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IOWA REMOTE SENSING LABORATORY

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PROCEEDINGS

SEMINAR IN APPLIED REMOTE SENSING

May 8 - 12, 1972

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FOREWORD

The Iowa Remote Sensing Laboratory, Iowa Geological Survey, sponsored a one-week seminar in Applied Remote Sensing at Drake University, Des Moines, Iowa from May 8 - 12, 1972. The Proceedings include, in some form, all of the lectures that were given. The format is dependant on the material received from each speaker and ranges through outlines, notes, resumes, to duplication of the paper as it was presented. The contributions of each speaker are gratefully acknowledged. Any errors of omission are mine.

Mary C. Parker, Editor
Iowa Remote Sensing Laboratory

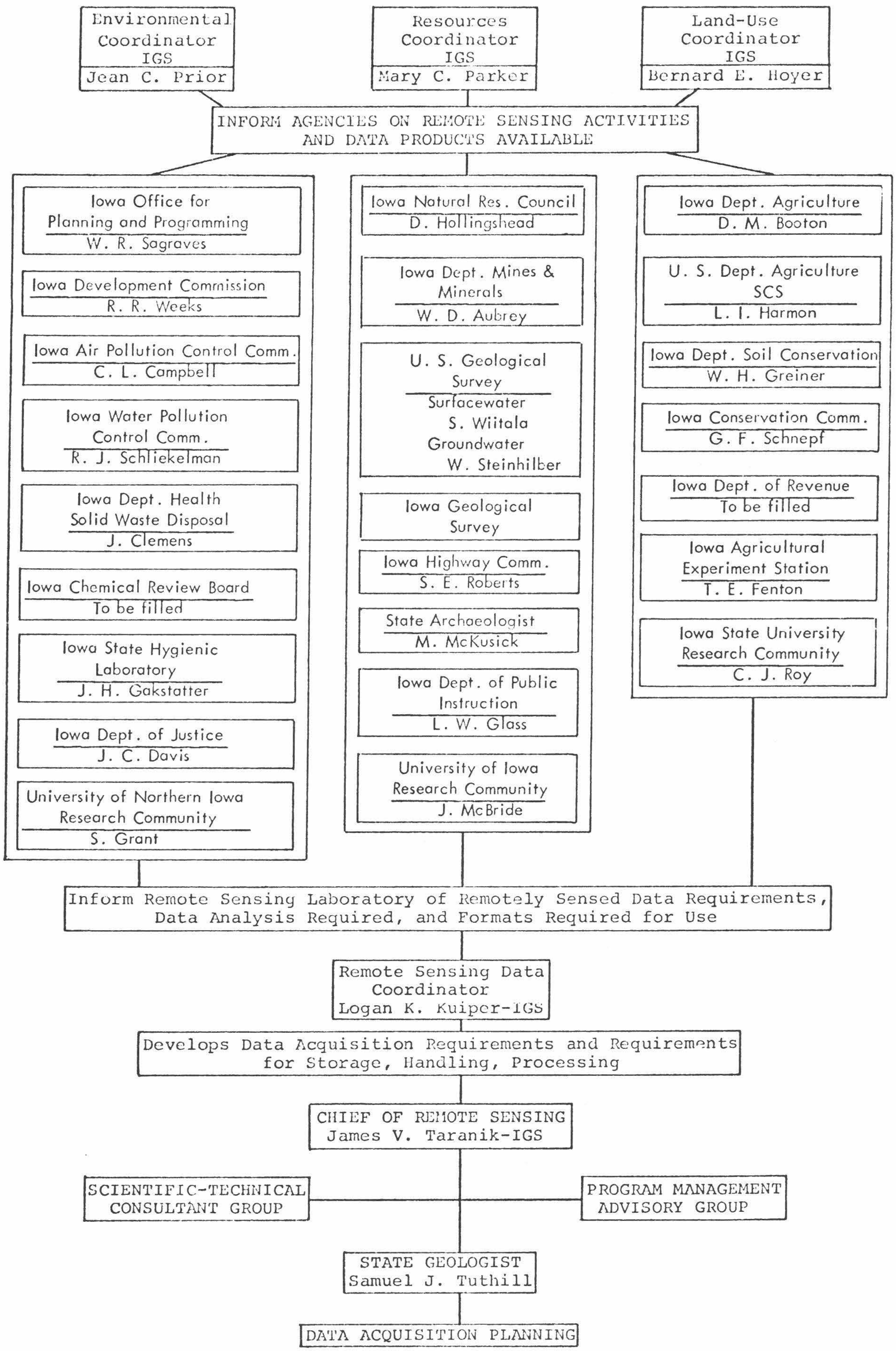
REMOTE SENSING, A TOOL FOR STATE MANAGEMENT -PLANNING IN IOWA

Samuel J. Tuthill
State Geologist

There is an increased emphasis on planning in state government because of population shifts and growth, increased urbanization, technological changes in industry, and changing patterns in the consumption of goods. The changing relationships between urban-industrial development and rural-agricultural landuse, and the increasing need for natural resources have placed stress on environmental quality and the state economic base. Recognizing the need for meaningful legislative control over resources, land utilization, and the environment, the State of Iowa has developed a remote sensing program capable of inventorying the Iowa landscape and providing knowledge for the technical analysis of problems related to State growth.

The data products from remote sensors imaging the State of Iowa should enable legislators and state agencies to map out state evolutionary trends, regulate economic growth, and maintain orderly state development. Remotely sensed data of Iowa has the potential for application to a broad spectrum of disciplines in state management and the Iowa remote sensing program is organized to identify those items of data input, from low-altitude missions to satellites, that will be useful to state agencies in their planning, regulatory, operational, and research functions. The remote sensing laboratory analysis team produces reports in formats which will be meaningful to and useable by individuals in the various agencies of the State of Iowa involved in planning and management.

IOWA REMOTE SENSING ORGANIZATION



Since 1892 the Iowa Geological Survey (Survey) has acted as a research and consulting agency for the State of Iowa in matters related to earth resources and the physical environment. It is the repository of hydrologic, geologic, and physical geographic data for Iowa. It has become apparent that remotely sensed imagery is a powerful tool for monitoring aspects of the environment, and the Survey has promoted its use by government agencies having research, regulatory, and/or action functions related to or affecting environmental protection. The Survey has developed a staff capable of acquiring, interpreting, and analyzing remote-sensor data and has organized a consortium of 24 state and federal agencies operating in Iowa who can employ these data.

There are eight Iowa state agencies that have major regulatory responsibility for aspects of the environment 1/. In addition, there are eight action agencies that use spatial and temporal data that characterize phenomena and processes on the earth's surface 2/. Supporting these 16 agencies as a significant part of their functions are the three state and two federal research agencies 3/. In the three state universities there are individuals and groups that are conducting research related to environmental protection, the subject of which does or could relate to, or depend upon, remote-sensor data.

1. Iowa State Conservation Commission; Iowa Dept. of Agriculture; Iowa Natural Resources Council; Iowa Dept. of Mines and Minerals; Iowa State Dept. of Health, Solid Waste Division; Iowa Water Pollution Control Commission; Iowa Air Pollution Control Commission; and Iowa Chemical Review Board.

2. Iowa Office for Planning and Programming; Iowa Development Commission; Iowa Dept. of Justice ; the State Archaeologist; Iowa Highway Commission; Iowa Dept. of Soil Conservation; Iowa Dept. of Revenue; and the Iowa State Dept. of Public Instruction.

3. U. S. Dept. of Agriculture, Soil Conservation Commission; U. S. Geological Survey, Water Resources Division; Iowa State Hygienic Laboratory; Iowa Geological Survey; and the Iowa State Agricultural Experiment Station.

The Survey has organized these 24 state and federal agencies into a consortium for the purpose of acquiring and applying remotely sensed data to planning and regulatory functions. The Survey coordinates imagery acquisition projects and information dissemination programs. It is our responsibility to conduct a monitoring service for specific phenomena and processes that the user-agencies identify as elements of their regulatory, planning, and/or research interests. We coordinate acquisition of "ground truth" data by the technical staffs of the various user-agencies and develop analytical advisory services, stimulate research in the field of applications of remotely sensed data to problems in the state, and publish completed studies in an open-file system that is freely available to the public.

At present it is not possible to describe the full usefulness of remote-sensor data to all of these agencies because it depends upon: imagery limitations, the amount of imagination each agency can bring to the program, and to a small degree the funding available in the individual agencies.

Sources of remotely sensed data currently are the Survey and their contractors. The Survey has a multispectral camera, a false color imaging viewer, a variety of light transmission viewers, an electronic false color enhancement and density slicing instrument, and is financing data acquisition missionsfrom low-and medium-altitude aircraft. The Survey has also provided a staff of four Ph.D.-level and three M.Sc.-level analysts and one photo interpreter. Reports of activities and research opportunities are now being disseminated in a newsletter to user-agencies and research results and being distributed in inter-agencies open-file reports, and formal publications. The Survey and its Iowa user-agencies have the prerogative of publishing data released by the Survey either independently or cooperatively.

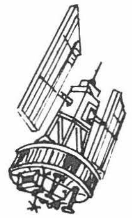
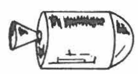
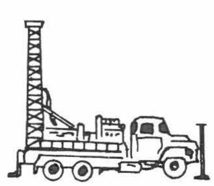
		Data Characteristics		Expected Applications in Iowa
ERTS and Skylab		Small Scale Low resolution Repetitive	495 nm	Synoptic mapping of: Soil groups Surficial geology Karstic terranes (w/ERTS "B") Cultural phenomena Crop distributions
			235 nm	Forestry distributions Hydrologic phenomena Identification of temporal aspects of above and changes and patterns of change.
High-Altitude Underflights		Moderate scale Moderate resolution Seasonal	60,000 ft	Large-systems analysis of all mentioned above at greater resolution and larger scale Fundamentally a correlation bridge from satellite data to ground truth.
Medium-Altitude Underflights		Large scale High resolution Specific missions	30,000 ft	Specific studies and strip monitoring of defined phenomena and processes Correlation of satellite data with ground truth Land use and land capability determinations.
Low-Altitude Underflights		Very large scale Very high resolution Specific missions	15,000 ft 1,000 ft	Scale modification of above where specific problems require higher resolutions.
Surface Studies		Instrument-acquired data at close range or by contact measurement		Fundamental validation of R S analyses; an organizational format for consolidation of extant and currently acquired earth resources data.
Subsurface Studies		Remotely-sensed geophysical and drilling data		Fundamental validation of airborne RS analysis for surficial geology, bedrock geology, hydrology and soils origins.

Figure 2. Expected General Characteristics and Expected Applications of Data in Iowa Geological Survey Remote-Sensing Program.

The Iowa Geological Survey has employed the following approach to accomplish the objectives of the remote sensing program:

1. Continued training of the liaison staff members from the user-agencies in the limitations and possibilities of applications of remote-sensor data to state planning-management. It is our function to keep the interpretations of remote sensing users within the engineering limitations of the method.
2. Confer with liaison staff on ground-truth needs and on imagery interpretations that relate to state planning-management.
3. Initiate acquisition of other remotely sensed data and ground truth where justified.
4. Identify and optimize unpredicted interfaces between various disciplines and applications of remotely sensed data to state planning-management.
5. Prepare publications and reports.

The Iowa Geological Survey envisions three fundamental results of the program proposed here:

1. One state agency provides the medium- and low-altitude imagery, "ground truth" and subsurface remotely sensed data required to inventory the Iowa environment. The disciplinary expertise of the user-agencies are available in research design phase and their personnel are used in a coordinated manner during the data acquisition phase. Thus, large highly trained, dicipline oriented staffs are not required on a standby basis and costs are held to a minimum practical level.

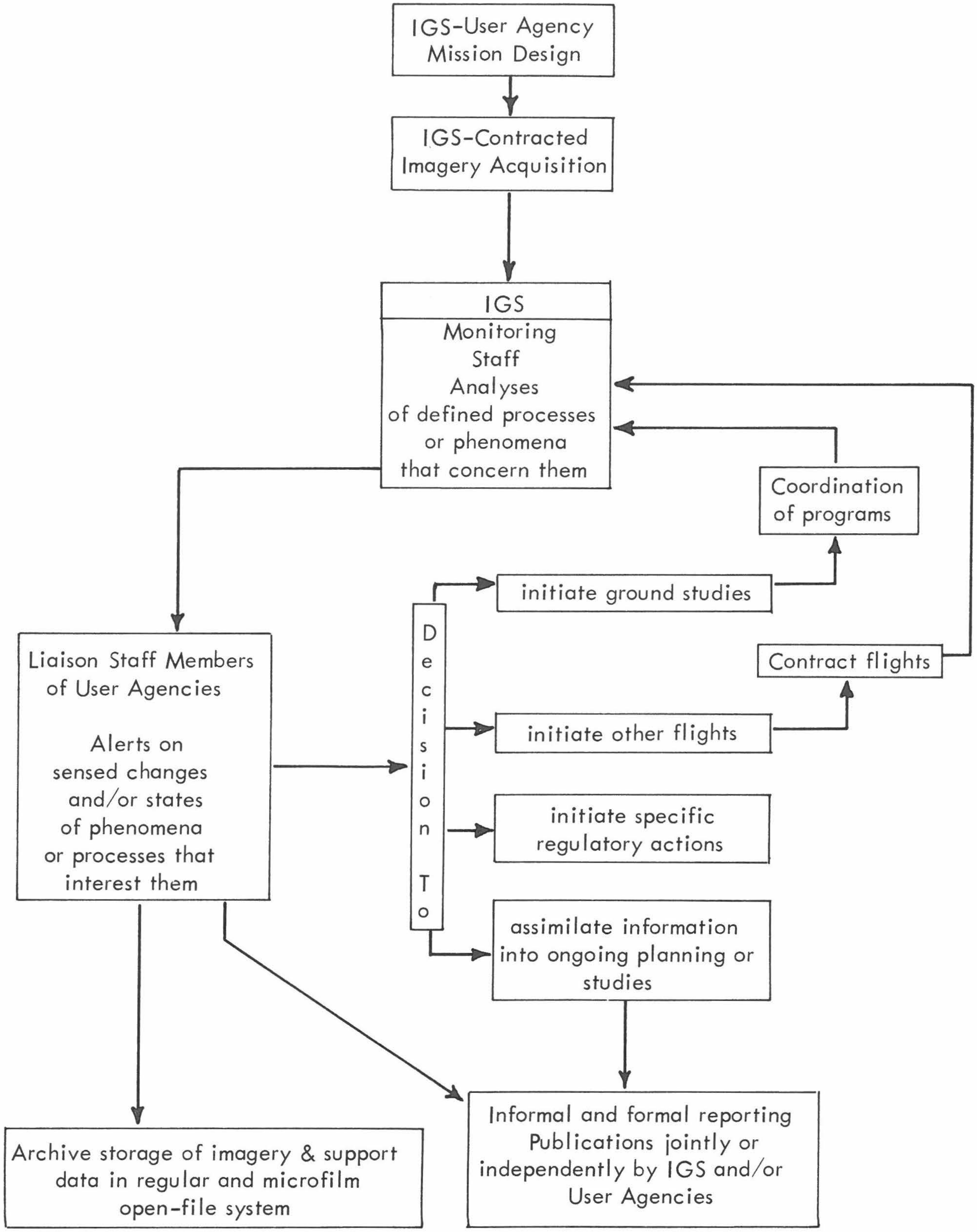


Figure 3. Information and Action Flow for Remote-Sensing Applications in Iowa

2. Development of a coordinated system of image acquisition, handling, analysis, storage, information dissemination, and ground-information feedback (both to analysts and data-acquisition systems planners).

3. Determination of the cost-effectiveness relationships between different kinds of remote sensing investigations.

4. The Iowa organization is truly multidisciplinary and is expected to provide an excellent environment for research because it will repeatedly bring together basic researchers from the academic community, analysts of imagery, and those applying the analyses to the practical problems of environmental protection and resource management and planning.

OVERVIEW OF REMOTE SENSING

James V. Taranik
Chief of Remote Sensing
Iowa Remote Sensing Laboratory

A generalized definition of Remote Sensing is the detection and/or evaluation of phenomena by remote means. Specifically, Remote Sensing is the detection and/or evaluation of electromagnetic energy. Electromagnetic energy consists of waves and bundles of energy which travel at the speed of light, 186,000 mi/sec. It enables us to use the radio, to feel heat, and to see with our eyes. Most of you are involved in remote sensing at this moment. You are detecting electromagnetic energy with your eyes, our primary sensor. We evolved as hominids in the presence of a source of electromagnetic energy (the sun) and developed sensors(our eyes) capable of detecting energy from the sun as it is reflected from our surroundings.

The technology of photography developed to detect and record reflected energy from the sun and thus make permanent records of our surroundings. In the late 1920's through the early 1940's, an entire technology was developed based on recording the visible electromagnetic energy by cameras and film. When cameras were coupled with aircraft as a camera platform, aerial photography rapidly evolved as an earth reconnaissance tool. Thus the field of photogrammetry, including both the mapping and interpretation of aerial photographs, was born.

At the close of World War II photographic techniques emerged which enabled photographic films to record electromagnetic energy not visible to the eye. In the early 1950's the military perfected scanners and sensors capable of recording wavelengths not detectible by conventional photographic means. These scanners and sensors either utilized electromagnetic energy from the sun and measured emitted energy from the earth, or they generated the energy themselves and measured the interaction of this energy with earth materials. Scientists determined that the manner in which electromagnetic energy emits from or interacts with earth materials can reveal characteristics of materials. Therefore, the detection of electromagnetic energy beyond the visible range could be of value in a wide variety of disciplines. As the electromagnetic properties of the earth could be sampled from aircraft, beyond the limits of vision and beyond the limits of photography, a new name was needed for this technology and the name Remote Sensing seemed to fill that need.

When the military declassified remote sensing systems, these systems were turned over to the scientific community. Scientists realized that these tools might have significant application to a variety of problems and research was undertaken in the universities and other scientific communities to determine applications for remote sensing. The National Aeronautics and Space Administration funded research and provided platforms and sensors.

One of the basic problems associated with the application of remote sensing has been created by the evolution of remote sensing technology. Essentially, the scientific method of analysis has been inverted. Rather than designing a tool to measure some parameter of the environment in which we are interested, we have been given tools and have been asked to find applications of their use. As a result, these tools often fall short of our needs and investigators have found that the promises of the remote sensing industry have not been fulfilled.

Early investigators felt that the best method to evaluate these new sensors and detectors was to fly them all and to see how each mapped the parameters of earth resources. The results were an abundance of imagery, but not much understanding of the meaning of the patterns on the imagery nor what earth phenomena was being mapped. This is what many in the earth resources community now refer to as the irrational phase of remote sensing.

This phase is being replaced by the rational scientific approach to remote sensing in which investigators have examined earth materials and their associated electromagnetic phenomena, then designed remote sensing overflights to map the electromagnetic phenomena which has been defined by careful ground measurements. This experimental phase is being undertaken by a number of scientists from a variety of disciplines throughout the United States.

The rational phase in the evolution of remote sensing technology has provided several applications beyond those of conventional photography and more applications are becoming evident every year. As more applications become evident, more agencies at the state and federal level are becoming interested in this rapidly growing technology. Now, more than any time in the recent past, we are in a position to apply remote sensing, and by being aware of its potential, to take advantage of new techniques as they are made available to us. Additionally, by being organized we are in a position to report back to the scientific community the success or failure of techniques, so that scientists can improve the technology.

PRINCIPLES OF REMOTE SENSING

by

Keith R. Carver
Physical Science Laboratory
New Mexico State University
Las Cruces, New Mexico

PREFACE

This paper was presented during a one-week seminar on Applied Remote Sensing at Drake University, May 8 - 12, 1972. Most of the attendees were from various state and federal agencies in Iowa with backgrounds encompassing such disciplines as geology, agriculture and meteorology.

Consequently this presentation was designed to be tutorial in nature, to be as self-contained as possible and to be short enough for a 90-minute talk. It covers in outline fashion several important physical principles in the remote sensing of the earth's surface, but has little depth in any one area. For further reading refer to the book "Remote Sensing", Printing and Publishing Office, National Academy of Sciences, 2101 Constitution Avenue, Washington, D.C. 20418, 1970. Also see Chapter 3 of "Radio Astronomy", J. D. Kraus, McGraw-Hill Book Co., New York, N.Y. 1966.

PRINCIPLES OF REMOTE SENSING

Keith R. Carver
Physical Science Laboratory
New Mexico State University
Las Cruces, New Mexico

I. Introduction to the Electromagnetic Spectrum

Fig. 1 is a bar chart showing the regions of the electromagnetic spectrum. Frequency is measured in hertz (1 cycle per second); thus a frequency of one thousand cycles per second is called a kilohertz. A million cps is a megahertz and a billion cps is a gigahertz. Wavelength, on the other hand, is measured in meters; 1 centimeter is $\frac{1}{100}$ meter, 1 millimeter is $\frac{1}{1000}$ meter, and 1 micron (or micrometer) is a millionth of a meter.

Frequency (f) is related to wavelength by the simple relation

$$f = \frac{c}{\lambda}$$

where c is the speed of light, or 3×10^8 meters/second.

The electromagnetic spectrum can be conveniently divided into the four major regions:

1. Radio
2. Infrared
3. Visible
4. Ultraviolet

There are two basic types of radiation sources in the spectrum:

1. Monochromatic (single-frequency) sources - e.g. radio, f.m., TV stations; microwave relay links, etc.
2. Wide-spectrum (many-frequency) sources - e.g. earth's atmosphere and terrestrial surface; extraterrestrial objects (sun, etc.).

The radio portion of the spectrum is shown in Fig. 2. Most of the remote sensing of the earth (in the radio spectrum) is

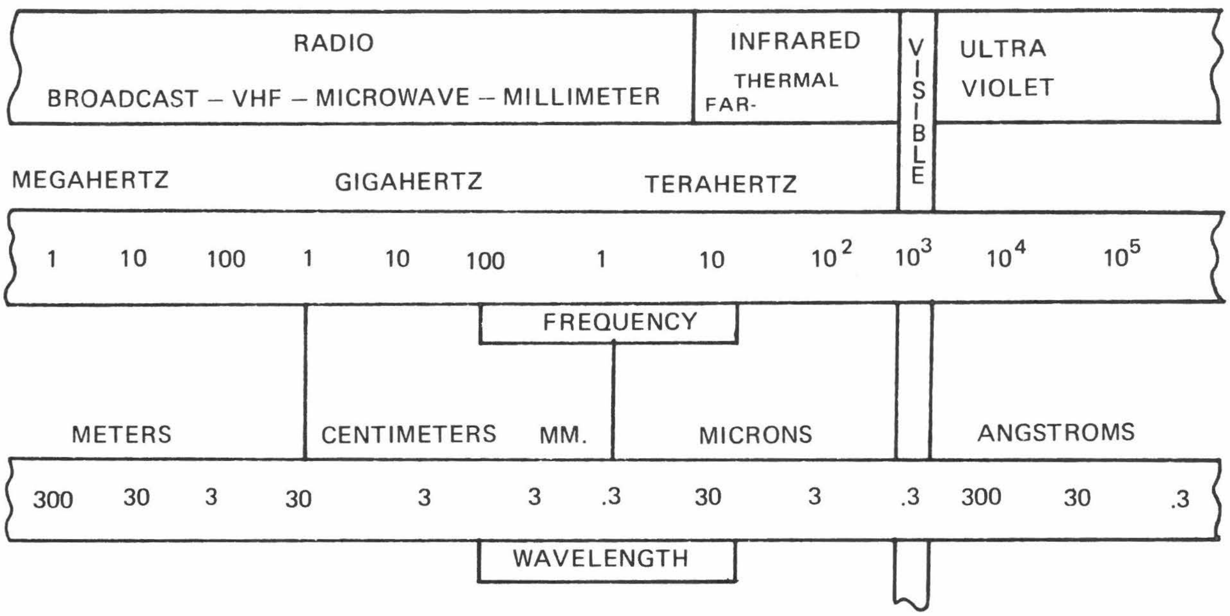


FIGURE 1 ELECTROMAGNETIC SPECTRUM

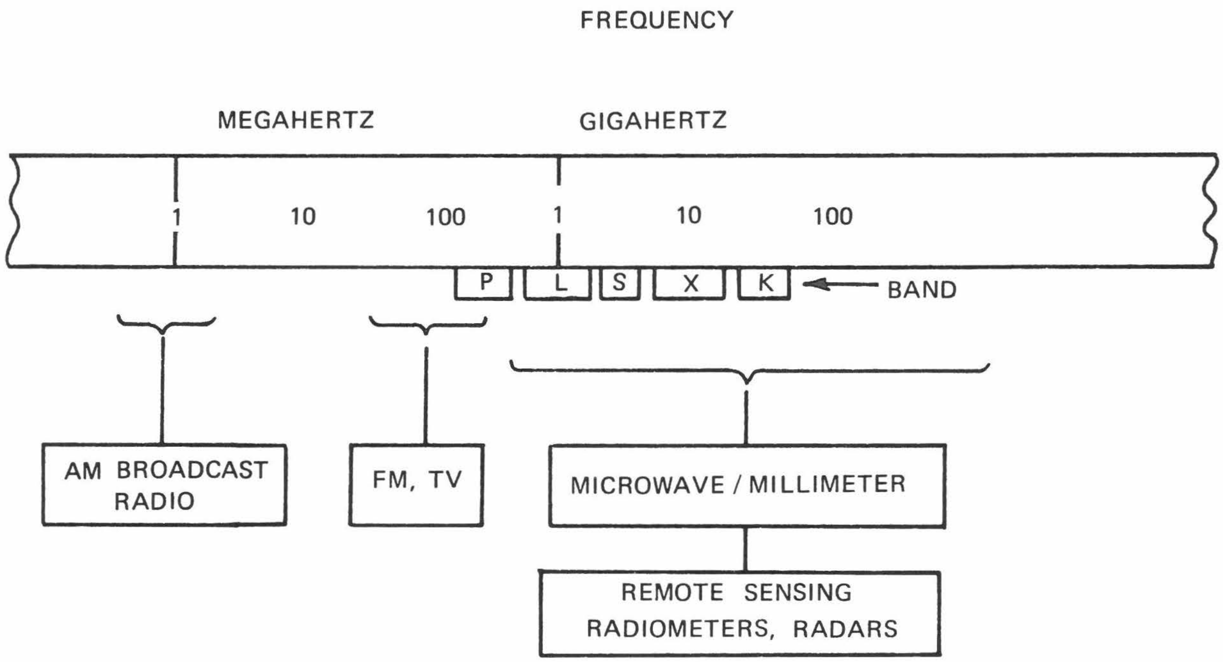


FIGURE 2 RADIO PORTION OF ELECTROMAGNETIC SPECTRUM.

carried out in the region 1-100 GHz. The earth radiates a noise-like signal throughout the radio spectrum; generally the radiation is higher as the frequency increases. The earth's atmosphere both radiates and absorbs radio signals; this will be discussed further later.

The infrared portion of the spectrum is illustrated in Fig. 3. Short wavelengths of radiation (but longer than optical wavelengths) are classified as the solar (or near) infrared. This is the band $.7\mu<\lambda<2\mu$.* Intermediate wavelengths ($2\mu<\lambda<50\mu$) are classified as the thermal IR. Long wavelengths ($300\mu<\lambda<500\mu$) are known as the far-IR portion.

Fig. 4 illustrates the visible portion of the spectrum. Visible radiation (light) spans the wavelength region .4 - .7μ. Long wavelengths are reddish in color, intermediate wavelengths yellowish, and short wavelengths violet. Wavelengths slightly shorter than .4μ are in the ultraviolet; very short wavelengths are called gamma-rays and X-rays. Wavelengths slightly longer than .7μ (red) are said to be in the infrared. It is to be emphasized that most of the remotely sensed data is taken in the narrow visible portion of the electromagnetic spectrum.

II. Properties of Electromagnetic Radiation

Fig. 5 illustrates the propagation of a monochromatic (single-frequency) electromagnetic wave. The electric field strength assoiated with the wave can be represented by a vector oscillating in time and space, as shown. The polarization of the wave is the

*The Greek letter μ is used to represent the word micron.

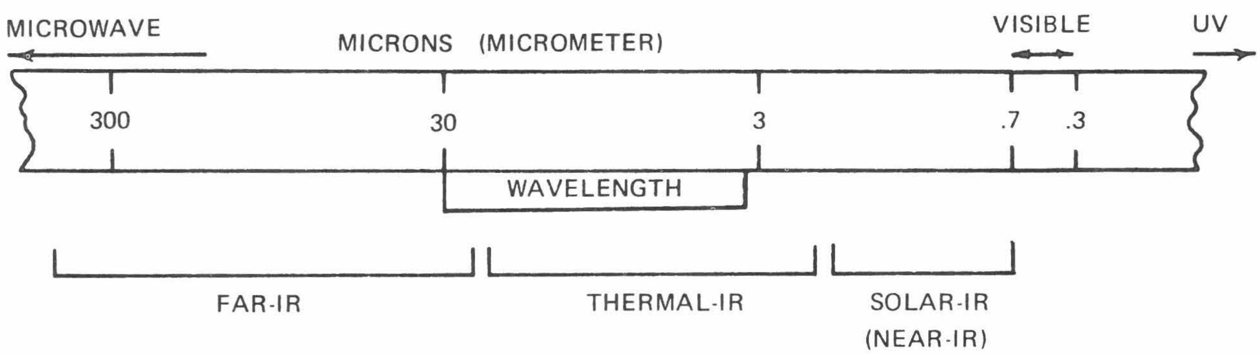


FIGURE 3 INFRARED PORTION OF ELECTROMAGNETIC SPECTRUM

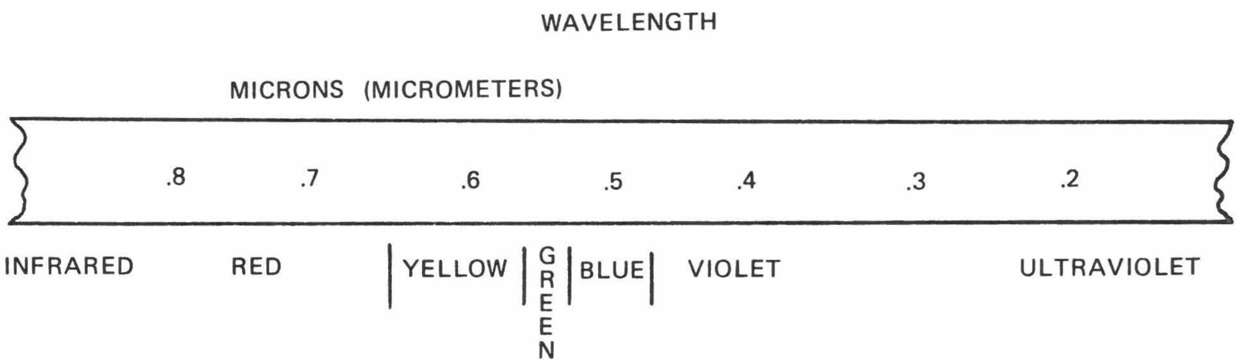


FIGURE 4 VISIBLE PORTION OF ELECTROMAGNETIC SPECTRUM

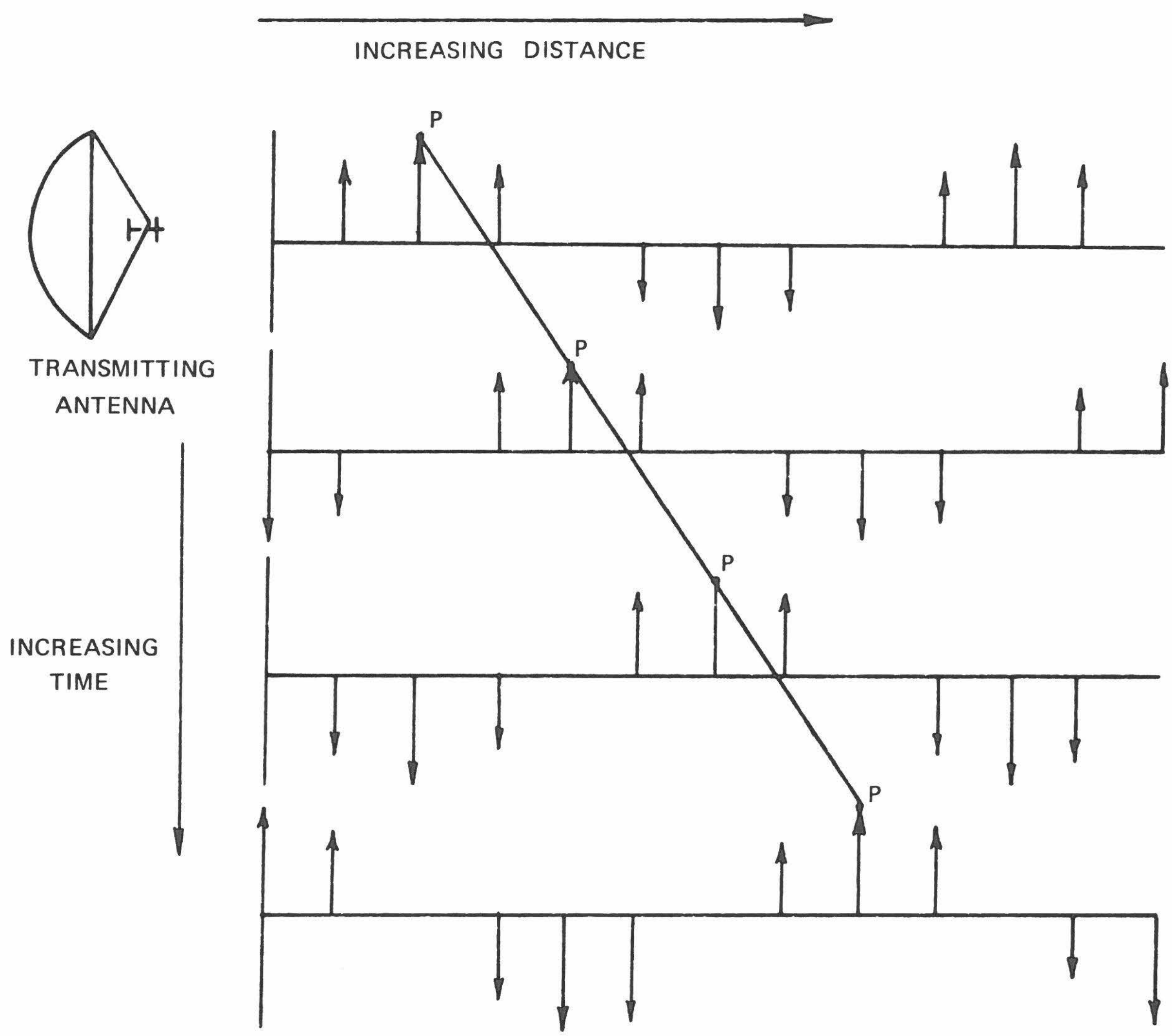


FIGURE 5 WAVE PROPAGATION

direction of the electric field vector - in this case, since the vector is vertical, the wave is said to be vertically polarized. If the E-vector were oscillating perpendicular to the page, it would be horizontally polarized. The propagation of the wave in Fig. 5 can be seen by following the point P of constant phase. The four graphs shown are "snapshots" of the wave taken at successive intervals of one quarter of the period of the wave. The wavelength is defined as the length between two adjacent points of identical phase. The propagation velocity of a radio or light wave in air is the velocity of light (300 million meters per second).

Consider a very large collection of dipole antennas with random orientation and each with its own separate frequency, as in Fig. 6a. A random phase distribution between oscillators is also assumed. The composite or total wave radiated from all these oscillator-antenna combinations would be a randomly polarized wave that contains many frequency components. The earth's surface behaves in exactly this way, as suggested in Fig. 6b. It generates a randomly polarized wave having frequency components throughout the spectrum. The earth is actually a collection of many atomic and molecular oscillators.

All objects at temperatures above absolute zero radiate energy in the form of electromagnetic waves. Not only do they radiate, but they may also absorb or may reflect such energy incident on them. A perfect absorber is called a blackbody - a perfect absorber is also a perfect radiator. A blackbody absorbs all the radiation falling on it at all wavelengths; the radiation from it is a function of only the wavelength and the temperature.

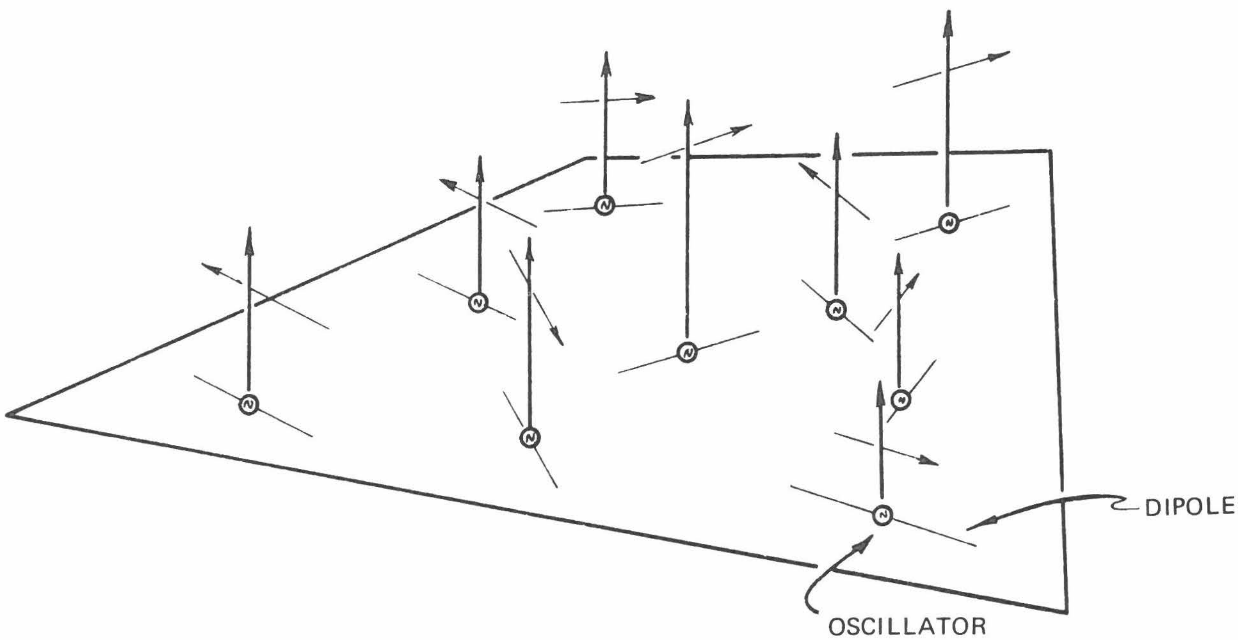


FIGURE 6 (A). ARRANGEMENT OF DIPOLE ANTENNAS FOR GENERATING RANDOMLY POLARIZED ELECTROMAGNETIC WAVE.

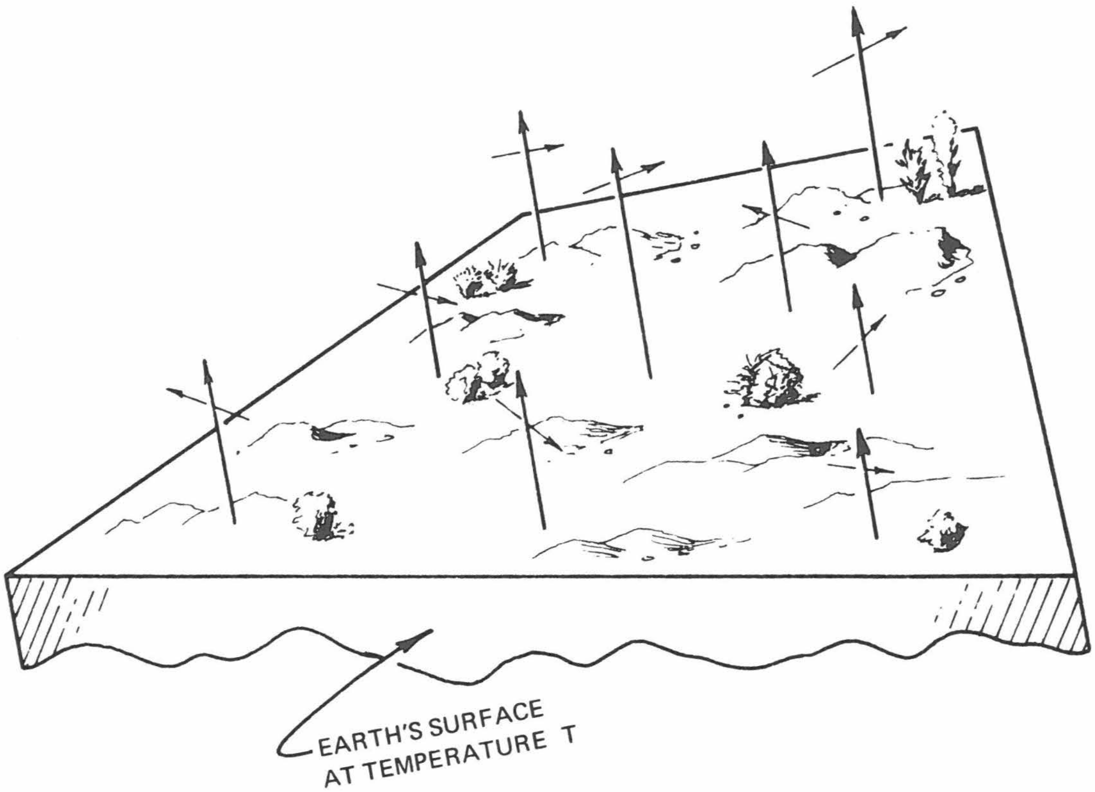


FIGURE 6 (B). EARTH'S SURFACE GENERATING A RANDOMLY POLARIZED ELECTROMAGNETIC WAVE.

The spectral power (power per unit bandwidth) from a surface element dA flowing out through a solid angle dΩ is given by (see Fig. 7)

$$dw = B \cos\theta \, d\Omega \, dA$$

where

dw = spectral power (watts/hertz)

B = brightness (watts/m^2/hz./rad^2)

θ = angle between normal to surface and dΩ (rad)

dA = element of area (m^2)

In the radio portion of the spectrum, the brightness of radiation from a blackbody is governed by the Rayleigh-Jeans law:

$$B = \frac{2kT}{\lambda^2} = \frac{2f^2kT}{c^2}$$

where

f = frequency (hertz)

λ = wavelength (meters)

k = Boltzmann's constant = 1.38×10^{-23} (joules/^{o}K)

T = temperature (^{o}K)

c = speed of light = 3×10^8 meters/second

The Rayleigh-Jeans law then predicts that if the temperature is doubled, the brightness doubles; however, if the frequency is doubled the brightness is quadrupled.

