Chapter 1: "Concept & Foundations"
Part 1 out of 6

What is Remote Sensing?

Remote sensing is the science & art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation,

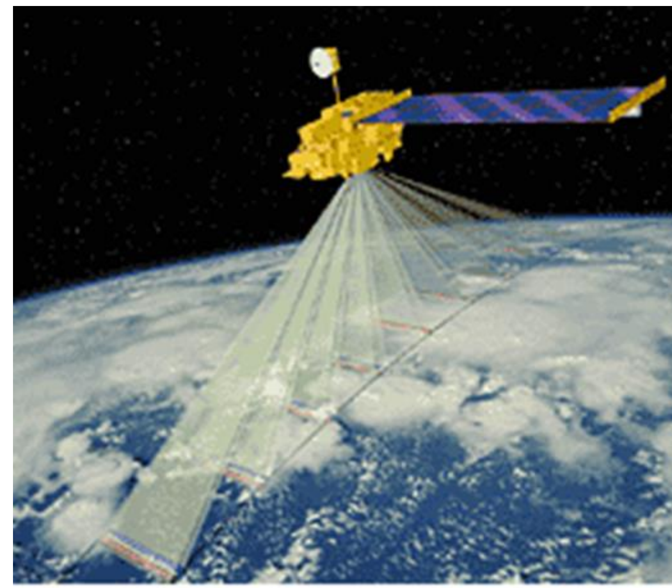
Lillesand et. al. 2007

Chapter 1: “Concept & Foundations”

What is Remote Sensing?

Remote sensing is the science & art of monitoring & studying the Earth through images,

Ahmad Alashaikh

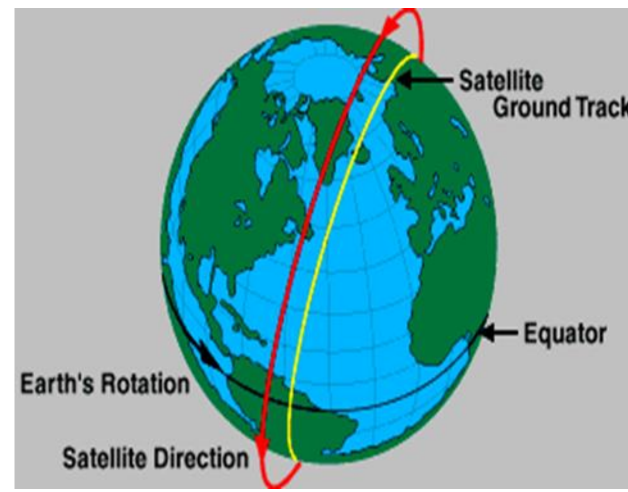


Chapter 1: "Concept & Foundations"

Why Images?

In addition of saving time, money, & effort, images could provide;

- *Improved vantage point.*
- *Capability to stop action.*
- *Permanent recording.*
- *Broadened spectral sensitivity.*
- *Increasing spatial resolution & geometric fidelity.*



Chapter 1: "Concept & Foundations"

What is Remote Sensing?

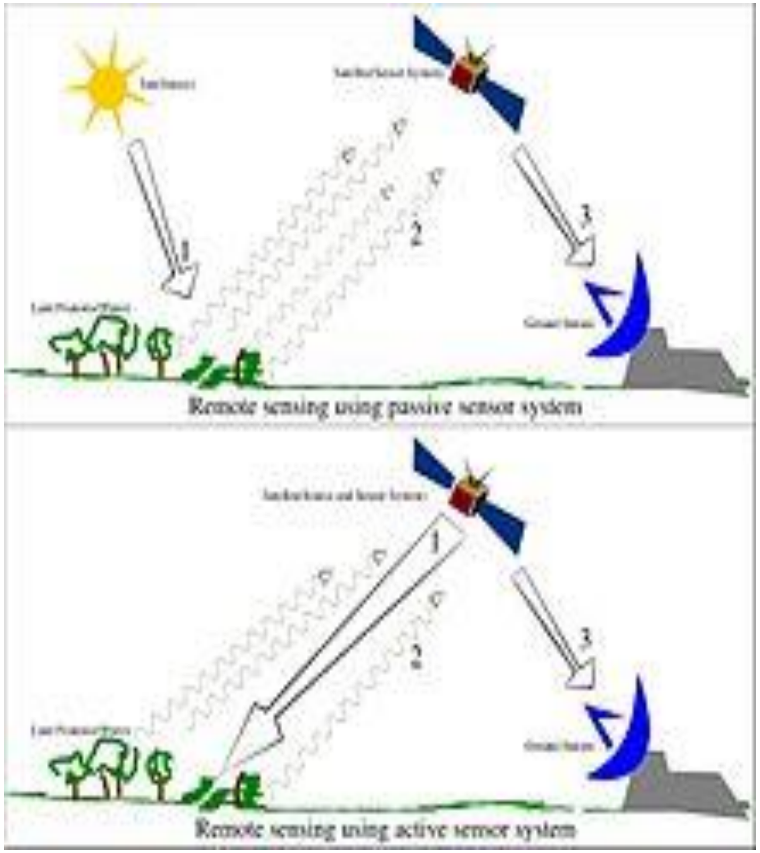
Remote sensing can be divided into 3 main parts:

1. Data acquisition,
2. Data analysis, &
3. Final products or output stage.

Chapter 1: “Concept & Foundations”

1. Data acquisition:

In data acquisition process, we use sensors to record variations in the way earth surface features reflect & emit electromagnetic energy.



Six elements in the data acquisition process;

1. *Energy source,*
2. *Propagation of energy through the atmosphere,*

Chapter 1: "Concept & Foundations"

