Principle of Remote Sensing

Hawassa University

Dep. of NREP

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Lecture Outline:

- Concept of Remote Sensing
- History and Development of RS Technologies
- Stages in Remote Sensing
- Electromagnetic Radiation/ Spectrum
- Interaction of EMR with Earth's Surface
- Energy Interactions in the Atmosphere
- Atmospheric Window
- Passive and Active Sensor
- Platforms, Orbit, and Concept of Resolution

- Types of Satellite sensor
  - Weather Satellite
  - Land Observation Satellite
- Image Interpretation and Analysis
  - Visual Image Interpretation
  - Elements of VII
  - Digital Image Processing
  - Digital Image Classifications

❑ Remote Sensing

- The science of remote sensing comprises the analysis and interpretation of measurements of electromagnetic radiation that is reflected from or emitted by a target and observed or recorded from a vantage point by an observer or instrument that is not in contact with the target.
- Earth observation (EO) by remote sensing is the interpretation and understanding of measurements made by airborne or satellite-borne instruments of electromagnetic radiation that is reflected from or emitted by objects on the Earth's land, ocean, or ice surfaces or within the atmosphere.
- An important principle underlying the use of remotely-sensed data is that different objects on the Earth's surface and in the atmosphere reflect, absorb, transmit or emit electromagnetic energy in different proportions, and that such differences allow these components to be identified.

- **Remote Sensing** is defined as the science and technology by which the characteristics of objects of interest can be identified, measured or analyzed the characteristics without direct contact with the object. Remote sensing means sensing things from a distance.
- Electro-magnetic radiation which is **reflected** or **emitted** from an object is the usual source of remote sensing data.
- A device to detect the electro-magnetic radiation reflected or emitted from an object is called a "remote sensor" or "**sensor**".
- Camera, radio frequency receivers, and radar systems, are examples of remote sensors.
- A vehicle to carry the sensor is called a "**platform**". Aircraft or satellites are used as platforms.
- In much of remote sensing, the process involves an interaction between incident radiation and the targets of interest (Detection and discrimination of objects).

- All definitions forwarded after the term was coined have the following main characteristics in common,

  - Physical separation between sensor and target
  - Medium = electromagnetic radiation
  - Device to sample and measure radiation (sensor)
  - Target is the terrestrial environment (atmosphere, oceans, land surface)

- Detection and discrimination of objects or surface features means detecting and recording of radiant energy reflected or emitted by objects or surface material.
- Different objects return different amount of energy in different bands of the electromagnetic spectrum, incident upon it.
- This depends on the property of material (structural, chemical, and physical), surface roughness, angle of incidence, intensity, and wavelength of radiant energy.
- Everything in nature has its own unique distribution of reflected, emitted and absorbed radiation.
- These spectral characteristics can be used to distinguish one thing from another or to obtain information about shape, size and other physical and chemical properties.

- In general remote sensing is a multi-disciplinary science which includes a combination of various disciplines such as photography, computer, electronics and telecommunication, satellite launching etc.
- All these technologies are integrated to act as one complete system in itself, known as Remote Sensing System.
- There are a number of stages in a Remote Sensing process, and each of them is important for successful operation.

❖ History and Development of Remote Sensing Technologies

- Human history has very close link with earth’s geography.
- Thus, Geospatial technology has been necessary for different purposes all along the history of human civilization to maintain
  - land ownership records and demarcations,
  - mineral exploration,
  - military requirement, and
  - navigation in high sea by sailors.

- Remote sensing integrates a broad set of knowledge and technologies used for observation, analysis and interpretation of terrestrial and atmospheric phenomena.

- Global adoption of mapping and navigation applications by billions of users has **transformed** the remote sensing industry in the past decade. Transformations were:
  - **Resolution, Accuracy, Speed** and **Analytics.**

- Thus, here we shall see the history and development of remote sensing technologies in the global scenario.

❑ History and Development

Early Photography and Aerial Images

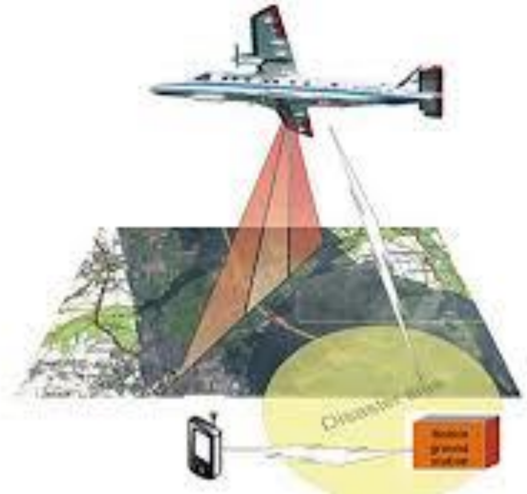
- The history of remote sensing begins with photography, because this was the first sensor to be developed and perfected.
- Literally, it means draw with light (2300 yrs ago Aristotle: camera obscura /light passing through small hole image upside down/.
- After its discovery in 1839, the use of photography spread rapidly.

Aerial photography

- The use of powered aircraft as platforms for aerial photography forms the next milestone.

- The two consecutive world wars provide an impetus for its further development.

- The concept of ***aerial photography*** was introduced in 1960s.



Emergence of Remote Sensing

- The origin of non-photographic remote sensing can be traced to World War II, with the development and improvement of
  - radar (radio detection and ranging),
  - thermal infra-red detection systems, and
  - sonar (sound navigation and ranging).
- The need for military reconnaissance led to development and use of scanner systems including thermal infra-red and multispectral scanners, television, and SLAR (side-looking airborne radar) in the 1950s.
- Early in the 1960s, Evelyn Pruitt, a scientist working for the U.S. Navy’s Office of Naval Research, coined ***remote sensing***
  - when she recognized that the term *aerial photography* no longer accurately described the many forms of imagery collected using radiation outside **the visible region of the spectrum.**

Satellite Remote Sensing

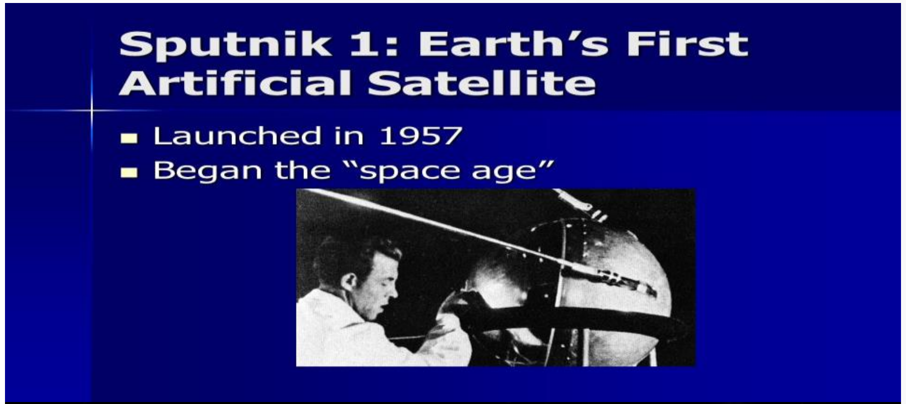
- Beginning from 1950s (particularly during cold war) there were attempts to release satellite to the space by the two super powers (USA and USSR) of the then world.

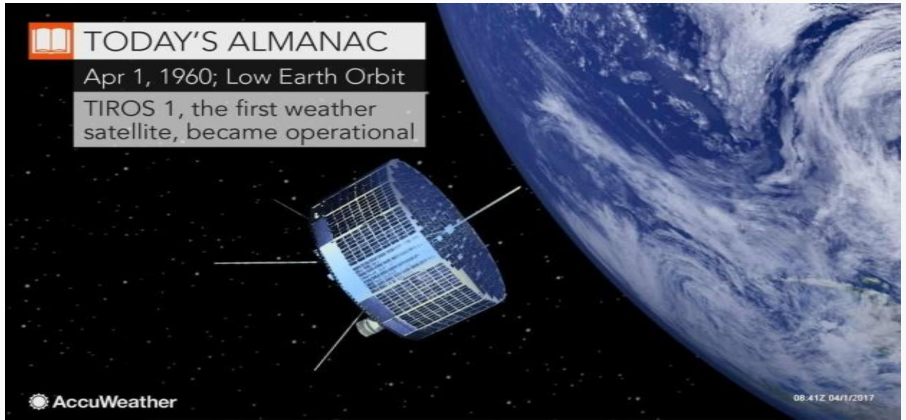
- It has been started by SPUTNIK launched by USSR and now reaching on the stages that can collect data representing the **entire earth** (after 1990s) and ease access to **public** through **internet** as virtual representation of the earth's surface, i.e., since 2005 Google earth was released.

- Therefore, Satellite remote sensing development can be seen in different eras:

Rudimentary space-borne satellite remote sensing era

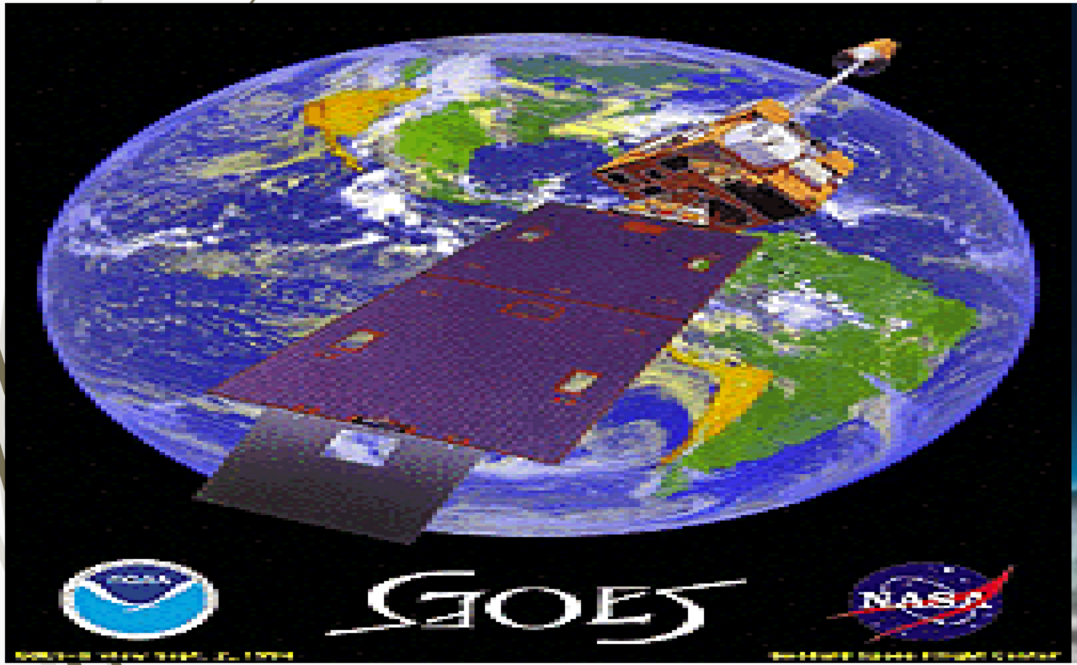
- began with launch of *test of concept* rudimentary satellites, i.e., in late 1950s
    - Sputnik 1 from Russia
    - Explorer 1 by the United States
    - Meteorological satellite: Television and Infrared Observational Satellite-1 (TIROS-1) by the United States.





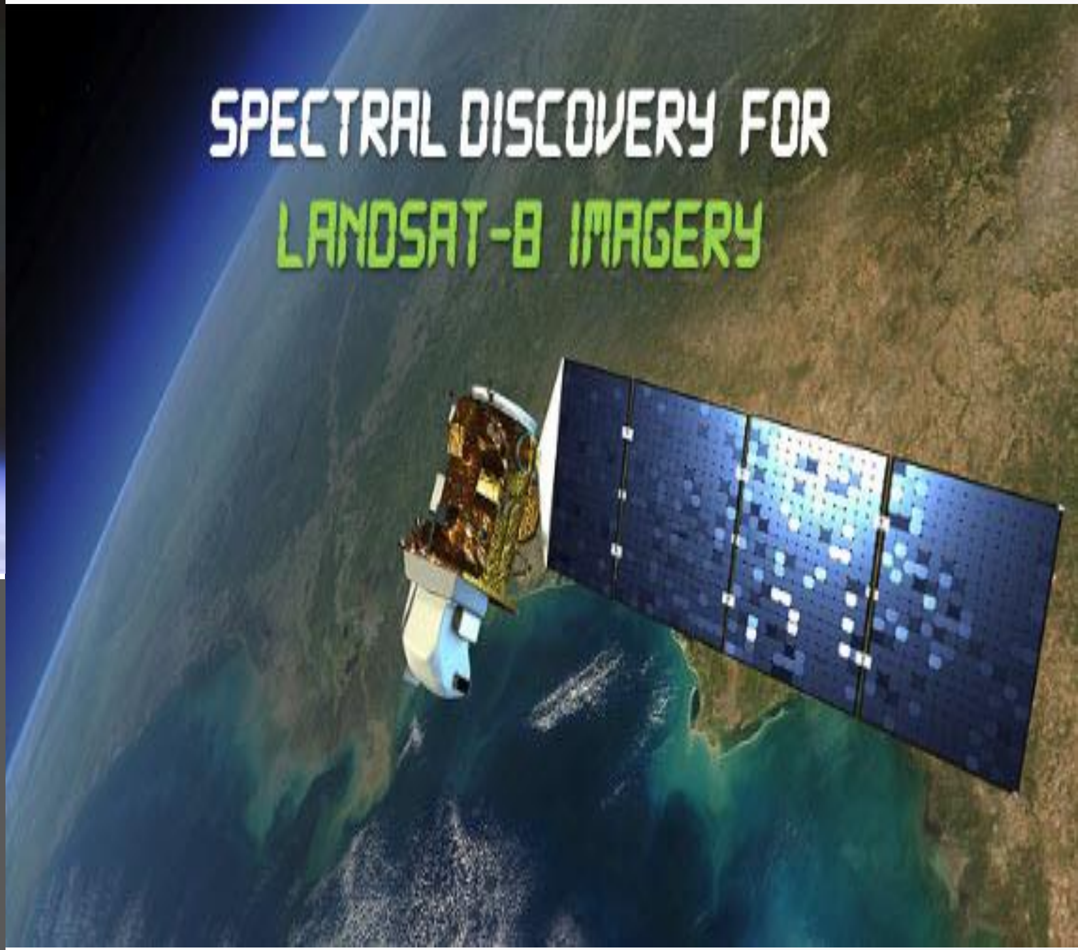
Meteorological satellite sensor remote sensing era

- consisted of Geostationary Operational Environmental Satellite (GOES) and polar orbiting National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR).
- This was also an era when global coverage became realistic and environmental applications practical.

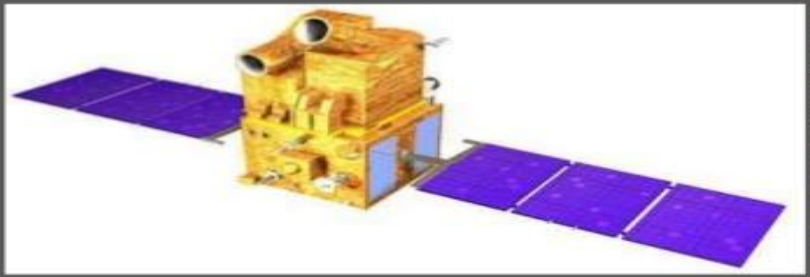


Landsat era:

- begins in 1972.
- Landsat
  - 1, 2 & 3- carry multi spectral scanner (**MSS**) sensor;
  - 4 & 5 carried Thematic Mapper (**TM**) sensor;
  - 7 carries Enhanced Thematic mapper (**ETM**+) sensor;
  - 8 carrying Operational Land Imager (**OLI**) sensor
  - 6 failed during launch.
- The Landsat era has equally good sun-synchronous Land satellites such as Systeme Pour l'Observation de Ia Terre (**SPOT**) of France
- Indian Remote Sensing Satellite (**IRS**) of India.

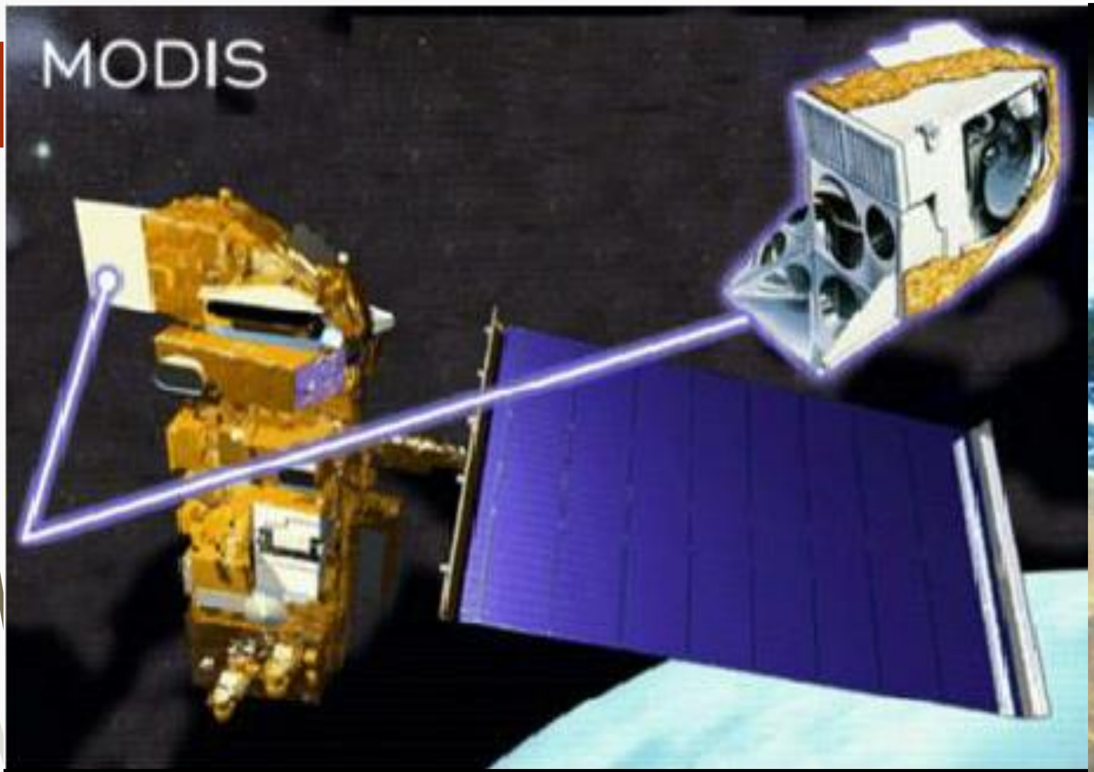


THE IRS (*Indian Remote Sensing*) SATELLITES

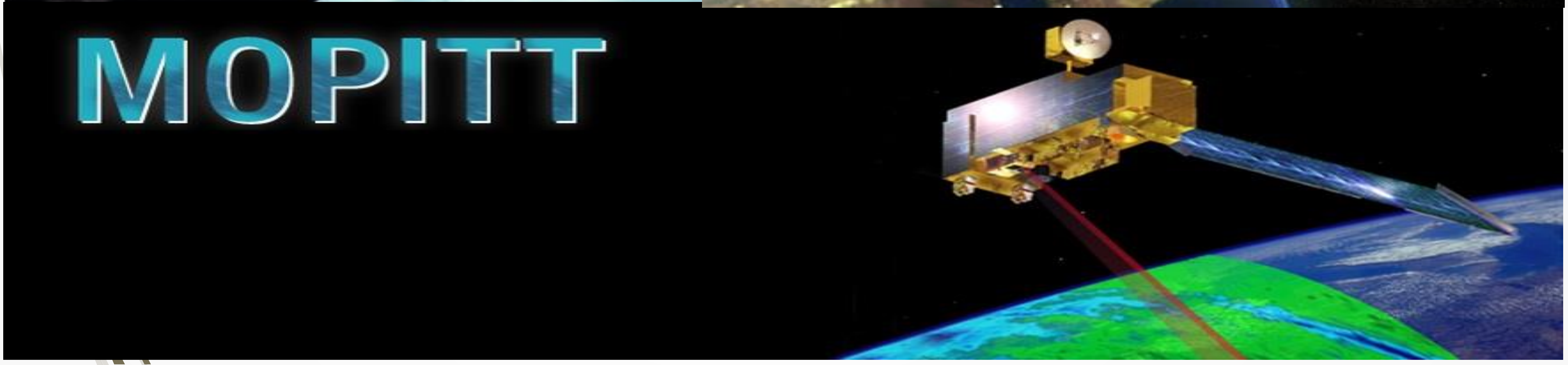


Earth Observing System era:

- began with launch of Terra/aqua satellite in 1999;
  - the global coverage, frequent repeat coverage, high level of easy and mostly free access to data.
  - carrying sensors such as Moderate Resolution Imaging Spectro-radiometer (**MODIS**) and Measurements of Pollution in the Troposphere (**MOPITT**)
- The active space borne remote sensing sensors using **radar technology**
  - European Radar Satellite (**ERS**),
  - Japanese Earth Resources satellite (**JERS**),
  - Radarsat
  - Advanced Land Observation Satellite (**ALOS**).
  - The Shuttle Radar Technology Mission (**SRTM**)


MODIS


ERS-2


MOPITT

New Millennium era:

- refers to highly advanced “test-of concept” satellites sent into orbit around the same time as EOS era, but the concepts and ideas are different.
- are basically satellites and sensors for the next generation.
  - carrying the first space borne hyper-spectral data.
  - Advanced Land Imager (ALI) as a cheaper, technologically better replacement for Landsat is also very attractive

Private industry era:

- began at the end of the last millennium and beginning of this millennium.
- consists of a number of innovations:
  - collection of data in very high resolution (<10 meter): e.g. **IKONOS** and **Quickbird** satellites.
  - a revolutionary means of data collection: e.g. **Rapid eye** satellite constellation of 5 satellites
  - the introduction of micro satellites, e.g. disaster monitoring constellation (**DMC**)
  - the innovation by **Google Earth**

Stages in Remote Sensing

- Energy Source or Illumination (A)
- Radiation and the Atmosphere (B)
- Interaction with the Target (C)
- Recording of Energy by the Sensor (D)
- Transmission, Reception, and Processing (E)
- Interpretation and Analysis (F)
- Application (G)

- All these elements comprise the remote sensing process from initial to end (energy source up to extract information from the imagery to assist in solving a particular problem)