This "law" is only valid for long wavelengths, say greater than 1 mm. In general, Planck's law governs the brightness-frequency curve and the Rayleigh-Jeans relation is an approximation holding only in the radio portion of the spectrum. Planck's law predicts brightness-frequency curves of the type shown in Fig. 8. The

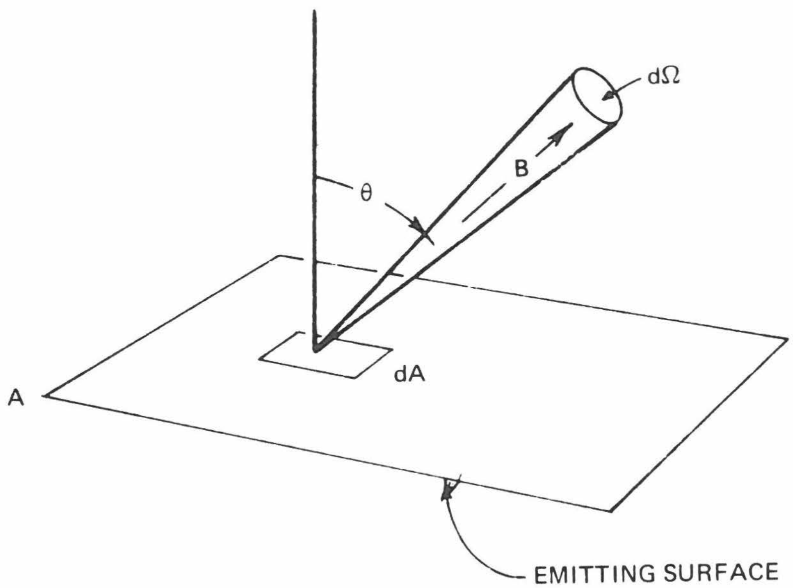


FIGURE 7 ILLUSTRATING BRIGHTNESS CONCEPT

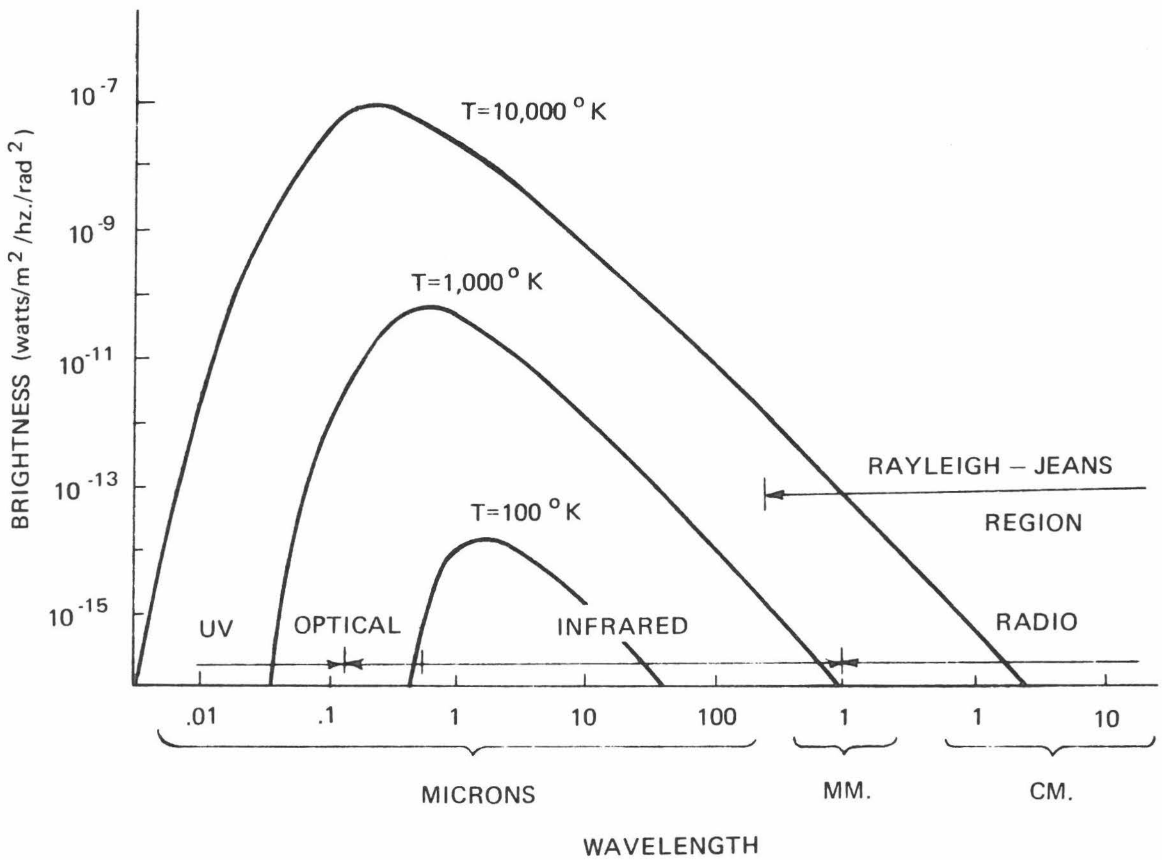


FIGURE 8 PLANCK'S LAW RADIATION CURVES.

brightness is maximum (for temperatures between $50^{\circ}K$ and $500^{\circ}K$) in the infrared portion of the spectrum.

The point of all this is that if we can measure B (using a remote thermal sensor, such as a microwave radiometer or IR radiometer), if we know the wavelength λ, and if we assume that a remotely sensed object is a blackbody, then we can compute the temperature of the object.

Referring to Fig. 9, the noise power per unit bandwidth available at the terminals of a resistor of resistance R and temperature T is given by

$$w = kT$$

where

$$k = \text{Boltzmann's constant}$$
$$= 1.38 \times 10^{-23} \text{ (joules/}^{\circ}\text{K)}$$
$$T = \text{temperature } (^{\circ}\text{K})$$

If the resistor is now replaced by a lossless matched antenna of radiation resistance R, the impedance presented at the terminals is unchanged. If the antenna is placed inside a blackbody at a temperature T, the noise power from the antenna terminals will also be $w = kT$. If the antenna is now pointed toward the earth at temperature T and if the earth were a perfect blackbody, essentially all of the received energy would be from the earth's radiation and a noise power per bandwidth of kT would again be measured. The temperature measured by the antenna is essentially the physical temperature of the region which the antenna beam sees.

The emission coefficient, or emissivity of an object is defined as

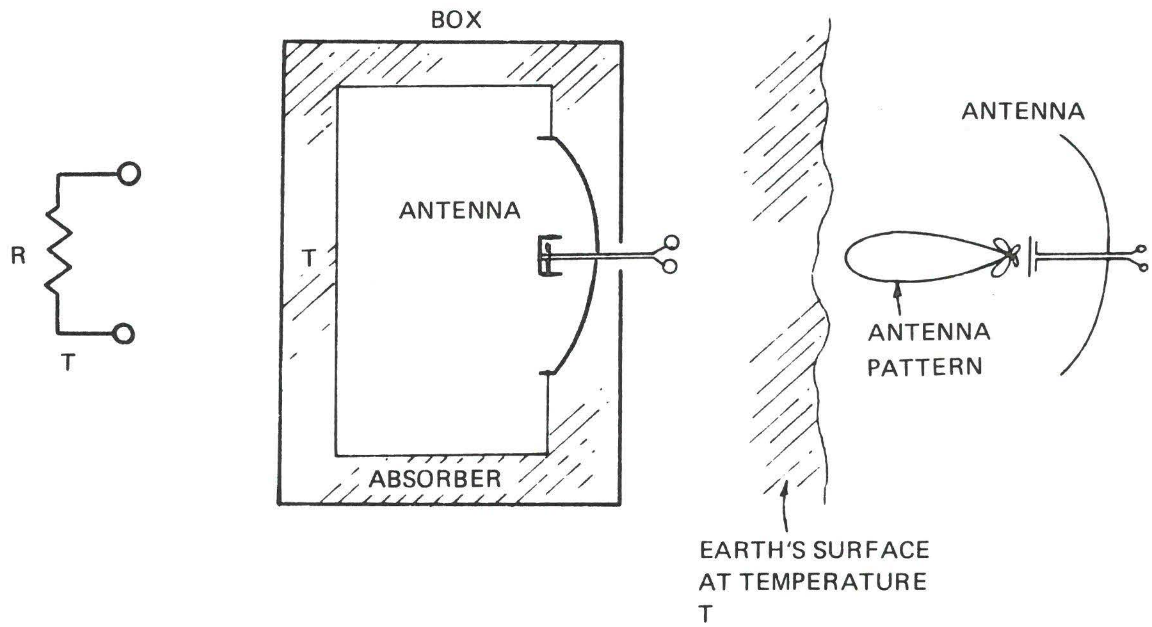


FIGURE 9 ILLUSTRATING BLACK–BODY CONCEPT.

$$\text{emissivity} = \frac{\text{power radiated by ground surface in direction } \theta \text{ at temperature } T}{\text{power radiated by perfect blackbody in direction } \theta \text{ at temperature } T}$$

For a perfect blackbody, the emissivity is 1.0. For a perfect reflector, the emissivity is 0.0. Thus the emissivity is a measure of how good a blackbody an object is. For ordinary terrain, the emissivity in the radio spectrum varies between 10% and 95%, depending strongly on polarization and angle of incidence. In the IR, the emissivity is usually above 90% for ordinary earth materials.

The reflectivity of an object is defined as

$$\text{reflectivity} = \frac{\text{power reflected by an object}}{\text{power incident on an object}}$$

In the radio region, both thermal radiation and reflected radiation play an important role in determining what the remote sensor "sees." In the thermal IR, the emissivity is usually high and the radiation follows Planck's law approximately. Referring to Fig. 10, note that for ordinary temperatures (100°K-500°K), the peak radiation occurs in the thermal IR at wavelengths between 4 and 25 μ. (On the ERTS-B satellite, for example, there is an IR remote sensing channel covering 10.4-12.6 μ, corresponding to the wavelengths of peak radiation from the earth at ordinary temperatures.) In the optical region, however, we are primarily interested in variations in reflectance across the color spectrum.

III. Sources of Electromagnetic Radiation

There are two principal types of radiation that can be detected by a remote sensor: (1) thermal and (2) reflected. As previously pointed out, a blackbody is the "best" thermal radiator,

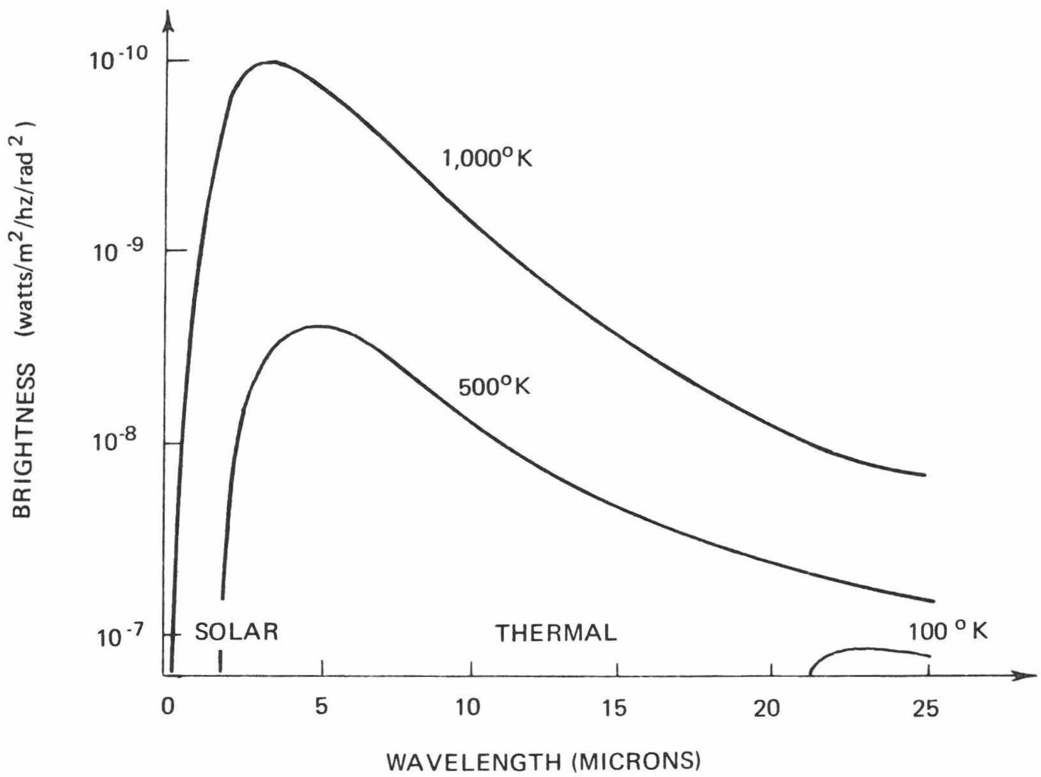


FIGURE 10 PLANCK'S LAW CURVES IN THE INFRARED

a graybody is a moderately good thermal radiator, but a reflector (emissivity zero) radiates no thermal energy. Conversely, a blackbody (emissivity unity) reflects no energy - it absorbs and then re-radiates all energy incident on it. Reflected radiation is strongly dependent on the angle of incidence and polarization.

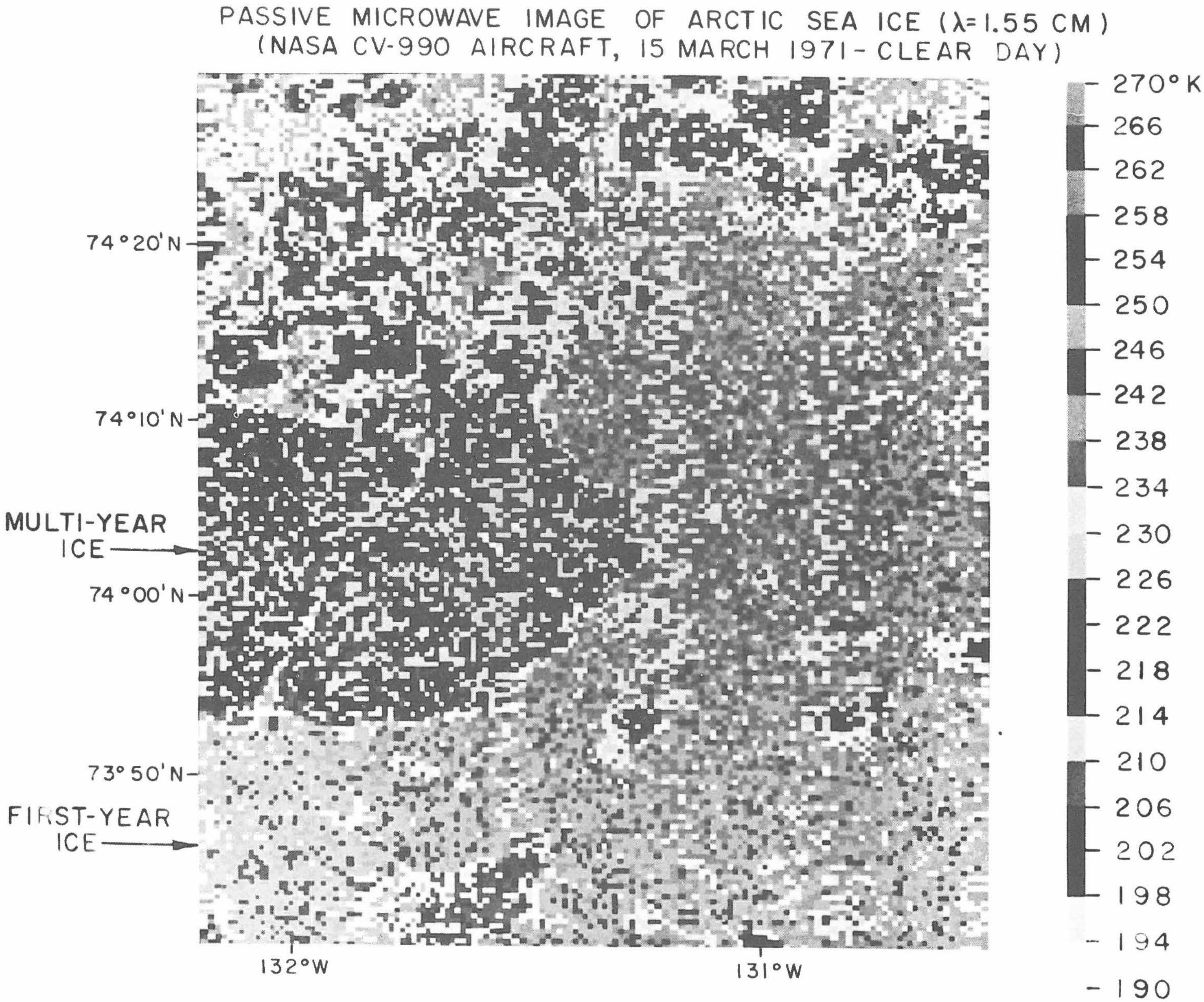
The apparent measured brightness temperature for earth surfaces depends on

1. The actual temperature of the surface
2. The emissivity of the surface
3. Atmospheric and sky noise effects

To illustrate this, Fig. 11 is a color coded image* of a region in the Arctic Sea as produced by a microwave radiometer operating at a wavelength of 1.55 cm, mounted on a Convair 990 aircraft. The image, taken on a clear day, is of Arctic Sea ice boundaries between first-year and multi-year ice packs. The colors represent temperature levels, as shown on the legend. The multi-year ice pack is shown as the dark blue mass on the left. Fig. 12 is an image of the same area, except that it was taken on a cloudy day. The effect of the intervening atmosphere is such as to change the apparent brightness temperature, but not enough to obliterate the ice pack boundary.

In the microwave spectrum, the dielectric constant (ε_r) of material plays an important part in determining the emissivity. For air, ε_r=1, for distilled water ε_r=81, and for ordinary soils ε_r may lie between 2 and 6; the water content of soil has considerable influence on the dielectric constant, as shown in the

*These images were kindly furnished by Dr. Per Gloersen of NASA Goddard Space Flight Center.


PASSIVE MICROWAVE IMAGE OF ARCTIC SEA ICE (λ=1.55 CM)
(NASA CV-990 AIRCRAFT, 15 MARCH 1971 - CLEAR DAY)
74°20'N
74°10'N
MULTI-YEAR ICE
74°00'N
73°50'N
FIRST-YEAR ICE
132°W
131°W
270°K
266
262
258
254
250
246
242
238
234
230
226
222
218
214
210
206
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194
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Figure 11

PASSIVE MICROWAVE IMAGE OF ARCTIC SEA ICE (λ=1.55 CM)
(NASA CV-990 AIRCRAFT, 16 MARCH 1971— CLOUDY DAY)

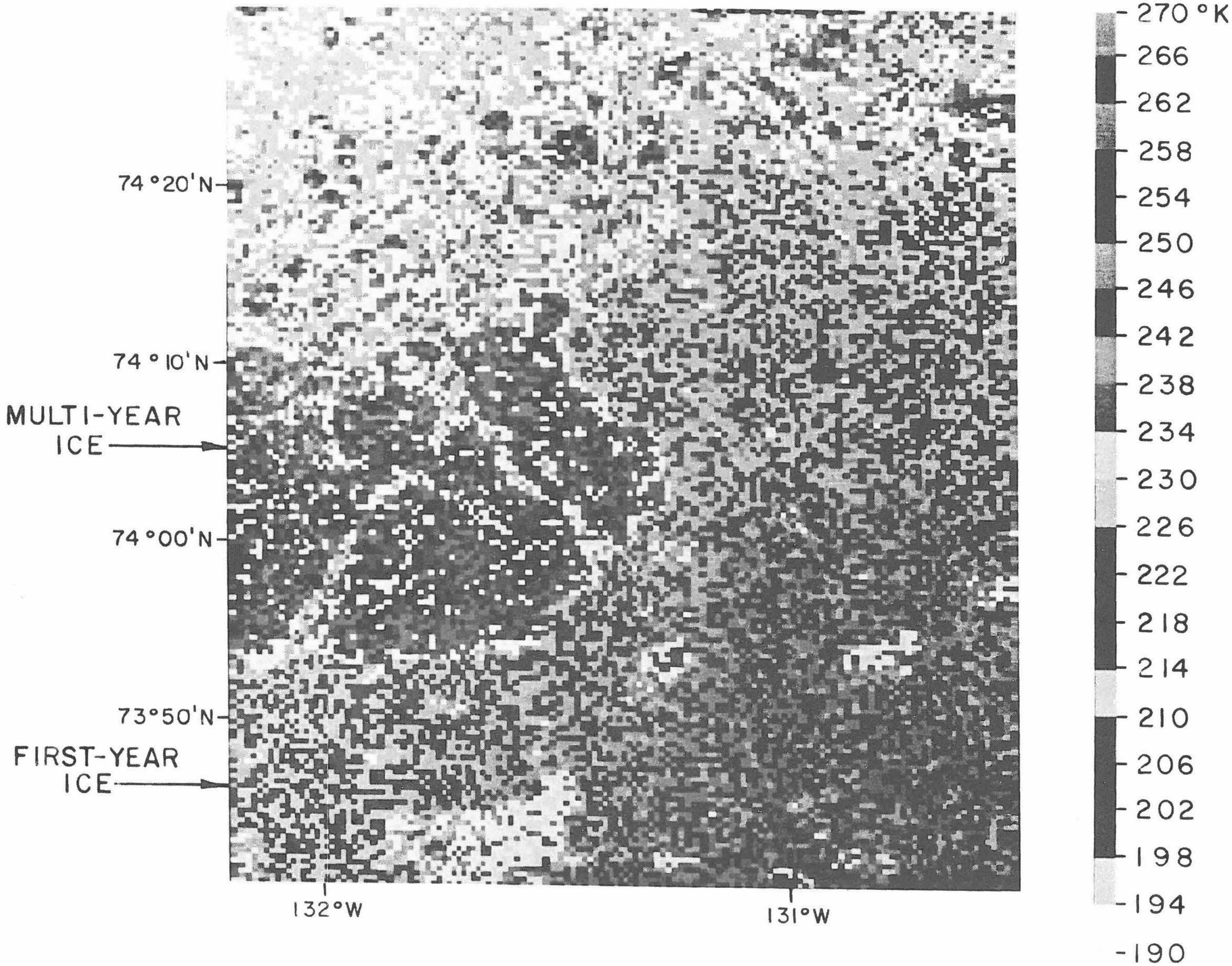
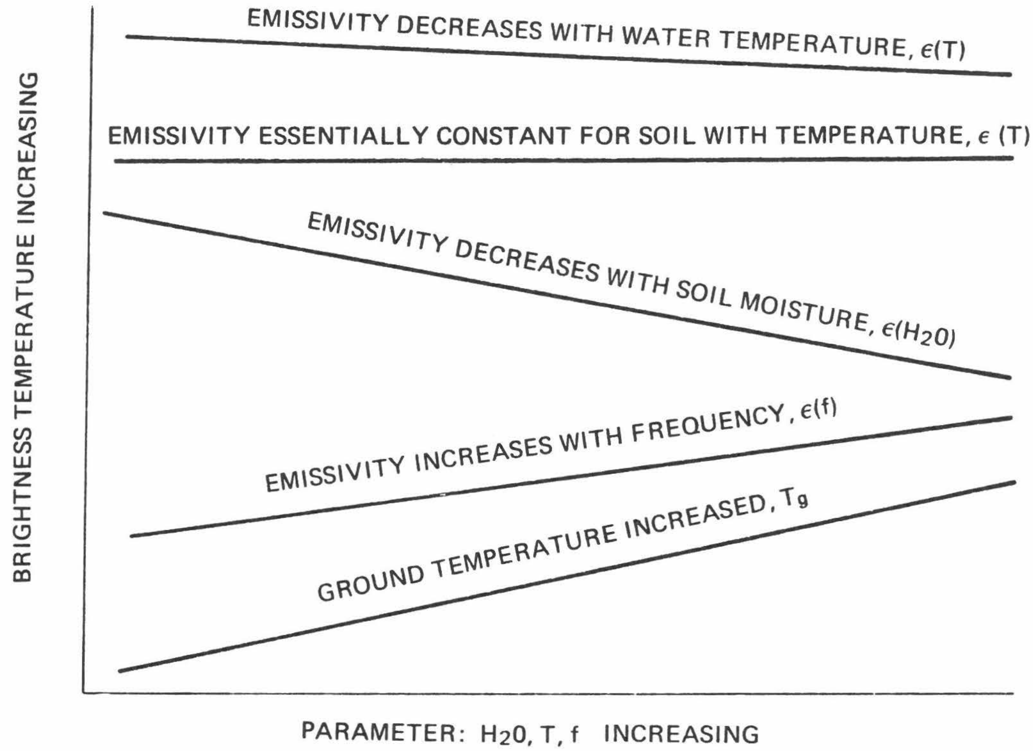


Figure 12

microwave signature graph of Fig. 13a. Fig. 13b shows the effect of angle of incidence on the brightness temperature of coal, asphalt, and limestone.

In the thermal IR spectrum, the crystal structure of minerals becomes important in determining emissivity. In the visible spectrum, the cell structure of a plant leaf will have much to do with its reflectance of sunlight. For example, the amount of water in the spongy mesophyll is important in determining how much incident solar IR energy will be reflected. It should be clear by now that the energy detected by a remote sensor depends strongly on the physical characteristics of the terrain being viewed and that accurate cause-effect models are needed in order to properly interpret the output of the remote sensor. These mathematical models are difficult to develop, particularly when an actual non-idealized earth surface is to be described. For example, in the interpretation of the apparent temperature of terrain as seen by a microwave radiometer, the following factors must be considered:

1. Instrument characteristics
   a. sensitivity
   b. resolution
   c. stability
   d. polarization
   e. frequency
2. Earth characteristics
   a. soil inhomogeneities
   b. vegetation cover
   c. surface roughness
   d. soil type
   e. soil moisture
   f. soil temperature and diurnal variations
3. Atmospheric effects
   a. relative humidity
   b. temperature-height profile
   c. cloud cover



VERTICAL POLARIZATION,
NEAR–VERTICAL INCIDENCE

FIGURE 13a. MICROWAVE RADIOMETER SIGNATURE PARAMETERS

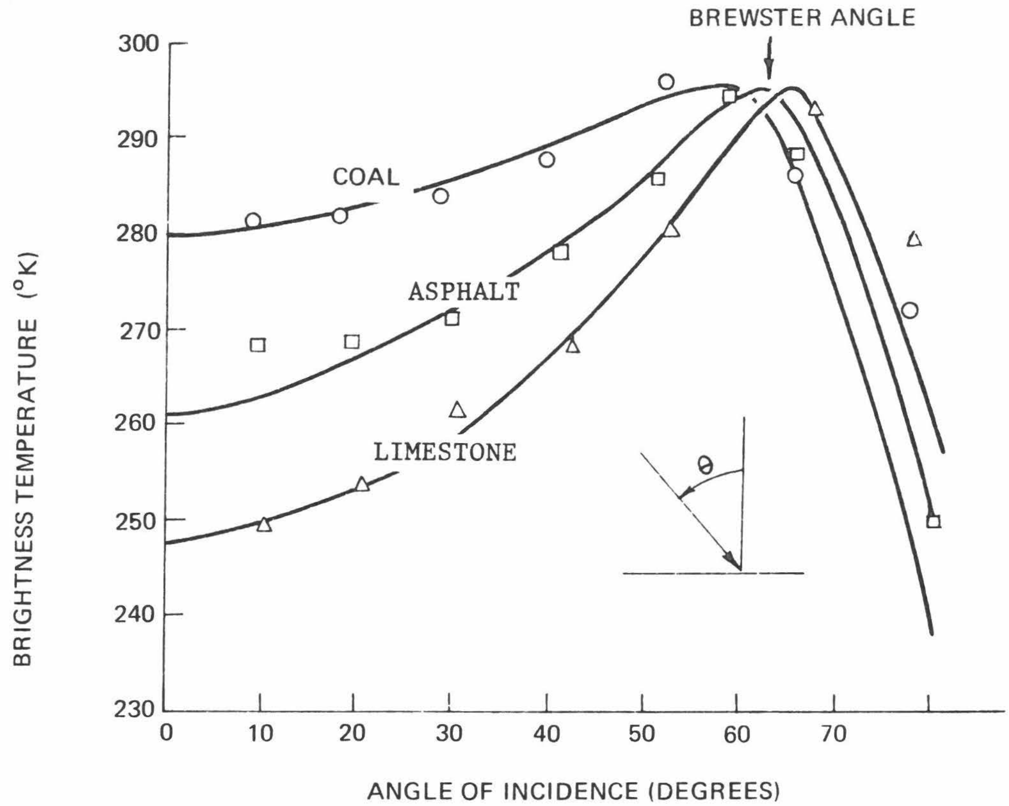


FIGURE 13b. COMPUTED AND MEASURED BRIGHTNESS TEMPERATURES (AFTER PEAKE, 1969)

IV. Interaction of Radiation with Earth's Surface and Atmosphere

Fig. 14 describes the processes which must be considered in constructing a radiative transfer model. We have previously noted that the earth's surface is an imperfect blackbody. The earth's atmosphere also absorbs, emits and reflects electromagnetic radiation. The understanding of these processes becomes very important in the modeling of radiative transfer in the microwave and IR portions of the spectrum.

The sun's apparent temperature is T_s, the atmosphere T_A, and the earth T_g. Furthermore, the atmosphere and the earth have their own emissivities ε_a and ε_g. Fig. 14 depicts the additive effect of each of these contributors.

In much of the microwave and most of the IR spectrum, the atmosphere attenuates signals propagating through it. The microwave attenuation is illustrated in Fig. 15 for frequencies from 10 GHz to 400 GHz. There are frequency bands in which the attenuation is high because of the absorption of energy by oxygen and water molecules, as shown.

The transmission characteristic of the earth's atmosphere throughout the entire spectrum is shown in Fig. 16. It can be seen that there are broad spectral "windows," i.e., frequency ranges in which the radiation can pass through virtually unattenuated. These windows can be used for remote sensing of the earth from a satellite above the atmosphere.

V. Detection of Electromagnetic Radiation

Detection of reflected radiation in the visible and solar IR is accomplished using light-sensitive film and/or scanning tech-

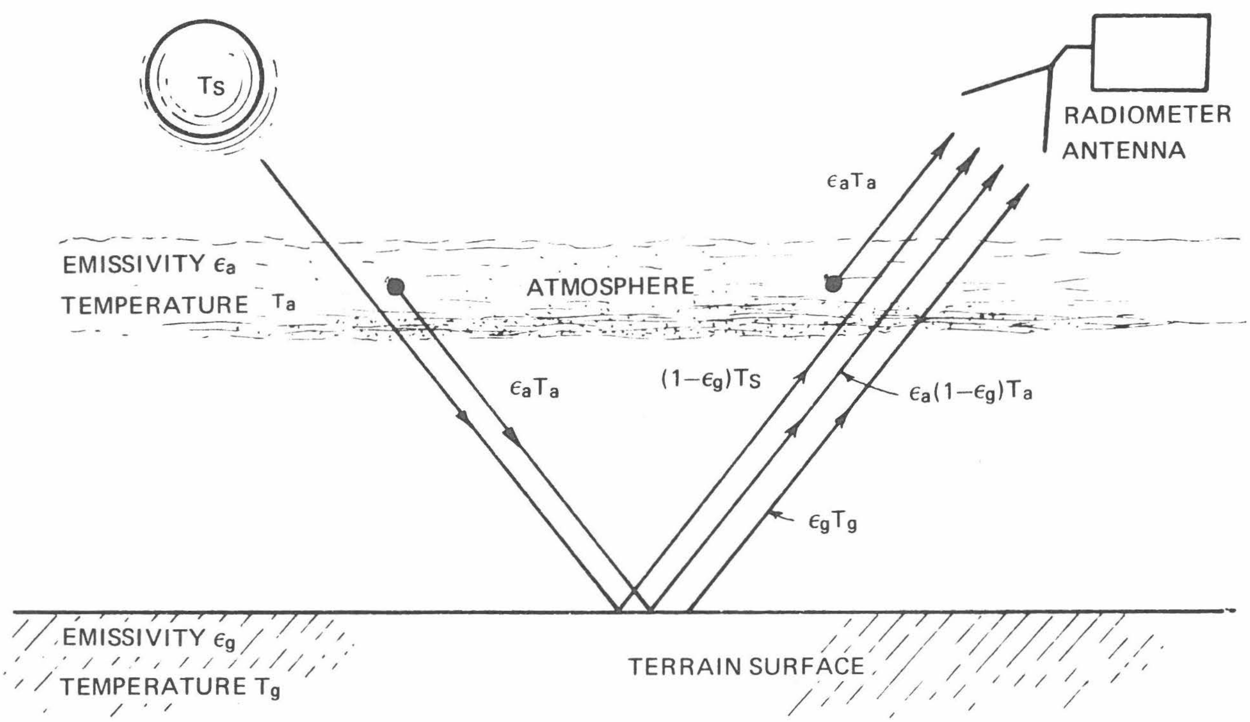


FIGURE 14 RADIOMETRIC BRIGHTNESS AT ANTENNA

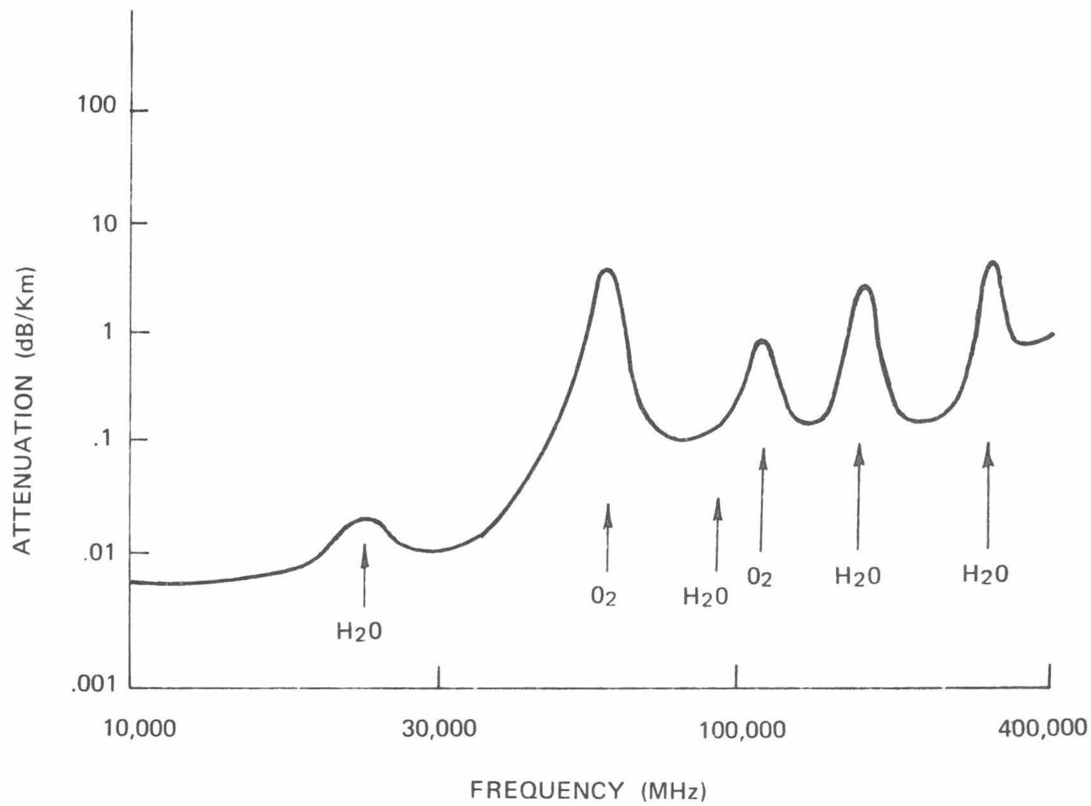


FIGURE 15 ATMOSPHERIC ATTENUATION FOR TYPICAL CONDITIONS

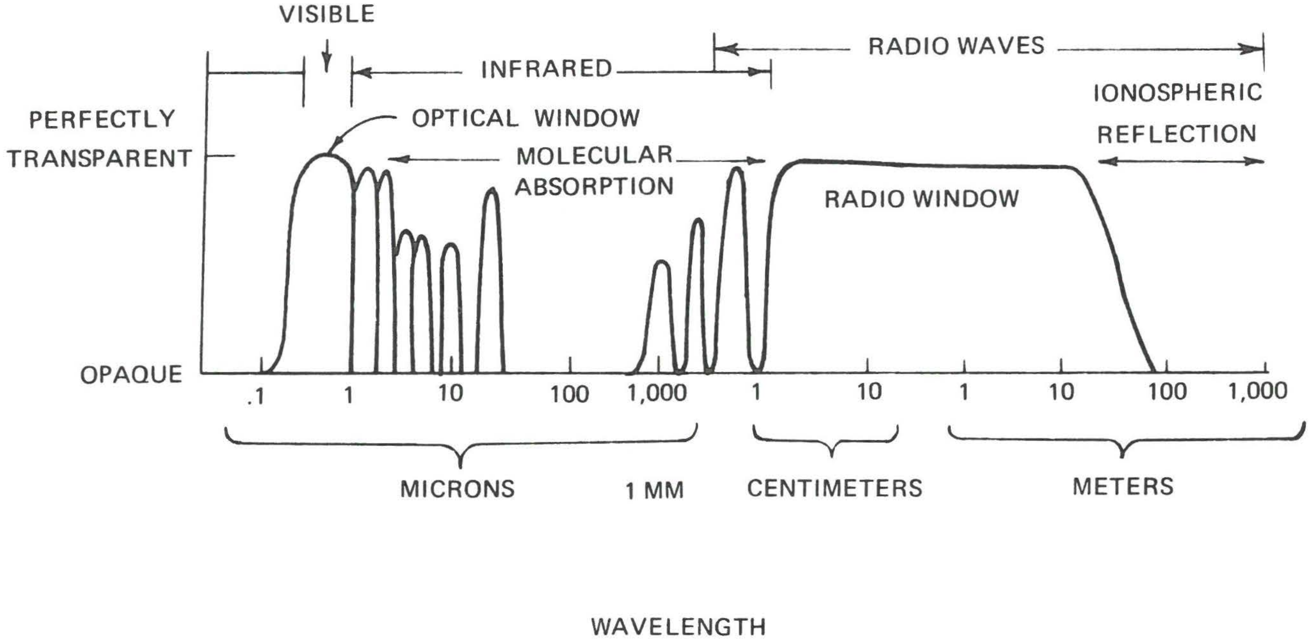


FIGURE 16 TRANSMISSION CHARACTERISTICS OF EARTH'S ATMOSPHERE
(after J. D. Kraus, "Radio Astronomy", McGraw-Hill, 1966)

niques. Photographic emulsions can be used, along with appropriate filters, to record the intensity distribution of earth scenes in various portions of the visible spectrum. These techniques are well-known and will not be discussed further here.

As the wavelength becomes longer (i.e., as we move into the thermal IR), photographic emulsions are no longer useful and thermal detectors, along with appropriate scanning techniques, must be used. Fig. 17a illustrates the principle of operation of an aircraft-mounted IR-scanner. As the aircraft advances, the detector field of view is swept back and forth, thus creating much the same type of raster image as produced by a TV picture tube. The scanning action is produced by a rotating or rocking mirror along with a focusing mirror, as shown in Fig. 17b. The detector may be any of a number of crystalline materials as shown in Fig. 18. Silicon is very sensitive, but has a narrow bandwidth; lead sulfide can be used to increase the bandwidth with a reduction in sensitivity. The sensitivity of the detector can be increased by cooling it in liquid nitrogen or liquid helium.

