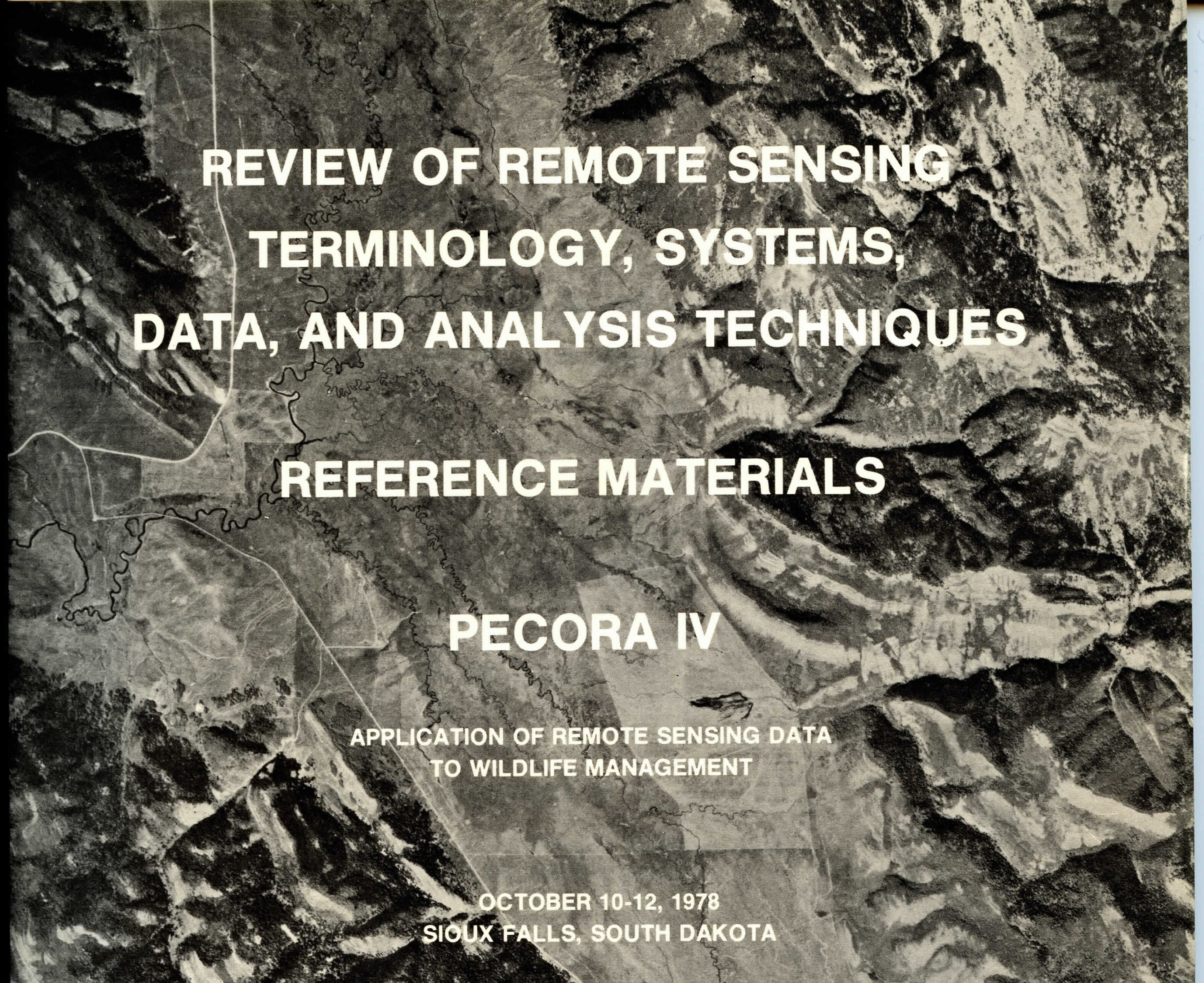
REVIEW OF REMOTE SENSING TERMINOLOGY, SYSTEMS, DATA, AND ANALYSIS TECHNIQUES

REFERENCE MATERIALS

PECORA IV

APPLICATION OF REMOTE SENSING DATA
TO WILDLIFE MANAGEMENT

OCTOBER 10-12, 1978
SIOUX FALLS, SOUTH DAKOTA



MAYBE CANYON PHOSPHATE MINE
CARIBOU COUNTY, IDAHO

REVIEW OF REMOTE SENSING TERMINOLOGY,

SYSTEMS, DATA, AND ANALYSIS TECHNIQUES

REFERENCE MATERIALS

PECORA IV

Application of Remote Sensing Data
to Wildlife Management

October 10-12, 1978
Sioux Falls, South Dakota

TABLE OF CONTENTS

OVERVIEW OF REMOTE SENSING

By Robert N. Colwell

A. Rationale for the Remote Sensing of Natural Resources.

(The 3-step process of inventory, analysis and implementation leads to better resource management and environmental protection)

B. Terminology

New More Inclusive Terms	Corresponding Old Terms
1. Remote Sensing	1. Photo Reconnaissance
2. Sensor	2. Camera
3. Imagery	3. Photography
4. Image Analyst	4. Photo Interpreter
5. Data Reduction by Humans	5. Photo Interpretation
6. Computer Assisted Analysis	6. No Corresponding Term

C. Important Historical Events

1. Remote sensing observations of our progenitor, the cave man.
2. Observation regarding the properties of light, as made by ancient philosophers in about 350 B.C.
3. Development of the camera obscura in the 14th century.
4. Development of the first practical photography in about 1840.
5. First successful attempts in the development of aerial photography in the 1850's.
6. The development of roll films and navigable camera platforms (aircraft)at about the turn of the century .
7. The impetus given to remote sensing by World War I.
8. The tremendously increased availability, during the 1930's, of aerial photographs for use by the managers of natural resources.
9. The impetus given to remote sensing by World War II.

10. The development of color and infrared-sensitive films, largely during the 1930's and early 1940's.

11. The post-war surge of interest in photo interpretation throughout the 1940's and early 1950's,

12. Improvements during the past quarter century in sensor platforms, sensor systems and data analysis capabilities.

D. Basic Matter and Energy Relationships (see Fig. 1)

1. Nature of Electromagnetic Energy

2. Relationships between wavelength, frequency and velocity

3. Sources of electromagnetic energy

4. The concept of "spectral bands"

5. Interactions between matter and energy

6. Atmospheric transmission and "windows"

7. Detectors used in various parts of the e-m spectrum

E. Remote Sensing Devices

1. Conventional Camera (See Fig. 2A)

2. Panoramic Camera (See Fig. 2B)

3. Mulitband Camera

4. Optical Mechanical Scanner (see Fig. 3)

5. Side Looking Airborne Radar Device (SLAR) (see Fig. 4)

6. Gamma Ray Spectrometer

7. Landsat's RBV and MSS systems

F. Photographic Films and Filters (see Fig. 5)

G. Remote Sensing Platforms

1. Conventional Fixed Wing Aircraft

2. High Performance Fixed Wing Aircraft

3. Rotary Winged Aircraft

4. Manned Spacecraft

5. Unmanned Spacecraft

    a. From which film is recovered

    b. From which digits are telemetered to Earth

H. Fundamentals of Photographic Interpretation

1. Procedures for storing and retrieving photos
2. Procedures for manipulating photos
3. Procedures for scanning photos
4. Convergence of Evidence
5. The conference system
6. Equipment for viewing, measuring, plotting
7. Optical enhancement of images
8. Electronic enhancement of images
9. Photo Interpretation keys (see Fig. 6)
10. Considerations in selecting and training photo interpreters.

I. Fundamentals of Computer-Assisted Analysis

1. The pixel-by-pixel record of scene brightness
2. Digital tone signatures based on spectral response patterns
3. Linear expansion to the full dynamic range
4. Histogram equalization
5. Supervised vs. unsupervised classification

J. The Multi Concept

(Multiband; Multidate; Multistage; Multipolarization; Multienhancement; Multidisciplinary analysis; multithematic presentation)

K. The Interface between Humans and Machines

1. Humans are best for perceiving differences in spatial relationships

2. Machines are best for quantifying differences in scene brightness

3. Unless a parameter can be digitized, "it does not compute"

L. Some Near-Term Predictions

1. Globally uniform inventories

2. Faster delivery of remote sensing data

3. Data compression

4. Improved resolution

5. Improved change detection

6. Space photos will replace orthophotos

7. Improved understanding of the human vs. machine "interface"

8. Increased rating of areas as simply or complexly structured

9. Increased borrowing of techniques from other disciplines

10. Increased use of "synthetic stereo"

11. Increased use of "shadow parallax"

12. More useful resource classification schemes (See Fig. 7)

13. More rational uses of the "multi" concept

M. Some Useful References

1. Manual of photographic interpretation

2. Manual of color aerial photography

3. Manual of remote sensing

4. Other references

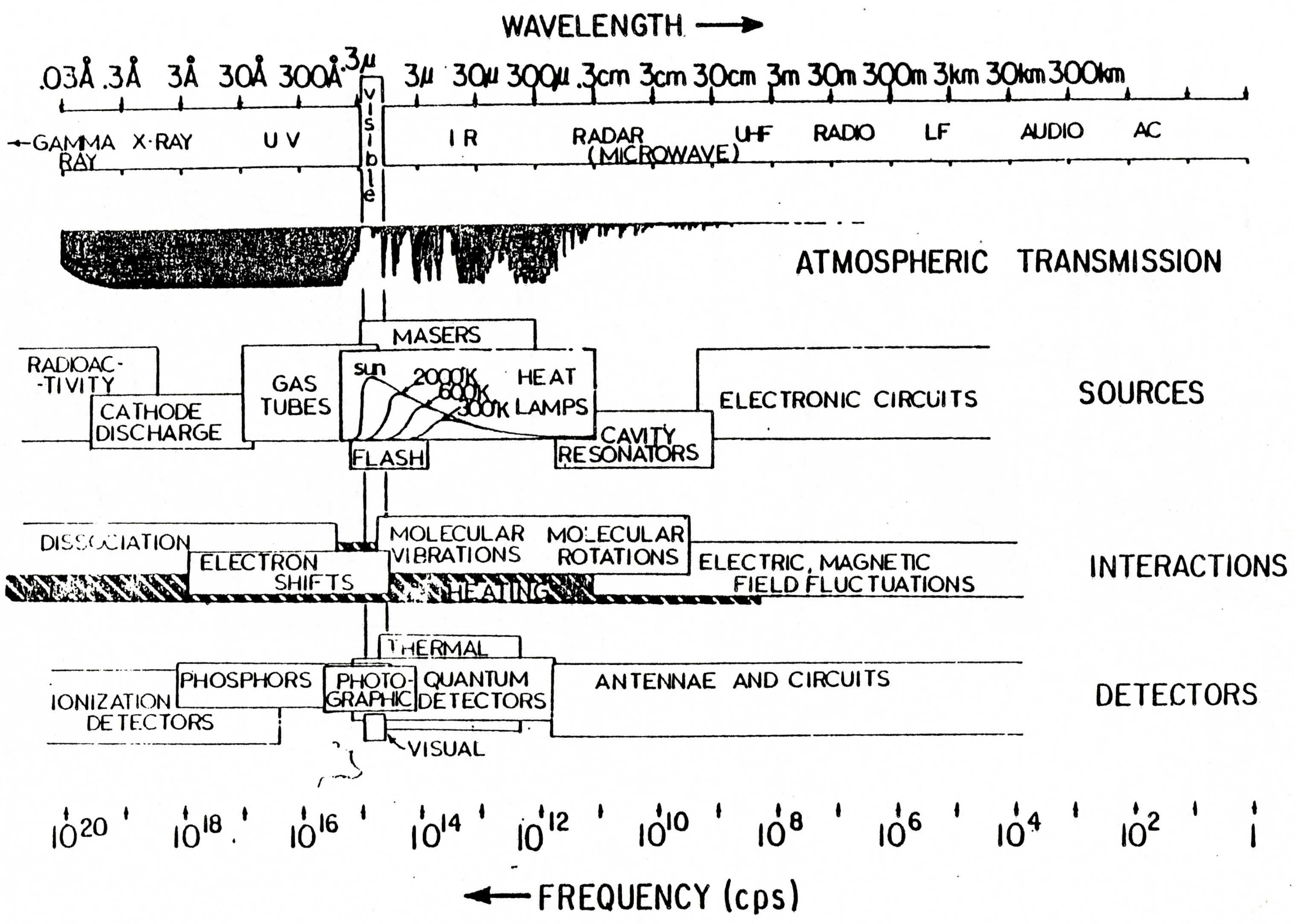


Figure 1 - The Electromagnetic Energy Spectrum

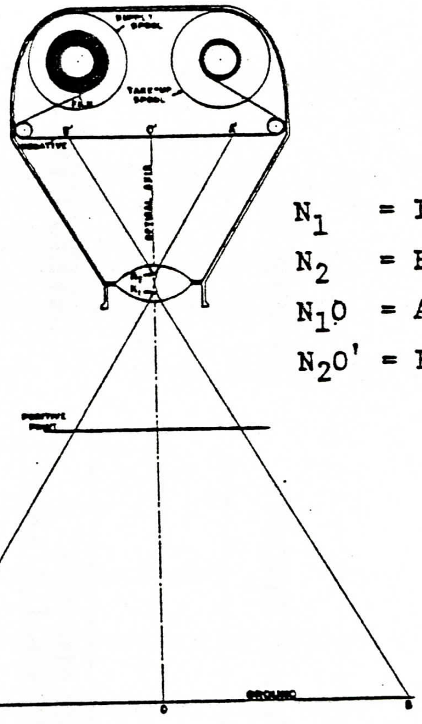


Figure 2A.-- A Conventional Aerial Camera

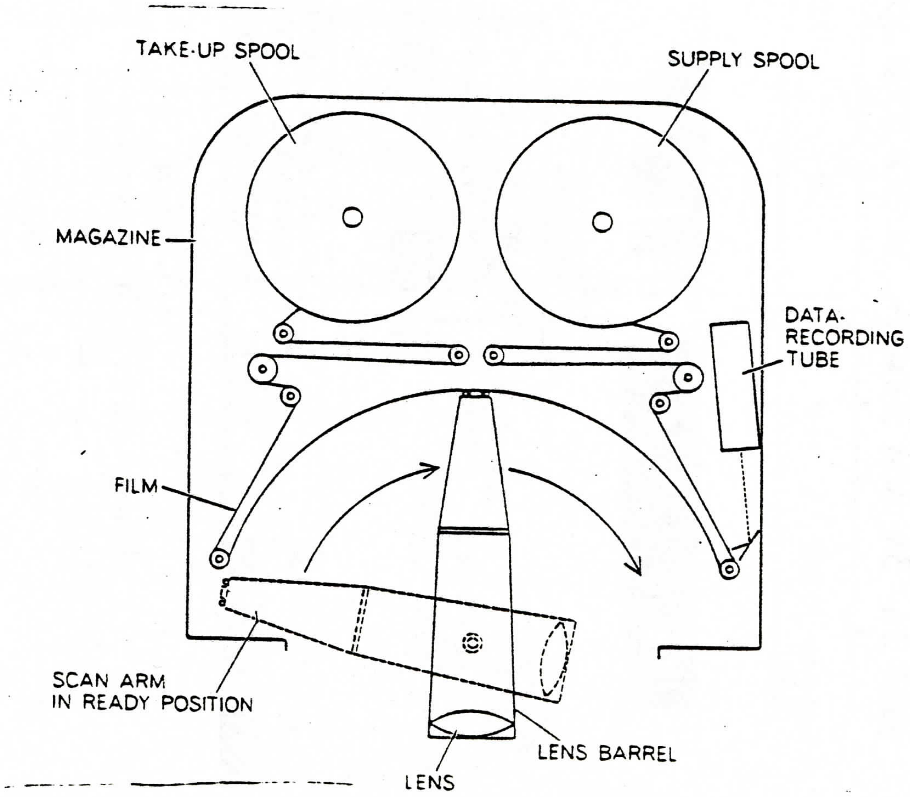


Figure 2B.-- Panoramic Aerial Camera

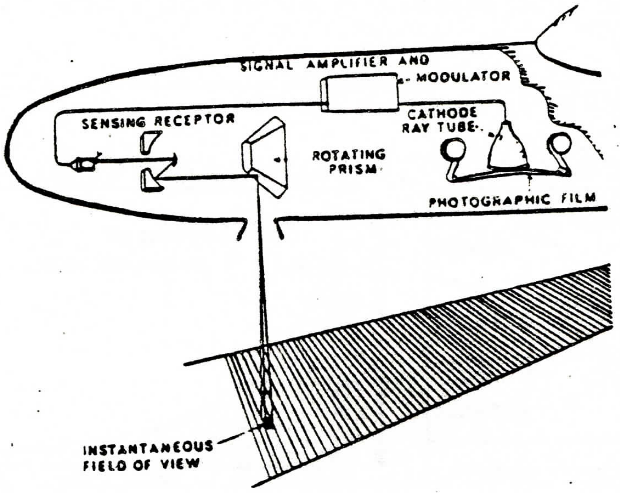


Figure 3.-- Principles of an optical mechanical scanner

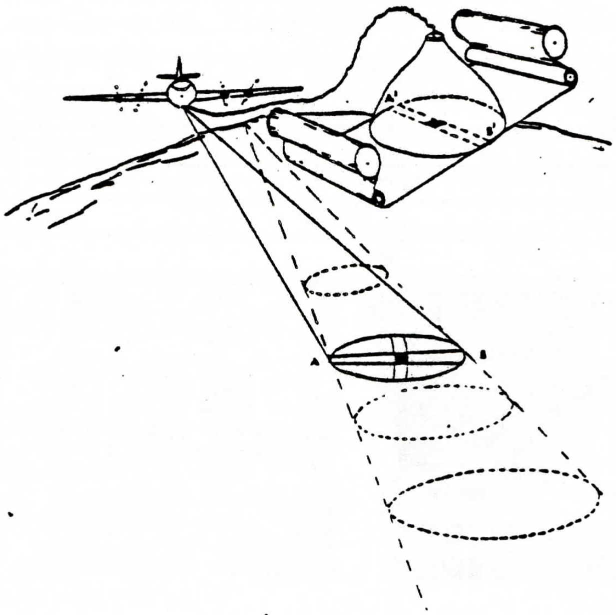
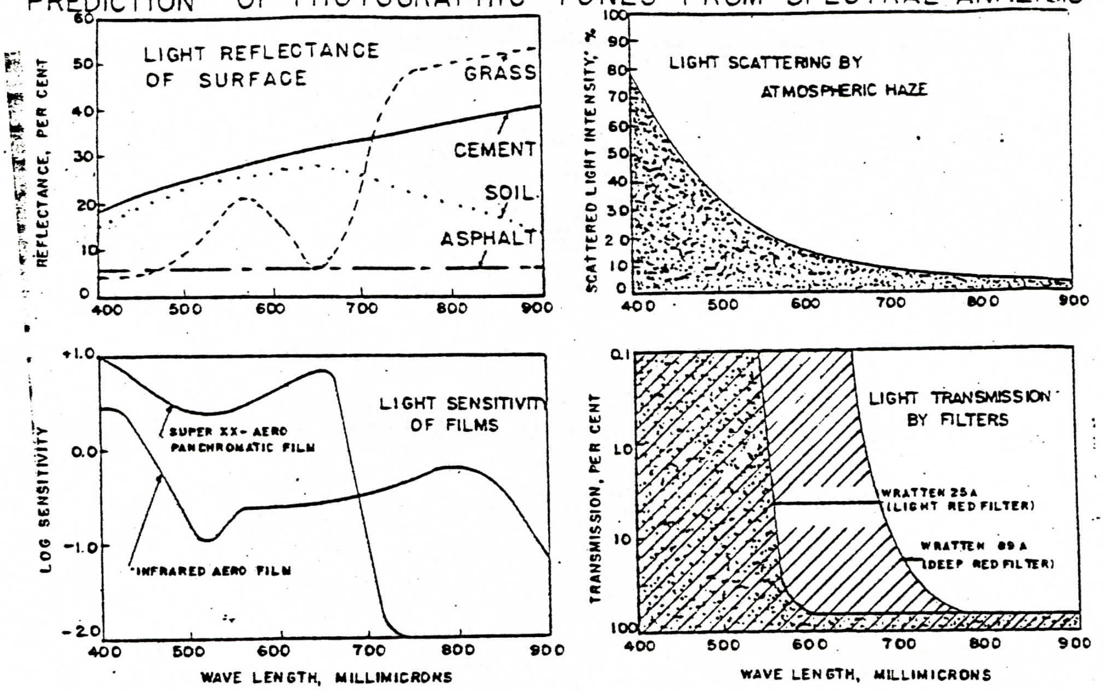


Figure 4.-- Side-Looking Airborne Radar(SLAR) equipment

PREDICTION OF PHOTOGRAPHIC TONES FROM SPECTRAL ANALYSIS



TYPE OF SURFACE	PREDICTED TONE ON POSITIVE PRINTS	
	PAN - 25A	INFRARED-89A
GRASS	DARK	LIGHT
CEMENT	LIGHT	LIGHT
ASPHALT	DARK	DARK
SOIL	LIGHT	DARK

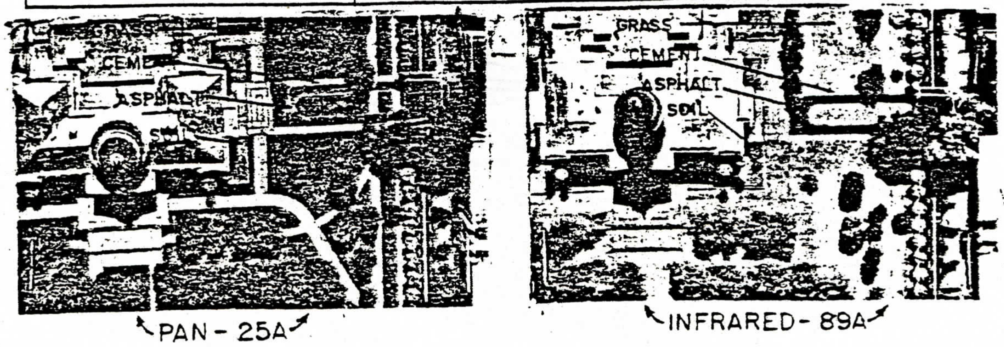


Figure 5 -- An example of the value of multiband spectral reconnaissance for differentiating four surfaces (grass, asphalt, cement and soil) that could not have been differentiated on a single black-and-white film-filter combination.

