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COURSE TITLE:
ELEMENTS OF REMOTE SENSING AND AERIAL PHOTO INTERPRETATION

ELEMENTS OF REMOTE SENSING AND AERIAL PHOTO INTERPRETATION

By

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1.0. PREAMBLE

Imagine you have been asked to investigate how temperature changes in a large body of water such as the Chesapeake Bay affect shellfish populations. Or imagine that you have been asked to perform an analysis of how land use in your region has changed over the past decade. Such projects are very real and very important on a regional scale, and the results of very similar environmental research are often used as the basis for policy decisions by local and state governments.

As you consider such a task, numerous questions come to mind. What kinds of measurements would you need to make? How often would you need these measurements? How much area should your research cover? What tools are available for such a research project? What are the costs involved? In many cases the answers to these questions identify a need for measurements and observations on temporal (time) and spatial scales that are impossible for a single person (or even a well organized group of researchers) to meet. Additionally, the manpower and the funding is often not available to carry out such research using traditional methods of field research.

These problems are increasingly faced by researchers by turning to remote sensing as a cost effective tool for performing environmental research on local and regional scales. Remote sensing is not a new concept and has been used extensively in global environmental research over the past several decades. However, recent advances in remote sensing technologies, lower cost, and greater availability of remotely-sensed data has made it a much more attractive solution for local and regional governments, schools, and universities interested in performing environmental research that may have real impact on their communities

1.1. What is Remote Sensing?

Remote sensing can be defined as the study of something without making actual contact with the object of study. More precisely, it can be defined as:

> "The acquisition and measurement of data/information on some property (ies) of a phenomenon, object, or material by a recording device not in physical, intimate contact with the feature(s) under surveillance"

it is also defined as the technique of obtaining information about objects through the analysis of data collected by instruments that are not in physical contact with the objects of investigation.

Whatever working definition you use to describe remote sensing, the key concept is that remote sensing involves making observations remotely, or without physical contact with the object under investigation. The remote nature of these technologies allow us to make observations, take measurements, and produce images of phenomena that are beyond the limits of our own senses and capabilities.

The technical term "remote sensing" was first used in the United States in the 1960's, and encompassed photogrammetry, photo-interpretation, photo-geology etc. Since Landsat-1, the first earth observation satellite was launched in 1972; remote sensing has become widely used.

The characteristics of an object can be determined using reflected or emitted electro-magnetic radiation, from the object. That is, "each object has a unique and different characteristics of reflection or emission if the type of deject or the environmental condition is different." Remote sensing is a technology to identify and understand the object or the environmental condition through the uniqueness of the reflection or emission.

This concept is illustrated in Fig. 1.1 while Fig. 1.2 shows the flow of remote sensing, where three different objects are measured by a sensor in a limited number of bands with respect to their, electro-magnetic characteristics after various factors have affected the signal. The remote sensing data will be processed automatically by computer and/or manually interpreted by humans, and finally utilized in agriculture, land use, forestry, geology, hydrology, oceanography, meteorology, environment etc.

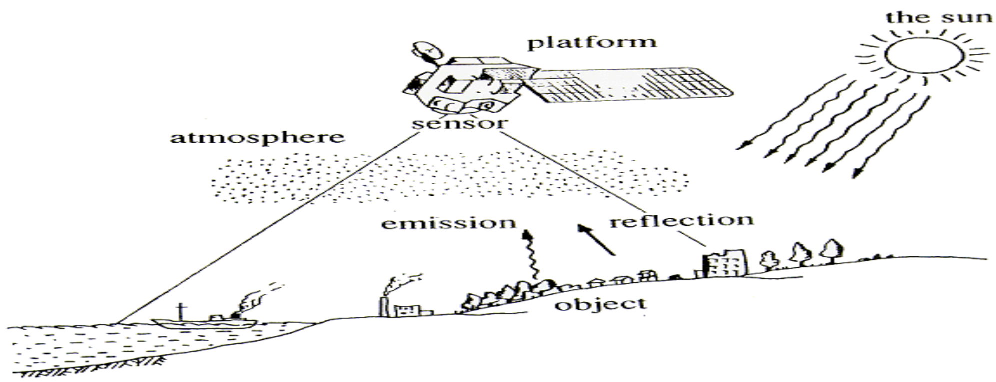


Figure1.1. Data collection by remote sensing

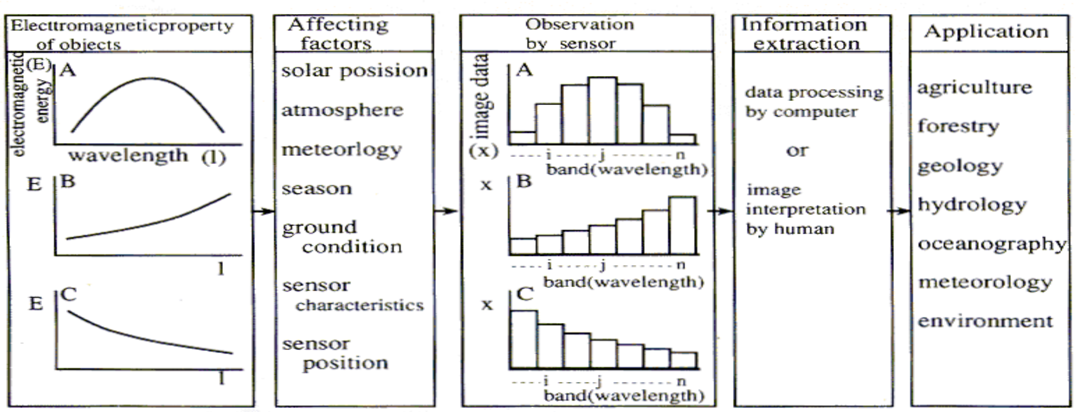


Figure1.1.2 Flow of remote sensing

1.2. Electromagnetic Radiation (EMR)

Energy is the capacity to do work. Energy can take many forms such as light, heat or sound, and can be transmitted between objects through three processes: conduction, convection and radiation. Conduction requires that the objects be in direct physical contact. Energy is transferred from the high-energy object to the low energy object until both objects are at the same energy level. For example, a hot water bottle warms a bed until the hot water bottle and the bed reach the same temperature, after which no further energy transfer occurs. Convection occurs in liquids and gases. Convection is based on currents that distribute energy throughout the volume of liquid or gas. Radiation does not require physical contact or the existence of a liquid or gas.

Environmental remote sensing systems focus on electromagetic energy, which is a dynamic form of energy caused by the oscillation or acceleration of an electrical charge. All objects that have a temperature higher than absolute zero (0^o K or -273.16^o C) emit electromagnetic energy. The wavelength of the emitted energy is a function of temperature.

Body	**Temperature (^{o}C)**	**Dominant Wavelength (λ)**
Sun	5727	0.3 - 0.7 µm
Volcano	1100	2.1 µm
Man	36.6	9.3 µm
Earth	27	9.7 µm

Electromagnetic radiation (EMR) is electromagnetic energy in transit. It can be thought of as a waveform having electrical and magnetic fields, which are perpendicular to each other and perpendicular to the direction of propagation. Both components of the wave pattern have a repetitive sinusoidal shape.

Almost all-electromagnetic energy in the Earth system, i.e. Earth and its atmosphere, is produced by the sun and is transmitted through the vacuum of space by radiation. A small amount of electromagnetic energy is produced by internal heat and radioactive decay.

Characteristics of Electro-Magnetic Radiation

(1) ***Characteristics as wave motion***

Electro-magnetic radiation can be considered as a transverse wave with an electric field and a magnetic field. A plane wave for an example as shown in Fig 1.3 has its electric field and magnetic field in the perpendicular plane to the transmission direction. The two fields are located at right angles to each other. The **wavelength** λ, **frequency** ν and the velocity υ have the following relation.

$$\lambda = \upsilon / \nu$$

Electro-magnetic radiation is transmitted in a vacuum of free space with the velocity of light c, (= 2.998 x 108 m/sec) and in the atmosphere with a reduced but similar velocity to that in a vacuum. The frequency n is expressed as a unit of hertz (Hz), which is the number of waves, which are transmitted in a second.

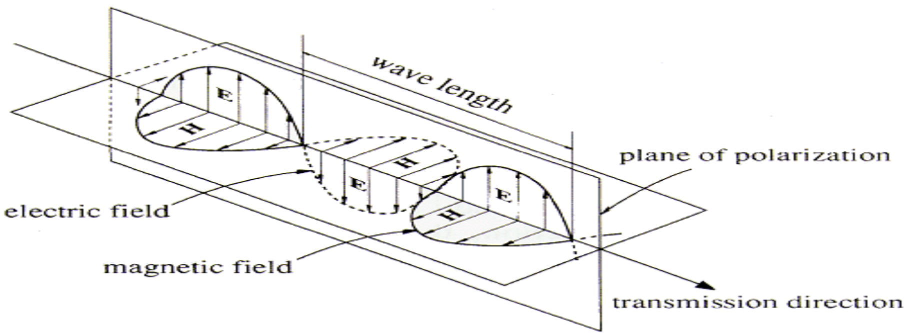


Fig. 1.3 **Electromagnetic radiation**

(2) **Characteristics as particle motion**
Electro-magnetic can be treated as a photon or a light quantum. The energy E is expressed as follow.

$$E = h\nu$$

where h = Plank's constant

ν: frequency

The photoelectric effect can be explained by considering the electro-magnetic radiation as composed of particles. Electro-magnetic radiation has four elements of frequency (or wavelength), **transmission direction**, **amplitude** and **plane of polarization**. The amplitude is the magnitude of oscillating electric field. The square of the amplitude is proportional to the energy transmitted by electro-magnetic radiation. The energy radiated from an object is called radiant energy. A plane including electric field is called a plane of polarization. When the plane of polarization forms a uniform plane, it is called linear polarization.

The four elements of electro-magnetic radiation are related to different information content as shown in Fig. 1.4. Frequency (or wavelength) corresponds to the color of an object in the visible region, which is given by a unique characteristic curve relating the wavelength and the radiant energy. In the microwave region, information about objects is obtained using the Doppler shift effect in frequency, which is generated by a relative motion between an object and a platform. The spatial location and shape of objects are given by the linearity of the transmission direction, as well as by the amplitude. The plane of polarization is influenced by the geometric shape of objects in the case of reflection or scattering in the microwave region. In the case of radar, horizontal polarization and vertical polarization have different responses on a radar image.

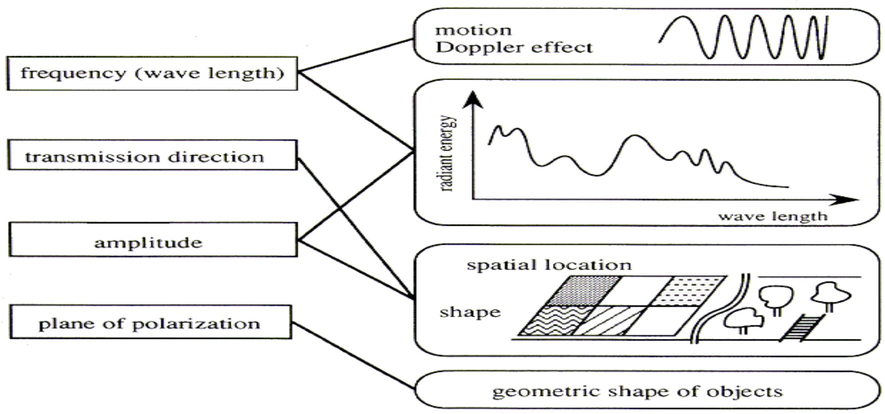


Fig. 1.4 Information derived from elements of electromagnetic radiation

1.3 Interactions between Matter and Electro-magnetic Radiation

All matter reflects, absorbs, penetrates and emits electro-magnetic radiation in a unique way. For example, the reason why a leaf looks green is that the chlorophyll absorbs blue and red spectra and reflects the green spectrum. The unique characteristics of matter are called **spectral characteristics**. Why does an object have a peculiar characteristic of reflection, **absorption** or emission? In order to answer the question, one has to study the relation between molecular, atomic and electro-magnetic radiation. In this section, the interaction between hydrogen atom and absorption of electro-magnetic radiation is explained for simplification.

A hydrogen atom has a nucleus and an electron as shown in Fig. 1.5. The inner state of an atom depends on the inherent and discrete energy level. The electron's orbit is determined by the energy level. If electro-magnetic radiation is incident on an atom of H with a lower **energy level** (E1), a part of the energy is absorbed, and an electron is induced by **excitation** to rise to the energy level (E2) resulting in the upper orbit.

The electro-magnetic energy E is given as follow.
$E = hc / \lambda$
where h : Plank's constant
c : velocity of light
λ: wavelength

The difference of energy level
$\Delta E = E2 - E1 = hc / \lambda H$ is absorbed.

In other words, the change of the inner state in an H-atom is only realized when electro-magnetic radiation at the peculiar wavelength lH is absorbed in an H-atom. Conversely electro-magnetic radiation at the wavelengthλ H is **radiated** from an H-atom when the energy level changes from E2 to E1.