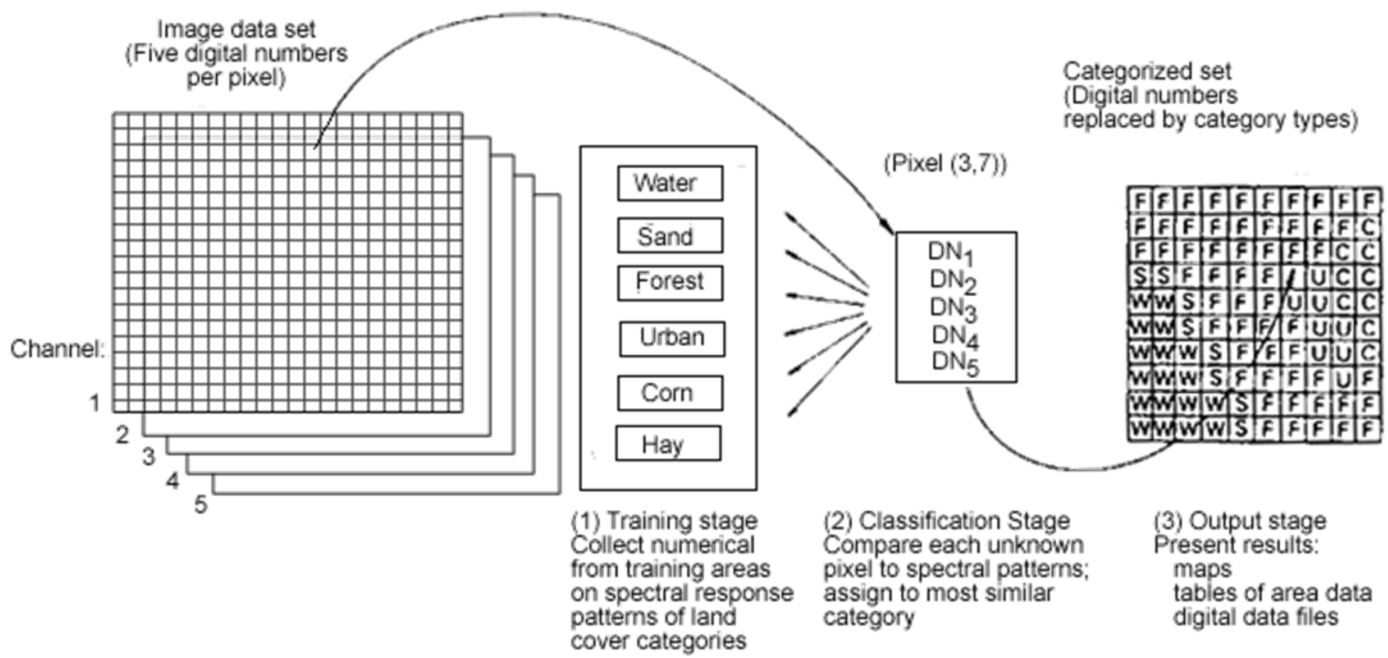
1. Data acquisition: (continue)

3. Energy interactions with earth surface features,
4. Retransmission of the energy through the atmosphere,
5. Airborne &/or spaceborne sensors, &
6. Generation of sensor data.

Chapter 1: "Concept & Foundations"

2.Data analysis:

The data analysis process involves examining the data using various viewing & interpretation devices to analyze pictorial data with the aid of computer.



Chapter 1: “Concept & Foundations”

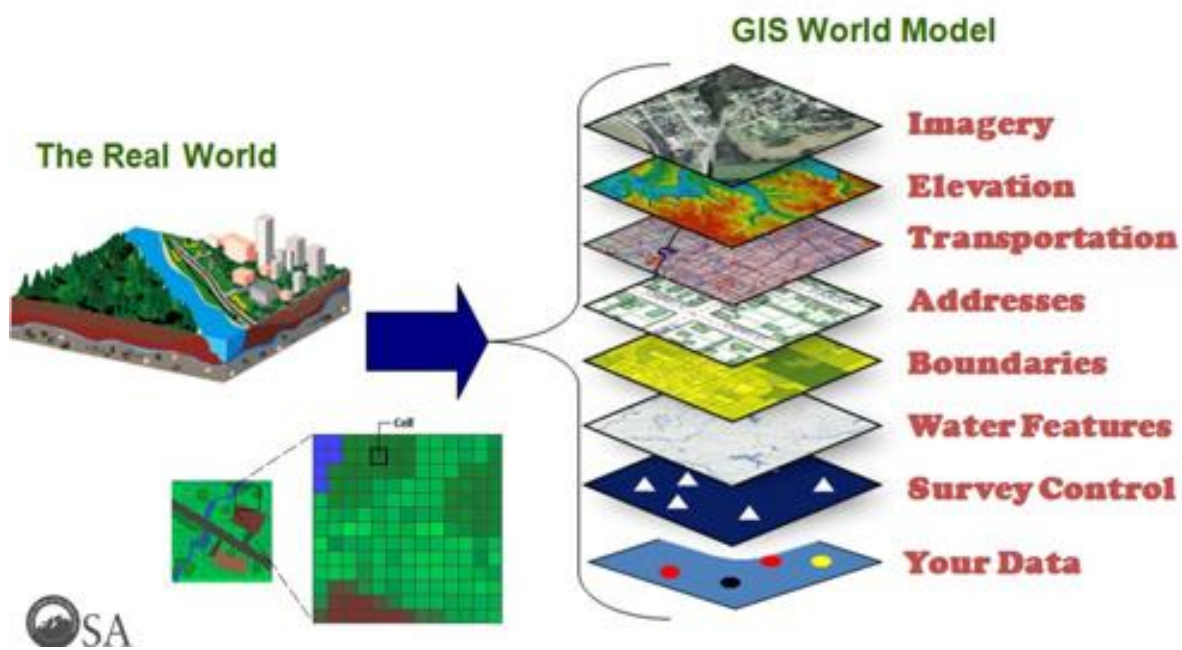
2. Data analysis: ***(continue)***

In order to do data analysis process correctly, we have to have some kind of information about the object, area, or phenomenon under investigation; we called this information as reference data or ground truth.

An analyst can use reference data to extract information about the type, extent, location & condition of the various resources over which the sensor data were collected.

3. Into the Output Stage:

In the output stage, the final extracted information is then compiled in the form of hard copy (maps & tables) &/or digital files & GIS.



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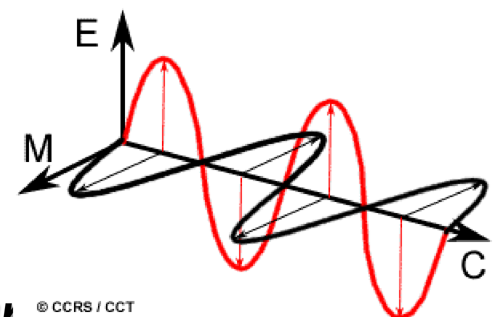
Energy source & Radiation Principles:

Data acquisition require an energy source to illuminate the earth's target. This energy is in the form of electromagnetic radiation.



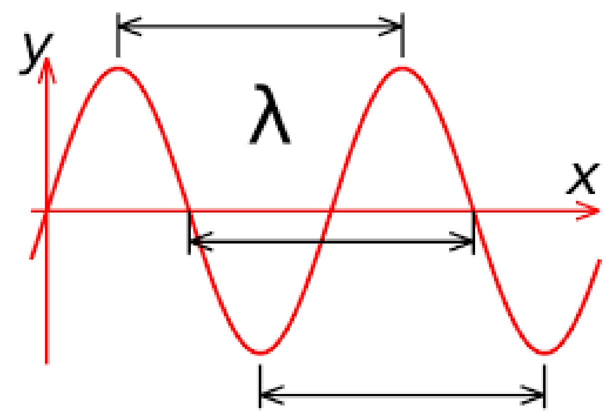
Electromagnetic radiation consists of an electrical field (E) which varies in magnitude in a direction perpendicular to the direction in which the radiation is traveling, & a magnetic field (M) oriented at right angles to the electrical field. Both these fields travel at the speed of light (c).