List of Photo Image Characteristics for Features in a Wildland Area

Type of Feature	Tone	Texture	Other Characteristics
R=Rock	L(light)	R(rough)	
G=Grass	L	S(smooth)	Stream meanders
T=Trees	D(dark)	R	
S=Shrub	D	S	
B=Bare Soil	L	S	
W=Water	D	S	Light-toned shoreline

Dichotomous Photo Interpretation Key based on Tabulations Appearing in Table above

1.	Tone Light	See 2
1.	Tone Dark	See 4
	2. Texture Rough	Rock
	2. Texture Smooth	See 3
3.	Stream Meanders present	Grass
3.	Stream Meanders absent	Bare Soil
	4. Texture Rough	Trees
	4. Texture Smooth	See 5
5.	Perimeter light in tone, forming a shoreline	Water
5.	Perimeter dark in tone, shoreline absent	Shrubs

Fig. 6 -- Top: The photo image characteristics

Bottom: The dichotomous photo interpretation key

Step 1. ACQUISITION OF DATA

Specify spectral and spatial resolution characteristics of sensors, atmospheric constraints, target illumination and the weight, power and volume requirements of the sensors. Specify performance characteristics of vehicles needed to transport the sensors, including speed, attitude control, service ceiling, stay time and ability to satisfy weight, power and volume requirements of the sensor package.

Step 2. STORAGE AND RETRIEVAL OF DATA

Specify the model or models that will best facilitate the storage of data and its retrieval periodically by those who are to convert the data into information that will satisfy specific requirements of the various users.

Step 3. CONVERSION OF DATA INTO INFORMATION THAT WILL SATISFY USER REQUIREMENTS

Establish the signature for each type of earth resource feature that is to be identified as a function of its spectral, spatial, goniometric and temporal characteristic. By proper use of humans and ADP machines, provide an in-place delineation, area-by-area, of each type of earth resource, including vegetation type, soil type, water quantity and quality, topography, culture and multiresource interrelationships.

Step 4. DEFINITION OF USER REQUIREMENTS FOR INFORMATION

Precisely define the kinds of earth resource information needed by those who must develop and implement management plans and policy decisions; also define the speed with which these types of information must be provided following acquisition of remote-sensing data, and the frequency with which these kinds of resource information are likely to be needed by the various users.

Step 5. DEVELOPMENT OF MANAGEMENT PLANS

Determine e.g., how best to manage the watershed with a view to multiple use management; also how and where to store water and to develop and distribute hydro-electric power from it and how best to transport water to farmlands, urban areas and other places of water consumption.

Step 6. MAKING OF POLICY DECISIONS

Determine e.g., whether to encourage or discourage (1)the growth of a megalopolis in a particular area, (2)the intensification of agriculture in a second area, etc.

Fig. 7. Steps by means of which remote-sensing techniques can be used to satisfy information requirements of various resource management groups. On the one hand, "hardware oriented" person is likely to view the matter as proceeding from top to bottom. On the other hand, the 'management and policy'-oriented person is likely view the matter as more logically proceeding from bottom to top.

REMOTE SENSING DATA PRODUCTS - TYPES AND CHARACTERISTICS

By David M. Carneggie
U.S.G.S. EROS Data Center
Sioux Falls, SD

I. Introduction

A. Objectives: To identify and define remote sensing data products available for analysis of wildlife management problems. To describe characteristics and formats as they relate to a choice of the data product to select for a particular analysis. To identify the various remote sensing data products discussed, displayed, and presented at the Symposium.

B. Rationale for understanding characteristics of remote sensing data products.

1. Select data products that maximize information content and information extraction.

2. Select proper data for particular application.

C. Definitions of data product terms.

1. Remote sensing data: a record of the electromagnetic energy within a wavelength band returned to the sensor by the target. Generally presented in an image format, but also includes data collected on mangetic tape and non-imaging sensor data such as telemetry, gamma ray radiation.

2. Photographs: most common form of remote sensing data. Record of visible and near infrared light recorded on film by a camera sensor.

3. Photo-like image: photographic record of electromagnetic energy collected by non-photographic imaging sensor, such as a line-scanner. Landsat and thermal infrared data are examples of line scan images (photo-like image) collected electronically yet presented on photographic material for viewing.

4. Imagery: general term referring to all forms of remote sensing data collected by imaging sensors. Includes photographs and line-scan images.

5. Imaging/non-imaging: Refers to two different systems for collecting remote sensing data. Imaging systems include cameras and multispectral scanners from which a pictorial representation of the target can be made. Non-imaging systems produce data in the form of counts, line graphs, radio signals, etc.

6. Magnetic tape (computer compatible tape, CCT): Refers to storage media for remote sensing data collected electronically, such as from a multispectral scanner. A CCT is a magnetic tape containing data that can be analyzed directly by computers and displayed electronically on a cathode ray tube (television screen).

D. Data products presented in Symposium.

1. Aerial photographs.

a. Conventional black and white (B/W) aerial photographs: Panchromatic photographs sensitive to visible wavelengths of light generally acquired at photo scales of 1:12,000 to 1:32,000. Often acquired using a yellow (minus blue) filter to remove effects of haze.

b. Conventional color photographs: Normal color photographs sensitive to blue, green, and red light acquired at scales from 1:12,000 to 1:32,000. Often a haze cutting filter is used to remove effects of haze.

c. Conventional color infrared: Color film sensitive to visible and near infrared light. Acquired at scales between 1:12,000 and 1:32,000, generally exposed through a yellow filter. Known also as infrared color, false color, or camouflage detection film. Healthy vegetation will appear red in color on this film.

d. Low altitude (large scale) color/color infrared: Color photographs acquired at low altitude either vertically or as obliques. Large scale photographs generally range from 1:600 to 1:5000.

e. 70 mm and 35 mm photographs: Refers to two common film widths, available in color or black and white. Camera systems that utilize 70 mm and 35 mm films are generally small and lightweight, and can be used to acquire either oblique or vertical photographs. 70 mm and 35 mm camera systems are generally operated at relatively low altitudes; however, 70 mm camera systems have been operated at high altitude and aboard spacecraft (Apollo 9).

f. High altitude aerial photographs (U-2, RB-57): Photography acquired from very high altitude, e.g. 60,000 ft. The U-2 and RB-57 are high flying aircraft operated by NASA. Generally small scale photographs (1:60,000 to 1:130,000) are acquired; however, photographic scales of 1:32,000 are acquired even at high altitude.

g. Multispectral aerial photographs: Generally refers to use of black and white panchromatic or black and white infrared film with two or more filters to acquire photographs that record visible and/or near infrared light in two or more different wavelength bands. Sometimes color and color infrared photographs are called multispectral because they have emulsion layers sensitive to three separate wavelength bands viz. blue, green, red (color) and green, red, near infrared, (color infrared), respectively.

2. Aerial line-scan data: Data recorded electronically on magnetic tape and reconstituted as a photo-like image.

   a. Thermal infrared: Refers to data that records emitted radiation within the wavelength interval of 2.5 - 14.0 µm. Terrain temperatures are generally recorded in the 8 - 14.0 µm range. Fires are recorded in the 3.5 - 5.5 µm band. The tones analyzed on the data are relatable to temperature differences.

   b. Multispectral scanner: An optical-mechanical scanning sensor with one or more detectors that can record wavelengths in the ultraviolet, visible, near infrared, and thermal infrared bands of the e-m spectrum.

   c. Radar imagery: Generally acquired using side-looking imaging radar systems that generate their own radio wave that is pulsed at the target. K-band radar imagery is quite common and is a record of wavelengths ranging from 1 to 3 cm. Other radar bands include X, S, L, and P, that record wavelengths respectively of : 3-6, 6-19, 19-77, and 77-133 cm. Radar images can be obtained night or day and in all types of weather.

3. Landsat multispectral scanner (MSS) data.

   a. Image format: Data from the Landsat MSS sensor is collected and transmitted electronically and reformatted in photo-like image format or as computer compatible tapes (CCT's) for analysis. Landsat 1 and 2 MSS images can be acquired in four black and white bands (4, 5, 6, and 7, sensitive to wavelengths of .5 - .6 µm, .6 - .7 µm, .7 - .85 µm, and .85 - 1.1 µm) or as a color composite that combines band 4, 5, and 7 data into a single color image. The color renditions of the composite image resemble those on color infrared film.

   b. Computer compatible tapes (CCT's): Magnetic tpaes on which Landsat digital data are recorded. This format is amenable to electronic image display (television screen) and analysis using computers.

4. Others (non-imaging).

   a. Telemetry: Use of transmitted radio signals to track animal locations and monitor physiological responses.

   b. Aerial census: Visual observations, generally of animals, made from aircraft.

II. Characteristics of Data Products

A. Spectral sensitivity: The range of wavelengths the sensor or film can record. In the case of photographic emulsions, filters are used to restrict the sensitivity to specified wavelengths.

B. Image tone and color: Image tone and color can ultimately be related back to the amount of radiation emitted or reflected from the target to the sensor, and to the sensitivity of the sensor or chemistry of the film. An understanding of the reflectance and/or emittance characteristics of targets is important to the selection of the sensor or image type that maximizes the separation between different targets.

C. Format: Refers to the media on which the remote sensing data are displayed. Generally, remote sensing data are presented in photographic format or as magnetic tapes. For photographic formats, image size and photographic material type are variable. Common photographic format sizes include: 35 mm, 70 mm, 5" x 5", 9" x 9", 9" x 18". Photographic material types include: film positives (black and white, and color transparencies), film negatives, and paper prints (black and white, and color). Oftentimes the image recording format is different than the image analysis format. For example, color infrared photos are generally acquired and processed as positive transparencies. A common analysis format is paper prints at contact size or enlargements.

D. Resolution: Refers to the amount of detail, i.e. sharpness, inherent in an image. It may be expressed quantitatively as the line pairs per millimeter of black and white bars that can be distinguished on a resolution target. High resolution refers to very sharp detail, low resolution implies detail is poorly defined. For line scan imagery, resolution often refers to the instantaneous field of view (IFOV). For Landsat the IFOV is approximately 1 acre in size. In reference to thermal infrared data resolution may express the extent to which small temperature differences can be recorded.

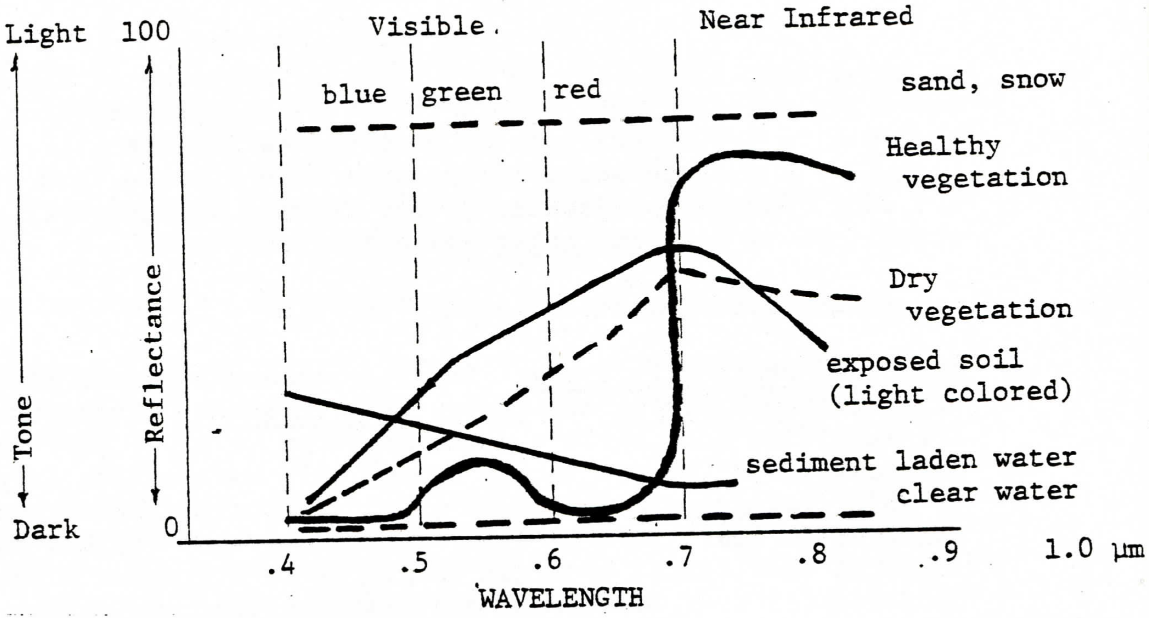
E. Scale: Photo or image scale refers to the ratio of image distance to corresponding ground distance. Remote sensing data may be characterized by an acquisition scale and/or by the scale of the image as displayed for analysis. For example, high altitude aircraft photographs acquired at an image scale of 1:120,000 may be enlarged four times (4x) to 1:30,000 for purposes of analysis. Small scale photography refers to acquisition scales from about 1:60,000 to 1:400,000; conventional scales include 1:12,000 to 1:32,000, and large scale photographs have a scale from 1:500 to 1:5,000. Generally speaking (other factors being equal), more detail can be seen on larger scale images.

III. Remote Sensing Data Recorded Directly on Film

A. Black and white film types: The two primary types of black/white film are panchromatic and aerographic infrared. Panchromatic films are sensitive to visible wavelengths from .4 to .7 μm. Some panchromatic films can record ultraviolet wavelengths (e.g., .3 to .7 μm). Aerographic infrared, oftentimes called black and white infrared or near infrared film, is sensitive to visible and near infrared wavelengths of light (e.g., .4 to 1.0 μm). A near infrared filter (that blocks out visible light and passes only near infrared light, .7 to 1.0 μm) is used in order to produce a black and white near infrared photograph. Black/white films can be exposed as positive transparencies or as negatives. The latter is more common.

Aerographic infrared film is commonly used to acquire multispectral photographs because it is sensitive to visible and near infrared wavelengths and can record selected wavelength bands when exposed through various filters (e.g., blue, green, red, near infrared).

The tones seen on black and white photographs (panchromatic and near infrared) indicate the relative amount of reflected light from the target. Targets which appear dark in tone on the photograph are reflecting relatively little light to the sensor. Targets which appear light in tone on a b/w photograph are reflecting a relatively high amount of light to the sensor. Healthy vegetation generally appears dark in tone on panchromatic photos because the chloroplasts in the leaves absorb blue and red light in the photosynthesis process, whereas vegetation appears very light-toned on near infrared (B/W) photographs indicating that plants are generally high reflectors of near infrared light. The relative amount of visible and near infrared radiation reflected by a target can be measured directly using a spectrometer or indirectly from photographs. A graph showing the amount of light reflected from a target as a function of wavelength is called a reflectance curve or spectral signature. Representative curves for a few natural terrain targets are shown in the accompanying graph. Note that the reflectance of some targets (e.g., healthy vegetation) changes considerably in the visible and near infrared spectrum, whereas other targets (e.g., clear water) change little. The value of the reflectance curves is for determining where in the visible and near infrared spectrum targets can be distinguised based upon differences in reflectance. For example, it may be difficult to distinguish water and vegetation in the visible spectrum because both appear dark in tone,



whereas it is easy to make this distinction in the near infrared, where vegetation appears light-toned and water very dark-toned.

B. Multispectral Photographs: Multispectral photographs can be acquired on either b/w panchromatic (.4 - .7 µm) or b/w near infrared (.4 - 1.0 µm) film. When using panchromatic film, one cannot obtain photographs in the near infrared; however, when using near infrared film, one can obtain photographs in the visible and near infrared spectrum. The most commonly acquired multispectral photographs are obtained in the blue, the green, the red, and near infrared bands. This can be accomplished in several ways:

a. Expose near infrared film through a blue filter plus a near infrared cut off filter, a green filter, a red filter, and a near infrared filter, respectively.

b. Expose panchromatic film through a blue, green, and red filter; and use near infrared film and a near infrared filter, respectively.

Either a multilens camera or a configuration of several cameras (enough for each spectral band desired) can be used. Multispectral photographs are frequently combined into color composites for the purpose of creating a more interpretable image. Accurate registration of the several multispectral photographs is important and best achieved when using a multilens camera.

C. Color Films: The two primary types of color films are normal (natural) color and color infrared. Normal color films have three emulsion layers that are sensitive to blue, green, and red light and can be obtained either as positive transparency film (color reversal) or as color negative film. Color infrared film also has three emulsion layers, and they are sensitive to blue, green, red, and near infrared light (.4 to 1.0 µm). Color infrared film is almost always exposed with a yellow filter that restricts the sensitivity of the film to green, red, and near infrared light. CIR film is almost always processed as a positive transparency (color reversal film). The emulsion layers of color and CIR film, the respective sensitivity of each layer and their associated dyes, are diagrammed below:

COLOR REVERSAL FILM

Sensitivity	Dye
blue	yellow
green	magenta
red	cyan

Yellow filter

COLOR INFRARED FILM

near infrared	cyan
green	yellow
red	magenta

A simple method for determining the color of a target as seen on "color reversal films" is to remember that:

a. The resultant color is a mixture of the dyes remaining in the film after it has been processed.

b. The amount of dye remaining in each emulsion layer after processing is inversely proportional to the amount of light (to which the layer is sensitive) that exposes each layer. For example, on color film vegetation appears green because green light sensitizes the green sensitive layer of the film and causes some of the magenta dye to be removed in processing. The remaining high amounts of yellow and cyan dye combine to produce a green color. Similarly, vegetation appears reddish in color on color infrared film because vegetation is a high reflector of near infrared light which activates the cyan dye causing it to be removed in processing. The remaining amounts of yellow and magenta dyes form to produce a reddish color.

D. Film formats and scales:

1. <u>Sizes</u>: Common aerial film sizes include 35 mm, 70 mm, 5" x 5", 9" x 9", 9" x 18".

2. <u>Format</u>: Formats for B/W and color include: negative, positive transparency or positive paper print. Generally positive images are easier to interpret than negatives. Transparencies are generally easier to interpret than paper prints due to better color rendition, contrast, and sharpness.

Transparencies require a light table for viewing and are more difficult to use in the field. The acquisition format and analysis format may be different. Positive prints used in an analysis may be made from either positive or negative film.

3. Scale: Image scale is defined as the ratio of image distance to ground distance. Image scale is also the ratio of focal length of the camera lens to flying altitude above the terrain. Scale can be varied by changing focal length of camera lens or by varying the altitude of the aircraft. Large scale photographs are generally acquired at low altitude and small scale photographs are generally acquired at high altitudes.

   The original image scale is controlled by the focal length of the lens and the flying altitude. Contact prints, original negatives, and original positive transparencies will have the same original photo scale. For analysis, the scale may be increased by photo enlargement. Generally, B/W and color films can be enlarged to 8 to 10x without appreciable loss of detail. Enlargements made from original film material often facilitate interpretation but do not increase detail that is not inherent in the original.

E. Comparison of films:

1. Costs: Black and white films and resulting photographic products are generally less expensive than color photo (by a factor of ¼ to ½). Costs for photo products produced from archive masters are generally fixed, but costs vary for contract photography based upon size of area. Transparencies ordered from an archive are generally more expensive than paper prints.

2. Resolution: Black and white films are generally of higher resolution than color film. Image sharpness is always a trade off between film graininess and exposure time (film speed). Generally, fine grain films require longer exposure that results in image movement. Color and CIR film have about the same film resolution. Atmosphere affects tone and color contrast, hence sharpness. Atmosphere effects are less apparent on infrared sensitive film.

3. Tone/Color: The eye can discriminate about four times as many colors as shades of gray; consequently, color films generally contain more interpretive information.

4. Availability: Black and white photography is available for most all areas of the U.S. through the U.S. Geological Survey. Most all national forests have been flown with black and white panchromatic photos. The U.S. Forest

Service is now acquiring color photos. The B.L.M. is acquiring color and color IR. The NASA high altitude aircraft have flown many areas of the U.S. with color and color IR; its availability can be determined at the EROS Data Center.

IV. Data Recorded Electronically

A. Aircraft data

1. Multispectral scanner data

a. Collected electronically using an optical mechanical scanner but formated in photographic or magnetic tape format.

b. Data can be simultaneously collected in many wavelength bands from the ultraviolet to the thermal infrared.

c. Data of lower resolution compared with photographic data.

d. Data difficult to rectify.

e. Data has inherent illumination differences.

2. Thermal infrared data: emitted radiation collected in wavelength bands between 3 to 14.0 µm.

a. Tones on the photo-like imagery are directly related to the temperature of the target.

b. Data can be collected during nighttime or day.

c. Data of lower resolution than camera data.

d. Wavelengths penetrate atmospheric haze and smoke.

3. Radar (Radio detection and ranging): microwave radiation ranging in wavelengths from a few centimeters to several meters.

a. "Active" radar sensors generate their own radio waves and propagate them to terrain targets.

b. Radar images generated daytime and nighttime and under most adverse weather conditions, including complete cloud cover.

c. Resolution usually lower than optical systems.

d. Longer radar wavelengths can penetrate some terrain targets.

e. Radar return affected by hardness of targets and angle of incidence to the sensor.

f. Refer to Dr. W. J. Richardson's paper

4. Telemetry: refer to Dr. W. W. Cochran's paper

a. Ground to ground

b. Ground to air/space

B. Satellite data

1. Landsat data: See LANDSAT system notes

a. System parameters

b. Sensors: MSS, RBV, DCP

c. Landsat image characteristics

d. Landsat data products

1. Black/white negative, positive images for MSS and RBV

2. Color composite (FCC)

3. Enhanced color composite images (EDIPS)

4. Computer compatible tapes (CCT's)

5. Landsat 3 RBV data

2. Other satellite data

a. Gemini/Apollo 9

b. Skylab

c. MET SAT

d. SEASAT

V. Summary: Factors Affecting Choice of Remote Sensing Data

A. Definition of problem

B. Maximize information content

1. Spectral sensitivity

2. Time of year

3. Scale/resolution

C. Maximize information extraction

1. Format (photographic--digital-magnetic tape)

2. Analysis equipment

3. Training/experience

4. Stereo viewing

D. Costs

APPROACHES TO REMOTE SENSING DATA ANALYSIS

By Lawrence R. Pettinger
U.S.G.S. - EROS Data Center
Sioux Falls, South Dakota

I. Introduction

A. Objectives: To present an overview of the essential steps in the remote sensing data analysis process, and to compare and contrast manual (visual) and automated analysis methods.

B. Rationale: This overview is intended to provide a framework for choosing a manual or digital analysis approach to collecting resource information. It can also be used as a basis for understanding/evaluating invited papers and poster sessions during the Symposium.

C. Definitions

1. Image analysis: The process of extracting resource information from remotely sensed images.

2. Image interpretation: The process of extracting resource information from remotely sensed images and judging its significance.

