; and sheets 1, 2, 3, 4, 5, 6, 11, 12, 13, 14, 15, 16, 23, 24, 25, 26, 27, 28, 34, 35, 36, 37, 38, 39, 44, 45, 46, 47, 48, 52 and 53 of the set of 54 negatives, covering the MOSAIC of summer season imagery, have been completed and are available now. Reproductions of these sheets may be purchased at scales and at prices indicated on page 4. Subsequent panels of sheets IV through VI and associated sheets defined by alphabet and by number will become available at approximately one month intervals, with completion of the entire project due during the summer of 1974.

Reproductions of Alaska are available now and may also be purchased at scales and at prices indicated on page 4. The layout of map sheets covering Alaska is presented on page 3.

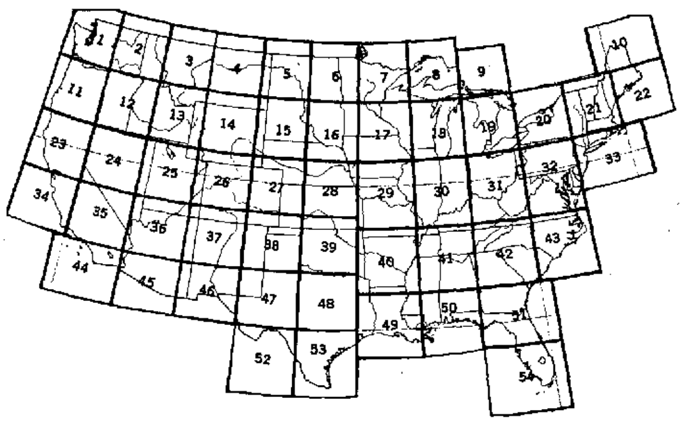


SET OF SIX NEGATIVES
SIZE 20" X 24". SCALE 1:5,000,000
I THROUGH VI

Areas also included on adjacent sheets to enable reproduction of state coverage with a minimum number of sheets.



SET OF 17 NEGATIVES, SCALE 1:1,000,000. SHEETS A THROUGH K AND N THROUGH Q, SIZE 40" X 48", AND SHEETS L AND M, SIZE 20" X 24". SHEETS N AND P WILL BE TRIMMED TO SHORTER LENGTH.

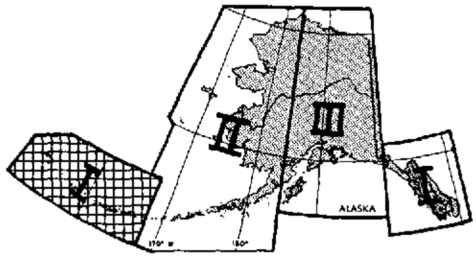


SET OF 54 NEGATIVES
SIZE 20" X 24", SCALE 1:1,000,000
1 THROUGH 54

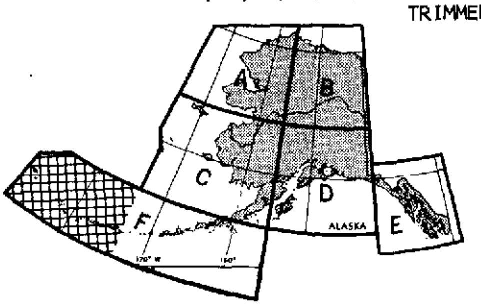
2. INDEX TO REPRODUCTIONS
ERTS-1 MOSAIC OF CONTERMINUOUS UNITED STATES

SET OF THREE NEGATIVES
SIZE 20" X 24", SCALE 1:3,300,000
I, II, III

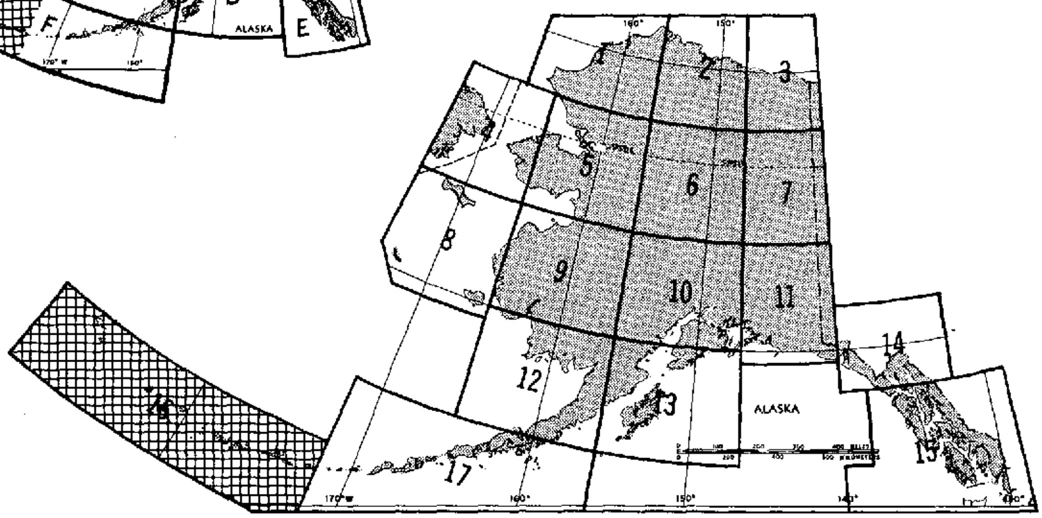
Mosaic of this portion not available at this time.