In the microwave region, an image can be produced in essentially the same way as for the thermal IR. An antenna is used as the collection and focusing element, and a sensitive receiver is used to amplify and electronically process the signal so that detection is possible. Such a device which collects the naturally emitted radio signals of the earth is called a microwave radiometer. A radiometer consists basically of an antenna, a receiver, and a recording device. The long wavelengths of radiation thus detected by the radiometer may emanate from as deep as 30 cm below the

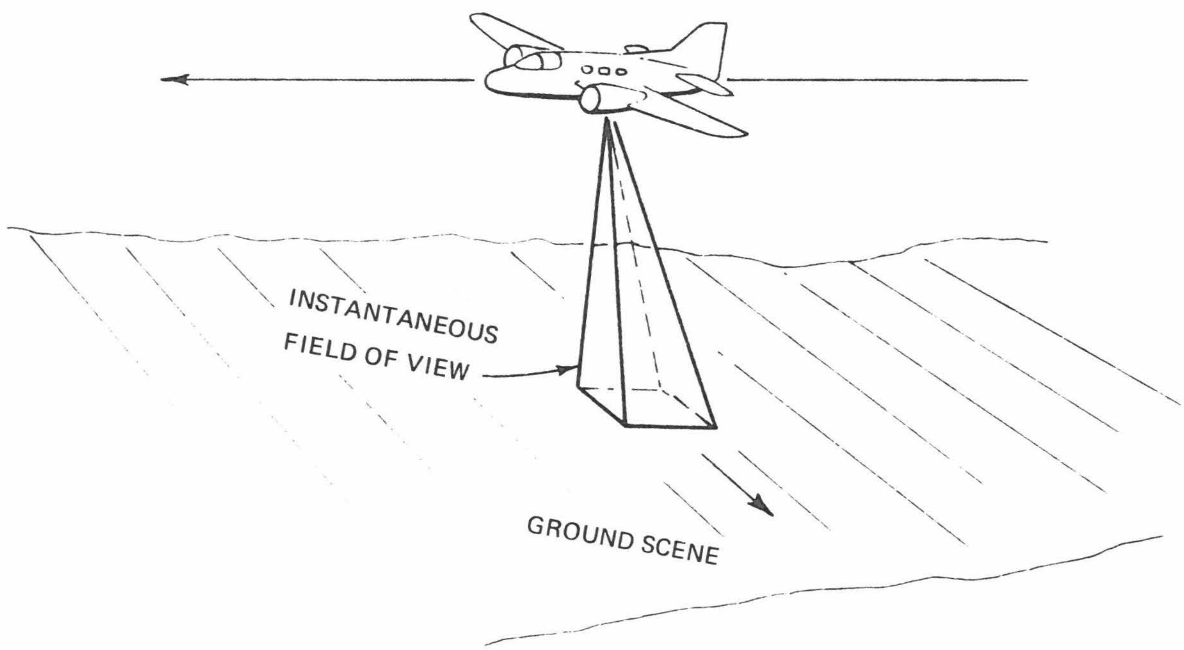


FIGURE 17a IR SCANNER AS A REMOTE SENSOR

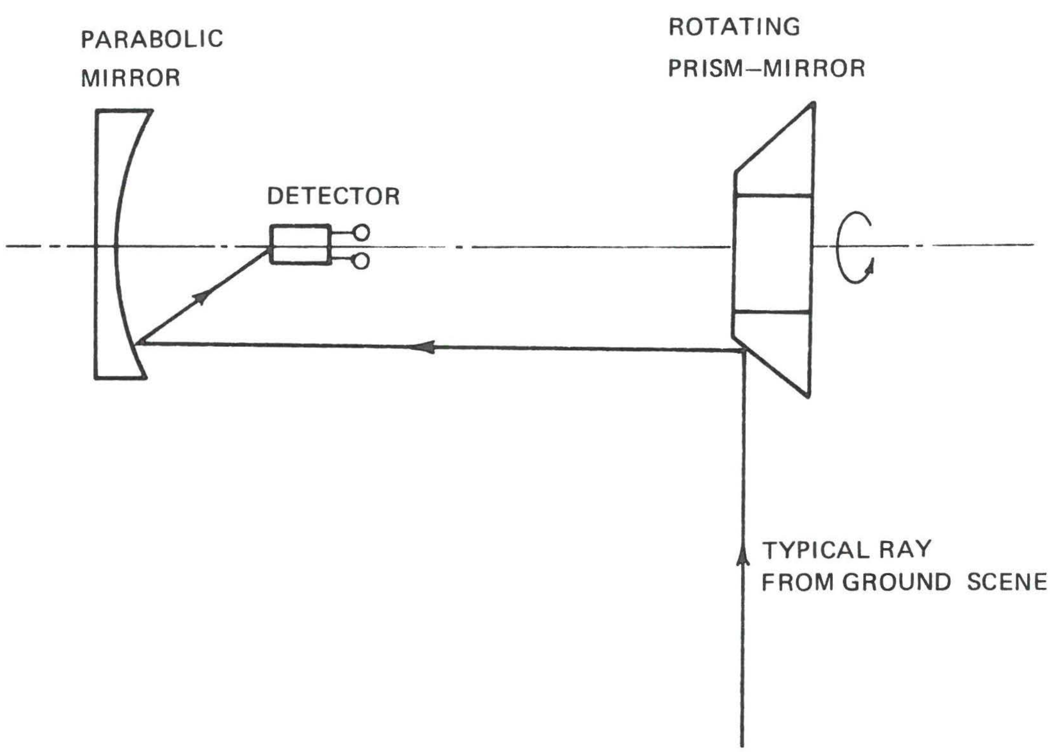


FIGURE 17b. IR SCANNER

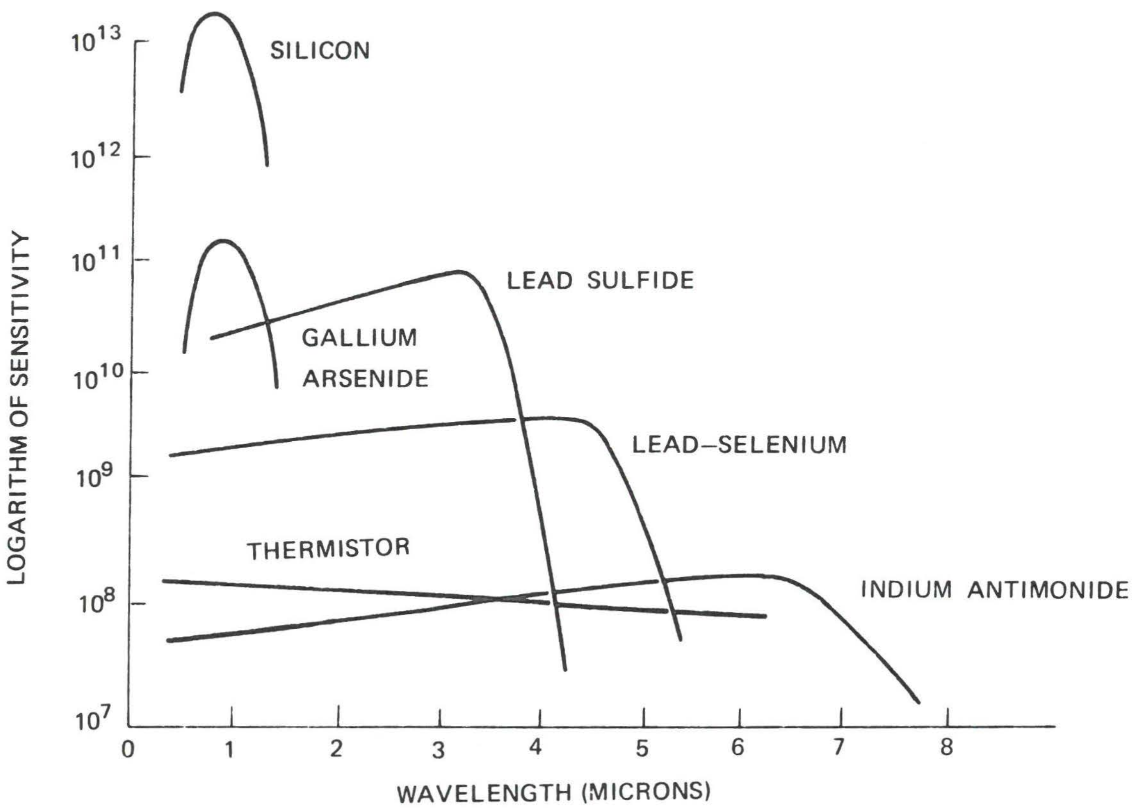


FIGURE 18 SENSITIVITY OF COMMONLY USED PHOTODETECTORS USED AT ROOM TEMPERATURE

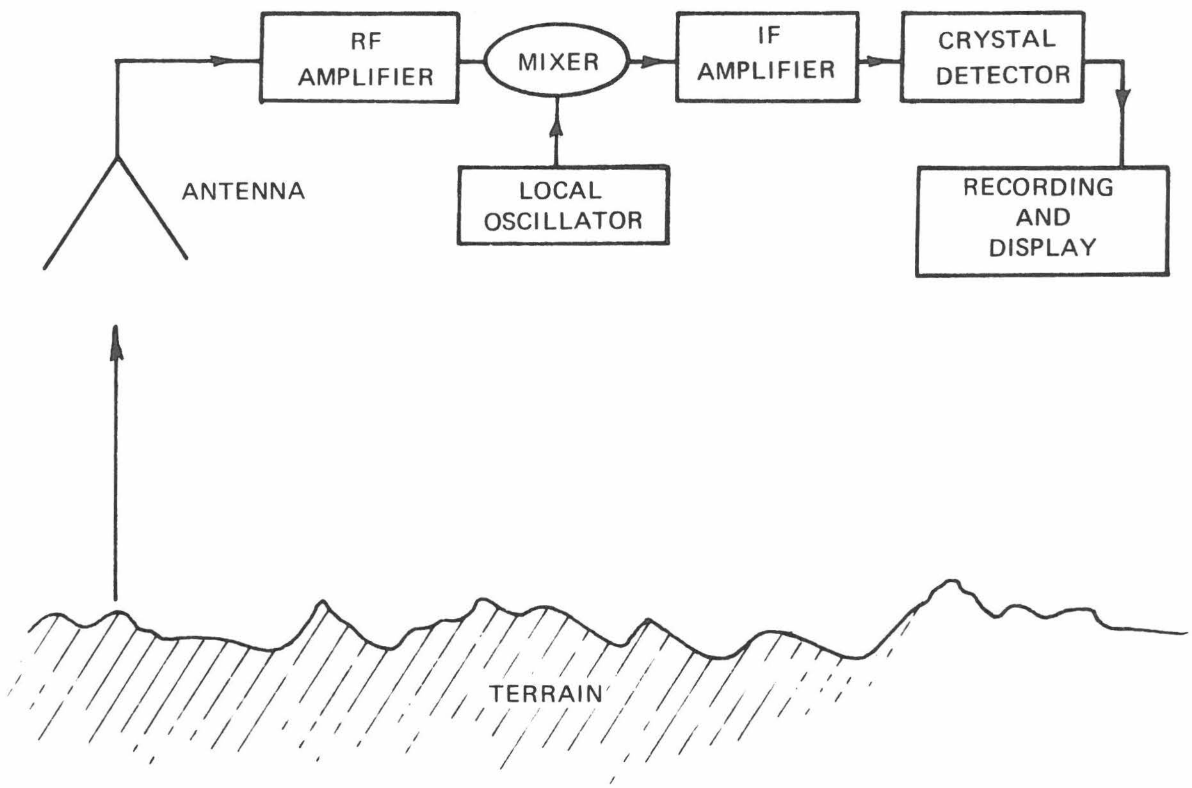


FIGURE 19 DIAGRAM OF SIMPLE MICROWAVE RADIOMETER

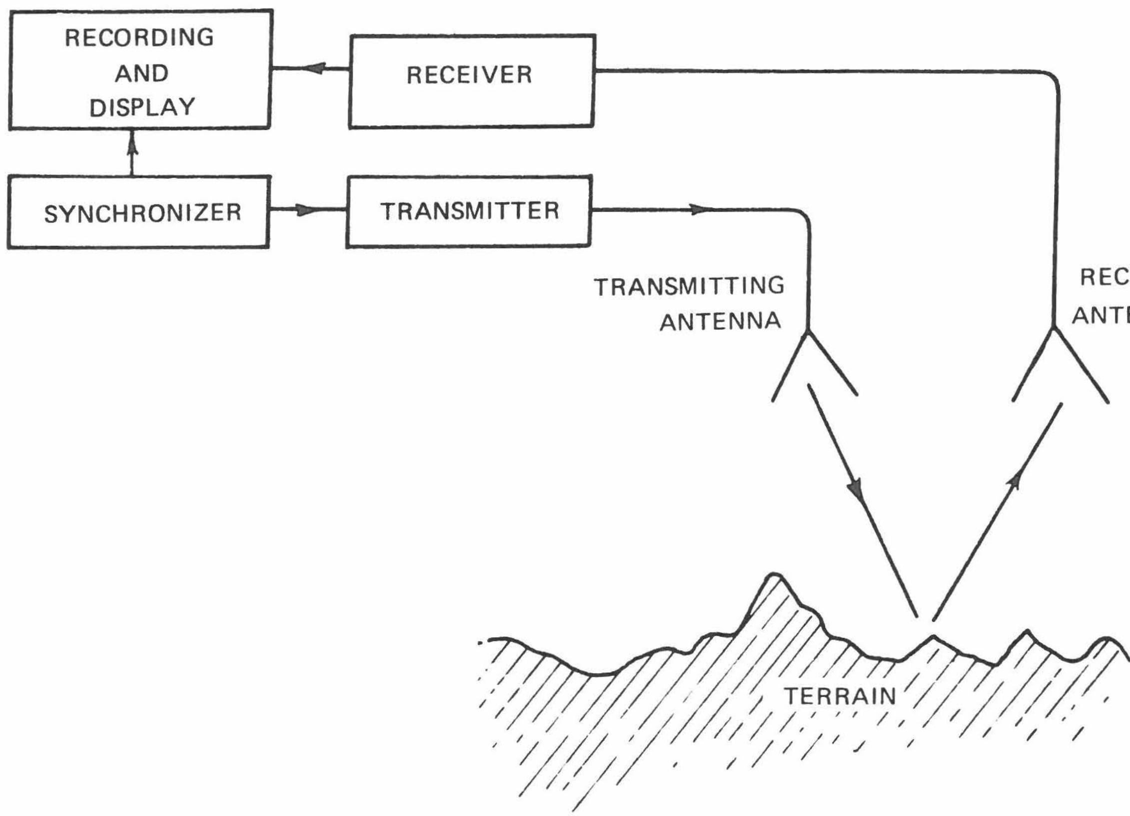


FIGURE 20 DIAGRAM OF SIMPLE MICROWAVE RADAR

earth's surface (root depths) when the frequency is around 1 GHz or lower. Since IR and visible remote sensors have no "earth-penetration" ability, it is evident that only in the microwave region can we extract information about subsurface conditions. This potential, however, comes at the cost of poor resolution. Resolution of 1 mile from a satellite-borne passive microwave radiometer would be considered exceptionally good.

A microwave radar can also be used for remote sensing. A transmitting signal is "bounced" off the earth's surface and then picked up by a receiver. By noting the angle of incidence and polarization of the transmitted signals, mathematical models can be used to analyze the return signals in order to characterize the terrain features. By scanning these antennas in raster fashion, an image may be produced. Radars have the advantage of all weather capability and independence from diurnal terrain temperature effects.

PHOTOGRAPHIC ASPECTS OF PHOTOGRAMMETRY

John C. Kizis
Aerial Reconnaissance & Mapping Markets
Eastman Kodak Company

Part I — History of aerial photography from Nadar over Paris in 1858 to the present - Slide presentation of 25 minutes.

Part II — "Introducing Photogrammetry" - a 25 minute 16mm color movie produced by Wild Heerbrugg. This film demonstrates in an easy way the principles of Photogrammetry and shows some applications to demonstrate the versatility of this modern survey technique. It includes the fixing of the geodetic foundation, air survey lenses, photographic flight with survey aircraft, rectification with the Wild E4 Rectifier, explaining the construction of the Wild A-8 using animated photography, short demonstration of relative orientation, determination of scale and leveling of the model in the plotting instrument and the plotting of the map.

Part III — Details of Photographic Technique - Starting with the aircraft and cameras, the photographic process is explained from raw aerial film thru the process to a negative, check prints, mosaic's, flight line, plan and profile, using both hand and mechanized processing. The Color Neg system and infrared color photography is discussed. Slide presentation of 30 minutes.

SOME GENERAL PRINCIPLES OF AERIAL PHOTOGRAPHY

Bernard E. Hoyer
Land Use Coordinator
Iowa Remote Sensing Laboratory

Aerial photography is a specialized form of photography. Generally, the same principles hold true for it as for conventional photography familiar to all. However, specialized equipment, the aerial perspective, and the critical usage of the final product differentiate it from conventional photography. This paper will attempt to explain some principles applicable to all photographic processes with special attention to situations and problems unique to aerial photography. It is hoped that this information may aid in appreciating both the uses and the limitations of aerial photography and help in any mission designs which may be undertaken by your respective agencies.

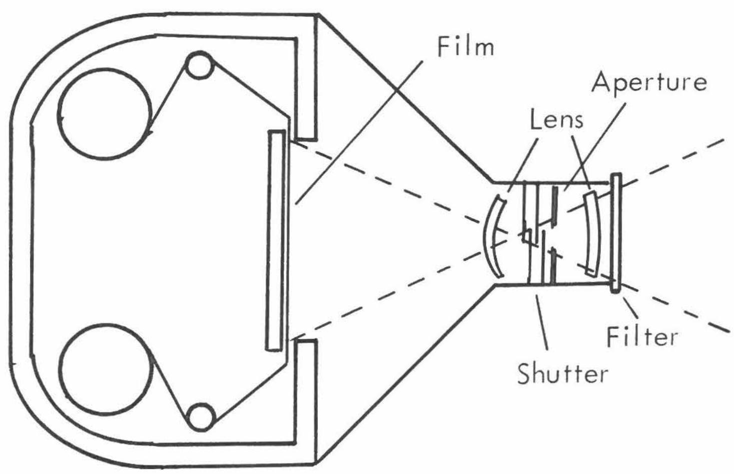
Energy Path Concept

Solar energy reflected from earth materials passes through the atmosphere and camera lens system to expose a film within a camera. Changes in the light, material, atmosphere, lens, or film will affect the resultant image. Thus, since each of these factors may affect the image produced, each may affect the suitability for some specific purpose.

Films

Black and white films are formed essentially of two layers. An acetate or polyester material forms a base for the film. On the base is the emulsion layer. The emulsion is a gelatinous matrix with billions of photo sensitive crystals throughout. Generally, silver bromide is the most common light-sensitive crystal used. A binding agent is added to adhere the emulsion to the base.

Figure 1



AERIAL CAMERA

Table 1

TRANSMITTANCE	DENSITY	APPEARANCE
100%	0	Clear
10%	1	Gray
1%	2	Dark Gray
1%	3	Black

Atmospheric conditions also affect the total irradiance. Cumulus clouds cause shadow areas in which contrast and illumination are reduced. High, thin cirrus clouds diffuse the light slightly which reduces the contrast between shadow and non-shadow areas, therefore, detail in shadow areas is increased.

Particulate matter in the atmosphere tends to scatter light and may reduce the illumination on the ground surface. In addition, since these particles may be relatively quite large, scattering may be very pronounced which results in a color shift toward the red end of the spectrum.

Exposure

Exposure is the total amount of irradiance striking the film surface. Thus, exposure is equal to the irradiance striking the film over a period of time. Exposure is measured in terms of meter-candle seconds. In a camera,exposure is controlled by the aperture and the shutter. Doubling the aperture area is equal to doubling the time in which the film is exposed.

Density is the darkening on the film caused by exposing the film to the reflected light. Density is defined as the common logarithm of the reciprocal of the transmittance. Thus, if one-tenth of the incident light passes through the film, after processing the density would be 1. Likewise if one-hundredth of the light passes through, the density would be 2.

Each film has a characteristic reaction to the varying exposures. This reaction can be represented by indicating density plotted against the logarithm of exposure. The slope of the straight portion of the curve is called the film's gamma. The higher the gamma, or the steeper the slope, the greater the density

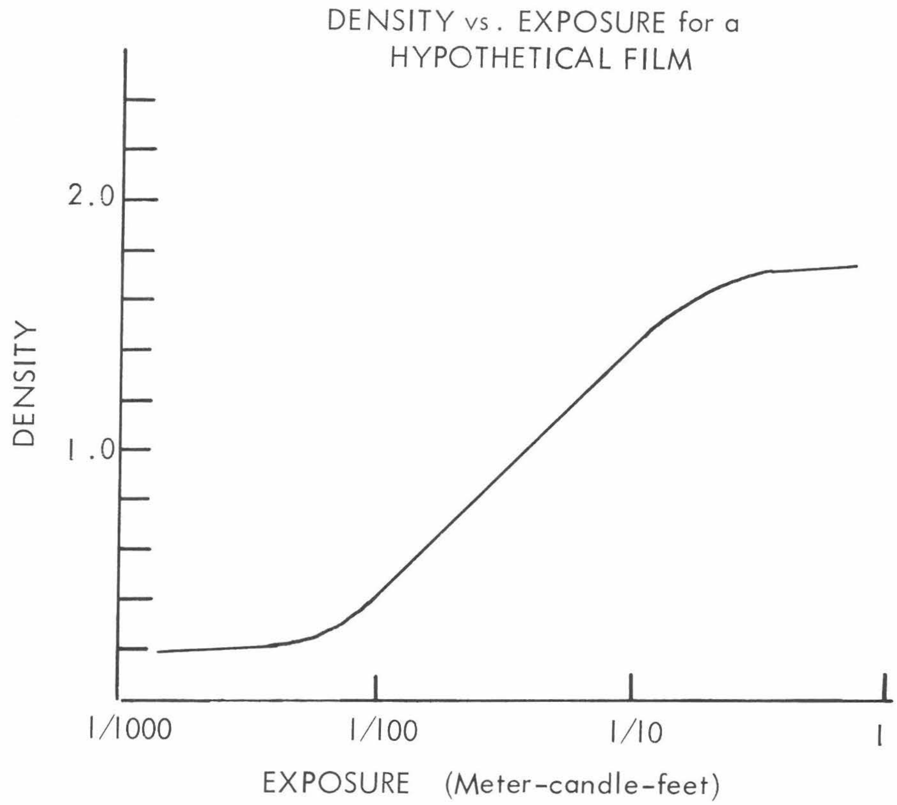


Figure 2: log E curve

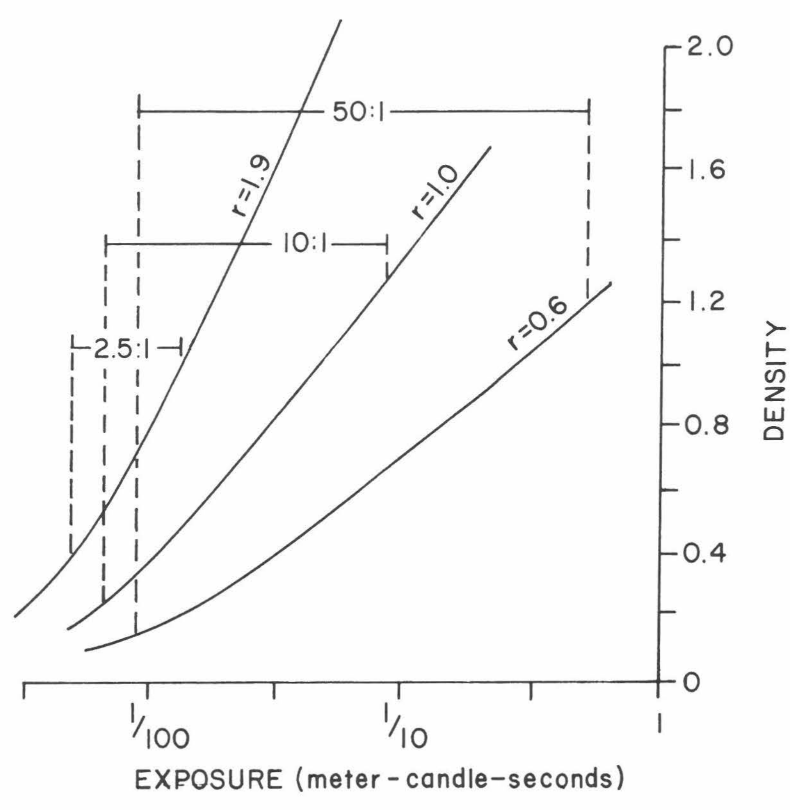


Figure 3: Brightness ratio and films

Latent Image

The basic phenomenon underlying all photography is the ability of silver halide crystals to react to light. These crystals act as light quantum detectors. Electrons in the crystals are excited by exposure to light. They move to crystal locations where energy differences exist. Since they bring a negative charge, Ag^+ ions migrate to the charged site. Crystals having undergone these changes seem to be attacked preferentially by chemical reducing agents and the whole crystal is reduced to silver. Since unexposed crystals are not chemically reduced, the process is proportional to the amount of light received. Thus, those areas on the film exposed to more light become dark and those that received less exposure to light will remain light colored.

Total Irradiance

The total illumination or irradiance on vegetation and earth materials is highly variable and to a limited extent is constantly changing. The total irradiance is determined by the sun angle and the atmospheric condition prevailing.

The sun angle varies with the latitude, day of year, and time of day. All of these factors affect the total illumination in the same manner. As the electromagnetic radiation from the sun strikes the earth's surface at an oblique angle, during low sun seasons (winter), or early and late in the day, the total irradiance on subjects is least. Additionally, low sun angles create long shadows obscuring much detail and further decreases the subject illumination. Therefore, aerial photographs generally obtained between the hours of 10:00 a.m. and 2:00 p.m. get maximum illumination with minimum shadow areas.

REFLECTANCE RATIO ≈ 10:1

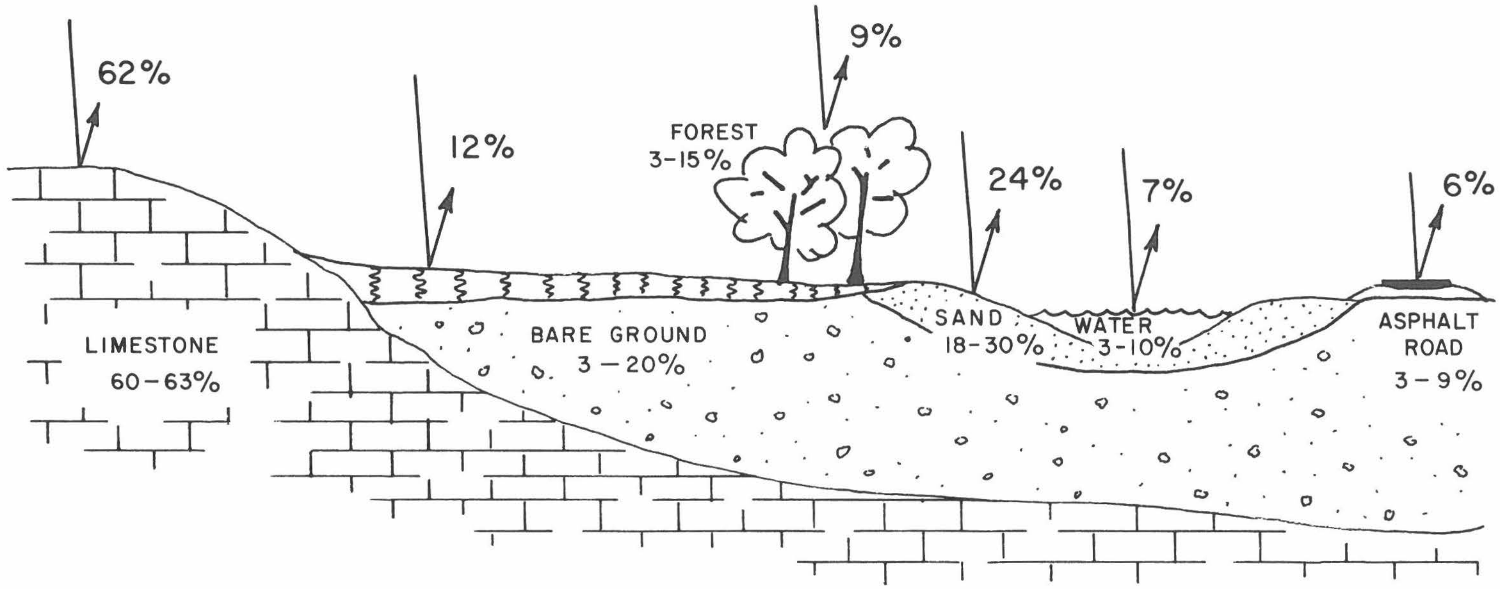


Figure 4: REFLECTANCE OF MATERIALS IN VISIBLE AND PHOTOGRAPHIC INFRARED PORTION OF SPECTRUM

change for the least change in exposure. Thus, two adjacent objects reflecting slightly different amounts of radiation may be discriminated by film with a low gamma. Film gammas greater than one enhance scene contrast, whereas film gammas of less than one reduce scene contrast.

Typically, aerial films have gammas of greater than one and often they are closer to a gamma of two. It should be noted that the film development procedures and chemicals do affect the film's gammas and the film processing can be used to change the scene contrast.

Films with high contrast are needed because earth materials are relatively low contrast subjects. Photography on the ground may result in a ratio of the brightest object and the darkest object of 50:1. This ratio will be reduced by photographing the same objects from the air because of atmospheric haze. Blue light especially is scattered randomly. Reflections off of the haze are non-imaging light and uniformly illuminates every part of the film. Thus the brightness ratio may be reduced to approximately 5:1 or 2:1.

Spectral Sensitivity

The response of film to various wavelengths is the film's spectral sensitivity. The most common types of black and white films are panchromatic film sensitive to blue, green, and red, and infrared film sensitive to blue, green, red, and the near photographic infrared. Because of the scattering of blue wavelengths it is almost a universal practice to filter out blue light in aerial photography. However, filters may be used also to exclude additional portions of the spectrum allowing, for example, only red and infrared wavelengths or just infrared radiation to be recorded.

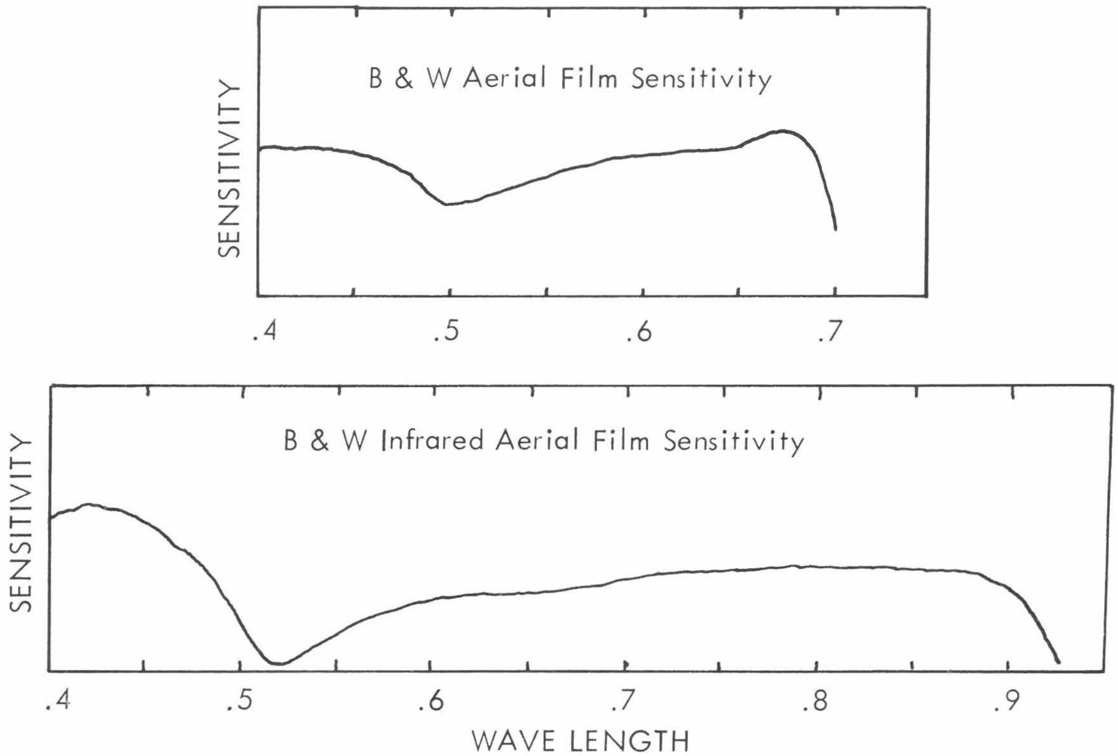
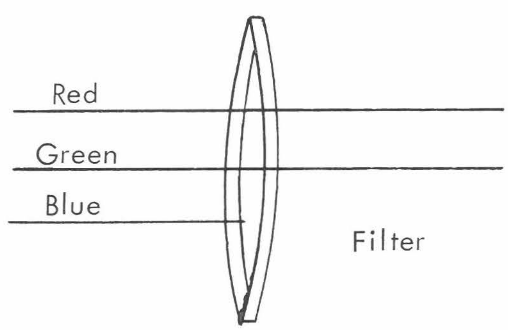


Figure 5: Spectral sensitivities of panchromatic and infrared films



MINUS BLUE FILTER REDUCES EFFECT OF HAZE

Figure 6

Generally, film sensitivities are not equal at all wavelengths. One film may image red light more densely than an equal amount of green light. Thus, while the green and red light may be equal, there will be more density produced on the negative from the red light. Typically, films are most sensitive to blue light--another reason for filtering out the scattered blue wave lengths. Film should be selected and filtered so that the resultant sensitivities will be commensurate with the purpose for which the imagery is being produced.

Resolution

The resolving power of a camera system is given in terms of line pairs per millimeter. It is a subjective measure (visual) determined in laboratory experimentations under controlled conditions . The resolution is a function of the lens, film, and subject contrast. In turn, the resolution of the lens depends on the wavelengths of light passing through it, the aperture at which the lens is set, and the angle from a line normal to the lens center. The size, number, and distribution of silver electrolyte grains on different film emulsions affect the resolving power. In general, films that are more sensitive to light have large silver halide grains and will not have as great a resolving power as a film with a finer grained emulsion. In addition, the film resolution can vary with different film processing conditions. Finally, test patterns may be made at line to space luminescence ratios of from 1000:1 to 1.6:1. The lower contrast results are important to aerial photography as low contrast reduces the resolving power of the system.

Actually, in aerial photography the values obtained in laboratories are of less consequence than those obtained under actual flying conditions. Thus, ground

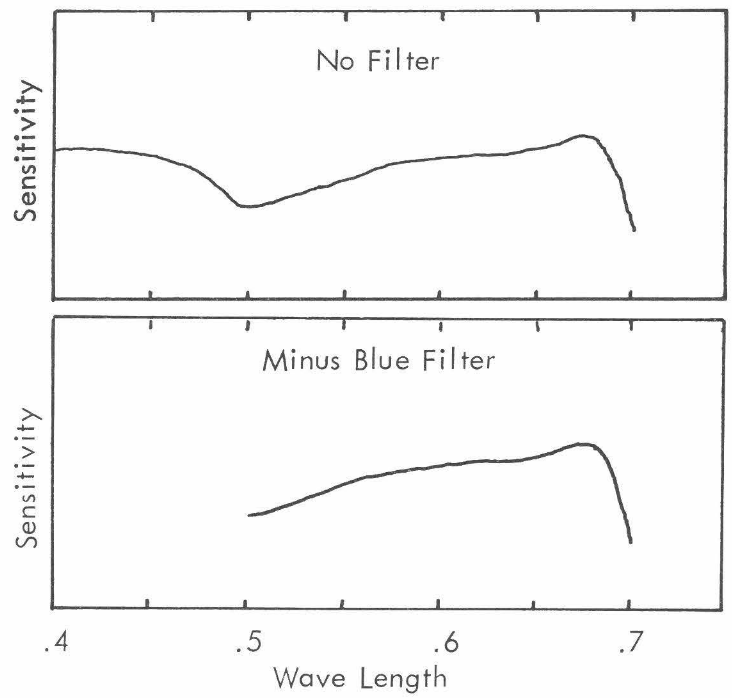


Figure 7: Effect of filter on film sensitivity and image.

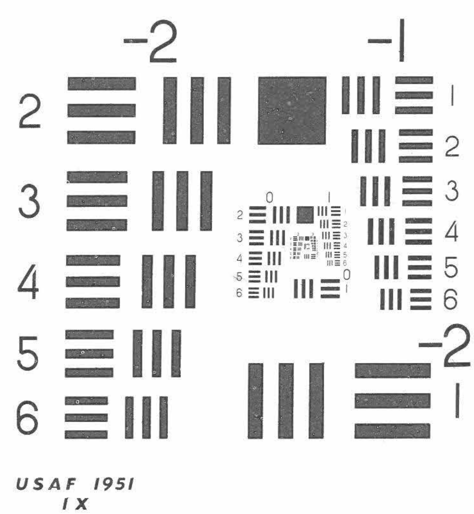


Figure 8: Standardized resolution test.

resolution is dependant on the flying height above the ground, the focal length of the lens, and the resolving power of the system.

$$\text{ground resolution} = \frac{\text{Height above ground level}}{\text{(focal length) (resolving power)}}$$

Holding resolving power constant, increased flying height will reduce ground resolution whereas increased focal length will permit better ground resolution.

PHOTOGRAPHIC DETECTION OF ELECTROMAGNETIC RADIATION--COLOR, FALSE COLOR, INFRARED, AND MULTIBAND PHOTOGRAPHY

James V. Taranik
Chief of Remote Sensing
Iowa Remote Sensing Laboratory

We as human beings, through evolution in the presence of a 5900 °K source of electromagnetic energy, have developed multispectral sensors (eyes) which are capable of detecting different wavelengths of "light" and our physiology allows us to assign colors to these wavelengths. There are animals which do not perceive colors and we are familiar with persons who are "color blind" and thus the perception of color is individual to the observer. If sunlight is passed through a prism the normal observer will generally observe a continuous spectrum of colors which all merge together. These colors (hues) are red, orange, yellow, green, blue, and violet. Apparently our eyes can detect three "primary psychological" hues which cannot be formed by combinations of spectral light; red, green, and blue. For high levels of intensity our eye sensitivity peaks in green and shifts to blue for low intensities.

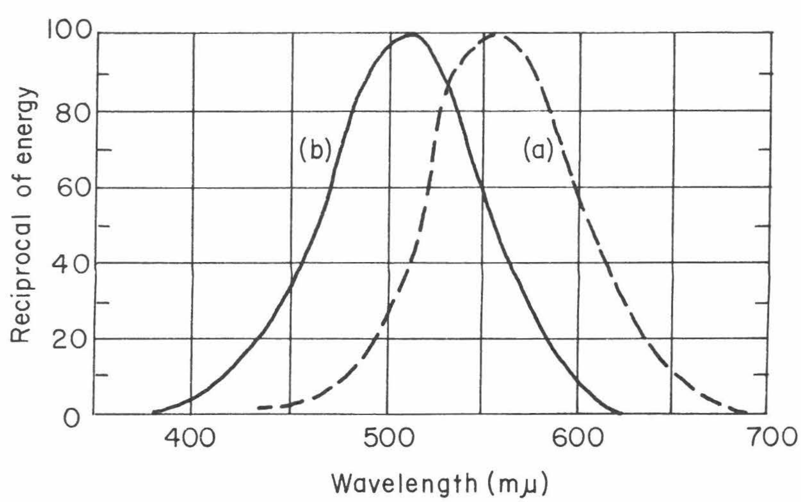
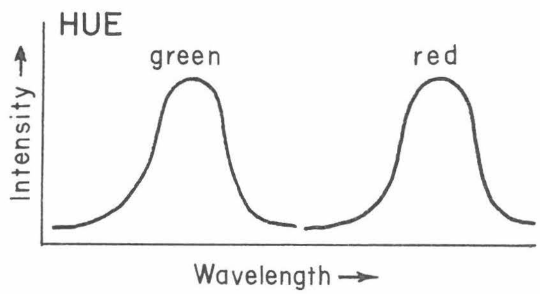
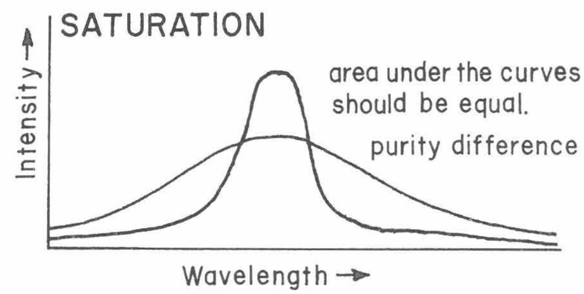
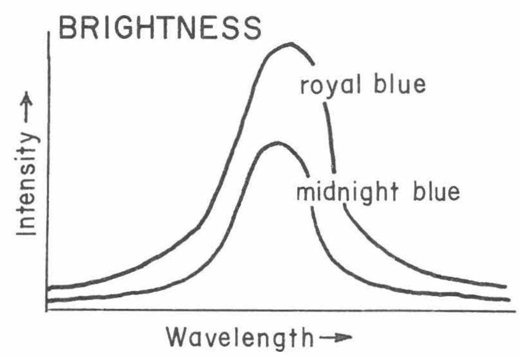


Figure 1. (a) Photopic and (b) scotopic luminosity curves (Crittenden, 1924, p. 614, and Hecht and Williams 1923, p 16)

We must describe colors in terms of our physiological reaction to wavelength distributions of radiant energy. The color attributes or sensations that we perceive are brightness (the amount of radiant energy), saturation (the degree of color purity), and hue (the spectral distribution of radiant energy.







It is important to recognize that the eye can see colors which do not exist in the spectrum:

Reddish-blue = magenta

By combining various amounts of the three primary colors any hue possible can be produced:

Red + green = yellow

Recall here that all this discussion deals with transmitted light, light transmitted through colored disks, and not colors created by mixing poster paint.

Given a color, there are an infinite number of combinations which may produce it:

Yellow =
1. A pure spectral color
2. Equal parts of red and green
3. 1 part green and 2 parts red

We can produce a neutral hue (white) by combining equal parts of the three primary colors; red, green, and blue.

If, as in the case of viewing a typical color photograph, white light is present to begin with, then it is possible to produce a desired color by subtracting the appropriate amounts of blue, green, and red from the white light.

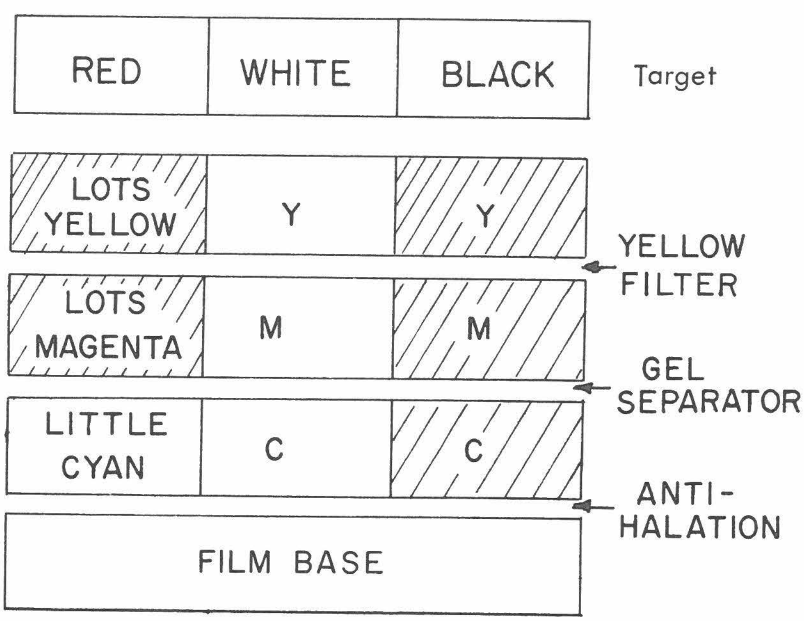
A color photograph does this by the action of three primary subtractive dyes:

1. Yellow = absorbs blue
2. Magenta = absorbs green
3. Cyan = absorbs red

The appropriate quantity of each dye is produced in each area of the photograph as a result of exposure and processing. Kodak color reversal films are films that give a positive image having the same color as the original scene. They are designed so that, after processing, the dyes present are present in amounts inversely proportional to the log of the exposure reaching a given area and layer of film.