3. Manual (visual) analysis: Extraction of information by a human through the visual process of detection, delineation, and identification.

4. Automated analysis: Extraction of information by machine (e.g., computer, densitometer) from data which is usually in digital format. Automated analysis is an interactive process in which a skilled analyst controls the machine operations, providing his judgement and direction to the automated analysis process.

   a. Electronic display: A pictorial representation of remotely sensed data made with a video (television) display system.

   b. Digital enhancement: Manipulation of digital data to improve the discrimination of terrain features. Enhancement is commonly used to produce a more interpretable image. Examples include contrast enhancement and edge enhancement.

   c. Density slicing: The process of separating the continuous gray tones of an image (or numerical values of digital data) into a series of discrete intervals or slices, each corresponding to a specific density range. These slices are often displayed in different colors on a video display. By assigning unique colors to density slices, one hopes to enhance the interpretability of classes of features which have similar density characteristics.

d. Digital image classification: The classification of a population of data points (e.g., Landsat pixels) into a specified number of computer classes which correspond to resource types. The assignment of each data point to a class is based upon the similarity of spectral characteristics of the data point with the characteristics of the established class. A major assumption is that the resource classes have distinct spectral characteristics which can be derived from the digital data.

D. There are a variety of analysis objectives which provide data to address wildlife/habitat information requirements.

1. Census/enumeration

2. Habitat (vegetative community) mapping

3. Inventory/sampling

4. Change detection

5. Quantitative wildlife habitat evaluation

E. Distribution of Pecora IV poster session topics by analysis method

	Method	
Analysis Objective	Manual	Digital
Census	5	5 (telemetry)
Habitat mapping	16	3
Inventory	5	2
Change detection	3	
Quantitative habitat evaluation	6	2
	35	12

II. Choice of Remote Sensing Analysis Method

A. Is a remote sensing approach feasible? To answer this question, one must consider previous experience, available funding and manpower, and alternatives to collecting information. For the discussion which follows, it is assumed that some type of remote sensing analysis is suitable.

B. Factors affecting choice of analysis method

1. Manpower/physical resources available

a. Personnel

(1) What capability and experience do personnel have with manual and digital methods?

(a) For in-house analysis?

(b) For effective interaction with service contractor?

(2) Are there institutional preference/biases?

b. Funding for data products and/or analysis services

(1) What will the analysis cost?

(2) Will the analysis be done in-house, or will a service contract be used?

(3) Is funding available to purchase existing data or acquire new data?

c. Equipment

(1) What equipment is available/accessible for analysis?

(2) Are personnel fully trained in its use?

d. Are data products with the optimum characteristics available, or must new data products be acquired?

2. Information requirements

a. Level of detail

b. Size of study area

c. Time available for analysis

d. Desired accuracy of final results

C. General comments

1. Manual analysis can be performed quickly and effectively for small areas. Images are relatively inexpensive, especially when considered within the context of total project cost. Manual analysis can be done with relatively simple equipment (pocket and mirror stereoscope, drafting equipment, simple measuring aids, acetate overlays). As project area size increases, the following considerations may affect the quality/accuracy of final manual analysis product: variability among individual interpreters (interpretation skill, motivation, susceptibility to fatigue); variation in image quality/image signatures throughout the project area (may necessitate frequent retraining); transfer of interpretations to base map, as well as other manual analysis steps, may become tedious if they must be performed for an extended time period.

2. Digital analysis is based on statistical decision rules which are applied in an unbiased fashion to digital data. As a result, analysis is consistent; however, accuracy may be high or low. Although preprocessing and training may be time consuming, classification is rapid, repeatable, and fatigue-free.

III. Manual and Digital Data Analysis in the Mapping/Inventory Process

(Note: The following steps are appropriate for mapping and inventory; certain steps are not appropriate for census, change detection, habitat evaluation.)

A. Define analysis problem

1. Level of detail

a. Desired scale for final products

b. Minimum map unit

c. Appropriate scale/resolution of remote sensing data

d. Information detail (resource categories)

2. Accuracy

3. Cost

B. Acquire data to appropriate specifications

1. Sources of data

a. Buy existing data

b. Contract to have new data acquired

c. Acquire data yourself

2. Consider factors governing amount of information extractable (independent of analysis method)

a. Sensor system/data analysis parameters

(1) Spectral band (film/filter combination/wavelength interval): Aerial photos offer wide range of film type and filter combinations. Landsat bands (MSS, RBV) are fixed, yet optimum for many applications.

(2) Resolution

(a) Resolution affects the minimum size of features that can be mapped.

(b) Different levels of resource classes can be mapped from imagery having different resolution.

(c) Small resolvable features can often be delineated more effectively on enlarged images.

(3) Season of year

(a) Careful choice of season often maximizes the discrimination between vegetation types due to vegetation phenology effects.

(b) Sun angle effects

(i) Low sun angle emphasizes relief or terrain, but may obscure surface features (this may seriously affect digital classification in mountainous terrain); animal shadows are enhanced, thus improving detection and identification.

(ii) High sun angle is usually preferable for most vegetation/land cover mapping purposes.

(c) Choice of appropriate season may optimize contrast of features and their background (examples: sheep should be detected more easily on color photos with green grass than dry grass background; caribou can be detected more easily against a snow-covered background than a snow-free background).

(4) Time of day

(a) Similar considerations as under 3b (sun angle)

(b) Shadow characteristics

(i) Shadow length may be used to provide estimate of feature height (e.g., tree heights).

(ii) Shadow shape may aid in feature identification. (Animal type can often be determined by shadow shape on large scale photographs.)

(5) Scale

(6) Parallax (the shift in relative position of one feature with respect to another due to a shift in the point of observation; this is the characteristic of overlapping aerial photographs which permits stereo viewing)

(a) Certain types of interpretation can be done effectively without stereoscopic analysis (e.g., stratification of agricultural land, delineation of homogeneous, spectrally distinct vegetation types).

(b) Stereoscopic analysis almost always improves the accuracy of interpretation and boosts the confidence of the analyst. Topographic and other environmental relationships are more easily assessed. For animal census/enumeration applications, it is often noted that animals move or change position between aerial photo exposures. Stereoscopic viewing reveals these changes clearly and enhances detection.

Binocular reinforcement--the process of simultaneously viewing the same feature on overlapping photographs--often provides added information due to slightly different illumination, texture, etc., of features on the two images.

C. Preprocessing of data prior to analysis

1. Film products

a. Enlarge to scale suitable for analysis

b. Specify color/tone balance for optimum interpretation

c. Use digitally enhanced Landsat images (EDIPS processing at EROS Data Center)

2. Digital data

   a. Radiometric correction

      (1) Correction to remove banding (destriping)

      (2) Fix bad data lines, line segments, pixel dropouts

   b. Geometric correction

D. Develop classification scheme

   1. Utilize existing classification schemes for vegetation/land cover mapping, such as:

      a. U.S.G.S. land use/land cover classification (USGS Professional Paper 964)

      b. National Wetland Inventory classification system

      c. U.S. Forest Service Modified ECOCLASS method

   2. Modify/develop appropriate scheme for specialized use.

   3. Levels of classification should be consistent with image resolution.

E. Training

   1. Correlate image characteristics with ground characteristics

      a. Recognize that manual and digital analysis rely on a different mix of image characteristics (table 1).

   2. Reconnaissance of area (ground/overflights)

      a. With images in hand, identify unknown features.

      b. Intensity depends on previous familiarity with area.

   3. Utilize auxiliary information

      a. Previous interpretation of similar geographic areas

      b. Existing maps or survey data

   4. Develop training aids

      a. Manual

         (1) Image analysis keys

Table 1.--Utility of image characteristics in manual and digital analysis.

[X = frequently used, (X) = infrequently used]

	Manual Analysis		
Image Characteristic	Aerial Photo	Landsat	Digital Analysis
tone/color	X	X	X
size	X	X	
shape	X	X	
pattern	X	X	(X)
texture	X	(X)	(X)
shadow	X	(X)	
parallax (permits stereoscopic analysis)	X	(X)	
location/association	X	X	

(2) Annotated aerial photographs

b. Digital

(1) Develop training statistics

(a) Supervised training: Analyst selects representative examples of each resource class, trying to encompass the range of spectral variability known to exist in the study area. This phase is often done using an interactive analysis system. The analyst outlines the training areas using a trackball cursor; their spectral characteristics are recorded by the computer system for use in classification.

(b) Unsupervised training: Assumes that analyst cannot select a complete set of truly representative training areas. Uses portions of image from which natural groupings (clusters) of data points (e.g., Landsat pixels) are determined. These clusters are compared to ground data or aerial photos to determine which resource classes they represent. Unsupervised training sets are selected 1) randomly by the computer, or 2) as image areas (blocks of pixels) chosen by an analyst, each of which contains several resource types.

(2) Utilize environmental stratification to reduce spectral overlap between classes (resource types) which are found in different environmental strata.

(3) Merge other data sets (e.g., elevation, slope, and aspect data) to improve classification.

F. Image analysis

1. Equipment

a. Basic manual analysis equipment: pocket stereoscope, tube magnifier, mirror stereoscope, light table, drafting pens, acetate overlay material

b. Basic digital image processing equipment: central computer processor, operator's terminal, magnetic tape drive, line printer (also desirable: interactive display/console, magnetic disc storage, film recorder output device)

2. Human factors that affect analysis success

   a. Visual/mental acuity, motivation

   b. Training/experience

      (1) Discipline background

      (2) Remote sensing training

         (a) Special remote sensing workshops

         (b) College courses in remote sensing

         (c) Self-learning (refer to selected bibliography of general remote sensing references and article by Nealey, "Remote Sensing/Photogrammetry Education in the United States and Canada")

3. Manual analysis: delineation and identification

4. Digital analysis

   a. Classification

      (1) Parallelepiped classifier: Algorithm which uses upper and lower brightness value in each spectral band to define an n-dimensional space (parallelepiped) as the training set for each particular class. Pixels are classified into a particular class if they fall within the parallelepiped space corresponding to the training set for that class. Using this method, some pixels are not classified because they do not fall within the parallelepipeds of any training set resource class.

      (2) Maximum likelihood classifier: Algorithm which assigns pixels to computer classes based on the calculation of a likelihood statistic. The likelihood statistic is calculated from the value of the pixel in question and the mean, variance, and covariance for the training sets (computer spectral classes). Each pixel is assigned to the class for which it has the maximum likelihood statistic; all pixels are classified.

   b. Band ratios for change detection

G. Field survey

1. Verify accuracy of detection, classification, or mapping

2. Measure physical resource parameters while in the field

H. Revise analysis

1. Manual: reinterpretation, changing type boundaries and labels

2. Digital: alter training statistics, reclassify

I. Accuracy assessment

J. Produce output products

1. Overlays to images or topographic maps

2. Color-coded maps

3. Tabular data summaries

IV. Case Studies

A. Manual image analysis: vegetation mapping in southeastern Idaho[1/]

1. Objective: produce a vegetation map of greater accuracy and with at least as much detail as environmental impact statement vegetation map.

2. Image types, format, scale

a. NASA U-2 CIR aerial photographs (paper prints, enlarged to 1:24,000 from 1:120,000)

b. Landsat color composite image (paper print, 1:250,000)

3. Delineation and identification of vegetation types

4. Output products

a. Image overlays

b. Overlays to topographic maps

(1) 7½' quadrangle (1:24,000) for aerial photo interpretation

(2) 1:250,000 topographic map for Landsat interpretation

B. Digital image analysis: land cover classification--southeastern Idaho[2/]

1. Objective: produce a vegetation/land cover map for same area as A.

2. Preprocessing

3. Training set selection: unsupervised, with spectral clusters determined from training blocks.

4. Environmental stratification to eliminate spectral overlap between vegetation types which occur on uplands and lowlands

5. Test classification in sample areas

6. Classification (maximum likelihood)

7. Accuracy assessment

8. Final output products

   a. Color-coded maps to fit topographic maps

   b. Flatbed plotter overlay to topographic map

1/ Carneggie, D. M., and Holm, C. S., 1977, Remote sensing techniques for monitoring impacts of phosphate mining in southeastern Idaho, in William T. Pecora Memorial Symposium, 2d, Sioux Falls, South Dakota, 1976, Proceedings: Falls Church, Virginia, American Society of Photogrammetry, p. 251-272.

2/ Pettinger, L. R., Digital classification of Landsat data for vegetation and land cover mapping in southeastern Idaho (manuscript in review for U.S.G.S. publication series).

THE LANDSAT SYSTEM

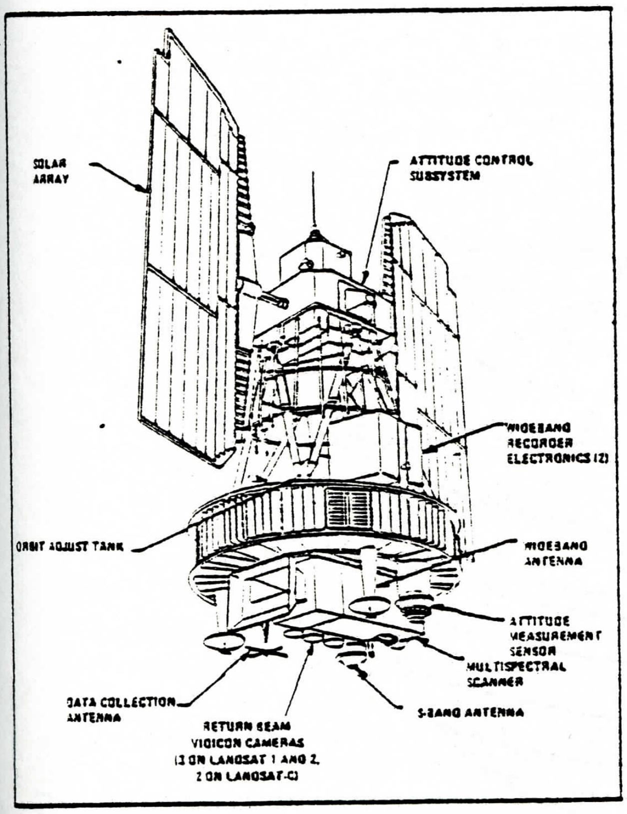
I. Characteristics of Landsats 1, 2, and 3

A. Launch dates

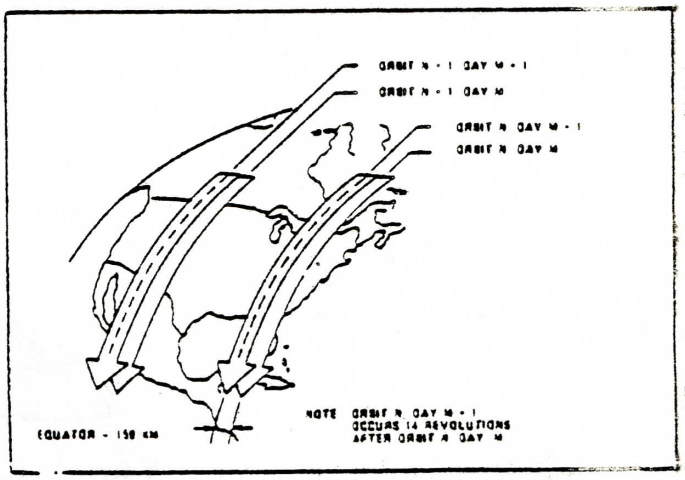
Landsat 1: 23 July 1972, ceased operations, January 1978
Landsat 2: 22 Jan 1975
Landsat 3: 5 March 1978

B. Orbital parameters and coverage cycle

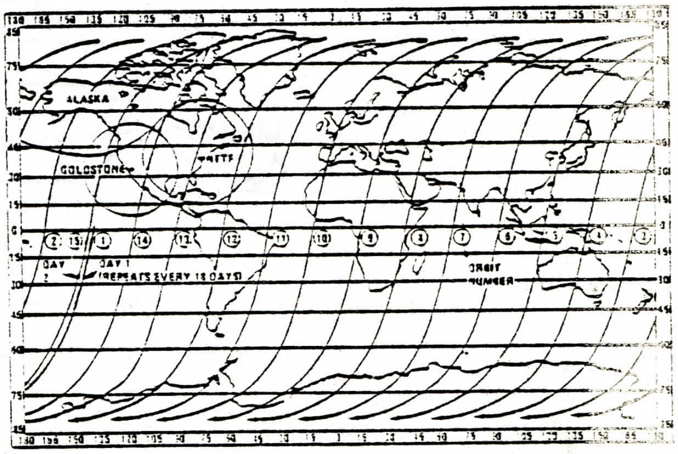
Altitude: 900-950 km
Inclination: 99°
Period: 103 min
Time of descending node, equator: 9:42
Distance between successive tracks: 2760 km at equator, 2129 km at 40° (14 orbits/day)
Distance between adjacent tracks: 158 km at equator, (sidelap = 27 km or 14%) 122 km at 40° (sidelap = 63 km or 34%) (18 days for repeat coverage)
Swath width: 185 km



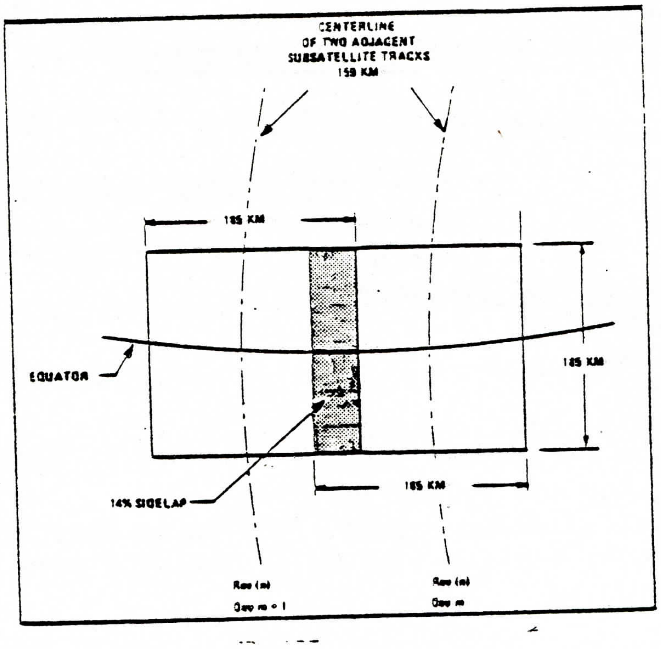
Landsat Observatory Configuration



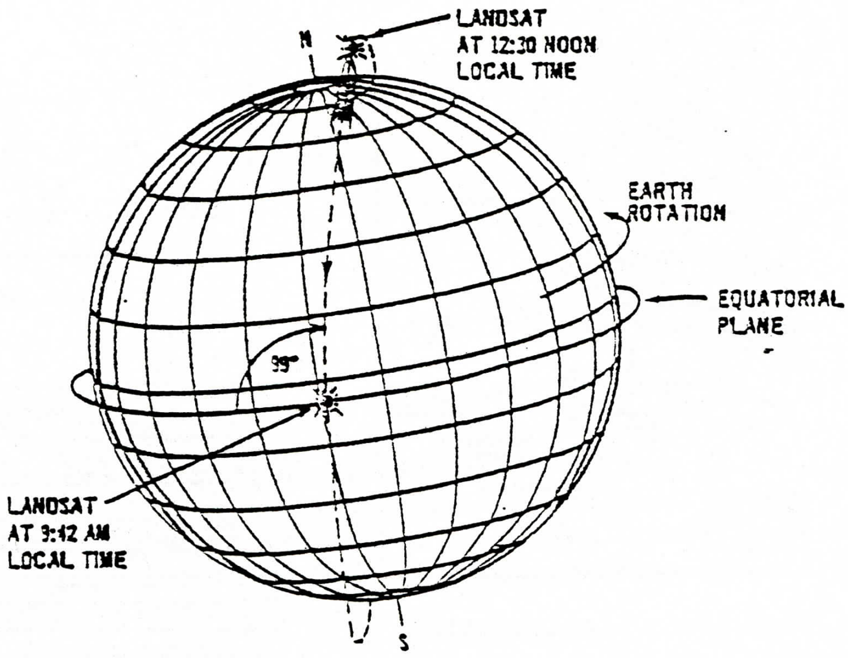
Ground Coverage Pattern



Typical Landsat Daily Ground Trace (Daylight Passes Only)



Imagery Sidelap at the Equator



Landsat Orbit

C. Data Telemetry and Ground Receiving Stations

S-band, 2229.5 and 2265.5 MH$_2$,

MSS Data Rate: 15 MBPS

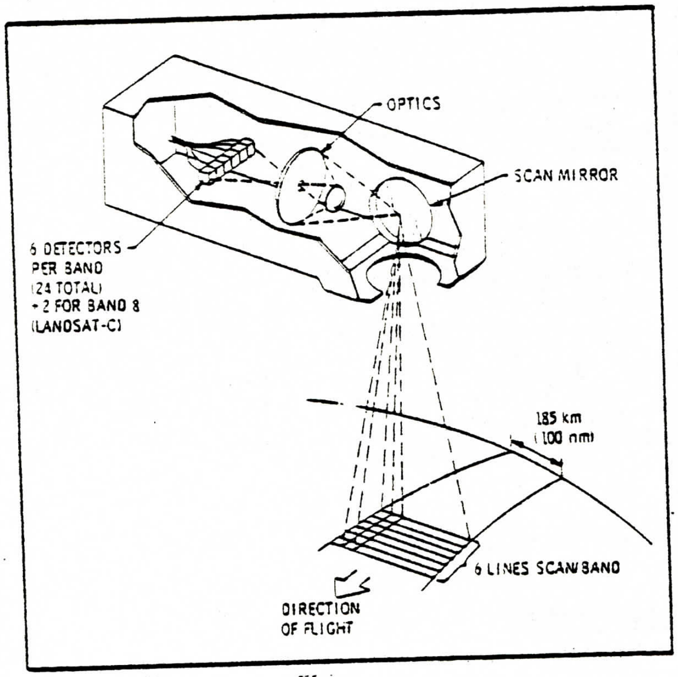
1. US Stations:
   - Goddard Space Flight Center, Greenbelt Maryland
   - Goldstone, California
   - Fairbanks, Alaska
2. Foreign Stations (by arrangement only):
   - Prince Albert
     Integrated Satellite Information
     Box 1630
     Prince Albert, Saskatchewan
     Canada S6U 5T2
   - Cuiabá
     Instituto De Pesquisas Espaciais (INPE)
     ATTN: Direcas
     Av. Dos Astronautas, 1758 - Caixa Postal 515
     12.200 - Sao Jose dos Campos, S.P. - BRASIL
     Tel. (0123)21-8900 Telex. (011)21534
   - Fucino
     Telespazio
     S.P.A. Per Le Comunicazioni Spaziali
     Corso D'Italia 42
     00198 Roma, ITALY
     ATTN: Mrs. G. Calabresi
   - St. John's
     Department of Forestry & Agriculture
     Building 810
     Pleasantville
     St. John's, Newfoundland A1A 1P9
   - Rawalpindi, Pakistan (Temporary)
   - Tehran, Iran
   - Mar Chiquita, Argentina
   - Kinshasa, Zaire
   - Santiago, Chile

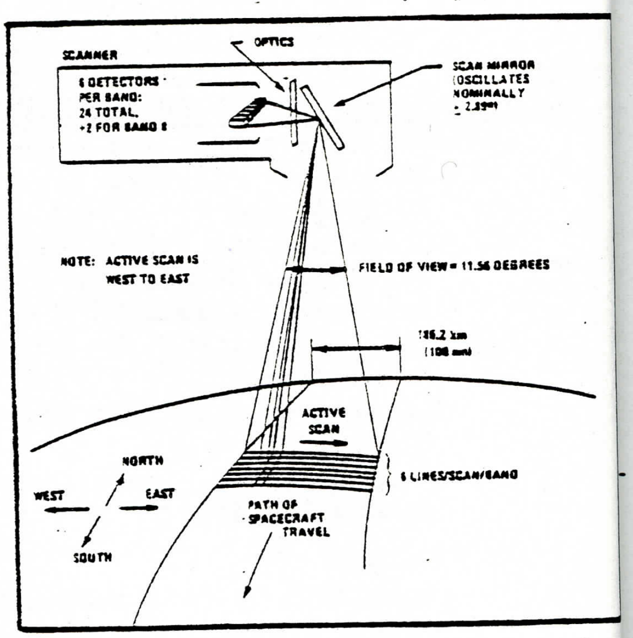
   } Planned

- Foreign data: real time readout to foreign stations or via tape recorder to U.S. stations.
- Station effective reception range: 2,300-2,800 km
- Two tape recorders per satellite, each with 30 min. capacity. Landsat 2, only one recorder functioning.