SET OF SIX NEGATIVES
SIZE 40" X 48", SCALE 1:1,000,000
A, B, C, D, E, F (SHEETS E AND F WILL BE TRIMMED TO SMALLER SIZE).



SET OF SIXTEEN NEGATIVES, SCALE 1:1,000,000.
SHEETS 1 THROUGH 15 AND 17. SIZE 20" X 24".



INDEX TO REPRODUCTIONS
ERTS-1 MOSAIC OF ALASKA

3.

Price List for ERTS Mosaic of Conterminous United States

Scale		Mode	Unit Price	Units in Set	Total Coverage Price
1:5,000,000	20" x 24"	Contact	$ 7.50	6	$ 45.00
1:3,300,000	30" x 40"	Enlargement	15.00	6	90.00
1:2,500,000	40" x 48"	Enlargement	18.00	6	108.00
1:2,000,000	40" x 60"	Enlargement	20.00	6	120.00
1:1,000,000	40" x 48"	Contact	18.00	15	285.00
	20" x 24"	Contact	7.50	2	
1:1,000,000	20" x 24"	Contact	7.50	54	405.00
1:750,000	30" x 40"	Enlargement	15.00	54	810.00
1:500,000	40" x 48"	Enlargement	18.00	54	972.00

Price List for ERTS Mosaic of Alaska

Scale		Mode	Unit Price	Units in Set	Total Coverage Price
1:3,300,000	20" x 24"	Contact	$ 7.50	3	$ 22.50
1:2,000,000	40" x 48"	Enlargement	18.00	3	54.00
1:1,000,000	40" x 48"	Contact	18.00	6	108.00
1:1,000,000	20" x 24"	Contact	7.50	16	120.00
1:750,000	30" x 40"	Enlargement	15.00	16	240.00
1:500,000	40" x 48"	Enlargement	18.00	16	288.00

All reproductions quoted above will be printed on stable-base photographic paper. All reproductions listed as "enlargement" (under column headed by "Mode") will be projected from 20" x 24" negatives.

When ordering ERTS mosaic reproductions, please indicate (1) the scale of reproduction (per above price list), (2) the size of reproduction (per above price list), (3) the season during which imagery was obtained (see page 1), (4) the spectral band number (see page 1), and (5) the identification letter or number of each sheet (see pages 2 and 3).

Please make check, money order or draft payable to the Soil Conservation Service, U.S.D.A., Orders or requests for further information should be addressed to the Cartographic Division, Soil Conservation Service, Federal Center Building No. 1, Hyattsville, Maryland 20782.

USDA-SCS-HYATTSVILLE, MD. 1973

Appendix D
ORGANIZATIONS HAVING CAPABILITY IN MULTISPECTRAL AND RADAR DATA COLLECTION AND ANALYSIS

The Bendix Corporation
Aerospace Systems Division
3300 Plymouth Road
Ann Arbor, MI

Daedalus Enterprises Inc.
7101 Jackson Road
Ann Arbor, MI

Environmental Research Inst. of Mi
P. O. Box 618
Ann Arbor, MI 48107

Earth Satellite Corporation
1747 Pennsylvania Ave., NW
Washington, D.C. 20006

Purdue University
LARS
1220 Potter Drive
West Lafayette, Ind. 47906

The University of Kansas
Center for Research, Inc.
Space Technology Laboratory
2291 Irving Hill Road
Lawrence, Kansas 66044

General Electric Company
Space Division
P. O. Box 8555
Philadelphia, Pa.

Goodyear Aerospace Corp.
Litchfield Park
Phoenix, Ariz. 85340

Remote Sensing Institute
South Dakota State University
Brookings, South Dakota 57006

McDonnell Douglas Astronautics Co.
5301 Bolsa Avenue
Huntington Beach, Ca. 92647