Chapter 1: "Concept & Foundations"

Energy source & Radiation Principles: (continue)

Wavelength & frequency are two important characteristics of electromagnetic radiation. The wavelength is the length of one wave cycle, which can be measured as the distance between successive wave crests. Wavelength is usually represented by the Greek letter lambda (λ).

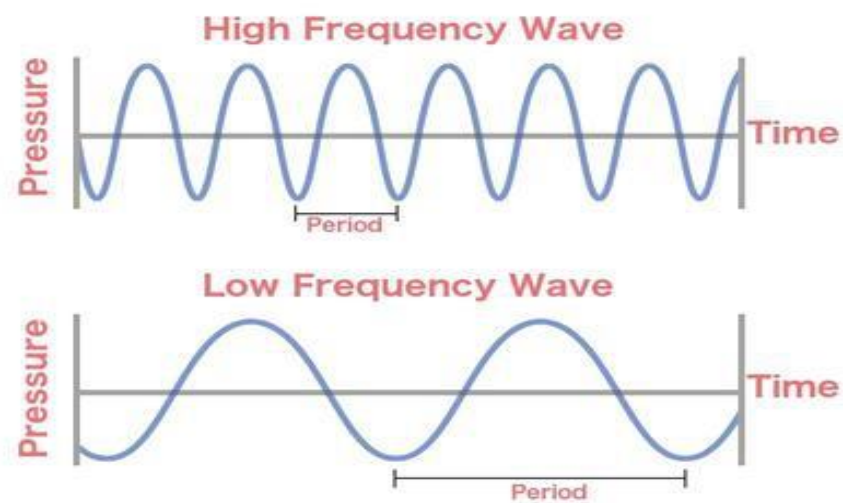
Wavelength is measured in meters (m) or some factor of meters such as nanometers (nm, 10^{-9} m), micrometers (µm, 10^{-6} m).



Chapter 1: "Concept & Foundations"

Energy source & Radiation Principles: ***(continue)***

Frequency, on the other hand, refers to the number of cycles of a wave passing a fixed point per unit of time. Frequency is normally measured in hertz (Hz), equivalent to one cycle per second, & various multiples of hertz, equivalent to one cycle per second, & various multiples of hertz.



Chapter 1: "Concept & Foundations"

Energy source & Radiation Principles: (continue)

Wavelength & frequency are related by the following formula:

$$C = \lambda * \upsilon$$

Where,

- C is the speed of light (3×10^8 m/s),
- λ is the wavelength (m), &
- υ is the frequency (Hz).

Chapter 1: "Concept & Foundations"

Energy source & Radiation Principles: ***(continue)***

Therefore, the two are inversely related to each other, the shorter the wavelength, the higher the frequency, & vies versa.

Understanding the characteristics of electromagnetic radiation in terms of their wavelength & frequency is crucial to understanding the information to be extracted from R.S. data.

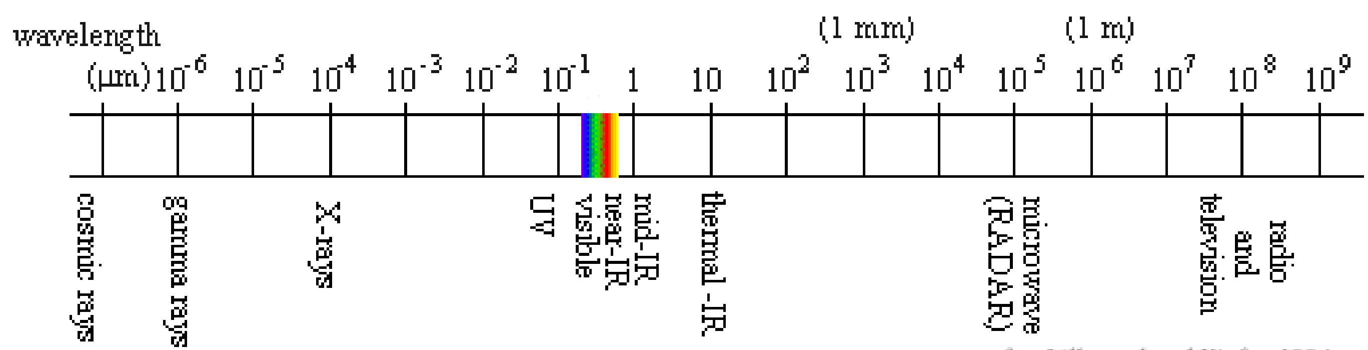
In R.S. it is most common to use λ measured in μm to refer to an electromagnetic radiation.

Chapter 1: "Concept & Foundations"

The Electromagnetic Spectrum:

The electromagnetic spectrum ranges from the shorter wavelengths (like gamma & x-rays) to the longer wavelengths (such as broadcast radio waves). There are several regions of the electromagnetic spectrum which are useful for R.S..

The Electromagnetic Spectrum



after Lillesand and Kiefer, 1994

Chapter 1: "Concept & Foundations"

The Electromagnetic Spectrum: (continue)

For most purposes, the ultraviolet or UV portion of the spectrum has the shortest wavelengths which are practical for R.S. This radiation is just beyond the blue portion of the visible wavelengths.

The visible portion of light consists only of an extremely small part relative to the rest of the spectrum. The visible wavelengths cover a range from approximately 0.4 to 0.7 µm. Blue (0.4 to 0.5 µm), green (0.5 to 0.6 µm), & red (0.6 to 0.7 µm) are the primary wavelengths of the visible spectrum.

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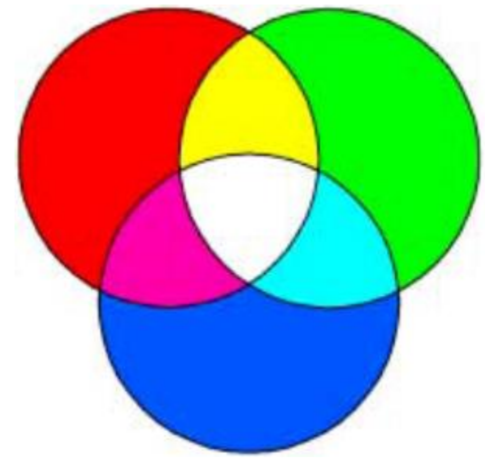
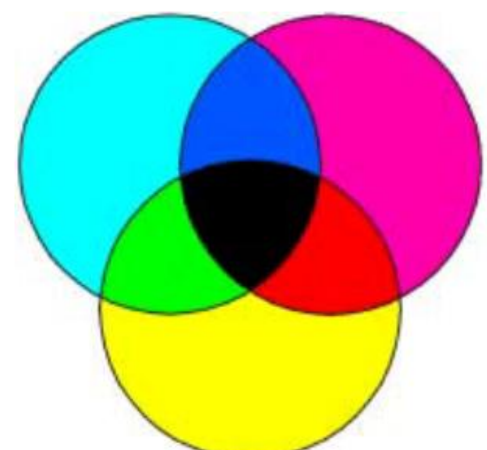
The Electromagnetic Spectrum: (continue)

Visible Light Components;

Visible Light is a small part of the electromagnetic spectrum that includes, its visible components; Blue, Green, & Red.