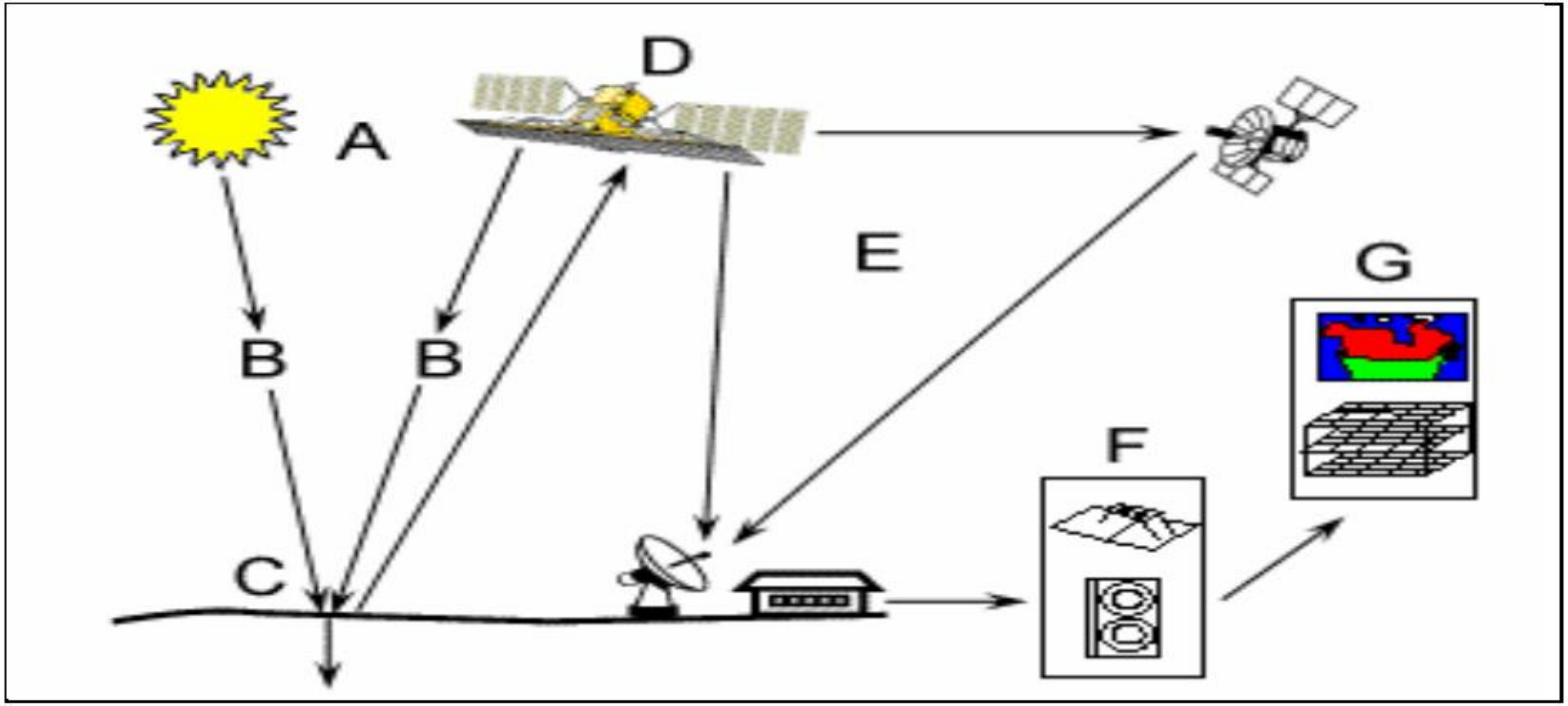


Figure 1. The remote sensing system

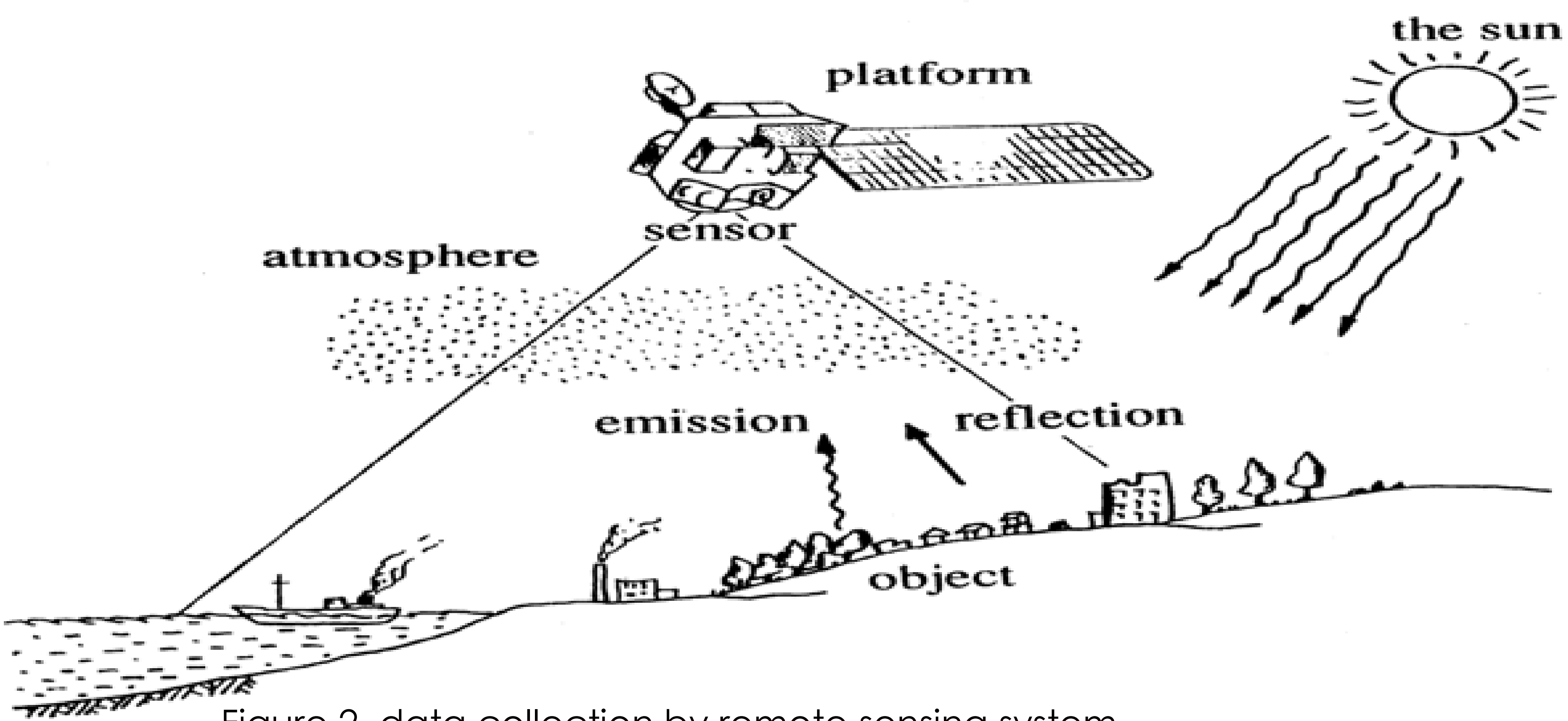


Figure 2. data collection by remote sensing system

❖ Electromagnetic Spectrum/Radiation

- Electromagnetic energy is the means by which information is transmitted from an object to a sensor.
- The information is propagated by electromagnetic radiation at the velocity of light from the source directly through free space, or indirectly by reflection and scattering to the sensor.
- The interaction of electromagnetic waves with natural surfaces and atmospheres is strongly dependent on the frequency of the waves.
- Waves in different spectral bands tend to excite different interaction mechanisms such as electronic, molecular, or conductive mechanisms.

- **EM spectrum** is the continuous range of electromagnetic radiation, extending from highest frequency & shortest wavelength to lowest frequency & longest wavelength.
- There are two characteristics of EMR that are particularly important for understanding remote sensing. These are the **wavelength** and **frequency.**
- **Wavelength** is the length of one wave cycle, which can be measured as the distance between successive wave crests.

- **Frequency** refers to the number of cycles of a wave passing a fixed point per unit of time.
- The shorter the wavelength, the higher the frequency. The longer the wavelength, the lower the frequency.

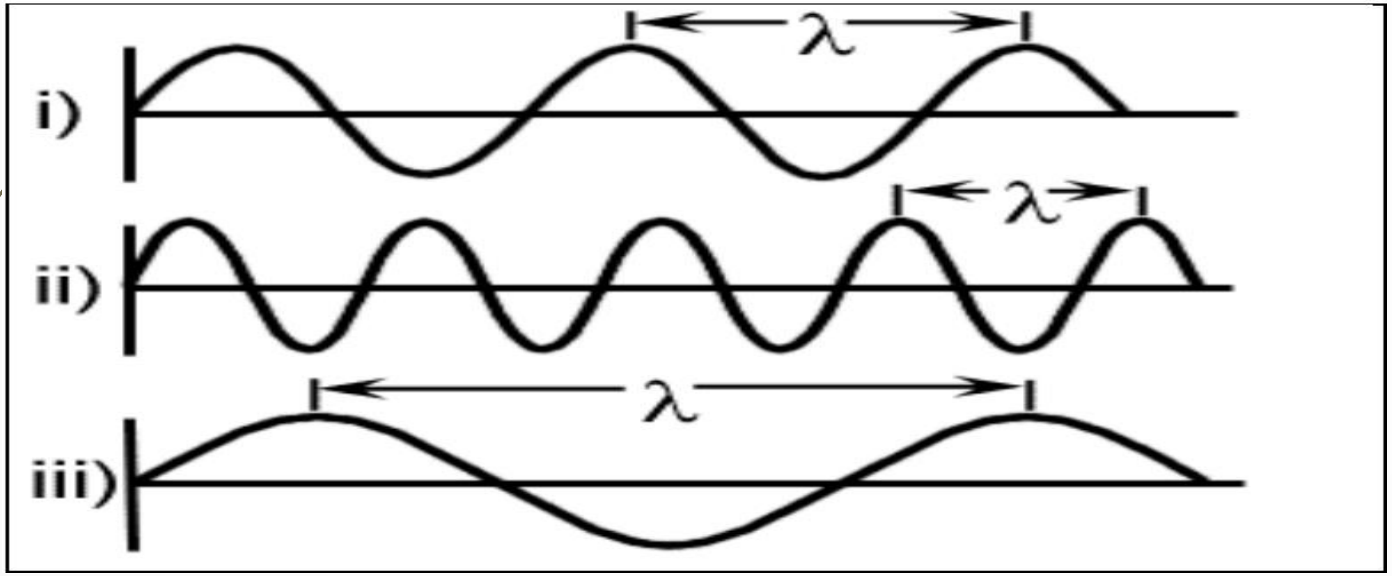
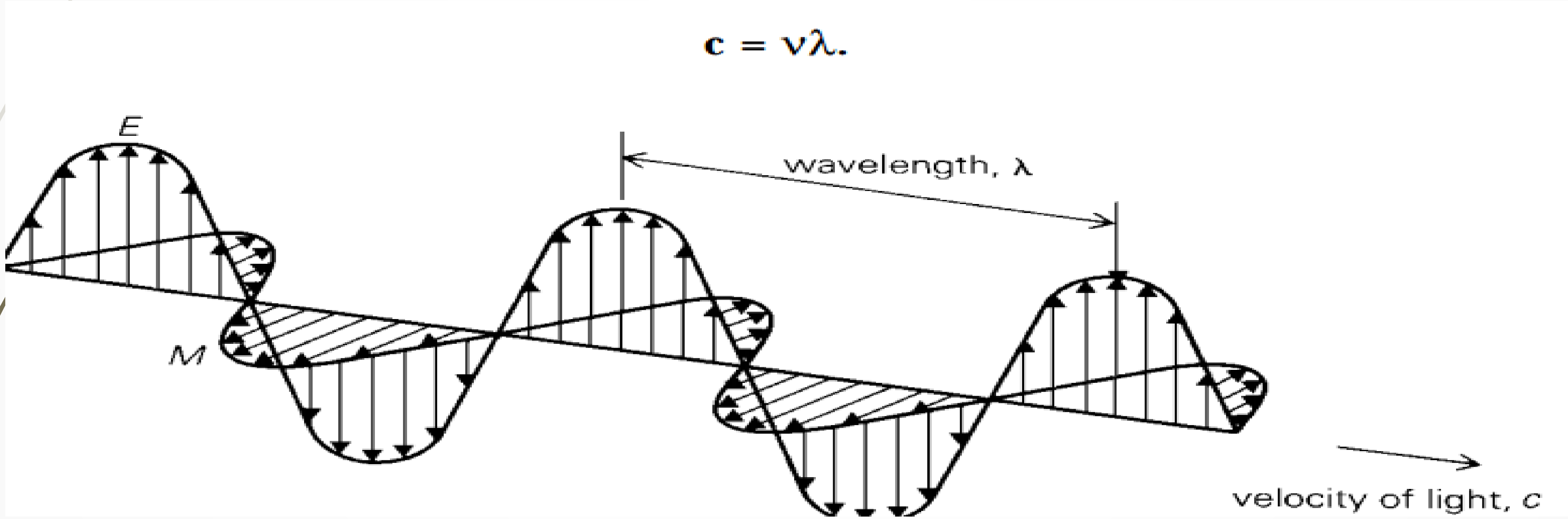


Figure 3: Wave length of electromagnetic radiation

- **EMR** is energy that is propagated through free space or through a material medium in the form of electromagnetic waves, such as radio waves, visible light, and gamma rays.



- An important principle underlying the use of remotely-sensed data is that different objects on the Earth's surface and in the atmosphere reflect, absorb, transmit or emit electromagnetic energy in different proportions, and that such differences allow these components to be identified.
- Sensors mounted on aircraft or satellite platforms record the magnitude of the energy flux reflected from or emitted by objects on the Earth's surface.
- A remotely-sensed image is made up of a rectangular matrix of measurements of the flux or flow of electromagnetic radiation (EMR) emanating from individual pixels,
- so that each pixel value represents the magnitude of upwelling electromagnetic radiation for a small ground area. This upwelling radiation contains information about:

(i) the nature of the Earth surface material present in the pixel area,

(ii) the topographic position of the pixel area and

(iii) the state of the atmosphere through which the EMR has to pass.

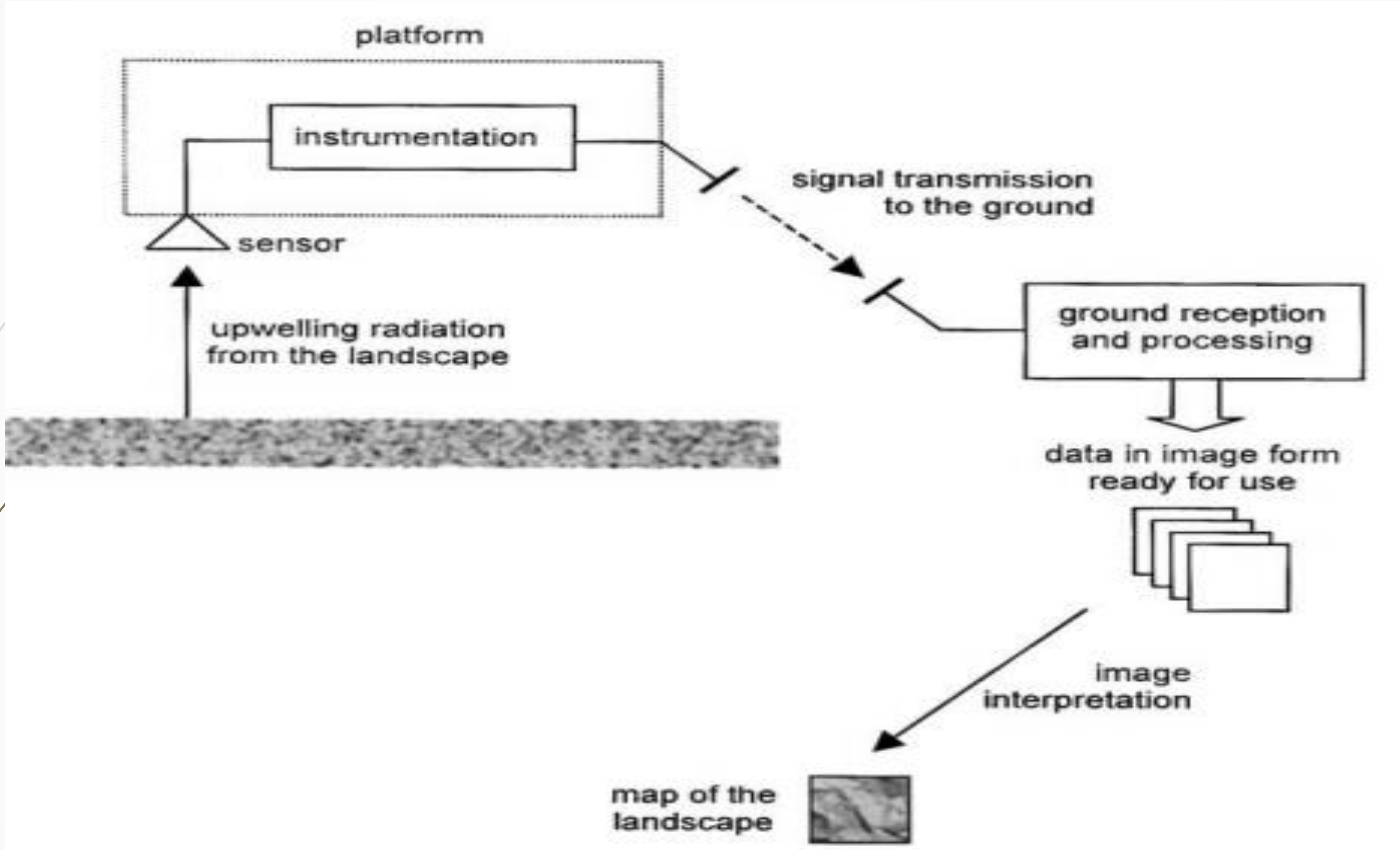


Fig. 4 Signal and data flow in a remote sensing system

- Electromagnetic radiation interacts with matter in different ways in different parts of the spectrum.
- The types of interaction can be so different that it seems to be justified to refer to different types of radiation.
- This classification goes in the increasing order of wavelength, which is characteristic of the type of radiation.
- The electromagnetic spectrum is divided into a number of spectral regions.
- These techniques cover the whole electromagnetic spectrum from low-frequency radio waves through the microwave, submillimeter, far infrared, near infrared, visible, ultraviolet, x-ray, and gamma-ray regions of the spectrum.

- The radio band covers the region of wavelengths longer than 10 cm (frequency less than 3 GHz). This region is used by active radio sensors such as imaging radars, altimeters, and sounders, and, to a lesser extent, passive radiometers.

- The microwave band covers the neighboring region, down to a wavelength of 1 mm(300 GHz frequency).
- In this region, most of the interactions are governed by molecular rotation, particularly at the shorter wavelengths. This region is mostly used by microwave radiometers/spectrometers and radar systems.

- The infrared band covers the spectral region from 1 mm to 0.7 m. This region is subdivided into subregions called submillimeter, far infrared, thermal infrared, and near infrared. In this region, molecular rotation and vibration play important roles.

- Imagers, spectrometers, radiometers, polarimeters, and lasers are used in this region for remote sensing. The same is true in the neighboring region, the visible region (0.7–0.4 m) where electronic energy levels start to play a key role.

- The EM spectrum can be divided into seven different regions
  - **Gamma rays**
  - **X-rays**
  - **Ultraviolet**
  - **Visible light**
  - **Infrared**
  - **Microwaves**
  - **Radio waves**

But among the above regions the most important for remote sensing is visible and infrared one

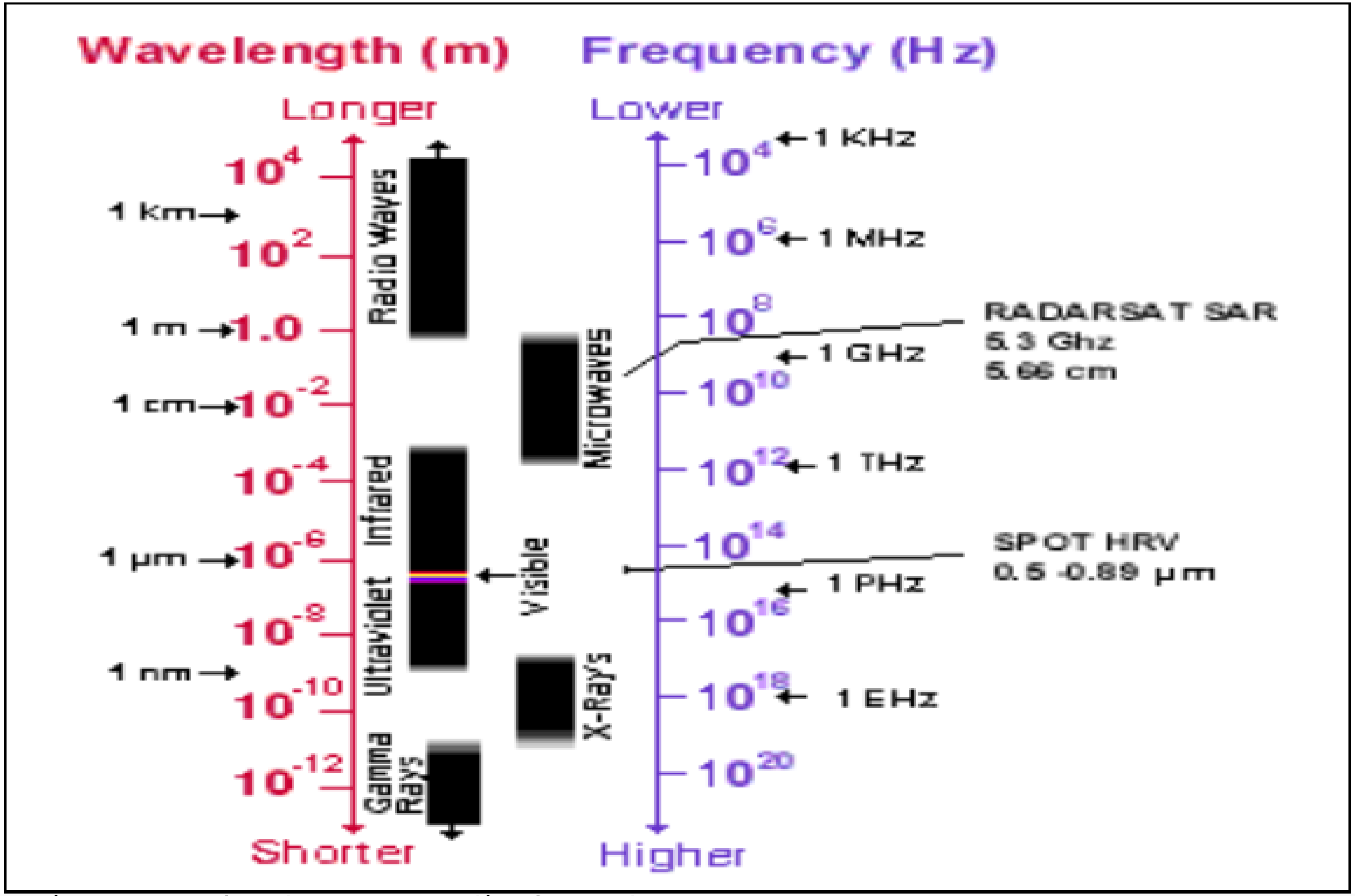


Figure 5. Electromagnetic Spectrum

❖ Visible and infrared regions

- The visible and near-infrared regions of the electromagnetic spectrum have been the most commonly used in remote sensing of planetary surfaces.
- This is partially due to the fact that this is the spectral region of maximum illumination by the sun and most widely available detectors (electrooptical and photographic).

- The sensor detects the electromagnetic waves reflected by the surface and measures their intensity in different parts of the spectrum.
- The significance of these different ranges lies in the interaction mechanism between the electromagnetic radiation and the materials being examined.
- In the visible/ infrared range the energy measured by a sensor depends upon properties such as the pigmentation, moisture content and cellular structure of vegetation, the mineral and moisture contents of soils and the level of sedimentation of water.

- By comparing the radiometric and spectral characteristics of the reflected waves to the characteristics of the incident waves, the surface reflectivity is derived. This in turn is analyzed to determine the chemical and physical properties of the surface.

- The chemical composition and crystalline structure of the surface material has an effect on the reflectivity because of the molecular and electronic processes that govern the interaction of waves with matter.

- The physical properties of the surface, such as roughness and slope, also affect the reflectivity, mainly due to geometric factors related to the source–surface–sensor relative angular configuration.

- As the solar waves propagate through a planet's atmosphere, they interact with the atmospheric constituents, leading to absorption in specific spectral regions, which depends on the chemical composition of these constituents. Figure 4 shows the sun illumination spectral irradiance at the Earth's surface.

- Strong absorption bands exist in the near infrared, particularly around 1.9, 1.4, 1.12, 0.95, and 0.76 _m. These are mainly due to the presence of water vapor (H2O), carbon dioxide (CO2), and, to a lesser extent, oxygen (O2).

- In addition, scattering and absorption lead to a continuum of attenuation across the spectrum. The absorption band near 2 _m is due to H2O.
- Another important factor in visible and near-infrared remote sensing is the relative configuration of the sun–surface–sensor.

- Because of the tilt of the Earth's rotation axis relative to the plane of the ecliptic, the sun's location in the sky varies as a function of the seasons and the latitude of the illuminated area(Dozier and Strahler, 1983; Wilson, 1980).