D. The Multispectral Scanner (MSS)

1. Scanner Operation
   - Swath width of 185.2 km
   - Scanning by means of oscillating mirror (13.62 cycles/sec) and spacecraft motion. Six detectors in each spectral band, so 6 scan lines obtained with each mirror oscillation. Data for swath is later divided into scenes, each approx. 185 km in along-track direction.



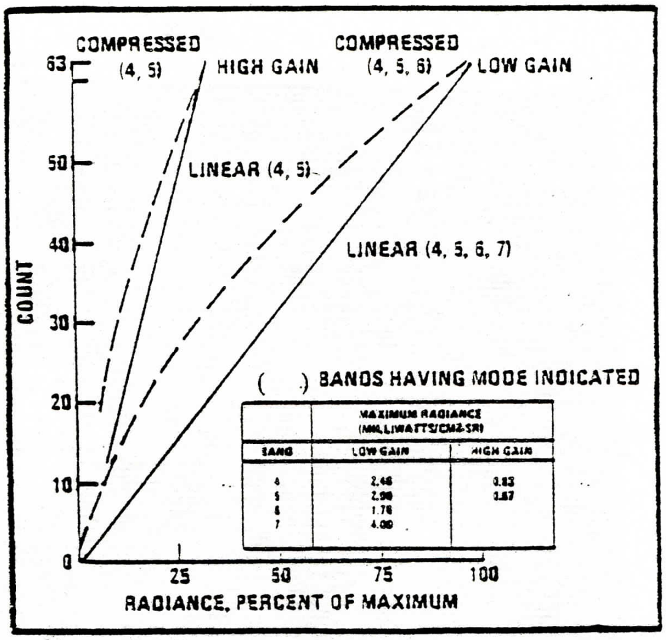


Landsat MSS Scanning Arrangement

2. Spectral Resolution and Sensitivity
   - Four wavelength bands:
     - Band 4 0.5 - 0.6 μm (green)
     - Band 5 0.6 - 0.7 μm (red)
     - Band 6 0.7 - 0.8 μm (near - IR)
     - Band 7 0.8 - 1.1 μm (near - IR)
     - Band 8 10.4 -12.6 μm (Thermal IR), Landsat 3 only
   - Each detector analog signal is encoded as a 6 - bit (64 level) digital word, each word corresponding to one picture element. Signal compression is generally employed to improve the signal-to-noise in bands 4, 5, and 6, never in band 7. In the final form, bands 4, 5, and 6 have 128 discrete radiance levels, band 7 has 64 levels.
   - There are two gain modes available for bands 4 and 5. In high gain mode, (rarely used), gain is increased by a factor of 4.

Spectral band	10.4 to 12.5 micrometers
Dynamic range (scene apparent temp)	230° to 340°K
Instantaneous field of view	237 x 237 meters (nominal)
Number of sensors	2
Information bandwidth	14.1 kHz
Effective aperture	308 cm^2
Lines/mirror scan	2
Swath width	100 nm
Detector material	Hg Cd Te
NEΔρ (noise equivalent radiance)	2.5 x 10^{-10} watts
Responsivity	3100V/watt (nom)
Detector operation temp	110°K
NEΔT (noise equivalent temperature)	1.4°K for 300 k scene
MTF min. (minimum modulation transfer function)	0.29 for 237 m bars
In-flight calibration	a) Ambient black body
	b) Reflected detector
Cooling	Passive radiation

Predicted MSS Band 8 Characteristics



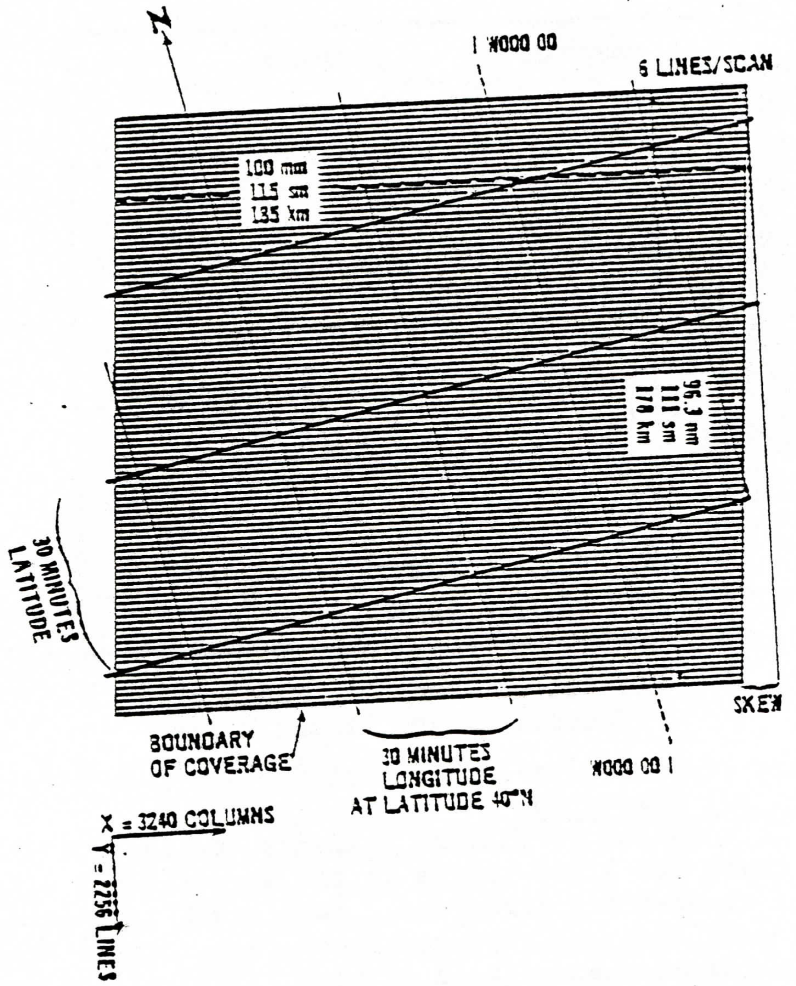
MSS Output Count Vs. Radiance,
Compressed and Linear Modes

- Dynamic range of band 8 is 260°K to 340°K (-13°C to 67°C)

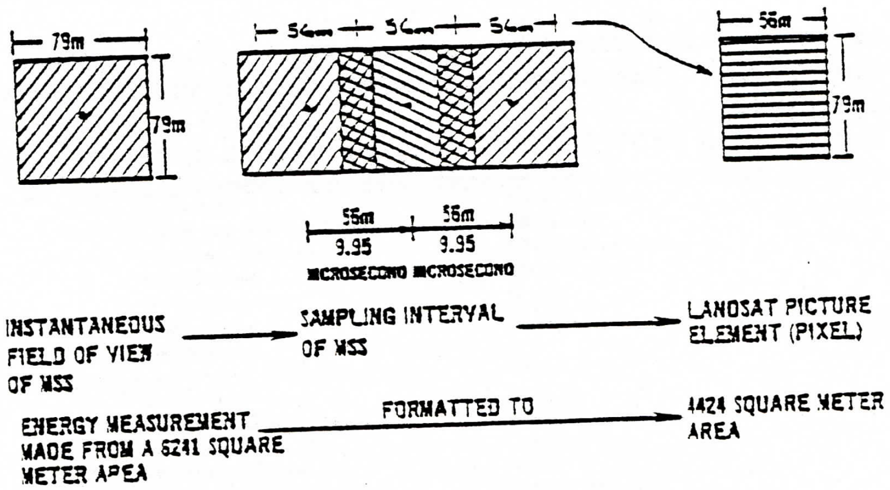
3. <u>Image Geometry and Resolution</u>
   - Each image is composed of picture elements, called "pixels." For bands 4-7, there are 3,240 pixels in the across-track direction and 2,340 in the along-track direction. Each pixel is treated spatially as an area 56m X 79m, but represents the data from an area 79m square, which is the instantaneous field of view (IFOV) of the scanner. The difference in size of pixels and the IFOV results from an effective overlap of IFOV's along scan lines.

     1 pixel ≃ 1.1 acres ≃ .444 ha (bands 4-7)

   - Due to earth's rotation, each scan line begins slightly west of the previous line. Thus the area imaged in a scene has skew and is a parallelogram.
   - For band 8, the IFOV is 237m square, with a pixel of 237m x 167m. Therefore, each pixel is equivalent to approximately 10 acres or 4 hectacres.



Landsat image coverage

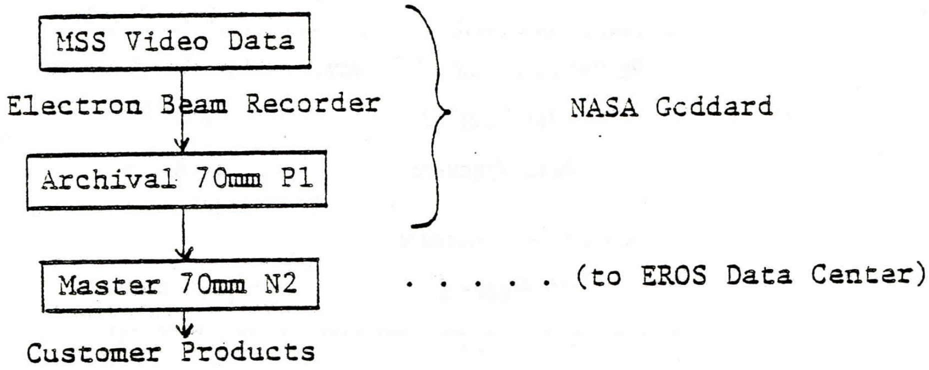


Formation of the MSS picture element (PIXEL)

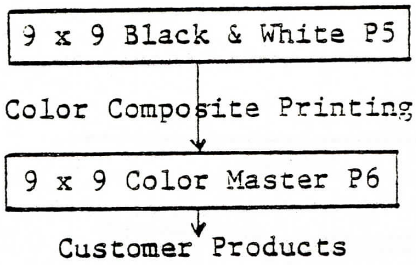
4. Image Data

a. Product generation

- Black-and-white:



- Color:



b. Image formats and annotation

		Black & White			Color	
Scale	Image size	Pos Film	Neg Film	Pos Paper	Pos Film	Pos Paper
1:3,369,000	55.8 mm	X	X	--	--	--
1:1,000,000	18.5 cm	X	X	X	X	X
1:500,000	37.1 cm	--	--	X	--	X
1:250,000	74.2 cm	--	--	X	--	X

5. Computer - Compatible Tapes (CCT)

a. Product Generation

- CCT made from high density tapes by NASA - Goddard

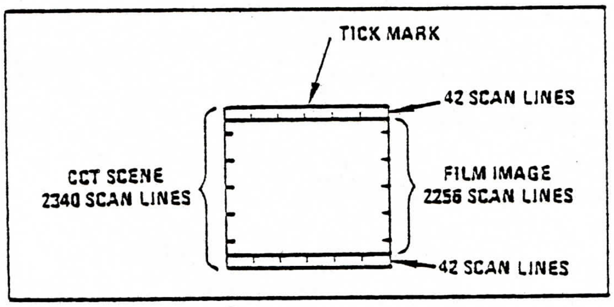
b. Format

- 7 track, 800 BPI
- 9 track, 800 or 1600 BPI
- Full frame segmented into four 46.3 by 185.2km strips in N-S direction
- Band - interleaved

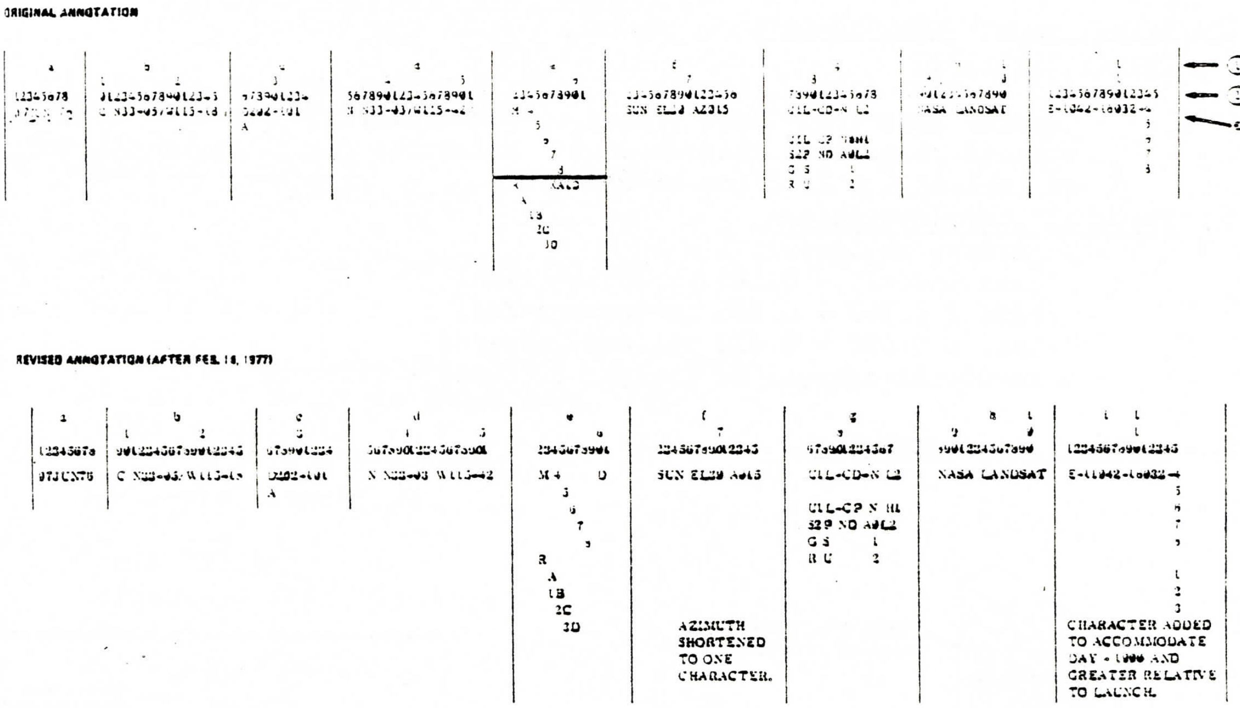
MSS Bulk Output Product

Residual Errors (rms)

Positional Mapping Accuracy	
Film Products	**743 meters**
Paper Products	**757 meters**
Registration Accuracy	
All Products	**159 meters**



CCT and Film Image Comparison



Note: (1) The letters "a" through "i" refer to items in this illustration that explain the annotation block.
(2) Character "position" in the annotation block.
(3) b = blank.

a. Character Positions 01-08. 17 JUN 76b
Day, month and year of picture exposure.

b. Character Positions 09-25.
C3N33-05/W115-18b
Format Center - Latitude and longitude of the center of the RBV and MSS image format is indicated in degrees and minutes.

c. Character Position 26-34. D202-101b
The "D" indicates spacecraft is descending; an "A" indicates spacecraft is ascending. Nominal path and row identifier. The 202 is path number and 101 is row number.

d. Character Positions 35-51
N0N33-03/W115-42b
Nominal latitude and longitude

e. Character Positions 52-61.
Characters in this group are sensor and spectral band identifiers:
For RBV images

52-56	Sensor spectral band or Landsat-C identification code
57-58	RBV Shutter Duration Code. The "XA" refers to shutter speed
59	Aperture Correction indicator. 1 - Aperture correction "in" 0 - Aperture correction "out"
60	"D" indicates direct transmission. "R" indicates stored data played back from the satellite WBVT recorder
61	Blank

For MSS images

52-59	The sensor spectral band identification code.
60	"D" indicates direct transmission. "R" indicates stored data played back from the satellite WBVT recorder
61	Blank

f. Character Positions 62-75. SUN4EL30b A015b
Sun Angles - the sun elevation angle and sun azimuth angle measured clockwise from true North at the time of midpoint of MSS frame is specified to the nearest degree. Blank for ascending node coverage

g. Character Positions 76-87. U1L-CD-N4L2b

Character position 76 defines the type of geometric correction applied to the data:
"U" = uncorrected
"S" = system level
"G" = geometrically corrected based on geodetic GCP's
"R" = geometrically corrected based on relative GCP's

Character position 77 indicates the scale of the image:
"1" = 185 km x 185 km (~100 nm x 100 nm)
"2" = 92.5 km x 92.5 km (~50 nm x 50 nm)

Character position 78 defines the projection:
"L" = Lambert projection
"P" = polar stereo projection
"S" = space oblique projection
"U" = UTM projection

Character position 80 indicates the resampling algorithm:
"C" = cubic
"N" = nearest neighbor

Character position 81 indicates the type of ephemeris data used to compute the image center:
"P" = predictive
"D" = definitive (for system level correction only)

Character position 83 gives the processing procedure:
"N" = normal processing procedure
"A" = abnormal processing procedure

Character position 84 defines whether an earth image or whether a RBV calibration image has been processed:
Blank = earth image
Either "0", "1", or "2" = RBV Radiometric calibration images, indicating lowest to highest exposure level respectively.

Character position 85 indicates the sensor gain option:
"H" = high gain
"L" = low gain

Character position 86 shows the type of MSS transmission:
"1" = linear mode
"2" = compressed mode

h. Character Positions 88-100
NASAbLANDSATb
Identifies the agency and the project

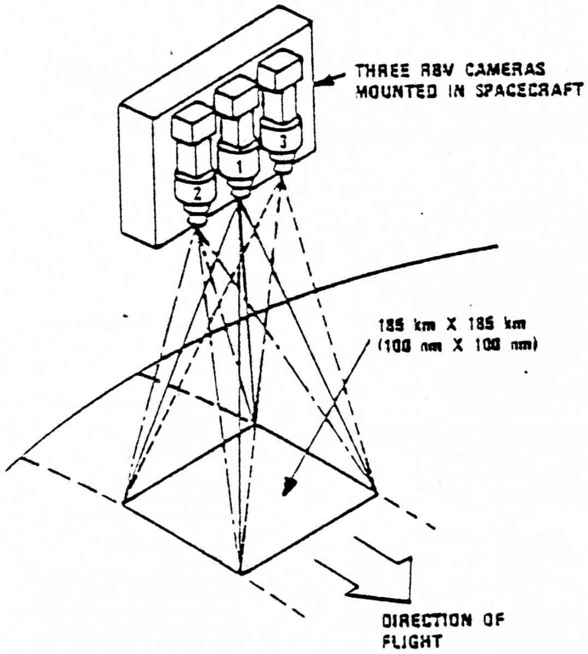
i. Character Positions 101-115
E-11942-18032-4
Frame identification number. Each image or frame will have a unique identifier which will contain encoded information consisting primarily of time of exposure relative to launch. Its format is E-ADDDD-HHMMS-B and is interpreted as follows:

"E"	Encoded Project Identifier
A	Landsat Mission: 1 - Landsat 1; 2 - Landsat 2; 3 - Landsat 3
DDDD	Day number relative to launch at time of observation
HH	Hour at time of observation
MM	Minute at time of observation
S	Tens of seconds at time of observation
B	NDPF identification code (RBV A, B, C, D; MSS 4, 5, 6, 7, 8) 1, 2, 3

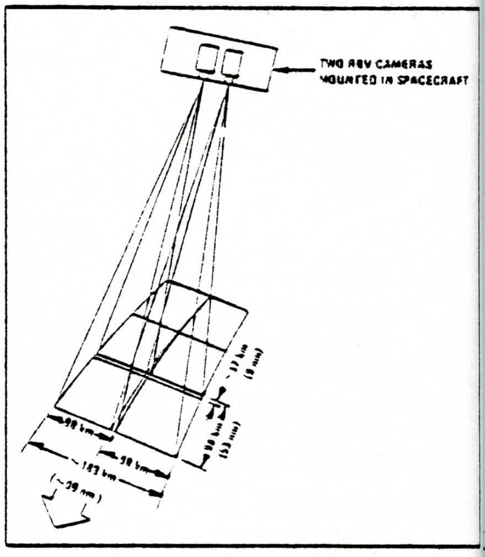
Details of Annotation Block

E. The Return-Beam-Vidicon Camera

1. Sensor operation
   - 185 x 185km area on Landsat 1 & 2, 98 x 98km area on Landsat 3
   - Cameras shutterd, image stored on photosensitive surface, then scanned to produce video output. Effective focal length = 126mm on Landsat 1 & 2, 236mm on Landsat 3
2. Spectral characteristics
   - 3 cameras on Landsat 1 & 2
     band 1 0.475 - 0.575 μm (blue-green)
     band 2 0.580 - 0.680 μm (orange-red)
     band 3 0.690 - 0.830 μm (red-infrared)
   - 2 identical cameras on Landsat 3, 0.505 - 0.750 μm
3. Geometry and Resolution



Landsat 1 & 2 RBV Scanning Pattern



Landsat 3 RBV Scanning Pattern

Landsat 1 & 2 RBV Precision Output Product

Residual Errors (rms)

Positional Mapping Accuracy	
Film Products	92 meters
Paper Products	104 meters
Registration Accuracy	
All Products	118 meters

4. <u>Product generation and format</u>
   - Generation and format similar to that for MSS images

II. <u>Availability of Satellite Data</u>

A. <u>EROS Data Center</u>
   Sioux Falls, South Dakota 57198
   USA

B. <u>Other U.S.</u> (See accompanying list)

C. <u>Foreign Sources</u>

Instituto de Pesquisas Espaciais (INPE)
Divisão de Banco de Dados (cod. 5.03)
Caixa Postal 515
12.200 São José dos Campos
São Paulo, Brazil

Terra Project
Telespazio SPA
Corso d'Italia
00198 Rome, Italy

The World Bank
Cartography Section, Room N-619
1818 H St., N.W.
Washington, D.C. 20433 USA

NASA Cumulative Non-US Standard Catalogs
Available through EROS Data Center
or
Main Government Printing Office Book Store
Attention: NASA Publications Clerk
710 North Capital St.
Washington, D.C. 20402

III. Future Satellite Systems (Landsat D)

A. <u>Schedule for Launch</u>
   Landsat D - 1980 - 81?

Landsat D:
- No RBV. May have MSS similar to Landsat C.
- Thematic Mapper: Altitude: 705km. (tentative)

6 channels

0.45 - 0.52 µm	(reflected)
0.52 - 0.6 µm	(reflected)
0.63 - 0.69 µm	(reflected)
0.76 - 0.9 µm	(reflected)
1.55 - 1.75 µm	(reflected)
10.4 - 12.5 µm	(emitted)

IFOV: 30m x 30m reflected
120m x 120m emitted

IV. Digitally enhanced Images (EDIES/EDIPS)

- Currently under development, operational by mid - 1978
- NASA will deliver high-density digital tapes to EDC, where images will be prepared
- Provide shorter delivery times to user and allow for geographic and radiometric manipulation of the data
- Geometric corrections to remove distortions introduced from earth rotation and variation in MSS mirror velocity
- Radiometric corrections to remove striping due to unequal detector response and to fix bad data lines
- Contrast enhancement to expand distribution of brightness values of CCT's over full range of 256 digital values
- Edge enhancement to enhance boundaries between features w/subtle differences in brightness along their boundaries

V. Data Collection System

Measurement Device → DCP → Satellite → Ground

Purpose: a relay for environmental information from remote stations to central data collection point for subsequent dissemination to User.