Chapter 1: "Concept & Foundations"

The Electromagnetic Spectrum: (continue)

The next portion of the spectrum of interest is the infrared (IR) region which covers the wavelength range from approximately 0.7 μm to 100 μm.

The IR region is divided into two categories; the reflected IR, ranging from 0.7 μm to 3.0 μm, & the emitted or thermal IR ranging from approximately 3.0 μm to 100 μm. The reflected IR region is used for R.S. purposes in ways similar to radiation in the visible portion.

The thermal IR region is quite different than the visible & reflected IR portions, as this energy is emitted from the Earth's surface in the form of heat.

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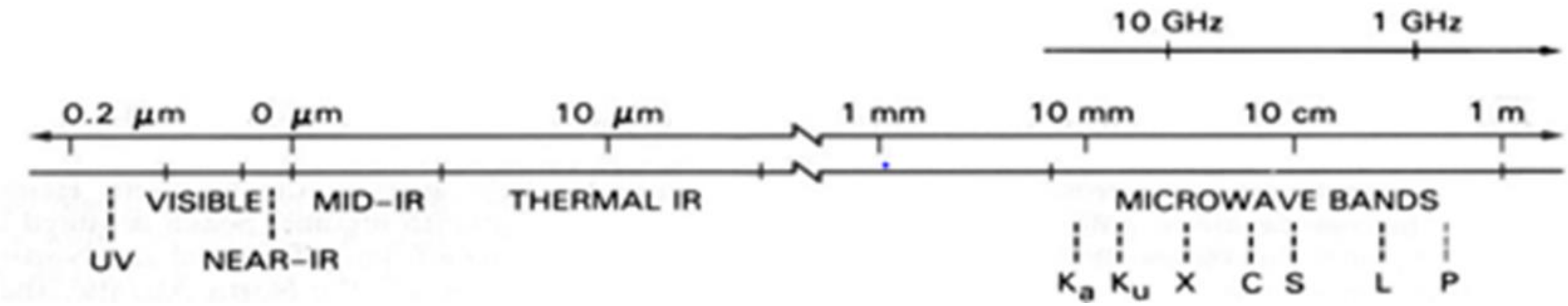
The Electromagnetic Spectrum: (continue)



The portion of the spectrum of more recent interest to R.S. is the microwave region from about 1 mm to 1 m. This covers the longest wavelengths used for R.S. The shorter wavelengths have properties similar to the thermal infrared region while the longer wavelengths approach the wavelengths used for radio broadcasts.

Chapter 1: "Concept & Foundations"

The Particle Theory:

This theory suggests that electromagnetic radiation is composed of many discrete units called photons or quanta. The energy of a quantum is given as:

$$Q = h * \upsilon$$

Where,

Q is the energy of a quantum in joules (J),

h is Planck's constant = 6.626×10^{-34} (J.s), &

υ is the frequency (Hz).

Chapter 1: "Concept & Foundations"

The Particle Theory: (continue)

We see from the equation above that the energy of a quantum is directly proportional to the frequency, thus, inversely proportional to the wavelength. This means that, in general, systems operating at longer wavelengths has less energy & must view larger areas of the earth at any given time in order to obtain a detectable energy signal.

Chapter 1: "Concept & Foundations"

The Particle Theory: (continue)

All maters at a temperature above absolute zero (0° K, or -273° C) continuously emit electromagnetic radiation. The energy any object radiates is a function of the surface temperature of the object. This can be found by Stefan-Boltzmann law as:

$$M = \sigma * T^4$$

Where,

M *is the total radiation existence from the surface of a material in watts per square meter (w m^{-2}),*

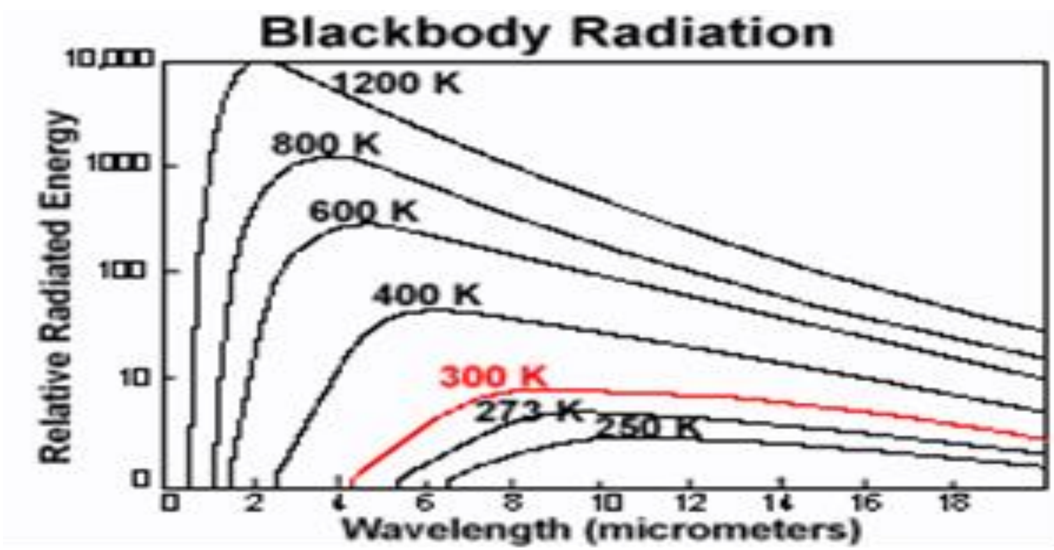
σ *is Stefan-Boltzmann constant = 5.6697 x 10^{-8} (w m^{-2} ° k^{-4}), &*

T *is the temperature of the emitting material (° k).*

Chapter 1: "Concept & Foundations"

The Particle Theory: **(continue)**

It should be noted that this law is expressed for an energy source that behaves as a blackbody. (A blackbody is a hypothetical, ideal radiator that totally absorbs & reemits all energy incidents upon it).