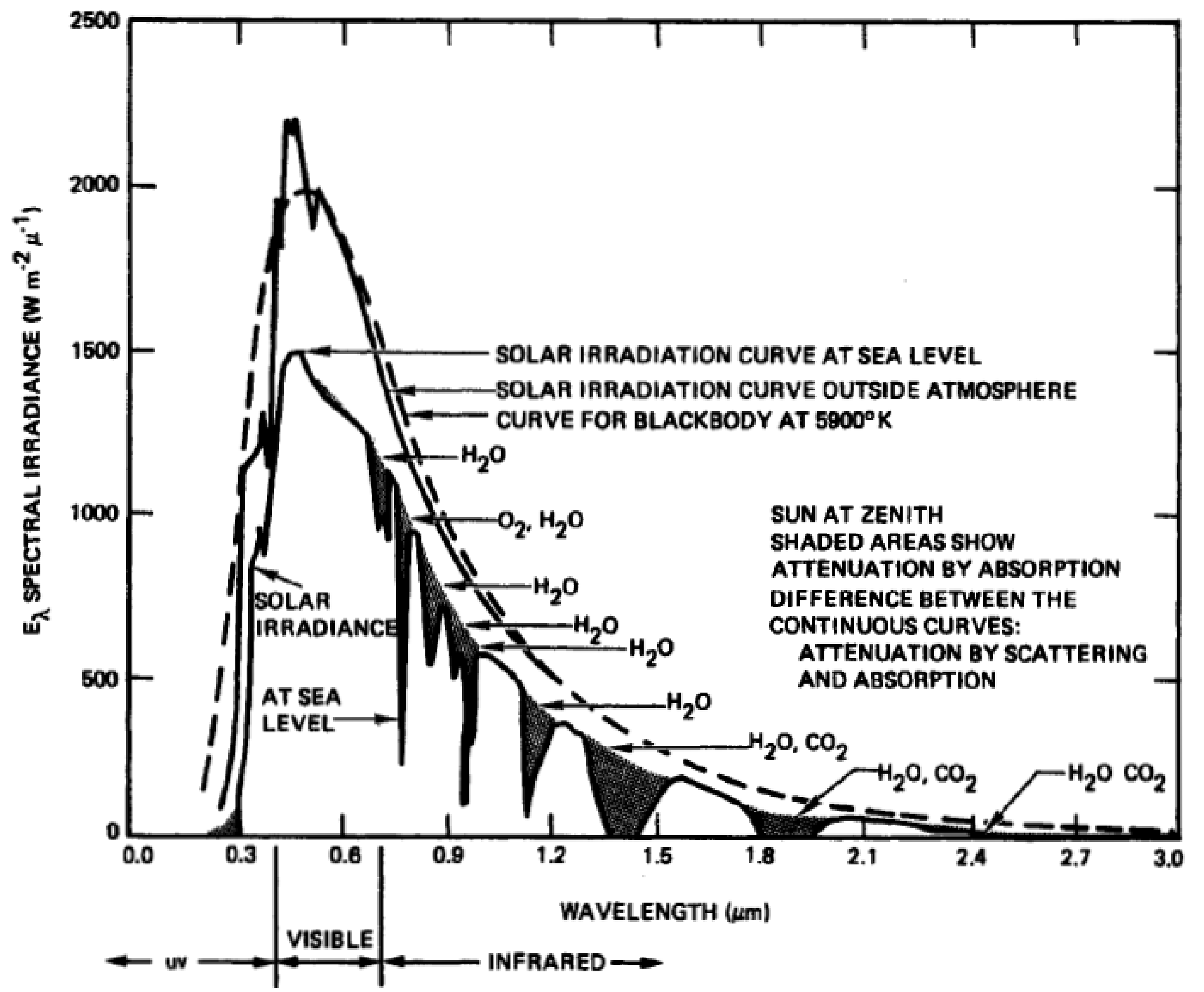


Figure 6 Sun illumination spectral irradiance at the Earth's surface. (From Chahine, et al. 1983.)

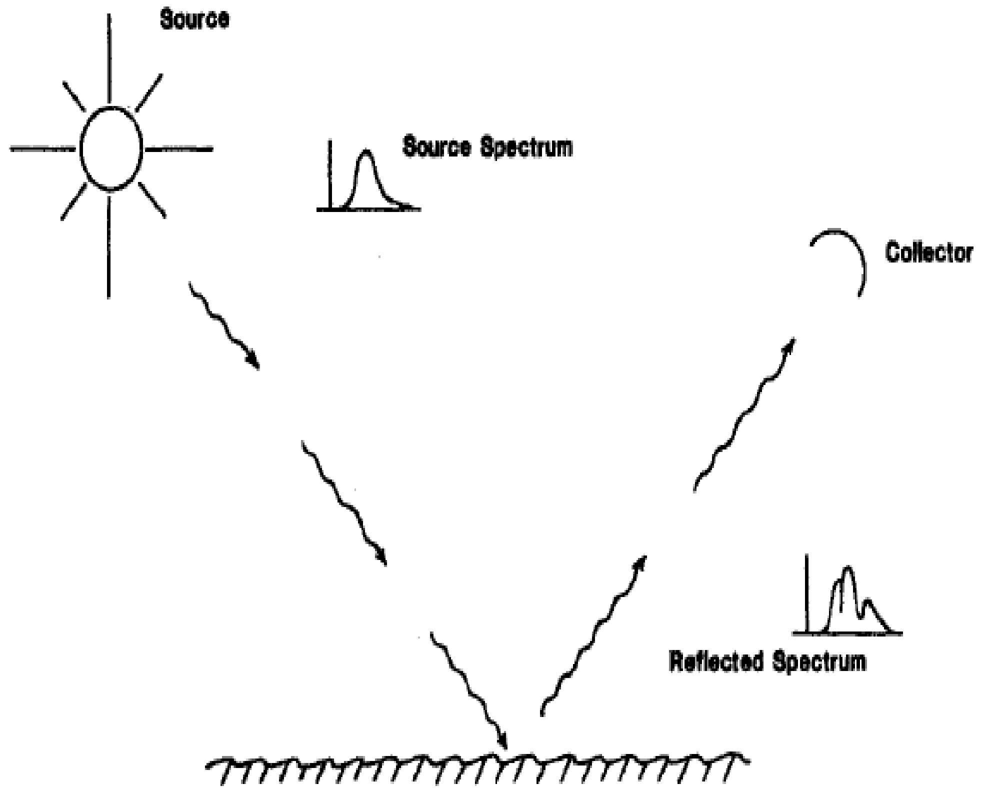


Figure 7 The surface spectral imprint is reflected in the spectrum of the reflected wave.

- **Infrared radiation**
- The infrared region can be divided into two categories based on their radiation properties the **reflected IR**, and **the emitted or thermal IR**.

- Radiation in the reflected IR region is used for remote sensing purposes in ways very similar to radiation in the visible portion.
- The reflected infrared part of the electromagnetic spectrum covers the range from roughly 300 GHz (1 mm) to 400 THz (750 nm).

- It can be divided into three parts:
  - **Far-infrared**
  - **Mid- infrared**
  - **Near – Infrared**

- **Far-infrared** - covers from 300 GHz (1 mm) to 30 THz (10 μm). The lower part of this range may also be called microwaves.
- The water in Earth's atmosphere absorbs so strongly in this range that it renders the atmosphere in effect opaque.
- **Mid-infrared**- covers from 30 to 120 THz (10 to 2.5 μm).
- Hot objects (black-body radiators) can radiate strongly in this range, and human skin at normal body temperature radiates strongly at the lower end of this region.
- **Near-infrared** - covers from 120 to 400 THz (2,500 to 750 nm).
- Physical processes that are relevant for this range are similar to those for visible light.
- The highest frequencies in this region can be detected directly by some types of photographic film, and by many types of solid state image sensors for infrared photography and videography.

Visible radiation (light)

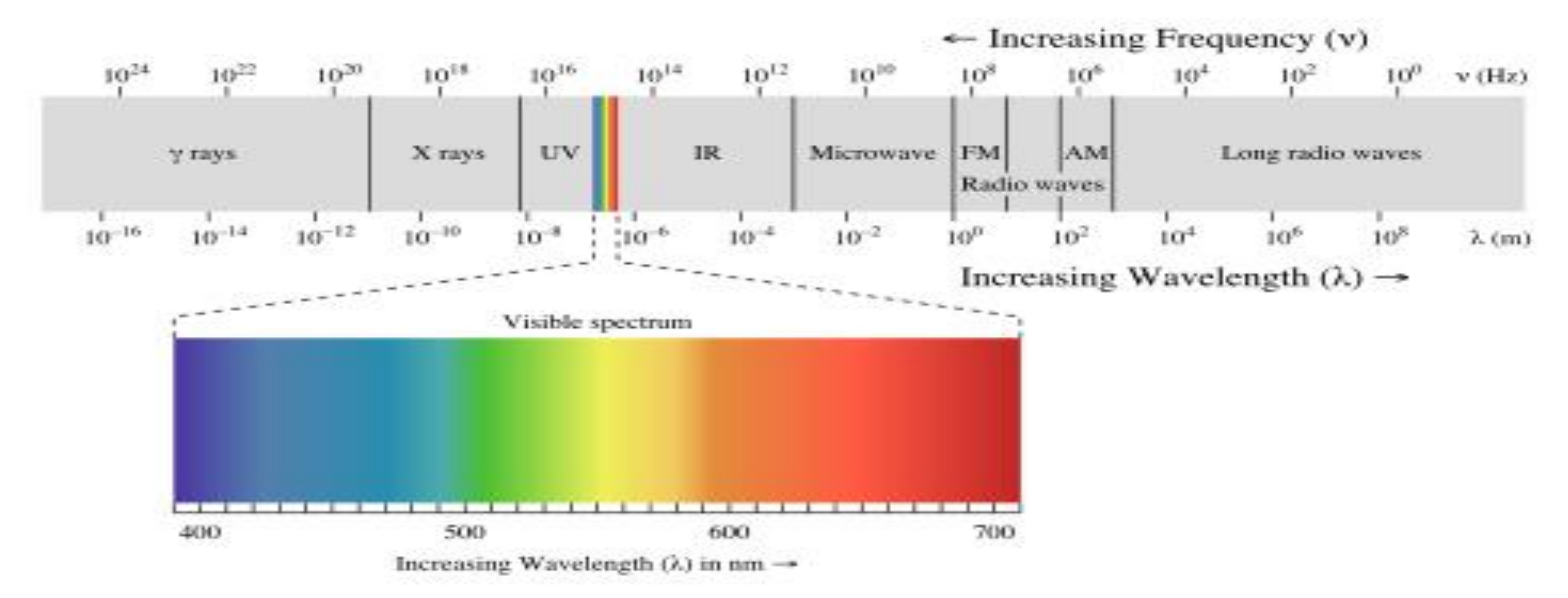
- Above infrared in frequency comes **visible light**.
- The Sun emits its peak power in the visible region, although integrating the entire emission power spectrum through all wavelengths shows that the Sun emits slightly more infrared than visible light.
- The Sun's light is the form of EMR that is most familiar to human beings.

Sunlight that is reflected by physical objects travels in most situations in a straight line to the observer's eye.

- On reaching the retina, it generates electrical signals that are transmitted to the brain by the optic nerve.

- The brain uses these signals to construct an image of the viewer’s surroundings. Visible light is called so because the eye detects it, whereas other forms of EMR are invisible to the unaided eye.
- The light which our eyes/our "remote sensors" - can detect is part of the visible spectrum.
- It is important to recognize how small the visible portion is relative to the rest of the spectrum.
- It is important to note that this is the only portion of the spectrum we can associate with the concept of **colours.**

- By definition, visible light is the part of the EM spectrum to which the human eye is the most sensitive.
- Electromagnetic radiation with a wavelength between 380 nm and 760 nm (400-790 terahertz) is detected by the human eye and perceived as visible light



Interaction of EMR with Earth's Surface

- Radiation from the sun, when incident upon the earth’s surface, is either reflected by the surface, transmitted into the surface or absorbed and emitted by the surface.
- The amount and spectral distribution of the reflected energy is used in remote sensing to infer the nature of the reflecting surface.
- A basic assumption made in remote sensing is that specific targets (soils , water, or vegetation of various species) have an individual and characteristic manner of interacting with incident radiation that is described by the spectral response of that target.
- In some instances, the nature of the interaction between incident radiation and Earth surface material will vary from time to time during the year, such as might be expected in the case of vegetation as it develops from the leafing stage, through growth to maturity and, finally, to senescence.

- In remote sensing the spectral reflectance of a given Earth surface cover type is influenced by a variety of confusing factors.
- For example the spectral reflectance curve of a particular agricultural crop such as wheat is not constant over time, nor is it the same for all kinds of wheat.
- The spectral reflectance curve is affected by factors such as soil nutrient status, the growth stage of the vegetation, the colour of the soil (which may be affected by recent weather conditions), the solar azimuth and elevation angles and the look angle of the sensor.
- The topographic position of the target in terms of slope orientation with respect to solar azimuth and slope angle also has an effect on the reflectance characteristics of the target, as will the state of the atmosphere.

- The EMR, on interaction, experiences a number of changes in magnitude, direction, wavelength, polarization and phase.
- These changes are detected by the remote sensor and enable the interpreter to obtain useful information about the object of interest.
- The remotely sensed data contain both **spatial information** (size, shape and orientation) and **spectral information** (tone, colour and spectral signature).
- There are three ways in which the total incident energy will interact with earth's surface materials.

These are

- Absorption
- Transmission
- Reflection

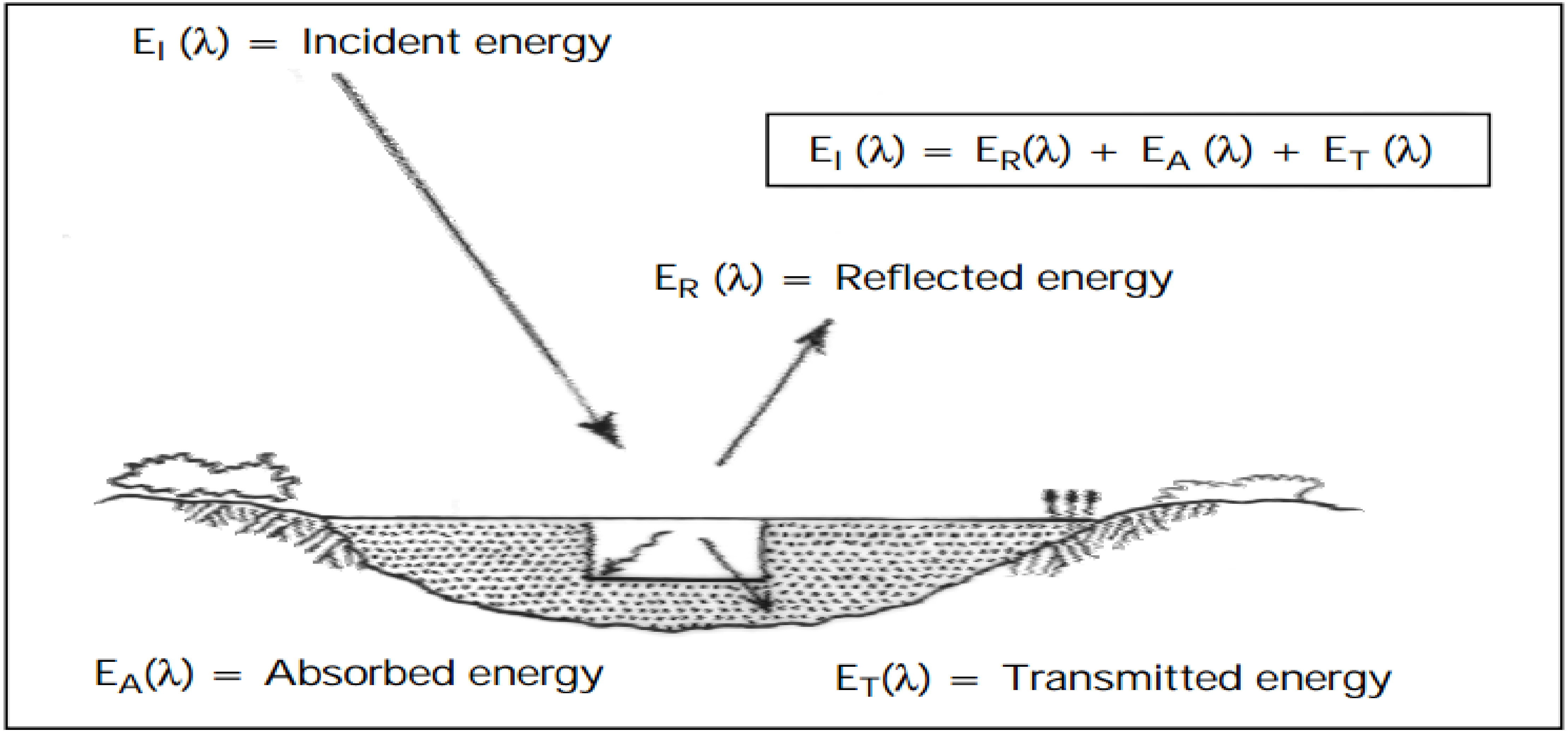
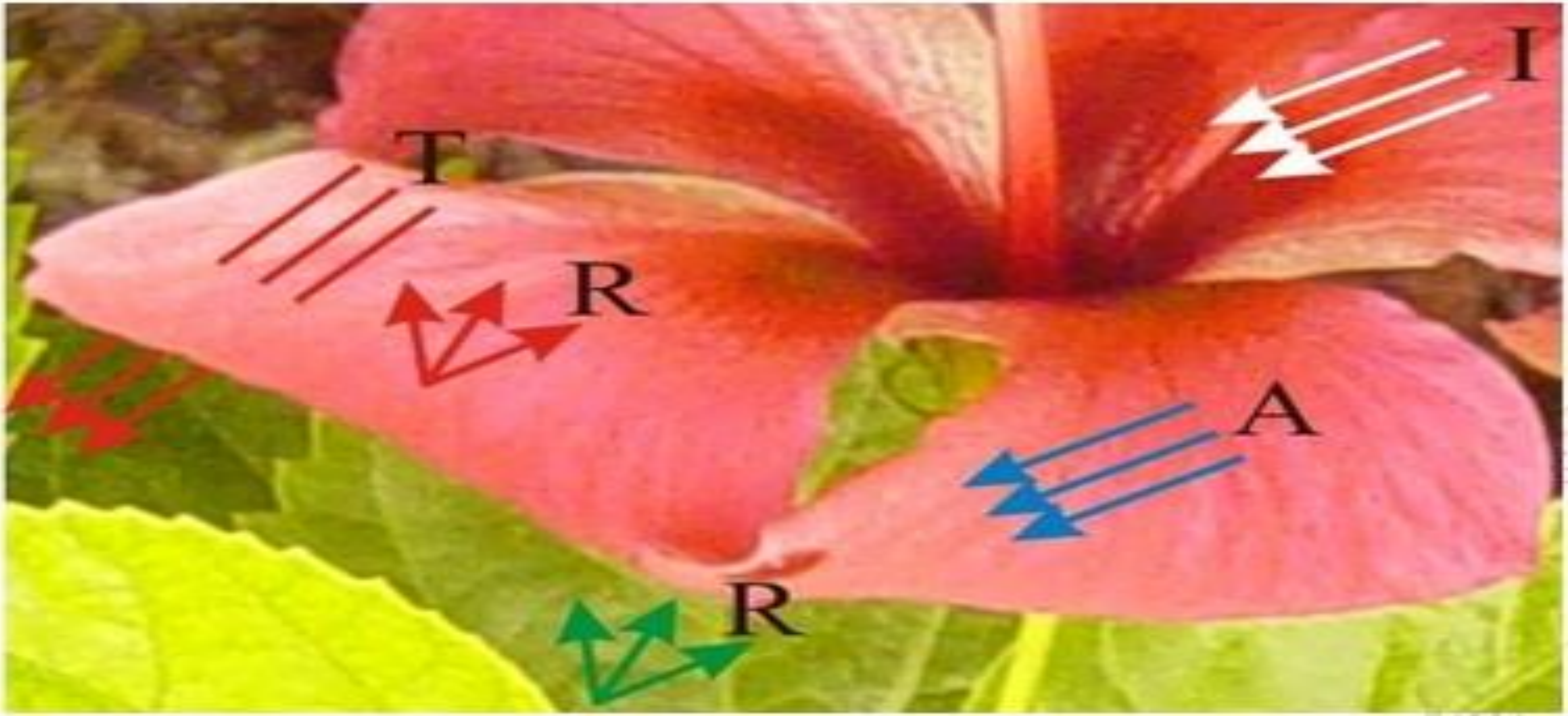


Figure 5: Interaction of Energy with the earth's surface

- **Absorption** occurs when radiation is absorbed into the target.
- **Transmission** occurs when radiation passes through a target.
- **Reflection** occurs when radiation "bounces" off the target and is redirected.
- How much of the energy is absorbed, transmitted or reflected by a material will depend upon:
  - ✓ Wavelength of the energy
  - ✓ Material constituting the surface, and
  - ✓ Condition of the feature.

Example for the interaction of incident energy

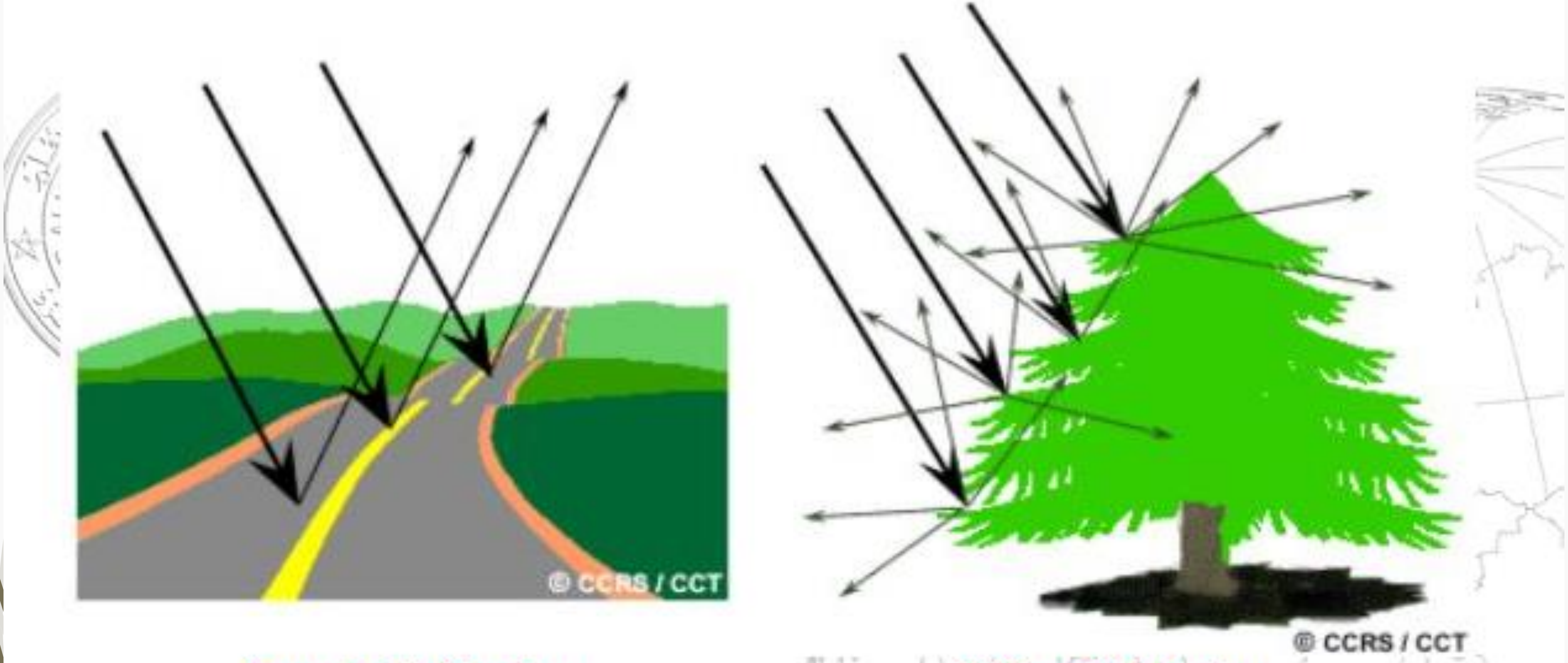


Reflection

- Of all the interactions in the reflective region, surface reflections are the most useful and revealing in remote sensing applications.
- Reflection occurs when a ray of light is redirected as it strikes a non-transparent surface.
- In remote sensing, we are most interested in measuring the radiation reflected from targets.
- Reflection from surfaces occurs in two ways:
- ✓ **Specular Reflection**
- ✓ **Diffuse Reflection**

- *Specular* reflection is that kind of reflection in which energy leaves the reflecting surface without being scattered, with the angle of incidence being equal to the angle of reflectance. Surfaces that reflect *specularly* are smooth relative to the wavelength of the incident energy.
- When the surface is smooth, we get a mirror-like or smooth reflection where all (or almost all) of the incident energy is reflected in one direction. This is called **Specular Reflection** and gives rise to images.
- *Diffuse* reflectance occurs when the reflecting surface is rough relative to the wavelength of the incident energy, and the incident energy is scattered in all directions
- A mirror reflects specularly while a piece of paper reflects diffusely. When the surface is rough, the energy is reflected uniformly in almost all directions. This is called **Diffuse Reflection.**

Example for Specular and Diffused Reflection



Specular Reflection

Diffuse Reflection

❖ Transmission

- Transmission of radiation occurs when radiation passes through a substance without significant attenuation.
- For a given thickness, or depth of a substance, the ability of a medium to transmit energy is measured as transmittance (τ).

$$\tau = \frac{\text{Transmitted radiation}}{\text{Incident radiation}}$$

Spectral reflectance of Earth surface materials

- Spectral reflectance, [$\rho(\lambda)$], is the ratio of reflected energy to incident energy as a function of wavelength.
- Various materials of the earth's surface have different spectral reflectance characteristics. Spectral reflectance is responsible for the color or tone in a photographic image of an object.
- The values of the spectral reflectance of objects averaged over different, well-defined wavelength intervals comprise the spectral signature of the objects or features by which they can be distinguished.
- To obtain the necessary ground truth for the interpretation of multispectral imagery, the spectral characteristics of various natural objects have been extensively measured and recorded.