Color Reversal Films:

Dye amount $\frac{1}{\text{Log}_{10} E}$

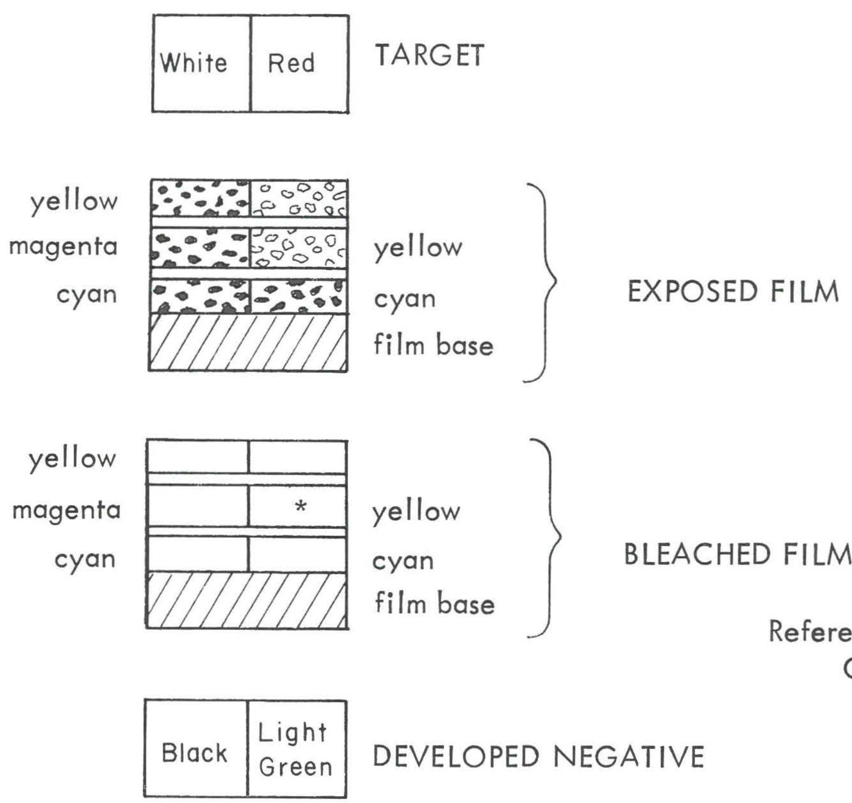


Dyes produced in a color reversal film after development have bleached silver halide grains and color couplers have been activated.

Color negative films:

In color negative films, dye is produced in quantities approximately directly proportional to the logarithm of the exposure and colors produced upon development are complementary to the original scene. When color negative film is exposed in the camera, each color in the scene is recorded on the emulsion layer which is sensitive to the wavelength. Cyan dye layer is sensitive to red, magenta dye layer to green, and yellow dye layer to blue. Other colors record proportionately on two or more layers. The dyes are formed in the developer step of the process by the action of couplers reacting with the oxidation products from the developer and silver halide. The dye formed is in proportion to the amount of silver developed.

A masking device is incorporated in two of the layers to improve the printing quality of the negative by overcoming the effects of incorrect dye absorptions when the negatives are printed. This mask gives the negative color film reddish cast.



Reference: Kodak E-66, Printing Color Negatives $2.00

Multiple Layer Films

Multiple layer films came into existance in the early 1930's and with today's technology they are superior to panchromatic films for mapping soils, rocks, vegetation, and cultural features. In a way, color films record the multispectral characteristics of the landscape as each layer in the film records a portion of the electromagnetic spectrum from blue through red. Unfortunately, there are several important reasons why color films do not suitably reproduce actual spectral characteristics:

> " (1) The absorption characteristics of the dyes used in color films do not sharply define specific wavelength bands.
>
> (2) There is considerable overlap of the three wavelength bands. Refer to figure 2.
>
> (3) The wavelength bands are fixed by the manufacturer.
>
> (4) As Sorem (1967) points out, the spectral response of color film is not flat, but shows DIB where the absorption cutoffs of the dyes cross. Sorem emphasizes that the color reproduction, whether it is in the camera film or in a print made from a camera negative, need not and almost never does have the same spectral characteristics as the original."

From Coldwell, 1970, p.7-10.

Note: The spectral transmittance of the reproduction from color photography does not necessarily reproduce the spectral transmittance of the original scene. This is mainly due to the color balancing of the dyes in the multi-layered film.

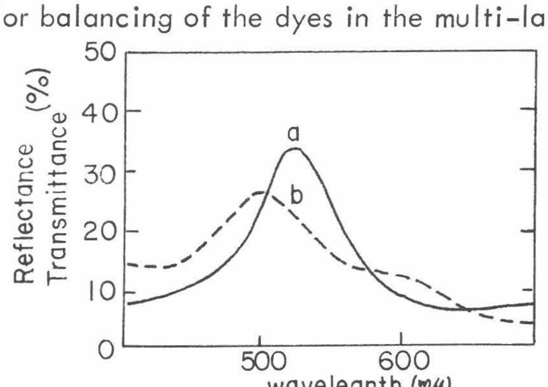
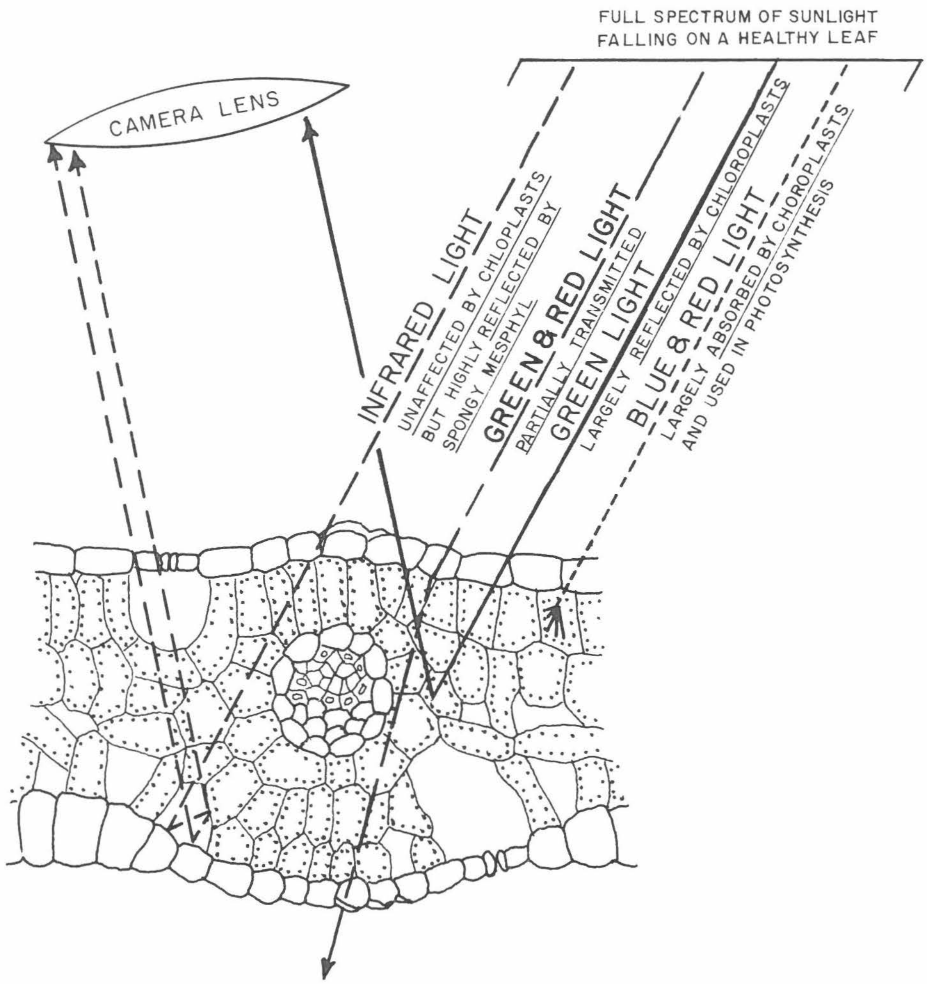


Figure 2. Spectral reflectance curve (a) of a dark green sample and spectral transmittance curve (b) of a typical photographic reproduction in a reversal color film. Sorem, Allan L., 1967, Principles of Aerial Color Photography: Photogrammetric Engineering, v.33, no. 9, p. 1008-1018.

Color Infrared Films

False Color Infrared Reversal Film was developed in the late 1930's and was made available to the military as Aero Kodacolor Reversal Film, Camouflage Detection. Kodak Extrachrome Infrared Aero Film, Type 8443 was used until a few years ago when it was replaced by Kodak Aerochrome Infrared, Type 2443. False color infrared film is a three layer film, with two of the three layers sensitive to visible wavelengths or light and one layer sensitive to invisible reflected electromagnetic radiation. The film derives its designation, "False Color", from the fact that the normally green and red visible band passes are assigned blue and green dye forming layers respectively, while the invisible reflected infrared is assigned a red dye forming layer. The film is variously referred to as Solar Infrared Color Film, Color Infrared Film, Camouflage Detection Film, False Color Infrared Film, etc. The user should note that the overlap between bands is greater than those of color film and that the film must be used with a Wratten 12 Filter. False Color Infrared Film, as well as black and white IR film, records only reflected energy originating from the sun, and it is not capable of recording any information about the temperature of earth materials. In a darkened room an object at 400°C, six feet from a camera loaded with infrared film, will barely make an image on the film plane after many hours of continuous exposure(K. Lee, personal communication).

Infrared films have the capability of providing much additional information about vegetation because trees, shrubs, etc., reflect more radiation in the infrared portions of the spectrum than they do in the visible. The amount of radiation reflected from one group of plants in the infrared is greatly influenced by soil moisture, soil composition, disease. Different types of plants can be distinguished on infrared



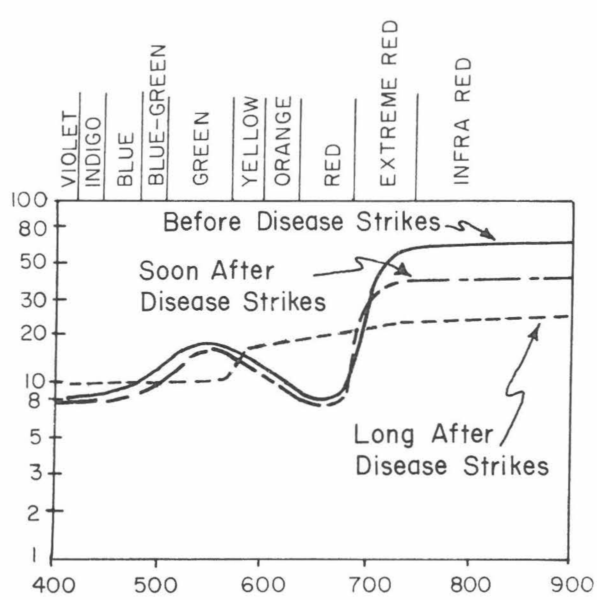
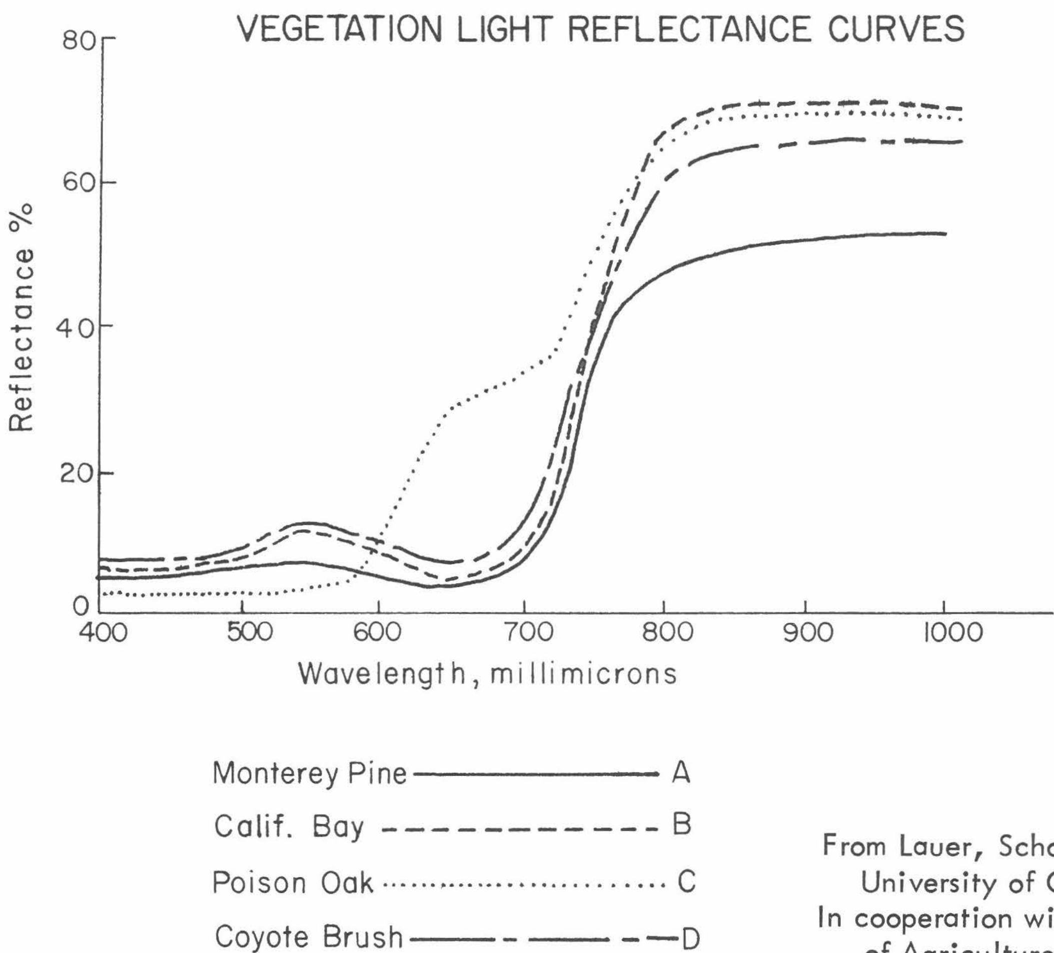


Figure 3. Top: Schematic drawing in which the highly infrared-reflective tissue of the lower half of a leaf is shown in its normal, healthy state. When the plant loses its vigor, this tissue may collapse long before the leaf's green color begins to fade. Hence, the disease may be detectable much sooner on infrared than on panchromatic photography. Bottom: Successive changes in the ligh reflectance from leaves, associated with a loss of plant vigor, are diagrammed here (x axis is in millimicrons). Not all species of plants respond in this manner, but a great many do. For further explanation, see text and Colwell (1956).

film because their leaves may reflect more or less infrared radiation owing to differences in the composition of mesophyll layers and their epidermis.



From Lauer, School of Forestry
University of California
In cooperation with U.S. Dept.
of Agriculture

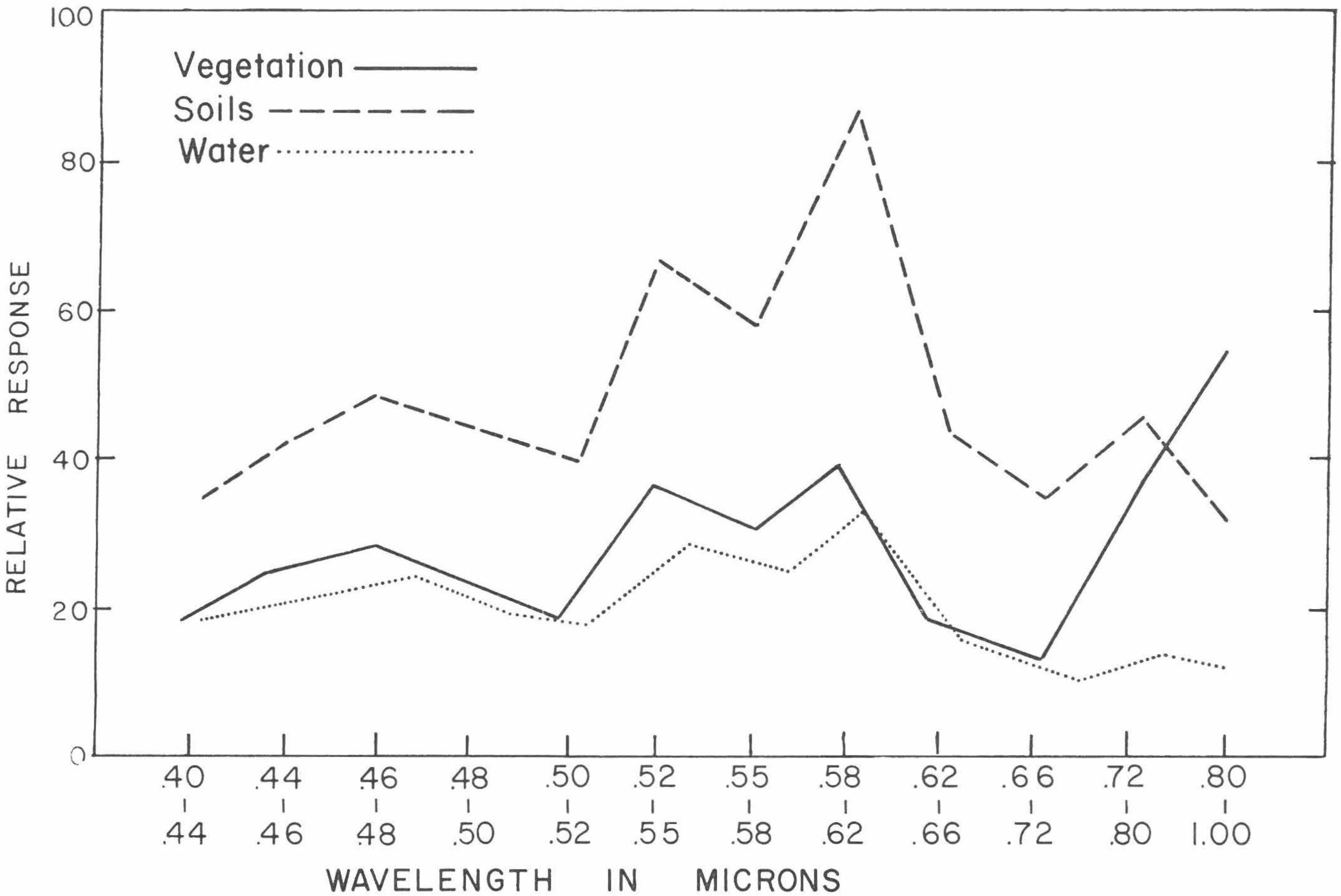
False-color infrared film has been used extensively in forestry, agriculture, land-use management and environmental protection. The two films from the John Deere Corporation should explain some of its potential uses in Iowa.

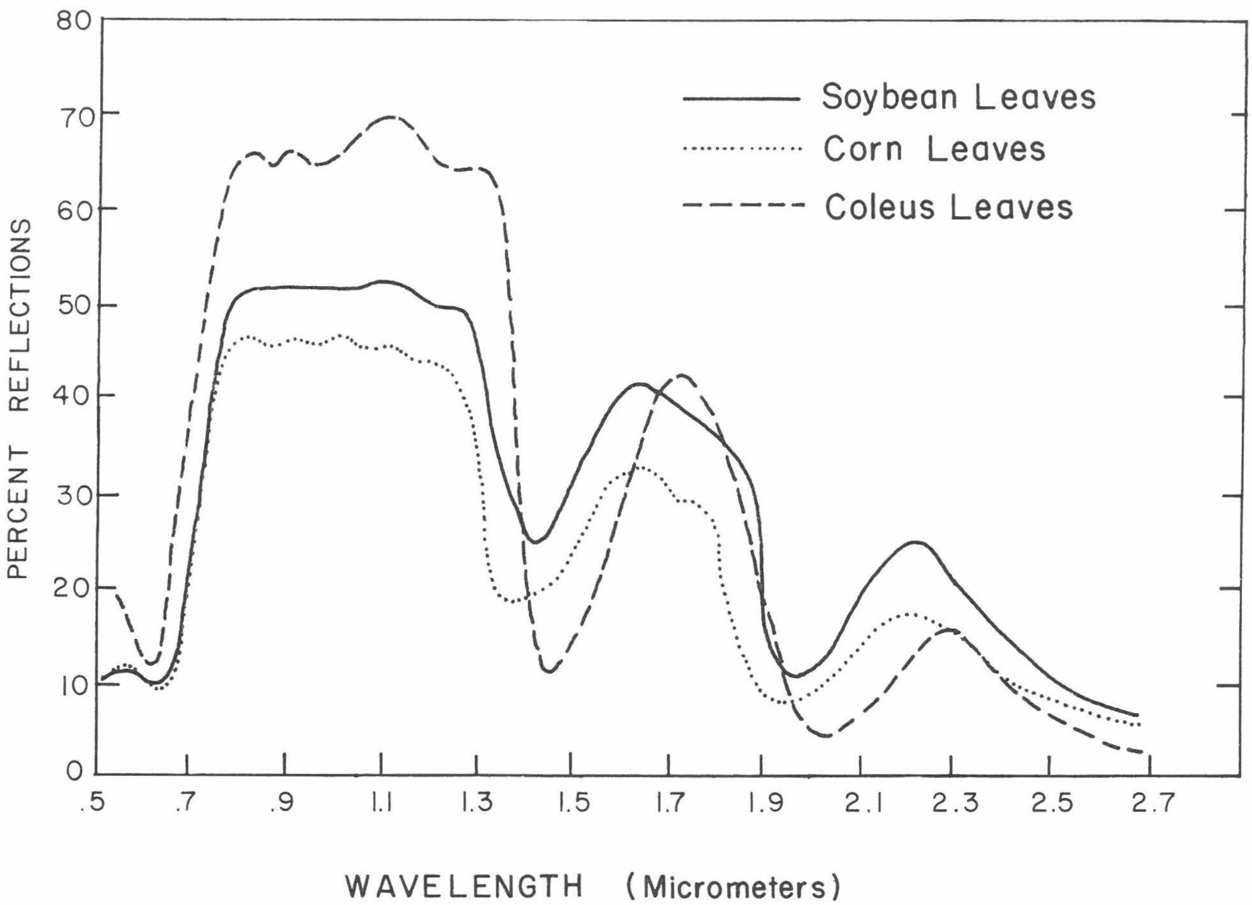
Multiband Photography

The working definition of multiband photography offered by Robert C. Colwell is, "If two or more photographs, each employing a different wavelength band, are taken of the same scene, the result is multiband photography." Multiband photography is based on the fact that earth materials reflect electromagnetic radiation differently across the visible and near visible wavelength interval. A tonal difference on film represents a difference in reflectance between one material and another. The goal in multiband photography is to identify those wavelength bands where maximum tonal differences(maximum reflectance differences) occur between materials. Once the spectral response differences of these materials have been identified by use of the optimum band pass or band passes, then earth materials can be identified, mapped, and inventoried.

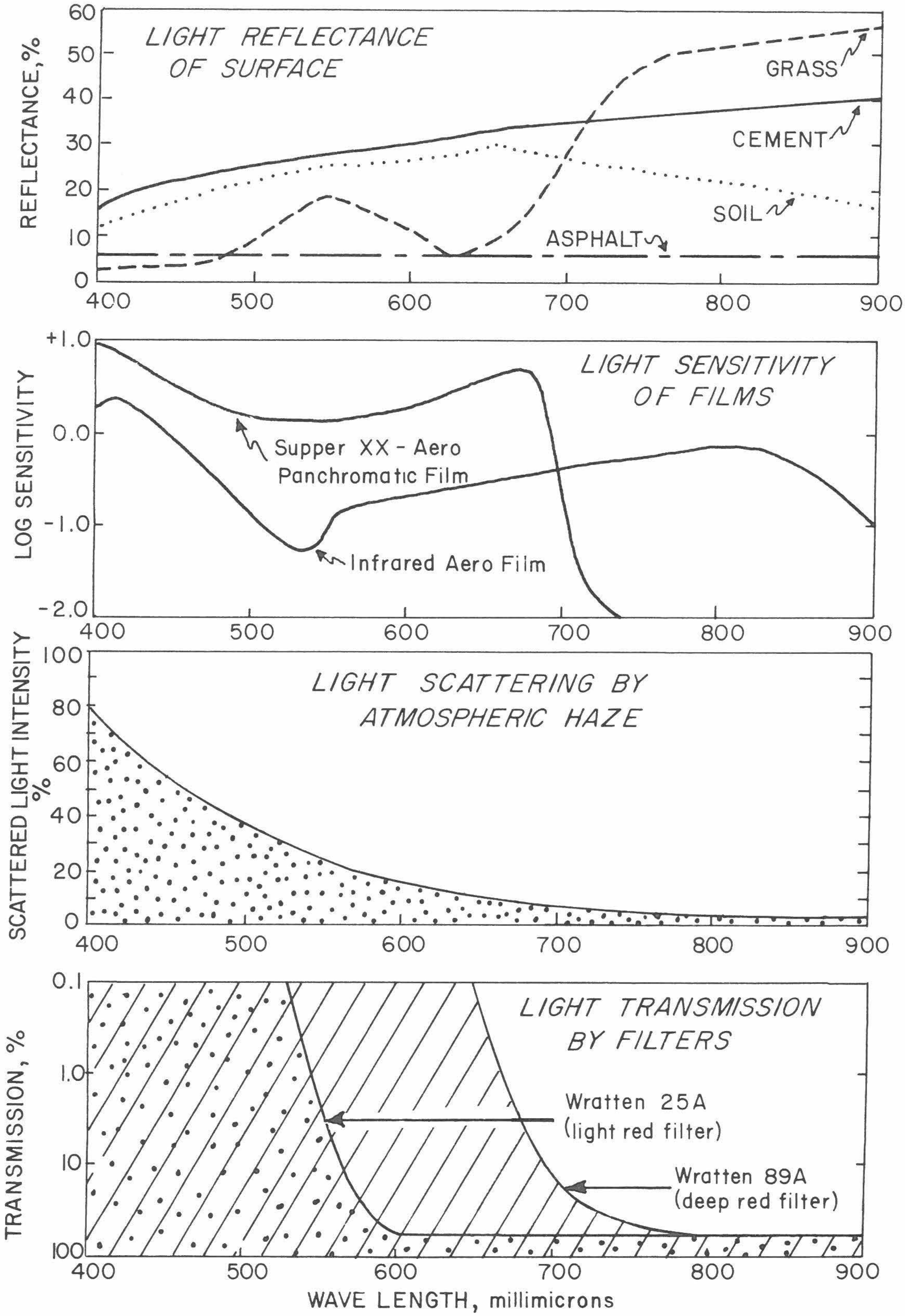
The rational approach to multiband photography usually begins with ground studies to determine the spectral response of the landscape over the photographic wavelength interval. This is usually done with a spectroradiometer like an ISCO, or Gamma Scientific device. The problem is simplified when measuring reflectance of soils or rocks - - but is compounded for vegetation. Vegetation spectral reflectance measurements must sufficiently sample any background effects from soils and rocks, particularly when sampling row crops. Measurements of this kind are often costly in terms of time and money, and often a test overflight with a multispectral camera will identify optimal band passes and films.

There are a wide variety of multiband systems on the market and all have certain "trade-off"advantages for the investigator. Multiband cameras usually have





after LARS, 1971



TYPE OF SURFACE	PREDICTED TONE ON POSITIVE PRINTS			
	PAN FILM	25A FILTER	I.R. FILM	89A FILTER
GRASS	DARK		LIGHT	
CEMENT	LIGHT		LIGHT	
ASPHALT	DARK		DARK	
SOIL	LIGHT		DARK	

Courtesy of R.N.Colwell

two common configurations, as a multiple camera cluster or as a single camera with multiple lenses. In the first case, different films can be utilized and in the second case one film is utilized and from four to nine images are recorded simultaneously on one frame.

In the cluster of cameras, usually four individual strips of 70 mm or 5-inch wide film have to be handled. In general, such systems are capable of high resolution (high resolution films can be used on one to three bands), but they usually have problems of registration, owing primarily to boresighting errors and lack of shutter synchronization.

Single cameras having multiple lenses and which utilize one strip of film, are better from the standpoint of data handling, and image registration, but usually black and white 2424 infrared film is utilized and only moderate resolution can be achieved with this film. If the shutter does not traverse all lenses simultaneously, then aircraft roll and pitch can introduce significant registration errors. In general, boresighting is not as difficult when lenses are mounted into a single rigid camera body.

Both multiple camera clusters and single cameras with multiple lenses, have some problems in common. Each lens must be wavelength corrected and focused for the band pass it receives. This means that if different filter combinations are tried then refocusing must be done. Also, the wavelength uniqueness of each lens might dictate that only blue filter be exchanged on the blue lens and that the experimenter should generaly avoid placing a red filter on a "blue lens".

One promising approach to the problem of multiband photography was recently communicated to me by Don Orr of the U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, Virginia. The ETL camera utilizes a single lens and diffracts electromagnetic radiation into four 70 mm film magazines by a series of prisms. The camera has no traveled free air space and visible and near visible energy travels in optical glass prisms until it reaches the film planes of the four magazines. High resolution panchromatic film is utilized in three magazines while infrared film is utilized in another. The system is still in the development stage, but it has already produced high quality imagery with excellent registration.

The investigator, using the multiband approach is faced with a major decision involving the "trade-off" between repeatability and the determination of optimal band passes for his particular problem. Our goal in multispectral photography is to be able to map the unique spectroradiometric properties of the landscape on a repetitive basis. Repeatability is important on a practical and applied basis and most investigators using this approach usually recommend four band passes (400 to 500, 500 to 600, 600 to 700, and 700 to 900nm approximately) and they usually use panchromatic and/or 2424 black and white infrared film. Most of these investigators depend upon the research community for the definition of better films or filters for their individual problems.

The experimental approach dictates that optimal film-filter combinations be selected for a specific problem. Thus, it may be desirable to change films and filters to best define spectroradiometric differences. Recall, if one filter is exchanged for another, the camera lens will have to be refocused and possibly exposure changed in accordance with the filter factor. When the film is placed in a viewer, the viewer may also have to be realigned and possibly refocused. Thus one seemingly small change can introduce many possible variables, any of which could destroy repeatability. The decision between whether to experiment with multiband combinations or to accept those combinations already defined by the State-of-the-Art must be based on the objectives of the investigator. Spectroradiometric repeatability is predicated upon uniform irradiance at the land's surface, the spectral uniqueness of the landscape, and the making of an accurate spectroradiometric record on film. We are all aware that atmospheric conditions and sun-angle introduce significant variations in the irradiance received at the land's surface. Additionally there are considerable variations in the spectral characteristics of earth materials introduced by seasonal conditions (soil moisture, leaf chlorophyll content, etc.). Thus, if we change nothing and fly a multiband system with the same films and filters, it could be over a year before the optimum times of day, and days of the year are identified for a particular problem. On the other hand, if filters and films were changed during a trial it might not be possible to assess the affects of sun angle, atmosphere, and seasonal conditions.

Therefore, if you anticipate that your organization will be primarily engaged in research, and that you can afford to experiment in terms of time and money, then those multiband systems which have been designed for research purposes will best suit your needs. On the other hand, if you are just starting out in an operational program and wish to apply the multiband approach to specific problems you may wish to select a system which is simple and durable, and you will probably want to hold system variables as constant as possible.

The second step in multiband photography is processing the exposed films. Recall, that for film to accurately record the spectroradiometric properties of the landscape there must be a unique relationship between irradiance and density on the processed film. Ideally, we would like our film to be equally sensitive for each segment of the visible and near visible wavelength interval and unfortunately, this is rarely the case. In processing Kodak type 2424 Infrared, I^2S recommends that the negative be processed so the infrared band has a gamma of 1.9. Usually, if the negatives are incorrectly processed, it will be very difficult for the investigator to identify problems with his imagery. The objective in processing multiband imagery should be the achievement of matched gammas for all bands so the relationships between irradiance and processed film density will be identical for each band. This condition is manditory for color additive viewing.

Most color additive viewers require positive transparencies from the original negatives acquired in the camera. For a 250-foot roll of infrared type 2424 (cost $125.00) processing to a negative costs $75.00 and contact printing to a positive costs $375.00. Thus, film and processing for a mission at 6000 feet covering 150 flight-line miles with the I^2S camera, will run around $575.00. Usually aircraft time will cost around $425.00, so the whole package costs $1,000.00 for one 250-foot roll acquired at 6000 feet. Processing separate rolls acquired in a multiple camera cluster usually runs considerably higher.

The third step in multiband analysis is viewing the result. Usually, the imagery is either viewed directly by comparative methods or is projected in a color additive viewer. There are a variety of viewers on the market capable of taking 70 mm, 5-inch, and 9½-inch photography.

Most viewers have to be aligned for the camera system they employ. Sometimes if a filter is changed on the camera, the camera lens must be refocused and reboresighted, and the viewer must be also realigned and refocused. Viewer alignment and camera boresighting and refocusing are very difficult operations requiring special tools and trained technicians. For operational programs, a very acceptable solution to this problem can be a maintenance contract with the equipment supplier. One equipment supplier will replace filters, reboresight camera and realign viewer for a nominal fee and often new improvements to the system are added at no cost to the purchaser.

Conclusions

The use of multiband photography in operational remote sensing is limited by the problems of data handling and current instrumentation. These problems prevent the use of multiband photography for the mapping of earth phenomena on a regional scale. Multiband photography does have a place in the early investigative phases of operational programs because it can define the films and filters to be used in metric cameras capable of mapping large areas at relatively low costs. Multiband cameras can be used effectively over small target areas where ground control is sufficient, mission variables are understood, and system variables are held constant.

There are several excellent references on multiband equipment:

Colwell, R. N , et al., 1970, Manual of Multiband Photography: A Final Report prepared for NASA under contract NAS 9-9577 by the Forestry Remote Sensing Laboratory, School of Forestry and Conservation, University of California, Berkeley.

Slater, P. N., 1972, Multiband Cameras: Am. Soc. Photogrammetry Bull. v.38, no.6, p.543-555.

Lauer, D. T., 1971, Multiband Photography for Forestry Purposes: International Union of Forestry Research Organizations' Joint Report, "Forestry Applications of Remote Sensing" (in press).

Yost, E. F., et al., 1970, NASA Apollo 9 SO 65 Experiment; Multispectral Terrain Photography. A report of research performed under contract NAS 9-9341 for the Earth Resources Division, NASA, by personnel of the Science and Engineering Group, Long Island University, New York.

AERIAL PHOTOGRAPHY STUDIES AT LOW ALTITUDES

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Environmental Coordinator
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Aerial photography is a sensing procedure, utilizing camera systems mounted in aircraft, which detect and record on film electromagnetic radiation in the visible and near-visible portions of the electromagnetic spectrum. The resulting photographs represent a vertical or oblique look, depending on the camera axis, at the earth's surface, and provide a unique communication capability in that they show from a different perspective relationships in size, quantity, and distribution. Low-altitude photography may be considered as that taken from 500 feet to 30,000 feet above the ground surface. The scale of the resultant imagery is "large scale"; it covers a relatively small area in great detail, whereas "small-scale" imagery is obtained from high altitudes and shows a larger geographic area in reduced detail. The larger the scale, the more closely the image-ground relationship comes to a 1:1 ratio. Note altitude-scale relationships in Table 1.

The advantages of low-altitude aerial photography exist in the detailed information and high ground resolution obtained from a close look at a small area. It has found wide application among federal, state, and local agencies as it provides study and documentation of air and water pollution, crop and forest evaluation, soil characteristics, patterns of cultural features, and monitoring of pollution-control measures.

The disadvantages of low-altitude aerial photography lie in the expenses involved. Because the size of the geographic area covered is relatively small,

IOWA REMOTE SENSING LABORATORY
Iowa Geological Survey

I^2S MULTISPECTRAL CAMERA

Altitude feet	Scale of imagery	Ground Coverage linear feet	Distance covered 250-foot reel (miles)	Aircraft Speed	Intervalometer Setting (sec.)	Percent of overlap (fwd)
500	1:1000	292	15	60K	3	1
1000	1:2000	584	30	100	3	1
2000	1:4000	1168	43	100	5	28
3000	1:6000	1752	49 - 68	100	5 - 7	51 - 32
4000	1:8000	2336	57 - 84	100	6 - 9	56 - 35
5000	1:10,000	2920	75 - 112	100	8 - 12	53 - 30
6000	1:12,000	3504	100 - 140	130	8 - 11	50 - 30
7000	1:14,000	4088	124 - 161	130	10 - 13	46 - 30
8000	1:16,000	4672	130 - 182	140	10 - 14	50 - 30
9000	1:18,000	5256	162 - 210	140	12 16	46 - 28
10.000	1:20,000	5840	171 - 231	150	12 - 16	48 - 30

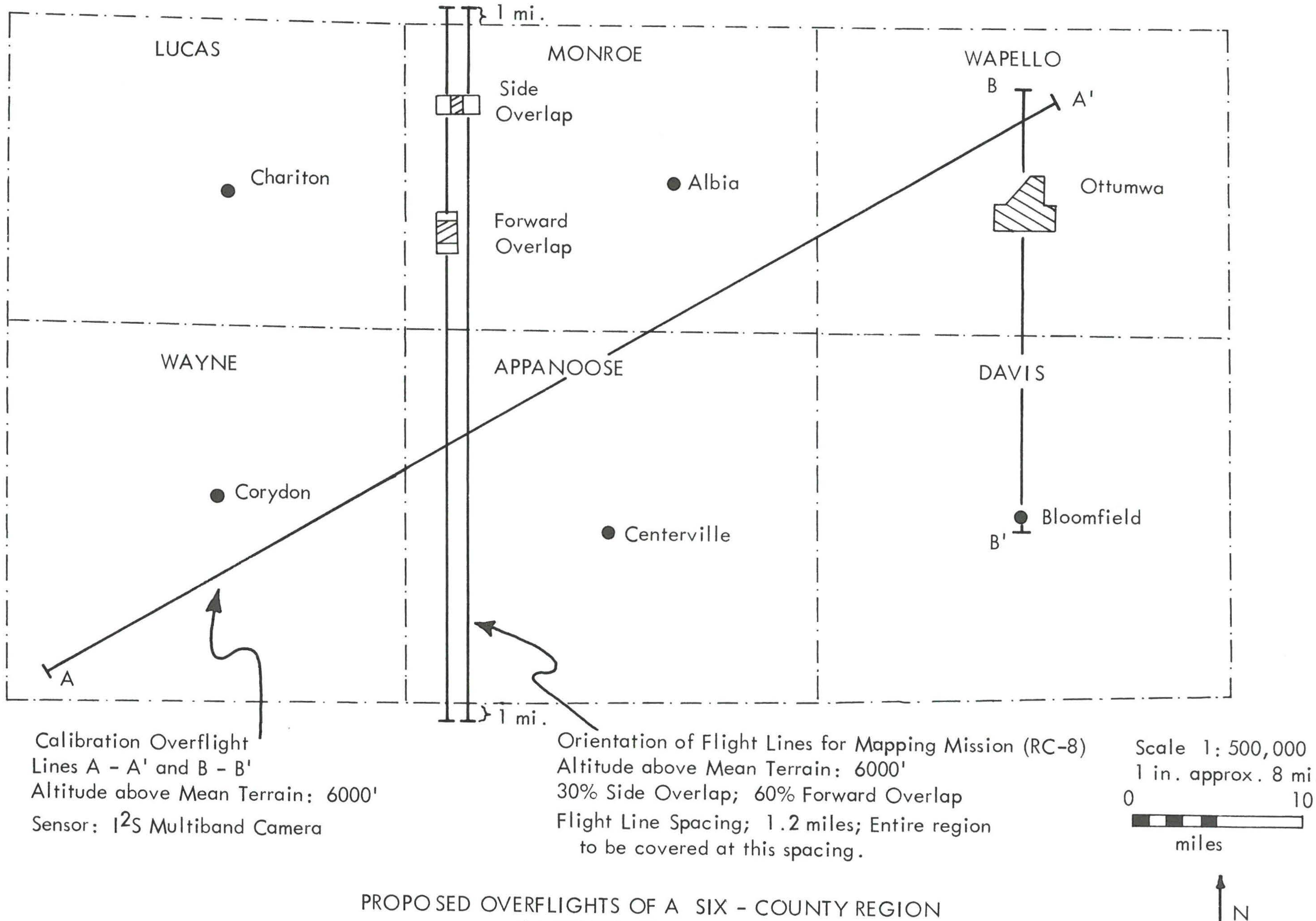
Table 1

more frames of imagery are produced, more flight-line miles are covered, more rolls of film are required, and more analysis time is needed.

The camera systems used to obtain low-altitude aerial photography vary from hand-held 35 mm cameras to complex configurations mounted in camera bays of specially modified aircraft. The two systems which will be referred to most often are the multiband camera and the RC-8 mapping camera. The multiband camera system produces four $3\frac{1}{2} \times 3\frac{1}{2}$-inch images registered on 9 x 9-inch film. These images are obtained through the four lens-filter combinations of the camera, recording light in the blue, green, red and infrared bands of the electromagnetic spectrum. This camera system is most often used in research, but may be used in calibration overflights to determine the film-filter combinations which will be most advantageous in the main mapping mission. The RC-8 mapping camera, usually contracted from an aerial service company, registers a single image on a 9 x 9-inch format. (Note flight design using these two systems in Figure 1).

The products obtained from low-altitude aerial missions include conventional black and white photography, infrared black and white photography, conventional color photography, color (also called "solor" or "near") infrared photography, ultraviolet and multiband photography. The choice between these available film types depends on the objectives of interpretation and the cost involved. (Note cost comparisons in Table 2).

Panchromatic, or black and white, film is available in various combinations of speed and resolving power. It has a wide exposure latitude and the fine grain permits enlargements to be made. The film provides good tonal contrast, is readily available and conveniently processed, and is least expensive.



PROPOSED OVERFLIGHTS OF A SIX - COUNTY REGION
IN SOUTH-CENTRAL IOWA

Figure 1

IOWA REMOTE SENSING LABORATORY
Iowa Geological Survey

Costs for photographic imagery in 250-foot rolls

1. Panchromatic film	
Unexposed film from supplier	$ 70.00
Processed to a negative in roll form	225.00
Prints processed on a log-E printer	200.00
	$ 495.00
2. Black and White infrared film	
Unexposed film from supplier	100.00
Contact film positive (use in addicol viewer) ($375.00)	225.00*
Prints processed on a log-E printer	200.00
	$ 525.00
*B and W processed to a negative	
3. Color reversal film	
Unexposed film from supplier	200.00
Processed to a film positive	225.00
First print color balance charge	18.00
Each print thereafter at $4.25 per print	1275.00
(log-E process $5.50 per print)	$1718.00
4. Color negative film	
Unexposed film from supplier	200.00
Processing to a negative	225.00
First print color balance charge	18.00
Each print thereafter at $2.50 per print	750.00
(log-E process $5.50 per print)	$1193.00
5. Color infrared film	
Unexposed film from supplier	300.00
Processing to a film positive	225.00
First print color balance charge	18.00
Each print thereafter at $4.25 per print	1275.00
	$1818.00

Table 2

On black and white infrared film, the film tone results from the infrared reflectiveness of an object, which is invisible to the eye. This film type penetrates haze better than the panchromatic film and is useful for distinguishing between vegetation types, especially timber. It also sharply delineates land and water areas, with water appearing black on the prints.

Conventional color film is available in either color-reversal film or color-negative film. Reversal color films provide positive transparencies with natural color rendition. Negative color film, on the other hand, provides a negative which can then be printed to a natural color print. Conventional color photography requires optimal weather conditions and has limited exposure latitude. It is especially useful in the identification of soils and rock types, and its capability of water penetration make it valuable in shoreline, lake and river studies.