Chapter 1: "Concept & Foundations"

The Particle Theory: (continue)

The dominant wavelength at which a blackbody radiation curve reaches a maximum, is related to its temperature by Wien's displacement law:

$$\lambda_{max} = A / T$$

Where,

λ_{max} is the wavelength of the maximum spectral radiant existence (μm),

A is a constant = 2898 (μm ° k), &

T is the temperature of the emitting material (° k).

Chapter 1: "Concept & Foundations"

Passive vs. Active Sensing:

R.S. systems which measure energy that is naturally available are called passive sensors.

Passive sensors can only be used to detect energy when the naturally occurring energy is available. For all reflected energy, this can only take place during the time when the sun is illuminating the Earth.

Energy that is naturally emitted (such as thermal infrared) can be detected day or night, as long as the amount of energy is large enough to be recorded.

Chapter 1: "Concept & Foundations"

Passive vs. Active Sensing: (continue)

Active sensors provide their own energy source for illumination. They emit radiation that is directed toward targets to be investigated. The radiation reflected from these target is detected & measured by sensors onboard.

Advantages for active sensors include the ability to obtain measurements anytime.

Active sensors can be used for examining wavelengths that are not sufficiently provided by the sun, such as microwaves, or to better control the way a target is illuminated. However, they require the generation of a fairly large amount of energy to adequately illuminate targets.

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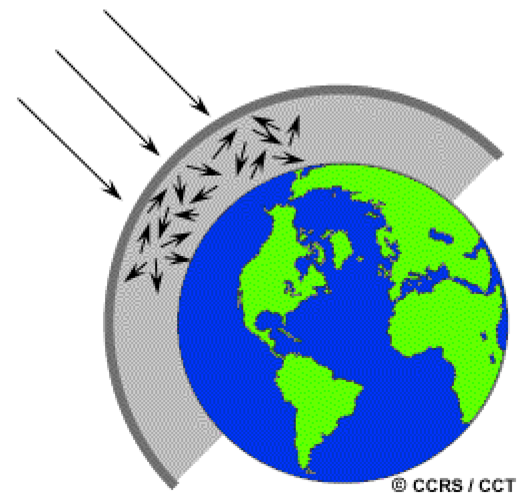
Radiation Interactions with the Atmosphere:

Before radiation used for R.S. reaches the Earth's surface it has to travel through some distance of the Earth's atmosphere. Particles & gases in the atmosphere can affect the incoming radiation. These effects are caused by the mechanisms of scattering & absorption.

Chapter 1: “Concept & Foundations”

Radiation Interactions with the Atmosphere: **(continue)**

Scattering occurs when gas particles molecules present in the atmosphere interact with & cause the electromagnetic radiation to be redirected from its original path.



How much scattering takes place depends on several factors including the wavelength of the radiation, the abundance of particles or gases, & the distance the radiation travels through the atmosphere.

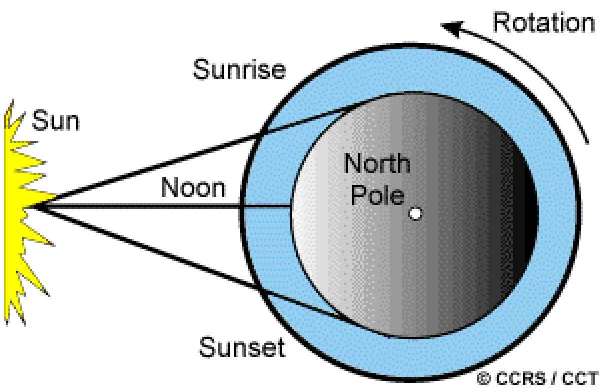
Chapter 1: "Concept & Foundations"

Radiation Interactions with the Atmosphere: (continue)

There are 3 types of scattering which take place.

Rayleigh scattering occurs when particles are very small compared to the wavelength of the radiation. It could causes shorter wavelengths of energy to be scattered much more than longer wavelengths.

The fact that the sky appears "blue" during the day is because of this phenomenon. As sunlight passes through the atmosphere, the shorter wavelengths (i.e. blue) of the visible spectrum are scattered more than the other.



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Radiation Interactions with the Atmosphere: ***(continue)***

Mie scattering occurs when the particles are just about the same size as the wavelength of the radiation. Mie scattering tends to affect longer wavelengths than those affected by Rayleigh scattering.

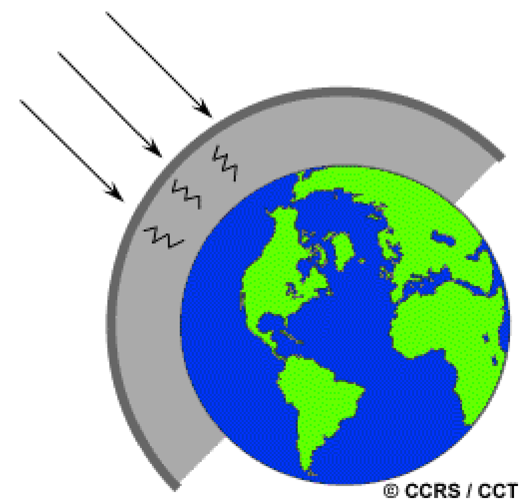
Nonselective scattering occurs when the particles are much larger than the wavelength of the radiation. This type of scattering causes fog & clouds to appear white to our eyes because blue, green, & red light are all scattered in approximately equal amounts.

Chapter 1: "Concept & Foundations"

Radiation Interactions with the Atmosphere: (continue)

Absorption is the other main mechanism at work when electromagnetic radiation interacts with the atmosphere. In contrast to scattering, this phenomenon causes molecules in the atmosphere to absorb energy at various wavelengths. Ozone, carbon dioxide, & water vapor are the three main atmospheric constituents which absorb radiation.

O3 serves to absorb the harmful UV radiation from the sun. Without this protective layer in the atmosphere our skin would burn when exposed to sunlight.