- The spectral reflectance is dependent on wavelength, it has different values at different wavelengths for a given terrain feature.
- The reflectance characteristics of the earth's surface features are expressed by spectral reflectance, which is given by:

$$\rho(\lambda) = [E_R(\lambda) \ / \ E_I(\lambda)] \times 100$$

Where,

$\rho(\lambda)$ = Spectral reflectance (reflectivity) at a particular wavelength.

$E_R(\lambda)$ = Energy of wavelength reflected from object

$E_I(\lambda)$ = Energy of wavelength incident upon the object

- The plot between $\rho(\lambda)$ and λ is called a spectral reflectance curve. This varies with the variation in the chemical composition and physical conditions of the feature, which results in a range of values.

- The spectral response patterns are averaged to get a generalized form, which is called generalized spectral response pattern for the object concerned.
- Spectral signature is a term used for unique spectral response pattern, which is characteristic of a terrain feature.

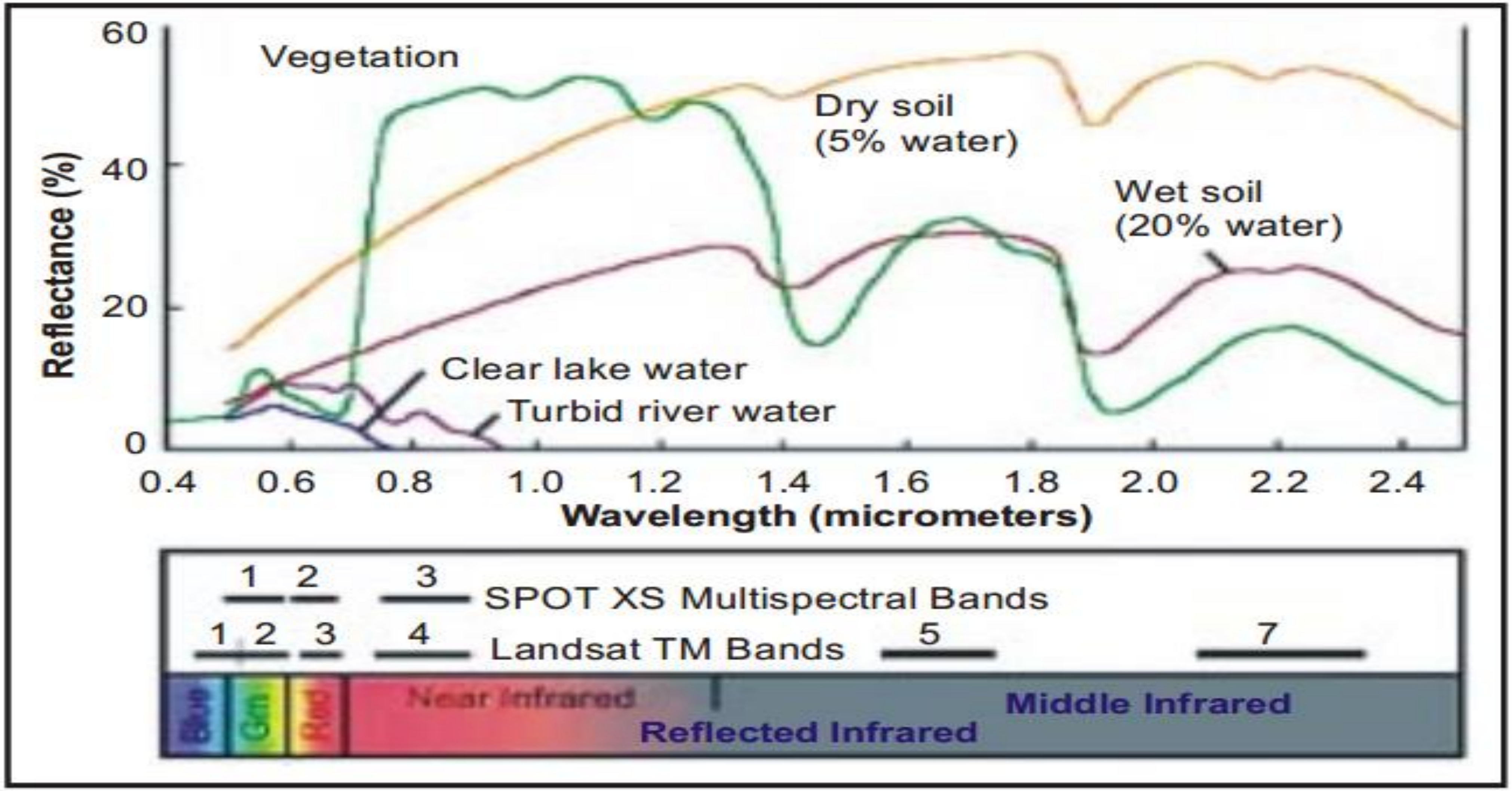


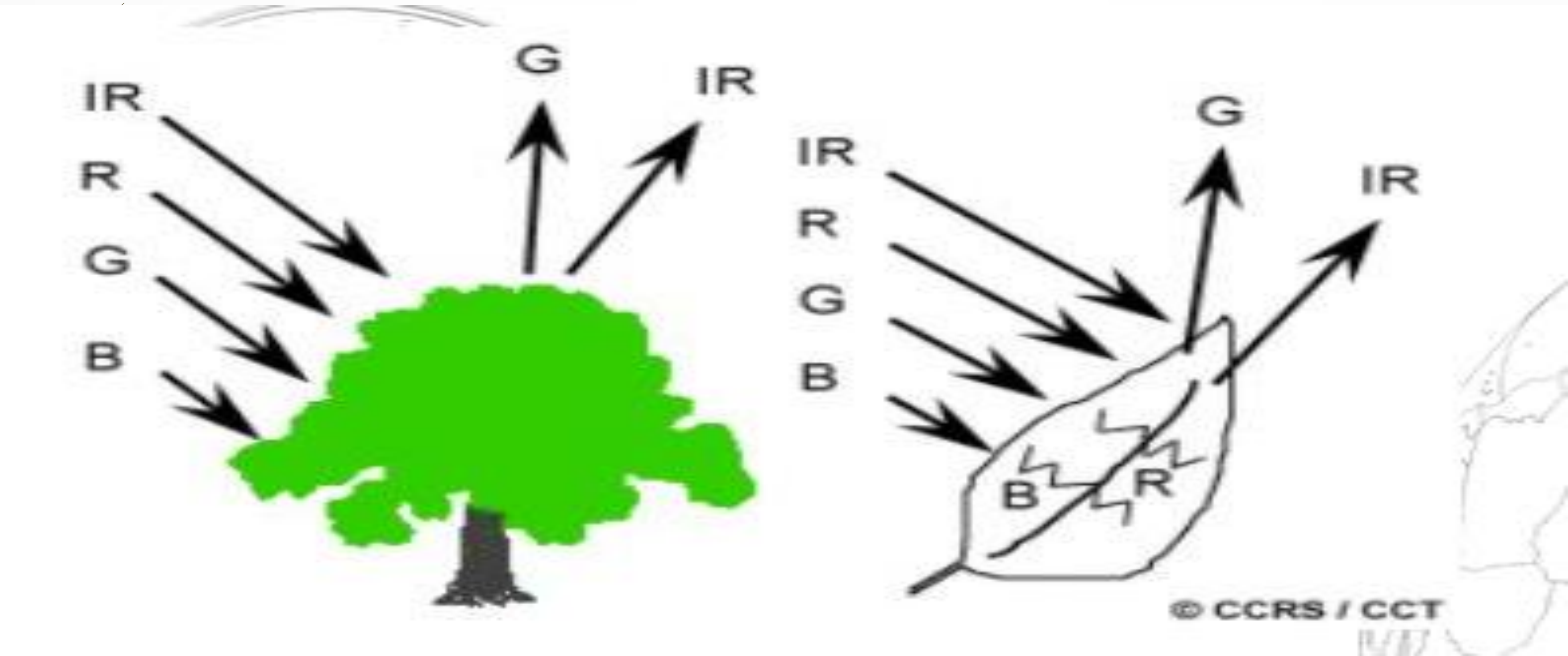
Figure 6: Typical Spectral Reflectance curves for vegetation, soil and water

- Typical spectral reflectance curves for characteristic types of Earth surface materials that are considered in this section are vegetation, soil, and water.

- ***Vegetation***

- A chemical compound in leaves called chlorophyll strongly absorbs radiation in the red and blue wavelengths but reflects green wavelengths.
- Leaves appear "greenest" to us in the summer, when chlorophyll content is at its maximum.
- In autumn, there is less chlorophyll in the leaves, so there is less absorption and proportionately more reflection of the red wavelengths, making the leaves appear red or yellow (yellow is a combination of red and green wavelengths).
- For photosynthetically active vegetation, the spectral reflectance curve rises sharply between about 0.65 μm and 0.76 μm, and remains high in the near-infrared region between 0.75 and 1.35 μm due to interactions between the internal leaf structure and EMR at these wavelengths.

- Internal leaf structure has some effect between 1.35 and 2.5 µm, but reflectance is largely controlled by leaf-tissue water content, which is the cause of the minima recorded near 1.45 µm and 1.95 µm.
- The status of the vegetation (in terms of photosynthetic activity) is frequently characterised by the position of a point representative of the steep rise in reflectance at around 0.7 µm.



Water bodies

- The characteristic spectral reflectance curve for water shows a general reduction in reflectance with increasing wavelength, so that in the near infrared the reflectance of deep, clear water is virtually zero.
- However, the spectral reflectance of water is affected by the presence and concentration of dissolved and suspended organic and inorganic material, and by the depth of the water body.
- Thus, the intensity and distribution of the radiance upwelling from a water body are indicative of the nature of the dissolved and suspended matter in the water, and of the water depth.
- The presence of chlorophyll is an indication of the trophic status of lakes and is also of importance in estimating the level of organic matter in coastal and estuarine environments.

- Whereas suspended matter has a generally broadband reflectance in the visible and near infrared, chlorophyll exhibits absorption bands in the region below 0.5 μm and between 0.64 and 0.69 μm.
- Detection of the presence of chlorophyll therefore requires an instrument with a higher spectral resolution than would be required to detect suspended sediment.

- Longer wavelength visible and near infrared radiation is absorbed more by water than shorter visible wavelengths.
- Thus water typically looks blue or blue-green due to stronger reflectance at these shorter wavelengths, and darker if viewed at red or near infrared wavelengths.

- If there is suspended sediment present in the upper layers of the water body, then this will allow better reflectivity and a brighter appearance of the water.
- Suspended sediment (S) can be easily confused with shallow (but clear) water. Algae absorbs more of the blue wavelengths and reflects the green, making the water appear more green in colour when algae is present.
- The topography of the water surface can also lead to complications for water-related interpretation due to potential problems of specular reflection and other influences on colour and brightness.

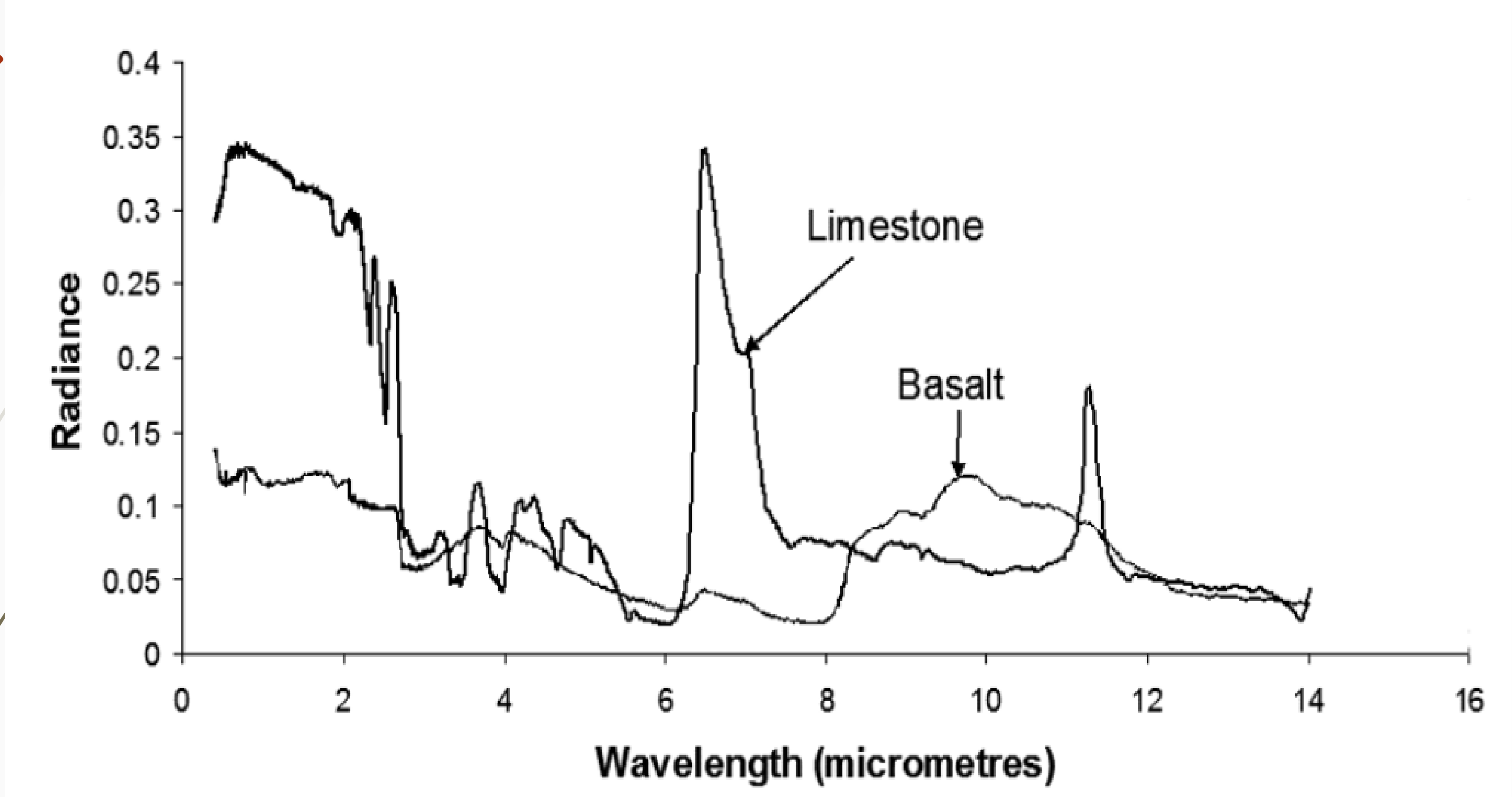
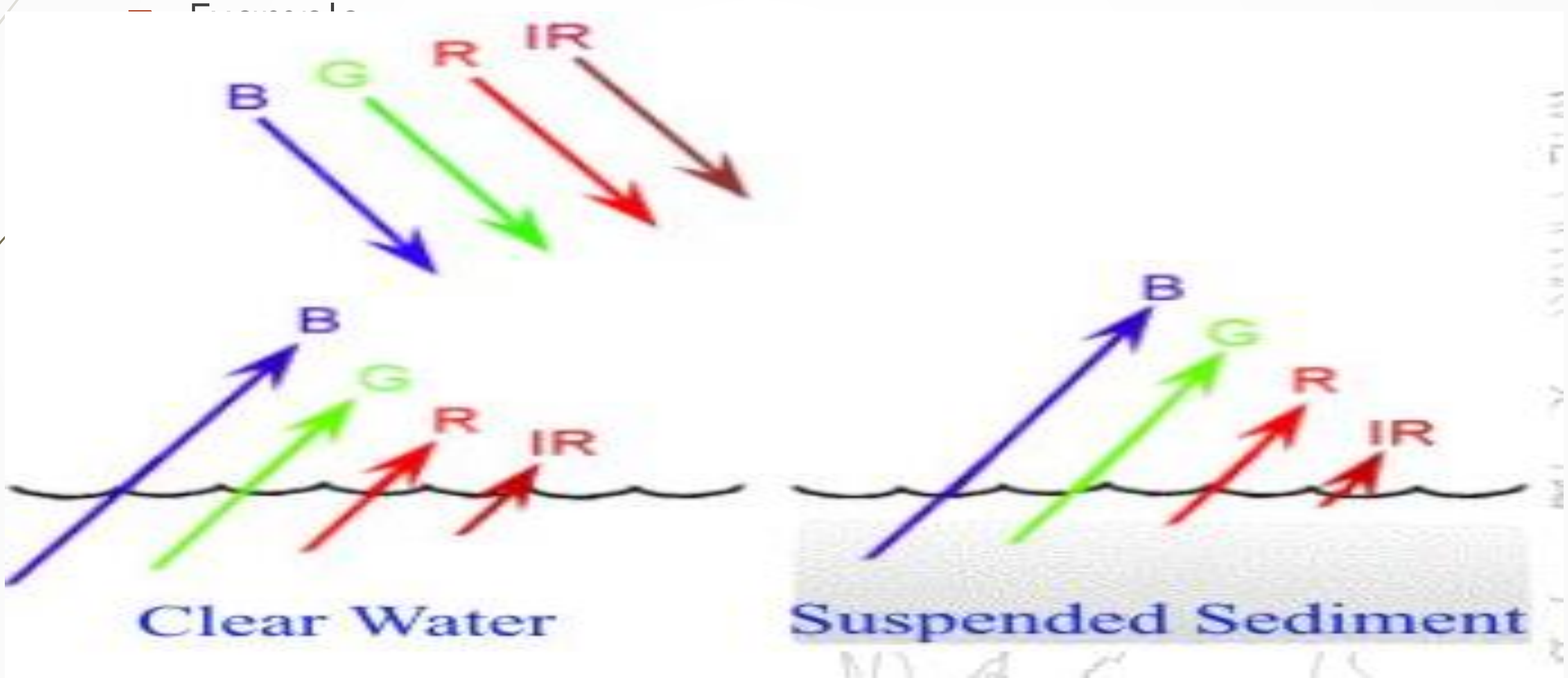


Figure Reflectance and emittance spectra of limestone and basalt samples.

Radiation – Target Interactions



- **Soil**

The majority of radiation incident on a soil surface is either reflected or absorbed and little is transmitted.

- The spectral reflectance curves of soils are generally characterized by a rise in reflectivity as wavelength increases - the opposite, in fact, of the shape of the spectral reflectance curve for water.
- Reflectivity in the visible wavebands is affected by the presence of organic matter in the soil, and by the soil moisture content, while at 0.85– 0.93 μm there is a ferric iron absorption band.

- The characteristics of soil that determine its reflectance properties are its moisture content, organic matter content, texture, structure and iron oxide content.
- The soil curve shows less peak and valley variations. The presence of moisture in soil decreases its reflectance.
- By measuring the energy that is reflected by targets on earth's surface over a variety of different wavelengths, we can build up a spectral signature for that object.

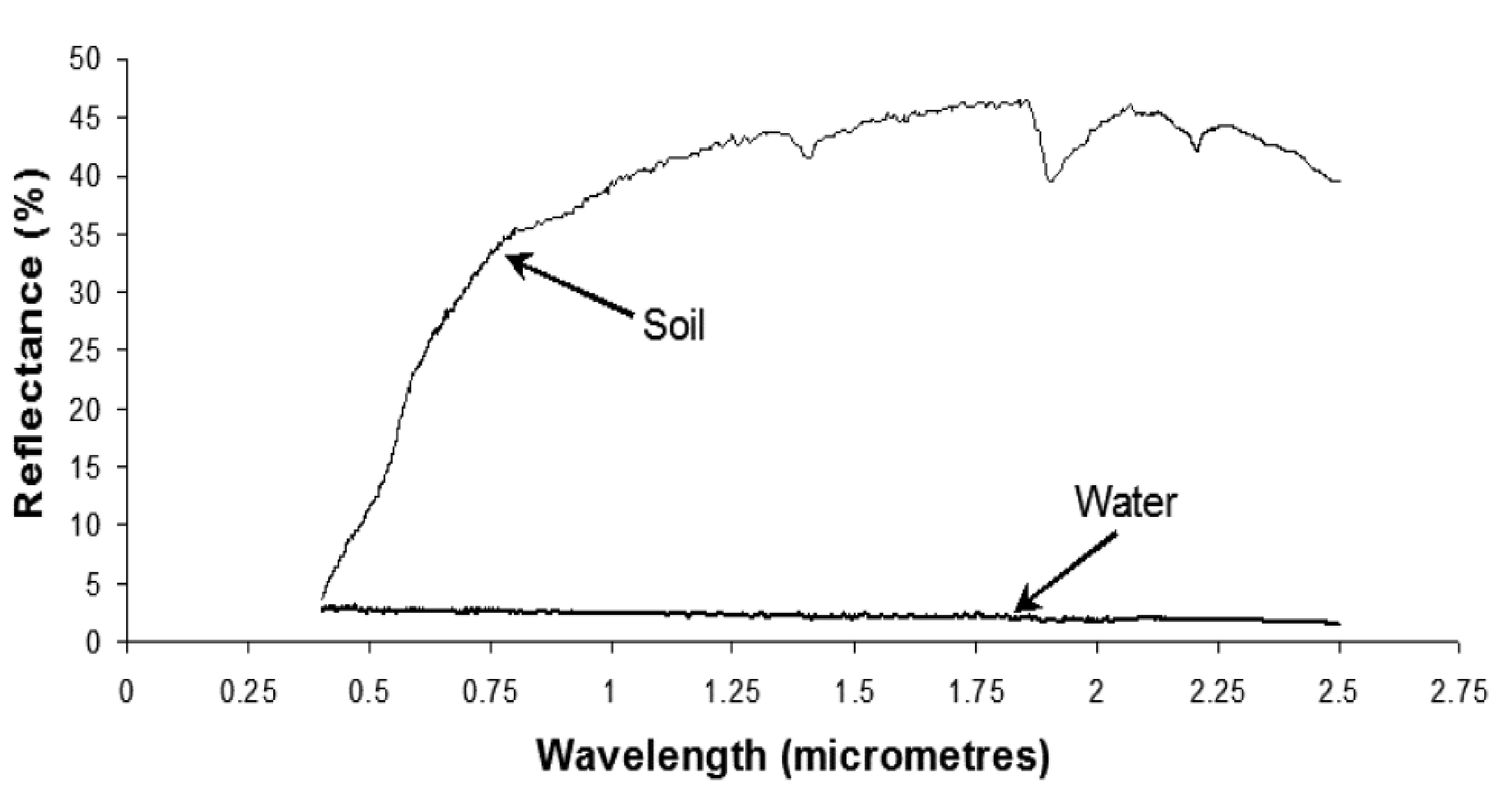


Figure 6 Reflectance spectra of water and soil from 0.4 μm to 2.5 μm.

❖ Interactions with the Earth's atmosphere

- The atmosphere is a mixture of gases with constant proportions up to 80 km or more from ground. The atmosphere can be divided into a number of well marked horizontal layers on the basis of temperature.

- **Troposphere**
- **Stratosphere**
- **Mesosphere**
- **Thermosphere**
- **Exosphere**

- It is clear that EMR from the Sun that is reflected by the Earth and detected by the satellite or aircraft-borne sensor must pass through the atmosphere twice, once on its journey from the Sun to the Earth and once after being reflected by the surface of the Earth back to the sensor.

- During its passage through the atmosphere, EMR interacts with particulate matter suspended in the atmosphere and with the molecules of the constituent gases. This interaction is usually described in terms of two processes.

- One, called *scattering*, deflects the radiation from its path while the second process, *absorption*, converts the energy present in electromagnetic radiation into the internal energy of the absorbing molecule.

- Both absorption and scattering vary in their effect from one part of the spectrum to another.

- Remote sensing of the Earth’s surface is impossible in those parts of the spectrum that are seriously affected by scattering and/or absorption, for these mechanisms effectively render the atmosphere opaque to incoming or outgoing radiation.

- Scattering is the result of interactions between electromagnetic radiation and particles or gas molecules that are present in the atmosphere.
- These particles and molecules range in size from microscopic to raindrop size (100 μm and larger). The effect of scattering is to redirect the incident radiation, or to deflect it from its path.
- Particles and gases in the atmosphere can affect the incoming light and radiation. These effects are caused primarily by the atmospheric **scattering** and **absorption**.

- The atmospheric gases that primarily cause scattering include oxygen, nitrogen, and ozone. Their molecules have radii of less than 1 μm and affect electromagnetic radiation with wavelengths of 1 μm or less.