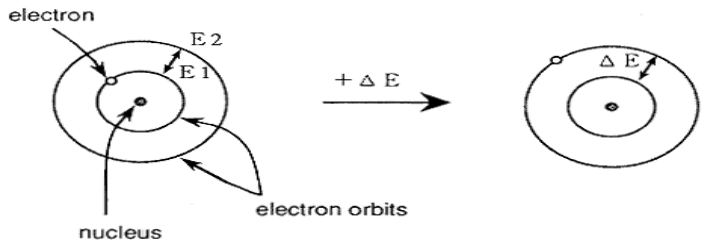


Fig. 1.5 Change in energy level of the electron of a H atom according to absorption of electromagnetic radiation wavelength λ H

All matter is composed of atoms and molecules with a particular composition. Therefore, matter will emit or absorb electro-magnetic radiation at a particular wavelength with respect to the inner state.

The types of inner state are classified into several classes, such as ionization, excitation, molecular vibration, molecular rotation etc. as shown in Fig. 1.6 and Table 1,1, which will radiate the associated electro-magnetic radiation. For example, visible light is radiated by excitation of valence electrons, while infrared is radiated by molecular vibration or lattice vibration.

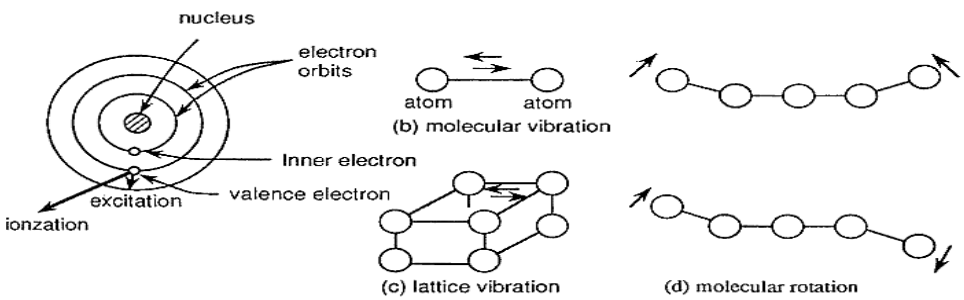


Fig. 1.6 Schematics of characteristic states associated with electromagnetic radiation

Table. Relation between characteristic state and electromagnetic radiation

Characteristic state	energy (eV)	associated electromagnetic wave
Nuclear transmission and disintegrations	$10^7 \sim 10^5$	γ - ray
Ionization by inner electron removal	$10^4 \sim 10^2$	X - ray
Ionization by outer electron removal	$10^2 \sim 4$	Ultra - violet
Excitation of valence electrons	$4 \sim 1$	Visible
Molecular vibration, Lattice vibration	$10 \sim 10^{-5}$	Infrared
Molecular rotations, electron spin resonance	$10^{-4} \sim 10^{-5}$	Microwave
Nuclear spin resonance	10^{-7}	Meter wave

[unit] energy of 1eV = 1.60219 × 10-19 Joule wavelength of 1eV light = 1.23985 μm

1.4 Wavelength Regions of Electro-magnetic Radiation

Wavelength regions of electro-magnetic radiation have different names ranging from γray, Xray, **ultraviolet (UV)**, **visible light**, **infrared (IR)** to radio wave, in order from the shorter wavelengths. The shorter the wavelength is, the more the electro-magnetic radiation is characterized as particle motion with more linearity and directivity.

Table 1.2 shows the names and wavelength region of electro-magnetic radiation. One has to note that classification of infrared and radio radiation may vary according to the scientific discipline. The table shows an example, which is generally used, in remote sensing.

Table Classification of electromagnetic radiations

class				wavelength	frequency
ultraviolet				100A ~ 0.4 μm	750 ~ 3,000 THz
visible				0.4 ~ 0.7 μm	430 ~ 750 THz
infrared	near infrared			0.7 ~ 1.3 μm	230 ~ 430 THz
	short wave infrared			1.3 ~ 3 μm	100 ~ 230 THz
	intermediate infrared			3 ~ 8 μm	38 ~ 100 THz
	thermal infrared			8 ~ 14 μm	22 ~ 38 THz
	far infrared			14 μm ~ 1 mm	0.3 ~ 22 THz
radio wave	submillimeter			0.1 ~ 1 mm	3 ~ 3 THz
	micro wave	millimeter	(EHF)	1 ~ 10 mm	30 ~ 300 GHz
		centimeter	(SHF)	1 ~ 10 cm	3 ~ 30 GHz
		decimeter	(UHF)	0.1 ~ 1 m	0.3 ~ 3 GHz
	very short wave		(VHF)	1 ~ 10 m	30 ~ 300 MHz
	short wave		(HF)	10 ~ 100 m	3 ~ 30 MHz
	medium wave		(MF)	0.1 ~ 1 km	0.3 ~ 3 MHz
	long wave		(LF)	1 ~ 10 km	30 ~ 300 KHz
	very long wave		(VLF)	10 ~ 100 km	3 ~ 30 KHz

The electro-magnetic radiation regions used in remote sensing are near UV(ultra-violet) (0.3-0.4 μm), visible light(0.4-0.7 μm), near shortwave and thermal infrared (0.7-14 μm) and micro wave (1 mm - 1 m).

Fig. 1.7. shows the spectral bands used in remote sensing. The spectral range of **near IR** and **short wave infrared** is sometimes called the **reflective infrared** (0.7-3 μm) because the range is more influenced by solar reflection rather than the emission from the ground surface. In the thermal infrared region, emission from the ground's surface dominates the radiant energy with little influence from solar reflection.

Visible light corresponds to the spectral colors. They are, in order from the longer wavelengths in the visible region, the so-called rainbow colors; red, orange, yellow, green, blue, indigo and violet are located with respect to the wavelength.

Short wave infrared has more recently been used for geological classification of rock types. Thermal infrared is primarily used for temperature measurement, while micro wave is utilized for radar and micro wave radiometry. A special naming of k band, X band, C band, L band etc. is given to the microwave region as shown in Fig. 1.7

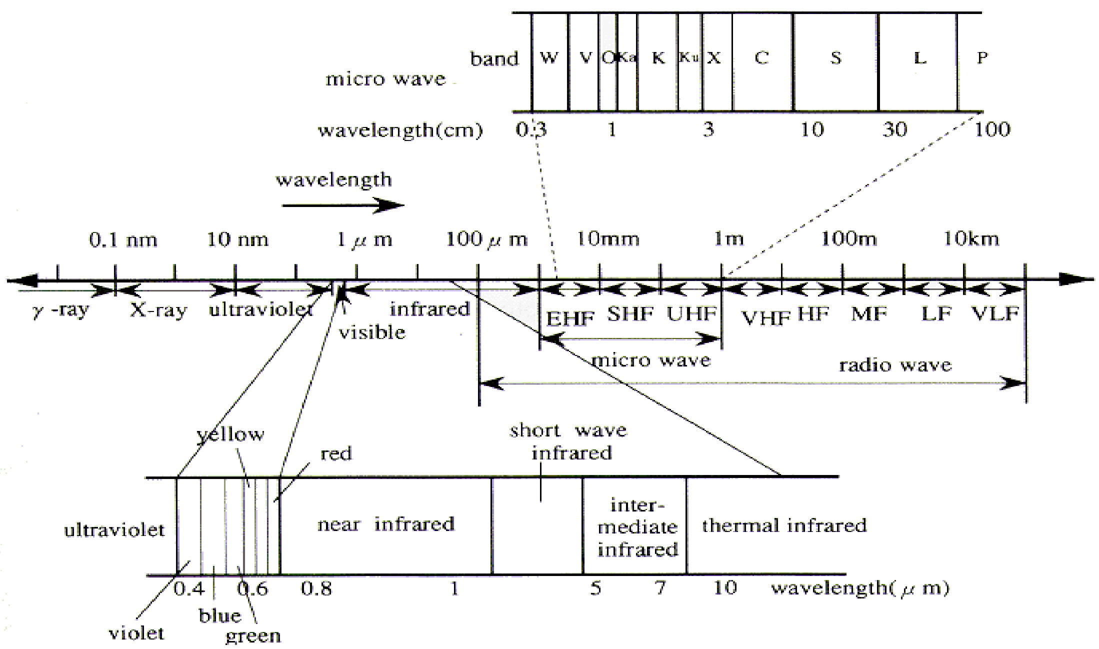


Fig. 1.7 **The bands used in remote sensing**

1.5 Types of Remote Sensing with Respect to Wavelength Regions

Remote sensing is classified into three types with respect to the wavelength regions; (1) **Visible and Reflective Infrared Remote Sensing**, (2) **Thermal Infrared Remote Sensing** and (3) **Microwave Remote Sensing**, as shown in Fig. 1.8.

The **energy source** used in the visible and reflective infrared remote sensing is the sun. The sun radiates electro-magnetic energy with a peak wavelength of 0.5 μm. Remote sensing data obtained in the visible and reflective infrared regions mainly depends on the **reflectance** of objects on the ground surface. Therefore, information about objects can be obtained from the spectral reflectance. However laser radar is exceptional because it does not use the solar energy but the laser energy of the sensor.

The source of radiant energy used in thermal infrared remote sensing is the object itself, because any object with a normal temperature will emit electro-magnetic radiation with a peak at about 10 μm, as illustrated in Fig. 1.8.

One can compare the difference of spectral radiance between the sun (a) and an object with normal earth temperature (about 300°K), as shown in Fig. 1.8. However it should be noted that the figure neglects atmospheric absorption, for simplification, though the spectral curve varies with respect to the reflectance, emittance and temperature of the object.

The curves of (a) and (b) cross at about 3.0 μm. Therefore in the wavelength region shorter than 3.0 μm, spectral reflectance is mainly observed, while in the region longer than 3.0 μm, **thermal radiation** is measured.

In the microwave region, there are two types of microwave remote sensing, passive microwave remote sensing and active remote sensing. In passive microwave remote sensing, the **microwave radiation** emitted from an object is detected, while the **back scattering coefficient** is detected in active microwave remote sensing.

Remarks: the two curves (a) and (b) in Fig. 1.8 show the black body's spectral radiances of the sun at a temperature of 6,000°K and an object with a temperature of 300°K, without atmospheric absorption.

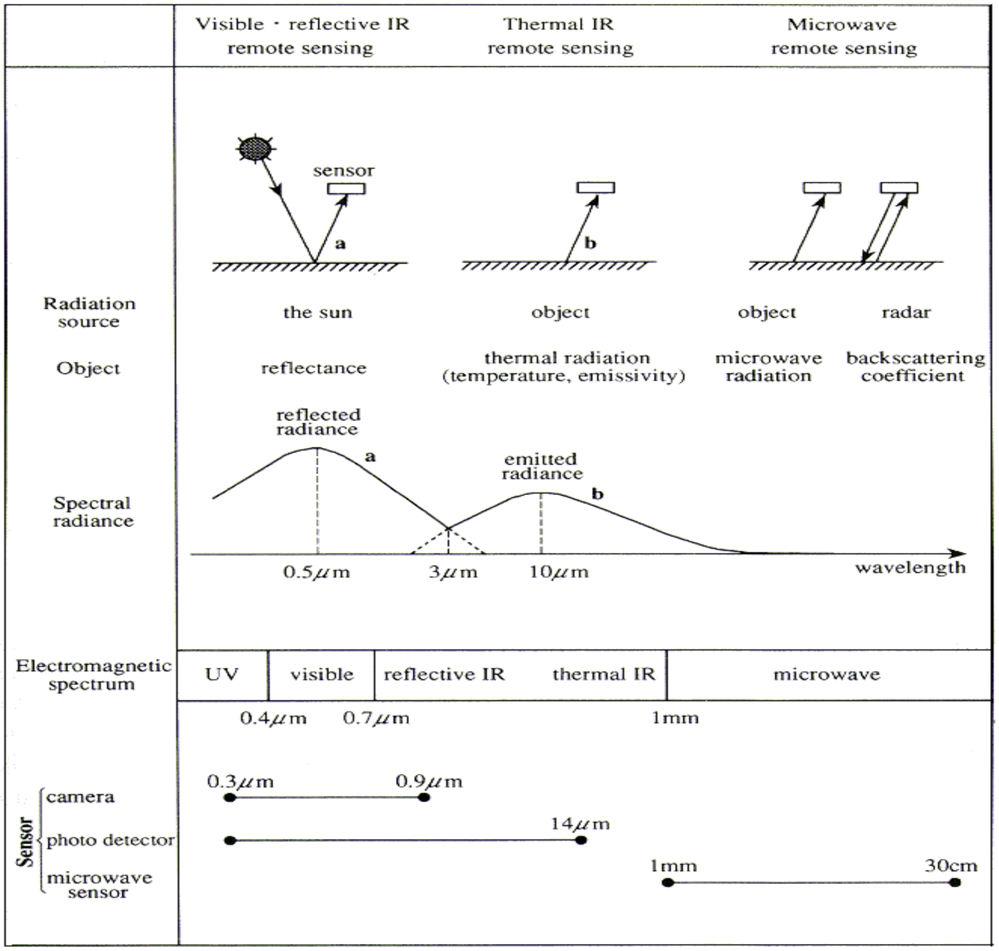


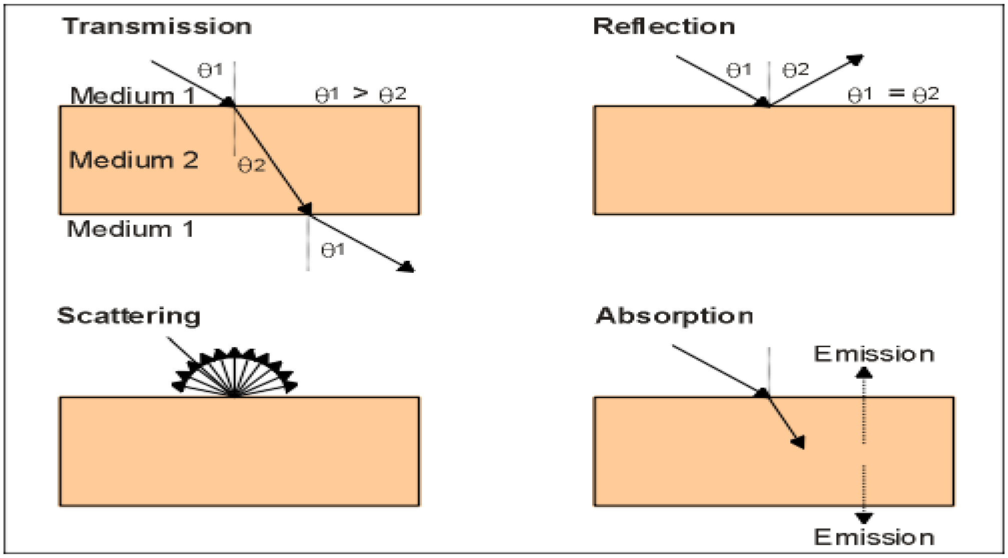
Fig. 1.8 **Three types of remote sensing with respect to wavelength regions**