Chapter 1: "Concept & Foundations"

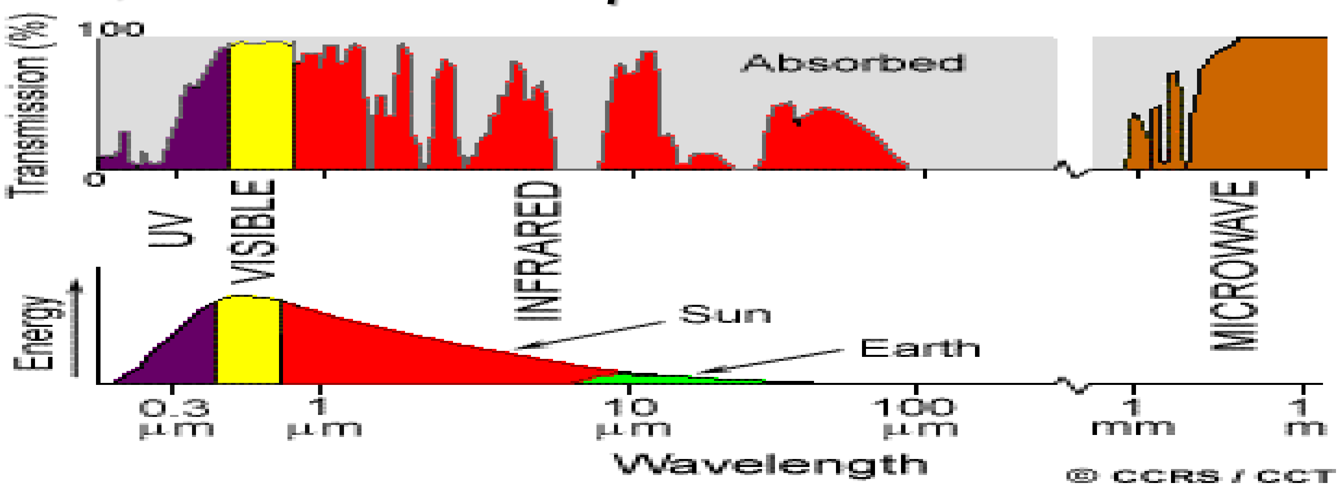
Radiation Interactions with the Atmosphere: *(continue)*

CO_2 tends to absorb radiation strongly in the thermal IR portion of the spectrum & traps this heat inside the atmosphere.

H_2O vapor in the atmosphere absorbs much of the incoming long wave infrared & shortwave microwave radiation (between 22 μm & 1 m). The presence of H_2O vapor in the lower atmosphere varies greatly from place to place & at different times of the year.

Radiation Interactions with the Atmosphere: (continue)

Because these gases absorb electromagnetic energy in very specific regions of the spectrum, they influence where (in the spectrum) we can "look" for R.S. purposes. Those areas of the spectrum which are not severely influenced by atmospheric absorption & thus, are useful to remote sensors, are called atmospheric windows.



Chapter 1: "Concept & Foundations"

Radiation Interactions with the Atmosphere: (continue)

The visible portion of the spectrum, to which our eyes are most sensitive, corresponds to both an atmospheric window & the peak energy level of the sun.

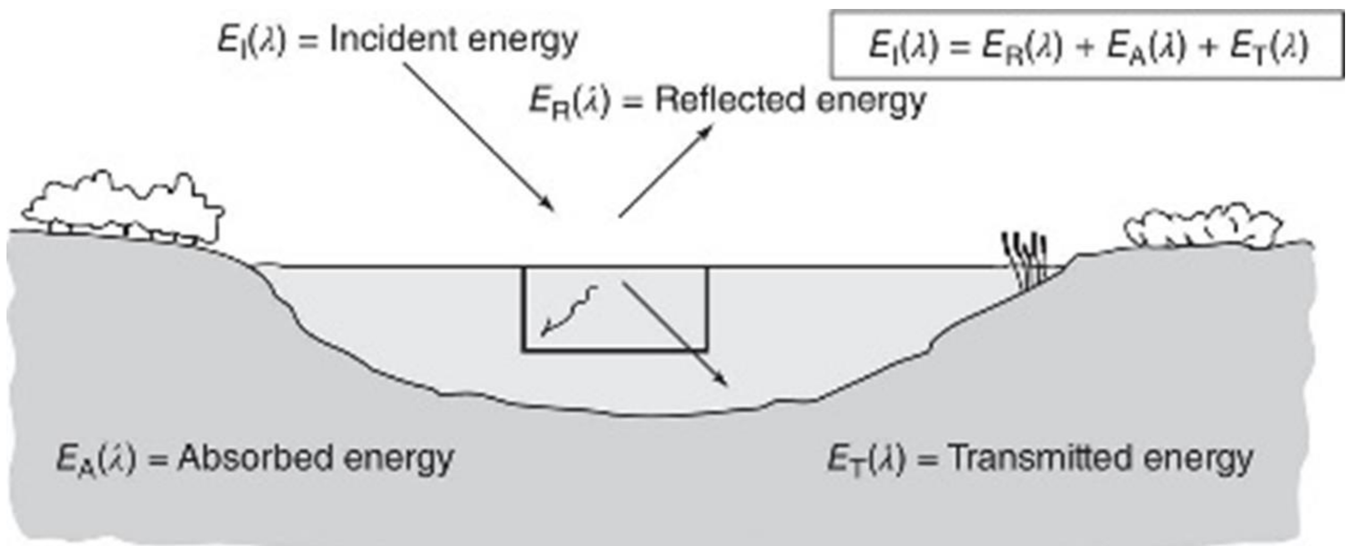
Note also that heat energy emitted by the Earth corresponds to a window around 10 μm in the thermal IR portion of the spectrum.

while the large window at wavelengths beyond 1 mm is associated with the microwave region.

Chapter 1: "Concept & Foundations"

Radiation Interactions with Earth Surface Features:

There are 3 forms of interaction that can take place when energy incident (EI (λ)) upon the surface. These are: absorption (EA (λ)); transmission (ET (λ)); & reflection (ER (λ)). The total incident energy will interact with the surface in one or more of these three ways.



Chapter 1: "Concept & Foundations"

Radiation Interactions with Earth Surface Features: (continue)

The proportions of each will depend on the wavelength of the energy, the material, condition of the feature & the atmospheric conditions.

$$E_I(\lambda) = E_A(\lambda) + E_T(\lambda) + E_R(\lambda)$$

In remote sensing, we are most interested in measuring the radiation reflected from targets. The spectral reflectance properties of any terrain material can be given as:

$$\rho_\lambda = E_R(\lambda) / E_I(\lambda)$$

Chapter 1: "Concept & Foundations"

Radiation Interactions with Earth Surface Features: (continue)

The geometric manner in which an object reflects energy is also important. We refer to two types of reflection, which represent the two extreme ends of the way in which energy is reflected from a target: specular reflection & diffuse reflection.