- Other types of particles reach the atmosphere both by natural causes or because of human activities (for instance, dust from soil erosion caused by poor land management practices, and smoke particles from industrial and domestic pollution).

I. Scattering

- **Scattering:** The redirection of EM energy by the suspended particles in the air.
- **Scattering** occurs when particles or large gas molecules present in the atmosphere interact with and cause the electromagnetic radiation to be redirected from its original path.
- Scattering takes place depends on several factors including
- ✓ The wavelength of the radiation
- ✓ The abundance of particles or gases, and
- ✓ The distance the radiation travels through the atmosphere.
- The mechanisms of scattering are complex, however, it is possible to make a simple distinction between **selective** and **non-selective scattering**.
- Selective scattering affects specific wavelengths of electromagnetic radiation, while non-selective scattering is wavelength-independent.

- There are three types of scattering. These are
  - **Rayleigh scattering**
  - **Mie scattering**
  - **Nonselective scattering**
- Different particle sizes will have different effects on the EM energy propagation

dp << λ	Rayleigh scattering Sr
dp =λ	Mie scattering Sm
dp >> λ	Non-selective scattering Sn

- **Rayleigh scattering** occurs when particles are very small compared to the wavelength of the radiation. These could be particles such as small specks of dust or nitrogen and oxygen molecules.
- Rayleigh scattering causes shorter wavelengths of energy to be scattered much more than longer wavelengths. Rayleigh scattering is the dominant scattering mechanism in the upper atmosphere.

- **Mie scattering** occurs when the particles are just about the same size as the wavelength of the radiation.
- Dust, pollen, smoke and water vapour are common causes of Mie scattering which tends to affect longer wavelengths than those affected by Rayleigh scattering.
- Mie scattering occurs mostly in the lower portions of the atmosphere where larger particles are more abundant, and dominates when cloud conditions are overcast.

- **Non selective scattering** occurs when the particles are much larger than the wavelength of the radiation. Water droplets and large dust particles can cause this type of scattering.
- This type of scattering causes fog and clouds to appear white to our eyes because blue, green, and red light are all scattered in approximately equal quantities (blue + green + red light = white light).
- We cannot see through clouds because all visible wavelengths are non-selectively scattered by the water droplets of which the cloud is formed. The effect of scattering is, as mentioned earlier, to increase the haze level or reduce the contrast in an image

II. Absorption

Absorption is the other main mechanism at which electromagnetic radiation interacts with the atmosphere.

Absorption: Atmosphere selectively absorbs energy in different wavelengths with different intensity.

In contrast to scattering, this phenomenon causes molecules in the atmosphere to absorb energy at various wavelengths.

- The atmosphere is composed of N2 (78%), O2 (21%), CO2, H2O, CO, SO2, etc
- Ozone, carbon dioxide, and water vapour are the three main atmospheric constituents which absorb radiation.

Ozone absorbs the high energy, short wavelength portions of the ultraviolet spectrum (λ< 0.24 µm) thereby preventing the transmission of this radiation to the lower atmosphere.

- Carbon dioxide is important in remote sensing as it effectively absorbs the radiation in mid and far infrared regions of the spectrum.
- It strongly absorbs in the region from about 13-17.5 µm, whereas two most important regions of water vapour absorption are in bands 5.5 - 7.0 µm and above 27 µm.

- Atmospheric absorption reduces the number of spectral regions that we can work with in observing the Earth.
- This affects our decision in selecting and designing sensor. So we have to consider the following points in selecting and designing sensor.
  - The spectral sensitivity of sensors available
  - The presence and absence of atmospheric windows
  - The source, magnitude, and spectral composition of the energy available in these ranges.

❖ Atmospheric Window

- The atmosphere selectively transmits energy of certain wavelengths.
- The spectral bands for which the atmosphere is relatively transparent are known as **atmospheric windows.**
- It refers to the relatively transparent wavelength regions of the atmosphere.
- Thus, areas of the spectrum which are not severely influenced by atmospheric absorption and thus, are useful to remote sensors.

- The visible portion of the spectrum, to which our eyes are most sensitive, corresponds to both an atmospheric window and the peak energy level of the sun.
- Atmospheric windows are present in the visible part (.4 µm - .76 µm) and the infrared regions of the EM spectrum.
- In the visible part transmission is mainly affected by ozone absorption and by molecular scattering.
- The atmosphere is transparent again beyond about λ= 1mm, the region used for microwave remote sensing.

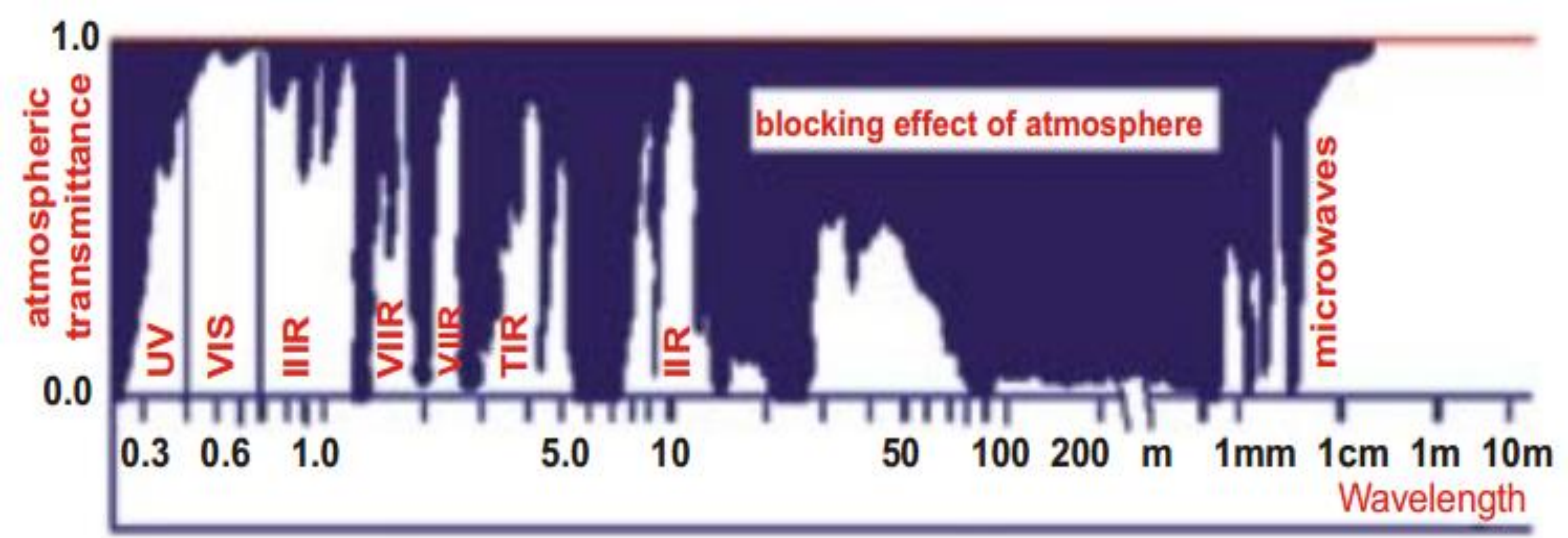


Figure 7 : Atmospheric windows

Types of Remote Sensing or sensor

There are two types of remote sensing or sensors, namely

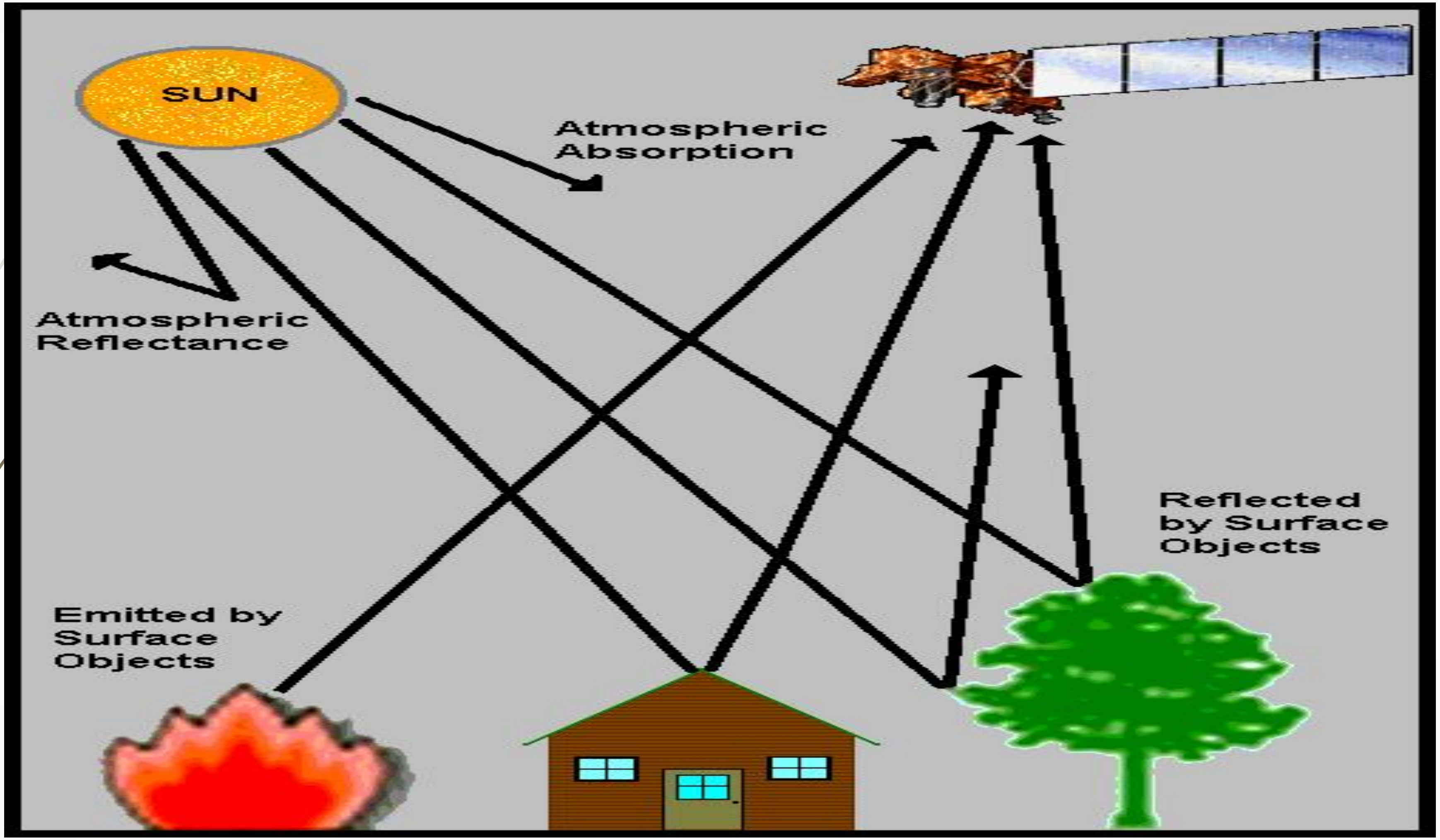
- Passive Remote Sensing
- Active Remote Sensing

Passive Remote Sensing or Sensor System

- Passive remote sensing systems record EM energy that is reflected or emitted from the surface of the Earth.
- A passive sensor system needs an external energy source . In most cases this source is the sun.
- Passive systems are much more common than active systems.
- Some examples of passive system are Aerial photo and satellite image

- Some examples of passive system are satellite images. These include the Gemini, Apollo, and Skylab cameras; the series of Landsat cameras, including the Multispectral Scanner (MSS),
- Landsat Thematic Mapper (TM), and the Enhanced Landsat Thematic Mapper Plus (ETM+);
- the series of SPOT Satellite Imagers; and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER).

Example for Passive sensor system



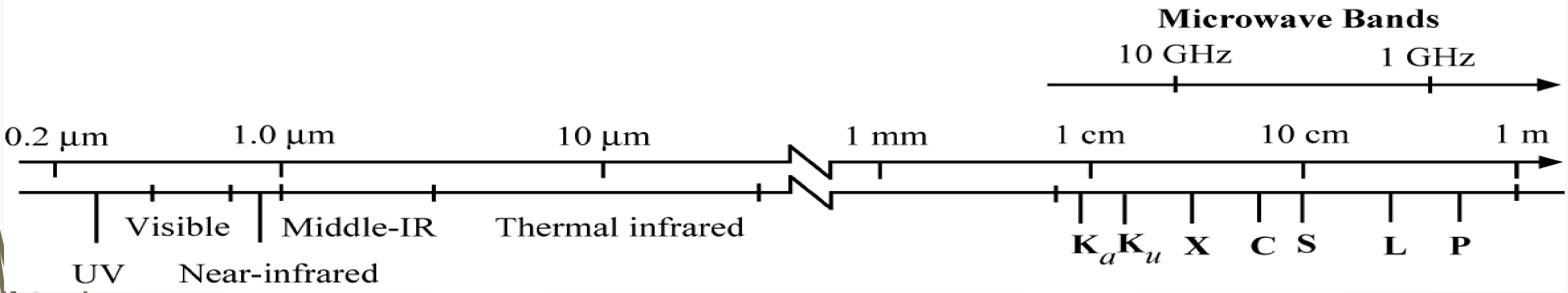
❑ Active Remote Sensor Systems

- *Active* remote sensors create their own electromagnetic energy that
- 1) is transmitted from the sensor toward the target and is largely unaffected by the atmosphere,
- 2) interacts with the target producing a backscatter of energy, and
- 3) is recorded by the remote sensor's receiver.

- In short an active sensor system provides its own energy source.
- As an example, a radar sensor sends out sound waves and records the reflection waves coming back from the surface.
- Some examples of active sensor are Active system
  - RADAR-Radio Detection And Ranging
  - LIDAR- Light Detection And Ranging
  - SONAR- Sound Navigation And Ranging

Radar Basics

Radar is an active remote sensing system operating at the *microwave* wavelength.



Radar is a ranging instrument: Radio Detection And Ranging

Basic Principles

- The sensor transmits a microwave signal towards a target and detects the backscattered radiation
- The strength of the backscattered signal indicates the target property
- The time delay between the transmitted and reflected signals determines the distance (or range) to the target

Advantages of Radar

- All-weather
- Day/night imaging
- Numerous Applications
- Detection/analysis of meteorological phenomena
- Navigation
- Law Enforcement, etc.

Data Reception, Transmission, and Processing

- Data obtained during remote sensing missions can be processed and delivered to the end user.

- There are **three** main options for **transmitting data** acquired by satellites to the surface.

1. The data can be directly transmitted to Earth if a Ground Receiving Station (GRS) is in the line of sight of the satellite.

2. If this is not the case (if they are not inline of sight), the data can be recorded on board the satellite for transmission to a GRS at a later time.

3. Data can also be relayed to the GRS through the Tracking and Data Relay Satellite System (TDRSS) which consists of a series of communications satellites in geosynchronous orbit.

- The data are transmitted from one satellite to another until they reach the appropriate GRS.
- The data are received at the GRS in a raw digital format.
- The raw data may be processed to correct systematic, geometric and atmospheric distortions to the imagery,
- be translated into a standardized format. Then delivered to the end user

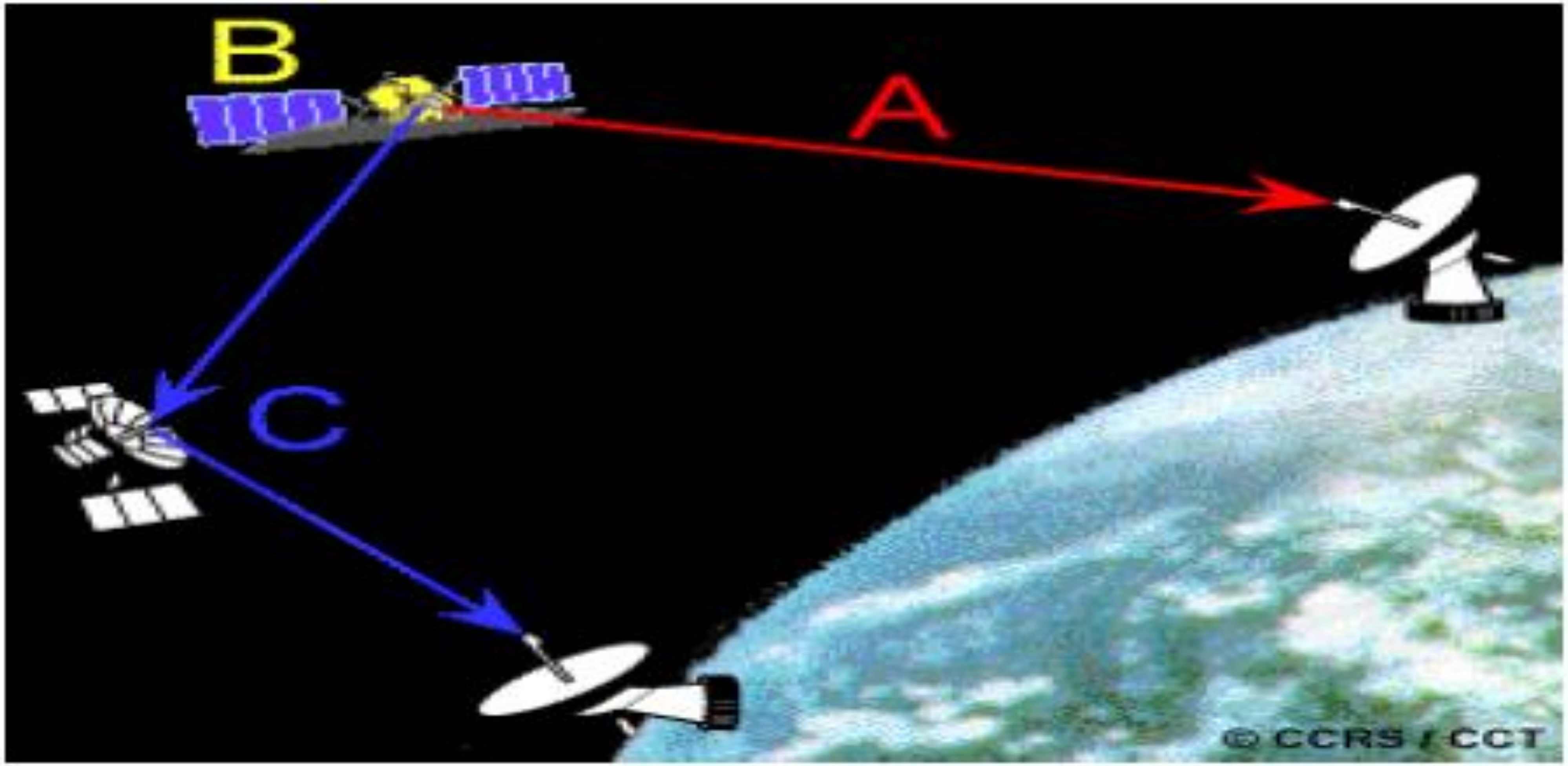


Figure8: different ways of transmitting data acquired by satellite

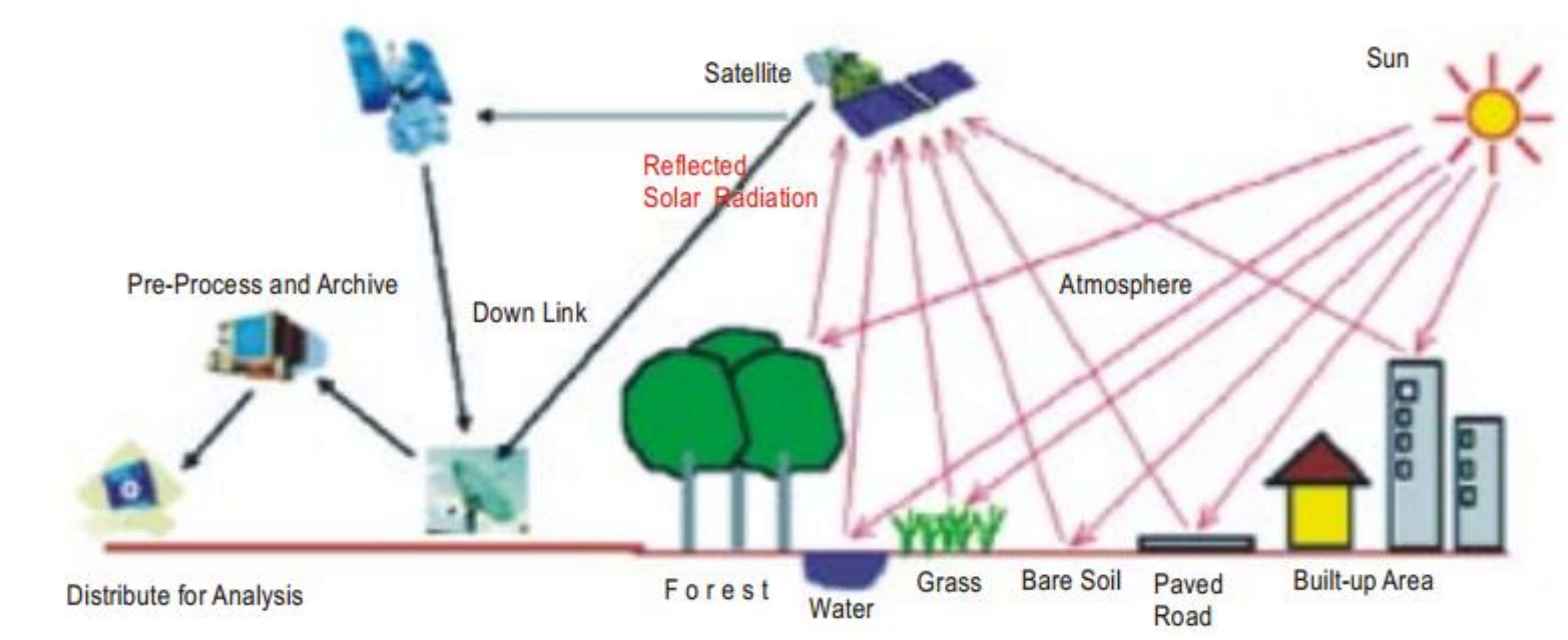


Figure 9: Data transmission, processing and analysis

Advantage of Remote Sensing

- The advantages of acquiring information by Remote Sensing apply, irrespective of platform or sensor.
- It is cheaper than conventional surveying.
- It is safer than hydrographic surveying in shoal areas such as coral reefs.
- It is capable of change detection in rapidly developing ports and regular monitoring of mobile areas such as deltas and sandbanks.
- World-wide coverage is commercially available, without security, political, or copyright restrictions, enabling data acquisition from remote areas.

Platforms, Orbit, and Concept of Resolution

Types of platforms used for remote sensing

- In order to collect and record energy reflected or emitted from a target or surface, it must reside on a stable **platform** removed from the target or surface being observed.
- Platforms for remote sensors may be situated on the ground, on an aircraft or balloon or on a spacecraft or satellite.
- There are three types of platforms these are
  - *Ground based platform*
  - *Air born*
  - *Space born platform*

❖ Ground based platform

Mobile Hydraulic Platforms
Carried on vehicles

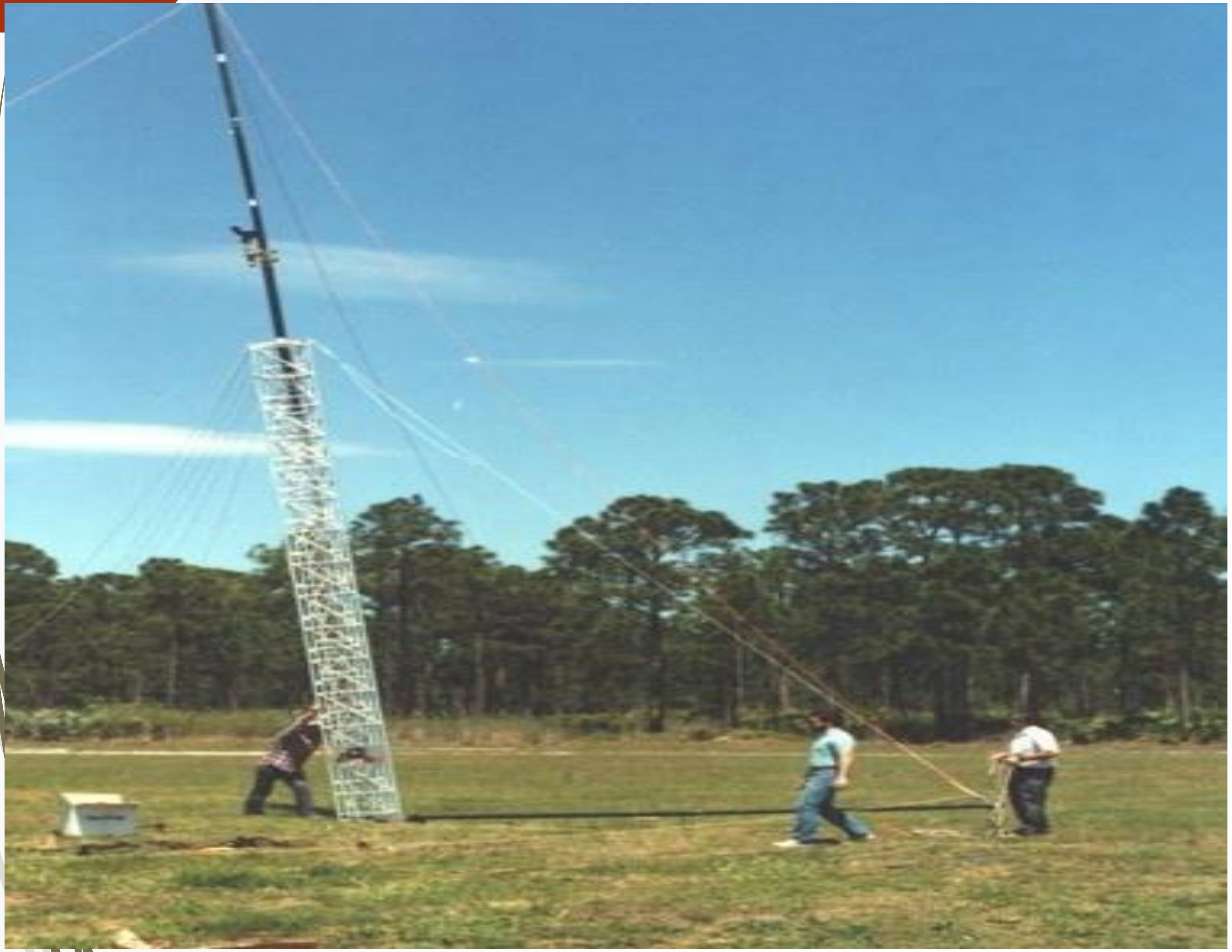
- Ground-based platforms: ground, vehicles and towers => up to 50 m
- Ground-based sensors are often used to record detailed information about the surface which is compared with information collected from aircraft or satellite sensors.