1. 6. Energy-Matter Interactions

Electromagnetic radiation is only detected when it interacts with matter. For example, we don't notice visible light passing through a room. What our eyes detect is the electromagnetic energy that is reflected off objects in the room. Only if the room was full of dust would we appear to see light passing through the room, but even then what our eyes detect is the reflection of visible energy off the dust particles in the air.

When electromagnetic radiation interacts with matter, it may be transmitted, reflected, scattered or absorbed. Transmission allows the electromagnetic energy to pass through matter, although it will be refracted if the transmission mediums have different densities. Reflection, or more precisely specular reflection, occurs when incident electromagnetic radiation bounces off a smooth surface. Scattering, or diffuse reflection occurs when incident electromagnetic radiation is dispersed in all directions from a rough surface. Absorption occurs when electromagnetic energy is taken in by an opaque medium. Absorption will raise the energy level of the opaque object and some electromagnetic energy will later be re-emitted as long wave (thermal) electromagnetic radiation.

Energy-Matter Interactions

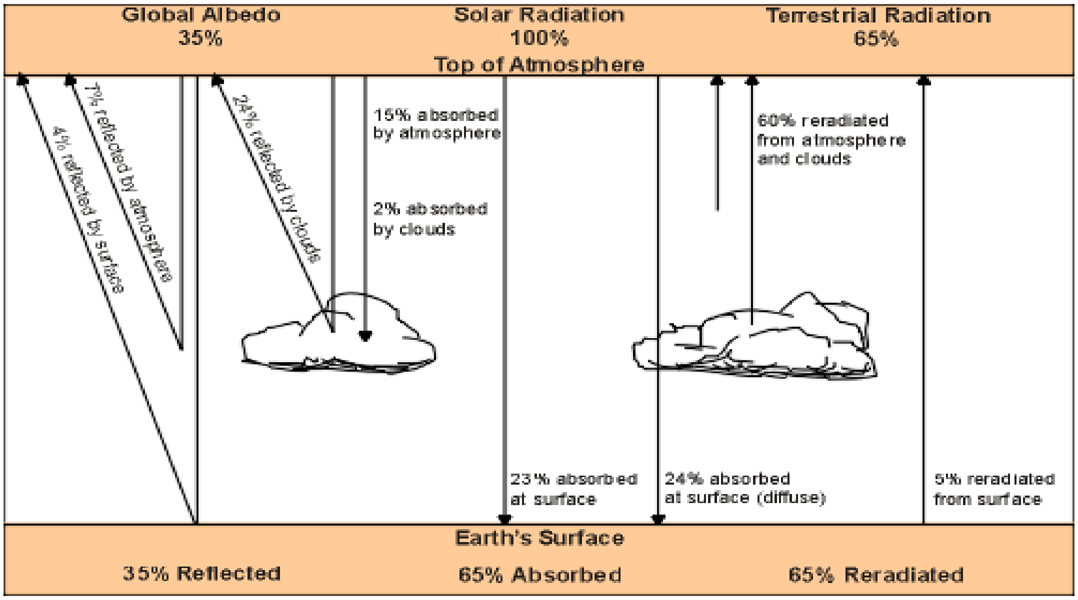


Effect of Atmosphere on EMR

In order to understand the potential and limitations of remotes sensing, it is necessary to consider what happens to solar electromagnetic radiation on its path from the sun to the satellite or airborne sensor. All of the solar emr passes through space to reach the top of the Earth's atmosphere, but not all reaches the Earth's surface. The atmosphere scatters, absorbs and reflects a portion of the in-coming solar radiation. The Earth scatters, absorbs and reflects the solar radiation that gets transmitted through the atmosphere. Finally the atmosphere scatters, absorbs and reflects the electromagnetic radiation that is reflected off the Earth's surface back toward the sensor.

Of the total in-coming solar radiation, about 35% is reflected by the Earth-atmosphere system: 4% is reflected by the Earth's surface; the atmosphere reflects 7%; and clouds reflect 24%. The remaining 65% of in-coming solar radiation (insolation) is absorbed by the Earth-atmosphere system: 16% is absorbed by the atmosphere; 2% is absorbed by clouds; 23% is absorbed directly by the Earth's surface; and a further 24% is absorbed indirectly by the Earth's surface as a result of diffuse scattering. The absorbed radiation is later re-radiated as long wave radiation: 60% by the atmosphere and clouds; and 5% by the Earth's surface.

Earth-Atmosphere System Energy Budget



The atmospheric effects on emr are wavelength selective. This means that certain wavelengths are transmitted easily through the atmosphere while others are reflected, scattered, or absorbed by gases such as oxygen(O_2), nitrogen(N_2), ozone(O_2) or carbon dioxide(CO_2), or by water vapour (H_2O). Areas of the electromagnetic spectrum where specific wavelengths can pass relatively unimpeded through the atmosphere are called transmission bands or atmospheric windows. Areas where specific wavelengths are totally are partially blocked are called absorption bands or atmospheric blinds. Oxygen and ozone effectively absorb all gamma and X rays while carbon dioxide, oxygen and water vapour absorb radiation in different segments of the infrared and microwave portions of the electromagnetic spectrum. The effect of atmospheric blinds is to limit the range of wavelengths that can be used to identify features or conditions on the Earth's surface.

Effect of Earth on EMR

On average, 51% of the in-coming solar radiation reaches the Earth's surface. Of this total, 4% is reflected back into the atmosphere and 47% is absorbed by the Earth's surface to be re-radiated later in the form of thermal infrared radiation. However, there is a great deal of variation in the way that different features on the Earth's surface reflect or absorb in-coming radiation. In general, surfaces that are good reflectors are poor absorbers. Thus some surfaces or objects will reflect much of the in-coming radiation while other surfaces will absorb most of the in-coming radiation. It is these differences in reflectivity that allow us to distinguish different features or conditions in remote sensing imagery.

The reflectivity of a surface can be measured for a specific wavelength or for the entire electromagnetic spectrum. The spectral reflectance of an object R(□) is the percentage of EMR reflected by the object in a specific wavelength or spectral band. The albedo of an object is its reflectance aggregated over a broader segment of the electromagnetic spectrum (e.g. over the visible portion of the spectrum) or over the entire spectrum. The higher the albedo, the more reflective the surface and the brighter the surface will appear in remotely sensed imagery.

Albedos of Selected Materials at Visible Wavelengths

Material	Albedo (% Reflected)
Fresh snow	80 - 95
Old snow	50 - 60
Thick cloud	79 - 80
Thin cloud	20 - 30
Water (sun near horizon)	50 - 80
Water (sun near zenith)	3 - 5
Asphalt	5 - 10
Light soil	25 - 45
Dark soil	5 - 15
Dry soil	20 - 25
Wet soil	15 - 25
Deciduous forest	15 - 20
Coniferous forest	10 - 15
Crops	10 - 25
Earth system	35

Spectral Signatures

Different objects may have similar albedos, measured over a broad portion of the electromagnetic spectrum but may still have very different patterns of reflectance within narrow spectral bands. These differences can be used to discriminate between different types of objects.

The spectral signature of an object is its pattern of reflectance over a range of wavelengths. Multi-spectral scanners can detect reflected EMR in a series of different wavelength bands. Older scanners have sampled a small number of spectral bands that have been carefully selected to suit particular purposes. New hyper-spectral scanners can sample 100s of spectral bands and offer the potential for a much broader range of remote sensing applications.

Spectral signatures are not unlimited in their ability to discriminate between different types of surfaces or objects. Spectral signatures are not necessarily unique. Objects that have similar spectral signatures will be difficult or impossible to tell apart. Spectral signatures also depend on the time of day since shadows affect the pattern of reflected EMR.

Spectral signatures for different surfaces can be obtained using a device called a radiometer. The radiometer detects the EMR reflected off a surface in a specified spectral band. By measuring reflectance in many different bands, the spectral signature over the full range of wavelengths can be obtained.

Electro-optical scanners such as Landsat MSS or Thematic Mapper are designed to detect EMR in narrow spectral bands. Photographic film records reflected EMR over a broad portion of the electromagnetic spectrum. However, a wide variety of filters can be used to make photographic film more selective.

1.7 Black Body Radiation

An object radiates unique spectral radiant flux depending on the temperature and emissivity of the object. This radiation is called **thermal radiation** because it mainly depends on temperature. Thermal radiation can be expressed in terms of **black body** theory.

A black body is matter, which absorbs all electro-magnetic energy, incident upon it and does not reflect nor transmit any energy. According to **Kirchhoff's law** the ratio of the radiated energy from an object in thermal static equilibrium, to the absorbed energy is constant and only dependent on the wavelength and the temperature T. A black body shows the maximum radiation as compared with other matter. Therefore a black body is called a perfect radiator.

Black body radiation is defined as thermal radiation of a black body, and can be given by **Plank's law** as a function of temperature T and wavelength as shown in Fig. 1.11 and Table 1.4.

In remote sensing, a correction for **emissivity** should be made because normal observed objects are not black bodies. Emissivity can be defined by the following formula-

$$\text{Emissivity} = \frac{\text{Radiant energy of an object}}{\text{Radiant energy of a black body with the same temperature as the object}}$$

Emissivity ranges between 0 and 1 depending on the dielectric constant of the object, surface roughness, temperature, wavelength, look angle etc. Fig. 1.12 shows the spectral emissivity and spectral radiant flux for three objects that are a back body, **a gray body** and a selective radiator.

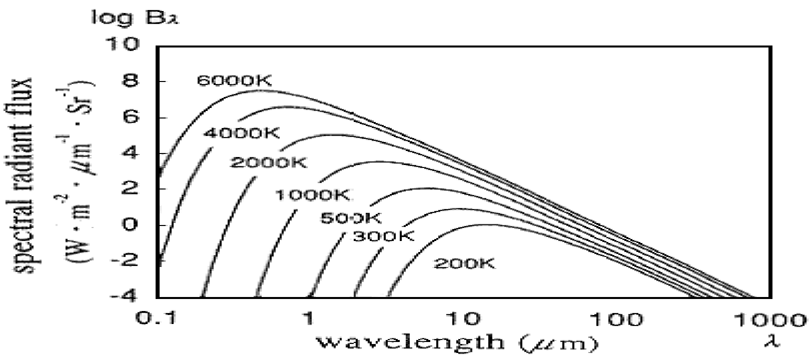


Fig. 1.11 **Plank's law of radiation**

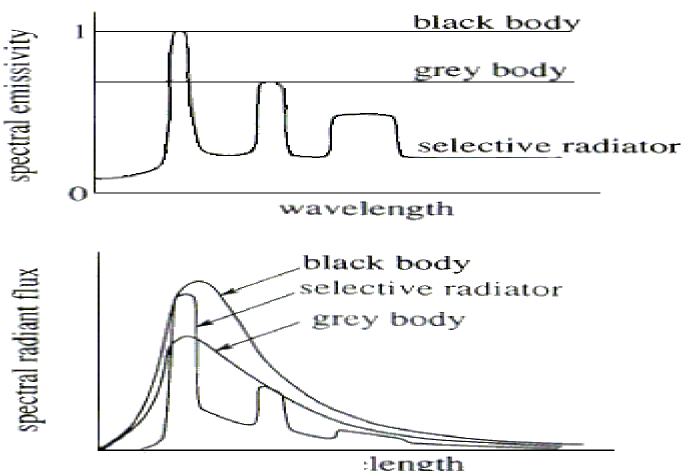


Fig. 1.12

Radiators

The temperature of the black body, which radiates the same radiant energy as an observed object, is called the **brightness temperature** of the object.