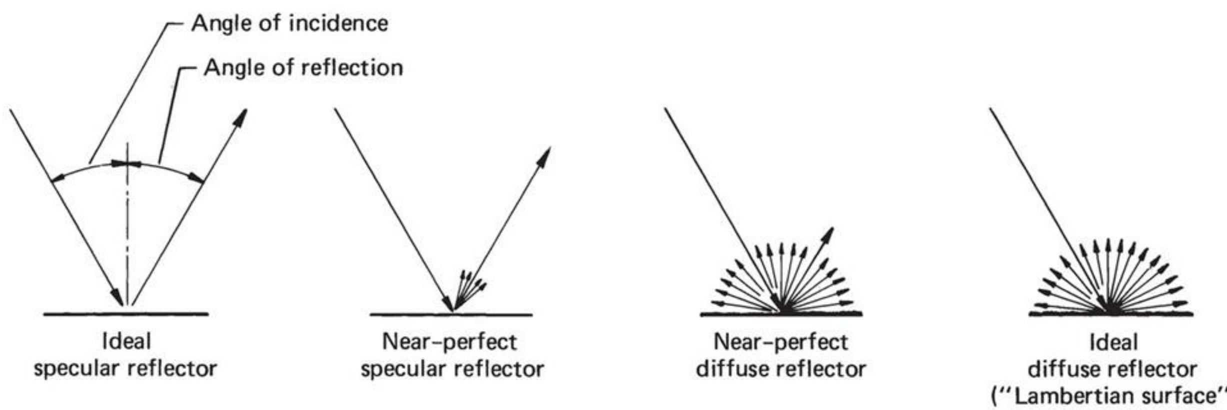
When a surface is smooth we get specular or mirror-like reflection where almost all of the energy is directed away from the surface in a single direction.

Diffuse reflection occurs when the surface is rough & the energy is reflected almost uniformly in all directions.

Chapter 1: "Concept & Foundations"

Radiation Interactions with Earth Surface Features: (continue)

Most earth surface features lie somewhere between perfectly specular or perfectly diffuse reflectors. The total incident energy will interact with the surface in one or more of these three ways, depends on the surface roughness of the feature in comparison to the wavelength of the incoming radiation.



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Radiation Interactions with Earth Surface Features: *(continue)*

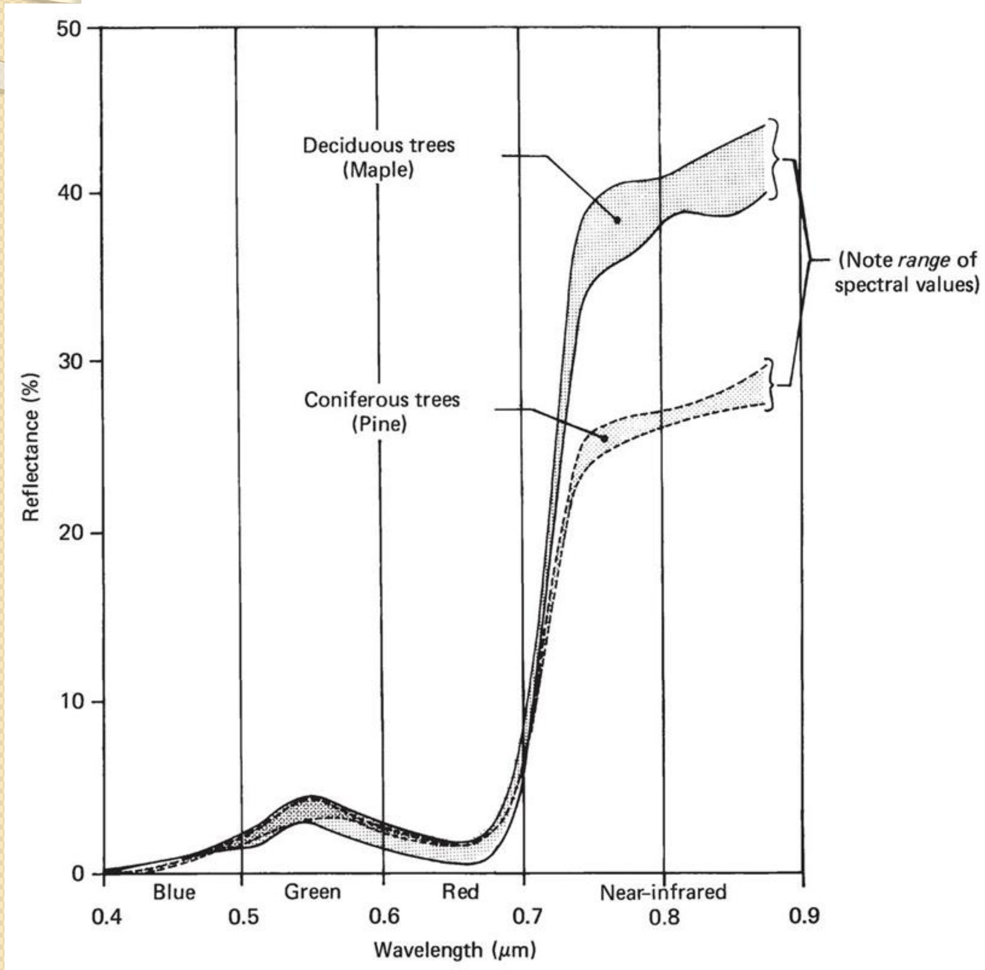
By comparing the response patterns of different features we may be able to distinguish between them, where we might not be able to, if we only compared them at one wavelength. For example, water & vegetation may reflect somewhat similarly in the visible wavelengths but are almost always separable in the infrared.

Spectral response can be quite variable, even for the same target type, & can also vary with time & location.

Knowing where to "look" spectrally & understanding the factors which influence the spectral response of the features of interest are critical to correctly interpreting the surface.

Chapter 1: “Concept & Foundations”

Radiation Interactions with Earth Surface Features: (continue)



Chapter 1: "Concept & Foundations" Part 4 out of 6

Characteristics of Images:

Electromagnetic energy may be detected either photographically or electronically.

The photographic process uses chemical reactions on the surface of light-sensitive film to detect & record energy variations.

Characteristics of Images: ***(continue)***

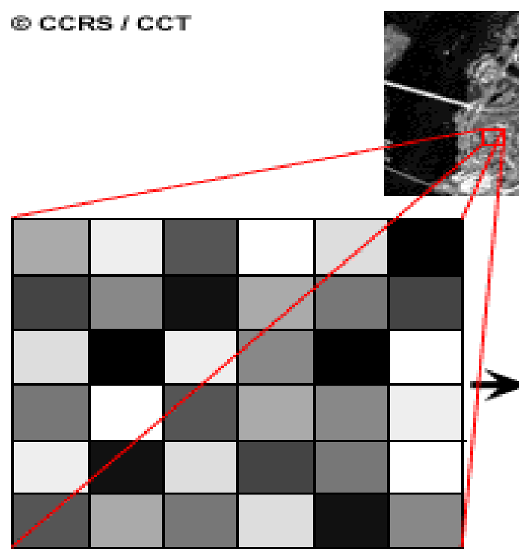
It is important to distinguish between the term image & the term photographs, in remote sensing. An image refers to any pictorial representation, regardless of what wavelengths or remote sensing device has been used to detect & record the electromagnetic energy.

A photograph refers specifically to images that have been detected as well as recorded on photographic film.