Satellite: GOES or LANDSAT

Frequency of transmission: -GOES, every 180 minutes
-Landsat, twice a day

Cost:

DCP	$3400.
Antenna	175.
Battery & Solar Panel	295.

October 1978

SOURCES OF REMOTELY SENSED DATA

Compiled by
Applications Branch
EROS Data Center

NATIONAL CARTOGRAPHIC INFORMATION CENTER (NCIC)
(formerly the Map Information Office)

NCIC was established within the USGS to provide a single-point contact source for cartographic-related information, including remotely sensed data. A computerized indexing system, the Aerial Photography Summary Record System (APSRS), shows all holdings of Federal agencies, with the long range goal of including data acquired on the state and local lavels and (eventually) by private industry.

The system directs the user to a particular agency which holds coverage over a particular unit area, based on the 7½ minute USGS quadrangle system. The data will remain in the hands of the source agency.

The cooperating Federal agencies include:

- U.S. Geological Survey (USGS)
- National Oceanic and Atmospheric Administration (NOAA)
- Agricultural Stabilization and Conservation Service (ASCS)
- Bureau of Land Management (BLM)
- National Archives and Records Service (NARS)
- U.S. Forest Service (USFS)
- Library of Congress, Geography and Map Division
- Soil Conservation Service (SCS)
- Tennessee Valley Authority (TVA)
- Department of Defense (DOD)
- U.S. Army Corps of Engineers (USACE)

To provide easier access to NCIC at the regional level, there are NCIC offices at four USGS mapping centers:

NCIC Eastern
U.S. Geological Survey
536 National Center
Reston, VA 22092
FTS: 928-6336
Comm: (703) 860-6336

NCIC Midcontinent
U.S. Geological Survey
1400 Independence Road
Rolla, MO 65401
FTS: 276-9107
Comm: (314) 364-3680

NCIC Rocky Mountain
U.S. Geological Survey
Stop 504, Box 25046
Denver Federal Center
Denver, CO 80225
FTS: 234-2326
Comm: (303) 234-2326

NCIC Western
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
FTS: 467-2427
Comm: (415) 323-2427

EROS DATA CENTER (EDC)

The EROS Data Center was established in 1971 as part of the Earth Resources Observation Systems (EROS) program of the Department of Interior, and is managed by the U.S. Geological Survey. It provides primary access to Landsat data, aerial photography acquired by the DOI, and aerial photography and other remotely sensed data acquired by NASA Research Aircraft and from Skylab, Apollo, and Gemini spacecraft.

Landsats 1, 2, and 3 have acquired approximately 280,000 individual scenes in four separate spectral bands. Nearly complete coverage of the world's land areas, except the polar areas, has been collected. Over 40,000 frames of Skylab, Apollo, and Gemini coverage have been archived at EDC. Only selected coverage was taken on these missions.

High altitude aerial photography (taken from 60,000 to 65,000 feet altitude) has been acquired by NASA for much of the United Stat at the request of investigators participating in the NASA Earth Resources Program. The most common scales are 1:60,000 and 1:120,000. Black-and-white, color, and color infrared photographs are generally available in a 9" film format. Since the inception of this program in 1964, approximately 1,300,000 frames have been acquired, covering about 80% of the contiguous 48 states. Many area have been flown more than once. Main inputs for this data are the NASA-Ames Research Center in Moffett Field, California, and the NASA-Johnson Space Center in Houston, Texas.

Conventional aerial photography flown by the USGS accounts for approximately 2,000,000 frames. The most common scale is 1:24,000, typically on 9" black-and-white panchromatic film.

A final category includes aerial photography acquired by various Federal agencies at various scales and film types. The following groups have input approximately 1,000,000 frames into the EDC archives:

- Army Map Service, Air Force, Navy
- U.S. Army Corps of Engineers
- Bureau of Land Management
- Bureau of Reclamation
- Wallops and Marshall Flight Centers (NASA)
- Mississippi Test Facility
- University of Michigan
- South Dakota State University

Since the EROS Data Center does not hold the complete collecti of aerial photography acquired by these individual groups, users should contact the originating agency for the possibility of additional coverage. For more information contact:

EROS Data Center
Attn: User Services
Sioux Falls, SD 57198
FTS: 784-7151
Comm: (605) 594-6511, Ext. 151

U.S. BUREAU OF LAND MANAGEMENT

The BLM has acquired photography in recent years at various scales and film types. For more information, contact:

Mr. Wallace Crisco
Office of Spacial Mapping
Bureau of Land Management
Denver Federal Center
Building 50
Denver, CO 80225
FTS: 234-5575
Comm: (303) 234-5575

AGRICULTURAL STABILIZATION AND CONSERVATION SERVICE (ASCS)

The ASCS has acquired coverage over about 80% of the United States excluding Alaska. Most commonly, surveys are flown at a scale of 1:20,000 on black and white 9" panchromatic film. Coverage is usually flown on a county-by-county basis on a 7 year cycle, dating back to the 1930's. Since about 1971, 1:40,000 scale photography has been acquired. Indexes of coverage for specific areas are available for inspection through the local county ASCS office. For more information contact:

Aerial Photography Field Office
ASCS - USDA
2222 West 2300 South
P.O. Box 30010
Salt Lake City, Utah 84125
FTS: 588-5856
Comm: (801) 524-5856

SOIL CONSERVATION SERVICE (SCS)

The SCS has acquired conventional aerial photography for many areas of the United States. Coverage was generally acquired at a scale of 1:20,000 on 9" black and white panchromatic film. Most recently, coverage has been acquired at scales ranging from 1:31,680 to 1:85,000. The SCS is currently undertaking orthophoto mapping projects with cooperation from the USGS. Surveys are not flown on a prescribed repetitive basis. For more information contact:

Soil Conservation Service, USDA
Cartographic Division
Federal Center Bldg.
Hyattesville, MD 20782
Comm: (301) 436-8187

NATIONAL ARCHIVES AND RECORDS SERVICE

This center is the archive for resource photography acquired by the ASCS, SCS, USGS, and the USBR prior to World War II. A catalog entitled "Aerial Photographs in the National Archives" is available upon request. For more information contact:

National Archives and Records Service
Cartographic Branch
General Services Administration
Washington, DC 20408
Tele: 205-523-3006

U.S. FOREST SERVICE (USFS)

The USFS has acquired aerial photography over most of the National Forest lands. Photography is primarily at scales of 1:20,000 to 1:24,000 on standard black and white 9" panchromatic film, and dates back to 1934. Standard coverage through the 1960's was at a scale of 1:15,840. More recently, color and color IR photography at smaller scales ranging up to 1:80,000 has been acquired. Coverage is updated as is deemed necessary by the USFS.

The Forest Service is geographically organized into nine regions with the regional headquarters listed below.

Region 1	Northern Federal Bldg. Missoula, MT 59801
Region 2	Rocky Mt. 11177 W. 8th Ave. Box 25127 Lakewood, CO 80225
Region 3	Southwestern 517 Gold Ave., SW Albuquerque, NM 87102
Region 4	Intermountain 324 25th St. Ogden, UT 84401
Region 5	California 630 Sansome St., Room 548 San Francisco, CA 94111

Region 6	Pacific Northwest 319 SW Pine St. P.O. Box 3623 Portland, OR 97208
Region 7	Does not exist
Region 8	Southern 1720 Peachtree Rd. Atlanta, GA 30309
Region 9	Eastern 633 West Wisconsin Ave. Milwaukee, WI 53203
Region 10	Alaska Federal Office Bldg. P.O. Box 1628 Juneau, AK 99502

Inquires may also be referred to:

Division of Engineering
U.S. Forest Service, USDA
Washington, DC 20250

NATIONAL PARK SERVICE (NPS)

The NPS has acquired aerial photography over the national parks at various scales with film types. For more information contact:

National Park Service
Denver Service Center
655 Parfet St.
P.O. Box 25287
Denver, CO 80225
Tele: (303) 234-5132
FTS: 234-4500

ENVIRONMENTAL PROTECTION AGENCY (EPA)

In 1974 EPA established a Remote Sensing Branch at the National Environmental Research Center in Las Vegas, Nevada. The data acquired are of various types and formats. For more information contact:

Environmental Protection Agency
Remote Sensing Branch
P.O. Box 15027
Las Vegas, NV 89114

or: EPA Interpretation Center
P.O. Box 1587
Vint Hill Farms
Warrenton, VA 22186

DEPARTMENT OF DEFENSE (DOD)

Estimates of the amount of aerial photography acquired by the DOD run between 100 - 200 million frames. The primary agency responsible for archiving this collection is the Defense Intelligence Agency (DIA). Photography was generally acquired by conventional means at scales of 1:15,000 - 1:40,000 on 9" black-and-white panchromatic film. Coverage dates back to the 1930's. Some of the early coverage, such as the AMS small scale coverage of the 1950's and the Navy/Army-acquired coverage of Alaska, has been transferred to the EDC archives. NCIC is currently handling the task of producing plots and indexes of DOD unclassified coverage.

The Defense Mapping Agency (DMA) was established in 1972, with primary responsibilities for mapping and charting within the DOD. Most current activities are being worked out in conjunction with the USGS.

For more information contact:

Defense Mapping Agency
Topographic Command
6500 Brooks Lane, NW
Washington, DC 20315
Att: Code 50320

Defense Intelligence Agency
Att: DS4A
Arlington Hall Station
Washington, DC 20301

U.S. ARMY CORPS OF ENGINEERS

The USACE has extensive involvement in civil projects such as dams, shoreline and flood protection, and waterway navigation. Aerial photographic coverage dating back to the 1930's was generally acquired with standard 9" black-and-white panchromatic film. Scales vary considerably with particular project requirements. More recently, coverage has been acquired using color and color IR film types. Although USACE is officially part of the DOD, most of its more recent coverage remains in the hands of the particular project office that collected it. The principal USACE organizations involved with remote sensing data are:

(A) Engineer Topographic Laboratories (ETL)
(B) Cold Regions Research and Engineering Laboratory (CRREL)
(C) Waterways Experiment Station (WES)
(D) Coastal Engineering Research Center (CERC)
(E) Construction Engineering Research Laboratory (CERL)
(F) Institute for Water Resources (IWR)

The Coastal Engineering Research Center at Ft. Belvoir, VA, has recently taken the responsibility of indexing much of the imagery collected by the Corps.

For more information, contact the USACE Remote Sensing Coordinator on the Division level.

Huntsville Division
William A. Newbern, Jr. - (HNDED-FC)
P.O. Box 1600 West Station
Huntsville, AL 35807
Tele: (205) 895-5190

Lower Mississippi Valley Division
Todd H. Riddle - (LMVED-G)
P.O. Box 80
Vicksburg, MS 39180
Tele: (601) 636-1311 ext. 339
or ext. 611

Missouri River Division
Charles G. Flagg - (MRDED-G)
P.O. Box 103 Downtown Station
Omaha, NE 68101
Tele: (402) 221-3204

New England Division
Joseph Horowitz - (NEDED-W)
424 Trapelo Road
Waltham, MA 92154
Tele: (617) 894-2400 ext. 632

North Atlantic Division
Dave Leiser - (NADPL-F)
90 Church Street
New York, NY 10007
Tele: (212) 264-7088

North Central Division
Mack L. Dixon - (NCDPD-PF)
536 S. Clark St.
Chicago, IL 60605
Tele: (312) 353-6395

North Pacific Division
Billy J. Thomas - (NPDEN-WC)
Room 210 Custom House
Portland, OR 97209
Tele: (503) 221-3757

Ohio River Division
Griffith Ray - (ORDED-T)
P.O. Box 1159
Cincinnati, OH 45201
Tele: (513) 684-3024

Pacific Ocean Division
Dr. James Maragos - (PODED-PV)
Bldg. 230, Ft. Shafter
Honolulu, HI 96813
Tele: (808) 438-2263

South Atlantic Division
James W. Erwin - (SADEG)
510 Title Bldg.
30 Pryor St. NW
Atlanta, GA 30303
Tele: (404) 526-6704

South Pacific Division
David L. Sveum - (SPDED-H)
630 Sansome St., Room 1216
San Francisco, CA 94111
Tele: (415) 556-5709

Southwestern Division
John W. Murchison - (SWDED-F)
1200 Main Tower
Dallas, TX 75202
Tele: (214) 749-3166

Field Operating Agencies

Robert Frost
Engineer Topographic Laboratories
Ft. Belvoir, VA 22060
Tele: (703) 664-3736

Coastal Engineering Research Center
Dennis Berg - (CERVE)
Kingman Bldg.
Ft. Belvoir, VA 22060
Tele: (703) 325-7172

Cold Regions Research and Engineering Laboratory
Dr. Duwayne Anderson
P.O. Box 282
Hanover, NH 03755
Tele: (603) 643-3200

Construction Engineering Research Laboratory
Dr. R. K. Jain
P.O. Box 4005
Champaign, IL 61820
Tele: (217) 352-6511

Institute for Water Resources
Kingman Bldg.
Ft. Belvoir, VA 22060

Waterways Experiment Station
Warren E. Grabau
P.O. Box 631
Vicksburg, MS 39180
Tele: (601) 636-3111

NATIONAL OCEAN SURVEY - COASTAL MAPPING DIVISION

The Coastal Mapping Division (formerly the Coast and Geodetic Survey) has acquired coverage over the nation's coastal areas. Multispectral metric mapping type coverage at scales ranging from 1:10,000 to 1:40,000 has been acquired in recent years. This agency also has the responsibility for acquiring aerial photography over the nation's major airports, back to World War II under the "Airport Obstruction Chart Survey Program." Coverage is typically black-and-white panchromatic with scales varying from 1:24,000 to 1:60,000. For more information contact:

Coastal Mapping Division
NOAA
Rockville, MD 20852
Tele: (301) 496-8601

DEFENSE METEOROLOGICAL SATELLITE PROGRAM (DMSP)

Data acquired by the USAF Global Weather Satellite Program is archived at the Space Science and Engineering Center at the University of Wisconsin. This data originates at USAF Global Weather Central, Offut AFB, Omaha, NE. For more information contact:

DMSP Satellite Data Library
Space Science and Engineering Center
University of Wisconsin
1225 West Dayton Street
Madison, WI 53706
Tele: (608) 262-5335

WALLOPS FLIGHT CENTER (NASA)

Wallops Flight Center has an active remote sensing program centered around its Chesapeake Bay Ecological Program. Generally, this is low to middle altitude multispectral photography. For more information contact:

Chesapeake Bay Ecological
  Program Office
NASA-Wallops Flight Center
Wallops Island, VA 23337
Tele: 804-824-3411 ext. 260

TENNESSEE VALLEY AUTHORITY

The TVA has acquired conventional aerial photography of the Tennessee River watershed area which includes the state of Tennessee and adjoining portions of Alabama, Georgia, Kentucky, Mississippi, North Carolina, and Virginia. Coverage, dating back to 1933, was taken at various scales although typically at 1:24,000. Recently, some special purpose color and color IR coverage has been acquired. For more information contact:

Map Information and Records Unit
Maps and Surveys Branch
Tennessee Valley Authority
101 Haney Bldg.
Chattanooga, TN 37401
Tele: 615-755-2122

PRIVATE AERIAL SURVEY COMPANIES

If existing coverage is not suitable, it may be necessary to contract for new photography to be flown. A good source of names of aerial survey firms is:

American Society of Photogrammetry
105 North Virginia Avenue
Falls Church, VA 22046
Tele: 703-534-6617

ENVIRONMENTAL SATELLITE IMAGERY

Low resolution imagery of the Earth is being acquired using visible and thermal infrared sensors by a variety of environmental satellites, including SMS-GOES, TIROS, Nimbus, ATS, and ESSA satellites. For more information contact:

Satellite Data Services Branch D543
Environmental Data Service
National Oceanic and Atmospheric
 Administration (NOAA)
World Weather Bldg. - Room 606
Washington, DC 20233
Tele: (301) 763-8111

SOURCES OF REMOTELY SENSED DATA IN CANADA

For aerial photography, contact:

National Air Photo Library
615 Booth Street
Ottawa, Ontario K1A 0E9
Canada
Tele: (613) 995-4597
Telex: 053-4328

Landsat data can be purchased directly from:

Integrated Satellite Information Services
 (ISIS) Ltd
P.O. Box 1630
Prince Albert, Saskatchewan S6V 5T2
Canada
Tele: (306) 764-3602 764-4259
Telex: 074-29242

Landsat data availability and ordering assistance (also information regarding airborne remotely sensed data) are provided by:

Canada Centre for Remote Sensing
Attn: User Assistance
717 Belfast Road
Ottawa, Ontario K1A 0Y7
Canada
Tele: (613) 995-1210
Telex: 053-3777

L. David Nealey
U. S. Geological Survey
Flagstaff, AZ 86001

Remote Sensing/Photogrammetry Education in the United States and Canada [1]

A listing of courses, programs, projects, and textbooks.

IV-1

Abstract: *Remote sensing and photogrammetry are an integral part of many programs at colleges and universities in the United States and Canada. In 1975, there were at least 470 courses in the United Staters and 64 in Canada that stressed remote sensing/photogrammetry. Thirty-eight universities in the United States and six in Canada have or plan to initiate majors, minors, or areas of specialization in remote sensing/photogrammetry. Many of the courses include field trips and several are offered in the evening. At least 63 books (listed) have been adopted as textbooks and reference books. The American Society for Engineering Education reported at least 110 basic engineering research projects underway at 31 member institutions in 1974 and 1975 (list included).*

Introduction

Remote sensing/photogrammetry is a critical tool in present-day research, one that can reduce field reconnaissance in a remote area of Alaska from a few months to a few days; tell a HUD planner where to site for greatest soil and rock competence; watch wheat in the United States, USSR, and the Peoples Republic of China; reveal the crop pattern of pre-historic Sinagua farming in Arizona; and make possible mapping for the search for life on Mars.

The status of remote sensing and photogrammetry in college and university curricula has been the subject of several works in the past few years. Stanton (1971) discussed photogrammetry and photogrammetry-related programs at 125 universities in the United States. In 1972, Eitel published a list of 80 remote sensing courses, and Bidwell (1975) and Morain (1975) recently researched colleges and universities for courses and programs in this field. The data presented here were obtained between May 1975 and February 1976, mainly from responses of faculty members of colleges and universities to a questionnaire on courses and programs in remote sensing/photogrammetry sent to more than 1200 institutions in the United States and Canada. In the United States today, there are at least 187 courses in remote sensing[1], 74 in photointerpretation[2], 23 in photogeology, 8 in as-

[1] Revised from the paper presented at the 42nd Annual Meeting, American Society of Photogrammetry, Washington, D. C., February 22-28, 1976, to include information on courses and programs in Canada.

[1] Used in the general sense of the term, the courses cover the electromagnetic spectrum from the ultraviolet through the radio range and include non-photographic sensor systems.

[2] Courses mainly concerned with aerial photography and camera systems.

Photogrammetric Engineering and Remote Sensing,
Vol. 43, No. 3, March 1977, pp. 259-284.

trogeology, 96 in photogrammetry, 18 in image processing, and 59 in other related subjects in the United States (List A). Of these, 23 are programmed for evening classes and 113 include trips. Courses are taught in 178 institutions in 24 academic areas.

Canadian programs in 1975 included at least 27 remote sensing courses, 10 photo-interpretation courses, 25 photogrammetry courses, and two other related couses (List B), taught at 13 institutions in seven academic areas. At least one of them is offered in the evening and 13 include trips.

About 75 percent of the remote sensing/photogrammetry courses in the United States are taught by departments of geography (22 percent), geology (19 percent), civil engineering (20 percent), and forestry (13 percent) (Table 1). Another four percent of the courses are in the curriculum of civil engineering departments if the Ohio State University's Department of Geodetic Science can be included in the category of civil engineering. Approximately one-third of all remote sensing courses are taught by geography departments, and 72 percent of all photogrammetry courses are taught by civil engineering departments (Ohio State included). The majority of the image processing courses are taught in electrical engineering departments, which reflects the infancy of computer applications to remote sensing. In the future, image processing courses are expected to increase in number and to be introduced to applications-oriented departments, i.e., geology, forestry, and geography.