Stefan-Boltzmann's law is obtained by integrating the spectral radiance given by Plank's law, and shows in that the radiant emittance is proportional to the fourth power of absolute temperature (T^4). This makes it very sensitive to temperature measurement and change.

Wien's displacement law is obtained by differentiating the spectral radiance, which shows that the product of wavelength (corresponding to the maximum peak of spectral radiance) and temperature, is approximately 3,000 (µm°K). This law is useful for determining the optimum wavelength for temperature measurement of objects with a temperature of T. For example, about 10 µm is the best for measurement of objects with a temperature of 300°K.

Table 1.7.1 Plank's law of radiation

spectral radiance of black body $B\lambda$ is given as follows.

$$B\lambda = \frac{2hc^2}{\lambda^5} \cdot \frac{1}{exp(hc/k\lambda T) - 1}$$

$B\lambda$	:	black body spectral radiance ($W \cdot m^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$)		
T	:	absolute temperature of Black body (K)		
λ	:	wavelength (μm)		
c	:	velocity of light	2.998×10^{8}	($m \cdot s^{-1}$)
h	:	plank's constant	6.626×10^{-34}	($J \cdot s$)
k	:	Boltzmann's constant	1.380×10^{-23}	($J \cdot K^{-1}$)

1.8 Reflectance

Reflectance is defined as the ratio of incident flux on a sample surface to reflected flux from the surface as shown in Fig. 1.13. Reflectance ranges from 0 to 1. Reflectance was originally defined as a ratio of incident flux of white light to reflected flux in a hemisphere direction. Equipment to measure reflectance is called spectrometers (see 2.6).

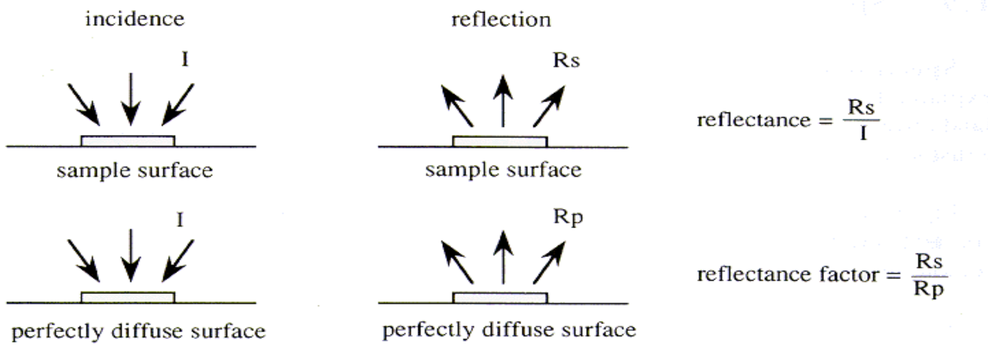


Fig. 1.13 **Reflectance and reflectance factor**

Albedo is defined as the reflectance using the incident light source from the sun. **Reflectance factor** is sometime used as the ratio of reflected flux from a sample surface to reflected flux from a perfectly diffuse surface. Reflectance with respect to wavelength is called **spectral reflectance** as shown for a vegetation example in Fig. 1.14. A basic assumption in remote sensing is that spectral reflectance is unique and different from one object to an unlike object.

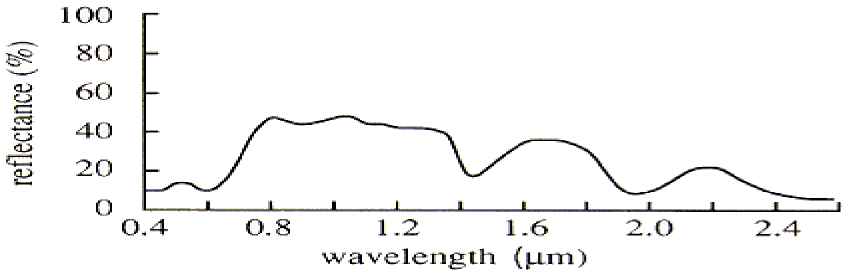


Fig. 1.14 **Spectral reflectance of vegetation**

Reflectance with a specified incident and reflected direction of electro-magnetic radiation or light is called **directional reflectance**. The two directions of incident and reflection have can be directional, conical or hemispherical making nine possible combinations.

For example, if incident and reflection are both directional, such reflectance is called bidirectional reflectance as shown in Fig. 1.15. The concept of bi-directional reflectance is used in the design of sensors.

Remarks; A perfectly diffuse surface is defined as a uniformly diffuse surface with a reflectance of 1, while the uniformly diffused surface, called a Lambertian surface, reflects a constant radiance regardless of look angle.

The Lambert cosine law, which defines a Lambertian surface, is as follows:

$I(\theta) = In .\cos\theta$

where $I(\theta)$: luminous intensity at an angle of θ from the normal to the surface.

In: luminous intensity at the normal angle

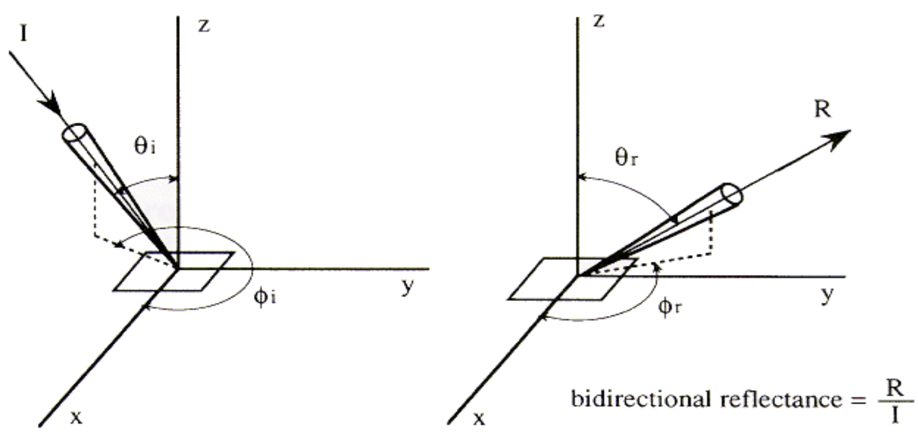


Fig. 1.15 **Bidirectional reflectance**

1.9 Spectral Reflectance of Land Covers

Spectral reflectance is assumed to be different with respect to the type of land cover. This is the principle that in many cases allows the identification of land covers with remote sensing by observing the spectral reflectance or spectral radiance from a distance far removed from the surface.

Fig. 1.16 shows three curves of spectral reflectance for typical land covers; vegetation, soil and water. As seen in the figure, vegetation has a very high reflectance in the near infrared region, though there are three low minima due to absorption.

Soil has rather higher values for almost all spectral regions. Water has almost no reflectance in the infrared region.

Fig. 1.17 shows two detailed curves of leaf reflectance and water absorption. Chlorophyll, contained in a leaf, has strong absorption at 0.45 μm and 0.67 μm, and high reflectance at near infrared (0.7-0.9 μm). This results in a small peak at 0.5-0.6 (green color band), which makes vegetation green to the human observer.

Near infrared is very useful for vegetation surveys and mapping because such a steep gradient at 0.7-0.9 μm is produced only by vegetation.

Because of the water content in a leaf, there are two absorption bands at about 1.5 μm and 1.9 μm. This is also used for surveying vegetation vigor.

Fig. 1.18 shows a comparison of spectral reflectance among different species of vegetation.

Fig. 1.19 shows various patterns of spectral reflectance with respect to different rock types in the short wave infrared (1.3-3.0 μm). In order to classify such rock types with different narrow bands of absorption, a multi-band sensor with a narrow wavelength interval is to be developed. Imaging spectrometers have been developed for rock type classification and ocean color mapping

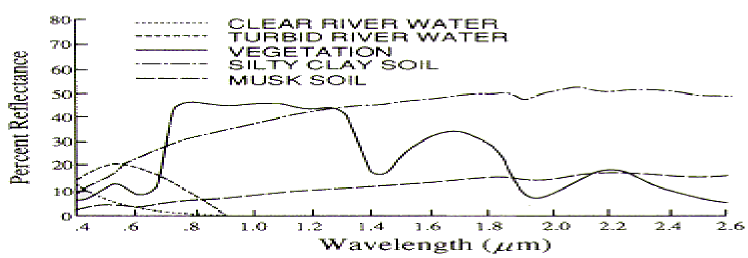


Fig. 1.16 **Spectral reflectance of vegetation, soil and water**

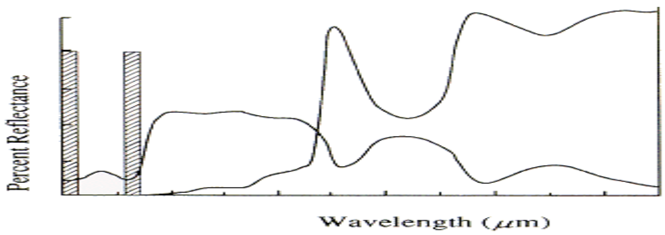


Fig. 1.17 **Spectral reflectance of a green leaf**

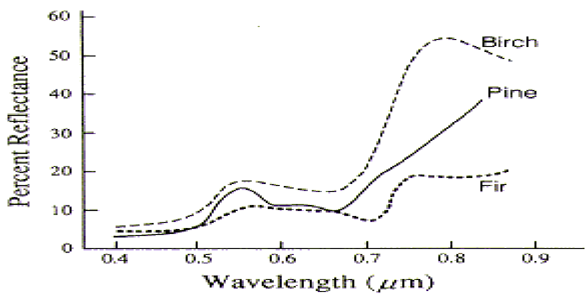


Fig. 1.19 **Spectral reflectance of different kind of plants**

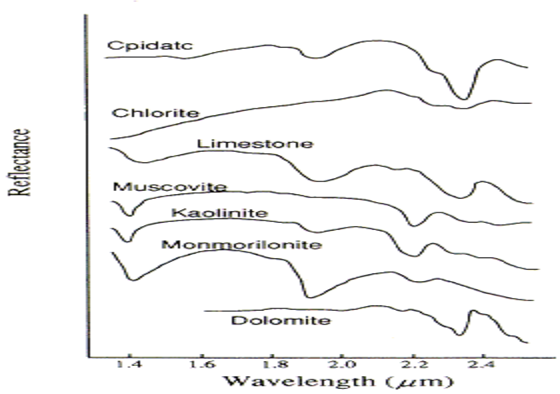


Fig. 1.19 **Figure 1.9.4 Spectral reflectance of rocks and minerals**

1.10 Spectral Characteristics of Solar Radiation

The sun is the energy source used to detect reflective energy of ground surfaces in the visible and near infrared regions.

Sunlight will be absorbed and scattered by ozone, dust, aerosols, etc., during the transmission from outer space to the earth's surface. Therefore, one has to study the basic characteristics of solar radiation.

The sun is considered as a black body with a temperature of 5,900°K. If the annual average of solar spectral irradiance is given by FeO(λ), then the solar spectral irradiance Fe(l) in outer space at Julian day D, is given by the following formula.

$Fe(\lambda) = FeO(\lambda)\{1 + \cos\varepsilon\ (2\pi(D-3)/365)\}^2$
where ε: 0.167 (eccentricity of the Earth orbit) λ: wavelength
D-3: shift due to January 3 as apogee and July 2 as perigee

The **sun constant** that is obtained by integrating the spectral irradiance for all wavelength regions is normally taken as $1.37Wm^{-2}$. Fig. 1.20 shows four observation records of solar spectral irradiance. The values of the curves correspond to the value at the surface perpendicular to the normal direction of the sunlight. To convert to the spectral irradiance per m^2 on the Earth surface with latitude of Φ, multiply the following coefficient by the observed values in Fig. 1.20.

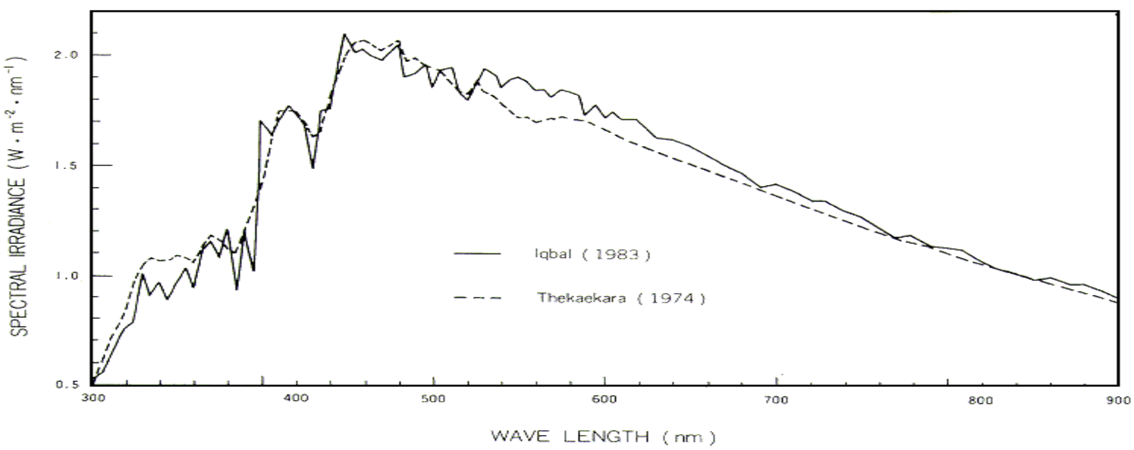


Fig. 1. 20 **Solar irradiance at the top of atmosphere (annual mean)**

$\alpha = (L0 / L)^2 \cos z$ $\cos z = \sin\varphi \sin\delta + \cos\varphi \cos\delta \cos h$
where z : solar zenith angle
δ: declination
h : hour angle,
L : real distance between the sun and the earth
L0: average distance between the sun and the earth

The incident solar radiation at the earth's surface is very different to that at the top of the atmosphere due to atmospheric effects, as shown in Fig. 1.21, which compares the solar spectral irradiance at the earth's surface to black body irradiance from a surface of temperature 5900°K.