Color-infrared film is a valuable tool for obtaining information not available through normal vision. It is sometimes referred to as a "false-color" film because the resulting images display colors that are false for most natural features. It was originally used in camouflage detection because it emphasized the difference between live, healthy vegetation, which appears red, and visually similar areas which were artificial. This film may be useful for the early detection of disease and insect outbreaks in crops and forest lands. It also can aid in the identification of tree species, as most evergreens have a lower infrared reflectance than deciduous trees. The effects and extent of pollution in lakes and streams, and the inventory of wildlife populations are other uses made of this film.

Mission Planning and Design

Aerial photographs are seldom an end product in themselves. Rather, they are a practical means of recording earth-surface data for a variety of uses. Once it has been determined that remote sensing (low-altitude aerial photography in this case) offers the lowest cost-effectiveness ratio and the highest probability of providing the needed qualitative and quantitative spatial, temporal, or taxonomic data, mission planning can begin. It is at this point that we come face-to-face with the problems of low-altitude remote sensing. When planning and design actually begin, we must take into account a number of factors and trade-offs in order to give us the best quality data for the greatest number of users, and for the least amount of money.

We saw earlier, that we receive detailed information, good resolution, and a close look at a small area with low-altitude aerial photography. However, this kind of information must be weighed against the cost of an increased number of flight-line miles, additional rolls of film, increased frames of imagery, and more analysis time. When flying at higher altitudes, the result is a synoptic view of large regional features. Coverage of extensive geographic areas is accomplished in a shorter period of time. There is less film required and fewer frames of imagery to analyse. All of these features of increased flying altitude reduce the cost of higher altitude missions, though it should be kept in mind that the higher the flight required, the more expensive the platform. As the altitude of the mission increases, ground resolution decreases, and only objects of larger and larger size can be detected and identified. In other words, information is lost, as is the ability for detailed analysis. The problem to keep in mind with low-altitude aerial photography is this trade-off that exists between cost and information. The optimum level to fly is one that balances the information required with the cost of data acquisition.

Therefore, in planning a low-altitude mission the above relationships must be kept in mind and the following steps carried out. 1) It is important to determine the kind of information desired, the use for which the data is being obtained and the parameters to be mapped. 2) The photography can then be designed to have the characteristics for best and most economically producing the required end product. Selection can be made from all available sources of the photographic equipment, materials and flight plans which most nearly fill the requirements of the project. The principal film types, discussed earlier, and their imagery characteristics should be reviewed. The types of camera systems and aircraft also must be chosen. 3) The flight design can then be prepared and this should include a) definition of the project boundaries to insure adequate coverage of the area under study; b) determination of the altitude above mean terrain, which in turn is dependent upon the required accuracy of information, the desired resolution of objects, and the size and shape of the area to be studied; c) determination of flight-line orientation, making them as few and as long as possible, with additional consideration given to sun angle, topographic relief, and the presence of navigational aids; d) determination of flightline spacing, or the distance between successive flight lines, which determines the percentage of side overlap (30 percent is considered optimal for complete coverage); e) determination of the intervalometer setting, or the interval at which the camera shutter is tripped, which determines the percentage of forward overlap (60 percent is considered optimal for stereoscopic viewing); and f) determination of the number of flight-line miles, including the turn-around areas. 4) The season of the year and the time of day the mission is to be flown are very important factors. Acceptable ground-cover conditions must be known for various types of studies. For example, soils probably photograph best in May, crops in July, and water resources in April or October. The time of day will determine the effect of sun angle and shadows on the terrain, as well as influence haze, fog and other atmospheric conditions. 5) Field control or "ground truth" is an additional step to consider in mission planning. Concurrent ground investigations may be required with an overflight to help quantify or identify features which will appear on the imagery. Standard calibration targets also may be utilized to provide reference data for the imagery being obtained. 6) Costs of data acquisition is the final and one of the most important steps in planning and design. Review the costs for photographic film and whether it will be processed to negative or positive imagery. Consider aircraft expenses, which will include the flight-line charge over the target area, the ferrying charge to and from the target area, and possible overnight accommodations for the crew. Take into account equipment and personnel costs for ground-truth investigations. Analysis costs will include interpretation of imagery using such techniques as stereoscopic analysis, color-additive viewing, and image-enhancement (Digicol). The number of people available, the number of frames of imagery to be analysed, and the amount of time spent on each frame should be taken into account. The conversion of the analysed data to map form and the eventual publication of the results are other cost factors to consider.

In summary, it is hoped that the potential as well as the limitations of low-altitude aerial photography are apparent. In order for maximum benefits to be gained from the Iowa Remote Sensing Program, it is important that there be a basic understanding of these factors as well as an understanding of what goes into mission planning and design at these altitudes. It is important to the Iowa Remote Sensing Laboratory that we know your needs, and what parameters you want mapped. The mission can then be designed, working back from the desired data product, and sensors can be selected which permit the best balance between cost, information, time, and supplementary data which can be made available to other interested agencies.

Selected References

Avery, T. Eugene, Interpretation of Aerial Photographs: Burgess Publishing Co., 2d Edition, 324 p., 1968.

Eastman Kodak Company, Photography from Lightplanes and Helicopters: Kodak Publication No. M - 5, 24p., 1971.

Smith, John T. and Abraham Anson (Editors), Manual of Color Aerial Photography: American Society of Photogrammetry, First Edition, 550p., 1968.

Thompson, Morris M. (Editor), Manual of Photogrammetry: American Society of Photogrammetry, Third Edition, Vol. 1, 536 p., 1966.

PRINCIPLES OF THERMAL INFRARED MAPPING

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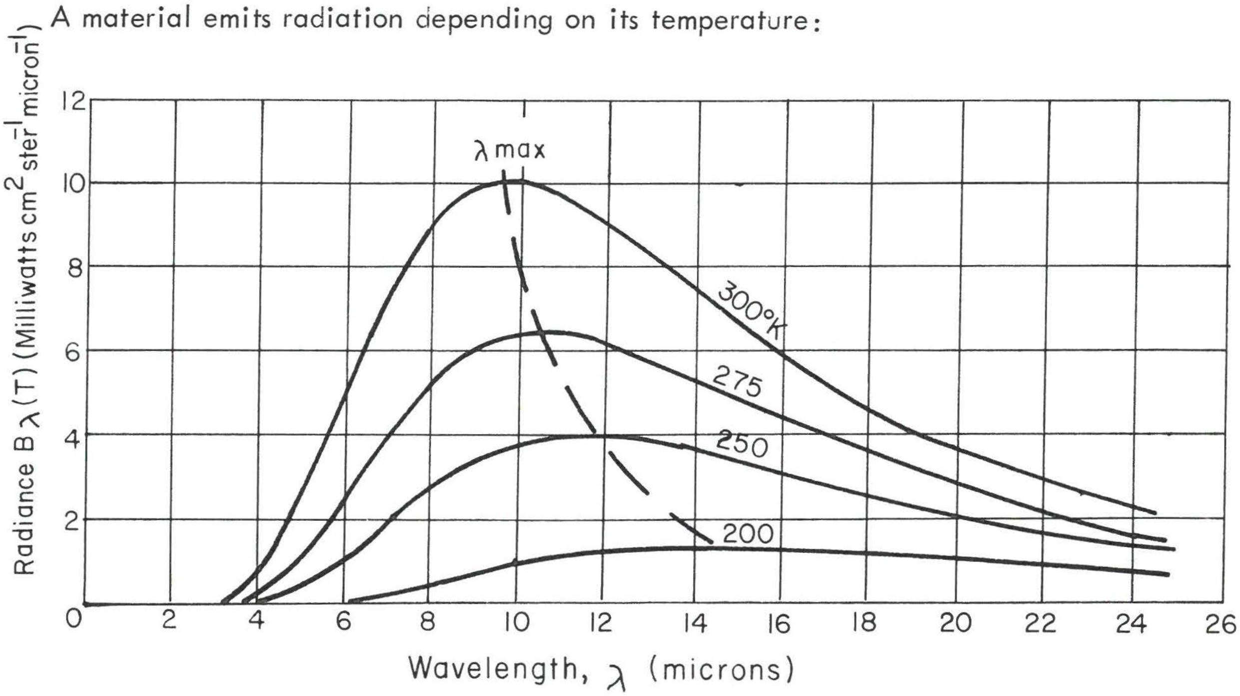
Ed. note: The following is an outline of the lecture delivered by Dr. Kuiper. It includes important diagrams and notes with the explanation of major principles involved in thermal imagery.

A material emits radiation depending on its temperature:



BLACKBODY SPECTRAL RADIANCE

1. To find at what wavelength the curves have their maximums:

$\lambda\ max = \frac{2900}{T}$ Where T = temperature of material in degrees Kelvin(K°)

$\lambda\ max = \frac{2900}{300} = 9.7\ \mu$ 300° is a typical temperature for a material on the surface of earth. 300°K = 23°C = 63°F

$\lambda\ max = \frac{2900}{6000} = .48\ \mu$ 6000° is approximate temperature of sun

II. Total radiant energy given off by a material is found by adding up the radiant energy given off at each wavelength (i.e., find the areas under curves shown):

$$W = \varepsilon \delta T^4$$

Where:

W = total energy Watts/(cm)^2

ε = emissivity (approximately equal to 1 for many thermal infrared mapping purposes)

δ = a constant 5.7×10^{-12}

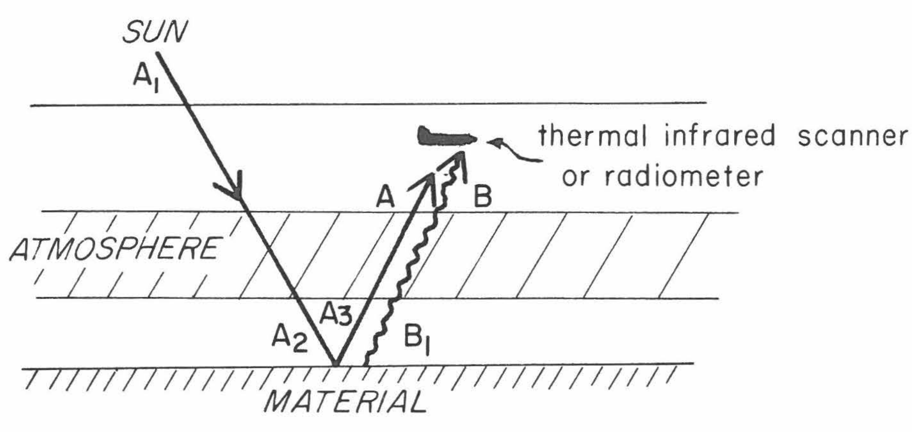
T = temperature of material °K

By finding how much energy the material gives off we can determine the material's temperature. This is the basis of thermal infrared mapping.

λ_{max}(6000°K=11,000°F)=.48 μ
λ_{max}(300°K=63°F)=9.7 μ
λ_{max}(273°K=32°F)=10.6 μ
λ_{max}(725°K=850°F)=4 μ

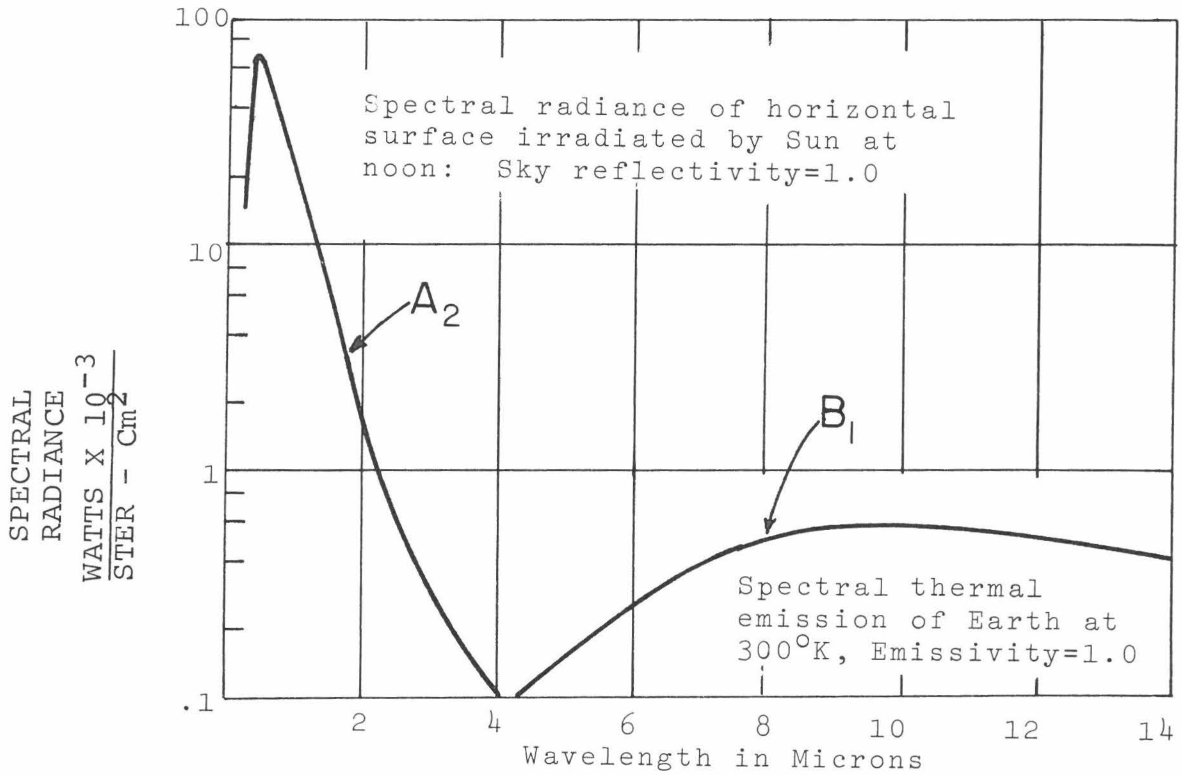
Thus the instrument used to measure W from most materials on the earth's surface should preferably be sensitive for wavelengths in the 9-11 micron region.

III.



A_1= W from sun before earth's atmosphere.
A_2= W striking earth's surface.
A_3= W reflected from earth's surface.
A = W detected at radiometer from reflection.
B = W emitted from surface dependant on T.
B1 = W detected by radiometer emitted by earth.

We want B_1 so we can find the temperature of the material. The detection instrument measures B and A added together. We would like A to be small as it only confuses our efforts to find B.



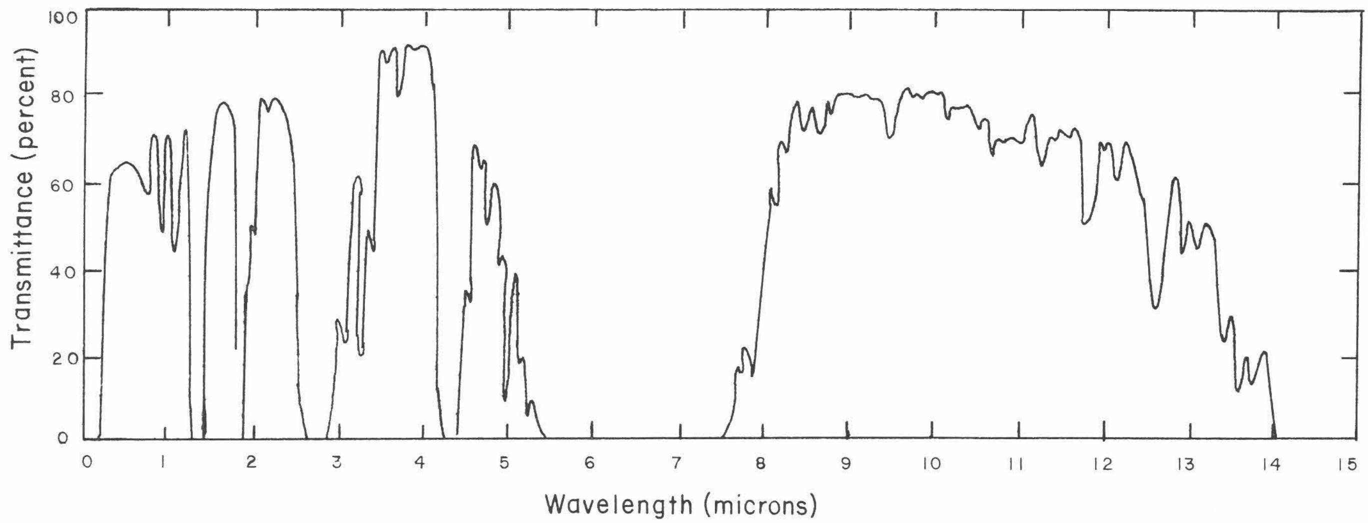
COMPARATIVE SPECTRAL RADIANCE FOR SOLAR ILLUMINATION AND 300°K SELF EMISSION

A_1/B_1	λ
8×10^{11}	1.2μ
160	3 μ
4	4 μ
.01	10 μ

$\frac{A_2}{A_1}$ = from 20 to 65 percent on clear day depending on sun angle

$\frac{A_3}{A_2}$ = from 5 to 15 percent for typical materials found on earth's surface

Atmospheric transmission:

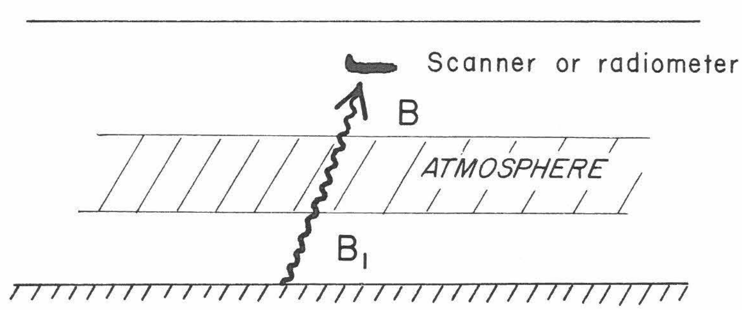


Thus two possible bands: 3 - 5 and 8 - 14 microns

3 - 5 micron band no good for day flights since A_3 would be comparable in size to B_1. A_3 would be considerably larger than B_1 at $\lambda = 3$ microns. Thus 3 - 5 micron -band can be used only for night flights.

8 - 14 micron-band can be used during the day. A_3 will be much less than B_1. The 8 - 14 micron-band contains the 9 - 11 micron region where materials on the earth's surface have their maximum remittance and is thus superior to the 3 - 5 micron-band for most purposes.

IV.



B will be less than B_1. The difference between B and B_1 depends upon the distance the instrument is from the ground and the nature of the atmosphere between instrument and ground. For good measurements this difference should be made as small as possible and should be as nearly constant as possible. Thus measurements increase in quality with lower flight altitude and clarity and consistency of atmosphere below instrument. Flights should not be made when there are clouds or during rapidly changing or overcast atmospheric conditions below instrument.

In order to remove measurement errors due to the atmosphere and errors due to other causes, ground measurements of surface temperatures are often needed. These ground measurements should be made at flight time. The more ground measurements made the better quality results obtained.

V. Sources of ground heating and cooling

Natural:

Heating--

a. sun (radiant heating)
b. atmosphere (radiant heating & wind)
c. geothermal
   1. from earth's center
   2. heata producing natural chemical reactions

Cooling--

a. radiant cooling
b. atmosphere (wind)
c. evaporation of H_2O
d. transpiration of H_2O from plants

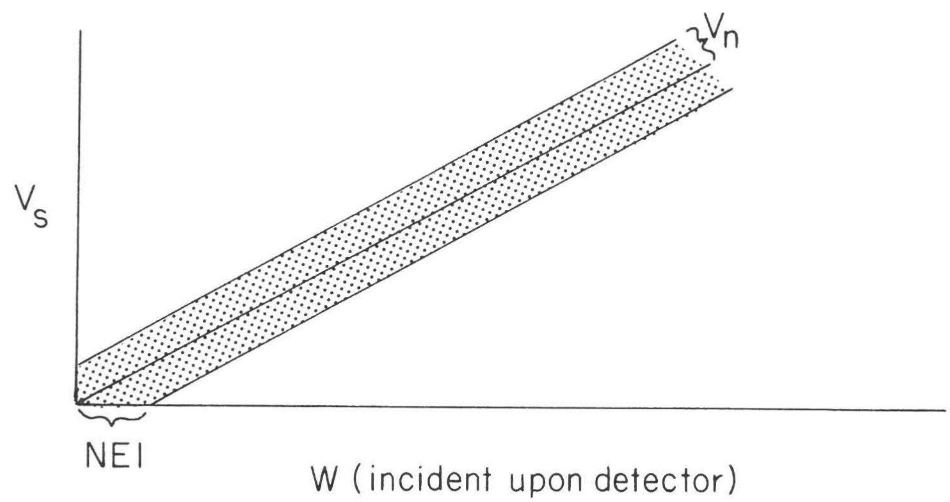
Man-made:

Heating (thermal pollution)-industries, nuclear reactors, etc.

The above natural forces usually combine to raise the material's temperature to a maximum around 1300-1400 hours and to cool the material to a minimum 0-1 hour before sunrise. The radiant heat from the sun is the dominant heating force. Due to basic inherent properties of materials, albedo, density, heat capacity, and ability to conduct heat, two different materials lying side by side on the earth's surface will have different temperatures. This forms the basis for the mapping of different types of materials on the earth's surface. The difference in temperature between two different materials is typically the largest when they reach their respective pre-dawn minimum temperatures. It can also be quite large around 1300-1400 hours when they reach their maximums. Thus to obtain maximum contrast, flights are usually flown during the pre-dawn period or occasionally during the period of 1300-1400 hours.

VI. Qualitative versus quantitative mapping.

VII. Thermal infrared detection devices



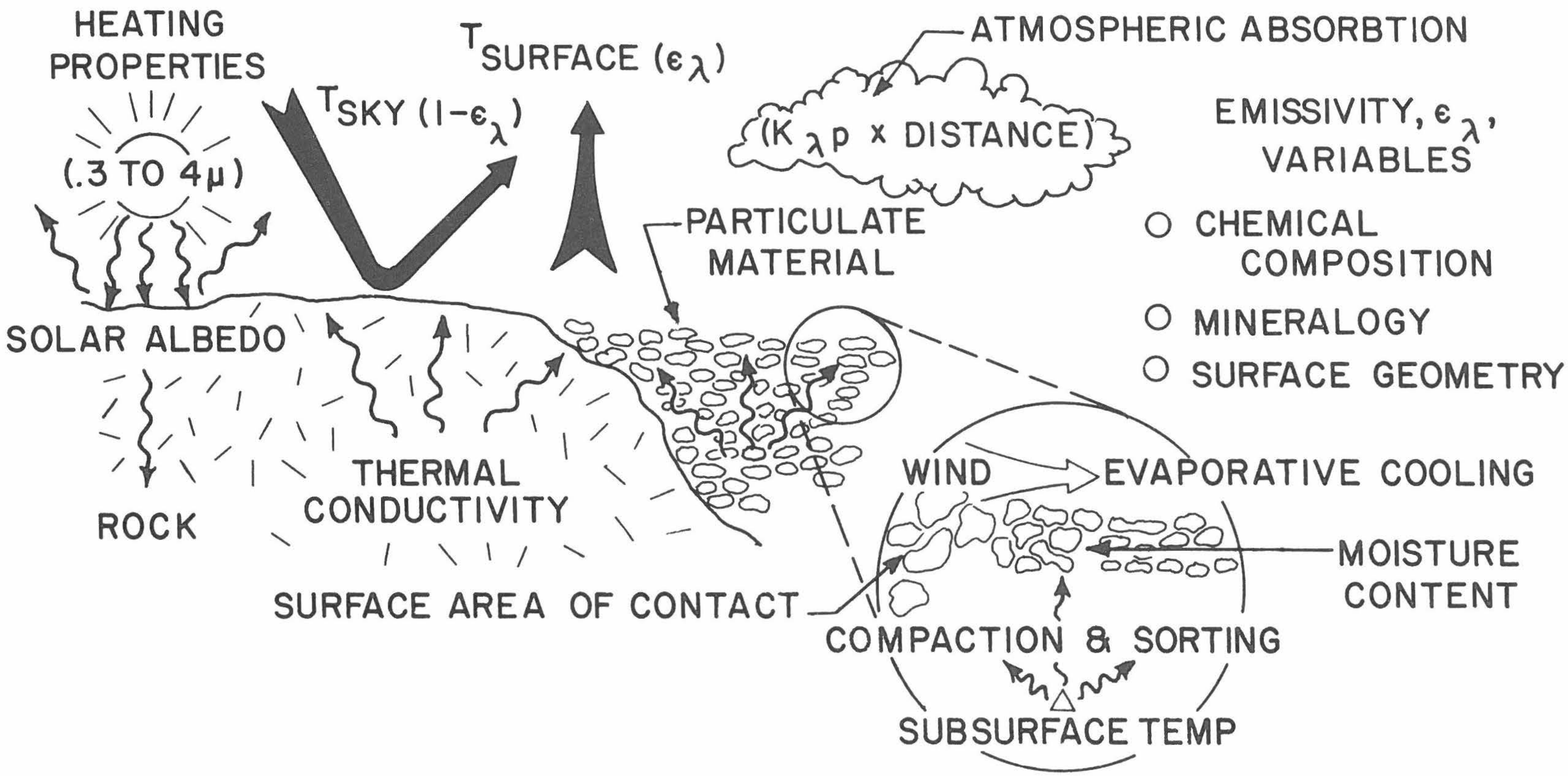
V_s Signal voltage from detector
V_n Noise voltage

1) Signal to noise ratio (V_s / V_n)

2) Noise equivalent irradiance (NEI)

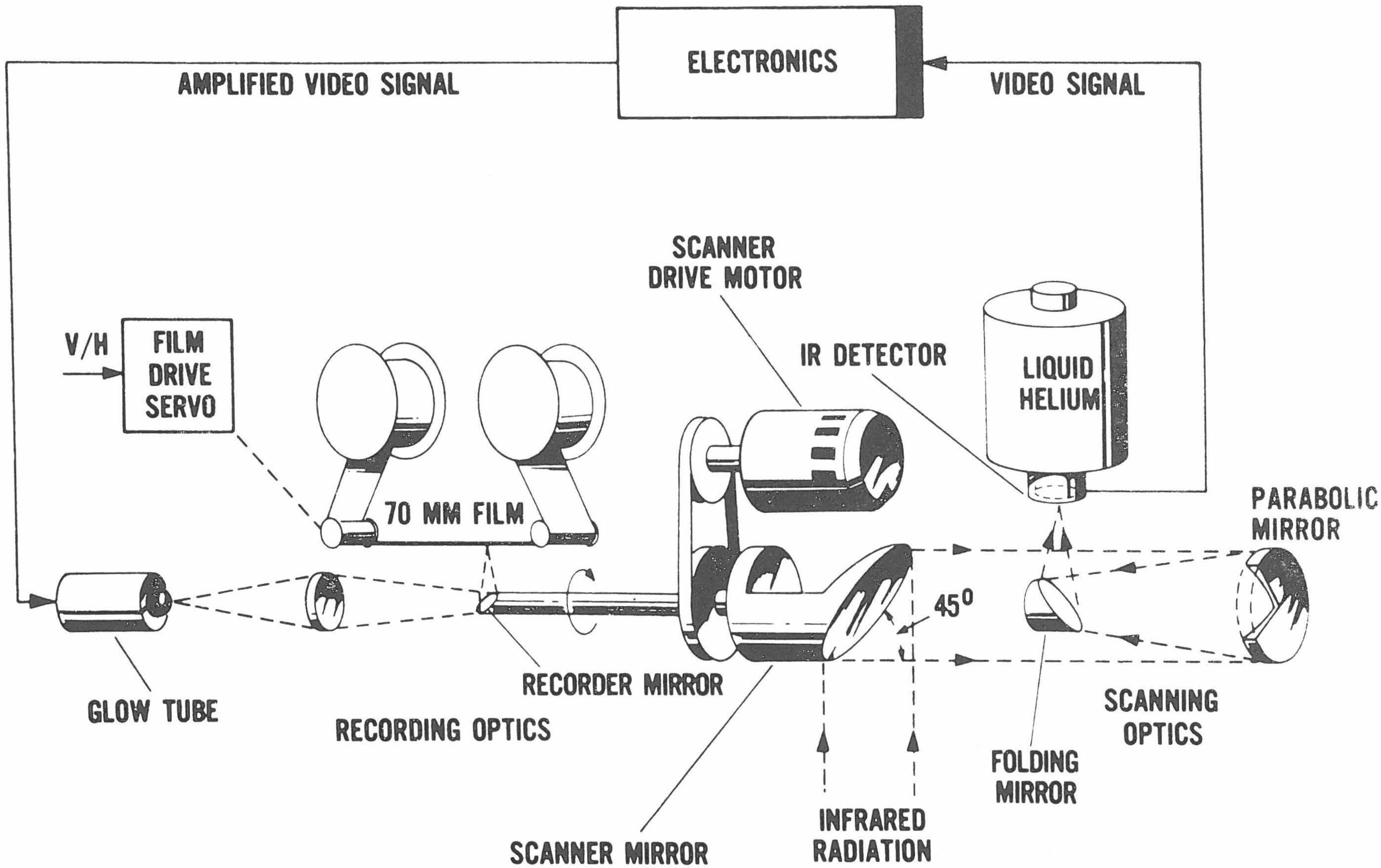
3) Radiometer, thermal infrared scanner

PARAMETERS AFFECTING THE INFRARED SIGNAL



VARIABLES (NOT SHOWN ABOVE) AFFECTING $T_{SURFACE}$

- DIURNAL HEATING & COOLING CYCLE
- SULFIDE OXIDATION
- VOLCANIC & HYDROTHERMAL ACTIVITY
- URANIUM & THORIUM DECAY
- ORGANIC DECAY



SCHEMATIC DIAGRAM OF AN AIRBORNE INFRARED SYSTEM

THERMAL INFRARED STUDIES AT LOW ALTITUDES

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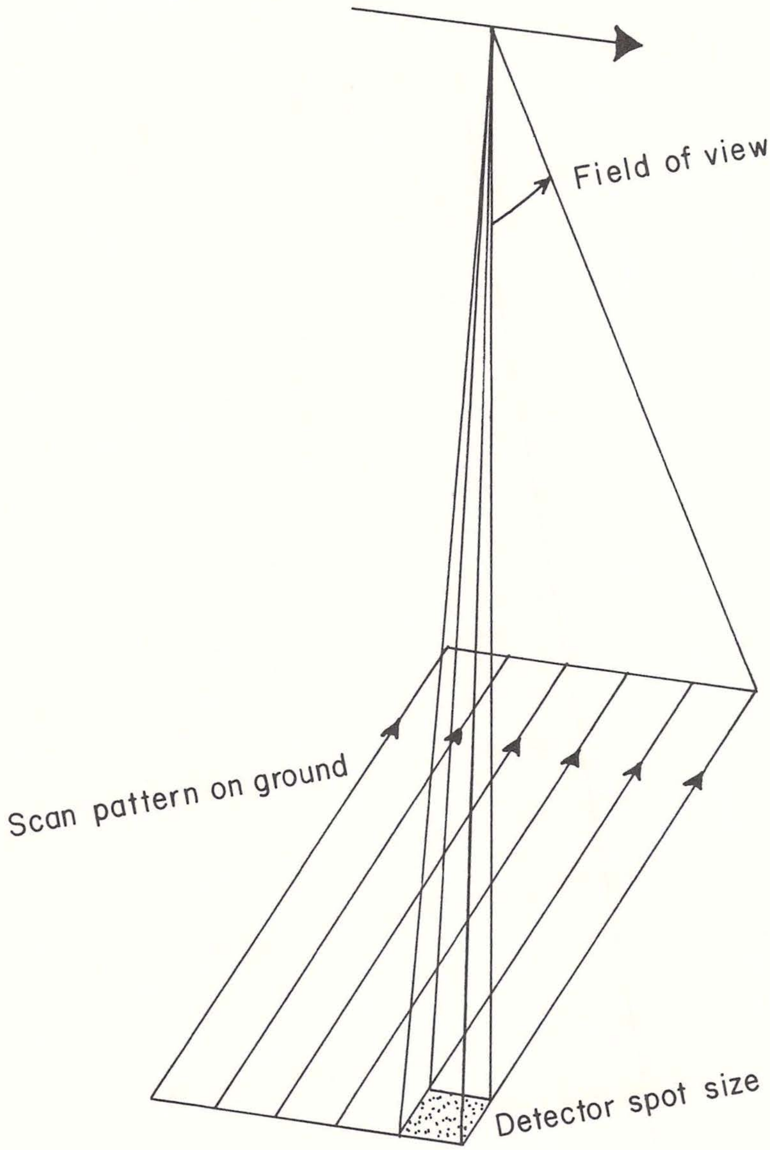
An infrared sensor is a scanning device that functions somewhat like a television receiver by producing a near-continuous image from a series of line scans. Because the terrain is not photographed directly, the term "infrared imagery" is used to describe the final image that is printed onto photographic film.

The line-scanning function is accomplished by means of a rotating mirror that scans the terrain in continuous strips perpendicular to the line of flight. The image from the mirror strikes an element sensitive to infrared radiation. The signal from the sensitive element is electronically amplified and produces a visual image on a cathode ray tube or by means of a glow tube. A final photographic record is made from this visual image.

The film moves across the exposure station at a rate proportional to the aircraft speed-to-altitude ratio, and the result after photographic development is a thermal radiation image of the area flown over. Film density represents effective radiation temperature. Dark areas depict cool thermal signals and light areas warm or hot thermal signals on a positive print. The width of the scanned strip in the direction of flight is directly proportional to the altitude of the aircraft above the terrain and the total scan angle.

The spot size, or instantaneous field of view, or "one-look" area of a detector system is rather small. A typical value is 2.5 milliradians. This means that at a height of 1000 feet above ground level, the detector receives infrared



Altitude (feet)	Spot size (feet)	Length of Scan Line: 120°FOV (Bendix) (feet)	(miles)	77°20'FOV (Daedalus) (feet)	(miles)
1,000	2.5 × 2.5	3,464	(.6±)	1,600	(.3±)
3,000	7.5 × 7.5	10,393	(1.9±)	4,800	(.9±)
5,000	12.5 × 12.5	17,320	(3.28±)	8,000	(1.5±)
7,000	17.5 × 17.5	24,248	(4.5±)	11,200	(2±)
10,000	25.0 × 25.0	34,640	(6.6±)	16,000	(3±)
20,000	50.0 × 50.0	69,280	(11±)	32,000	(6±)
65,000	162.5 × 162.5	221,750	(420±)	104,000	(20±)

Figure 1. Detector spot size and length of scan line

radiation from a ground area or spot size of approximately 2.5 x 2.5 feet. Altitudes and corresponding spot sizes are given in figure 1. From these data it is obvious that a flight of over 3,000 AGL is not very useful in a wild life census, however, flights of 7 - 10,000 AGL are useful for mapping the thermal regimen of a river system.

The aircraft ground speed is on the order of 150 - 180 mph and flying height is generally less than 10,000 feet. Greater heights are used for regional investigations with smaller scale imagery and lower heights (less than 5,000 feet) are used for detailed investigations.

Depending on the make and model of scanner, the angular field of view or total scan angle ranges from 73° to 120°. The average scan rate is 80 - 120 scans/second. The length of a single scan line for two common scanners also is given in figure 1.

Radiant temperature sensitivity of infrared scanners varies with detector size and optical configuration. Manufacturers claim 0.1°C - 0.3°C and this has been established on the ground and in the laboratory. However, experience has shown that we can really only map temperature at best to 0.5°C and usually only to 1°C.

Quantitative temperatures are not recorded; rather, the gray scale of the imagery records the relative amount of radiation emitted by one spot on the ground as compared with adjacent spots. Since the technique is passive, that is no energy is transmitted to the ground, it is restricted to observing the thermal properties of the upper few microns of the earth's surface -- land or water -- really a "skin" phenomenom.

Infrared images often bear strong resemblances to conventional photographs, but they have inherent geometric distortions due to the nature of line scanning. The scanner operates at a constant angular rate, so the detector spot size or look element at either edge of the field of view is larger than in the center, directly beneath the aircraft. The imagery is recorded on the film, however, at a constant linear rate, so that each look element is recorded in an equal space on the film trace. This compresses the edges of the imagery, resulting in the distortions. Hence, except along the nadir line directly beneath the flight line, the final image is an oblique view of the terrain and the scale varies with distance from the nadir line. Because scale along the line of flight may differ appreciably from that across the flight path, precise measurements of images may not be feasible. Infrared imagery may therefore be regarded as more suitable for making identifications than for purely mensurational uses and they should be regarded as supplements to, rather than replacements for conventional aerial photograph.

It is common practice to correct the imagery for roll, but usually no correction is used for pitch or yaw. If there is a crosswind at the time the imagery is made, the aircraft heading and aircraft track do not coincide. Because of this, all points except those at the nadir are skewed in the direction of the aircraft crab (fig. 2). Any turns of the aircraft during the imagery run will cause straight roads parallel to the flight track to appear curved, and straight roads that cross the flight path at oblique angles may appear to be S-shaped (fig. 2). To minimize the effects of distortion, interpreters generally work with the central two-thirds of the image strip. Ideally, adjacent flight lines are spaced to allow at least one-third overlap on the edges.

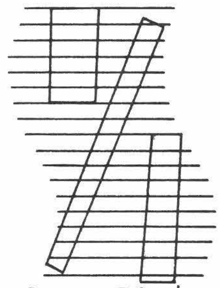
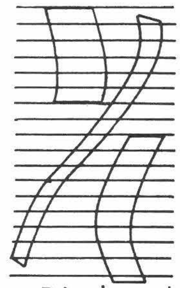
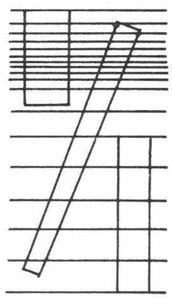
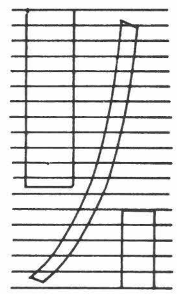
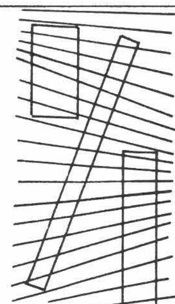
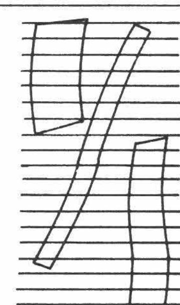
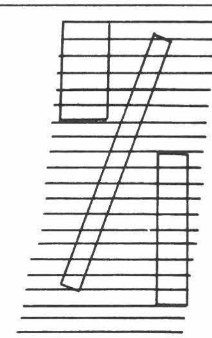
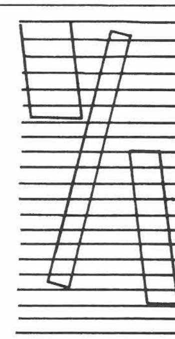
	Aircraft Motion	Scan Mode	Recording Mode	Identification
Direction of Flight →	Roll	 Scan Raster Displaced Sideways	 Images Displaced Sideways	Wavy appearance of straight lines (roads). Cyclic displacement of imagery synchronizing with the aircraft rolling.
	Pitch	 Uneven Scanline Spaceing	 Images Compressed and Stretched	Compresses and elongates images of objects (occurs) less frequently than roll).
	Yaw	 Scan Lines Skewed	 Image Edges Skewed or Displaced	Compresses and elongates images of objects laterally across the film. Wedging takes place and image edges are skewed.
	Drift	 Scan Lines Displaced Uniformly	 Images Displaced Uniformly	Rectangles are distorted into parallelograms. Angle of distortion is approximately equal to the drift angle. Under normal conditions of drift (less than 10°) this distortion will be quite small.

Figure 2. Image Distortions on Infrared Imagery Resulting from Aircraft Motion
Reference: TM 30-245/NAVAIR 10-35-685/AFM 200-50

It is advisable not to use roll compensation in rough air as the gyroscope does not react as quickly as the turbulance affects the aircraft and the resultant imagery is useless. The roll compensation is best in gentle air as the gyroscope and air currents are more in phase.

Some scanners have an automatic gain control device. This means that the responses of "hot" and "cold" areas are electronically enhanced automatically and that film densities as related to temperature values are constantly changing. This renders the resultant imagery useless in a quantatative study, however, it may have some usefullness in a qualitative study that only requires relative differences between two adjacent points rather than an exact temperature difference.

A calibrated scanner has built-in thermal black body references. During each revolution, the detector looks at a black body reference set at the low end and at a black body reference set at the high end of the temperature range. These usually are -10°C and +40°C. The resultant gray scale of values of film density is related to the black body references.

Additional calibration may be obtained by use of an on-board PRT-5 Precision Radiation Thermometer. The usual field of view objective is 2° and tracks the nadir of each flight line and an electric analog of the terrain temperatures are recorded on strip chart recorders.

A calibrated scanner still requires ground station data. The radiometer in the aircraft is calibrated with radiometers used at ground stations. It is best to have a PRT-5 at each end of the flight line recording temperatures, for example, in a slough area where the water is static or at some point on land where constant conditions are maintained during the flight. Additional PRT's may be used along the flight line. All of these should be calibrated and justified with the black body references and with each other before and after the flight.

From what I have just discussed it should be obvious that the difference between an uncalibrated scanner and a calibrated scanner is the difference between qualitative and quantitative results.

Solar radiant energy provides the principal source of infrared emissions. In daylight, surfaces with a high absorbance for sunlight store up large amounts of heat, while surfaces having high reflectivity for solar radiation absorb little heat. The temperature that results depends both on the color and on the physical structure of surfaces. A concrete highway will absorb heat at a rapid rate, but its temperature may rise very slowly. This is because the heat capacity of concrete is quite high, and the thermal connection between a highway and the earth is well established. By contrast, grass and other low vegetation heats up quickly, but their capacity for storing heat is limited. As a result, temperatures of such vegetation tend to closely follow diurnal changes in thermal conditions. Bodies of water have high capacities for storing heat. Water surfaces heat up more slowly than adjacent soil and rock surfaces, and they also release heat at a much slower rate during a cooling period. In general, cooler surfaces, such as water and trees, will appear dark in an infrared image, while warmer surfaces, highways, industrial plants, houses, thermal springs, and liquid effluents will appear brighter in tone. Infrared radiation may penetrate dust and haze, depending on the size of the aerosol particles, but clouds, high surface winds, and rain greatly reduce image quality. Infrared systems produce good daytime imagery. However, since they respond to energy radiated from beyond the visible spectrum, night infrared missions yield excellent results. For many purposes, far infrared data flights obtain their best imagery after dark when there is no interference from solar insolation. The best times for thermal infrared missions are between 10:00 a.m. and 2:00 p.m. and before dawn or after dark. Times depend on the purpose of the mission. For a deer census, for example, a nighttime mission would be desirable as during the daytime hours the deer seek cover in the dense foliage of wooded areas, however, at night they leave the protective cover and come to the open areas to feed and for water.