The number of students enrolled in remote sensing/photogrammetry courses could not be accurately determined from the information received in response to the questionnaire. Many responses were received that did not include enrollment figures, and

Table 1. Relation of Types of Courses to Departments in Which They are Offered (U.S.)

LEGEND

RS—Remote Sensing
RSr—Remote Sensing related
PI—Photo-Interpretation
PIr—Photo-Interpretation related
PG—Photogrammetry
PGr—Photogrammetry related
MPI—Map & Photo-Interpretation
PGe—Photogeology
AG—Astrogeology
SD—Systems Design
IP—Image Processing
OP—Optics

TYPE COURSE / DEPARTMENT	Geography	Geology	Forestry	Civil Engineering	Geodetic Science	Electrical Engineering	General Engineering	Other	Total	Percent
RS	72	42	22	13	1	5	4	28	187	40
RSr	1	1		2				5	9	2
PI	17	7	25	10	2		1	3	74	16
PIr	2	1		2					5	1
PG	1	1	13	54	15		10	2	96	20
PGr				5	1		1		7	1
MPI	9	7	2					1	19	4
PGe		23							23	5
AG		8							8	2
SD						10		4	14	83
IP	1	1		1		8	1	6	18	4
OP						4		6	10	2
TOTAL	103	91	62	96	19	27	17	55	470	
PERCENT	22	19	13	20	4	6	4	12		

many of these were from large universities having fairly comprehensive programs in remote sensing and photogrammetry. A tally of the responses shows that at least 4000 students are enrolled annually in a remote sensing/photogrammetry course, but there is no way to determine from this information how many of them enroll in two or more such courses. It is thought that the number of students enrolled in remote sensing/photogrammetry courses annually is as high as 6000.

Trips taken as an integral part of at least 113 courses include visits to local aerial survey firms or government agencies. Field trips provide the students with practice in ground-truth verification, occasionally in actual data acquisition from remote-sensing platforms.

Thirty-eight universities in the United States (List C) and six in Canada (List D) have or plan to initiate majors, minors, or areas of specialization in remote sensing, photogrammetry, or astrogeology (planetary geology). Several universities that offer more than one course in remote sensing/photogrammetry do not provide degree programs in these areas. Colorado State University, for instance, has at least 13 undergraduate and graduate courses in remote sensing and photogrammetry but does not offer a degree in either field, whereas the University of Miami, with only one remote sensing course, offers a minor and Ph. D. in remote sensing.

IV-2

An example of the curriculum required for a Masters degree in photogrammetry is included as List E, taken from the pamphlet *Curriculum Information*, the Department of Geodetic Science, The Ohio State University.

There are no known programs in the United States or Canada similar to the South Australian Institute of Technology's graduate diploma in remote sensing, a two-year part-time graduate program that teaches remote sensing to professionals within the framework of their discipline. The program contains six courses: remote sensing I & II, applied interpretation I & II, and field assessment A & B. The first year of the program is concerned with the physical, environmental, and human factors of remote sensing data acquisition and interpretation and the interpretation of visual imagery. The second year covers non-photographic remote sensing techniques and the analysis of digital data. A good place for programs of this kind is the junior college, an excellent facility for training remote sensing and photogrammetric technicians.

Two American universities have developed innovative teaching techniques. Colorado State University videotapes its photogrammetry classes. The tapes are used by nonresident students at 21 cooperating institutions and seven county libraries in Colorado and Wyoming. Oregon State University's School of Forestry has developed a self-instruction approach to aerial photo-interpretation instruction. This course is "self-paced and is built around the unit mastery concept." The student must obtain a "B" (80 percent) in each unit and may retake an exam twice. In addition to the unit exams, two midterms, a final, a photo-mission report, and a landform map report are included in the grading scheme. The faculty at the University believes that this approach produces:

(1) An increased mastery and longer retention of material over the lecture-lab approach;
(2) A higher percentage of A's, B's, and C's, and fewer D's and F's;
(3) More highly motivated students and greater student satisfaction, and;
(4) More material covered in the same amount of time.

Classroom lectures of the various institutions are reinforced and supplemented by the use of readings in at least 64 textbooks (List F). The most widely used remote sensing/photointerpretation text is T. Eugene Avery's *Interpretation of Aerial Photographs* (1968) (List G). When included in the category of remote sensing, it is used in 39 percent of the courses. As a text on photointerpretation, it is used for 50 percent of the courses. The next most used text on photointerpretation is U. S. Geological Survey Professional Paper No. 373 by Richard G. Ray (1960), *Aerial photographs in geologic interpretation and mapping*. The photogrammetry text most widely used is Paul Wolf's *Elements of Photogrammetry* (1974).

Many instructors find no single text satisfactory for all their needs and consequently employ two required texts. Several instructors utilize only readings in various journals such as *Photogrammetric Engineering and Remote Sensing*, symposia proceedings, and textbooks.

The *Manual of Remote Sensing* (American Society of Photogrammetry, 1975 has been used at several institutions. The cost ($22.50 to students), size (two volumes), and complexity of this work will probably preclude its becoming the leading remote-sensing text in the United States, but it will continue to be used extensively as a reference book and for additional reading assignments for its excellent technical papers by leading researchers.

Several remote-sensing texts are being prepared for publication. They include works by Floyd Sabins, Chevron Oil Research; David Simonett, University of California at Santa Barbara; and Alan Gillespie and Barry S. Siegal, Jet Propulsion Laboratory. Sabin's text will include a workbook that has interpretation exercises keyed to the text. The workbook will contain unannotated images not included in the text. This is a needed instructional aid at present, especially at institutions where the instructors are new to remote sensing and are unaware of the many sources of data.

Visual aids are available in formats that provide the instructor with selected 35-mm slides of satellite, aircraft, ground, and microscope data of various areas from several sensors and involving many scientific problems. Facilities where slides can be obtained without permission of the author or the U.S. Geological Survey include: Pilot Rock Inc., Arcata, California; the EROS Data Center USGS, Sioux Falls, South Dakota; the Technology Applications Center, University of New Mexico, Albuquerque, New Mexico; John Wiley & Sons (slides by Norman Gillmeister and Barry Siegal); McGraw-Hill (slides by John S. Shelton); and Purdue University, Laboratory for the Applications of Remote Sensing, West Lafayette, Indiana.

A wide range of remote sensing and photogrammetry equipment, from pocket stereoscopes to analytical stereoplotters, is available to students at institutions in the United States and Canada, and a few schools utilize their own aircraft to acquire specialized data. In addition to internal resources, several institutions maintain a close working relation with federal, state, and commercial agencies. Only one formal internship was found in the survey, an arrangement of South Dakota State University with the U.S. Geological Survey EROS Data Facility, Sioux Falls, South Dakota.

The American Society for Engineering Education (ASEE) annually publishes a summary and analysis of engineering research and graduate study activities of the 195 ASEE member institutions in its journal, *Engineering Education*. The list does not represent all engineering research projects, since all institutions are not members, and all of those surveyed do not subdivide their projects into specific disciplines such as remote sensing and photogrammetry. Many of the subdivisions have peripheral applications to remote sensing. Readers interested in specialized areas are referred to the journal of the American Society of Engineering Education and to the various engineering departments.

The ASEE indicated that Remote Sensing/Photogrammetry engineering research projects[a] were underway at at least 27 institutions in the 1973-1974 school year (Engineering Education, 1974) and 31 institutions in the 1974-1975 school year (Engineering Education, 1974) and 31 institutions in the 1974-1975 school year (Engineering Education, 1975) (List H). There were more than 122 research projects in the 1973-1974 time period and 110 in the 1974-1975 time period.

The author wishes to thank Mrs. Carolyn Waller and Mrs. Velma Jean Reed for their help in the preparation of this paper. The cooperation of the institutions and individuals who made this paper possible is greatly appreciated, especially Dr. Philip J. Howarth, who helped with the gathering of information on Canadian programs.

References

American Society For Engineering Education, "Engineering College Research and Graduate Study Survey," *Engineering Education*, Vol. 65, No. 6, March 1975.

American Society for Engineering Education, "Engineering College Research and Graduate Study Survey," *Engineering Education*, Vol. 66, No. 6, March 1976.

Bidwell, Timothy G., "College and University Sources of Remote Sensing Information," *Photogrammetric Engineering and Remote Sensing*, Vol. 41, No. 10, October 1975.

Eitel, Dean F., "Remote Sensing Education in the U.S.A.," *Photogrammetric Engineering*, Vol. 38, No. 9, 900-906.

Morain, S. A., *Geographic Education in Remote Sensing at the University Level*, Special Report for the American Association of Geographers Committee on Remote Sensing, March 1975.

Reeves, Robert G., "Education and Training in Remote Sensing," *Photogrammetric Engineering*, Vol. 40, No. 6, 691-696, June 1974.

Stanton, B. T., "Education in Photogrammetry," *Photogrammetric Engineering*, Vol. 37, No. 3, 293-303, March 1971.

The Department of Geodetic Science, The Ohio State University Curriculum Information, April 1975.

[a] Note: Research projects of an applications nature are not included in this paper; only basic engineering research projects are listed.

SELECTED BIBLIOGRAPHY:

GENERAL REMOTE SENSING REFERENCES

Compiled by Applications Branch

EROS Data Center

Allum, J. A. E., 1966, Photogeology and regional mapping: New York, Pergamon Press, 107 p.

Avery, T. E., 1966, Forester's guide to aerial photo interpretation: Washington, D.C., U.S. Department of Agriculture, Forest Service, Agricultural Handbook 308, 40 p.

---1977, Interpretation of aerial photographs (3d ed.): Minneapolis, Minnesota, Burgess Publishing Company, 392 p.

Barrett, E. C., and Curtis, L. F., 1974, Environmental remote sensing: applications and achievements: New York, Crane, Russak & Company, Inc., 309 p.

Bernard, B., 1970, A B C's of infrared: New York, H. W. Sams & Company, Inc., 144 p.

Branch, M. C., 1971, City planning and aerial information: Cambridge, Massachusetts, Harvard University Press, 283 p.

Colwell, R. N., 1971, Monitoring Earth resources from aircraft and spacecraft: Washington, D.C., NASA-SP 275, 170 p.

Darden, L., 1974, The Earth in the looking glass: New York, Anchor Press, 324 p.

Davis, K. M., 1966, Uses of air photos for rural and urban planning: Washington, D.C., U.S. Department of Agriculture, Economic Research Service, Agriculture Handbook 315, 42 p.

Denny, C. S., Warren, C. R., Dow, D. H., and Dale, W. J., 1968, A descriptive catalog of selected aerial photographs of geologic features in the United States: U.S. Geological Survey Professional Paper 590, 79 p.

Estes, J. E., and Senger, L. W., 1974, Remote sensing--techniques for environmental analysis: Santa Barbara, California, Hamilton Publishing Company, 340 p.

Harper, D., 1976, Eye in the sky; introduction to remote sensing: Montreal, Multiscience Publications, 164 p.

Holz, R. K., 1973, The surveillant science, remote sensing of the environment: Boston, Massachusetts, Houghton Mifflin Company, 380 p.

Howard, J. A., 1970, Aerial photo-ecology: New York, American Elsevier Publishing Company, Inc., 325 p.

Jenson, N., 1968, Optical and photographic reconnaissance systems: New York, John Wiley and Sons, Inc., 211 p.

Johnson, P. L., 1969, Remote sensing in ecology: Athens, Georgia, University of Georgia Press, 244 p.

Kroeck, D., Everyone's space handbook: Arcata, California, Pilot Rock, Inc., 175 p.

Lattman, L. H., and Ray, R. G., 1965, Aerial photographs in field geology: New York, Holt, Rinehart, and Winston, Inc., 221 p.

Lueder, D. R., 1959, Aerial photographic interpretation: New York, McGraw-Hill Book Company, 462 p.

Miller, V. C., and Miller, C. F., 1961, Photogeology: New York, McGraw-Hill Book Company, 248 p.

National Academy of Sciences, 1970, Remote sensing with special reference to agriculture and forestry: Washington, D.C., National Academy of Sciences, 424 p.

NASA, 1974, Skylab Earth resources data catalogue: Houston, Texas, Lyndon B. Johnson Space Center, 359 p.

Ray, R. G., 1960, Aerial photographs in geologic interpretation and mapping: U.S. Geological Survey Professional Paper 373, 230 p.

Reeves, R. G., editor, 1975, Manual of remote sensing: Falls Church, Virginia, American Society of Photogrammetry, 2 vol., 2142 p.

Rudd, R. D., 1974, Remote sensing--a better view: Belmont, California, Duxbury Press, 135 p.

Sabins, F. F., Jr., 1978, Remote sensing-principles and interpretation: San Francisco, W. H. Freeman and Company, 426 p.

Scherz, J. P., and Stevens, A. R., 1970, An introduction to remote sensing for environmental monitoring: Madison, Wisconsin, University of Wisconsin, Remote Sensing Program, Report No. 1, 80 p.

Short, N. M., and Lowman, P. D., Jr., 1973, Earth Observations from space--outlook for the geological sciences: Greenbelt, Maryland, Goddard Space Flight Center, 115 p.

Short, N. M., Lowman, P. D., Jr., Freden, S. C., and Finch, W. A. Jr., 1976, Mission to Earth: Landsat views the world: Washington, D.C., National Aeronautics and Space Administration, NASA SP-360, 459 p.

Smith, J. T., editor, 1968, Manual of color aerial photography: Falls Church, Virginia, American Society of Photogrammetry, 550 p.

Soil Survey Staff, 1966, Aerial-photo interpretation in classifying and mapping soils: U.S. Department of Agriculture, Soil Conservation Service, Agriculture Handbook 294, 89 p.

Spurr, S. H., 1960, Photogrammetry and photo-interpretation: New York, Ronald Press Company, 472 p.

Strandberg, C. H., 1967, Aerial discovery manual: New York, John Wiley and Sons, Inc., 249 p.

Thompson, M., editor, 1966, Manual of photogrammetry (3d ed.): Falls Church, Virginia, American Society of Photogrammetry, 2 vol., 1199 p.

UNESCO, 1968, Aerial surveys and integrated studies--Toulouse Conference Proceedings: Paris, France, UNESCO, 575 p.

von Bandat, H. F., 1962, Aerogeology: Houston, Texas, Gulf Publishing Company, 350 p.

Way, D. S., 1973, Terrain analysis: Stroudsburg, Pennsylvania, Dowden, Hutchinson and Ross, Inc., 392 p.

Wiedel, J. W., and Kleckner, R., 1974, Using remote sensor data for land use mapping and inventory--a user guide: U.S. Geological Survey Interagency Report USGS-253, 54 p.

A SELECTED BIBLIOGRAPHY:

REMOTE SENSING IN WILDLIFE

1978

Wildlife Habitat Mapping, Inventory, and Evaluation

Terrestrial

Best, R. G., and Sather, S., 1978, The interpretation of available winter wildlife habitat from Landsat imagery: Brookings, South Dakota, South Dakota State University, Remote Sensing Institute, SDSU RSI-J-78-02.

Brabander, J., 1975, The evaluation of wildlife habitat on the Lake Carl Blackwell land use area utilizing ERTS [Landsat] satellite imagery: Oklahoma Wildlife Research Unit Quarterly Report, v. 28, no. 3.

Carneggie, D. M., 1969, Remote sensing applications to wildlife management and habitat control, in The use of remote sensing in conservation, development, and management of the natural resources of the state of Alaska: Juneau, Alaska, Department of Economic Development, p. 91-97.

---1972, Large scale 70 mm aerial photographs for evaluating ecological conditions, vegetational changes, and range site potential: Berkeley, California, University of California, Ph.D. thesis, 180 p.

Craighead, J. J., 1976, Studying grizzly habitat by satellite: National Geographic, v. 150, no. 1, p. 148-158.

Driscoll, R. S., and Reppert, J. N., 1968, The identification and quantification of plant species, communities and other resource features in herbland and shrubland environments from large scale aerial photography: Fort Collins, Colorado, U.S. Forest Service, USDA, Rocky Mountain Forest and Range Experiment Station, Annual Progress Report, 52 p.

Frentress, C. D., and Frye, R. G., 1975, Wildlife management by habitat units - a preliminary plan of action, in Proceedings of the NASA earth resources survey symposium, Houston, Texas, June, 1975: Houston, Texas, National Aeronautics and Space Administration, v. 1-A, p. 245-262.

George, T. H., Stringer, W. J., and Baldridge, J. N., 1977, Reindeer range inventory in western Alaska from computer-aided digital classification of Landsat data, in Proceedings of the 11th international symposium on remote sensing of environment, Ann Arbor, Michigan, Environmental Research Institute of Michigan, v. 1, p. 671-682.

Lent, P. C., 1975, Use of Landsat imagery for wildlife habitat mapping in northeast and east-central Alaska: Fairbanks, Alaska, University of Alaska, 19 p.

Lent, P. C., and LaPerriere, A. J., 1974, Application of ERTS [Landsat] imagery to study of caribou movements and winter habitat: Fairbanks, Alaska, University of Alaska, Alaska Cooperative Wildlife Reserve Unit, Final Report for NASA, Goddard Space Flight Center, Greenbelt, Maryland, 44 p.

Merchant, J. W., Jr., and Waddell, B. H., 1974, The use of high altitude photography and ERTS-1 [Landsat-1] imagery for wildlife habitat inventory in Kansas, in Proceedings of the 1974 fall convention, Washington, September 10-13, 1974: Falls Church, Virginia, American Society of Photogrammetry, p. 220-231.

Meyer, M. P., 1975, 35 mm aerial photography applications to wildlife population and habitat analysis, in Workshop on remote sensing of wildlife: Quebec, Canada.

Meyers, V. I., 1977, Application of remote sensing technology in South Dakota to access wildlife habitat change, describe meandering lakes, improve agricultural censusing, map Aspen, and quantify: Brookings, South Dakota, South Dakota State University, 80 p.

Miller, D. R., and Barnhart, H. W., 1973, Coloured aerial photography as an aid to the study of taiga as caribou winter range in Aerial color photography in the plant sciences and related fields: Falls Church, Virginia, American Society of Photogrammetry, p. 259.

Poulton, C. E., ed., 1975, Range resources; inventory, evaluation and monitoring, chap. 18 of Reeves, R. G., ed., Manual of remote sensing: Falls Church, Virginia, American Society of Photogrammetry, v. 2, p. 1427-1478.

Reeves, H. M., Cooch, F. G., and Munro, R. E., 1976, Monitoring Arctic habitat and goose production by satellite imagery: Journal of Wildlife Management, v. 40, no. 3, p. 532-541.

Scheierl, R., and Meyer, M. P., 1977, Habitat analysis of the Copper River Delta Game Management Area (East Side), Alaska: St. Paul, Minnesota, University of Minnesota, Institute of Agriculture, Forestry, and Home Economics, Remote Sensing Laboratory Research Report 77-8, 104 p.

Shanholtzer, G. F., and Alexander, L. D., 1975, The application of Landsat data to habitat mapping in site and route selection studies, in Proceedings of the American Society of Photogrammetry and American Congress on Surveying and Mapping fall convention, Phoenix, Arizona, October 26-31, 1975: Falls Church, Virginia, American Society of Photogrammetry, p. 483-494.

Varney, J. R., Craighead, J. J., and Summer, J. S., 1974, An evaluation of the use of ERTS-1 [Landsat-1] satellite imagery for grizzly bear habitat, in Third Earth Resources Technology Satellite-1 [Landsat-1] symposium, Washington, D.C., December 10-14, 1973: Washington, D.C., National Aeronautics and Space Administration, Goddard Space Flight Center, NASA SP-351, v. 1, sec. B, p. 1653-1670.

Wetlands

Anderson, R. R., Carter, Virginia, and McGinness, John, 1974, Applications of ERTS [Landsat] data to coastal wetland ecology with special reference to plant community mapping and typing and impact of man, in Third Earth Resources Technology Satellite-1 [Landsat-1] symposium, Washington, D.C., December 10-14, 1973: Washington, D.C., National Aeronautics and Space Administration, Goddard Space Flight Center, v. 1, sec. B, p. 1225-1255.

Anderson, R. R., and Wobber, F. J., 1973, Wetlands mapping in New Jersey: Photogrammetric Engineering, v. 39, no. 4, p. 353-358.

Arp, G. K., 1975, The rationale for attempting to define salt marsh mosquito-breeding areas in Galveston County by remote sensing the associated vegetation, in Proceedings of the NASA earth resources survey symposium, Houston, Texas, June, 1975: Houston, Texas, National Aeronautics and Space Administration, v. 1-A, p. 289-299.

Austin, A., and Adams, R., 1978, Aerial color and color infrared survey of marine plant resources: Photogrammetric Engineering and Remote Sensing, v. 44, no. 4, p. 469-480.

Brown, W. W., 1978, Wetland mapping in New Jersey and New York: Photogrammetric Engineering and Remote Sensing, v. 44, no. 3, p. 303-314.

Burge, W. G., and Brown, W. L., 1970, A study of waterfowl habitat in North Dakota using remote sensing techniques: Ann Arbor, Michigan, University of Michigan, Willow Run Laboratories, Institute of Science and Technology, Technical Report No. 2771-7-F, 61 p.

Carter, V., and Schubert, J., 1974, Coastal wetlands analysis from Earth Resources Technology Satellite multispectral scanner, in Proceedings of the ninth international symposium on remote sensing of environment, Ann Arbor, Michigan, April 15-19, 1974: Ann Arbor, Michigan, Environmental Research Institute of Michigan, v. 2, p. 1241-1260.

Colwell, John C., 1978, Use of Landsat data to assess waterfowl habitat quality: Ann Arbor, Michigan, Environmental Research Institute of Michigan, 92 p.

Cowardin, Lewis, and Myers, V. I., 1973, Remote sensing for identification and classification of wetland vegetation: Journal of Wildlife Management, v. 38, no. 2, p. 308-314.

Enslin, W. R., 1973, The use of color infrared photography for wetlands mapping with special reference to shoreline and waterfowl habitat assessment: East Lansing, Michigan, Michigan State University, 33 p.

Klemas, Vytautas, Daiber, F. C., Bartlett, David, and others, 1974, Inventory of Delaware's wetlands: Photogrammetric Engineering, v. 40, no. 4, p. 433-439.

Reimold, R. J., Gallagher, J. L., and Thompson, D. E., 1973, Remote sensing of tidal marsh: Photogrammetric Engineering, v. 39, no. 5, p. 477-488.

Scheierl, R., and Meyer, M., 1976, Evaluation and inventory of waterfowl habitats of the Cooper River Delta, Alaska, by remote sensing: St. Paul, Minnesota, University of Minnesota, Institute of Agriculture, Forestry and Home Economics, Remote Sensing Laboratory Research Report 76-3, 46 p.