The solar spectral irradiance at the earth's surface is influenced by the atmospheric conditions and the zenith angle of the sun. Beside the direct sunlight falling on a surface, there is another light source called sky radiation, diffuse radiation or skylight, which is produced by the scattering of the sunlight by atmospheric molecules and aerosols.

The skylight is about 10 percent of the direct sunlight when the sky is clear and the sun's elevation angle is about 50 degree. The skylight has a peak in its spectral characteristic curve at a wavelength of 0.45 μm.

1.11 Transmittance of the Atmosphere

The sunlight's transmission through the atmosphere is affected by **absorption** and **scattering** of atmospheric molecules and aerosols. The reduction of sunlight intensity is called extinction. The rate of **extinction** is expressed as **extinction coefficient**.

The **optical thickness** of the atmosphere corresponds to the integrated value of the extinction coefficient at each altitude by the atmospheric thickness. The optical thickness indicates the magnitude of absorption and scattering of the sunlight. The following elements will influence the transmittance of the atmosphere.

a. Atmospheric molecules (smaller size than wavelength):
carbon dioxygen, ozone, nitrogen gas, and other molecules

b. Aerosols (larger size than wavelength):
water drops such as fog and haze, smog, dust and other particles with a bigger size

Scattering by atmospheric molecules with a smaller size than the wavelength of the sunlight is called **Rayleigh scattering**. Raleigh scattering is inversely proportional to the fourth power of the wavelength.

The contribution of atmospheric molecules to the optical thickness is almost constant spatially and with time, although it varies somewhat depending on the season and the latitude.

Scattering by aerosols with larger size than the wavelength of the sunlight is called **Mie scattering**. The source of aerosols will be suspended particles such as sea water or dust in the atmosphere blown from the sea or the ground, urban garbage, industrial smoke, volcanic ashes etc., which varies to a great extent depending upon the location and the time. In addition, the optical characteristics and the size distribution also change with respect to humidity, temperature and other environmental conditions. This makes it difficult to measure the effect of aerosol scattering.

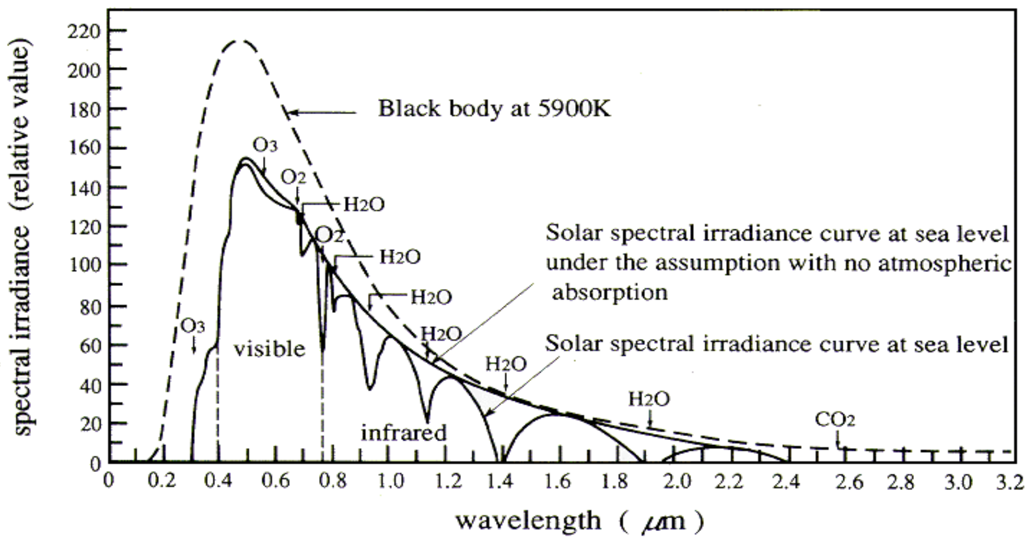


Fig. 1.21 **Comparison of spectral irradiance of solar light at sea level with black body radiation**

Scattering, absorption and transmittance of the atmosphere are different for different wavelengths. Fig. 1. 22 shows the spectral transmittance of the atmosphere. The low parts of the curve show the effect of absorption by the molecules described in the figure. Fig. 1.23 shows the spectral transmittance, or conversely absorption, with respect to various atmospheric molecules. The open region with higher transmittance in called "an atmospheric window".

As the transmittance partially includes the effect of scattering, the contribution of scattering is larger in the shorter wavelengths. Fig. 1.24 shows a result of simulation for resultant transmittance multiplied by absorption and scattering, which would be produced for a standard "clean atmospheric model" in the U.S.A. The contribution by scattering is dominant in the region less than 2mm and proportional according to the shorter wavelength. The contribution by absorption is not constant but depends on the specific wavelength.

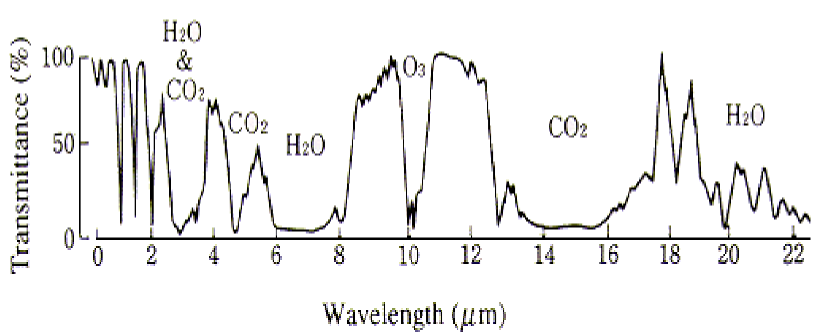


Fig. 1.23 **Characteristic of atmospheric spectral transmittance**

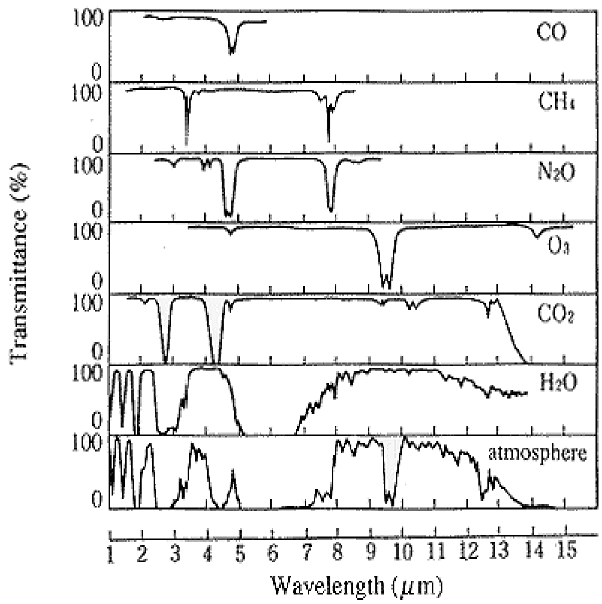


Fig. 1.24 **Characteristics of absorption in infrared region by atmospheric molecules**

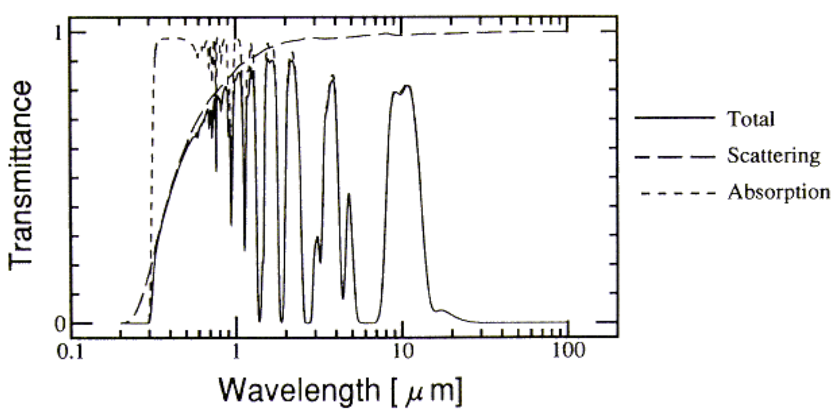


Fig. 1.24 **Atmospheric transmittance with contributions of absorption and scattering for "Clean" U.S. standard atmospheric model**

1.12 Radiative Transfer Equation

Radiative transfer is defined as the process of transmission of the electro-magnetic radiation through the atmosphere, and the influence of the atmosphere. The atmospheric effect is classified into multiplicative effects and additive effects as shown in Table 1.5.

Table 1.5 Atmospheric effects

Effect	Mechanism	Wavelength	Related physical variables
Multiplitive	Absorption	All region	Absorption coefficient, Absorber amount, Temperature Pressure
(Extinction)	Scattering	Visible & near IR	Scattering coefficient, Scatterer amount, Phase function
Additive	Thermal radiation	Thermal IR	Absorption coefficient, Absorber amount, Temperature Pressure
(Emission)	Scattering	Visible & near IR	Scattering coefficient, Scatterer amount, Phase function

The multiplicative effect comes from the **extinction** by which incident energy from the earth to a sensor will reduce due to the influence of absorption and scattering. The additive effect comes from the **emission** produced by thermal radiation from the atmosphere and atmospheric scattering, which is incident energy on a sensor from sources other than the object being measured.

Fig. 1. 25 shows a schematic model for the absorption of the electro-magnetic radiation between an object and a sensor, while Fig. 1.26 shows a schematic model for the extinction. Absorption will occur at specific wavelengths when the electro- magnetic energy converts to thermal energy. On the other hand, scattering is remarkable in the shorter wavelength region when energy conversion does not occur but only the direction of the path changes.

As shown in Figs. 1.27 and1.28, additional energy by emission and scattering of the atmosphere is incident upon a sensor. The thermal radiation of the atmosphere, which is characterized by **Plank's law**, is uniform in all directions. The emission and scattering of the atmosphere incident on the sensor, is indirectly input from other energy sources of scattering than those on the path between a sensor and an object.

The scattering depends on the size of particles and the direction of incident light and scattering.

Thermal radiation is dominant in the thermal infrared region, while scattering is dominant in the shorter wavelength region.

Generally, as extinction and emission occur at the same time, both effects should be considered together in the **radiative transfer equation** as indicated in the formula in Table 1.6.

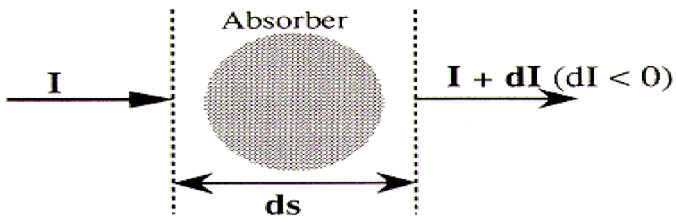


Fig. 1 Absorption (extinction)

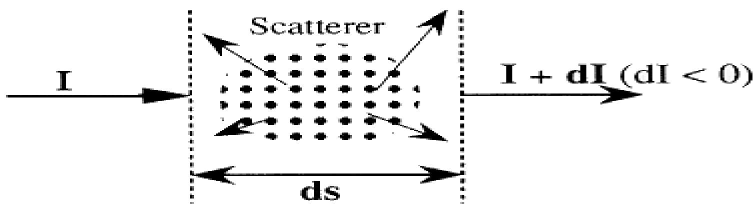


Fig. : Scattering (extinction)

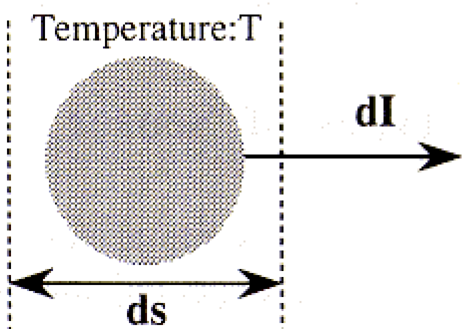


Fig. Thermal radiation (emission)

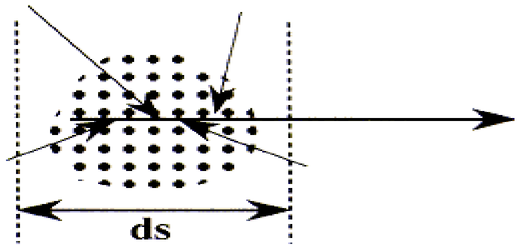


Fig. Scattering (emission)

Table 1.12.2 Radiative transfer equation

Definition of extinction coefficient K

$$dI = \rho \cdot K \cdot I \cdot ds$$

I : Incident radiance
dI : Increment of radiance
ρ : Absorber / Scatterer density
ds : Path length

Definition of emission coefficient j

$$dI = \rho \cdot j \cdot ds$$

(1) Thermal radiation

$$j = \rho \cdot B(T)$$

ρ : Absorber density
B : Planck function
T : Temperature [K]

(2) Scattering

$$j = \omega_0 \frac{K}{4\pi} \rho \int_{\Omega} P(\Omega, \Omega)\, I\, (\Omega')\, d\Omega$$

ω_0 : Albedo for single scattering
ρ : Scatterer density
P : Phase function
Ω : Solid angle of incidence
Ω' : Solid angle of scattering
K : Extinction coefficient

Remote Sensors

Remote Sensing Platforms

Environmental remote sensing devices can be mounted on a variety of platforms. Hand-held cameras can be used to acquire (usually) oblique photo images and hand-held radiometers can be used to measure the reflectance characteristics of a surface. If a wider field of view is required, the camera, radiometer or scanner can be mounted on a tower or cherry picker (trucks used by hydro department to repair electrical lines or replace burnt out street lamps). These platforms are commonly used to collect radiometer data representing the reflectance of different surfaces or land cover types. For mapping and analysis of spatial patterns, however, we usually rely on remote sensing devices mounted on low or high altitude aircraft or on satellites. In general, the higher the altitude of the platform, the smaller the scale of the resulting remote sensing imagery, although scale is also dependent on the configuration of the remote sensing device.