One should keep in mind that remote sensor data are only tools that aid in decision making. Sensor data does not provide a panacea. The data content on a single image obtained by remote sensing can be enormous, usually consisting of tones, sizes, shapes, heights, textures, patterns, and shadows. It is rough unfiltered information. The maximum utility of sensor data can be obtained only if the relevant information can be extracted and accurately correlated with supplemental imputs obtained on the ground. To correlate the remote sensor data with the geologic, hydrologic, flora, fauna, and cultural features, it is necessary to investigate ground conditions in great detail. Studies conducted on the ground, of course, depend on the kind of data you wish to obtain. Two important questions to be answered before planning any mission are "Why do I want the data?" and "What am I going to do with the data?"

Because infrared imagery is presented on standard photographic film, there is an immediate attempt on the part of the interpreters to compare infrared imagery with visual photography. It should be remembered that the information recorded on this imagery is based on thermal radiation characteristics of surfaces rather than their light-reflective photographic qualities. The amount of infrared energy transmitted is proportional to the object's emissivity and temperature. Unless these factors are understood, the unique advantages of infrared reconnaissance cannot be gained, and some interpreters may decide that an infrared image is nothing but aerial photography with poor resolution qualities.

Now what use can we make of thermal infrared imagery? Thermal patterns can be mapped in great detail especially in surface water. It can be useful in finding the location of ground water discharge and in studying the circulation and diffusion of natural waters and of liquid discharge from industrial plants and sewage effluents. It can be used for prediction and assessment of flood damage, improved water management, assessing the characteristics of lakes and reservoirs, surveillance of snow and ice distribution, and monitoring water pollution.

Thermal infrared can aid in the detection and mapping of forest fires because of the great contrasts in surface temperatures that accompany such fires. Infrared will penetrate smoke and can detect seperate spot fires undiscernible when normal vision is obscured by smoke. At night it can detect incipient fires located beneath the forest cover and can aid search parties in locating lost or run-a-way persons.

Leaf temperatures can be remotely measured or relative temperatures inferred. Potential applications exist in determining various aspects of plant health, age, relative water supply or degree of irrigation. Large area coverage appears to offer the hope of early detection of frost damage to fruit trees.

Thermal infrared mapping can be of immense value in updating geologic maps, reconnaissance for new mineral resources, detection of unknown archeological sites, and the prediction of natural disasters such as landslides.

To examine the cost of Thermal Infrared Missions let us plan to fly the Mississippi River as it flows past Iowa. The length of this portion of the Mississippi River is 330 statute miles. We will plan for two flights, one at mid-day and one either in the evening or pre-dawn. We will request: 1-that the scanner utilize the 8-14 micron range so that it will record emitted rather than reflected energy; 2-that the scanner has a high resolution--that is, the smallest "spot-size" possible at the altitude we wish to fly; 3-that the scanner have a tri-metal detector for the highest thermal sensitivity; 4-that the scanner be internally calibrated by two black body references set at the high and low end of the scale; 5-that the data be recorded on electromagnetic tape as well as film. The estimate from the contractor is $8,500.00 for the two flights, copies of the thermal imagery and reduction of the data in digitized form. A breakdown of this estimate is given in the appendix.

Additional costs to be considered are the cost of the ground crews. We will select stations to sample a variety of river conditions, such as single-channel areas, multiple-channel areas, backwater slough, urban areas, proximity to locks and dams, and incoming tributary drainage. Let us assume that we will require 15 3-man crews for a total of 45 men. We have estimated that the ground crews will spend approximately 15 hours in travel time, preparation of stations, occupation of the stations during the overflights, time in between the flights, etc. Roughly estimating salaries and expenses the cost of the 15 stations will be $3,600.00 In addition the cost of analysis time using the digitized data is estimated to be $1000.00.

Total cost of the mission, therefore, is approximately $13,100.00. A lot of money. But what would be the cost of acquiring these kind of data by conventional means? It would be impossible to acquire and "instantaneous look" of the thermal regimen of the Mississippi River in a few hours or even in a single day by man-power taking point data. The logistics of fielding personnel and equipment is staggering. I doubt if there are enough personnel available and, if there were, a very conservative estimate for salaries and expenses alone would be approximately $36,000.00. Considerable time would be required to reduce these data into usuable form before the final end product--a thermal map of the river system--could be produced.

Therefore, the cost of thermal infrared data acquisition and interpretation is an economical method of data collection and data reduction.

Selected References

Avery, T. Eugene, 1962, Interpretation of Aerial Photographs: Burgess Publishing Co., Minneapolis, Minn., p.142-149.

Sabins, Floyd F., Jr., 1969, Thermal infrared imagery and its application to structural mapping in southern California: Geol. Soc. Am. Bull., v. 80, p. 397-404.

Appendix I
Summary of costs for Thermal Infrared missions

Aircraft ferry time and flight-line time(per hour)	120-150.00
Instrumentation and use charge	1500 .00
Aircraft crew (per day)	475.00
Scanner film cassettes (each)	
(1 cassette covers approx. 100 miles)	9.00
Scanner tape (each)	
(1 tape covers approx. 45 miles)	30.00
Duplication of thermal imagery	
1 cassette, 15 feet at $0.75/foot	11.25
transportation and handling charge (each)	4.00
Thermal scanner imagery processing charge	
tape to film (each)	120.00
Digitized, 6 or 8 levels (per tape)	120.00
charge per line mile	3.00
Ground stations (each)	250.00
Analysis time	
using digitized data	1000.00
without digitized data	4000.00

The above costs are based on information from two different contractors. These figures should be considered as estimates only. They are presented to give you a "ball park" estimate for planning. Most contractors prefer to bid on a total mission plan. Therefore the total cost could vary by 25 percent, depending on the mission.

Most thermal missions also include multi-spectral or color infrared photography on the mid-day flight. These costs can be estimated from the data presented by Prior(this Proceedings) and would be included in the bid-price by the contractor for the total mission.

SIDE-LOOKING AIRBORNE RADAR

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Side-looking airborne radar (SLAR) is a relatively recent, sophisticated remote sensing technique. Many possible uses have been identified, but relatively few of these have been used extensively due to the high cost of SLAR equipment, military classification of systems until recently, and research being restricted mainly to one research institution-the University of Kansas.

This paper will attempt to describe the operation of the SLAR system and some of its uses which have been demonstrated to some extent. However, it should be noted that this paper has certain limitations because the author has no first hand practical experience with SLAR.

Radar Theory and Operation

A general understanding of the design, operation, and theory of radar imagery is essential to the scientist for maximum data retrieval with minimum interpretive errors. Just as it is important for the photo interpreter to know the limitations and capabilities of a lens-film system, it is important for a radar interpreter to know the limitations and capabilities of a radar system. Therefore, certain instruments and concepts are presented and some comparisons are made with the more familiar photographic systems before any evaulation of radar imagery is presented.

There are three basic differences between the principles of radar systems and photographic systems. First, radar uses the microwave spectral region with wave lengths of .1 cm to 100 cm. The wave lengths are much longer than the

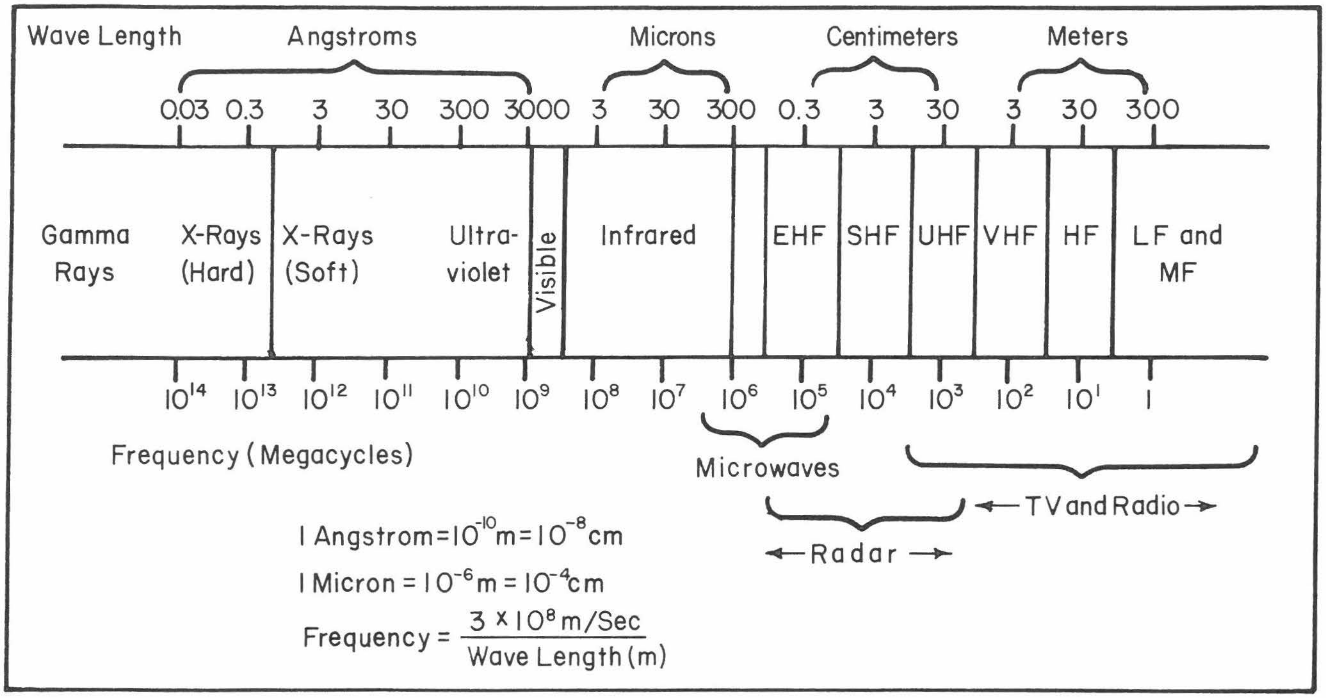


Figure 1. The Electromagnetic Spectrum

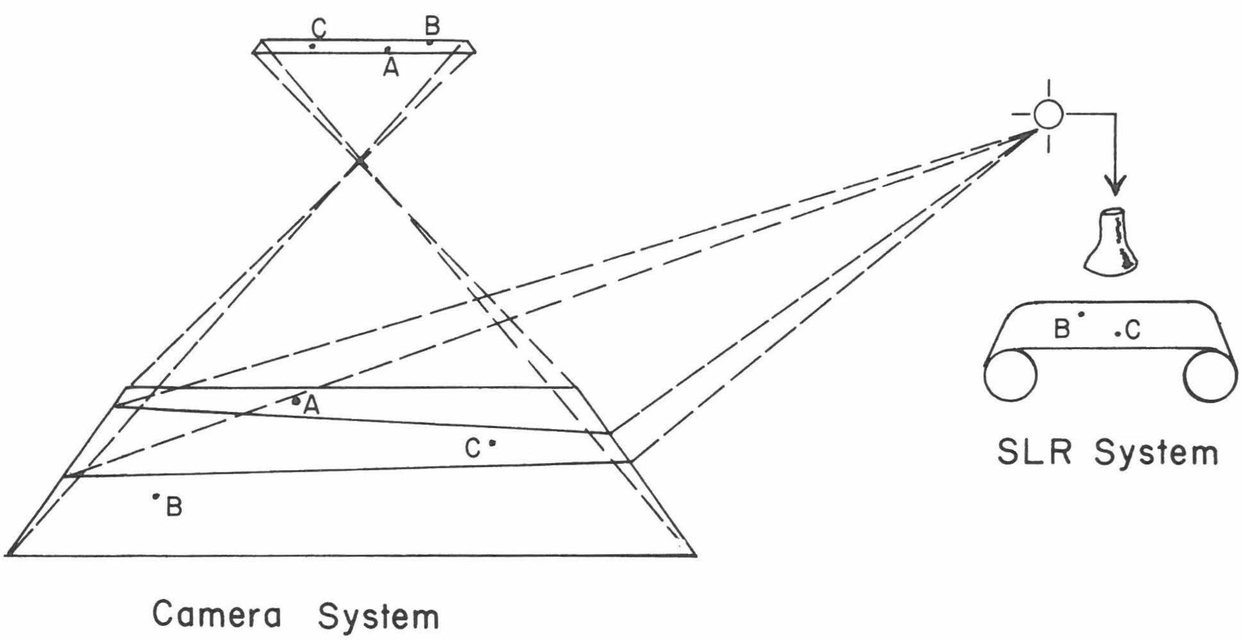


Figure 2. Comparison of Imaging Systems- Photographic and Radar

wave lengths used in conventional aerial photography. The increased wave length gives radar some penetration abilities and necessitates an elaborate electronic imaging system. Second, radar provides its own "illumination" source in the form of microwaves transmitted from the airplane. A photographic system measures energy which originated from the Sun. Third, radar systems and photographic systems measure different properties. Radar is a range detecting device while photography is an angle measuring device. Radar emits a signal ranging from several seconds to ten nano seconds in duration and measures the time required for the signal to return after striking objects and reflecting back. Time, then, is a function of distance. These three differences account for the differences between images produced by the two systems.

The component parts of the radar apparatus are shown below in the block diagram. It should be noted that only a single antenna is needed which serves both in transmission and reception because the transmitter only operates for very short bursts of energy and waits for a return of energy before it operates again. Thus, the return signal can be correlated to a particular transmitted signal.

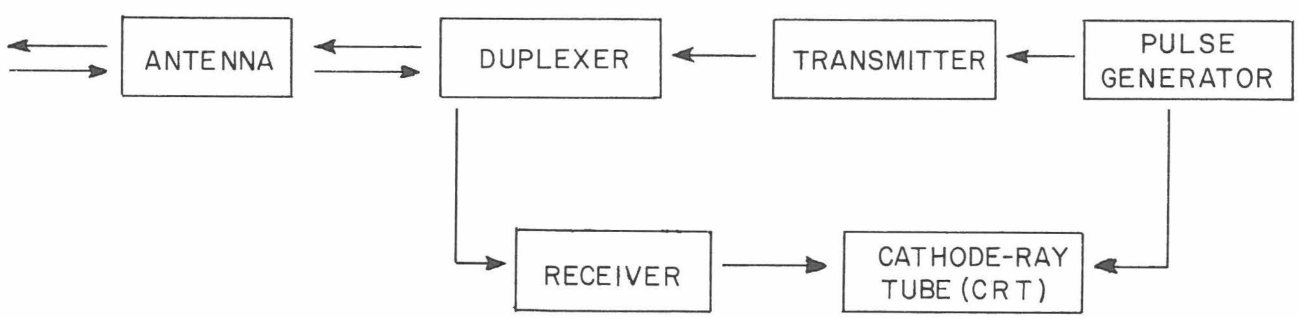


Figure 3. Components of a side-looking radar system.

The functions of the various components are as follows:

1. The pulse generator produces a steady train of pulses to drive the transmitter and to initiate the sweep on the cathode-ray tube screen in synchronism with the transmitted pulse.

2. The transmitter converts each pulse from the pulse generator into a burst of radio-frequency energy.

3. The duplexer is a switch that connects the antenna to the transmitter during the brief pulse period that the radio-frequency energy is generated, and then connects the antenna to the receiver for the rest of the time.

4. The antenna radiates the energy into space in a narrow, shaped beam, and "captures" the weak radiation reflected by distant objects.

5. The receiver is basically similar to a superheterocyne radio receiver, the common type in home use.

6. The CRT display forms a map-like picture in a manner quite similar to a conventional television set.

The operation of an SLAR system is diagrammed in figure 4. The airplane carrying the radar antenna (A) flies with a velocity (Va) in an azimuth direction as indicated by the arrow. At one moment, microwave energy radiates through angle B. The antenna beams in the range direction perpendicular to the azimuth direction. The beam has a definite width (as indicated by the stipled area) which is determined by the antenna construction. The terrain feature capable of intercepting the energy is irradiated at point (a) and a fraction of this is reradiated back to the antenna (A). Point (b) will also reradiate energy back to the antenna but at a later time, as will points (c) and (d) respectively. The difference in time is a function of distance since the energy is moving at a constant 3×10^8 m./sec. The strength (amplitude) of the signal return from any object is a function of many properties. The area discriminated (resolving power), as indicated by crossed area,

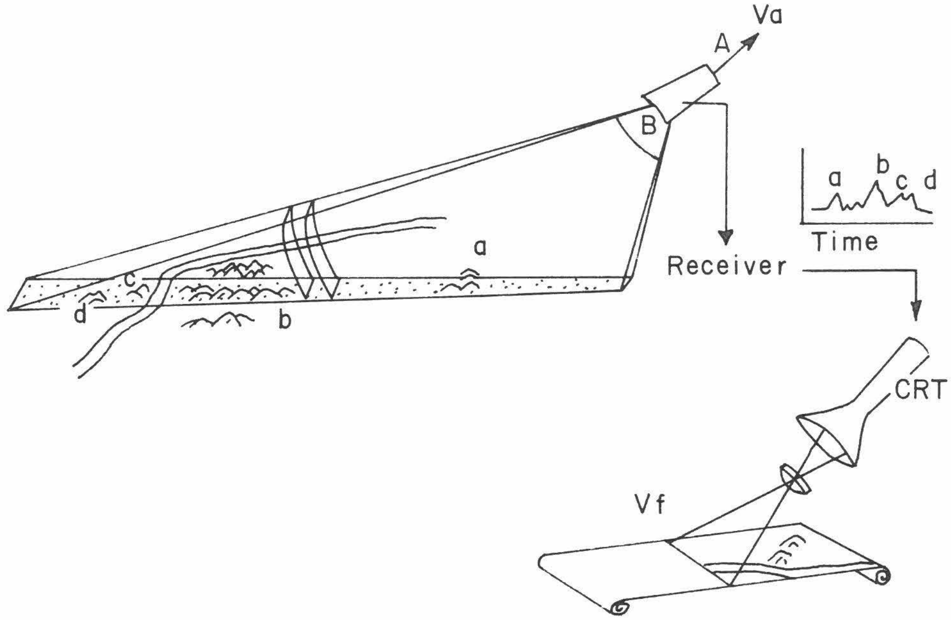


Figure 4: Sketch diagram showing typical SLAR system.

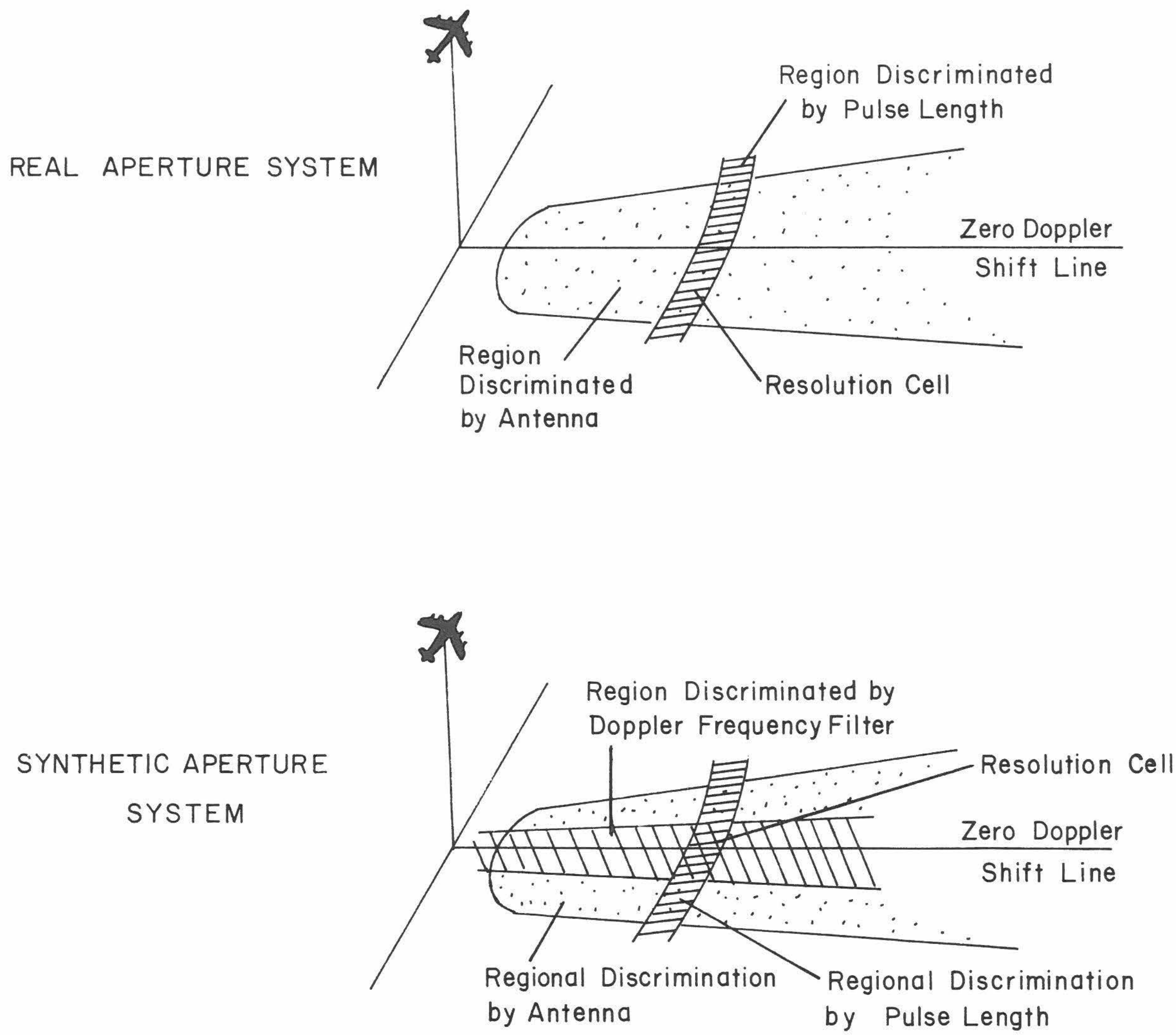


Figure 5: Real and Synthetic Aperture Systems.

is a function of the beam width and the duration of the signal. The signal received back from the terrain features is converted into a video signal by a receiver and displayed on a cathode-ray tube (CRT). The intensity of light on the CRT is a function of the amplitude of the returned signal received by the antenna. The video signal is recorded on photographic film. The CRT scans across the film either at a constant rate or at a rate proportional to actual ground distances. The film advances at a rate proportional to the velocity of the aircraft. Thus, a continuous map-like image is produced. (MacDonald, 1969).

Resolution

Radar resolution is a measure of the minimum seperation between two ground objects which appear individually on the output imagery. It is given in terms of range resolution in the direction normal to the ground track, and azimuth resolution in the direction parallel to the ground track.

The antenna design is important in determining the actual area that is being recorded at one time. The area resolved will obviously determine to some degree the amplitude of the return signal. Two antenna types are shown in figure 5. Generally, the beam width in radians is equal to the wave length of energy divided by the length of the antenna. Therefore, to get high resolution radar imagery a very long antenna is required. Real aperture radar systems have antennas of a maximum of 50 feet in length and have a beam width of one or two degrees. Synthetic aperture systems have very short antennas, but they are equipped to store phase and frequency information through time and distance in flight, thus, becoming effectively very long. Synthetic systems actually do not use beam width to determine resolution at all. They use the slight shift in frequency adjacent to the line of zero change in frequency which lies perpendicular to the flight path. Synthetic aperture systems, using the slight Doppler frequency shift, measure a beam width of less than .1 degrees. (Holter, 1970).

Resolution, or the distinguishable spot size, also is related to the duration of the signal. Very short signals give higher resolution. Typical signal durations are approximately one-tenth second.

Return Signal Strength

The factors affecting radar return strength include system parameters, surface parameters, and atmospheric parameters. The system and surface parameters are important in differentiating materials, while the atmospheric parameters are limiting factors to the system's capabilities.

The wavelength used can have significant importance in the return signal. Almost all radar research has been done with monochromatic wave length transmitters ranging from .86 to 15.0 centimeters. The longer the wavelength, the greater the penetration it will have before it is reradiated. The wavelength determines whether the reflectance comes from the vegetation, ground surface, or subsurface areas.

While on the topic of wave length, it should be noted that the longer wave lengths of radar are responsible for its all weather capabilities. Clouds, regardless of thickness, yield little reflectance to SLAR at normal operating wave lengths. Precipitation, having larger particle size, causes some minor problems. Radar with a wave length of 1 cm. can penetrate moderate rainfall of .5 cm/hr, while radar with a wave length of 3 cm. can penetrate heavy rainfall of 2 cm/hr. Radar with shorter wave lengths become unuseable in precipitation.

Probably the most important factor in the amplitude of the return signal is the angle of incidence of the energy on the object imaged. The angle of incidence is formed by a beam of radar energy and the perpendicular to the surface at the point of incidence. As the angle gets smaller, the energy returned gets larger.

The angle of incidence is controlled by two factors. First, the angle is related to the distance from the flight line and the altitude of the aircraft. See figure 6. The angles which are used range from about 20° to 75° or 80°. Lower angles of incidence are not used because geometric considerations make it difficult to discriminate ground distance using time measurements. Near horizontal angles are not used because shadows become excessive. Second, the angle of incidence is dependant on the slope of the terrain features. On flat terrain, the angle is only dependant on the aircraft's altitude and the distance from the flight line. However, slopes facing toward the radar unit have a decreased angle of incidence. Therefore, slopes that face the radar yield a higher signal return than normally would be expected for their distance from the flight line and slopes that face away from the radar will yield a lower signal return. (Figure 7)

All SLAR systems use polarized energy waves. Most systems use receivers which only receive the same direction of polarization. Other systems receive either cross polarized signals or both like and cross polarized signals. The amplitude of the return may be different with different radar designs depending on terrain characteristics. The material imaged may have a characteristicly strong

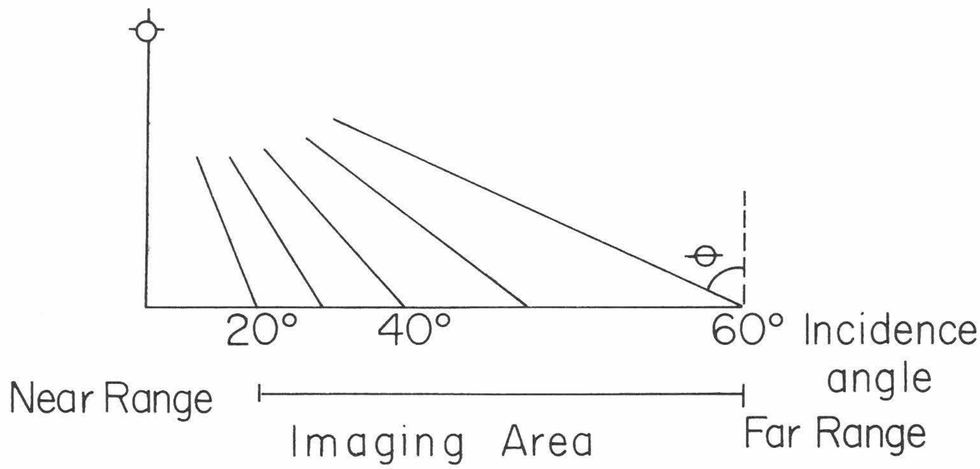


Figure 6: The change in the angle of incidence with distance from flight line.

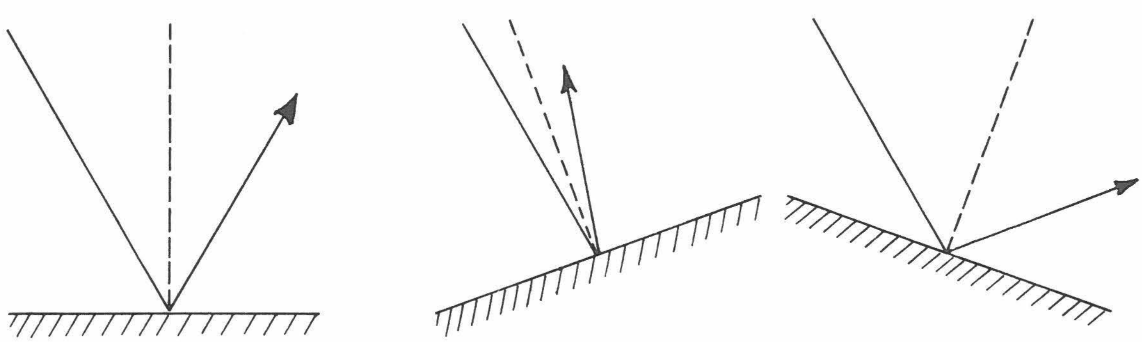


Figure 7: Slope affects signal return.

directional component of polarization. Polarization, therefore, is both a function of the radar design and surface parameters.

Properties of the objects are important to the signal returned to the radar receiver unit.

Dialectic properties of earth materials vary. Reflectivity of the object is influenced by porosity and absorption by conductivity of the radar waves. Highly porous materials holding much water tend to reflect high signal return.

The surface roughness of the material imaged also is important in the amplitude of the returned signal. Roughness refers to the size of surface irregularities in relation to the wave length of the energy used. A smooth surface is one in which the surface irregularities are less than one-half the wave length and a rough surface is one in which the surface irregularities are more than one-half the wave length. Smooth surfaces reflect specularly and yield strong return signals, while rough surfaces scatter the energy through many angles yielding weak return signals. Rough surfaces yield return signals nearly independant of the angle of incidence. It should be noted that by changing the wave length of energy, one might differentiate between objects that previously had not been differentiated at another wave length.

The size of the object affects radar signal return. In general, large features reflect more strongly than smaller ones.

Resonance properties are very important also and can lead to high reflectance even from quite small objects. Particularly important is the corner reflection effect. Energy striking near the intersection of two or three orthogonal planar surfaces undergoes multiple reflections and emerges parallel and opposite to the incident beam. These corner reflections are particularly common in urban areas.

Basically, atmospheric parameters are limiting factors. Oxygen is absorbed in the .5cm wave length and water vapor is absorbed in the 1.36cm wave length. Absorption is not important at larger wave lengths. Radar reflections off of large raindrops can be significant also, but light rain and clouds are not important deterrents.

Radar Geometry

The geometry of radar imagery is important in making interpretations. SLAR systems use either slant range or ground range presentation on the imaging CRT screen. Slant range recording sweeps are linear. Therefore, the spacing between return signals is directly proportional to the time interval between them. Ground range sweeps are modified to equate the image scale to the relative positions of features on the ground. This distinction is shown in figure 8. Radar waves, equally spaced are shown. Thus, slant range imagery would indicate points a, b, and c as being equally spaced (at a', b', and c'), while ground range would image them proportionally as they really are located on the ground with the distance between a and b being greater than the distance between b and c. Ground range is computed from a known altitude of the aircraft and a measured slant range distance. The relationship used in the calculation for GR_3 in figure 8 is $GR_3 = \sqrt{SR_3^2 - h^2}$ (LaPrade and Leonardo, 1969)

The slant range imagery, therefore, leads to significant distortions. Figure 9 shows graphically two representations of this distortion. Figure 9A shows a com-

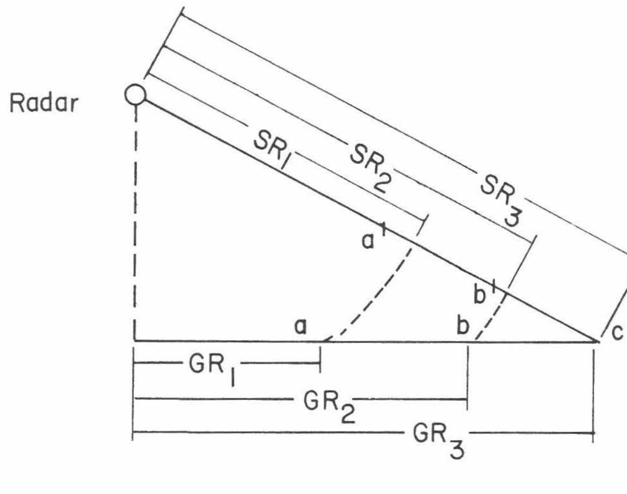
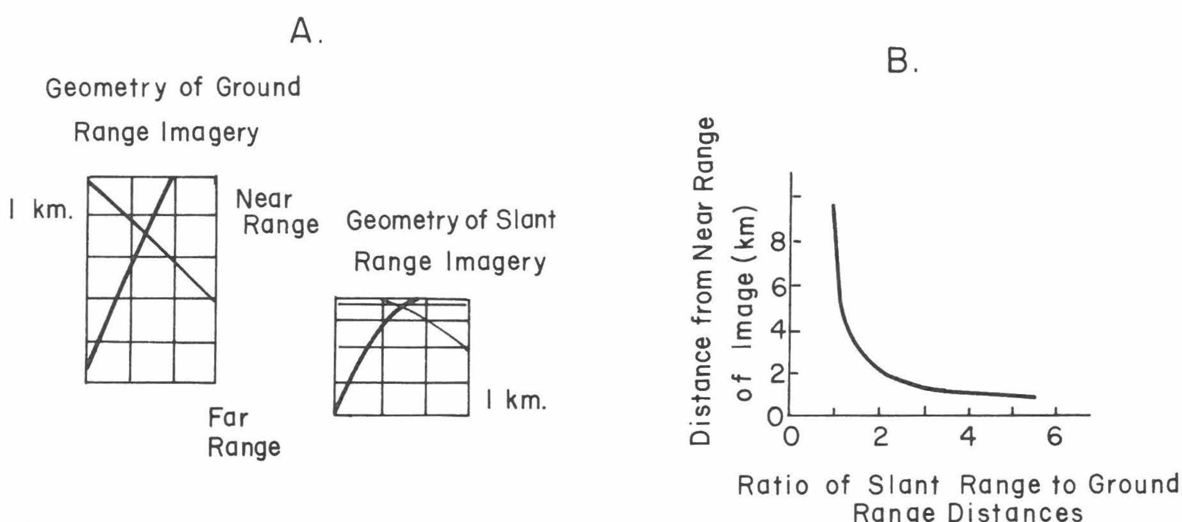


Figure 8: Measurement of slant range and ground range.



A. Geometry of Radar Imagery.

B. Conversion from Slant to Ground Range.

Figure 9: Radar geometry and distortions

parison of the geometry of the imagery as one moves from the near to far ranges. Note that as the slant range imagery goes into the far range the distortion decreases. Figure 9B indicates the ratio of the images from slant range to ground range approaches 1:1 as the distance increases into the far range. Obviously, slant range imagery can't be used for accurate planimetric measurements or maps, but accurate range and azimuth scales can be computed for geological reconnaissance studies. (MacDonald, 1969).

Some other properties of radar images should be noted, as they often are different from those found in conventional aerial photography.

Radar foreshortening is inherant in all radar imaging systems on irregular terrain. It is a function of the angle of incidence and the angle of slope. Slopes which face the radar are recorded as short, while slopes which face away from the radar are recorded as long. In figure 10 $\overline{ab}$ is equal to $\overline{cd}$. T1, T2, etc. are lines recording equal time. Note that $\overline{ab}$ is recorded in a time of less than one unit, while $\overline{cd}$ is recorded in approximately two units of time. Therefore, on the CRT display, the line corresponding to $\overline{cd}$ will be longer. A photograph from the same direction would show $\overline{ab}$ as longer than $\overline{cd}$. (MacDonald, 1969).

Radar layover also is caused because the image is produced proportional to time. This type of distortion is most pronounced in the near range of the radar scan in an area of high relief. If the top of a terrain feature is closer to the radar source in a slant distance than the bottom, the top will be imaged first. Thus, in figure 11 since the energy hits C and D before E and F, C and D will be imaged first. Thus, the order of the recording on the CRT would be B, C/D, E/F, and G. This distort-

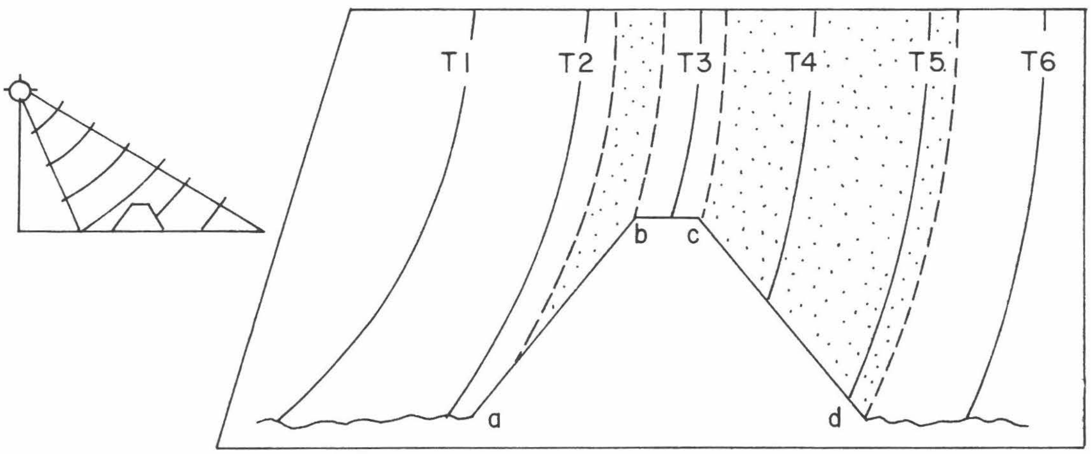


Figure 10: Radar foreshortening.

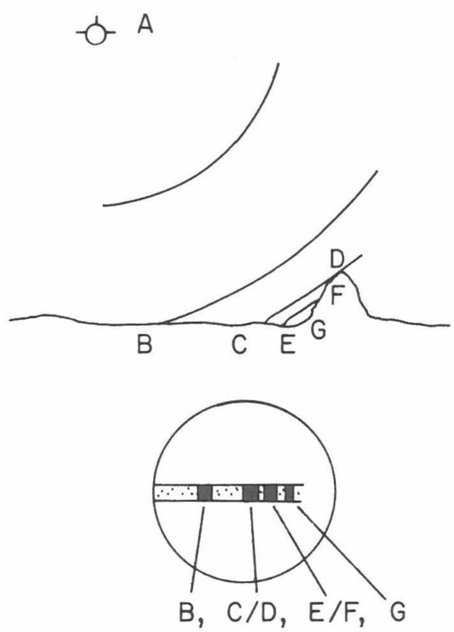


Figure 11: Radar layover.

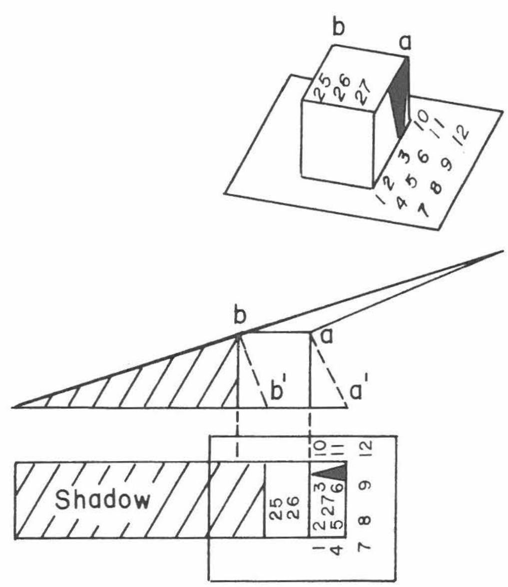


Figure 12: Simulation of radar striking a box with the resultant shadow and layover.

ion is a primary reason for not using radar coverage for angles of incidence in the near range of less than about 20°. (Leonardo, 1963).

Figure 12 shows graphically a simulation of how a box would be imaged in the near range. Notice that the movement of the top of the box is towards the radar. Conventional photography would appear to move it away. The inversion caused by the radar would not be caused by conventional photography. (Leonardo, 1963).

The shadow formed on SLAR imagery is very important. Since SLAR provides its own illumination, all shadows lay directly away from the radar unit. But, while they are always away from the source of radar, the length is constantly getting longer with increasing distance from the flight line. See figure 13.

In addition, it should be noted that radar imagery can be distorted in several other ways. First, changes in the altitude of the radar can cause constant variation in scale in the range direction. Second, improper synchronization of the film speed to the air speed can cause a change of scale in the azimuth direction.

The geometry of radar imagery is important not only because of distortions which might cause interpretive problems, but properties of the geometry can be exploited to determine certain information.

Layover and shadows are the basis for determining the heights of objects when combined, in some cases, with certain flight parameters. A full discussion of this topic can be found in LaPrade and Leonardo (1969). Here, only some basic geometric relations will be shown. These may aid our understanding of slant and ground range imagery as well as aid our methods of radar interpretation.

In figure 14, the wave front first reaches point A and then point E on the tower. Therefore, $\overline{AB}$ represents the time that radar energy is received on the tower. There is no energy received between points E and C because it is in a shadow. Thus, in slant range imagery, the top and bottom of the tower are recorded at points A and B respectively and the shadow would correspond to $\overline{BC}$. In ground range imagery, the top and bottom of the tower would be recorded at points D and E respectively and the shadow would be recorded as $\overline{EC}$. These basic relationships are important in all measurements of height.

But terrain features are not just vertical. Therefore, in figure 15, the flight parameters, as well as shadow lengths, must be known. H is the height of the airplane, G is the ground distance from the flight line to the end of the shadow, R is the slant distance to the end of the shadow, h is the height of the mountain, S_R is the shadow length represented on slant range imagery, S_G is the shadow length represented on ground range imagery, A is the top of the mountain on slant range imagery, and B is the top of the mountain on ground range imagery. For slant range imagery, the height is computed by: $h = S_R \frac{H}{R}$. For ground range imagery, the height is computed by $h = S_G \frac{GH}{\sqrt{G^2 + H^2}}$. This method produces results which are accurate to about three percent. (LaPrade and Leonardo, 1969).

Dalke and McCoy (1969) have used the distortion of foreshortening to determine regional slopes. When used in an conjunction with statistical methods, the values they obtained were highly accurate.

One last technical detail should be mentioned before beginning the discussion of the interpretation and use of radar imagery. Most of the research that

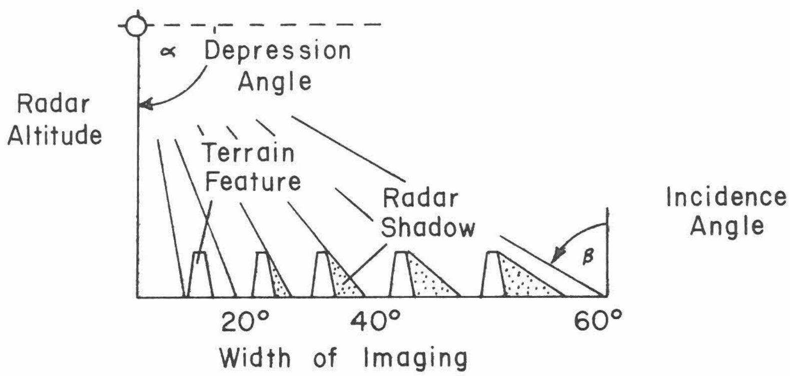


Figure 13: Characteristics of shadows in SLAR system.