Portable Masts

Used to support cameras and scanners

E.g. a Land Rover fitted with an extending aerial

Towers



- Can be dismantled and moved from one place to another.
- Offer greater rigidity than masts but are less mobile and require more time to erect

- **Airborne platforms**: are airplanes, helicopters, high-altitude aircrafts, balloons => up to 50 km
- Sensors may be placed on a ladder, scaffolding, tall building, cherry-picker, crane, etc.
- Aircraft are often used to collect very detailed images and facilitate the collection of data over virtually any portion of the Earth's surface at any time.

AIRCRAFT PLATFORMS INSTALLED IN THE WINGS

- **Aircraft have several useful advantages as platforms for remote sensing systems.**

- Aircraft can fly at relatively low altitudes thus allowing for sub-meter sensor spatial resolution.
- Aircraft can easily change their schedule to avoid weather problems such as clouds, which may block a passive sensor's view of the ground.
- Sensor maintenance, repair and configuration changes are easily made to aircraft platforms.
- Aircraft flight paths know no boundaries except political boundaries.

Disadvantages of aircraft as platforms in remote sensing.

- Getting permission to intrude into foreign airspace can be a lengthy and frustrating process.
- The low altitude flown by aircraft narrows the field of view to the sensor requiring many passes to cover a large area on the ground.
- The turnaround time it takes to get the data to the user is delayed
- due to the necessity of returning the aircraft to the airport before transferring the raw image data to the data provider's facility for preprocessing.

Space borne platforms

In space borne remote sensing, sensors are mounted on-board a spacecraft (space shuttle or satellite) orbiting the earth.

- **Satellites** are objects which revolve around another object - in this case, the Earth.
- Space borne platforms include the following:
  - Rockets
  - Satellites and
  - space shuttles.

- Space borne platforms range from 100 to 36000 km above the earth's surface.

- This is shown below,
  - ✓ Space shuttle: 250-300 km
  - ✓ Space stations: 300-400 km
  - ✓ Low level satellites: 700-1500 km
  - ✓ High level satellites: About 36000 km

Space borne remote sensing provides the following advantages:

- Large area coverage; Frequent and repetitive coverage of an area of interest;
- Quantitative measurement of ground features using radiometrically calibrated sensors;
- Semi automated computerized processing and analysis;
- Relatively lower cost per unit area of coverage

Examples for space borne shutter and satellites

❑ Orbit

- The path followed by a satellite is referred to as its **orbit**.
- Satellite orbits are matched to the capability and objective of the sensor(s) they carry.
- Orbit selection can vary in terms of altitude (their height above the Earth's surface) and
- Their orientation and rotation relative to the Earth.
- Satellites orbits classified in to:
  - Low-level orbit
  - High-level orbit

- **Low-level orbit** mounted from 700-1500 km

- Earth observation satellites classified into three broad groups:

i. Equatorial orbiting satellites

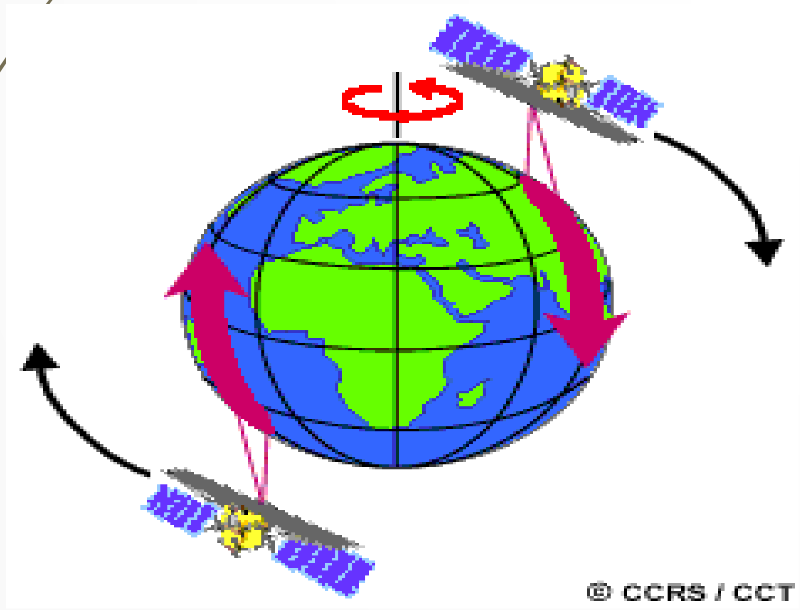
ii. Polar orbiting satellite

iii. Oblique orbiting (near-polar) satellites

- LEO satellites are often on sun-synchronous orbits.

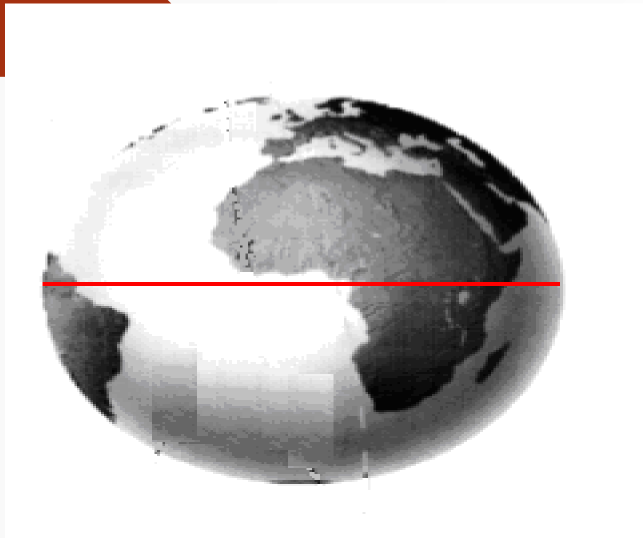
- Sun-synchronous means that the satellite remains fixed with respect to the Sun with the Earth rotating under the satellite (i.e., satellite passes over its target on the Earth at roughly the same local time).

- In the case of near polar orbits, which the satellite travels northwards on one side of the Earth and then to ward the southern pole on the second half of its orbit.
- These are called **ascending and descending passes**, respectively.
- Ascending pass is when the satellite travels from south to north.
- Descending pass when the satellite travels from north to south.

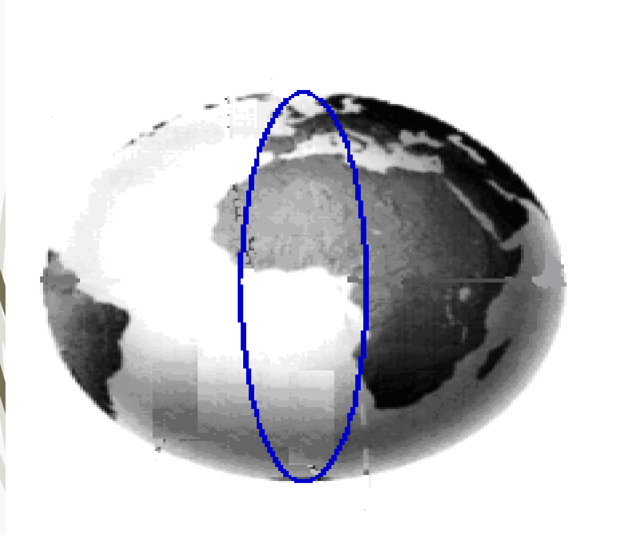


The satellite travels (North- south)

- A satellite in a **polar orbit** travels over the North and South Poles.
- A polar orbit may be from several hundred miles to several thousand miles above Earth.
- This type of satellite circles the Earth approximately 14 times each day.
- Because the Earth is turning more slowly than the satellite, the satellite gets a slightly different view on every revolution.
- Over the course of a few days, a satellite in a polar orbit will cover almost all the planet.

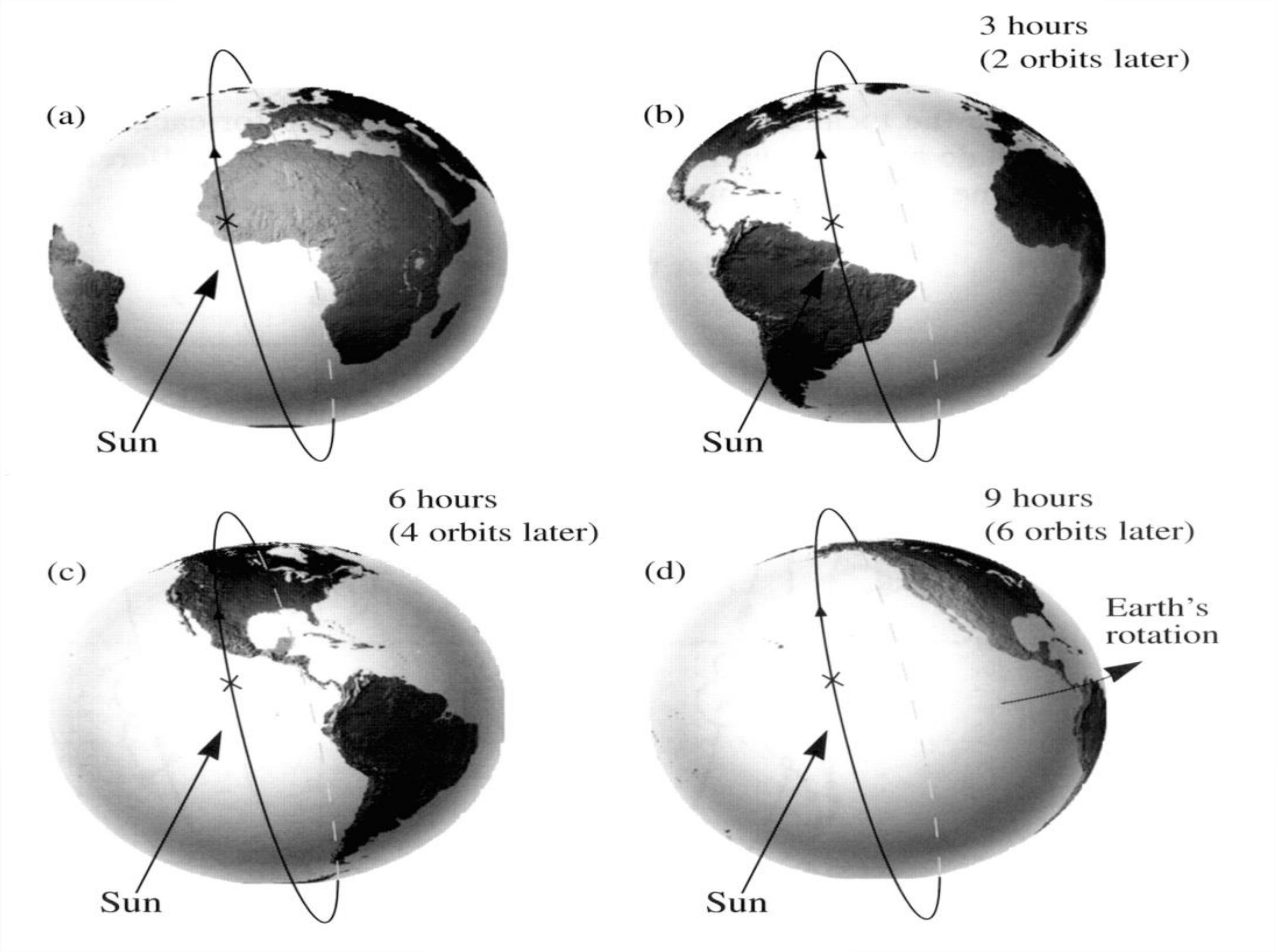


Equatorial orbiting satellites, whose orbits are within the plane of the Equator



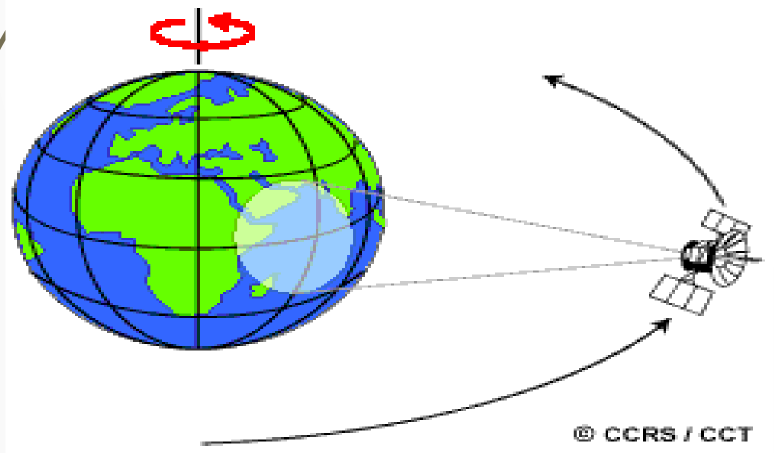
Polar orbiting satellites, whose orbits are in the plane of the Earth's polar axis

Oblique orbiting (near-polar orbiting) satellites: Sun-synchronous orbits (each3 hours)



- Oblique orbiting satellites can be launched eastwards into direct (called pro grade) orbit (so called because the movement of such satellites is in the same direction as the rotation of the Earth), or westwards into retrograde orbit.
- The inclination of a orbit is specified in terms of the angle between its ascending track and the Equator.

- **Swath** is the area imaged on the surface by the sensor.



- **High-level orbit(Geosynchronous satellites)**
- **Geostationary** satellites (often called weather satellites) are “fixed” above a given point on the Earth surface because their circular orbits above the equator have rotation period equals to the earth’s rotation period.
- Satellites at very high altitudes, which view the same portion of the Earth's surface at all times have **geostationary orbits**.

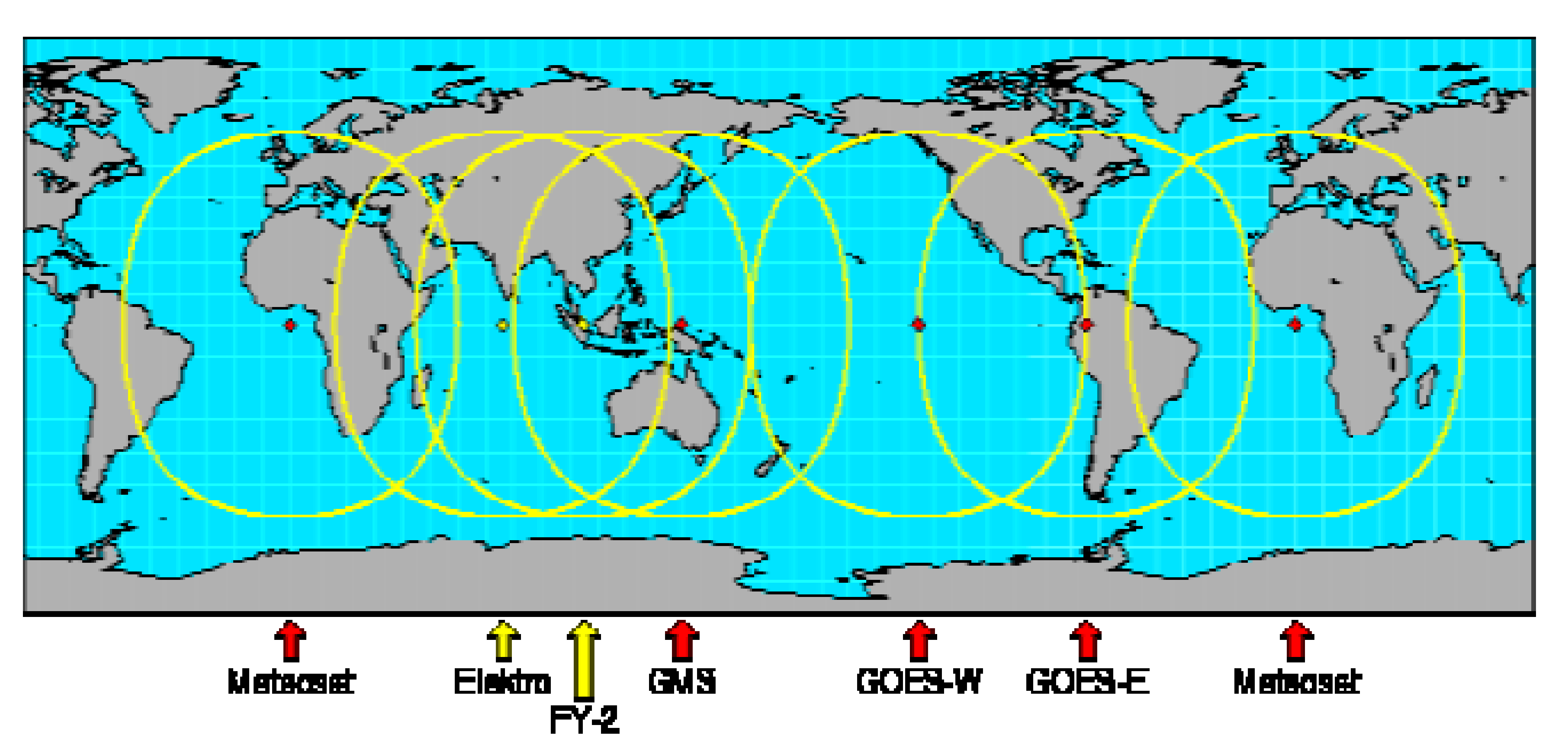
- These geostationary satellites, at altitudes of approximately 36,000 kilometers,
- revolve at speeds which match the rotation of the Earth so they seem stationary, relative to the Earth's surface.

- This allows the satellites to observe and collect information continuously over specific areas.
- Weather and communications satellites commonly have these types of orbits.

- Due to their high altitude, some geostationary weather satellites can monitor weather and cloud patterns covering an entire hemisphere of the Earth.

- A satellite in a **high-altitude, geostationary orbit** circles the earth once every 24 hours, the same amount of time it takes for the Earth to spin on its axis.
- The satellite turns eastward (like our Earth) along the Equator.
- It stays above the same point on Earth all the time.
- To maintain the same rotational period as the Earth, a satellite in geostationary orbit must be 22,237 miles above the Earth.
- At this distance, the satellite can view a huge portion of the Earth's surface

Example of geostationary satellite coverage.



Resolution

- Resolution is defined as the ability of a system to render the information at the smallest discretely separable quantity in terms of distance(spatial), wavelength band of EMR(spectral), time(temporal) and radiation quantity(radiometeric).

- **Spatial**: the size of the field-of-view, e.g. 10 x 10m
- **Spectral**: the number and size of spectral regions the sensor records data in, e.g. blue, green, red, near-infrared, thermal infrared, microwave.
- **Temporal** - how often the sensor acquires data, e.g. every 30 days.
- **Radiometric** - the sensitivity of detectors to small differences in electromagnetic energy.

❖ Spatial resolution

- **Spatial resolution** refers to the ability of the sensor to distinguish/detect the smallest possible feature between two closely spaced objects on an image.

- **It** refers to the size of the smallest possible feature that can be detected. Normally given in meters and It is based on the pixel size.

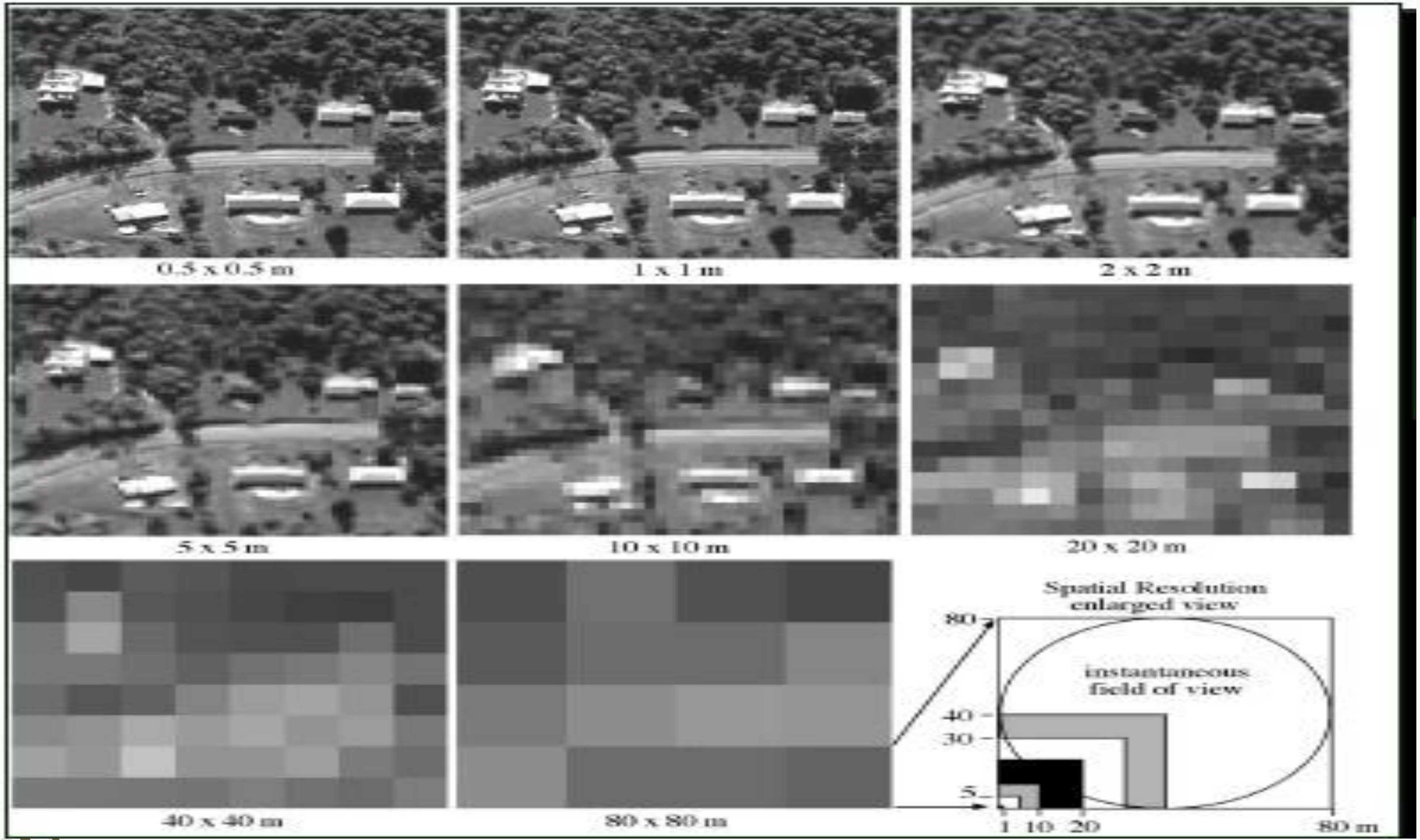
- The distance between the target being imaged and the plat form, plays a large role in determining the detail of information obtained and the total area imaged by the sensor.