Cameras

Photographic Camera/Film Systems

The term "photographic" refers to systems that use films coated with photosensitive silver halide emulsions to record an image. Silver halide crystals are structurally changed when exposed to light, producing a latent image on the film. When the exposed film is placed in a developer solution, the silver halide crystals turn to black metallic silver. The speed of this transformation depends upon the intensity of light striking the silver halide crystals at the instant of exposure: crystals exposed to intense light turn black very quickly while crystals exposed to less intense light turn black more slowly. The development process can be arrested by rinsing the film to remove all traces of the developer solution. The result is a continuous tone negative (bright spots appear black and vice versa) image.

Photographic camera/film systems have been used since the first decades of the 20th century to collect spatial data. Aerial photographs are the primary data input for production of topographic maps, although various types of "ground truth" information are needed to verify interpretation of the air photo imagery and to ensure accurate transformation of the image data into map or GIS database format. Photographic films are sensitive to reflected EMR in wavelengths ranging from the mid-ultraviolet to the near-IR. The camera's entire field of view is recorded instantaneously. The film detects and records the EMR reflected from surfaces within the field of view as a continuous tone image.

Digital Cameras

Digital cameras are a recent development. Like the traditional photographic camera, they use a lens to focus reflected EMR but use an array of EMR sensors rather than photographic film to record the image. Sensor arrays can have different spatial resolutions, ranging from 512 by 512 for a 35 mm equivalent image up to 2048 by 2048 for applications requiring finer spatial detail. The sensors detect reflected EMR for each wavelength for which they are calibrated. The resulting image is comprised of picture elements or pixels, each of which records a brightness value for the spatial field of view it detects. A 2048 by 2048 pixel image contains 4.2 million pixels!

Trimetregon Cameras

A trimetregon camera is actually an array of three cameras that take simultaneous overlapping images of the terrain. This type of camera is used to take air photos in areas of mountainous terrain. The central camera in the array takes a vertical air photo while the left and right cameras record oblique images of adjacent terrain. This type of camera is used to obtain images of steep valleys. By flying along the valleys and collecting overlapping images of the floor and sides of the valleys, trimetregon cameras can overcome the problems that are associated with normal parallel traverse air photo coverage in areas with high local relief.

Optical-Electrical Scanners

Electro-optical scanners used in both airborne and satellite remote sensing are somewhat similar to digital cameras in that they use an array of electronic sensors, in combination with mirror/lens optical devices to scan a scene and record an image. Each sensor in the array produces an electrical signal for each wavelength detected. The electrical signals can be recorded on magnetic tape. In the case of satellite sensors, the continuous electrical signals are usually converted into digital numbers representing up to 256 gray levels before being transmitted to Earth-based receiving stations. Optical-electrical scanners offer the potential of real time data acquisition since there is no delay while film is being developed and prints produced for distribution.

Active vs Passive Remote Sensors

Remote sensing devices can be classified according to whether they are active or passive devices. Passive remote sensing devices detect reflected EMR while active remove sensing devices emit a signal and detect the intensity of the signal reflected back off an object. A photographic camera used with available light and Landsat MSS, Landsat Thematic Mapper, or SPOT satellite imagery are examples of passive remote sensing systems. A photographic camera used with a flash attachment, radar and sonar are examples of active remote sensing systems.

2.0 Concepts of Aerial Photography

What is an aerial photograph?

An aerial photograph, in broad terms, is any photograph taken from the air. Normally, air photos are taken vertically from an aircraft using a highly accurate camera. There are several things you can look for to determine what makes one photograph different from another of the same area, including type of film, scale, and overlap. Other important concepts used in aerial photography are stereoscopic coverage, fiducial marks, focal length, roll and frame numbers, and flight lines and index maps. The following material will help you understand the fundamentals of aerial photography by explaining these basic technical concepts.

What information can I find on an air photo?

Unlike a map, features on an aerial photograph are not generalized or symbolized. Air photos record all visible features on the Earth's surface from an overhead perspective. Although the features are visible, they are not always easily identifiable. The process of studying and gathering the information required for the identification of the various cultural and natural features is called photo interpretation. With careful interpretation, air photos are an excellent source of spatial data for studying the Earth's environment.

Basic Concepts of Aerial Photography

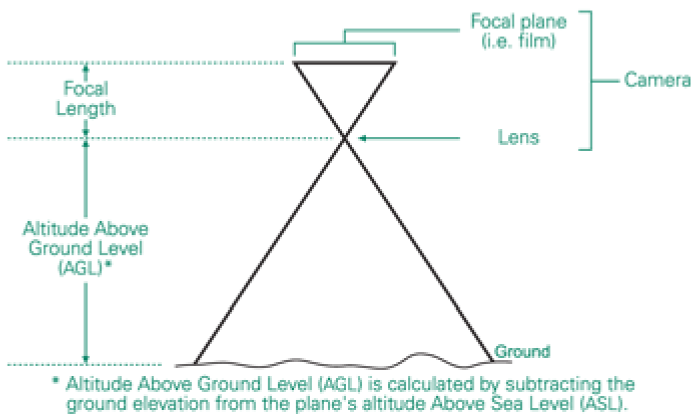
Film: most air photo missions are flown using black and white film, however colour, infrared, and false-colour infrared film are sometimes used for special projects.

Focal length: the distance from the middle of the camera lens to the focal plane (i.e. the film). As focal length increases, image distortion decreases. The focal length is precisely measured when the camera is calibrated.

Scale: the ratio of the distance between two points on a photo to the actual distance between the same two points on the ground (i.e. 1 unit on the photo equals "x" units on the ground). If a 1 km stretch of highway covers 4 cm on an air photo, the scale is calculated as follows:

$$\frac{\text{PHOTO DISTANCE}}{\text{GROUND DISTANCE}} = \frac{4\text{ cm}}{1\text{ km}} = \frac{4\text{ cm}}{100\,000\text{ cm}} = \frac{1}{25\,000} \qquad \textbf{SCALE: 1/25 000}$$

Another method used to determine the scale of a photo is to find the ratio between the camera's focal length and the plane's altitude above the ground being photographed.



If a camera's focal length is 152 mm, and the plane's altitude Above Ground Level (AGL) is 7 600 m, using the same equation as above, the scale would be:

$$\frac{\text{FOCAL LENGTH}}{\text{ALTITUDE (AGL)}} = \frac{152\ \text{mm}}{7\ 600\ \text{m}} = \frac{152\ \text{mm}}{7\ 600\ 000\ \text{mm}} = \frac{1}{50\ 000} \quad \textbf{SCALE: 1/50 000}$$

Scale may be expressed three ways:

- Unit Equivalent
- Representative Fraction
- Ratio

A photographic scale of 1 millimetre on the photograph represents 25 metres on the ground would be expressed as follows:

- Unit Equivalent - 1 mm = 25 m
- Representative Fraction - 1/25 000
- Ratio - 1:25 000

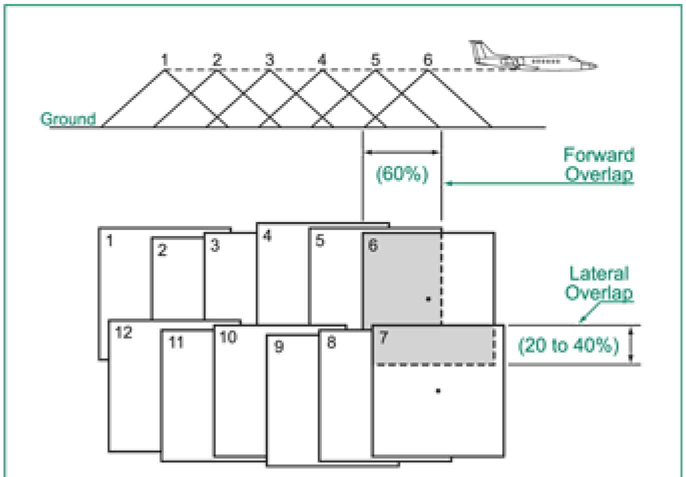
Two terms that are normally mentioned when discussing scale are:

- **Large Scale** - Larger-scale photos (e.g. 1/25 000) cover small areas in greater detail. A large scale photo simply means that ground features are at a larger, more detailed size. The area of ground coverage that is seen on the photo is less than at smaller scales.
- **Small Scale** - Smaller-scale photos (e.g. 1/50 000) cover large areas in less detail. A small scale photo simply means that ground features are at a smaller, less detailed size. The area of ground coverage that is seen on the photo is greater than at larger scales.

The National Air Photo Library has a variety of photographic scales available, such as 1/3 000 (large scale) of selected areas, and 1/50 000 (small scale).

Fiducial marks: small registration marks exposed on the edges of a photograph. The distances between fiducial marks are precisely measured when a camera is calibrated, and cartographers when compiling a topographic map use this information.

Overlap: is the amount by which one photograph includes the area covered by another photograph, and is expressed as a percentage. The photo survey is designed to acquire 60 per cent forward overlap (between photos along the same flight line) and 30 per cent lateral overlap (between photos on adjacent flight lines).



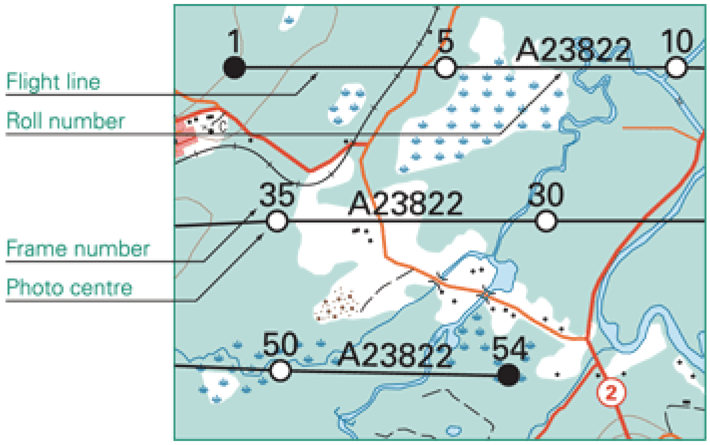
Photographic Overlap

Stereoscopic Coverage: the three-dimensional view, which results when two, overlapping photos (called a stereo pair), are viewed using a stereoscope. Each photograph of the stereo pair provides a slightly different view of the same area, which the brain combines and interprets as a 3-D view.

Roll and Photo Numbers: each aerial photo is assigned a unique index number according to the photo's roll and frame. For example, photo A23822-35 is the 35th annotated photo on rolls A23822. This identifying number allows you to find the photo in NAPL's archive, along with metadata information such as the date it was taken, the plane's altitude (above sea level), the focal length of the camera, and the weather conditions.

Flight Lines and Index Maps: at the end of a photo mission, the aerial survey contractor plots the location of the first, last, and every fifth photo centre, along with its roll and frame number, on a National Topographic System (NTS) map. Small circles represent photo centres, and straight lines are drawn connecting the circles to show photos on the same flight line.

This graphical representation is called an air photo index map, and it allows you to relate the photos to their geographical location. Small-scale photographs are indexed on 1/250 000 scale NTS map sheets, and larger-scale photographs are indexed on 1/50 000 scale NTS maps.



Mosaic: A **mosaic** is a photographic reproduction of a series of aerial photographs put together in such a way that the detail of one photograph matches the detail of all adjacent photographs. Mosaics are, for the most part, reproduced at a much smaller scale than the original photography, and consist of three main types: **uncontrolled mosaics**, **semi-controlled mosaics** and **controlled mosaics**.