Chapter 1: “Concept & Foundations”

Characteristics of Images: (continue)

Digital image is represented & displayed in a digital format by subdividing the image into small equal-sized & shaped areas, called picture elements or pixels. Each pixel represents the brightness of each area with a numeric value or digital number.



170	238	85	255	221	0
68	136	17	170	119	68
221	0	238	136	0	255
119	255	85	170	136	238
238	17	221	68	119	255
85	170	119	221	17	136

Chapter 1: "Concept & Foundations"

Characteristics of Images: **(continue)**

We see color because our eyes detect the entire visible range of wavelengths & our brains process the information into separate colors. That is how many sensors work. The information from a narrow wavelength range is gathered & stored in a channel, or a band.

We can combine & display channels of information digitally using the three primary wavelengths (blue, green, & red).

Chapter 1: “Concept & Foundations”

Characteristics of Images: (continue)

The data from each channel is represented as one of the primary wavelengths. Depending on the relative brightness (i.e. the digital value) of each pixel in each channel, the primary wavelengths combine in different proportions to represent different colors.

Chapter 1: "Concept & Foundations"

Characteristics of Images: (continue)

Photographic

- *Panchromatic*
- *Color*

Multi-Spectral Scanners

- *Images scanned via sensors*
- *Sensors for as many wavelengths as necessary*

Visible, Ultraviolet (UV) & Infrared (IR)

- *Photographic; (Visible, UV, & near-IR)*
- *MSS; Visible, UV, & IR (near-, mid-, & thermal-IR) sensors*

Radar

- *RAdio Detection And Ranging*
- *active imaging*

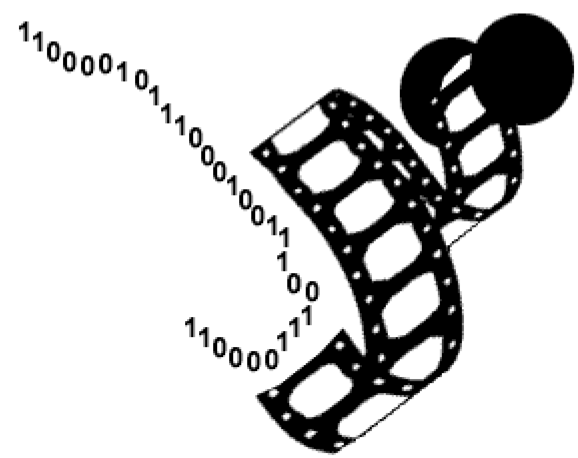
Chapter 1: "Concept & Foundations"

Data Reception, Transmission, & Processing:

Data obtained during airborne remote sensing missions can be retrieved once the aircraft lands. It can then be processed & delivered to the end user.

However, data acquired from satellite platforms need to be electronically transmitted to Earth.

The technologies designed to accomplish electronic transition can also be used by an aerial platform if the data are urgently needed on the surface.



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Data Reception, Transmission, & Processing:

The data are then transmitted to & received at an Earth if a Ground Receiving Station (GRS) is in the line of sight of the satellite in a raw digital format, or can be recorded on board the satellite for transmission to a GRS at a later time.

The data may then, if required, be processed to correct systematic, geometric & atmospheric distortions to the imagery, & be translated into a standardized format.

Low resolution quick-look imagery is used to preview archived imagery prior to purchase. They are useful for ensuring that the overall quality, coverage & cloud cover of the data is appropriate.

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Interpretation & Analysis:

In order to make good use of remotely sensed data, we must be able to extract meaningful information from the imagery.

Interpretation & analysis of remotely sensed imagery involves the identification &/or measurement of various targets in an image in order to extract useful information about them.

Chapter 1: "Concept & Foundations"

Interpretation & Analysis: (continue)

Targets in remote sensing images may be any feature or object which can be observed in an image, & have the following characteristics:

- *Targets may be a point, line, or area feature. They can have any form, from a plane on a runway, to a bridge or roadway, to a large expanse of water or a field.*
- *The target must be distinguishable; it must contrast with other features around it in the image.*

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***Interpretation & Analysis**: (continue)*

Image interpretation can be performed visually on an analogue imagery or on digital imagery displayed on a computer screen. Both analogue & digital imagery can be displayed as black & white or as color images.

Digital image processing may be performed, if data are available in digital format, using a computer. Digital processing can also be used to enhance data as a prelude to visual interpretation.

Digital processing is done to supplement & assist the human analyst & rarely is digital processing & analysis carried out as a complete replacement for manual interpretation.

Chapter 1: "Concept & Foundations"

***Interpretation & Analysis**: (continue)*

Visual interpretation & analysis dates back to the early beginnings of remote sensing for air photo interpretation. Digital processing & analysis is more recent with the advent of digital recording of remote sensing data & the development of computers.

It is important to reiterate that visual & digital analyses of remote sensing imagery are not mutually exclusive. Both methods have their merits. In most cases, a mix of both methods is usually employed when analyzing imagery.

Chapter 1: "Concept & Foundations"

Interpretation & Analysis: (continue)

Reference Data:

Rarely, if ever, is RS employed without the use of some form of reference data, or more often used term ground troth.

Acquisition of reference data involves collecting measurements or observations about the objects, area, or phenomena that are being remotely sensed.

These data can take on any of a number of different forms & may be derived from a number of sources.

Chapter 1: "Concept & Foundations"

Interpretation & Analysis: *(continue)*

Reference Data: (continue)

The identity & location of some of land cover types are known through a combination of fieldwork, analysis of aerial photography, maps personal experience, etc.

Reference data can be very expensive & time consuming to collect properly. They can consist of either time-critical &/or time-stable measurements.

Chapter 1: "Concept & Foundations"

Interpretation & Analysis: (continue)

Reference Data: (continue)

Reference data might be used to serve any or all of the following purposes:

1. To aid in the analysis & interpretation of RS data.
2. To verify information extracted from RS data.
3. To calibrate a sensor.

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Final products & Applications:

No single combination of sensors & interpretation procedure is appropriate to all application. All designs of successful RS efforts involve, at the minimum:

1. *Clear definition of the problem.*
2. *Evaluation of the potential for addressing the problem with RS techniques.*
3. *Identification of the RS data acquisition, procedures appropriate to the task.*

Chapter 1: "Concept & Foundations"

Final products & Applications: *(continue)*

4. Determination of the data interpretation procedures to be employed & the reference data needed.
5. Identification of criteria to judge the quality of the extracted information.

Chapter 1: "Concept & Foundations"

Final products & Applications: *(continue)*

The success of many applications of R.S. can be improved considerably by using multiple sources of information, multispectral, Multi-sensor, Multi-temporal.

Finally, it must be recognized that RS is a tool, best applied in concert with others; it is not an end in itself.