- Images where only large features are visible are said to have coarse or low resolution. In fine or high resolution images, small objects can be detected.

Exam for Low Resolution

Example for High Resolution

Imagery of residential housing



- Factors affecting spatial resolution are

- Atmosphere
- haze, smoke
- low light
- particles or
- blurred sensor systems

- Typical Spatial Resolution Values of Some Remote Sensing Instruments

Satellite & Sensor	Spatial Resolution
IRS-1C Panchromatic	6 meters
SPOT Panchromatic	10 meters
Seasat Radar	25 meters
Landsat Thematic Mapper	30 meters
IRS-1B LISS-II	36 meters
Landsat Multispectral Scanner	80 meters
Advanced VHRR	1,100 meters

Spectral Resolution

- The term *spectral resolution* refers to the width of these spectral bands measured in micrometres (µm) or nanometres (nm).
- Spectral resolution describes the ability of a sensor to define fine wavelength intervals
- It reflects the number of bands that a sensor is able to acquire from a given part of the electromagnetic spectrum.
- The finer the spectral resolution, the narrower the wavelength range for a particular channel or band.
- Black and white film records wavelengths extending over much, or all of the visible portion of the electromagnetic spectrum.

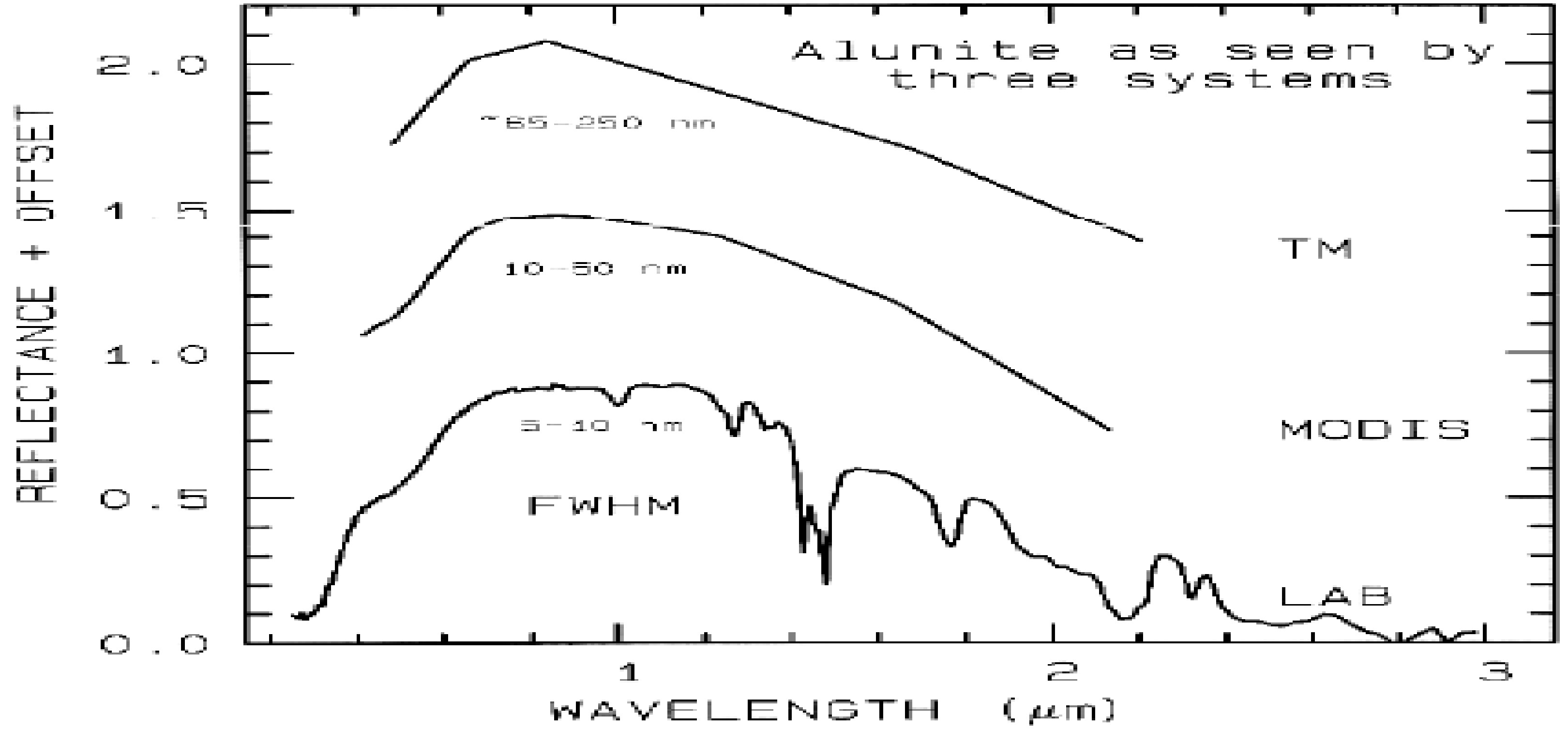
- Its **spectral resolution** is fairly coarse, as the various wavelengths of the visible spectrum are not individually distinguished and the overall reflectance in the entire visible portion is recorded.
- Colour film is also sensitive to the reflected energy over the visible portion of the spectrum, but has higher spectral resolution, as it is individually sensitive to the reflected energy at the blue, green, and red wavelengths of the spectrum.
- Thus, it can represent features of various colours based on their reflectance in each of these distinct wavelength ranges.
- Many remote sensing systems record energy over several separate wavelength ranges at various spectral resolutions. These are referred to as **multi-spectral sensors** .

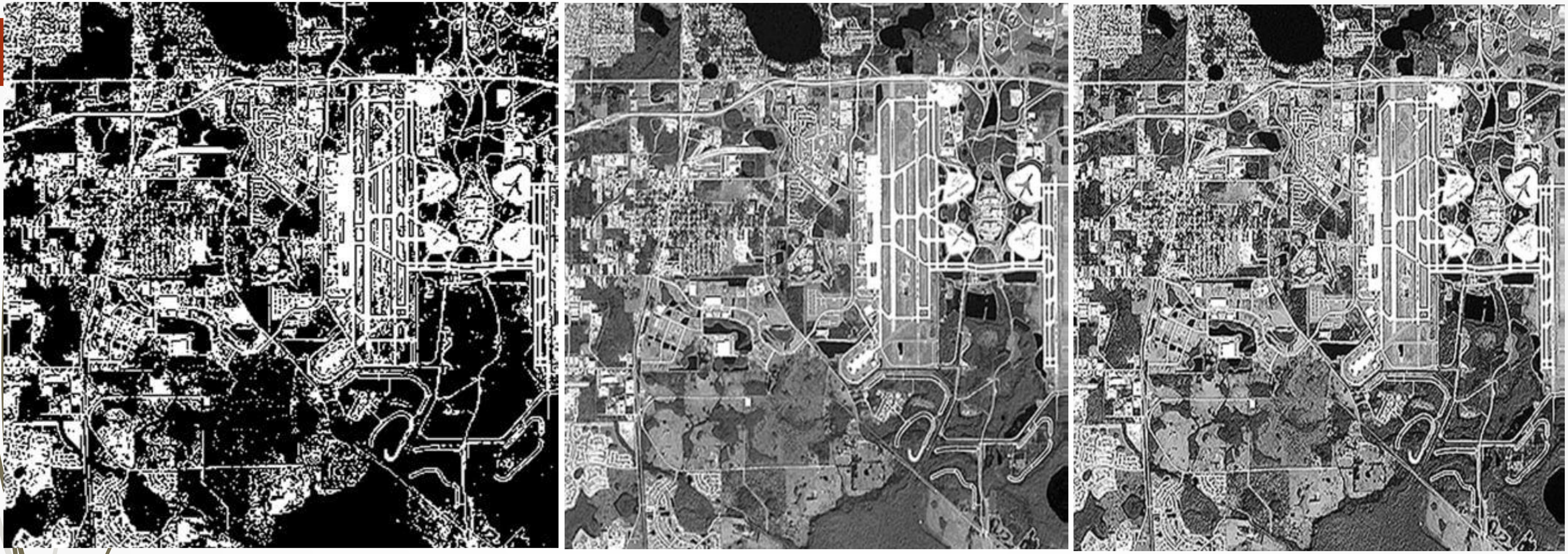
- Advanced multi-spectral sensors called **hyperspectral** sensors,
- detect hundreds of very narrow spectral bands throughout the visible, near-infrared, and mid-infrared portions of the electromagnetic spectrum.
- Their very high spectral resolution facilitates fine discrimination between different targets based on their spectral response in each of the narrow bands.

- The following example illustrates two important points, namely, that (i) the position in the spectrum, width and number of spectral bands determines the degree to which individual targets (vegetation species, crop or rock types) can be discriminated on the multispectral image, and
- (ii) the use of multispectral imagery can lead to a higher degree of discriminating power than any single band taken on its own.
- Differences between the reflectance spectra of various rocks, for example, might be very subtle and the rock types might therefore be separable only if the recording device was capable of detecting the spectral reflectance of the target in a narrow waveband.

- A wide-band instrument would simply average the differences. Figure (a) is a plot of the reflection from a leaf from a deciduous tree against wavelength. Figure (b) shows the reflectance spectra for the same target as recorded by a broad-band sensor such as the Landsat-7 ETM+.
- Broad-band sensors will, in general, be unable to distinguish subtle differences in reflectance spectra, perhaps resulting from disease or stress.
- To provide for the more reliable identification of particular targets on a remotely sensed image the spectral resolution of the sensor must
- match as closely as possible the spectral reflectance curve of the intended target.
- Only in an ideal world would it be possible to increase the spectral resolution of a sensor simply to suit the user's needs

- There is a price to pay for higher resolution. All signals contain some noise or random error that is caused by electronic noise from the sensor and from effects introduced during transmission and recording.

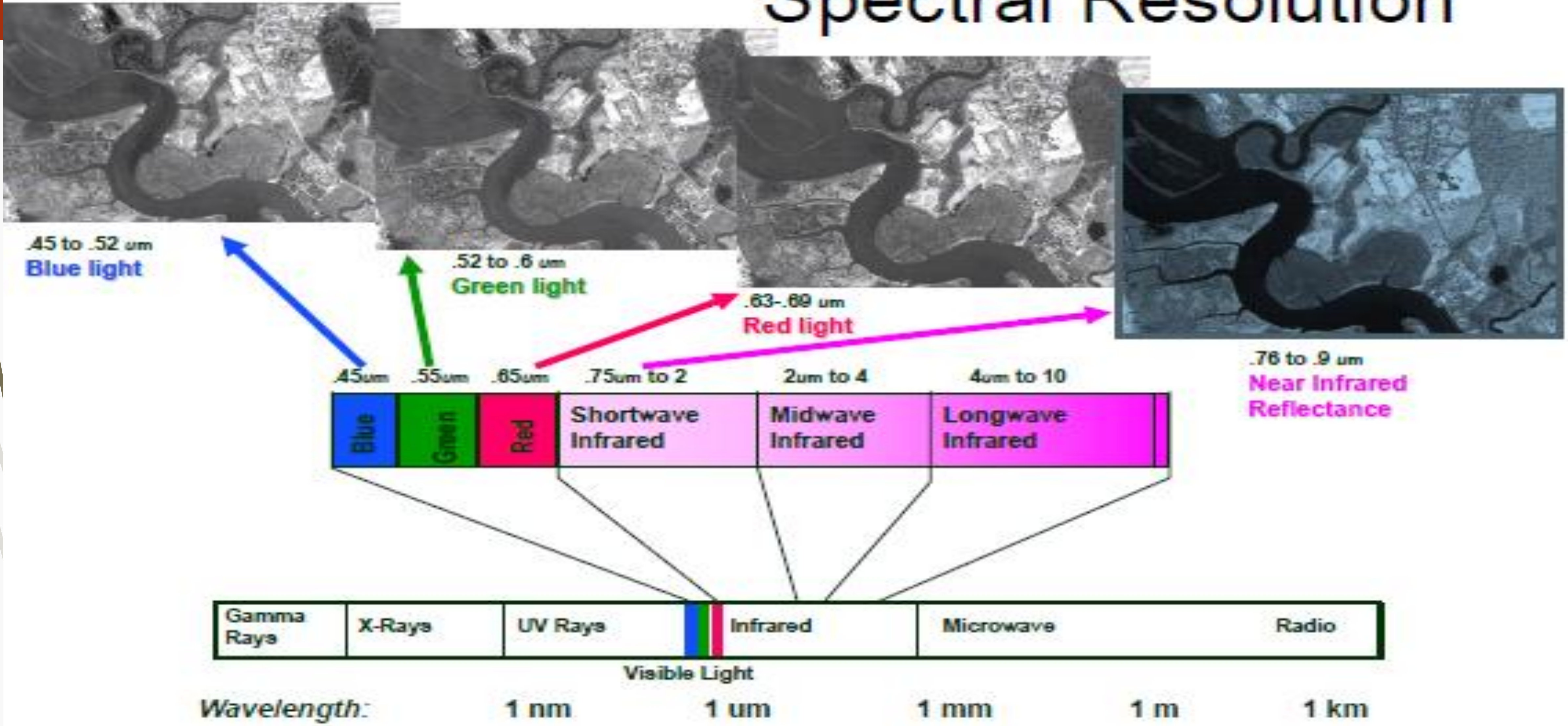




a b c

Figure SPOT HRV panchromatic image of part of Orlando, Florida, displayed in (a) two grey levels, (b) 16 grey levels, and (c) 256 grey levels.

Spectral Resolution



Radiometric resolution

- The **radiometric resolution** of an imaging system describes its ability to discriminate very slight differences in energy. Simply it is refers to the number of digital quantisation levels used to express the data collected by the sensor.
- Also known as radiometric sensitivity - refers to the number of digital levels used to express the data collected by the sensor.
- The higher resolution the higher variability can be seen in a picture. The greater the number of levels, the greater the detail of information.
- It is given by a number of **bits**: 8 = 256 values, digital values available, ranging from 0 to 255.

- Image data are generally displayed in a range of grey tones, with black representing a digital number of 0 and white representing the maximum value (for example, 255 in 8-bit data).
- By **comparing a 2-bit image with an 8-bit image**, we can see that there is a large difference in the level of detail discernible depending on their radiometric resolutions.
- At one extreme one could consider a digital image composed of only two levels in which level 0 is shown as black and level 1 as white. As the number of levels increases to 16 the amount of detail visible on the image increases.
- With 256 levels of grey (c) there is no discernible difference, though readers should note that this is as much a function of printing technology as of their visual systems.

- The number of grey levels is commonly expressed in terms of the number of binary (base two) digits (bits) needed to store the value of the maximum grey level1.
- Just two binary digits, 0 and 1, are used in a base two number rather than the 10 digits (0–9) that are used in base 10 representation.
- Thus, for a two level or black/white representation, the number of bits required per pixel is 1 (giving two states – 0 and 1), while for 4, 16, 64 and 256 levels the number of bits required is 2, 4, 6, and 8, respectively.

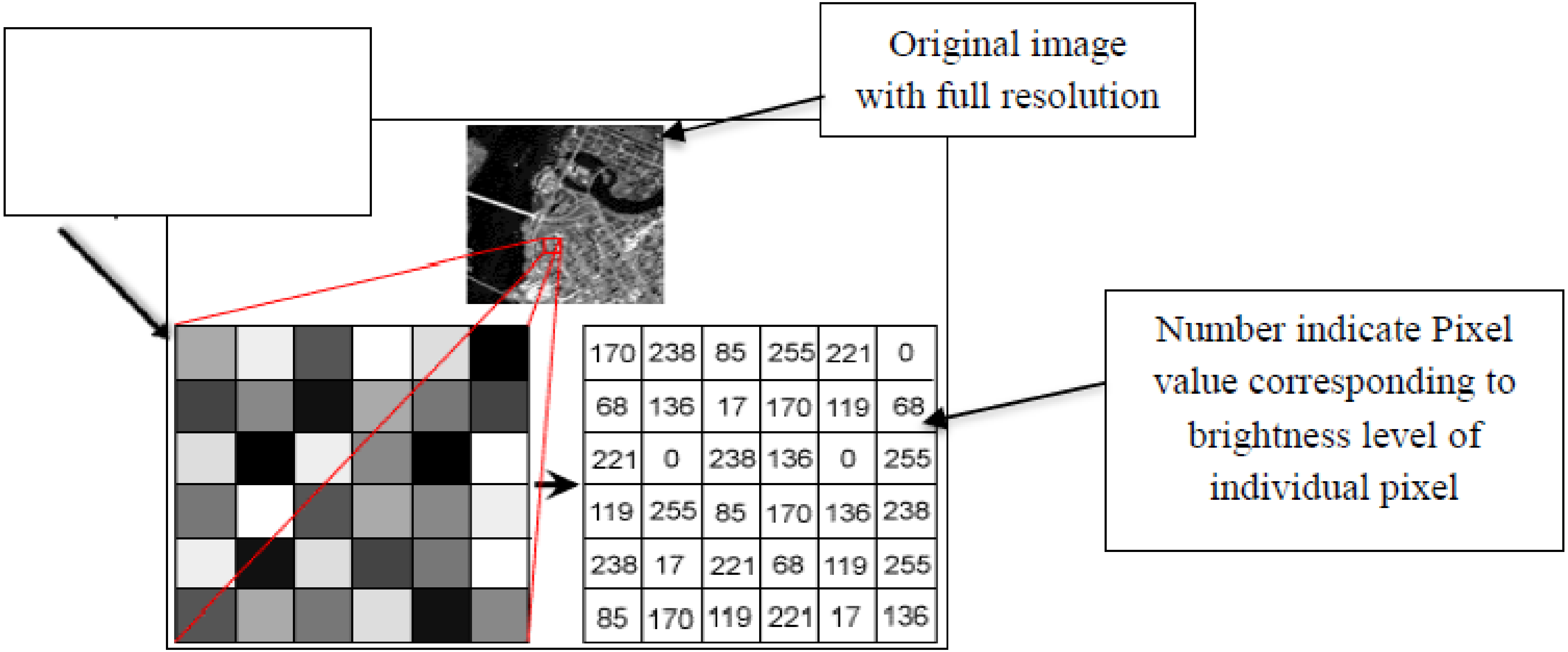
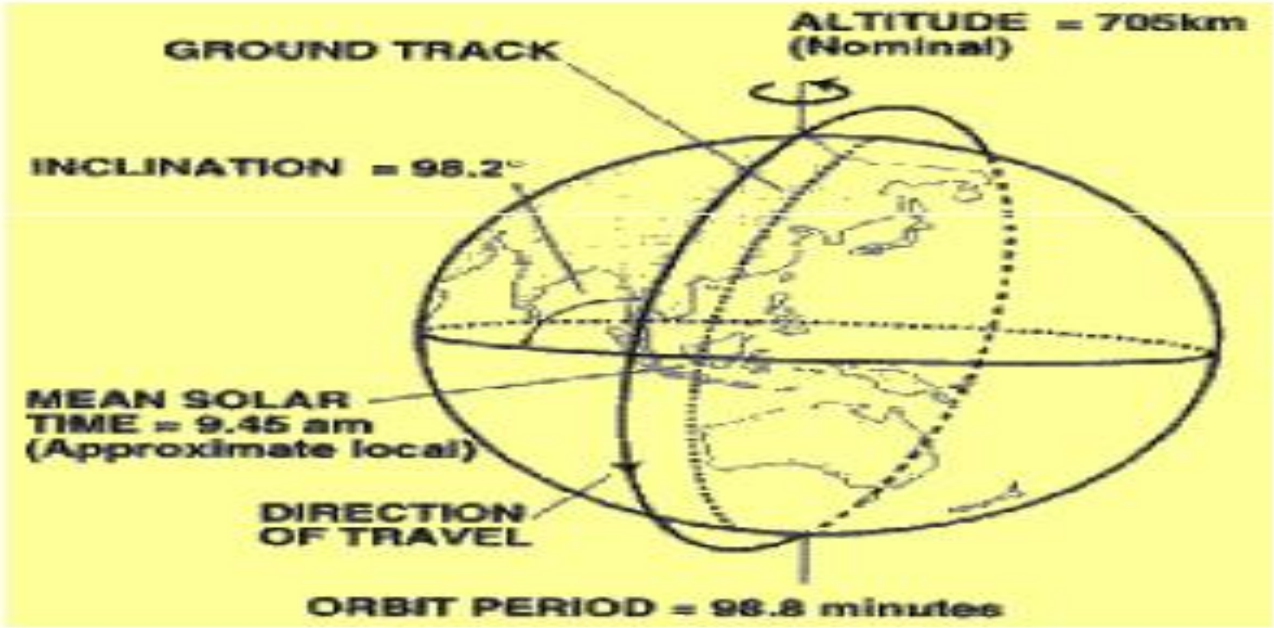


Figure Image and corresponding to pixel value

- The radiometric resolution of an imaging system describes its ability to discriminate very slight differences in energy
- The finer the radiometric resolution of a sensor, the more sensitive it is to detecting small differences in reflected or emitted energy.

- **Temporal resolution**
- The ability to collect imagery of the same area of the Earth's surface at different periods of time.
- The length of time it takes for a satellite to complete one entire orbit cycle.



- The ability to collect imagery of the same area of the Earth's surface at different periods of time is one of the most important elements for applying remote sensing data.
- Spectral characteristics of features may change over time and these changes can be detected by collecting and comparing **multi-temporal** imagery.
- For example, during the growing season, most species of vegetation are in a continual state of change and our ability to monitor those subtle changes using remote sensing is dependent on when and how frequently we collect imagery.

- By imaging on a continuing basis at d/t times we are able to monitor the changes that take place on the Earth's surface such as changes in natural vegetation cover or flooding or
- induced by humans such as urban development or deforestation. The time factor in imaging is important when:
- Persistent clouds offer limited clear views of the Earth's surface (often in the tropics) short-lived phenomena (floods, oil slicks, etc.) need to be imaged multi-temporal comparisons are required (e.g. the spread of a forest disease from one year to the next).

Types of sensor/ Scanners

- Satellite remote sensing offers operator's relevant opportunities for both the objects' identification and surface dynamic process analysis.

- The development of satellite technology is also fundamental for studying, observing, monitoring and assessing terrestrial resources.

- The multispectral scanner is a sensor that collects data in various wavelength bands of the EM spectrum.
- The scanner can be mounted on an aircraft or on a satellite. There are different types of sensors with different purpose and applications some of them are:

1. Weather Satellites/Sensors

- Weather monitoring and forecasting was one of the first civilian (as opposed to military) applications of satellite remote sensing.
- The first true weather satellite, was TIROS-1 (Television and Infrared Observation Satellite-1), launched in 1960 by the United States.
- Several other weather satellites were launched over the next five years, in near-polar orbits, providing repetitive coverage of global weather patterns.

- In 1966, NASA launched the geostationary Applications Technology Satellite (ATS-1) which provided hemispheric images of the Earth's surface and cloud cover every half hour.
- For the first time, the development and movement of weather systems could be routinely monitored.
- Today, several countries operate weather, or meteorological satellites to monitor weather conditions around the globe.
- Generally speaking, these satellites use sensors which have fairly coarse spatial resolution and provide large areal coverage.
- Here we review a few of the representative satellites/sensors used for meteorological applications.

I. GOES

- The GOES (Geostationary Operational Environmental Satellite) System is the follow-up to the ATS series.
- They were designed by NASA for the NOAA to provide the US National Weather Service with frequent, small-scale imaging of the Earth's surface and cloud cover.
- The GOES series of satellites have been used extensively by meteorologists for weather monitoring and forecasting for over 20 years.

- These satellites are part of a global network of meteorological satellites spaced at approximately 70° longitude intervals around the Earth in order to provide near-global coverage.
- Two GOES satellites, placed in geostationary orbits 36000 km above the equator, each view approximately one-third of the Earth
- One is situated at 75°W longitude and monitors North and South America and most of the Atlantic Ocean.
- The other is situated at 135°W longitude and monitors North America and the Pacific Ocean basin. Together they cover from 20°W to 165°E longitude.

II. NOAA-15

- NOAA stands for National Oceanic and Atmospheric Administration, which is a US-government body.
- The sensor onboard of NOAA missions that is relevant for Earth Observation is the Advanced Very High Resolution Radiometer (AVHRR).
- NOAA is also responsible for another series of satellites which are useful for meteorological, as well as other, applications.
- These satellites, in **sun-synchronous, near-polar orbits** (830-870 km above the Earth), and provide complementary information to the geostationary meteorological satellites.