Uncontrolled Mosaics

- Prints are laid out so as to join together in a "best fit" scenario.
- Prints may be tone-matched.

Semi-Controlled Mosaics

- The prints used in the mosaic are tone-matched but not rectified.
- Prints are laid down to fit a map base of the same scale.
- A title and scale may be added.

Controlled Mosaics

- Clients must supply a map base as well as a minimum of three (3) ground control points per print.
- Prints are tone-matched and rectified to fit the map base.

3.0 Elements, Aids, Techniques, Methods & Procedures of Airphoto Interpretation

I. Definitions

Photo Interpretation: The act of examining aerial photographs/images for the purpose of identifying objects and judging their significance.

Photography: The art or process of producing images on a sensitized surface by the action of light or other radiant energy.

Image: A reproduction or imitation of the form of a person or thing. The optical counterpart of an object produced by a lens or mirror or other optical system.

Photogrammetry: The science or art of obtaining reliable measurements by means of photography.

Before an interpreter commences the reading of the photo, the concept of stereoscopy must be understood.

Stereoscopy

A pair of stereoscopic photographs or images can be viewed stereoscopically by looking at the left image with the left eye and the right image with the right eye. This is called **stereoscopy**. Stereoscopy is based on Porro-Koppe's Principle that the same light path will be generated through an optical system if a light source is projected onto the image taken by an optical system. The principle will be realized in a **stereo model** if a pair of stereoscopic images is reconstructed using the relative location or tilt at the time the photography was taken. Such an adjustment is called relative orientation in photogrammetric terms. The eye-base and the photo-base must be parallel in order to view at a stereoscopic model, as shown in the Fig. 3.1.

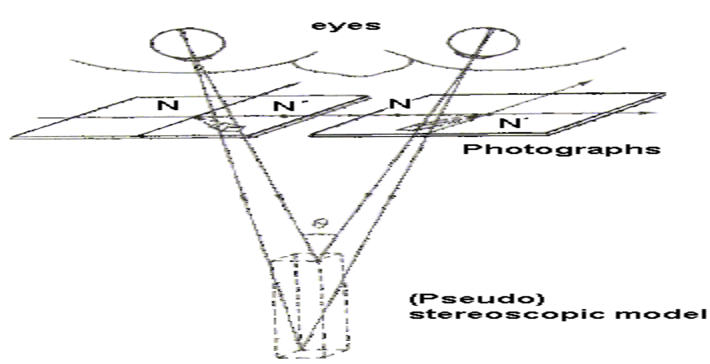


Fig. 3.1 Schematic diagram of stereoscopic vision

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Usually a stereoscope is used for image interpretation. There are several types of stereoscope, for example, portable lens stereoscope, stereo mirror scope (see Fig. 3.1) stereo zoom transfer scope etc.

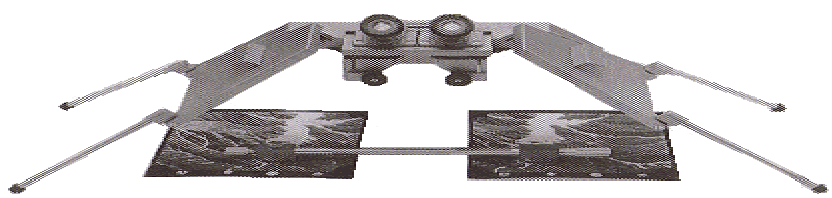
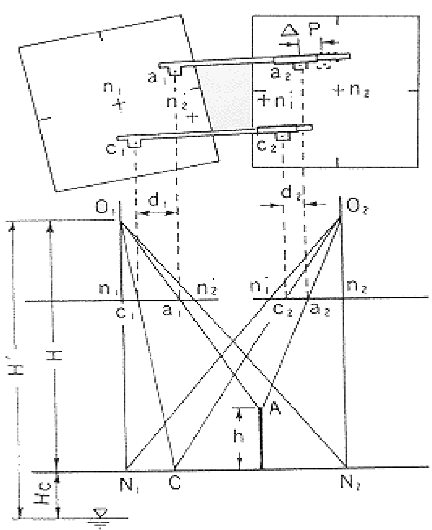


Fig. 3.2 Stereoscopic viewer

The process of stereoscopy for aerial photographs is as follows. At first the center of both aerial photographs, called the **principal point**, should be marked. Secondly the principal point of the right image should be plotted in its position on the left image. At the same time the principal point of the left image should be also plotted on the right image. These principal points and transferred points should be aligned along a straight line, called the base line, with an appropriate separation (normally 25-30 cm in the case of a stereo mirror scope as shown in Fig. 3.3. By viewing through the binoculars a stereoscopic model can now be seen.



Hc : flight height

c : control point

Hc : height of control point

H : H' - Hc

$\overline{n_1 \cdot n_2}$: principal points on a pair of stereo photos

$\overline{n_1 \cdot n_2}$: transferred points from each principal point of the photos

$\overline{n_1 \cdot n_2}$: principal distance

$\overline{c_1 \cdot c_2}$: distance between at point c on a pair of stereo photos

$\overline{a_1 \cdot a_2}$: distance between at point a on a pair of stereo photos

parallax at point c : $P = \overline{n_1 \cdot n_2} - \overline{c_1 \cdot c_2}$

parallax distance between point a & c : $\Delta P = \overline{c_1 \cdot c_2} - \overline{a_1 \cdot a_2}$

obtained height : $h = H \cdot \Delta P / (P + \Delta P)$

Fig. 3.3 Principle of height measurement

The advantage of stereoscopy is the ability to extract three dimensional information, for example, classification between tall trees and low trees, terrestrial features such as height of terraces, slope gradient, detailed geomorphology in flood plains, dip of geological layers and so on.

The principle of height measurement by stereoscopic vision is based on the use of **parallax**, which corresponds to the distance between image points, of the same object on the ground, on the left and right image. The height difference can be computed if the **parallax difference** is measured between two points of different height, using a parallax bar, as shown in Fig. 3.3 above.

II. Activities of Airphoto/Image Interpretation

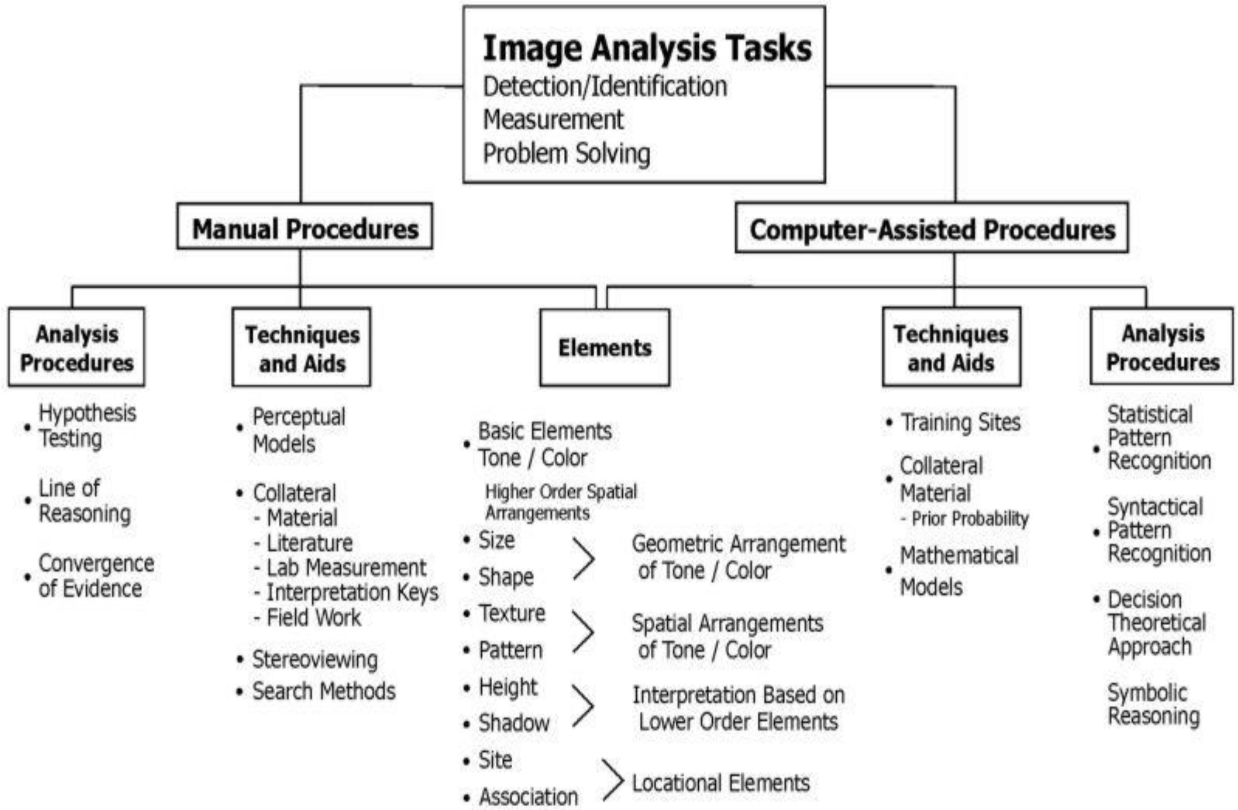
Detection/Identification - This is primarily a stimulus and response activity. The stimuli are the elements of image interpretation. The interpreter conveys his or her response to these stimuli with descriptions and labels that are expressed in qualitative terms e.g. likely, possible, or probable. Very rarely do interpreter use definite statements with regard to describing features identified on aerial photography.

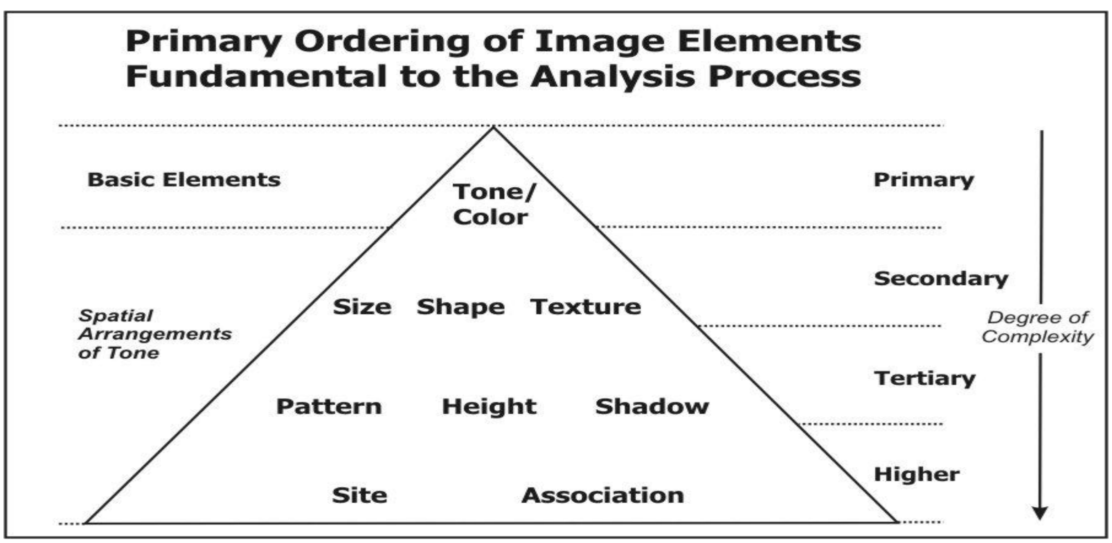
Measurement - As opposed to detection and identification, the making of measurements is primarily quantitative. Techniques used by air photo interpreters typically are not as precise as those employed by photogrammetrists who use sophisticated instruments in making their measurements. Measurements made by photo interpreters will get you close; given high quality, high resolution, large-scale aerial photographs and appropriate interpretation tools and equipment, you can expect to be within feet; whereas with photogrammetry if you employ the same type of photography and the appropriate equipment you could expect to be within inches.

Problem Solving - Interpreters are often required to identify objects from a study of associated objects that they can identify; or to identify object complexes from an analysis of their component objects. Analysts may also be asked to examine an image, which depicts the effects of some process, and suggest a possible or probable cause. A solution may not always consist of a positive identification. The answer may be expressed as a number of likely scenarios with statements of probability of correctness attached by the interpreter.

Air photo interpretation is to photogrammetry as statistics is to mathematics; one deals with precision the other with probability.

III. Elements of Airphoto/Image Interpretation





A. Basic - 1st Order

1. Tone/Color **:** Tone can be defined as each distinguishable variation from white to black. Color may be defined as each distinguishable variation on an image produced by a multitude of combinations of hue, value and chroma. Many factors influence the tone or color of objects or features recorded on photographic emulsions. But, if there is not sufficient contrast between an object and it's background to permit, at least, detection there can be no identification. While a human interpreter may only be able to distinguish between ten and twenty shades of gray; interpreters can distinguish many more colors. Some authors state that interpreters can distinguish at least 100 times more variations of color on color photography than shades of gray on black and white photography

2. ***Resolution:*** Resolution can be defined as the ability of the entire photographic system, including lens, exposure, and processing, and other factors, to render a sharply defined image. An object or feature must be resolved in order to be detected and/or identified. Resolution is one of the most difficult concepts to address in image analysis because it can be described for systems in terms of modulation transfer (or point spread) functions, or it can be discussed for camera lenses in terms of being able to resolve so many line pairs per millimeter. There are resolution targets that help to determine this when testing camera lenses for metric quality. Photo interpreters often talk about resolution in terms of ground resolved distance, which is the smallest normal contrast object that can be identified and measured.