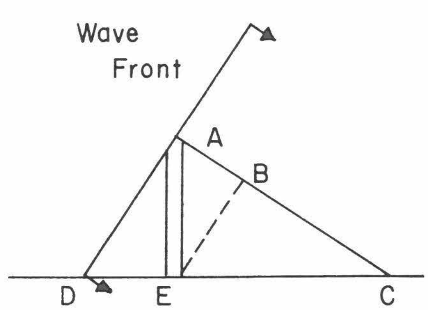


Figure 14: Geometric relations for determining height of tower.

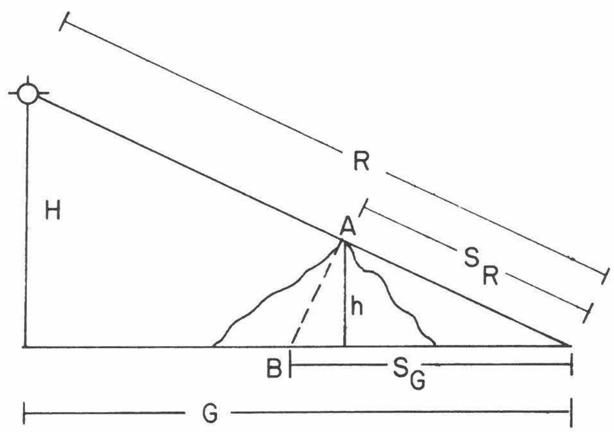


Figure 15: Determining height of non-vertical terrain feature.

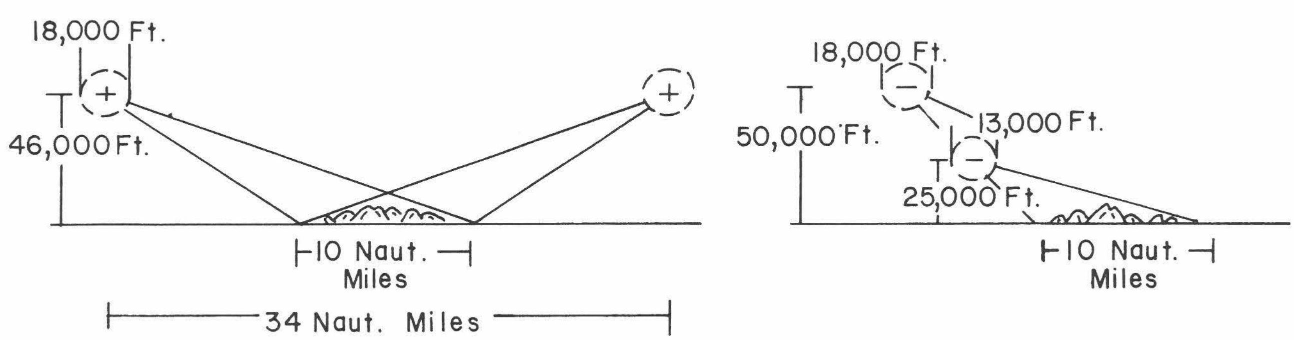


Figure 16: Permissable radar stereo flight configurations.

has been done with radar has not provided stereo coverage. However, true stereo coverage is possible. Figure 16 indicates the requirements that must be met. The aircraft must be positioned within prescribed altitudes and flying radii. Note that the imagery can be produced either from the same or opposite sides. (LaPrade, 1963).

Interpretation of Radar Imagery

Generally it has been concluded that photo interpreters can make the switch to radar interpretation without much difficulty. Radar interpretation is concerned with the same tone, texture, shape, and pattern with which photo interpretation is concerned. These criteria are handled in essentially the same way both in radar and photo interpretation.

Tone is dependant on the amplitude of the returning radar signal which has been converted into a video signal and recorded on photographic film as various shades of gray Tone varies with the many factors affecting the strength of the returning signal.

Texture relates to the erosional dissection of the area covered. Frequently, it is an aid in determining general lithologic units and the attitude of the beds. Slight textural differences are enhanced by radar imagery because the "lighting" is always oblique.

Shape is defined as spacial form. As in conventional aerial photography, many geologic and land use features are interpreted easily by their shape alone on radar imagery.

Pattern relates to the arrangement of features. Radar imagery, with its wide areal coverage, can often give much information about regional land use as well as large regional structures, joints, and tectonics of the area.

The large areal coverage of SLAR imagery makes it a useful tool for large reconnaissance studies. Trained photointerpreters seem capable of interpreting 100 square miles per hour according to one study. There seems to be little problem for a photointerpreter trained previously on aerial photography to adapt to SLAR imagery.

Previous Studies

Relatively little SLAR research has been undertaken. The following describes briefly some of the types of studies which have been completed in various fields.

The field of geology has used SLAR imagery the most effectively and extensively. The wide areal coverage and all weather capabilites made radar a good reconnaissance tool to image a portion of Panama. The imagery indicated essential structural features as well as discriminated major lithologic groups.

Joint systems, faults, and dip slopes also were found. However, these features were either enhanced or obscured depending on the direction from which they were imaged. Thus, it was concluded that geological structure was best imaged from two or preferably four directions.

Surficial material textures have been differentiated by using varying wave lengths of radar. Weathered rock material was differentiated from unweathered rock and gravel.

Certain sedimentary rock units have been better discriminated by radar, but generally conventional photographs are better for this distinction.

Drainage patterns especially are noticeable as a result of the oblique illumination of radar. The high reflectance of slopes facing the radar unit and the shadow areas behind the slopes emphasize minor as well as major stream valleys.

Field boundaries, some crop types, crop height, and crop densities can be determined by SLAR with two polarization directions imaged at two periods of time. Thus, agricultural land use can be documented to some degree.

Urban areas and transportation-communication networks, are easily identified. Thus certain land usage, census, and planning information may be obtained.

The nature of snow cover can be determined also. Ice can be differentiated from dry snow and wet snow. In addition, some penetration is possible to image beneath thin dry snow coverage.

References Cited

Dalke, G. W. and McCoy, R.M., 1969. Regional Slopes with Non-Stereo Radar: Photogrammetric Engineering v. 35, no. 5, p.446-452.

Holter, M. R., 1970. Imaging with Non-Photographic Sensors: in Remote Sensing, Nat. Acad. Sci., Washington, D.C.

LaPrade, G L., 1963. An Analytical and Experimental Study of Stereo for Radar: Photogrammetric Engineering v. 29, no. 2, p. 294-300.

__________ and Leonardo, E S., 1969. Elevations from Radar Imagery: Photogrammetric Engineering v. 35, no. 4, p. 366-371.

Leonardo, E. S., 1963. Comparison of Imaging Geometry for Radar and Camera Photographs: Photogrammetric Engineering v. 29, no. 3, p. 376-380.

MacDonald, H. C., 1969. Geologic Evaluation of Radar Imagery from Darien Province, Panama: Modern Geology v. 1, no. 1, p. 1-63.

Information Note 012272

1971 CORN BLIGHT WATCH EXPERIMENT DATA PROCESSING, ANALYSIS, AND INTERPRETATION

by

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INTRODUCTION

The nature of the Corn Blight Watch Experiment and available resources to conduct the experiment dictated that there be several centers of activity supporting the overall objectives. In this paper the Corn Blight Watch Experiment will be described from the point of view of data processing, analysis, and interpretation procedures. Data availability will be illustrated by discussing the data flow for the experiment and the data catalog system. Descriptions of the analysis procedures, a storage and retrieval system called the Corn Blight Record, and a capability for results summarization will be presented.

Early planning meetings for the experiment resulted in the concept of a central data reduction center where all preprocessing and processing functions would be performed. The data collected would be delivered to this center and a final output would be sent to the USDA Information Center in Washington. The advantage of a central site was that maximum communications between the individuals performing separate reduction functions would occur. Also, the time required for transferring data between data reduction locations would be minimized. The central reduction site concept was considered optimum for achieving the greatest possibility of success for the experiment; however, the resources available to the experiment did not permit its implementation. An alternate plan was conceived and implemented. Centers were identified where resources were made available to perform particular processing functions. A data flow plan which maximized the efficiency of data transfer and minimized the data delivery time was designed.

The principal data acquisition centers were: NASA/MSC for the collection of high-altitude photography, Willow Run Laboratories at the University of Michigan for collection of multispectral data, and the ASCS and CES county personnel to serve as ground enumerators. The principal data processing centers were: NASA/MSC for the processing of high altitude film and the identification of frames showing the segments identified in the sampling plan; the Statistical Reporting Service of USDA in Washington, which assumed the responsibility for collecting, editing, and collating all ground observations, drawing inferences from them, and delivering products to the data reduction center at LARS; the Willow Run Laboratories at the University of Michigan, which accepted the responsibility to process 15 flightlines of multispectral data and report the results to the LARS/Purdue Data Reduction Center; and the LARS/Purdue data reduction center, where the other flightlines of multispectral data were to be reduced and the 210 segments of photography were to be interpreted. LARS was also responsible for collating and analyzing all interpreted results and for reporting them to SRS in Washington and to other participants in the experiment.

Since the principal data reduction center was located at LARS/Purdue and most data products were handled at this center, a method of keeping track of data products was required. Therefore, a data storage and retrieval system was established and maintained to aid in accessing the data collected.

The purpose of the system was to:

Store data products in an organized library.

Maintain a record of all data stored and reduced for future access.

Report to the photointerpreters and multispectral data reduction teams all required information in a format that allowed the simplest access possible by the teams.

Record data reduction results from photographic and multispectral scanner data reduction teams and merge the results with the data collected.

Report data reduction results to the Statistical Reporting Service in Washington and to other participants in the experiment.

DATA FLOW

The Corn Blight Watch Experiment was conducted in three phases. The data flow plan is best presented by describing the transfer of data from data acquisition centers to and between the data processing centers for each phase. The data flow plan is graphically shown on diagrams which include each center and each tranfer of data between the centers. Each center is shown on the diagrams as a node with an abbreviation for the center. These abbreviations are identified in Table 1.

Phase 1

During Phase 1, baseline data for the entire Corn Blight Watch Experiment were collected between April 15 and May 15. Data acquisition for Phase 1 included the collection of black and white photography by ASCS enumerators. Processing included the reduction of photography to a scale of 1:20,000, the outlining of tracts and fields on the reduced photography, and the reporting of farm operator

Table 1. Principle Centers of Data Acquisition and Processing

NASA/MSC	- NASA Manned Spacecraft Center, Houston, Texas
WRL/U. of Michigan	- Willow Run Laboratories, University of Michigan aircraft system
ASCS County	- Agricultural Stabilization and Conservation Service of USDA County Offices
SRS/Washington	- Statistical Reporting Service of USDA Washington, D.C.
SRS/State	- Statistical Reporting Service of USDA State Offices
CES/State	- Cooperative Extension Service of the seven states
CES/County	- Cooperative Extension Service County Agency
DRC/WRL	- Data Reduction Center, Willow Run Laboratories, University of Michigan
DRC/LARS	- Data Reduction Center, Laboratory for Applications of Remote Sensing, Purdue University
USDA Information Center	- United States Department of Agriculture: Agricultural Information Center Washington, D.C.

interviews through SRS to the data reduction center at LARS. Figure 1 shows the data flow for Phase 1.

NASA flew two six-inch focal length cameras at 50,000 feet to obtain two original exposures of 36 flightlines containing the 210 sample-sites. The scale of this black and white panchromatic photography was 1:100,000. The segments were located, enlarged to a scale of 1:20,000, and three identical prints of each site were delivered to SRS in Washington. A duplicate set of the original photography was also sent to ASCS. All baseline photography was collected with less than 10 percent cloud cover present. For some segments not photographed within the time period or cloud cover condition, existing ASCS photography was used.

At SRS the segment was outlined on one copy of each print and this was sent with initial interview forms to the Agricultural Stabilization and Conservation Service county enumerators. Each farm operation in the segment was outlined and visited by the ASCS enumerators. During the interviews a field ID was assigned to each field, field boundaries and ID annotations were added to the photograph, and the initial interview forms were delivered to SRS. The annotations were copied onto the other two sets of prints and the data on the forms were coded, punched, edited, and recorded in digital format. One set of baseline photographs and a digital copy of the initial interview data were sent to the Data Reduction Center at LARS/Purdue. A second set of baseline photographs was sent to the Cooperative Extension Service in each state where segments were located.

Phase 2

In Phase 2, between May 10 and May 30, color IR photography was collected over the 210 segments and multispectral scanner data were collected over

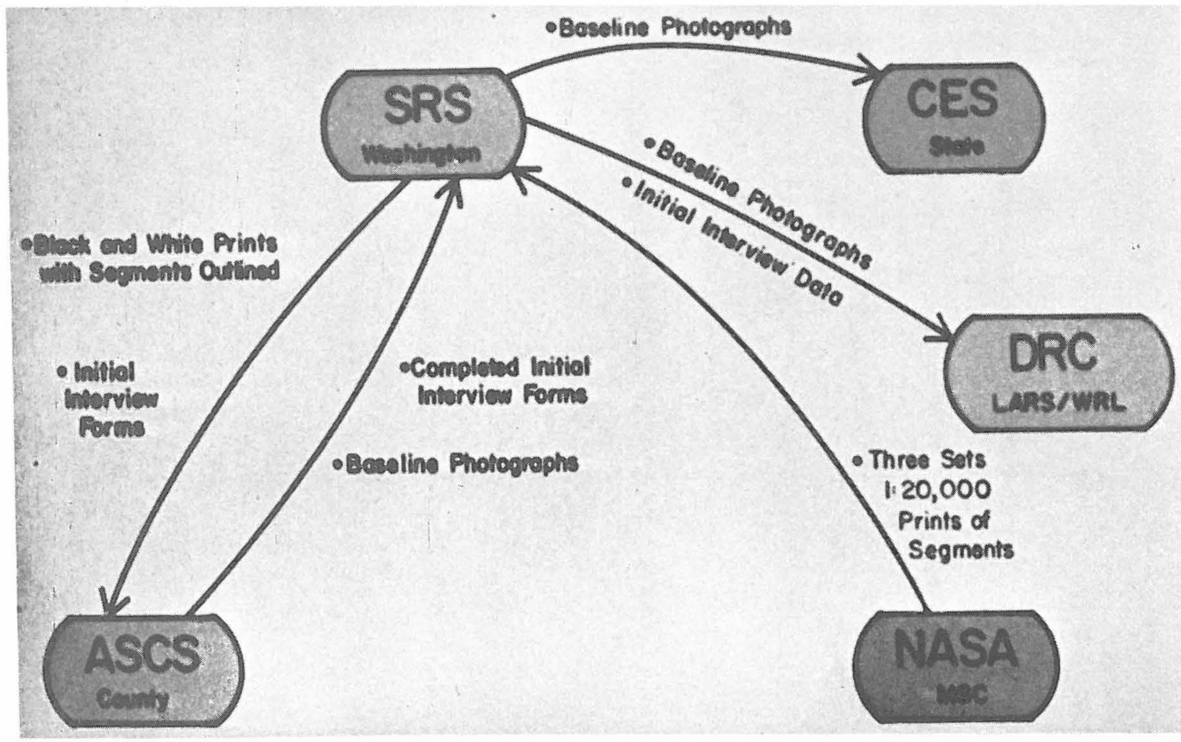

Figure 1. The data flow for obtaining baseline information is designed to provide baseline photographs to the Cooperative Extension Service of each state and baseline photographs and initial interview data to the Data Reduction Center by May 15, 1971. This aspect of the 1971 Corn Blight Watch Experiment was called Phase I, the first of three phases.

the 30 intensive study area segments. This data was analyzed for soils characteristics to provide soils background information for corn fields in the segments. The flow diagram for Phase 2 is shown in Figure 2.

Phase 3

Eight missions were conducted during Phase 3 between June 14 and October 13, 1971. During this phase, color IR photography was collected every 14 days over all 210 segments and multispectral measurements were collected every 14 days over the 30 segments in the Intensive Study Area. Early in each 14-day period, ground observations of up to 12 corn fields in each segment were acquired. These data were processed and sent to the data reduction center at LARS. Fifteen segments of multispectral data and accompanying ground observations were sent to the data reduction center at WRL. The photographic and multispectral data were analyzed and results recorded by the data storage and retrieval system. The analysis results were reduced and reported to SRS in Washington and to other participants in the Corn Blight Watch Experiment. The major data transfers for Phase 3 are shown in Figure 3.

During Phase 3 a new mission was started every other Monday, June 14, June 28, July 12, July 26, August 9, August 23, September 6, and September 20. Each mission was completed in 21 days and results were punched, checked, collated, and reported 23 days after the mission had begun.

Only 14 days were scheduled for the collection of color IR and multispectral data. Data were collected initially over segments when cloud cover was 30 percent or less. If time and weather permitted, reflights were made when data on

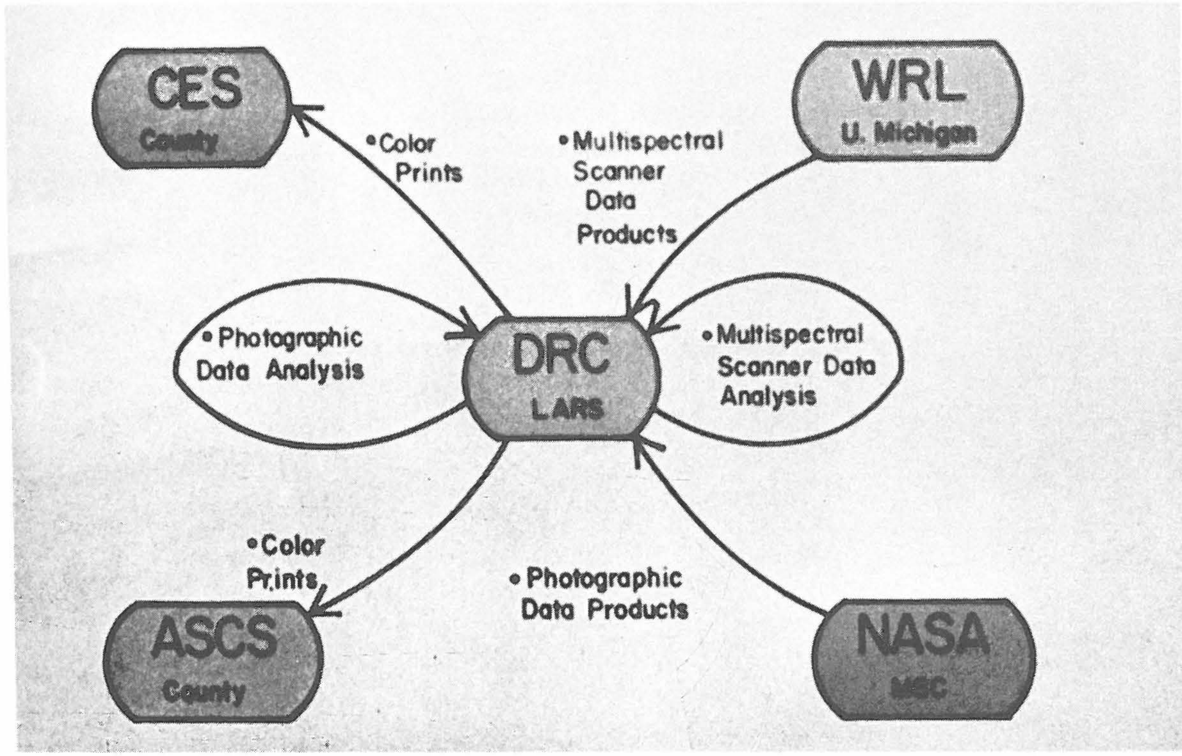

Figure 2. Phase II of three phases for the 1971 Corn Blight Watch Experiment was designed to collect data and perform analysis to determine soils background information for the corn fields. This data flow diagram shows how the objective was completed.

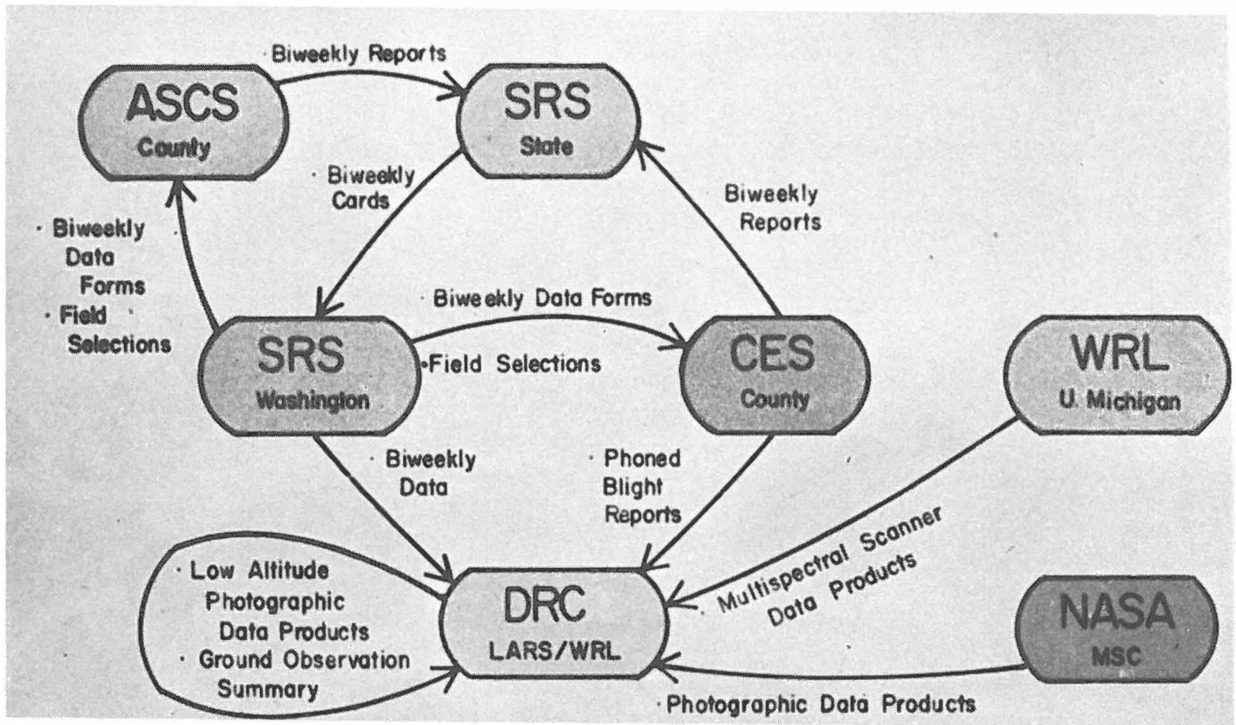

Figure 3. This data flow diagram for the last phase (Phase III) of the 1971 Corn Blight Watch Experiment shows the data acquisition for the experiment. The principal data products are biweekly field data, photographic data, and multispectral scanner data.

initial collection over segments resulted in more than 10 percent cloud cover. All such repeated flights were made when segments in question were expected to be covered by clouds 10 percent or less.

As in Phase 2, color IR photography (film type 2443) was collected at a scale of 1:120,000 over 36 flightlines. NASA/MSC identified the frame numbers to be analyzed and indicated the best frames when re-flights were taken. NASA/MSC sent two transparencies and two positive contact prints of all color IR photography to the data reduction center at LARS.

The WRL aircraft collected multispectral data over the 30 segments in the Intensive Study Area. All data over the segments were checked at the data reduction center at LARS and immediately sent to the analysis center for processing.

When required by the analysis teams, low-altitude large-scale photography was collected over a number of segments within the Intensive Study Area. These data were analyzed in conjunction with ground measurements to establish the exact condition of a number of fields. This information was used both to evaluate the performance of interpretation or of machine processed data results and to determine the source of any difficulty in data reduction.

Six to twelve corn fields in each of the 210 segments were designated by SRS to be visited by CES and data forms were distributed to each enumerator. Their biweekly reports were sent to the SRS state offices during the first week of the period, and, for the 30 flightlines in the Intensive Study Area, results were phoned to the Data Reduction Center at LARS and WRL. In each of 24 segments, up to 6 fields were designated to be visited by ASCS enumerators to provide test field information for data reduction results. These reports were also channeled to the SRS state offices where they were edited, coded, and punched onto data cards. At SRS in Washington, they were error checked, copied onto digital data tapes, and listed on ground observation printouts. The biweekly data were delivered to the Data Reduction Center, and Ground Observation Summaries, described later, were distributed to the analysis teams by day 10 of each biweekly period, the same day as photographic data were available.

Data Catalog

The Data Catalog, a previously existing system at LARS, was used for the Corn Blight Watch Experiment. This data storage and retrieval subsystem includes a method of storing film, analog tapes, and digitized tapes for access by the data reduction teams. The Data Catalog subsystem uses an indexing scheme and computer programs for listing information about the storage location of available data.

Figure 4 shows a block diagram for the Data Catalog subsystem. As the data was received, it was stored in a physical location specifically suited for the storage of particular data types. . . .At LARS, 15 flightlines recorded on the analog tapes were digitized, reformatted, and stored on digital tapes. The remaining 15 flightlines of analog data were entered into the Data Catalog and sent to the University of Michigan. Each set of data, i.e., analog tape, digital tape and physical roll of film, was assigned a storage bin number for retrieval.

The next step in cataloging data was to record the parameters of each flightline for the non-intensive area and of each segment for the Intensive Study Area on a data catalog form. The information or data index recorded included

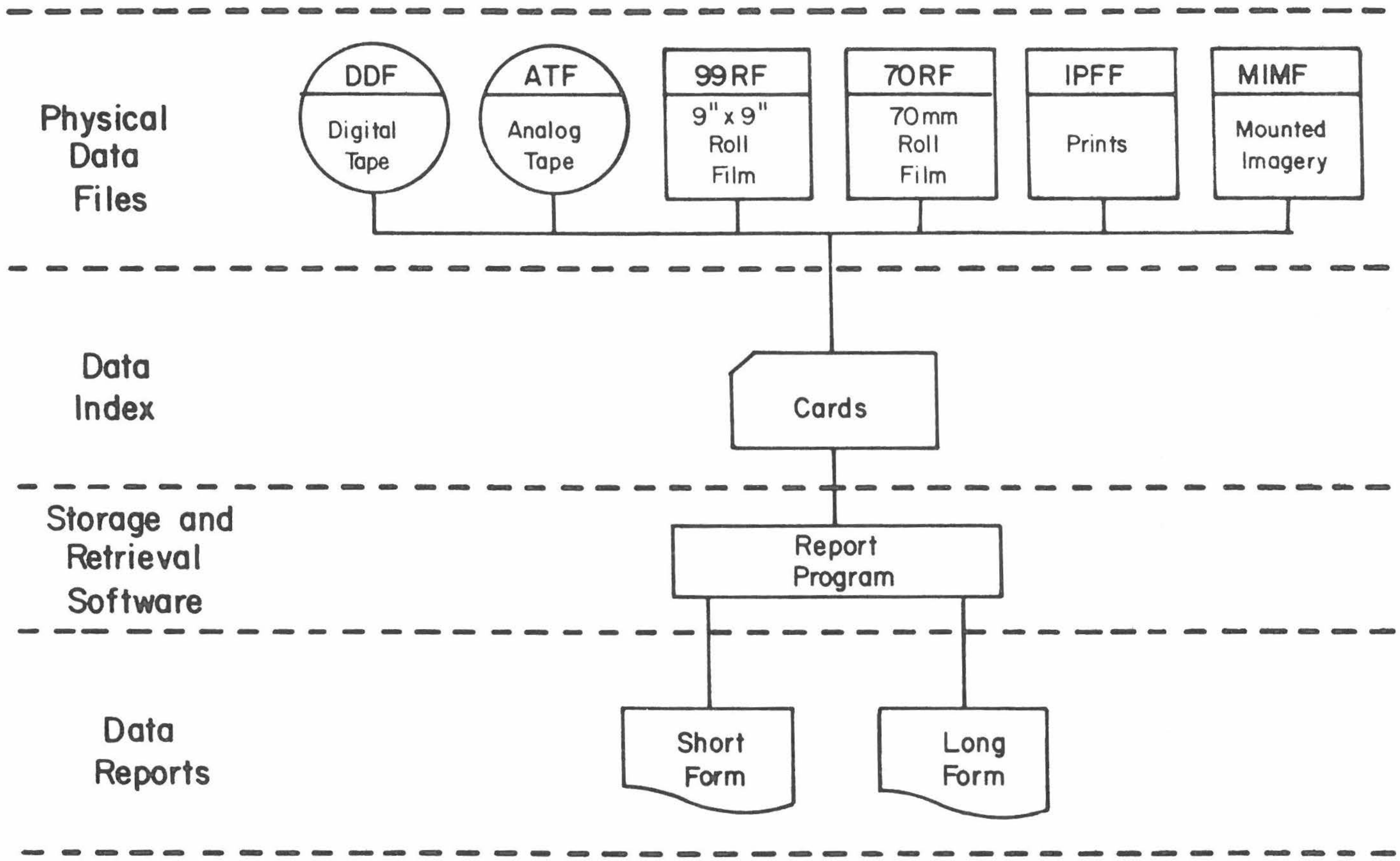

Figure 4. Data for the 1971 Corn Blight Watch Experiment was stored using a data storage and retrieval system called the Data Catalog.

the date, time, ground heading, equipment, film type, and type of data. This information was punched on computer cards and entered into computer data files. Storage and retrieval software was written to make use of the data files in reporting to the analysis teams what data was available for analysis and its physical location. Two forms of output were implemented. The short form, or table of contents, included a brief description of all data collected. In most cases this listing was adequate for retrieval due to the familiarity of the analysis groups with the data collected. A reference number included on the short form pointed to a page in the long form Data Catalog. The longer description of data received included most or all of the parameters originally recorded about a flightline or segment of data. This information proved useful to interpreters less familiar with the data.

The importance of the Data Catalog was not apparent during the Corn Blight Watch Experiment, since most data was analyzed immediately upon receipt at the Data Reduction Center. Now that the experiment is over, however, the Data Catalog, the organized method of storing and indexing along with the computer-generated reports, is important in locating data. It should also be noted that with this system an on-line retrieval of the data is possible.

ANALYSIS PROCEDURES

Each of the data analysis teams was given a Ground Observation Summary for the segments to be analyzed or interpreted. A new summary was distributed each period so that pertinent information required for analysis would always be available. Although the form of the summary, shown in Figure 5, was the same

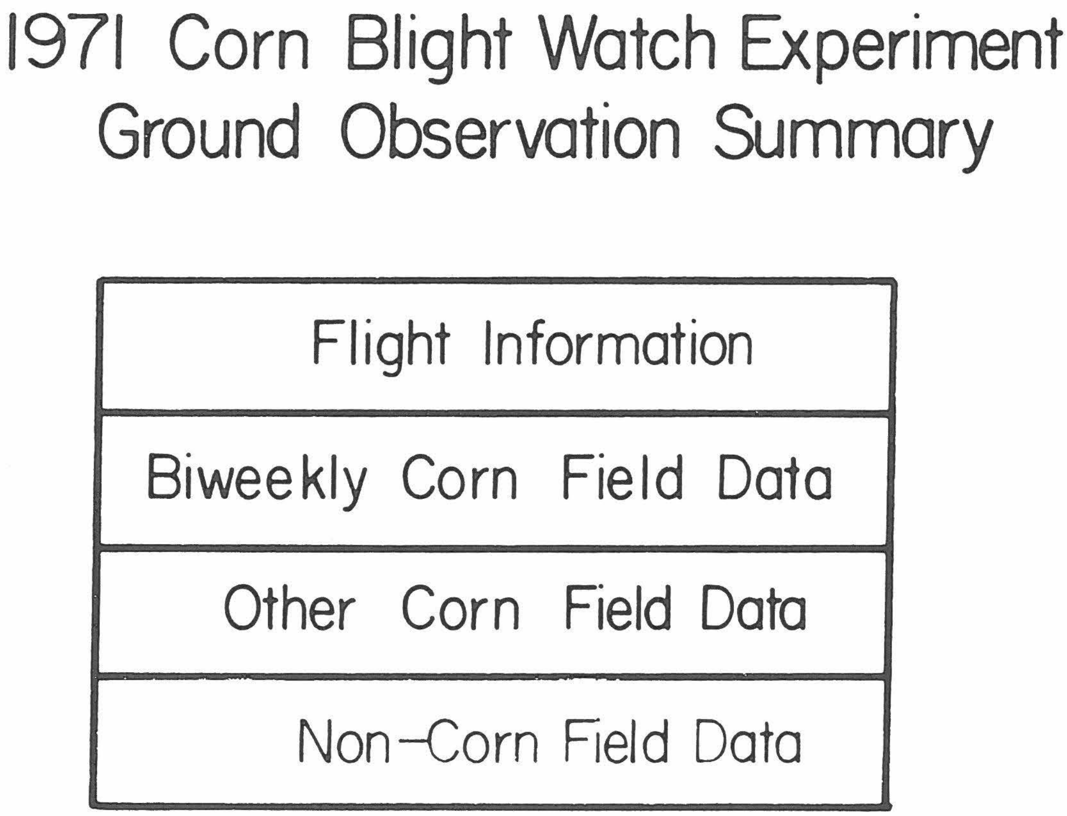

Figure 5. The Ground Observation Summary was distributed to analysis teams every two weeks. It contained the flight parameters, new biweekly training field observations (which provided the data foundation in the analysis extrapolation) and basic information of all other fields in the segment.

each period, parameters listed were added or dropped from the format according to the needs of analysis teams. In the flight information area of the summary, the segment number, film roll number, frame number, date and time of the flight, and flight direction were listed. Next information for the corn fields visited biweekly was listed as well as some information for all other corn fields and non-corn fields in the segment.

Photointerpretation

With the film roll transparencies mounted in the Variscan, a rear projection system, the frame indicated by the Ground Observation Summary could be located by a photographic analysis team. Using the summary and the baseline photograph, the biweekly corn fields were located and studied so the teams could train themselves on the appearances of blight levels in the segment. The number of fields used for training varied during the experiment; not all biweekly field information was used.

Next each corn field in the segment was located and interpreted, and the results were recorded on a recording form. These results were coded, punched, edited, and added to the Corn Blight Record for each of the 210 segments. The six teams of photo analysts completed their analysis by day 23 of each period. On the average each segment was analyzed by one week after the data collection date.

Multispectral Data Analysis

Fifteen segments out of 30 in the Intensive Study Area were analyzed by LARS. The analog tapes were digitized and displayed on a digital display. The biweekly fieldswere located using a baseline photograph and lightpen. The data from these fields were analyzed using a clustering procedure, and the results were used to determine classes for the analysis and data points for generating class statistics. Next the channel selection program was used to pick four optimum channels for classification at Purdue and 6 optimum channels for classification at WRL. In general all channels of data collected were used during the season. There was no single best set of channels; however, a thermal channel, two reflective IR channels and a visible channel were usually selected for the classification of the segment.

At WRL a similar analysis procedure was followed using analog techniques on the other 15 segments in the Intensive Study Area. Results for all 30 segments were reported both on a total segment basis and on a field-by-field basis with LARS and WRL using the same reporting forms. It should be noted that results on a total segment basis were not obtained by photographic analysis. Instead the entire segment was classified into non-corn and corn classes of different blight levels. This is a more complicated classification than is interpreting blight levels only in corn fields. The multispectral scanner results were also completed by day 23 of the period and were finished on an average of 10 days after the segments had been flown. These results were also recorded on the Corn Blight Record.

Corn Blight Record

A record of the information obtained for every field in each of the 210 segments has been maintained on digital tape. The system designed for accomplishing this task and implemented for the Corn Blight Watch Experiment is called the Corn Blight Record and is shown in Figure 6. The initial interview data, Form A, and biweekly field observations, Form B, were merged with flight log information,

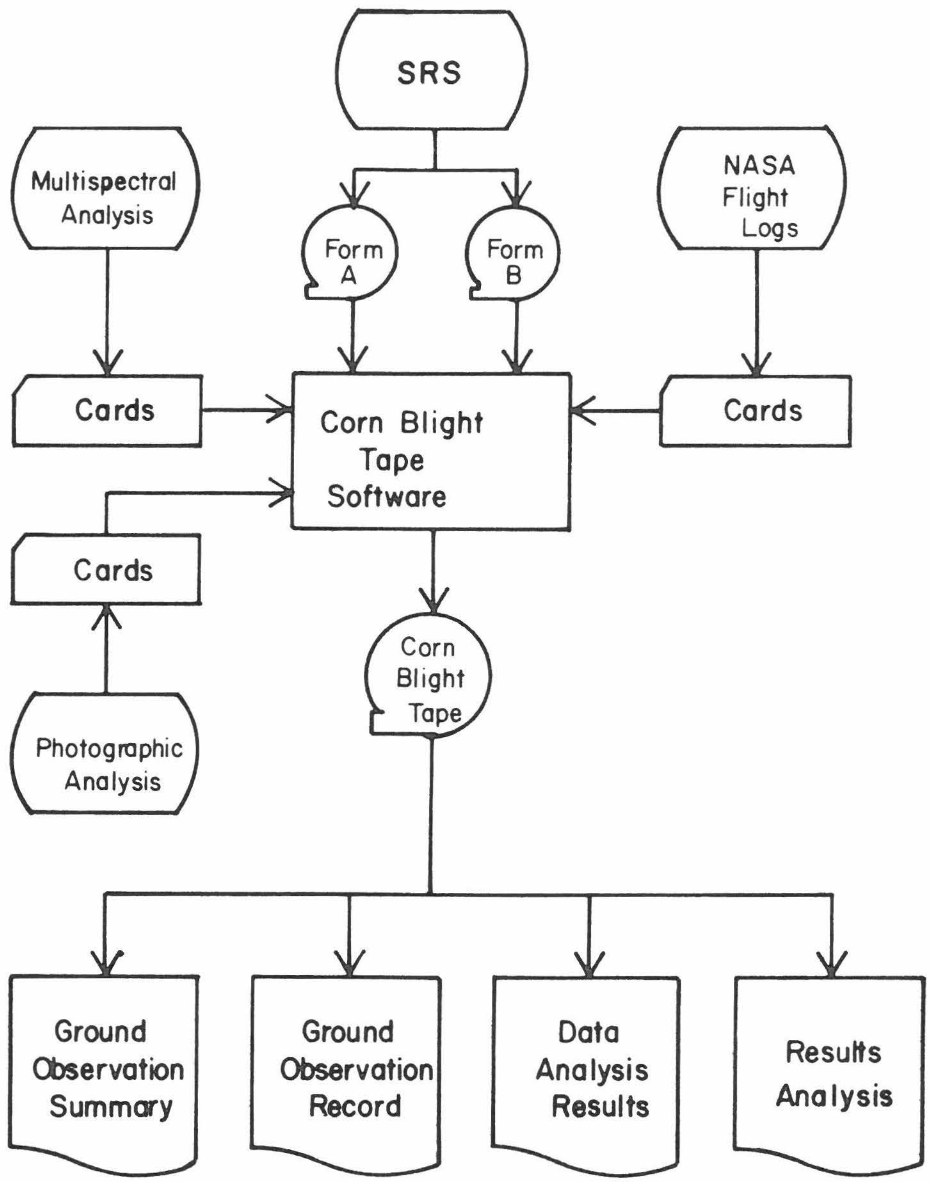

Figure 6. All ground data, flight logs, and analysis results were stored on magnetic tape. These merged data were used to report and analyze results for the 1971 Corn Blight Watch Experiment.

multispectral analysis results, and photointerpretation results. The resulting tapes, one for the seven state area and one for the intensive study area, were the source of most of the listings and tabulations generated during the experiment. We have already discussed the Ground Observations Summary. The Ground Observation Record, which is a sorted listing of all information on the tape, was generated periodically for results analysis.

Data analysis results in the form of remote sensing analysis tabulations were generated on day 23 of each period for SRS in Washington. Expansion of results according to the sampling model for ground observations, photographic analysis, and multispectral data analysis were also generated for each period. Breakdowns of blight results for cytoplasm and for many other parameters were made. Yield calculations and other such studies are now in the process of being made. In addition, the results are now being analyzed using standard statistical techniques such as correlation, analysis of variance, and others.

One last note on the corn blight tapes should be mentioned. The format of the tape and a description of the parameters stored have been documented. The resulting document and a copy of the tape can be made for anyone requiring this data.

Results Summarization and Dissemination

In Figure 7 the data flow for dissemination of the blight analysis results is summarized. For each biweekly period, color IR photographs were sent to the county enumerators for their particular segments. Questions and training materials were sent with the prints and results were returned for analysis and evaluation.

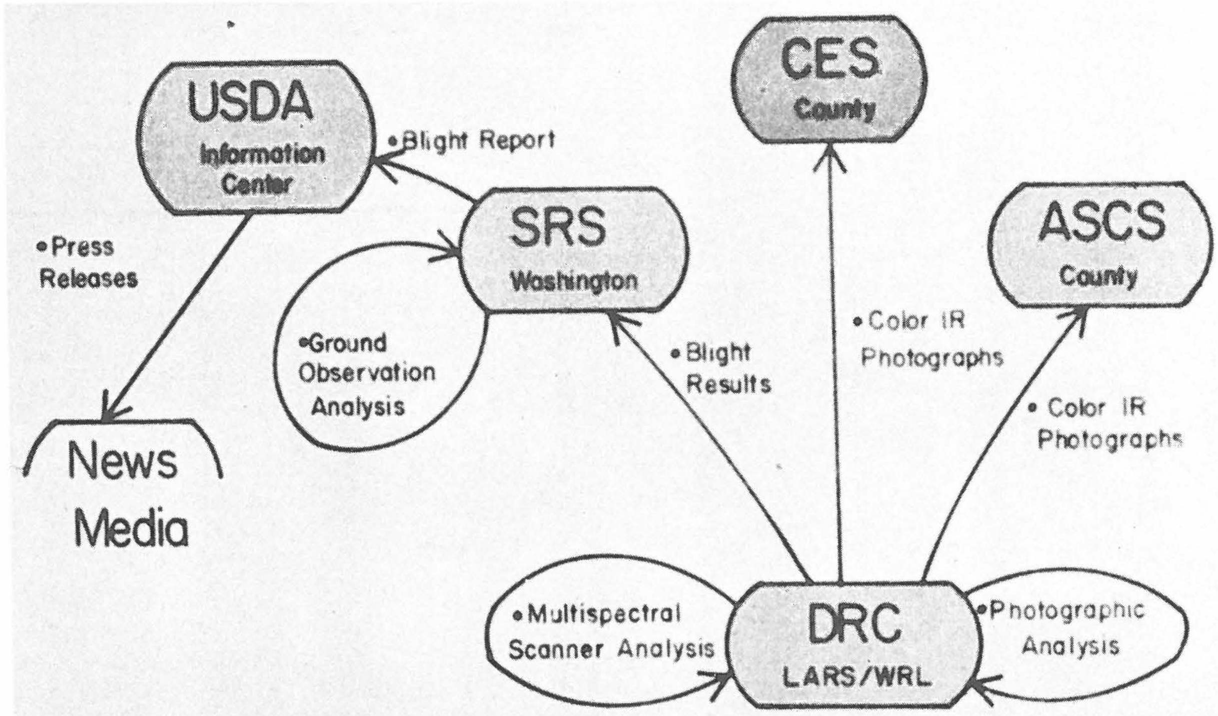

Figure 7. The data flow for results dissemination is diagrammed for Phase III of the Corn Blight Watch Experiment. This last phase of the experiment included the reporting of results to the public.