Seher, J. S., 1972, Color and color infrared aerial photography for waterfowl habitat evaluation: Reno, Nevada, University of Nevada, Nevada Agricultural Experimental Station, Technical Bulletin 16, 55 p.

Seher, J. S., and Tueller, P. T., 1973, Color aerial photos for marshland: Photogrammetric Engineering, v. 39, no. 5, p. 489-499.

Work, E. A., Jr., 1974, Application of the Earth Resources Technology Satellite [Landsat] for monitoring the breeding habitat of migratory waterfowl in the glaciated prairies: Ann Arbor, Michigan, University of Michigan, Masters thesis, 107 p.

Work, E. A., Jr., Gilmer, D. S., and Klett, A. T., 1974, Utility of ERTS [Landsat] for monitoring the breeding habitat of migratory waterfowl, in Third Earth Resources Technology Satellite-1 [Landsat-1] symposium, Washington, D.C., December 10-14, 1973: Washington, D.C., National Aeronautics and Space Administration, Goddard Space Flight Center, NASA SP-356, v. 2, p. 102-115.

Aquatic

Clarke, G. L., and Ewing, G. C., 1972, Remote spectroscopy of the sea for biological production studies, in Proceedings of the optical aspects of oceanography symposium, Copenhagen, Denmark, June 15-23, 1972: New York, New York, Acad Press, p. 389-413.

Dobie, J., and Johnson, R., 1951, Pond mapping by aerial photographs: Journal of Wildlife Management, v. 15, no. 2, p. 221.

Gilmer, D. S., and Work, E. A., 1975, Utilization of satellite data for inventorying prairie ponds and lakes. Landsat-1 data were used to discriminate ponds and lakes for waterfowl management: Jamestown, North Dakota, Northern Prairie Wildlife Research Center, 10 p.

Greentree, W. J., and Aldrich, R. C., 1976, Evaluating stream trout habitat on large-scale aerial color photographs: Berkeley, California, Pacific Southwest Forest and Range Experiment Station, USDA Forest Service Research Paper PSW-123, 21 p.

Meyer, M. P., Eng, R. L., and Gjersing, F. N., 1974, Waterfowl management using color IR: Photogrammetric Engineering, v. 40, no. 2, p. 165-168.

Moore, D. G., Wehde, M., and Martin, D., 1974, Evaluation of remotely sensed data for estimating water quality and fish habitat of the Missouri River Reservoirs in central South Dakota: Brookings, South Dakota, South Dakota State University, Remote Sensing Institute, Report No. SDSU-RSI-74-11, 66 p.

Pearcy, W. G., 1971, Remote sensing and the pelagic fisheries environment off Oregon, in Proceedings of the symposium on remote sensing in marine biology and fishery resources: College Station, Texas A and M University, Remote Sensing Center, p. 158-171.

Work, E. A., Jr., and Gilmer, D. S., 1976, Utilization of satellite data for inventorying prairie ponds and lakes: Photogrammetric Engineering and Remote Sensing, v. 42, no. 5, p. 685-694.

Work, E. A., Jr., Gilmer, D. S., and Klett, A. T., 1974, Utilization of Skylab (EREP) for appraising changes in continental migratory bird habitat: Greenbelt, Maryland, Goddard Space Flight Center, Type III final report, 86 p.

Wildlife Census

General Methodology

Caughley, G., and Goddard, J., 1972, Improving the estimates from inaccurate censuses: Journal of Wildlife Management, v. 36, no. 1, p. 135-140.

Caughley, G., Sinclair, R., and Scott-Kemmis, D., 1976, Experiments in aerial survey: Journal of Wildlife Management, v. 40, no. 2, p. 290-300.

Heyland, J. D., 1972, Vertical aerial photography as an aid in wildlife population studies, in Proceedings of the first Canadian symposium on remote sensing, Ottawa, Ontario, February, 1972: Ottawa, Ontario, Canada, Canada Centre for Remote Sensing, v. 1, p. 121-136.

---1975, Increase the accuracy of your airborne censuses by means of vertical aerial photographs, in Workshop on remote sensing of wildlife: Quebec, Canada.

Marten, G. G., 1972, The remote sensing approach to censusing: Researches on Population Ecology, v. 14, no. 1, p. 36-57.

Norton-Griffiths, M., 1974, Reducing counting bias in aerial census by photography: East Africa Wildlife Journal, v. 12, no. 3, p. 245-248.

Mammals

Bergerud, A. T., 1963, Aerial winter census of caribou: Journal of Wildlife Management, v. 27, p. 438-449.

Buechner, H. K., Craighead, F. C., Jr., Craighead, J. J., and Cote, C. E., 1971, Satellites for research on free roaming animals: Bioscience, v. 21, no. 24, p. 1201-1205.

Craighead, J. J., 1971, Satellite monitoring of black bear: Bioscience, v. 21, no. 24, p. 1206-1211.

Croon, G. W., McCullough, D. R., Olson, C. E., and Queal, L. M., 1968, Infrared scanning techniques for big game censusing: Journal of Wildlife Management, v. 32, no. 4, p. 751-759.

Croze, H., 1972, A modified photogrammetric technique for assessing age-structures of elephant populations and its use in Kidepo National Park: East Africa Wildlife Journal, v. 10, no. 2, p. 91-115.

Dairon, L. N., and Wilson, R. T., 1974, Remote sensing techniques for wildlife inventories in the coastal marsh - the muskrat, in Shahrohki, F., ed., Remote sensing of Earth resources: Tullahoma, Tennessee, the University of Tennessee, v. 3, p. 685-696.

Driscoll, R. S., and Gill, R. B., 1972, Middle Park deer study - remote sensing of deer population parameters: Colorado Division Wildlife Game Section, Federal Aid Project W-38-R-14, Game Research Report, pt. 3, p. 253-265.

Driscoll, R. S., and Watson, T. C., 1974, Aerial photography for pocket gopher populations, in Proceedings of the symposium on remote sensing and photo interpretation, Banff, Alberta, Canada, October 7-11, 1974: Ottawa, Ontario, Canada, Canada Centre for Remote Sensing, v. 2, p. 481-492.

Garvin, L. E., Beatty, F. D., and Zanon, A. J., 1964, Infrared detection of moose: Rome, New York, Rome Air Development Center, Reconnaissance Data Extraction Branch, Interpretation and Analysis Section, 39 p.

Goddard, J., 1967, The validity of censusing black rhinoceros populations from the air: East Africa Wildlife Journal, v. 5, p. 18-23.

Graves, H. B., Bellis, E. D., and Knuth, W. M., 1972, Censusing white tailed deer by airborne thermal infrared imagery: Journal Wildlife Management, v. 36, no. 3, p. 875-884.

Heyland, J. D., 1974, Aspects of the biology of Beluga (Delphinapterus Leucas Pallas) interpreted from vertical aerial photographs: Guelph, University of Guelph, 390 p.

Huddleston, H. F., and Roberts, E. H., 1968, Use of remote sensing for livestock inventories, in Proceedings of fifth symposium on remote sensing of environment, Ann Arbor, Michigan, April 16-18, 1968: Ann Arbor, Michigan, University of Michigan, p. 307-323.

Isakson, R. E., Werner, H. D., and Schmer, F. A., 1975, White-tail deer census in selected areas of eastern South Dakota using remote sensing techniques: Brookings, South Dakota, South Dakota State University, Remote Sensing Institute, SDSU-RSI-75-04, 38 p.

Lavigne, D. M., 1976, Counting Harp seals with ultra-violet photography: Polar Record, v. 18, no. 114, p. 269-277.

Lavigne, D. M., and Oritsland, N. A., 1974, UV photography a new application for remote sensing of mammals: Canadian Journal of Zoology, v. 52, no. 7, p. 939-941.

LeResche, R. E., and Rausch, R. A., 1974, Accuracy and precision of aerial moose censusing: Journal of Wildlife Management, v. 38, no. 2, p. 175-182.

Marchinton, R. L., 1969, Portable radios in determination of ecological parameters of large vertebrates with reference to deer, in Johnson, P. L., ed., Remote sensing in ecology: Athens, Georgia, University of Georgia Press, p. 148-163.

McCullough, D. R., Olson, C. E., Jr., and Queal, L. M., 1969, Progress in large animal census by thermal mapping, in Johnson, P. L., ed., Remote sensing in ecology: Athens, Georgia, University of Georgia Press, p. 138-147.

Parker, H. D., Jr., 1972, Airborne infrared detection of deer: Fort Collins, Colorado, Colorado State University, Ph.D. thesis, 186 p.

Rice, W. R., and Harder, J. D., 1977, Application of multiple aerial sampling to a mark-recapture census of white-tailed deer: Journal of Wildlife Management, v. 41, no. 2, p. 197-206.

Siniff, D. B., and Skoog, D. O., 1964, Aerial censusing of caribou using stratified random sampling: Journal of Wildlife Management, v. 28, no. 2, p. 391-401.

Wride, M. C., and Baker, K., 1977, Thermal imagery for census of ungulates, in Proceedings of the 11th international symposium on remote sensing of environment, Ann Arbor, Michigan, April 25-29, 1977: Ann Arbor, Michigan, Environmental Research Institute of Michigan, v. 2, p. 1091-1099.

Birds

Bartholomew, G. A., and Pennycuick, C. J., 1973, The flamingo and pelican populations of the Rift Valley Lakes in 1968-1969: East Africa Wildlife Journal, v. 11, no. 2, p. 189-198.

Blokpoel, K., 1973, Radar studies of airborne bird movements, in Workshop on remote sensing of wildlife: Quebec, Canada.

Chattin, J. E., 1952, Appraisal of California waterfowl concentrations by aerial photography, in Transactions of the 17th North American wildlife conference, Washington, D.C., 1953: p. 421-426.

Grzimek, M., and Grzimek, B., 1960, Flamingoes censuses in East Africa by aerial photography: Journal of Wildlife Management, v. 24, no. 2, p. 215-217.

Henny, C. D., Anderson, D. R., and Pospahala, R. S., 1972, Aerial surveys of waterfowl production in North America, 1955-1971: U.S. Fish and Wildlife Service, Special Science Report - Wildlife No. 160, 48 p.

Heyland, J. D., 1975, Monitoring nesting success of greater snow geese by means of satellite imagery, in Proceedings of third Canadian symposium on remote sensing, Edmonton, Alberta, Canada: Ottawa, Ontario, Canada, Canadian Aeronautics and Space Institute, p. 243-254.

Hickman, G. L., 1972, Aerial determination of golden eagle nesting status: Journal of Wildlife Management, v. 36, no. 4, p. 1289-1292.

Kerbes, R. H., and Moore, H. D., 1975, Use of current satellite imagery to predict the nesting success of lesser snow geese, in Workshop on remote sensing of wildlife: Quebec, Canada.

Leonard, R. M., and Fish, E. B., 1974, An aerial photographic technique for censusing lesser sandhill cranes: Wildlife Society Bulletin, v. 2, no. 4, p. 191-195.

Pospahala, R. S., Brazda, A. R., Hansom, R. C., and others, 1975, Aerial surveys of waterfowl breeding populations in North America, 1955-1973: U.S. Fish and Wildlife Service, Special Science Report--Wildlife Service, 48 p.

Fish

Eicher, G. J., 1953, Aerial methods of assessing red salmon population in eastern Alaska: Journal of Wildlife Management, v. 17, no. 4, p. 521-527.

Kelez, G. B., 1947, Measurement of salmon spawning by means of aerial photography: Pacific Fisherman, v. 45, no. 3, p. 49-51.

Maughan, P. M., and Marmelstein, A. D., 1971, Operational use of remote sensors in commercial fishing, in Proceedings of the symposium on remote sensing in marine biology and fishery resources: College Station, Texas A and M University, Remote Sensing Center, p. 8-24.

Midttun, Lars, 1971, Acoustic methods for estimation of fish abundances, in Proceedings of the symposium on remote sensing in marine biology and fishery resources: College Station, Texas A and M University, Remote Sensing Center, p. 218-226.

Roithmayr, C. M., 1970, Airborne low-light sensor detects luminescing fish schools at night: Commercial Fisheries Review, v. 32, no. 12, p. 42-51.

Saila, S. B., 1971, An application of the theory of games toward improving the efficiency of certain pelagic fishing operations, in Proceedings of the symposium on remote sensing in marine biology and fishery resources: College Station, Texas A and M University, Remote Sensing Center, p. 249-265.

Savastano, K. J., and Leming, T. D., 1975, The feasibility of utilizing remotely sensed data to assess and monitor oceanic game fish, in Proceedings of NASA earth resources survey symposium, Houston, Texas, June, 1975: Houston, Texas, National Aeronautics and Space Administration, V-I-C, p. 2023-2062.

Stevenson, W. H., Kemmerer, A. J., Atwell, B. H., and Maughan, P. M., 1973, A review of initial investigations to utilize ERTS-1 data in determining the availability and distribution of living marine resources, in Third Earth Resources Technology Satellite-1 [Landsat-1] symposium, Washington, D.C., December 10-14, 1973: Washington, D.C., National Aeronautics and Space Administration, Goddard Space Flight Center, v. 2, p. 1317-1320.

General Wildlife Applications

Dornfeld, Rick, 1976, Operational uses of remote sensing by the Fish and Wildlife Service in North Dakota, in Dando, W. A., and Johnson, G. E., eds., Innovations in land use management, 1976: Grand Forks, North Dakota, University of North Dakota Press, p. 123-128.

Drennan, K. L., 1975, Some potential applications of remote sensing in fisheries, in Symposium on remote sensing in marine biology and fishery resources: College Station, Texas A and M University, Remote Sensing Center, p. 25-65.

Freidel, J. J., and Best, R. G., 1978, Remote sensing a new tool in wildlife management: Brookings, South Dakota, South Dakota State University, Remote Sensing Institute, SDSU-RSI-J-78-06, 10 p.

Grumstrup, P., and Meyer, M. P., 1977, Applications of large scale 35 mm color and color infrared aerial photography to analysis of fish and wildlife resources on disturbed lands: St. Paul, Minnesota, University of Minnesota, Institute of Agriculture, Forestry and Home Economics, Remote Sensing Laboratory Research Report 77-3, 70 p.

Hawes, R. A., and Hudson, R. J., 1976, A method of regional landscape evaluation for wildlife: Journal of Soil and Water Conservation, v. 31, no. 5, p. 209-211.

Howard, J. A., 1970, Aerial photo-ecology: New York, New York, American Elsevier Publishing Company, Incorporated, 325 p.

Kansas Applied Remote Sensing Program, Kansas Forestry, Fish and Game Commission, 1976, The application of remote sensing to wildlife management in Kansas: Lawrence, Kansas, Kansas Applied Remote Sensing Program, The University of Kansas, 30 p.

Leedy, D. L., 1948, Aerial photographs, their interpretation and suggested uses in wildlife management: Journal of Wildlife Management, v. 12, no. 2, p. 191-210.

---1953, Aerial photo use and interpretation in the fields of wildlife and recreation: Photogrammetric Engineering, v. 19, no. 1, p. 127-137.

---1960, Photo interpretation in wildlife management, Chapter 8 of Colwell, R. N., ed., Manual of photographic interpretation: Washington, D.C., American Society of Photogrammetry, p. 521-530.

Nelson, H. K., Klett, A. T., and Burge, W. G., 1970, Monitoring migratory bird habitat by remote sensing methods, in Transactions of 35th North American wildlife and natural resources conference: Washington, D.C., Wildlife Management Institute, p. 73-84.

Nichol, J. E., 1975, Collection and processing of remote sensing data related to wildlife conservation in natural environments, in Proceedings of the tenth international symposium on remote sensing of environment, Ann Arbor, Michigan, October 6-10, 1975: Ann Arbor, Michigan, Environmental Research Institute of Michigan, v. 1, p. 369-372.

Pipland, R. O., 1973, Remote sensing techniques for support of coastal zone resource management, in Proceedings of the approaches to earth survey problems through use of space technology symposium, Constance, Germany, May 23-25, 1973: Berlin, Germany, Akad-Verlag, p. 357-372.

Reeves, H. M., Munro, R. E., and Marmelstein, A. D., 1975, U.S. Fish and Wildlife activities in application of satellite imagery to goose management, in Workshop on remote sensing of wildlife: Quebec, Canada.

Savastano, K. J., 1975, Application of remote sensing for fishery resources assessment and monitoring: Bay Saint Louis, National Marine Fisheries Service, 92 p.

Thompson, M. D., 1977, Remote sensing in operational range management programs in western Canada, in Proceedings of the 11th international symposium on remote sensing of environment, Ann Arbor, Michigan, April 25-29, 1977: Ann Arbor, Michigan, Environmental Research Institute of Michigan, v. 2, p. 1101-1110.

GLOSSARY OF REMOTE SENSING TERMS

Prepared by Applications Branch
EROS Data Center

Active Remote Sensing - Remote-sensing methods that provide their own source of electromagnetic radiation. Radar is one example.

Additive Color Theory - Theory of production of color images by addition of colored light rather than by subtraction of unwanted colors from white light. Additive color methods are used to create composite color images from multiband photographs.

Additive Primary Colors - The colors blue, green, and red. Filters of these colors transmit the primary color of the filter and absorb the other two colors.

ADP - Automatic data processing.

Albedo - The ratio of the amount of electromagnetic energy reflected by a surface to the amount of energy incident upon it.

Altitude - Height of sensor platform above a specified datum, usually above mean sea level.

Analog - A form of data display in which values are shown in graphic form, such as curves. Also a form of computing in which values are represented by directly measurable quantities, such as voltages or resistances. Analog computing methods contrast with digital methods in which values are treated numerically.

Aperture - Any opening through which radiation may pass, such as a lens diaphragm opening.

ASP - American Society of Photogrammetry.

Aspect Ratio - The numerical ratio of Landsat pixel width to height.

Atmospheric Windows - Wavelength intervals at which the atmosphere transmits most electromagnetic radiation.

Attenuation - Reduction in intensity of radiation with distance from its source due to absorption and/or scattering (does not include the inverse square decrease of intensity of radiation with distance from the source).

Band - A wavelength interval in the electromagnetic spectrum. For example, in Landsat the bands designate specific wavelength intervals at which images are acquired.

Batch Processing - The method of data processing in which data and programs are entered into a computer, which then carries out the entire processing operation with no further instructions.

Black Body - A substance that radiates energy at the maximum possible rate per unit area at each wavelength for any given temperature. A black body also absorbs all the radiant energy incident upon it. No actual substance behaves as a black body although some substances, such as lampblack, approach these properties.

BPI - Bits per inch - a measure of the density of information written upon a magnetic computer tape. Usually 800 or 1600 BPI. 800 BPI would indicate that one (1) inch of tape holds 800 bits (binary digits).

Brightness Value - A numeric value assigned to each Landsat pixel in an image representing the relative reflectance or brightness of that pixel. Band 4, 5, and 6 have values of 0-127 and Band 7, 0-63.

Camera - A lightproof chamber or box in which the image of an exterior object is projected upon a sensitized plate or film, through an opening usually equipped with a lens or lenses, shutter, and variable aperture.

Camera Station - The point in space occupied by the camera lens at the moment of film exposure.

Camera, Metric - A specially constructed and calibrated camera used to obtain geometrically accurate photographs for use in photogrammetric instruments.

Camera, Multiband - A camera that exposes different areas of one film, or more than one film, through one lens and a beam splitter, or two or more lenses equipped with different filters, to provide two or more photographs in different spectral bands.

CCT - Computer Compatible Tape. Digital Landsat data are recorded on a CCT or a set of CCT's.

CIR - Color infrared (film or photograph).

Classification - The process of assigning individual pixels of a multispectral image to categories, generally on the basis of spectral reflectance characteristics.

Cluster - Any configuration of elements (pixels) occurring closely together in n-dimensional space.

Cluster Statistics - The mean, variance, and covariance statistics calculated for a group of pixels.

Clustering Algorithm - Unsupervised classifier - finds natural groupings of pixels, in multispectral scanner (MSS) data, on the basis of cluster statistics inherent within the data.

Color Composite - A color image produced with either an additive or subtractive color process utilizing three bands of data. A Landsat color composite image is made with additive processing, wherein blue is assigned to MSS band 4, green to MSS band 5, and red to MSS band 7. This procedure results in an image which approximates a color-infrared photograph.

Color Enhancement - Utilization of contrasting colors, rather than differences in grey values, to indicate subtle changes in film density. Can be applied in single or multiemulsion situations.

Confusion Matrix - A two axis matrix (table) that shows on one axis the known classes and on the other axis the classes that have been interpreted or classified in an analysis. The matrix indicates similarities that exist between classes and where confusion or misclassification may exist within the data.

Contact Print - A photographic image produced by the exposure of a sensitized emulsion in direct contact with a negative or positive transparency.

Continuous-Strip Photography - Photography of a strip of terrain in which the image remains unbroken throughout its length along the line of flight.

Contrast - Difference between tones on a photograph; the variation in brightness of different parts of a negative or positive.

Contrast Enhancement - Image enhancement technique used to expand the distribution of brightness values within a scene or subscene over the available dynamic range.

Convergence of Evidence - Bringing together several kinds of evidence in the photo interpretation process so that a conclusion may be drawn from all available data.

CRT - Cathode ray tube (television screen for displaying electronic images).

DAL - Data Analysis Laboratory at EROS Data Center, which contains specialized equipment used to extract information from digital remotely sensed data.

Datum Level - A level surface, sometimes referring to mean sea level, which may be used as a reference for computing elevations or altitude.

DCP - Data collection platform - on Landsat the system that acquires information from ground-based instruments such as seismometers, flood gauges, and other measuring devices. These data are transmitted to the satellite and in turn are relayed to an Earth receiving station.

Definition - The degree of sharpness with which an image is brought out by a lens.

Densitometer - Device used to measure the grey-tone density of images on a piece of film. The measurement may be a meter reading or an electronic signal. When the densitometer aperture is smaller than a few hundred microns, the instrument is called a microdensitometer.

Density - The comparative amount of silver (or dye) in a given area of a photograph resulting from exposure to light and development.

Density Slicing - The process of converting the continuous gray tone of an image into a series of density intervals, or slices, each corresponding to a specific digital range. These slices are commonly displayed in different colors on a CRT.

Destriping - Removal of the residual differences after calibration constants have been applied to the six Landsat MSS detectors of any band.

Detector - The component of a remote-sensing system that converts electromagnetic radiation into a signal that is recorded.

Diaphragm - The device for controlling the size of the opening of a lens. The size of the lens opening governs the amount of light reaching the film. This, together with the shutter, governs the amount of light exposure on the film.