B. 2nd Order - Geometric Arrangements of Tone/Color

1. ***Size:*** Size can be important in discriminating objects and features (cars vs. trucks or buses, single family vs. multifamily residences, brush vs. trees, etc.). In the use of size as a diagnostic characteristic both the relative and absolute sizes of objects can be important. Size can also be used in judging the significance of objects and features. The size of the crowns of trees can be related to board feet that may be cut for specific species in managed forests. The size of agricultural fields can be related to water use in arid areas, or the amount of fertilizers used. The size of runways gives an indication of the types of aircraft that can be accommodated.

2. ***Shape:*** The shape of objects/features can provide diagnostic clues that aid identification. The Pentagon building in Washington is a diagnostic shape. For example, man-made features have straight edges while natural features tend not to. Roads can have right angle (90°) turns, railroads can't. Other examples include freeway interchanges, old fortifications (European cities), and military installations (surface to air missile sites).

C. 2nd. Order - Spatial Arrangement of Tone/Color

1. ***Texture:*** Texture is the frequency of change and arrangement of tones. This is a micro image characteristic. The visual impression of smoothness or roughness of an area can often be a valuable clue in image interpretation. Still water bodies are typically fine textured, grass medium, brush rough. There are always exceptions though and scale can and does play a role; grass could be smooth, brush medium and forest rough on higher altitude aerial photograph of the same area.

2. ***Pattern:*** Pattern is the spatial arrangement of objects. Patterns can be either man-made or natural. Pattern is a macro image characteristic. It is the regular arrangement of objects that can be diagnostic of features on the landscape. An orchard has a particular pattern. Pattern can also be important in geologic or geomorphologic analysis; drainage pattern

can reveal a great deal about the lithology and geologic structural patterns of the underlying strata. Dendridic drainage patterns develop on flat-bedded sediments, radial on domes, linear or trellis in areas with faults etc. It must be noted here that pattern is highly scale dependent.

D. 3rd. Order - Locational or Positional Elements

1. ***Site:*** Site refers to how objects are arranged with respect to one another, or with respect to terrain features. Aspect, topography, geology, soil, vegetation and cultural features on the landscape are distinctive factors that the interpreter should be aware of when examining a site. The relative importance of each of these factors will vary with local conditions, but all are important. Just as some vegetation grows in swamps others grow on sandy ridges or on the sunny side vs. the shaded sides of hills. Crop types may prefer certain conditions (e.g. orchards on hillsides). Man made features may also be found on rivers (e.g. power plant) or on hilltops (e.g. observatory or radar facility).

2. ***Association:*** Some objects are so commonly associated with one another that identification of one tends to indicate or confirm the existence of another. Smoke stacks, cooling ponds, transformer yards, coal piles, railroad tracks = coal fired power plant. Arid terrain, basin bottom location, highly reflective surface, sparse vegetation = playa, which typically have halophytic vegetation e.g. saltbush. Association is one of the most helpful interpretation clues in identifying man made installations. Aluminum manufacture requires large amounts of electrical energy. Schools of different grade levels typically have characteristic playing fields, parking lots and clusters of buildings. Nuclear power plants are associated with a source of cooling water; weather patterns can be associated with pollution sources etc.

E. 3rd. Order - Interpreted from lower order elements

1. ***Height:*** For some types of analysis e.g. land forms, forestry and some intelligence applications, some interpreters believe that after tone/color height is the most important element for identification. This is a point of debate, but height can add significant information in many types of interpretation tasks, particularly those that deal with the analysis of man-made features and vegetation. How tall a tree is can tell something about the expected amount of board feet. How deep an excavation is can tell something about the amount of material that was removed (in some mining operations excavators are paid on the basis of material removed as determined by photogrammetric measurement of volume).

2. ***Shadow:*** Geologists like low sun angle photography because of the features that shadow patterns can help identify (e.g. fault lines and fracture patterns). Church steeples and smokestacks can cast shadows that can facilitate their identification. Tree identification can be aided by an examination of the shadows thrown. Shadows can also inhibit interpretation. On infrared aerial photography shadows are typically very black and can render targets in shadows uninterpretable.

IV. Techniques of Photographic/Image Interpretation

Collateral Material

A review of all existing source material that pertains to a given area, process, type of facility or object, can aid in the interpretation process. The use of collateral material may also result in a better definition of the scope, objectives and problems associated with a given project. Also called "ancillary data", collateral material may come in the form of text, tables, maps, graphs, or image metadata. Census data, a map or description of the flora of a given area, a land use map, meteorological statistics, or agricultural crop reports can all be used in support of a given interpretation. Basically, collateral material represents data/information that an interpreter may use to aid in the interpretation process. Material contained within a Geographic Information System (GIS) that is used to assist an interpreter in an analysis task can be considered collateral data. Two classes of collateral materials deserve special mention: interpretation keys and field verification.

Interpretation Keys

An interpretation key is a set of guidelines used to assist interpreters in rapidly identifying features. Determination of the type of key and the method of presentation to be employed will depend upon,

a) The number of objects or conditions to be identified; and,

b) The variability typically encountered within each class of features or objects within the key.

Some authors say that as a general rule, keys are more easily constructed and used for the identification of man-made objects and features than for natural vegetation and landforms. For analysis of natural features, training and field experience are often essential to achieve consistent results. Basically, an interpretation key helps the interpreter organize the information present in image form and guides him/her to the correct identification of unknown objects. Keys can be used in conjunction with any type of remotely sensed data. Such keys can differ from those employed in other disciplines in that they can consist largely of illustrations, e.g. landforms, industrial facilities, military installations. Many types of keys are already available, if you can find or get your hands on them. This can often be very difficult and a reason why people develop their own keys.

Depending upon the manner in which the diagnostic features are organized, two types of keys are generally recognized.

1) Selective keys, and

2) Elimination keys.

Selective keys are arranged in such a way that an interpreter simply selects that example that most closely corresponds to the object they are trying to identify, e.g. industries, landforms etc. Elimination Keys are arranged so that the interpreter follows a precise step-wise process that leads to the elimination of all items except the one(s) that he is trying to identify. Dichotomous keys are essentially a class of elimination key. Most interpreters prefer to use elimination keys in their analyses.

Field Verification

Field verification can be considered a form of collateral material because it is typically conducted to assist in the analysis process. Essentially, this is the process of familiarizing the interpreter with the area or type of feature. This type of verification is done prior to the interpretation to develop a visual "signature" of how the feature(s) of interest appear on the ground. After an interpretation is made field verification can be conducted to verify accuracy. Fieldwork is sometimes calculated as being three times as expensive as lab analysis. (This is why good interpreters can be so valuable). The nature, amount, timing, method of acquisition, and data integration procedures should be carefully thought out. Will you use windshield surveys, point or transect sampling? Will the sampling be random or systematic?

The amount and type of field work required for a given project may vary greatly and is generally dependent upon the,

a. Type of analysis involved.
b. Image quality, including scale resolution and information to be interpreted.
c. Accuracy requirements for both classification, and boundary delineation.
d. Experience of the interpreter and the knowledge of the sensor, area, and subject.
e. Terrain conditions, and the accessibility of the study area.
f. Personnel availability, access to ancillary material.
g. Cost considerations.

Handling of Imagery

Although a good deal of photo interpretation is still done using paper prints, the use of diapositive transparencies is increasing. Transparencies can be used either as single frames or as a roll. Care should be taken when handling transparencies so that they are not marred. An orderly procedure for the handling of either prints or transparencies should be developed and adhered to in any interpretation project. Airphotos are typically numbered with flight name and/or frame number, and should be kept in order in so far as practical. Different dates and flight lines should be kept separate, etc. Anytime transparencies are used surfaces should be as clean as possible and the interpreter should either wear cotton gloves or be sure not to touch the emulsion surface as skin oils can cause image deterioration.

Stereo Viewing

Binocular vision is natural to all of us, but to the trained interpreter the ability to perceive stereo is an incredibly valuable asset. Stereoviewing will be covered in detail later, but suffice it to say that viewing high quality stereo aerial photography though a mirror stereoscope is like seeing in another dimension. Although the identification and interpretation of many landscapes can be accomplished with mono, stereo is required for certain types of studies. The following are some tips for using stereo effectively.

Basics for Stereoviewing

1. Make certain that the photos are properly aligned, preferably with the shadows falling toward the viewer.

2. Keep the eye base and the long axis of the stereoscope parallel to the flight line.

3. Maintain an even glare free illumination on the prints or transparencies.

4. Arrange for comfortable sitting and sufficient illumination.

5. Keep the lenses of the stereoscope clean, properly focused and separated to your interpupillary distance.

6. The novice interpreter should not work with stereo more than 30 minutes out of any hour period. You have not had a headache until you've had one that comes from doing stereo interpretation for too long!

Trouble Shooting Stereo

1. Your eyes may be of unequal strength. If you normally wear glasses for reading or close-up work, you should also wear glasses when using the stereoscope.

2. Poorly illumination, misaligned prints or uncomfortable viewing positions may result in eye fatigue.

3. Illness or severe emotional distress may create sensations of dizziness in one using a stereoscope.

4. Reversal of prints may cause psuedo-stereo. A similar problem may occur if prints are aligned with the shadows falling away from rather than towards the interpreter.

5. Objects that change positions between exposures cannot be viewed in stereo.

6. In areas of steep topography, scale differences in adjacent photographs may make it difficult to obtain a three dimensional image.

7. Dark shadows or clouds may prohibit stereo viewing of an area by obscuring an object on one photo.

D. Further Definitions: The Multi Concept

Multi-Station: The successive overlapping of images taken along a given flight line as being flown by an aircraft or by a satellite along an orbit path. Think of it like "multi-position". Not to be confused with multi-stage.

Multi-Band: Multi-band indicates individual spectral bands within a given region of the EM spectrum (e.g. the red green and blue bands of the visible portion of the EM spectrum). Often seen to have an overlapping meaning with the next term, multi-spectral.

Multi-Spectral: The use of images from various regions of the EM spectrum (e.g. ultra-violet, visible, infrared, thermal and microwave)

Multi-Date: The use of multiple aerial photographs or remotely sensed images taken over time of a given area.

Multi-Stage: This typically means using ground based photos, oblique low altitude photos and vertical photographs or remotely sensed images from platforms flying at different altitudes. Multi-stage has also been applied to sampling strategies; A multi-stage sampling scheme as used in statistics is one where progressively more information is obtained for progressively smaller sub-samples of the area being studied.

Multi-Direction: There are times when more information can be obtained using viewing angles other than vertical

Multi-Disciplinary: Basically, no one interpreter can know everything about a system in question. By using teams of interpreters and experts with expertise in different disciplines more information may be gained for a given application. In the legal system this is most similar to the "convergence of evidence" idea; having different viewpoints and different information sources to prove a point adds validity.

Multi-Thematic: Remote sensing images are one-time write, many times read. Many different themes (e.g. hydrology, vegetation, transportation, urban areas, etc.) can be extracted from a single set of images.

Multi-Use: Many potential users from environmental planners to resource managers to public policy decision-makers can use outputs derived from image analysis and interpretation.

E. Methods of Search

There are basically two techniques that people tend to follow when searching for imagery. One is logical search and the other can be termed the "fishing expedition". In the latter, the fishing expedition, the interpreter searches the imagery in a random fashion attempting to find recognizable features or object that will lead to whatever the interpretation goal happens to be. At some point even this type of interpretation begins to logically converge. Patterns of anomalous vegetation may lead to looking for water sources, which may lead to looking for transportation systems, illegal growing etc. Logical search is a more systematic method of analysis most often used by interpreters.

The logical search involve these things:

1. The interpreter should always keep in mind the basic qualities of the imagery they are dealing with, e.g. film filter combination, the season and time of day of acquisition, and the image scale, etc. In addition the interpreter should always remember to examine all the titling information on an image.

2. Interpretation should begin with the general and proceed to the specific. After gaining an overall impression of the photograph the interpreter should begin to examine the physical features (e.g. water bodies, mountains, forests, etc.) and cultural features (e.g. urban areas, farms, road networks etc.). The interpreter should then move to more specific questions e.g. what type of trees makes up the forest? What types of roads are present?

3. Interpretation should be conducted logically one step at a time. Following from 2 above it is good to go from a detailed examination of landforms to vegetation, to hydrology and so on. Then address cultural features in the same fashion. What types of urban features are present single-family residences, multi-family residences, industries, retail districts and so on.

F. Convergence of Evidence

1. Image interpretation is basically a deductive process. Features that can be detected and identified lead the interpreter to the location and identification of other features. This is convergence, and for many applications of air photo interpretation this involves the activities of one or two individuals synthesizing a large amount of information.

2. Deductive interpretation requires either the conscious or unconscious consideration of all of the elements of image interpretation. The completeness and accuracy of an interpretation is in some measure proportional to the interpreters understanding of the "how and the why" of the elements, techniques and methods of interpretation.

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