The purpose of this aspect of the experiment was to acquaint the enumerators with small-scale photography in preparation for future technology.

Summarization of ground observations was performed by SRS within one week of data collection. Photographic and multispectral analysis results were sent to SRS within an average of two weeks after data was collected. These results were available to SRS for compiling blight reports to the USDA information center, which in turn, handled press releases to the news media.

CONCLUSIONS

In conclusion this near-operational test of remote sensing systems rapidly advanced our knowledge of their potential. In addition, it is expected that the data collected will continue to be useful in future research. Data over an agriculturally important area of the country have been collected through a growing season. More than 40,000 fields were included in the initial interview records. Ground observations were obtained for 1,600 corn fields visited biweekly. The results of photointerpretation for 16,000 corn fields were recorded every two weeks, and over 300 square miles of multispectral scanner data were analyzed eight times during the growing season.

The procedures designed for handling the large amounts of data were successful. Where problems were encountered, adjustments were made to insure maximum results, available promptly and in a way that was consistant with the rapidly advancing state-of-the-art.

ACKNOWLEDGMENT

The 1971 Corn Blight Watch Experiment was planned by representatives of, and supported by, the experiment participants. The procedures summarized herein are a product of the total experimental plan; however, special appreciation goes to Mrs. S. K. Hunt and the Applications Programming group of LARS for their contributions in data management aspects of the experiment. Their work and that of other LARS staff to the experiment was supported by NASA under Grant NGL 15-005-112. References are made to the work of Mr. R. P. Mroczynski with the photointerpretation group, Dr. P.H. Swain with the LARS multispectral analysis teams, and Mr. F. Thompson with WRL multispectral analysis teams.

CARTOGRAPHIC APPLICATIONS OF REMOTE SENSING AT MEDIUM AND HIGH ALTITUDES AND FROM SPACE

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Ed. note: The outline, list of slides, and list of references for Mr. Colvocoresses are duplicated here. Abstracts of the references listed are included where practical. The numbers refer to the number of the reference.

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List of References

1. National Academy of Sciences Remote Sensing, National Academy of Science, Washington, D.C., 1970 (Price $12.95).

2* Doyle, F. J., "Imaging Sensor for Space Systems" Proceedings of XII Congress of International Society of Photogrammetry, July/Aug. 1972.

3* Colvocoresses, A.P., "Comparison of Basic Modes for Imaging the Earth" AIAA paper No. 70-294.

3.1* Colvocoresses, A.P., "The Case for High Altitude Airphoto Coverage of the U.S, June 1970.

3.2* Department of Interior, "Proposal to NASA for a Film Return Earth Sensing Experiment--Dec. 1970.

4.* Colvocoresses, A.P., "Surveying the Earth from 20,000 Miles," Image Technology, Dec/Jan. 1970.

5* Colvocoresses, A.P., "Platforms" preliminary version of Chapter 8 Manual of Remote Sensing, to be published by American Society of Photogrammetry.

6. American Society of Photogrammetry, Manual of Photogrammetry, Third Edition ASP, Washington, D.C., 1966.

7* Colvocoresses, A.P., "A Unified Plane Coordinate Reference System" World Cartography, Vol. IX, United Nations, New York 1969.

8* Colvocoresses, A.P., "Gridded Maps," Proceedings of the 32nd Annual Meeting of the American Congress on Surveying and Mapping, March 1972.

9* Radlinski, W.A., "Orthophotomapping" USGS, Washington, D.C., 1969.

10* Scher, Marvin B., "Orthophotomaps for Urban Areas, Surveying and Mapping, September 1969.

11* Edson, Dean, "Thematic Mapping in the EROS Program," ASP Fall Convention, September 1971.

12* Colvocoresses, A.P., Mapping Cameras in the EROS Program," ACSM/ASP Technical Conference, October 1970.

12.1* R&TS, Topographic Division, USGS, "Annual Report on Research and Development" April 1971, or May 1972 (available about June 1, 1972).

13. American Society of Photogrammetry, "Manual of Color Aerial Photography, ASP, Washington, D.C., 1968.

14* Welch, Roy, "Photomap Image Quality," presented to ACSM/ASP Convention, March 1972.

15* Colvocoresses, A.P., "Cartographic Applications of High Altitude Aircraft Photographs," Proceedings of the Operational Remote Sensing Symposium of the ASP, Houston, Texas, February 1972.

16* Cartography Coordinator, EROS Program, "Samples of Diazo Orthophotoquads made from U-2 Photography, 1;24,000, 1:50,000, and 1:250,000 scales," February 1972.

17* Cartography Coordinator, EROS Program, Experimental 1:250,000-scale line map, space photomap, and U-2 orthophotoquad (Phoenix), March 1972. (Includes plastic coordinate reader with explanation.)

18* Cartography Coordinator, EROS Program, Experimental 1:500,000 scale Space Photomap (Phoenix South), August 1970.

19* Colvocoresses, "ERTS-A Satellite Imagery" Photogrammetric Engineering, June 1970.

20* Colvocoresses, "Image Resolutions for ERTS, Skylab and Gemini/ Apollo," Photogrammetric Engineering, Jan. 1972.

*Available from EROS Cartography Coordinator (Colvocoresses).
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2. Among the most significant technological accomplishments of the last four years has been the almost routine operation of successful missions in space. Spacecraft have orbited the Earth, Moon, and Mars carrying both film and television systems for acquiring image data.

One consequence of the diversity of sensors is a blurring of the distinction between what is and what is not a photogrammetric system. Quite obviously a calibrated metric camera from which the original film is returned to Earth for processing and measuring would be considered a photogrammetric instrument. But what about a sensor in which the active element is a light sensitive diode generating an electrical signal which is transmitted back to Earth and recorded on magnetic tape? The tape may be processed directly by computer and an image, if created at all, may only be an adjunct to the interpretation of the data. Is this a photogrammetric system?

In this review, it has been elected to include systems for which a planimetric display is inherent. There are two reasons for this decision:

a. Televised data represent the only currently feasible means of returning information from unmanned vehicles around the Moon and planets and for transmitting earth sensed space data in near real time.

b. The particular knowledge of photogrammetrists is essential to establishing the spatial relationships of the data recorded.

On the other hand there is a wide variety of radiometers and spectrometers utilizing optical systems and energy detectors for which the data output is primarily numerical and positional information is either not obtained or is of minor importance. Such sensor systems have not been included in this review.

In presenting the characteristics of imaging sensors for space vehicles, the organization is by satellite program rather than by sensor type.

3. The Department of the Interior has developed the Earth Resources Observation Satellite (EROS) program so that earth-sensing systems can be put to practical use. The Department further recognizes that surveying the earth's resources requires remote sensing from spacecraft for the global synoptic approach and from aircraft for localized use. NASA has designated the Earth Resource Technology Satellites (ERTS) as a series of space flights to meet the needs of Interior and other departments, such as Agriculture and Commerce.

The EROS program recognizes that any one satellite system may not fully meet the operational needs and has in fact defined four basic modes for remote sensing of the earth and its resources, as follows:

> Airborne, generally film return. --Aircraft, balloon, or similar platform within the atmosphere (MSC aircraft).*
>
> Space, data transmission, global. --Sun-synchronous, long-lived, 300 to 900-km altitude (ERTS A and B).*
>
> Space, film return, global. --Sun-synchronous, short-lived, 150 to 300-km altitude (ERTS C and D).*
>
> Space, data transmission, geosynchronous. --Near-geostationary, long-lived, 36,000-km altitude (Advanced Technology Satellite, ATS).*

*Designation of NASA programs that exemplify the mode.

In addition to these four basic modes, there are numerous variations, including elliptical orbits which can concentrate on a given area or set of areas. There are also combinations of modes; in fact, there are already indications that no one single mode could possibly answer the varied requirements related to earth resources.

NASA and Interior are collaborating on a research project aimed at comparing the basic modes and eventually coming up with relative cost/benefits for various applications. . . . . This paper will discuss only the more obvious characteristics of each mode without attempting any overall comparison.

3.2 In defining its requirements to NASA, Interior has indicated that telemetered imagery and returned film photography are both required. ERTS A and B describes the returned film photography. . . . .This proposed film return experiment is considered a vital step in a program aimed at surveying and management of the Earth's resources. We believe the surveying aspect of such a program can and should be fully operational on a global basis before 1980. . . .The present proposal involves the use of 305mm focal length metric cameras.

4. Current space programs aimed at monitoring the earth's resources concentrate on the lower orbital altitudes of 100 to 500 nautical miles. An earth synchronous (geo-stationary) orbit is 19,400 n.mi. above the earth. A powerful telephoto camera at such a location can monitor and record many time-variant phenomena far more effectively than instruments at lower altitudes. The geo-stationary systems characteristics and problem areas related to optics and telemetry are outlined and detailed, and on-going programs are discussed as they relate to the geo-stationary system.

5. Typical vehicles which carry remote sensors into the atmosphere or beyond into space are described and illustrated and their performance characteristics are listed. No attempt is made to completely catalog or to cover the history of remote-sensing vehicles. Airborne platforms and spacecraft in use or defined as of 1970-71 were selected from the vehicles which have gained widest acceptance, demonstrated a unique capability, or have been defined for future remote-sensing missions. Except for a unique British kite balloon, only American platforms are covered, and therefore, this chapter could be viewed as a contribution to any international effort to cover the subject.

Remote sensing of the earth is the prime consideration, but sensing of the other planets and moons is also considered. Astronomy, except to the extent indicated above, is not included.

7. This study deals with the problem of developing a reference system of plane co-ordinates by which any point on the earth can be described within certain degrees of positional accuracy. Since the selected degrees of accuracy are high, the mapping involved is necessarily of relatively large scale. The small-scale depiction of large portions of the earth's surface on single projections is not covered in this study.

No attempt has been made here to add anything new to the theory of map projections or plane co-ordinate reference systems. However, the various suitable systems that have been developed over the years are analysed with the view of selecting the best system of projection and reference by which the earth's surface can be defined at large scale. The main purpose of this study is to present a comprehensive mapping system that can be applied world-wide and will meet the most rigid requirements of the users; it is thus basically a study of topographic engineering.

8. Historically the U.S. Geological Survey and many other civil mapping agencies have preferred the ungridded map. Grid ticks have long been accepted -- so why carry a full grid? There are requirements developing that indicate that civil as well as military maps should now be gridded. There are many technical problems involved but when properly executed the final product is more accurate and in many other ways more versatile than its ungridded counterpart.

9. The orthophotographic equivelents of terrain with little relief can be prepared simply with rectification of the perspective photographs, but for the composition of an orthophotograph of an area with considerable relief the perspective image must be restored in small segments by means of the observation at a distance of narrow strips in the stereoscopic model with an orthophotoscope or a similar instrument. Several similar instruments have been perfected including those which photographically reproduce the projected images and the automatic restitution machines which correlate the corresponding images of photographs interpreted in the form of profiles and produce a rectified image in the shield of a cathode ray tube, which at the same time imprints the orthophotograph. The products of the orthophotos are useful in various forms such as individual orthophotographs, ortho-photo-mosaics, and orthophotomaps. These are used in the planning and in studies which involve natural details and facts for man; for the measurement of position, distances, directions and areas; and for reference material in the composition and

revision of the planimetric details on conventional maps. The techniques in photographic treatments were developed a t the beginning of this decade and recently are being improved for use in the colored lithographic impression of photographic images without using the process called Half Tone Screening. Cartographic details, such as cartographic networks, impressions of symbols and legends are applied at the time the person who makes use of the map needs them in order to make the details clear. Various orthophotomaps have been published as type products in the Program of National Topographic Mapping and many more are presently being prepared.

10. Today's urban problems have focused attention on the need for adequate maps to assist in the assessment of these problems and the planning for their effective solution. The desirable characteristics of urban area maps for such applications are discussed in terms of scale, content, accuracy, and rate and cost of preparation and revision. A multipurpose map series at a scale somewhere between 1:2,400 and 1:12,000 is recommended. The maps should contain a great amount and variety of potentially usefull information that can be readily enlarged or reduced without significant loss in readability; their accuracy should be consistent with the requirements of planning projects involving high-value properties; and they should be capable of quick and economical preparation and revision.

The orthophotograph, the orthophotomosaic, and the orthophotomap are described in detail, and the characteristics that make them superior to conventional photographs and photo products are explained. The unique features of the orthophotomap that enable such a product to fully satisfy the above requirements for maps of urban areas are given. The paper concludes with a brief history of the increasing interest in orthophotographs and the development of instrumentation for their production.

11. Many of the users of remote-sensed data must depend on theme-extraction techniques for the proper analysis of a particular phenomenon. The Earth Resources Observation Systems (EROS) program of the USGS is developing a thematic mapping system which will produce binary graphic overlays of selected phenomenon. In serving the needs of a wide spectrum of users, the capability of extracting four themes is being developed--open water, snow and ice, reflective IR vegetation, and the massed works of man. The thematic mapping system, when developed for operational use, will be installed at the planned data center in Sioux Falls, S.D.

12. Wide-angle film-return frame cameras, such as are common to aircraft use, have been defined for space use in both 6-inch and 12-inch focal lengths. Narrow-angle cameras producing a near-orthographic telemetered image are also considered important for planimetric mapping, map revision, and thematic mapping. A third mapping system involves telemetered telescopic images of the area obtained from two widely separated satellites in geostationary or geosynchronous orbit. All three systems are considered potentially important to the mapping of the Earth and its resources.

14. Both image and photomap scales are being reduced and consequently the retention of detail in the cartographic process becomes increasingly difficult. It is suggested, therefore, that a systematic method based on MTF theory may be of value for evaluating the transfer of detail when planning map products. In order to maximize photomap detail the original photograph should be enlarged to a point where the MTF of the enlargement will not degrade the printing MTF. As the

printing process is often limited by the method of screening the image, screening techniques which result in the retention of spatial frequencies to beyond 5.1 mm are required. Based on theoretical analyses of different types of imagery, enlargement factors of 4 to 8x for high-altitude aerial photography, less than 7x for ERTS A imagery and from 10 to 20x for SKYLAB photographs will result in quality photomap products, provided compatible printing techniques are employed.

15. For the past 10 years the Topographic Division, U. S. Geological Survey, has been producing orthophotoproducts from such planes as the RB-57 and the U-2 become available. During the past 3 years NASA and the USAF have been flying these aircraft at altitudes of 60,000 and 70,000 feet. Among the sensors used, mapping cameras of 6-inch and 12-inch focal length have been predominant, and the films used include panchromatic, color, and color infrared. The conversion of the resulting photographs into useful cartographic products is the subject of this paper.

19. The first satellite designed to survey the Earth's resources is scheduled to be launched in 1972. This satellite, known as ERTS-A, will telemeter frames of imagery each covering 100-nautical-mile squares of the Earth. Except for the internal anomalies in the sensor system, the imagery, after being properly scaled, rectified, and controlled, may be considered an orthographic view of the Earth and used as a planimetric photomap. The accuracy of this photomap will be limeted principally by the geometric fidelity of the sensor system rather than by external effects, such as relief displacement, which restrict the direct cartographic use of the conventional photograph. ERTS-A is not designed as a topographic mapping satellite but does

have real potential for thematic mapping particularly in areas now covered by topographic maps.

20. Early in 1972 the first Earth Resource Rechnology Satellite (ERTS-A) is scheduled for launch in near-polar orbit. It will carry three return-beam-vidicon (RBV) TV cameras and a multispectral scanner (MSS).

In 1972 a post-Apollo manned space flight called SKYLAB will orbit the earth at an inclination of 50° to the Equator. In addition to other sensors it will carry a battery of six multispectral cameras identified as experiment S190.

This paper compares the images expected from ERTS and SKYLAB with those already obtained from GEMINI/APOLLO, all in terms of the photographic criterion of resolution. Recently provided data have led to several changes in the resolution figures of ERTS-A forecast a year ago.

AGRICULTURE AND FORESTRY APPLICATIONS

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Ed. note: Resume based on "Image Interpretation and Enhancement" in Analysis of Remote Sensing Data for Evaluating Vegetation Resources: Forestry Remote Sensing Laboratory, University of California, Annual Progress Report, 30 September 1970.

The basic function of the Image Interpretation and Enhancement Unit is to develop methodology for extracting useful resource information from remote sensing imagery using human photo interpreters. This effort requires a thorough understanding of the components of the image interpretation process. Evaluations are continually being made of the following factors that relate directly to the perception and interpretation of imagery: (1) sensitivity characteristics of the film-filter combination or other detector; (2) exposure and processing; (3) season of year; (4) time of day; (5) atmospheric effects; (6) image scale; (7) resolution characteristics of the imaging system; (8) image motion; (9) stereoscopic parallax; (10) visual and mental acuity of the interpreter; (11) interpretation equipment and techniques, and (12) training aids. Obviously, certain combination of these factors would better allow an interpreter to perform an interpretation task better than other combinations. Consequently, one of the primary objectives of the Image Interpretation and Enhancement Unit is to define, to the best of our ability, the optimum combination of factors needed to solve specific problems with the aid of remote sensing.

The work performed at the Pheonix Test Site (NASA Test Site No. 29) clearly illustrates the approach used for deriving a method by which an agricultural crop survey can be made. In this case, the objective was to inventory, by means of remote sensing, the acreage of all cereal grains (i.e., wheat and barley) found in Maricopa County, Arizona. (A full account of this research is documented in Appendix 1, Ann. Progress Rpt. 30 Sept. 1970, Forestry Remote Sensing Laboratory). Prior to implementing this type of semi-operational survey, certain quantitative techniques were applied in an attempt to select the proper inputs to the interpretation system. For example, (1) thorough interpretation testing led to the selection of a particular film-filter type deemed best for discriminating wheat from barley and wheat-barley from all other crops, (2) optimum photographic dates on which these crop discriminations could best be made were selected using the crop calendar concept, (3) rigorous testing and screening of interpreters led to the selection of three highly skilled and motivated persons who then performed the interpretation, and (4) ground truth data collection, compilation, and analysis procedures were developed that were compatible with a sampling scheme using ratio estimators. In addition, the photos used during this survey were selected on the basis that they were obtained with the NASA RB57F aircraft (1) at midday (high sun angle) assuring minimum shadow density, (2) with a six-inch focal length Wild RC8 metric camera providing large format, high quality imagery, (3) at maximum flying altitude (approximately 60,000 feet above mean sea level) simulating, insofar as possible, spaceborne photography, and (4) with no stereo overlap -- stereo parallax will have negligible influence on the interpretability of satellite photography taken of agricultural areas.

The stated purpose of the experiment was to investigate the feasibility of performing inventories of agricultural resources using very small scale aerial or space photography. Further, it was hoped that by remaining cognizant at all times of the constraints that would be faced when carrying out an operational survey, findings would be more valuable than those resulting from the more usual limited-area tests.

Certainly the results to date are encouraging on two counts: (1) the questions posed initially are being answered, i.e., the very practical problems of an operational survey are being faced and solutions are being found, and (2) it would seem that a fully operational agricultural inventory using space photography is not beyond the scope of present technology.

Probably the biggest problem that will be faced in establishing a functional inventory system are those concerning logistics and data handling. Further, data must be provided not at those times and for those geographic units which lend themselves well to the data gathering techniques, but rather at times and for area units which are geared to use requirements as nearly as possible. However, most of the data handling problems are not much more complex than those faced by government agencies gathering agricultural data by more conventional means at the present time.

In addition to the extensive amount of work being done in the agricultural areas significant progress has been made in developing remote sensing techniques applied to the forest or wildland environment.

The following studies have been geared towards determining the information content on imagery obtainable from orbiting spacecraft. Since, however, space-borne data have yet to be procured over the forestry test sites located in the upper latitudes of the United States, this work was done on small intermediate scale aerial photography. Nevertheless, the subject matter in each case (i.e., image resolution and additive color image enhancement) relates directly to the ultimate usefulness of spacecraft imagery.

A. Vegation/Terrain Classification -- on Degraded Imagery

The objective of this study is to determine the information content of simulated space photos as a function of various levels of image resolution. The experiment was performed using a series of images taken of the San Pablo Reservoir Test Site (NASA Test Site No. 48), each purposely degraded optically to a different level of ground resolvable distance (GRD). This research seeks to answer two questions. First, given low resolution ERTS data how well can a skilled image analyst identify the major vegetation-terrain types found to occur within the chaparral-hardwood-grassland cover type of California? Second, if certain vegetation/terrain types cannot be consistently identified on simulated low resolution imagery what level of image resolution is required that would allow a skilled interpreter to discriminate between various types?

This project applies to a resource inventory problem indigenous to the mid-latitude western United States and also approaches the resource inventory problem from a user's standpoint, i.e., given a particular problem, what kinds of space-borne imagery (in this case, what level of resolution) is required so that useful information can be extracted from the imagery.

The results of this experiment help answer the two questions stated earlier. First, given (within the next few years) low resolution ERTS data taken of chaparral-hardwood grassland type, one could expect that a skilled image analyst could delineate and identify on these images woody vegetation and water bodies with better than 80 percent accuracy. In addition, annual grassland areas could also be identified with approximately the same accuracy provided the imagery is taken late in the growing season. (It is reasonable to assume that imagery will be available showing natural vegetation in nearly all seasonal states, since the ERTS vehicle will pass over the same point on the earth approximately every eighteen days.) However, the most interesting outcome of this research is in reference to the second question. Even if the image resolution capability of the ERTS sensor system was improved from 400 feet GRD to 100 feet GRD, the imagery would remain inadequate for identifying the four primary types of woody vegetation found to occur in this area: Monterey pine, eucalyptus, mixed hardwoods and chaparral. Discrimination between these kinds of vegetative cover is done mainly by recognizing shape, size, texture and shadow characteristics within each type. To include these kinds of information, imagery must have a ground resolvable distance of at least 50 feet. Spaceborne and airborne data most certainly compliment one another in that an analysis of low resolution synoptic view space photos gives guidance to where and, more importantly, where not to procure supplementary aerial coverage.

B. Vegetation Typing -- on Color Enhanced Imagery

Earlier studies performed by the FRSL staff and others have adequately demonstrated that black-and white multiband photographs obtained simultaneously in more than one spectral band can be efficiently acquired and interpreted. This work has shown that the success of this relatively new and interesting technique

IMAGE CHARACTERISTICS FOR NINE VEGETATION/TERRAIN TYPES

FOUND TO OCCUR IN THE FEATHER RIVER WATERSHED AREA

Based on High-altitude, Small Scale, False-color Infrared Imagery

FEATURE	TONE OR COLOR	TEXTURE	TOPOGRAPHY	LOCATION/ASSOCIATION
CONIFERS	Variable: purple-red to red-blue	Variable: rough, spiked	Mountainous slopes, ridges, gullies, all topographic types	Understory of brush and grass sometimes is visible
HARDWOODS, DRY SITE	Bright pink	Variable: medium texture, billowy	Mountainous slopes, and gullies	Usually associated with drier slopes
HARDWOODS, RIPARIAN	Bright red	Medium texture, billowy	Flat areas and gully stringers	Red fir forest; meadow areas
MEADOW, DRY	Light pink to pink	Smooth	Flats, depressions	Sometimes with streams and/or riparian hardwoods
MEADOW, WET	Bright red	Smooth	Flats, depressions	Sometimes with streams and/or riparian hard-woods; with alpine forest
LOW HERBACEOUS AND GRASS	Grey, grey-pink, grey-blue	Smooth	All topographic types	Burned areas; serpentine soils; under forest canopy
BRUSH	Medium pink	Smooth	Mountainous slopes and gullies	May be scattered trees; usually associated with drier slopes
WATER	Blue or black	Smooth	--	--
NON-VEGETATED	White to light white-pink	Variable: medium to rough	Any topographic types, especially steep granite	Granitic outcroppings; mining operations; cleared areas

A WILDLAND VEGETATION/TERRAIN CLASSIFICATION SCHEME

Vegetation Density

1 - 0-5%

2 - 5-20%

3 - 20-50%

4 - 50-80%

5 - 80-100%

Vegetation Type

C - Conifers

H - Hardwoods, dry site

R - Hardwoods, riparian

Md - Meadow, dry

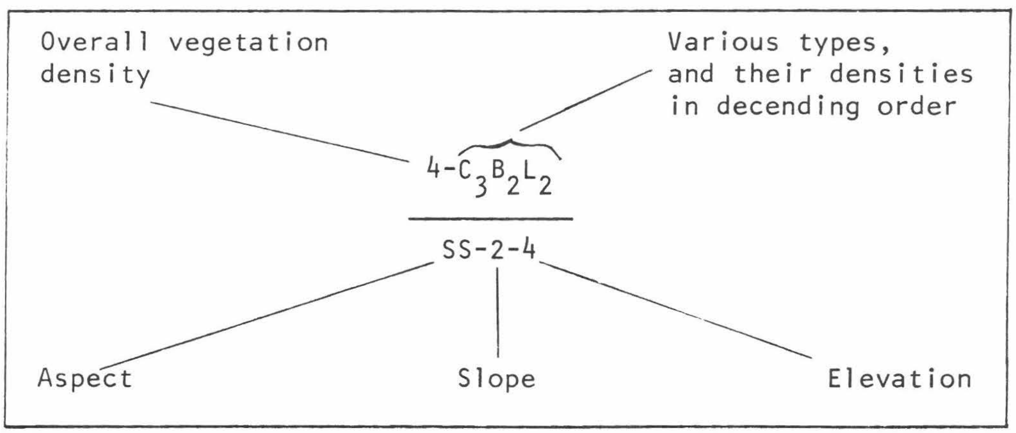
Mw - Meadow, wet

L - Low herbaceous & grass (not M)

B - Brush

W - Water

N - Non-vegetated, bare soil or rock



Aspect

NN - North

NE - Northeast

EE - East

SE - Southeast

SS - South

SW - Southwest

WW - West

NW - Northwest

LL - Level

Slope

1 - Level; 0-3%

2 - Gentle; 3-10%

3 - Moderate; 10-50%

4 - Steep; >50%

Elevation

2 - 2000-3000 feet

3 - 3000-4000 feet

4 - 4000-5000 feet

5 - 5000-6000 feet

6 - 6000-7000 feet

is heavily dependent upon the employment of advanced aids to photo interpretation, such as additive color image enhancement.

Vegetation types can be classified by additive color enhancement and also timber volume estimates can be made. Investigations showed that two characteristics of a forest stand, i.e., percent crown closure and average crown diameter, can be accurately measured on small scale non-stereo imagery and can be related to timber volume. For a selected timbered area both of these parameters were estimated by means of visual comparison of the stand in question with aerial photo examples of stands for which closure and crown diameter were known. The estimated average volume per acre derived from the imagery was then compared with an estimate made using conventional on-the-ground techniques. Eight field plots were visited by a field crew within this stand and timber volume was determined using Bitterlich variable-plot procedures and volume tables compiled for the region by the U.S. Forest Service. The volume of timber estimated by making measurements off the imagery was within 5 percent of the volume estimated by the field crew. Furthermore, the time and effort required to estimate by means of vertical aerial photography the volume of commercial timber on this site was just a fraction of that required by the ground survey team.

The following tabulations of the applications of remotely sensed data for Agricultural Lands, Forest Lands, and Land Utilization are the results of research at the Forestry Remote Sensing Laboratory.

APPLICATIONS - AGRICULTURAL LANDS

Agricultural Land-Use

- Stratification
- Classification
- Change detection

Crop Vigor and Yield

- Damage; insects and disease
- Damage; wind and floods
- Crop condition estimates
- Crop yield forecasting

Crop Inventory

- Identification
- Acreage estimation
- Statistics

Additional Topics

- Soils surveys
- Livestock inventories
- Rangeland condition/trend surveys

APPLICATIONS - FOREST LANDS

Inventory

- Classification
- Direct volume estimation
- Indirect volume estimation
- Forest products

Protection

- Fire
- Insects
- Diseases
- Air pollution

Monitoring

- Logging
- Reforestation
- Stand damage
- Erosion
- Pollution

Management

- Timber
- Forest engineering
- Watershed
- Fish and wildlife
- Recreation

APPLICATIONS - LAND UTILIZATION

Land

- Land-use
- Expressways
- Parking lots
- Auto junkyards
- Waste disposal
- Sanitary landfills
- Housing developments
- Heavy industry
- Open pit mining
- Strip mining
- Quarrying
- Soil erosion
- Cattle feedlots
- Disasters
- Flood plain degradation

Water

- Sedimentation
- Sewage discharge
- Algae
- Ground water systems
- Agricultural runoff
- Oil spills
- Industrial discharge
- Power plant effluents

Air

- Dust storms
- Smoke
- Fires
- Smog
- Contrails
- Environmental noise

ENVIRONMENTAL QUALITY APPLICATIONS

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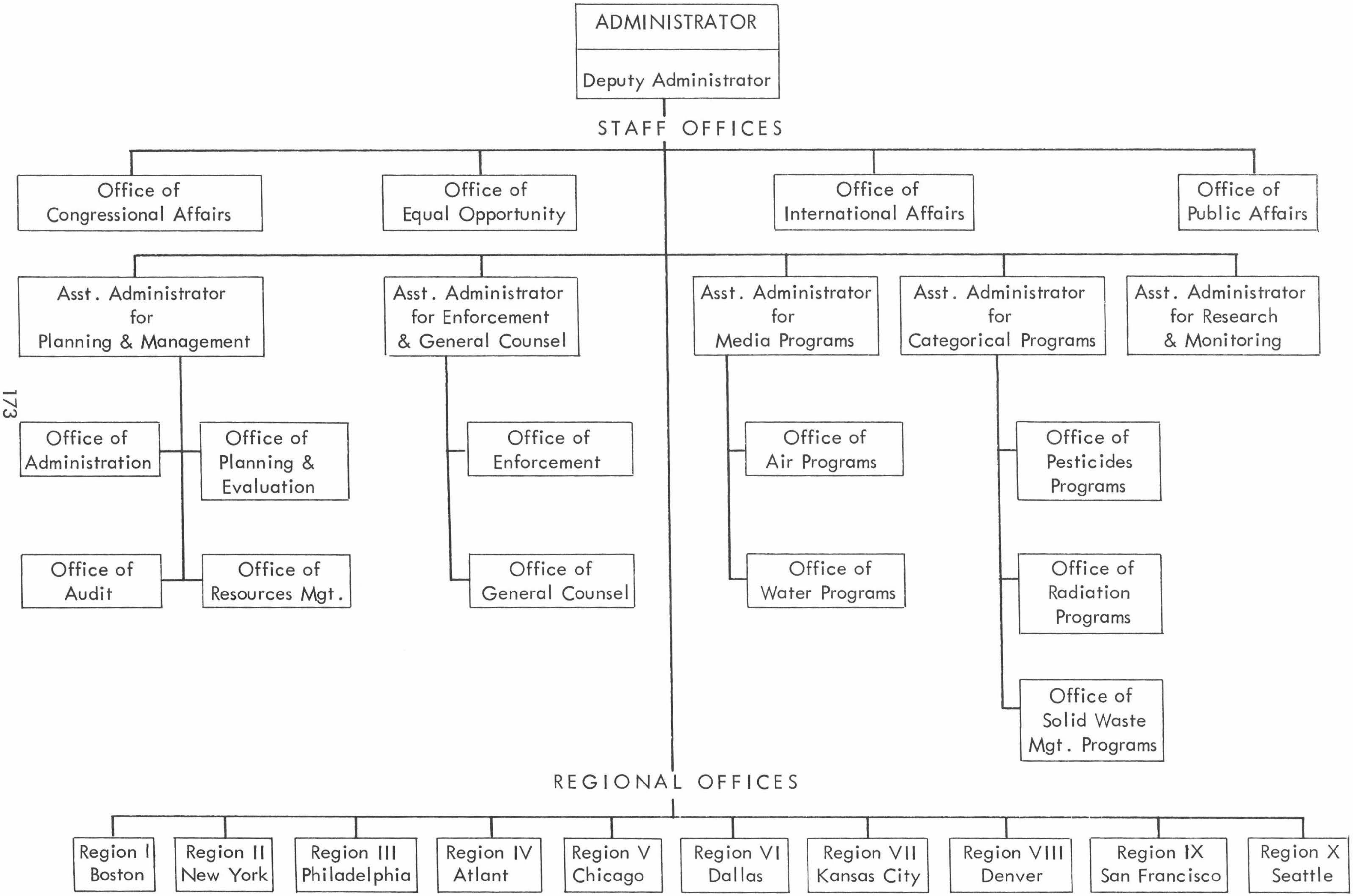
The Environmental Protection Agency (EPA) was established as an independent agency under the executive branch of the government in December 1970. The EPA was created to permit coordinated and effective governmental action to assure the protection of the environment by abating and controlling pollution on a systematic basis. Reorganization Plan 3 of 1970 transferred to EPA a variety of research, monitoring, standard setting, and enforcement activities to integrate environmental activities as a single interrelated system. The EPA was created from portions of five governmental agencies: Department of Interior, Atomic Energy Commission, Department of Health, Education and Welfare, Department of Agriculture, and the Federal Power Commission. Complementary to these activities is the EPA's coordination and support of research and antipollution activities of state and local government, private and public groups, and educational institutions, as well as antipollution activities of other federal agencies.

The remote sensing program is headquartered at the Western Environmental Research Laboratory (WERL). It is under the Assistant Administrator for Research and Monitoring. The pilot program is an attempt to establish remote sensing techniques as a court-worthy data acquisition system. While WERL operates nationally, it generally works through the ten regional EPA offices. Kansas City is the headquarters for Region VII which includes Iowa.

ENVIRONMENTAL PROTECTION AGENCY



The remote sensing facilities of WERL include 12 aircraft equiped variously with mapping cameras, airborne radar, multispectral cameras, radiometers, and scanner systems. In support of these systems are ground truth teams and laboratories (some mobile), photographic laboratories, computer facilities, technical and engineering personnel, and an engineering laboratory. The personnel and equipment are organized so that they may be used as emergency task forces as well as on-going monitoring and research teams.

The remote sensing program is working under the philosophy of using current, available, tested sensors. The Laboratory is not involved in developing new systems, but rather applying current systems to higher standards of accuracy than may have been demanded previously. The EPA uses the remote sensing systems in research, planning, monitoring and enforcement. Enforcement demands high accurancy standards because the data must be acceptable in the court system.

Currently the EPA has nine operational projects using remote sensing techniques. Little or no description of these projects are included here. For information on any of these projects contact WERL in Las Vegas, Nevada. The current projects include:

1. Thermal and Photographic infrared reconnaissance studies.
2. Reconnaissance of oil and hazardous chemicals spilled into waterways.
3. Eutrophication study of 1200 lakes.
4. Regional Air Pollution Surveillance (RAPS)
5. Nuclear reactor radiation surveillance.

6. Mill tailings studies.

7. Air pollution energencies.

8. Research into quantitative techniques of remote sensing systems.

9. Land-use studies.

WATER RESOURCES APPLICATIONS

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Ed. Note: Resume based on: Data Relay System Specifications for Earth Resources Technology Satellite Image Interpretation: U. S Geol. Survey Prof. Paper 750-C, p. C192-C195, 1971 and Powell, W. J. Copeland, C.W., and Drahovzal, J.A., 1970. Delineation of Linear Features and Application to Reservoir Engineering Using Apollo 9 Multispectral Photography. Information Series 41.

Experiments with the Data Collection System (DCS) of the Earth Resources Technology Satellites (ERTS) have been developed to stress ERTS applications in the Earth Resources Observation Systems (EROS) program. The DCS ground-data platforms are electronic packages containing a transmitter and antenna. Some of the planned experiments intend to make use of DCS data as an aid in image interpretation, wheras, some will make use of the capability to relay data from remote locations.

One of the key elements in determining ERTS performance requirements was, and is, the capability of satellite sensors to monitor change in terrestrial features. Changes occur in important features in all disciplines which will make use of ERTS data, but the time frame of changes varies from a few minutes or hours for water features to millions of years for some land features. The concept of time rate of change is also important to the DCS. Ground data planned for relay in each of the experiments are applicable to one or more of several goals tentatively grouped into the two broad categories of interpretation aids and real-time uses.

Interpretation aids

Ground-sensed parameters which fulfill goals basically categorized as interpretation aids are those which furnish quantitative information regarding:

1. Conditions within an image or image set (solar radiation, air temperature, wind, and so forth).

2. Changes in successive images (water levels, precipitation, and so forth).

3. Image features (areal extension of point-collected water-quality data).

4. Applicability of images to the problem or experiment (water levels are high, low, median, and so forth).

Categories 1 and 4 require the collection of background data concurrent with imagery in order to fully satisfy requests for imagery representing specific climatic or hydrologic conditions.

All four of these categories have application to image interpretation whether there is a functioning DCS or not. A report on Apollo 9 photography (Powell and others, 1970) is an example of the use of ground data to help interpret imagery. All hydrologic data within the photographed area for the time of overflight, as well as all historical data for the area, were used to formulate a conceptual working model of the geo-hydrologic system in that area. This use of ERTS-A data will be typical and significant, but the model can be constructed within a leisurely paced time frame. When interpretation of the imagery must proceed in real time, The DCS is required in order to shorten the data collection process, and a conceptual or mathematical model of the system being studied must already be in existence. The criteria for experiments with the DCS related to interpretation are (1) relayed parameters must relate to one or more of the four stated categories; (2) a working model of the image area must be in existence: and (3) interpretation must be done in near real time (hours or a very few days).

Real-time uses

The other advantages of the DCS which include ground-sensed parameters usable in real time are:

1. Ground sensors may be located where they cannot be physically reached in a resonable time frame (mountainous or estuarine environments).

2. Data may be used by management units for operational decision making (hydroelectric power development, municipal water supplies, and so forth).

3. Data are the basis for standing requests for imagery collection and (or) precision processing for specific climatic or hydrologic conditions (ERTS data management).

4. Ground sensors are useful in determining proper exposure or probability of successful exposure of satellite sensors (net or total radiation in ERTS spectral bands; oceanic turbidity near shore for effect on bottom detail).

The last advantage specifically relates to satellite sensor management, little of which may be done with ERTS-A (excluding tape recorder usage). However, experimentation with these sensors on ERTS-A will allow development of techniques for managing forthcoming operational satellites.

These four uses are intrinsically time related and hence require real-time data relay system. The sole criterion for experiments with the DCS related to real-time uses is that the DCS (exclusive of satellite cost) can be an economical method of data collection at the present time.

Very few management requirements for data can be satisfied with the once-every-12 hour capability of ERTS-A for data collection. Most users will eventually

Table 1. EROS Data Collection System networks for ERTS experimentation

Experiment location	Discipline	Purpose	Parameters	Number of platforms
1. Delaware River basin, Pennsylvania and New Jersey.	Hydrology	Water management	Water quality Stream stage Reservoir stage Ground-water stage	20 ERTS-A
2. Central Arizona	. . do. .	Arid hydrology	Precipitation Solar radiation Air temperature	2 ERTS -A 4 ERTS-B 6 total
3. South Dakota	. . do. .	Snow and ice, shallow aquifers.	Ground-water stage Air temperature Solar radiation	2 ERTS -A 4 ERTS- B 6 total
4. Lake Ontario, New York and Canada	. . do. .	Prototype ocean, circulation	Water quality Current velocity and direction Solar radiation	2 ERTS -A 4 ERTS -B 6 total
5. San Jauan Mountains Colorado	. . do. .	Atmospherics modification	Precipitation Snow (water equivalent) Wind Stream stage Rime ice	12 ERTS - A
6. Cascade Range, Wash: Central America	Geology	Volcano monitoring	Seismic events Tilt	10 ERTS - A 20 ERTS - B 30 total
7. . . . Do. . .	. . do. .	. . do. .	Temperature	5 ERTS - A 5 ERTS - B 10 total
8. Baltimore, Md.	Geography	Image evaluation	Solar radiation	8 ERTS - A
				98 total

require an online capability. Therefore, the performance of the DCS in all the experiments will be used to determine the applicability of an ERTS relay sytem to the economic alternative of a series of orbiting satellites, geosynchronous satellites, or combination of the two. Each of these alternatives would supply an online data relay capability. There are eight planned DCS experiments for ERTS listed in table 1. Each of these satisfies one or more of the design goals. These experiments respresent the major disciplines of hydrology, geology, and geography.

For several of the experiments relating to image interpretation, aircraft imagery in the ERTS spectral bands is required in order to complete the local DCS networks. As aircraft data are obtained, the local networks of ground sensors (in some cases these number in the hundreds) will be analyzed to determine which types of sensors and how many of each type are desirable for DCS instrumentation. After this preliminary analysis, the final choice of sites will be made. During the actual experiments, aircraft flights are needed at some sites during ERTS image overflights for integrated ground, air, and space data collection. Therefore, many of these experiments will be included in the aircraft program.

One set of Apollo 9 multispectral photographs covering 6400 square miles area of Alabama has been used by the U.S. Geological Survey and the Geological Survey of Alabama to study groundwater hydrologic systems. Long linear traces appearing on the imagery intersected Appalachian structural trends. Since no offsets were observed, these traces are thought to represent fractures.

Known wells were located along some of these fractures. Many of these wells had especially large water production capacity suggesting a correlation of fractures to groundwater. Known stream flow anomalies gave increased evidence for this correlation. Talladega Creek, for example, increases at low flow from 10 million gallons per day to 45 million gallons per day within a 5.5 mile length crossing a series of these discovered fractures. In addition, the discovery of the fractures may explain the leakage known to exist at Logan Martin Dam. The photographs indicate that the dam is located directly on one of these fractures.

The Apollo imagery and the supplimentary ground data suggest that small scale multispectral photography may be considered an important tool for hydrology. The results of this study indicate that the imagery may be useful for determining possible locations of large groundwater quantities, study groundwater movement, determining stream gaging location, and locating optimal placement of dam sites.