Diazo Film - A transparent material on which image transparencies may be reproduced in specific colors.

Digital Image - Image having numeric values representing gray tones. Each numeric value represents a different gray tone.

Digital Image Processing - Computer manipulation of the digital values for picture elements of an image.

Digital Value - Data are said to have digital values when they can be represented numerically. Necessary for computation within a computer.

Digitization - The process of converting an image recorded originally on photographic material into numerical format. Also refers to the referencing of ground control points or lines to a remotely-sensed image.

Displacement, relief - The difference in the position of a point above or below the datum, with respect to the datum position of that point, owing to the perspective of an aerial photograph. Relief displacement is radial from the photo nadir. In truly vertical photography, relief displacement is radial from the principal point of the photograph.

Display - Graphic representation of output data from a device or system, for example, on a radar scope. The CRT is a widely used display device for output of "electronic" sensors data.

Distortion - Any shift in the position of an image on a photograph which alters the perspective characteristics of the photograph. Causes of image distortion include lens aberration, differential shrinkage of film or paper, and motion of the film or camera.

Dot Grid - Film positive with regularly space dots placed over a photo or map to determine areas.

EDC - EROS Data Center. The U.S. Geological Survey facility at Sioux Falls, South Dakota. Here aircraft and satellite images are archived and made available for purchase.

Edge Enhancement - Digital processing technique to enhance boundaries between features which exhibit subtle differences in brightness values along their edges.

EDIES - EDC Digital Image Enhancement System.

EDIPS - EDC Digital Image Processing System.

Effective Area - For any aerial photograph that is one of a series in a flight strip, that central part of the photograph delimited by the bisectors of overlaps with adjacent photographs. On a vertical photograph, all images within the effective area have less displacement than their conjugate images on adjacent photographs.

Electromagnetic (E-M) Radiation - Energy propagated through space or through a medium as waves of variations of electric and magnetic fields; known as radio waves, heat waves, light waves, etc., depending upon frequency. The term radiation, alone, is used commonly for this type of energy, although it actually has a broader meaning. Also called electromagnetic energy or simple radiation.

Electromagnetic Spectrum - Ordered array of known electromagnetic radiations, extending from the shortest--cosmic rays--through gamma rays, X-rays, ultraviolet radiation, visible radiation, infrared radiation, and including microwave and all other wavelengths of radio energy.

Emission - With respect to electromagnetic radiation, the process by which a body emits electromagnetic radiation as a consequence of its temperature only.

Emissivity - Ratio of the radiation emitted by a surface to the radiation emitted by a black body at the same temperature under similar conditions. May be expressed as total emissivity (for all wavelengths), spectral emissivity (as a function of wavelength) or goniometric emissivity (as a function of angle).

Emulsion - The light-sensitive coating on film, paper, and other bases consisting of a mixture of silver salts and other chemicals emulsified in gelatin.

Enhancement - Various processes and techniques designed to render optical densities on imagery more interpretable.

ERIM - Environmental Research Institute of Michigan (Ann Arbor).

EROS - Earth Resources Observation Systems, administered by U.S. Geological Survey.

ERSAL - Environmental Remote Sensing Applications Laboratory (Oregon State University).

ERTS - Earth Resources Technology Satellite (now Landsat).

ESL - Electromagnetic Systems Laboratories.

Exposure - Used as a synonym for a photograph. Also, the control of light in making a photograph. Exposure-data refers to camera shutter and aperture settings, together with light intensity measurements, filter factors, and all such controls of light reaching the film.

FCC - False Color Composite.

Fiducial Marks - Small markers rigidly connected to the sensor which form images on the edges of the negative which are used to locate the principal point of the photograph.

Field of View - All of the target area on the object side of the lens that is subtended by the angle of view and images on the focal plane.

Film Recorder - Generates a high resolution film output product (analog) using digital tape as an input medium. Film is usually scanned one line at a time.

Film Speed - A measure of the sensitivity of photographic film to light.

Filter - Selectively transparent material placed over a camera lens to eliminate or reduce certain wavelengths or frequencies while leaving others relatively unchanged.

Flight Line - The ground trace of the flight path of an aircraft. For truly vertical aerial photography, it is the line connecting the map position of principal points of successive air photos.

Focal Length - The distance measured along the lens axis from the rear nodal point of the camera lens to the plane of best average definition over the entire field used in the aerial camera.

Focal Plane - The plane in a camera occupied by the film and on which the image is focused by the lens.

Focal Point - The point toward which rays of light converge to form an image after passing through a lens or having been reflected by mirrors. The condition of sharpest imagery.

Focus - The degree of sharpness of an image as recorded at the focal plane.

Geometric Correction - Spatial reorganization of a data set to match a predetermined set of spatial conditions.

GOES - Geostationary Operational Environmental Satellite.

Ground Control Point - Any point that has a known location on the Earth's surface which can be identified on remote sensing imagery.

Ground Data - Information concerning the actual state of ground conditions at the time of a remote sensing overflight. Often referred to as ground truth.

Ground Receiving Station - A facility that records image data transmitted by Landsat.

GSFC - Goddard Space Flight Center. The NASA facility at Greenbelt, Maryland that includes a Landsat ground receiving station.

Hardware - Physical components which make up a computer system. Contrast with software.

Hardwired - Logic function or algorithm that is "built-in" to a system enabling rapid execution.

HDDT - High density digital tape.

Histogram Normalization - Technique used to minimize effects of striping by calculating a mean brightness value for each detector in each band and ratioing either the maximum or minimum mean with the mean (normalization factor). Brightness values of pixels are then multiplied by the normalization factor and new values assigned to pixels.

Hot Spot - An elliptical area of high solor reflectivity which appears on vertical aerial photographs at the antisolar point, or 180° from the direction of the Sun. Also called the "no shadow" point since the shadows of ground features within the hot spot are not seen.

IDIMS - Interactive Digital Image Manipulation System (produced by ESL).

Image - The recorded representation of an object produced by optical, electro-optical, optical-mechanical, or electronic means. It is generally used when the EMR emitted or reflected from a scene is not directly recorded on film (e.g., thermal infrared or radar image).

Image Enhancement - Any one of a group of operations which improve the detectability of the targets of interest. These operations include, but are not limited to, contrast enhancement, edge enhancement, spatial filtering and noise suppression, and image sharpening.

Image 100 - Multispectral Image Analyzer (produced by General Electric).

Image Motion - The smearing or blurring of images on an aerial photograph because of the relative movement of the camera with respect to the ground during the time the shutter is open.

Image Motion Compensation (IMC) - Movement intentionally imparted to film at such a rate as to compensate for the forward motion of an aircraft when photographing ground objects during exposure.

Imagery - Representation or reproduction of objects recorded on photographic emulsions; visual representation of energy recorded by remote sensing instruments.

Index, Photo - An index map showing photographic coverage, made by arranging the individual photographs in their relative positions and photographing the montage at a reduced scale, or by plotting photoframe coverage areas on a map or map overlay.

Infrared Film - Photographic film sensitized to record near infrared wavelengths beyond the red end of the light spectrum. It is also sensitive to blue and ultraviolet light and must be used with a red filter to screen out these wavelengths.

Infrared Radiation (IR) - Electromagnetic radiation lying in the wavelength interval from about .7 micrometers to an indefinite upper boundary sometimes arbitrarily set at 1,000 micrometers (0.01 centimeter). At the lower limit of this interval, the infrared radiation spectrum is bounded by visible radiation, whereas on its upper limit it is bounded by microwave radiation of the type important in radar remote sensing.

Infrared Scanner - Instrument for obtaining thermal infrared imagery through line scanning techniques.

Infrared Thermal Sensing - Line scanning techniques using infrared scanners with detectors. Usually, the imagery is obtained from selected portions of the 3 to 14 micron region of the spectrum.

Instantaneous field of view (IFOV) - The solid angle through which a detector is sensitive to radiation. In a scanning system this refers to the solid angle subtended by the detector when the scanning motion is stopped. Instantaneous field of view is commonly expressed in milliradians.

Interactive Processing - The method of data processing in which the operator views preliminary results and can alter the instructions to the computer to achieve optimum results.

Intervalometer - An instrument for operating aerial cameras automatically by taking photographs at regular, pre-determined intervals of exposure.

ISI - Interpretation Systems, Inc.

JPL - Jet Propulsion Laboratory. A NASA facility at Pasadena, California operated by the California Institute of Technology.

LACIE - Large Area Crop Inventory Experiment (NASA/USDA/NOAA project).

Landsat - An unmanned Earth-orbiting NASA satellite that transmits multispectral images in the 0.4 to 1.1 μm region to Earth receiving stations (formerly called ERTS).

Landsat Coordinates - X and Y (column and line) coordinates which are referenced to a Landsat scene with the origin (1,1) in the upper left corner and extending to 3240 in the X and 2340 in the Y directions.

LARS - Laboratory for Applications of Remote Sensing (Purdue University).

LARSYS - LARS software for Digital Image Analysis.

LBR - Laser Beam Recorder.

Light - That form of radiation that is capable of detection by the human eye. Visible radiation (about 0.4 to 0.7 micrometer in length).

Light, Transmitted - Light that has traveled through a medium without being absorbed or scattered.

Maximum Likelihood Classifier - A decision criterion to classify picture elements into computer spectral classes based on the calculation of a likelihood statistic. The likelihood statistic is calculated from the value of the pixel in question and the mean, variance, and covariance for the computer spectral classes. A picture element is assigned to the class for which it has the maximum likelihood statistic. It can also be used to resolve overlap in classification results from other classifiers.

Microwave Region - Commonly, that region of the radio spectrum between approximately 1000 and 300-000 magahertz. Corresponding wavelengths are 30 centimeters to 1 millimeter.

Micrometer (μm) - Unit of length equal to one millionth of a meter.

Minicomputer - A small general purpose digital computer with a central processor and core memory. Current machines vary in word lengths, I/O facilities, instruction sets, software and performance.

Mosaic - An assemblage of aerial photographs, usually overlapping, which have been matched to form a continuous photographic image.

Mosaic, Controlled - A mosaic oriented and scaled to horizontal ground control; usually assembled from rectified photographs.

Mosaic, Semi-Controlled - A mosaic composed of corrected or uncorrected prints laid to a common basis of orientation other than ground control.

Mosaic, Uncontrolled - A mosaic composed of unrectified prints, the detail of which has been matched from print to print without ground control.

MSS - Multispectral Scanner - Sensor used in Landsat.

Multispectral Scanner - A non-photographic imaging system which utilizes a rotating mirror and a fiber optic bundle sensor. The mirror sweeps from side to side and sequentially records brightness values (i.e., signal strengths) on magnetic tape for successive pixels, one swath at a time. The forward motion of the sensor platform carries the instrument to a position along the orbital path where an adjacent swath can be imaged. The recorded signal can be played back through a device which will convert signal strength to brightness on a photographic emulsion, thereby producing a photo-like image of the terrain that has been sensed.

Multispectral Scanner, Landsat (MSS) - On Landsat 1 and 2 the MSS system gathers data by imaging the surface of the Earth in several spectral bands simultaneously. It is a four-band scanner operating in the solar reflected spectral band region from 0.5 to 1.1 micrometer. Landsat 3 also contains the four bands, but a fifth band has been added. The bands are nominally referred to as bands 4, 5, 6, 7, and 8, operating in the following wavelength bands, respectively (.5-.6 μm; .6-.7 μm; .7-.8 μm; .8-1.1; and 10.4-12.6 μm).

Multiband Photography (Multispectral Photography) - Photography obtained by using a camera or other device that gives simultaneous imagery in each of several portions of the spectrum.

Nadir - The image position on an aerial photograph corresponding to the ground position vertically beneath the camera.

Nanometer (nm) - Unit of measure equal to one millimicron or one millionth of a millimeter.

NCIC - National Cartographic Information Center.

Near Infrared - The preferred term for the shorter wavelengths in the infrared region extending from about 0.7 micrometers (visible red), to around 2 or 3 micrometers (varying with the author). The longer wavelength end grades into the middle infrared. The term includes the radiation reflected from plant materials, which peaks around 0.85 micrometers. It is also called solar infrared, as it is only available for use during the daylight hours.

Negative - Photographic image in wich the subject tones to which the emulsion is sensitive are reversed or complementary.

NOAA - National Oceanic and Atmospheric Administration.

Oblique (Photography or Camera Station) - Photographs with the aerial camera pointed between the horizontal and vertical; also, the camera position or station in an aircraft for taking such photography. An oblique photograph is taken with the optical axis of the camera tilted appreciably from the vertical.

Optical Axis - An imaginary line drawn directly through the optical center of the camera lens to the geometric center of the film.

Optical Density - Photographic transmission density.

Orthophoto - A photographic copy in which image displacements due to tilt and relief have been removed.

Overexposure - The result of allowing too much light to reach the film in a camera when making an exposure; this results in an excessively dark negative (with normal development) and loss of photo quality and detail.

Overlap - The amount by which one photograph duplicates the area covered by another photograph, usually expressed as a percentage. The overlap between successive aerial photographs along a flight line is called forward overlap or end lap. The overlap between photographs in adjacent parallel flight lines is called sidelap.

Overlay - A transparent medium on which annotations are plotted, thus avoiding defacing a map or image.

Parallax - Apparent shift in position of an imaged feature with respect to a reference point which is caused by a shift in the point of observation.

Parallelepiped Classifier - A digital classification algorithm which is based on calculating the minimum and maximum brightness values in each spectral band (4 bands for Landsat MSS data) to define training sets. Pixels are assigned to a computer class (classified) when all pixel brightness values fall within the brightness value ranges calculated for the training set.

Pattern - In a photo image, the regularity and characteristic placement of tones or textures. Some descriptive adjectives for patterns are regular, irregular, random, concentric, radial and rectangular.

Photographic Interpretation - The act of examining photographic images for the purpose of identifying objects and judging their significance. Photo interpretation, photointerpretation, image interpretation, and image analysis are other widely used synonyms.

Photographic Interpreter (PI) - An individual specially trained or skilled in photographic interpretation. Photointerpreter, photo interpreter, image interpreter, and image analyst are other widely used terms.

Photography - The process of producing images on sensitized material by exposure to light.

Photo Interpretation Key - Reference materials designed to facilitate rapid and accurate identification and assessment of objects or conditions from an analysis of their photo images.

Picture Element - Unit of resolution on Landsat imagery. One pixel on Landsats 1 and 2 MSS data corresponds to a ground area measuring approximately 57 meters by 79 meters.

Pixel - A contraction of picture element.

Platform, Sensor - Vehicle on which a remote sensing device is mounted and carried aloft; an aircraft platform, space platform, etc.

Positive - Photographic image having approximately the same rendition of tones as the original subject, i.e., light tones for light and dark tones for dark.

Primary Colors - The three colors, either additive (blue, green, and red) or subtractive (cyan, yellow, and magenta) that may be combined to produce the full range of colors.

Principal Point - The geometric center point of an aerial photograph, corresponding to a point on the perpendicular line through the axis of the lens.

Radiance - Measure of the energy radiated by an object. In general, radiance is a function of viewing angle and spectral wavelength and is expressed as energy per solid angle.

Radiant Energy - Energy transmitted as electromagnetic radiation.

Radiation - Process by which electromagnetic energy is propagated through free space by virtue of joint undulatory variations in the electric and magnetic fields in space. This concept is to be distinguished from conduction and convection. Also, the process by which energy is propagated through any medium by virtue of the wave motion of that medium, as in the propagation of sound waves through the atmosphere, or ocean waves along the water surface. Also called radiant energy. Also called electromagnetic radiation, specifically, high-energy radiation such as gamma rays and X-rays. Radiation also refers to corpuscular emissions, such as A or B radiation. Includes nuclear radiation and radioactivity.

Radiometer - Instrument for detecting and measuring radiant energy.

Ratio Image - An image prepared by processing digital multispectral data. For each pixel the value for one band is divided by that of another. The resulting digital values are displayed as an image.

Ratioing - A processing function that allows an analyst to divide data from one or more channels by data from one or more other channels. After ratioing, the data are scaled over the range of 0-256 digital values. Three common ratioing techniques include: 1) ratio of adjacent spectral channels, 2) ratio of the difference to the sum of adjacent channels, and 3) ratio of each channel to the sum of all four channels (normalization). Ratioing occurs on a pixel-by-pixel basis, and thus requires exact registration between channels.

RBV - Return Beam Vidicon camera--sensor on Landsat.

Rectification - The process of converting a tilted or oblique photograph to the plane of the vertical by projecting it onto a horizontal reference plane, with the angular relationship determined by the use of control points recognizable on the photograph and an accurate map.

Remote Sensing - The act of obtaining information about certain objects or conditions through the use of aerial cameras or other sensing devices that are situated at a distance from them. Remote sensing can be accomplished in the ultraviolet, visible, infrared, microwave and gamma ray regions of the electromagnetic spectrum.

Resolution - Ability of a remote sensing system to render a sharply defined image, and including the three following terms: 1) Ground Resolution - the minimum distance between two or more adjacent ground features, or the minimum size of a ground feature which can be detected; usually measured in conventional distance units, e.g., feet or inches; 2) Image Resolution - resolution expressed in terms of lines per millimeter, for a given photographic emulsion under specified situations; 3) Thermal Resolution - image resolution expressed as a function of the minimum temperature difference between two objects or phenomena.

RSI - Remote Sensing Institute (South Dakota State University).

RSRP - Remote Sensing Research Program (University of California, Berkeley).

Scale - The ratio existing between a distance on the map or photograph and the corresponding distance on the ground. The scale of an aerial photograph is determined by two factors, the focal length of the camera lens and the altitude above terrain at which the exposure was made.

Scan Line - The ground trace of a narrow strip that is recorded by the instantaneous field of view of a detector in a scanner system.

Scanning Densitometer - Device used to convert image data from film or photographic format to electronic video signal format. Usually the film is placed on a glass cylinder which rotates and slowly translates. A fine beam of light is focused on the film, passed through the film, and is detected by a photomultiplier where it is amplified to a usable video signal.

Sensor - Detecting device which collects and conveys some interpretable data; the component of an instrument that converts an input signal into a quantity which is measured by another part of the instrument.

Shutter - A component of an aerial camera which opens to admit light to the film as required for an exposure, and controls the duration of light affecting the film. Commonly used shutters which operate between the lens elements are called between-the-lens shutters. Those which operate at the focal plane are called focal plane shutters.

Sidelap - Measure of the percentage overlap between one photograph in one flight line and a second photograph in a parallel flight line.

Signature Extension - Processing technique that allow spectral signatures to be applied over geographic areas that are great distances from the original training areas.

Software - A set of computer programs, procedures, and associated documentation concerned with the operation of a data processing system (i.e., compilers, library routines, manuals).

SLAR - Side looking airborne radar.

Spatial - Refers to the location of, proximity to, or orientation of objects with respect to one another in n-dimensional space.

Spectral Signature - Quantitative measure of the electromagnetic radiation that is recorded by a sensor from a target in one or several wavelength intervals.

Stereoscopic Coverage - Aerial photography taken with sufficient overlap to permit complete stereoscopic observation. Sixty percent forward overlap between frames is usually recommended for adequate stereoscopic coverage.

Stereoscopic Pair - Two photographs of the same area taken from different camera stations so as to afford stereoscopic study of the overlap area. Also called a stereo pair.

Stereo Triplet - Three photographs, the center photo having a common field of view with the two adjacent photos, to permit complete stereoscopic viewing of the center photograph.

Stereoscope - An optical instrument which permits the operator to view two properly prepared photographs and perceive the three-dimensional effect.

Subtractive Primary Colors - Yellow, cyan, and magenta. When used as filters for white light these colors remove blue, red, and green, respectively.

Sun Synchronous Orbit - An Earth satellite orbit in which the orbit plane is near-polar and the altitude such that the satellite passes over the same latitude on each successive orbit at the same local sun time.

Supervised Training - Process whereby an analyst selects known training areas from which training statistics are calculated to define a resource class for use in a digital classification.

<u>Sun Elevation Angle</u> - Angle of the sun above the horizon measured in degrees.

<u>Target</u> - An object on the terrain of specific interest in a remote-sensing investigation.

<u>Target</u> - (1) The distinctive marking or instrumentation of a ground point to aid in its identification on a photograph. In photogrammetry, target designates a material marking so arranged and placed on the ground as to form a distinctive pattern over a geodetic or other control-point marker on a property corner on line, or at the position of an identifying point above an underground facility or feature. (2) In radar, an object returning a radar echo to the receiver.

<u>Telemeter</u> - To transmit data by radio or microwave links.

<u>Texture</u> - In a photo image, the frequency of change and arrangement of tones. Some descriptive adjectives for textures are fine, medium or coarse; and stippled or mottled.

<u>Thermal Infrared</u> - Electromagnetic radiation emitted by any substance as a consequence of the thermal excitation of its molecules. Thermal radiation ranges in wavelength from the longest infrared radiation to the shortest ultraviolet radiation.

<u>TIR</u> - Thermal Infrared.

<u>TM</u> - Thematic Mapper - multispectral sensor to be operated on Landsat D.

<u>Tone</u> - A distinguishable variation in shade of grey between black and white.

<u>Training Set</u> - A group of points (pixels) from which training statistics are calculated.

<u>Transparency</u> - A positive photographic print made on a transparent base such as film and viewed by transmitted light. Although a negative is also a transparency, the word is not generally used in referring to negatives.

<u>Unsupervised Training</u> - Process of finding natural groupings (clusters) in digital data and correlating these groupings with known resource classes. Training statistics are calculated from the cluster data for use in a digital classification.

<u>UV</u> - Ultraviolet, a portion of the electromagnetic spectrum with wavelengths shorter than the visible portion of the spectrum.

<u>Vignetting</u> - A gradual increase in density from the center of a photograph towards the edge caused by the stopping of some of the light rays entering the lens. Thus, a lens mounting may interfere with the extreme oblique rays. An antivignetting filter is one that gradually decreases in density from the center toward the edges; it is used with aerial wide-angle lenses to produce a photograph of uniform density by cutting down the exposure of the photograph center.

Vertical Photograph - An aerial photograph taken with the axis of the camera being maintained as closely as possible to a truly vertical position with the resultant photograph lying approximately in a horizontal plane.

Wavelength (symbol λ) - Wavelength = velocity/frequency. In general, the mean distance between maximums (or minimums) of a roughly periodic pattern. Specifically, the least distance between particles moving in the same phase of oscillation in a wave disturbance. Optical and IR wavelengths are measured in nanometers (10^{-9} m), micrometers (10^{-6} m) and Angstroms (10^{-10} m).