- A prototype AVHRR sensor as developed and first launched in October 1978 to acquire meteorological data, including cloud mapping, surface water delineation, and sea surface temperatures.
- AVHRR data are used primarily in day-to-day meteorological forecasting where it gives more detailed information than Meteosat.
- AVHRR data are used to generate *Sea Surface Temperature maps* (SST maps), which can be used in climate monitoring, the study of El Nino.
- *Cloud cover maps* based on AVHRR data, are used for rainfall estimates, which can be input into crop growing models.

- Another derived product of AVHRR data are the *Normalized Difference Vegetation Index maps* (NDVI). These 'maps' give an indication about the quantity of biomass (tons/ha)
- NDVI data are used as input into crop growth models and also for climate change models.
- The NDVI data are, for instance, used by FAO in their food security early warning system (FEWS).
- AVHRR data are appropriate to map and monitor regional land cover and to assess the energy balance of agricultural areas.

System	NOAA-15
Orbit	850 km, 98.8°, sun-synchronous
Sensor	AVHRR-3 (Advanced Very High Resolution Radiometer)
Swath width	2800 km (FOV = 110°)
Off-track viewing	No
Revisit time	2–14 times per day, depending on latitude
Spectral bands (μm)	0.58–0.68(1), 0.73–1.10 (2), 3.55–3.93(3), 10.3–11.3(4), 11.4–12.4(5)
Spatial resolution	1 km (at nadir), 6 km (at limb), IFOV=1.4 mrad
Data archive at	www.saa.noaa.gov

Specifications of NOAA-AVHRR

III. Meteosat-5

- Meteosat is a geostationary satellite that is used in the world meteorological programme.
- The programme comprises seven satellites in total. The first Meteosat satellite was placed in orbit in 1977. Meteosat satellites are owned by the European organization Eumetsat.
- The spectral bands of the VISSR sensor are chosen for observing phenomena that are relevant to meteorologists:
- a panchromatic band, a mid-infrared band, which gives information about the water vapour (WV) present in the atmosphere, and a thermal band (TIR).

- In case of clouds, the thermal data relate to the cloud top temperature, which is used for rainfall estimates and forecasts.
- Under cloud-free conditions the thermal data relate to the surface temperature of land and sea.

System	Meteosat-5
Orbit	Geo-stationary, 0_ longitude
Sensor	VISSR (Visible and Infrared Spin Scan Radiometer)
Swath width	Full Earth disc (FOV = 18_)
Off-track viewing	Not applicable
Revisit time	30 minutes
Spectral bands (μm)	0.5–0.9 (VIS), 5.7–7.1 (WV), 10.5–12.5 (TIR)
Ground pixel size	2.5 km (VIS and WV), 5 km (TIR)

Meteosat-5 VISSR Characteristics

2. **Land Observation Satellites/Sensors**

There are different land observation satellites some of them are:

I. Landsat

- The Landsat earth resources satellite system was the first designed to provide near global coverage of the earth's surface on a regular and predictable basis.
- Many of the weather satellite systems are also used for monitoring the Earth's surface, but they are not optimized for detailed mapping of the land surface.
- The first satellite designed specifically to monitor the Earth's surface,Landsat-1 satellite carrying the MSS multispectral sensor, was launched by NASA in 1972.
- **Landsat** was designed as an experiment to test the feasibility of collecting multi-spectral Earth observation data.

- Since that time, this highly successful program has collected an abundance of data from around the world from several Landsat satellites.
- After 1982, the Thematic Mapper (TM) replaced the MSS sensor.
- The most popular instrument in the early days of Landsat was the Multi Spectral Scanner (MSS) and later the Thematic Mapper (TM).
- Each of the sesensors collected data over a swath width of 185 km, with a full scene being defined as 185km x 185 km.
- The MSS senses the electromagnetic radiation from the Earth's surface in four spectral bands.

- Each band has a spatial resolution of approximately 60 x 80 metres and a radiometric resolution of 6 bits, or 64 digital numbers.
- In April 1999 Landsat-7 was launched carrying the ETM+ scanner.
- There are many applications of Landsat Thematic Mapper data: land cover mapping, land use mapping, soil mapping, geological mapping, sea surface temperature mapping.

- For land cover and land use mapping Landsat Thematic Mapper data are preferred, e.g., over SPOT multispectral data, because of the inclusion of middle infrared bands.
- Landsat Thematic Mapper is the only non-meteorological satellite that has a thermal infrared band.
- Thermal data are required to study energy processes at the Earth's surface, for instance, the crop temperature variability within irrigated areas.
- Table below gives the principle applications of the various imaging instruments have been used with the Landsat satellites to date. These are the Return Beam Vidicon (RBV), the Multispectral Scanner (MSS) and the Thematic Mapper (TM)

- **TM sensor**

- The **TM** sensor provides several improvements over the MSS sensor including:
- higher spatial and radiometric resolution; finer spectral bands; seven as opposed to four spectral bands; and an increase in the number of detectors per band.
- This difference from the MSS increases the **dwell time** and improves the geometric and radiometric integrity of the data.
- Spatial resolution of TM is 30 m for all but the thermal infrared band which is 120 m.
- All channels are recorded over a range of 256 digital numbers (8 bits).

- Data from both the TM and MSS sensors are used for a wide variety of applications, including resource management, mapping, environmental monitoring, and change detection (e.g. monitoring forest clearcutting).

- **Landsat ETM (+)**

- multispectral scanner of the thematic mapper (TM) type, enhanced by improvement in its spatial resolution.
- This was called the enhanced thematic mapper (ETM).It incorporated the same seven bands and the same spatial resolution as the TM.
- In addition, the ETM was going to have a panchromatic band (0.50-0.90 µm) with a spatial resolution of 15m.

Table Characteristics of the Landsat imaging devices

Instrument	Spectral bands (μm)		IFOV (m)	Dynamic range (bits)
RBV[m]	1.	0.475– 0.575 (blue)	79 × 79	
	2.	0.580– 0.680 (red)	79 × 79	
	3.	0.689– 0.830 (near IR)	79 × 79	
RBV[p]		0.505– 0.750 (panchromatic)	40 × 40	
MSS	4.[a]	0.5 – 0.6 (green)	79 × 79	7
	5.	0.6 – 0.7 (red)	79 × 79	7
	6.	0.7 – 0.8 (near IR)	79 × 79	7
	7.	0.8 – 1.1 (near IR)	79 × 79	6
	8.[b]	10.4 –12.6 (thermal)	237 × 237	
TM	1.	0.45 – 0.52 (blue)	30 × 30	8
	2.	0.52 – 0.60 (green)	30 × 30	8
	3.	0.63 – 0.69 (red)	30 × 30	8
	4.	0.76 – 0.90 (near IR)	30 × 30	8
	5.	1.55 – 1.75 (mid IR)	30 × 30	8
	7.[c]	2.08 – 2.35 (mid IR)	30 × 30	8
	6.	10.4 –12.5 (thermal)	120 × 120	8
ETM+	1.	0.450– 0.515 (blue)	30 × 30	8
	2.	0.525– 0.605 (green)	30 × 30	8
	3.	0.630– 0.690 (red)	30 × 30	8
	4.	0.775– 0.900 (near IR)	30 × 30	8
	5.	1.550– 1.750 (mid IR)	30 × 30	8
	7.	2.090– 2.350 (mid IR)	30 × 30	8
	6.	10.40 –12.50 (thermal)	60 × 60	8
	pan	0.520– 0.900	13 × 15	8

Table Landsat payloads, launch and out of service dates

Satellite	Imaging Instruments			Launched	Out-of-service
Landsat 1	RBV[m]	MSS		23 Jul 1972	6 Jan 1978
Landsat 2	RBV[m]	MSS		22 Jan 1975	27 Jul 1983
Landsat 3	RBV[p]	MSS[t]		5 Mar 1978	7 Sept 1983
Landsat 4		MSS	TM	16 Jul 1982	Aug 1993
Landsat 5		MSS	TM	1 Mar 1984	–
Landsat 6			ETM	lost on launch	–
Landsat 7			ETM+	15 Apr 1999	–

m – multispectral RBV
p – panchromatic RBV
t – MSS with thermal band

II. SPOT

- **SPOT** (Système Pour l'Observation de la Terre) is a series of Earth observation imaging satellites designed and launched by CNES (Centre National d'Études Spatiales) of France, Sweden and Belgium government.

- SPOT-1 was launched in 1986, with successors following every three or four years. At that time, the 10 m panchromatic spatial resolution was unprecedented.
- In March 1998 a significantly improved SPOT-4 was launched: the HRVIR sensor has 4 instead of 3 bands and the VEGETATION instrument was added.
- VEGETATION has been designed for frequent (almost daily) and accurate monitoring of the globe's landmasses.

- The SPOT satellites each have twin **high resolution visible (HRV)** imaging systems, which can be operated independently and simultaneously.
- Each HRV is capable of sensing either in a high spatial resolution single-channel **panchromatic** mode, or a coarser spatial resolution three-channel **multispectral** mode.
- All satellites are in sun-synchronous, near-polar orbits at altitudes around 830 km above the Earth, which results in orbit repetition every 26 days.
- SPOT was designed to be a commercial provider of Earth observation data, and was the first satellite to use along-track, or push broom scanning technology.

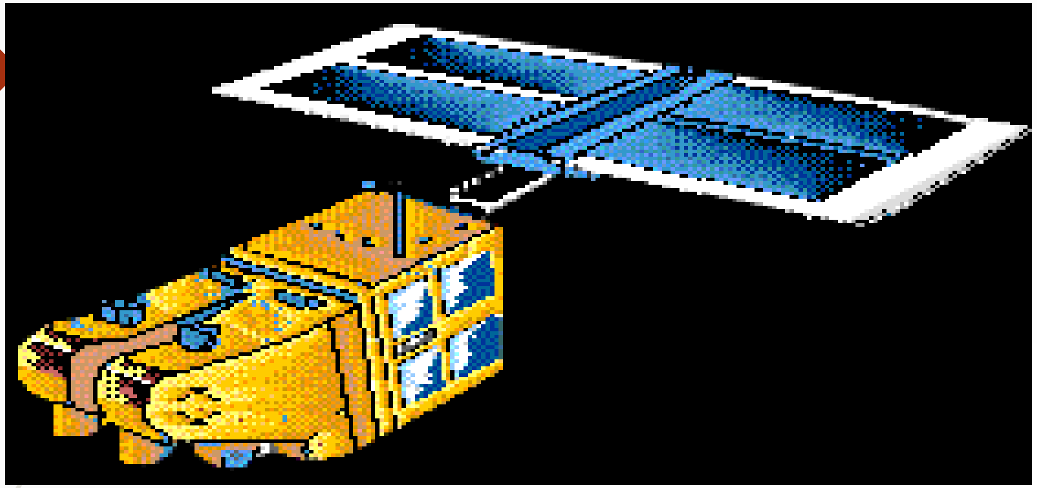


Figure: Overview of SPOT satellite

Mode/Band	Wavelength Range (µm)
Panchromatic (PLA)	0.51 - 0.73 (blue-green-red)
Multispectral (MLA)	
Band 1	0.50 - 0.59 (green)
Band 2	0.61 - 0.68 (red)
Band 3	0.79 - 0.89 (near infrared)

Table: Band specification of SPOT satellite

Figure: Overview of SPOT satellite image

III. IKONOS

Since its launch in September 1999, Space Imaging's IKONOS earth imaging satellite has provided a reliable stream of image data that

- has become the standard for commercial high resolution satellite data products.
- IKONOS produces 1-meter black-and-white (panchromatic) and 4-meter multispectral (blue, green, red, near infrared).
- The orbit has an altitude of 681 km and a swath width of only 11 km. The revisit time is approximately 3 days at 1 m resolution.
- IKONOS delivers the highest spatial resolution so far achieved by a civilian satellite.

- IKONOS' first task will be to acquire imagery of all major USA cities.
- Until now, the mapping and monitoring of urban areas from space (not only in America) was possible only to a limited extent.
- IKONOS data can be used for small to medium scale topographic mapping, not only to produce new maps, but also to update existing topographic maps.
- Another potential application is 'precision agriculture'; this is reflected in the multispectral band setting, which includes a near-infrared band.
- Regular updates of the 'field situation' can help farmers to optimize the use of fertilizers and herbicides.

Band	Wavelength interval (μm)
MS-1	0.445 – 0.516
MS-2	0.506 – 0.595
MS-3	0.632 – 0.698
MS-4	0.757 – 0.853
Panchromatic	0.526 – 0.929

Table: Band specification of IKONOS satellite

IV. IRS-1D

- India puts much effort into remote sensing and has many operational missions and missions under development.
- The most important Earth Observation programme is the Indian Remote Sensing (IRS) programme.
- Launched in 1995 and 1997, two identical satellites, IRS-1C and IRS-1D, can deliver image data at high revisit times.

- For a number of years, up to the launch of IKONOS in September 1999, the IRS-1C and -ID were the civilian satellites with the highest spatial resolution.
- Applications are similar to those of SPOT and Landsat. IRS-1C and IRS-1D carry three sensors:
  - the Wide Field Sensor (WiFS) designed for regional vegetation mapping,
  - the Linear Imaging Self-Scanning Sensor 3 (LISS3), which yields multispectral data in four bands with a spatial resolution of 24 m.

System	IRS-1D
Orbit	817 km, 98.6°, sun-synchronous, 10:30 AM crossing, 24 days repeat cycle
Sensor	PAN (Panchromatic Sensor)
Swath width	70 km
Off-track viewing	Yes, ± 26° across-track
Revisit time	5 days
Spectral bands (μm)	0.50–0.75
Spatial resolution	6 m
Data archive at	www.spaceimaging.com

Table: specification of IRS-1D satellite

V. Quick Bird

- QuickBird was launched on October , 2001 from Vandenburg Air Force Base in California.
- It was able to collect over 75 million square kilometers of satellite imagery annually.
- QuickBird satellite collected image data to 0.65m pixel resolution degree of detail.
- This satellite was an excellent source of environmental data useful for analyses of changes in land usage, agricultural and forest climates.
- QuickBird's imaging capabilities had applied to a host of industries, including oil and gas exploration and production , construction and environmental studies.

Quick Bird satellite specification

Imaging Mode	Panchromatic	Multispectral
Spatial Resolution	.61 meter GSD at Nadir	2.4 meter GSD at Nadir
Spectral Range	445-900 nm	450-520 nm (blue) 520-600 nm (green) 630-690 nm (red) 760–900 nm (near IR)
Swath Width	16.4 km at nadir	
Off-Nadir Imaging	0-30 degrees off-nadir Higher angles selectively available	
Dynamic Range	11-bits per pixel	
Mission Life	Ceased new collections January 27, 2015	
Revisit Time	Approximately 3.5 days (depends on Latitude)	
Orbital Altitude	450 km	

Quick Bird satellite and image scanned by the satellite

IMAGE INTERPRETATION AND ANALYSIS

Digital Image Processing

- Digital image processing may involve numerous procedures including:
  - formatting and correcting of the data, digital enhancement to facilitate better visual interpretation, or even automated classification of targets and features entirely by computer.
- In order to process remote sensing imagery digitally, the data must be recorded and available in a digital form suitable for storage on a computer tape or disk.
- Most of the common image processing functions available in image analysis systems can be categorized into the following four categories:
  - Preprocessing
  - Image Enhancement and Visualization
  - Image Transformation
  - Image Classification and Analysis

❑ Pre-processing of Remotely-Sensed Data

- In their raw form, as received from imaging sensors mounted on satellite platforms, remotely-sensed data generally contain flaws or deficiencies.
- The correction of deficiencies and the removal of flaws present in the data is termed *pre-processing* because, quite logically, such operations are carried out before the data are used for a particular purpose.
- Despite the fact that some corrections are carried out at the ground receiving station there is often still a need on the user's part for some further pre-processing.

- Pre-processing operations, sometimes referred to as image restoration and rectification,
- It is intended to correct for sensor- and platform-specific **radiometric** and **geometric** distortions of data.
- Radiometric and geometric corrections may be necessary due to variations in scene illumination and viewing geometry, atmospheric conditions, and sensor noise and response.
- Each of these will vary depending on the specific sensor and platform used to acquire the data and the conditions during data acquisition.

- Because of the difficulty of deciding what should be included under the heading of pre-processing methods, an arbitrary choice has been made.
- The investigator should decide which preprocessing techniques are relevant on the basis of the nature of the information to be extracted from the remotely-sensed data.
- The pre-processing techniques described here are concerned with the removal of data errors and of unwanted or distracting elements of the image.

- So the first step in the processing chain, often referred to as pre-processing, involves radiometric and geometric corrections.

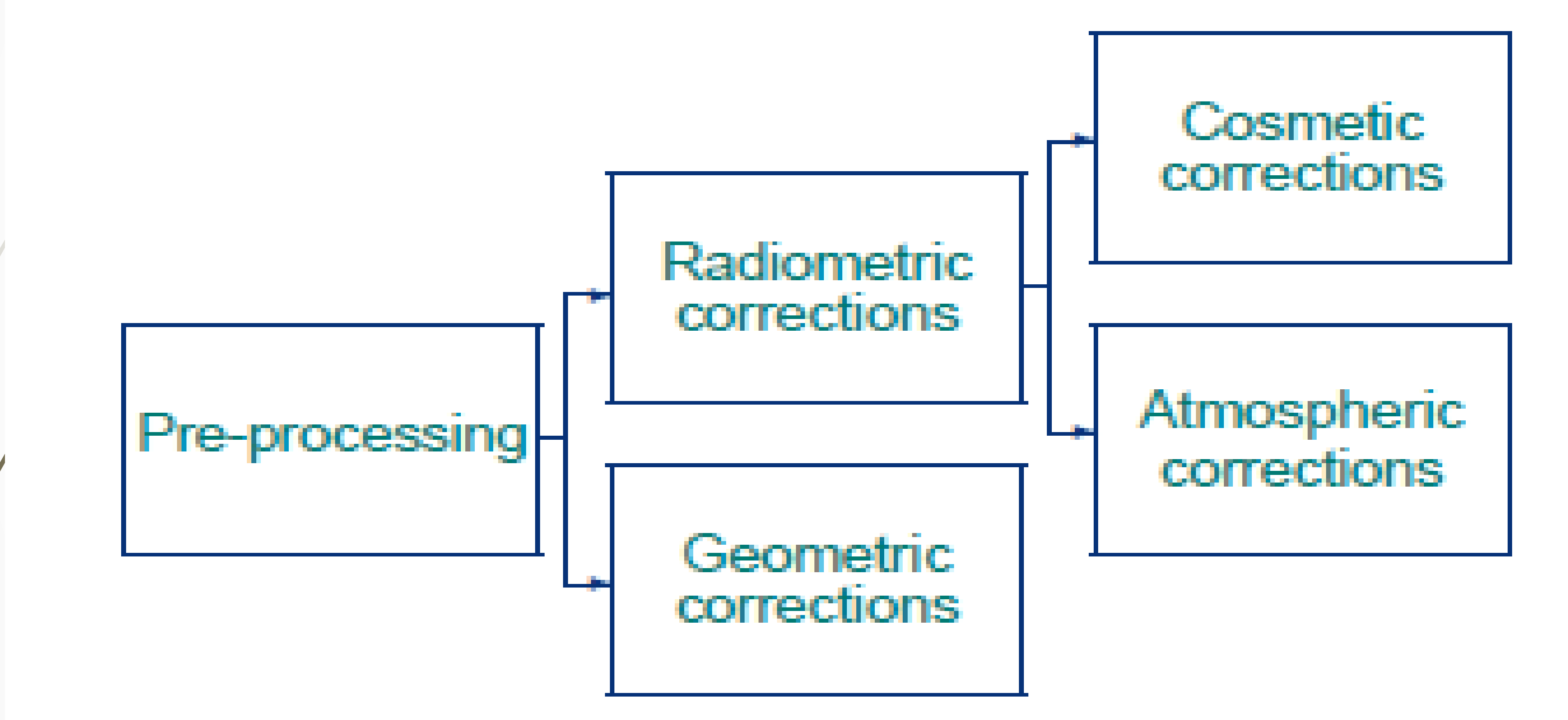


Figure: Image processing steps

I. Radiometric Correction

- Radiometric corrections constitute an important step in the pre-processing of remotely sensed data.
- Radiometric correction comprise of **cosmetic corrections and Atmospheric corrections**
- **Cosmetic corrections** helps to reduce the influence of atmospheric and illumination parameters.
- **Atmospheric corrections** are particularly important for generating image mosaics and for comparing multitemporal remote sensing data.

A. Cosmetic corrections

- A special kind of error in remote sensing images related to sensor characteristics is called ***image noise***.
- Image noise is any unwanted disturbance in image data due to limitations in the sensing, signal digitization, or data recording process.
- It can be the result of periodic drift or malfunction of a detector, electronic interference between sensor components and
- intermittent data losses in data transmission and recording sequence of an image.
- Noise can either degrade or totally mask the true radiometric information content of a digital image.

- The first is the correction of digital images that contain either partially or entirely missing scan lines.
- Such defects can be due to errors in the scanning or sampling equipment, in the transmission or recording of image data, or in the reproduction of the media containing the data, such as magnetic tape or CD-ROM.
- Whatever their cause, these missing scan lines are normally seen as horizontal black or white lines on the image, represented by sequences of pixel values such as zero or 255.
- Their presence intrudes upon the visual examination and interpretation of images and also affects statistical calculations based on image pixel values.

- Cosmetic corrections involve all those operations that are aimed at correcting visible errors and noise in the image data.
- Defects in the data may be in the form of periodic or random missing lines (line dropouts), line striping, and random or spike noise.
- These effects can be identified visually and automatically. Well-known types of image noise in remote sensing are:

B. Atmospheric correction

- The composition of the atmosphere has an important effect on the measurement of radiance with remote sensing.
- The atmosphere consists mainly of molecular nitrogen and oxygen (clean dry air).
- In addition, it contains water vapour and particles (aerosols) such as dust, soot, water droplets and ice crystals.
- So, the adverse effects of the atmosphere needs to be removed before remotely sensed data can be properly analyzed for most land applications.

- These distortions are wavelength dependent. Their effect on remote sensing data can be reduced by applying 'atmospheric correction' techniques.
- These corrections are related to the influence of
- ✓ haze
- ✓ sun angle
- ✓ Skylight

❖ **Haze correction**

- Light scattered by the atmospheric constituents that reaches the sensor constitutes the 'haze' in remote sensing image data.

- Haze has an additive effect resulting in higher DN-values and a decrease in the overall contrast in the image data.
- The effect is wavelength dependent, being more pronounced in the shorter wavelength range and negligible in the infrared.
- Haze corrections are based on the assumption that the infrared bands are essentially free of atmospheric effects and in these bands black bodies, such as:
- large clear water bodies and shadow zones, will have zero DN-value.

- The DN-values in other bands for the corresponding pixels can be attributed to haze and should be subtracted from all pixels of the corresponding band.
- A simple method to correct for atmospheric effects like haze in an image is the so called ***darkest pixel method*.**
- In this method objects are identified from which we know they have very low reflectance values (and thus have a dark appearance in the image).
- To correct for the atmospheric haze, the measured signal value is subtracted from all image pixels in that band.
- This method also accounts for aerosol composition of the atmosphere and so-called adjacency effects.

- The final result of an atmospheric correction procedure are surface reflectance values for all image pixels which can be used for further image processing, e.g., classification and variable estimation (LAI).

Figure: Example of Landsat TM image before atmospheric correction (left) and after atmospheric correction (right)

II. **Geometric Correction**

- Information extracted from remotely-sensed images is integrated with map data in a GIS or presented to consumers in a map-like form for example, gridded.
- If images from different sources are to be integrated or if pairs of d/t images are to be used to develop digital elevation models then the images from these different sources must be expressed on a common coordinate system.
- The transformation of a remotely sensed image so that it has the scale and projection properties of a given map projection is called geometric correction or georeferencing.
- Each projection represents an effort to preserve some property of the mapped area, such as uniform representation of areas or shapes, or preservation of correct bearings.

- Only one such property can be correctly represented, though several projections attempt to compromise by minimizing distortion in two or more map characteristics.
- There are potentially many more sources of geometric distortion of image data than radiometric distortion and their effects are more severe. They can be related to a number of factors, including:

(i) the rotation of the earth during image acquisition,
(ii) the finite scan rate of some sensors,
(iii) the wide field of view of some sensors,
(iv) the curvature of the earth,
(v) variations in platform altitude, attitude and velocity, and
(vi) panoramic effects related to the imaging geometry

- The process of geometric correction can be considered to include:

- (i) the determination of a relationship between the coordinate system of map and image (or image and image in the case of registration),
- (ii) the establishment of a set of points defining pixel centres in the corrected image that, when considered as a rectangular grid, define an image with the desired cartographic properties, and

(iii) the estimation of pixel values to be associated with those points.

Image Enhancement and Visualization

Image Enhancement is the process of manipulating an image so that the result is more suitable than the original for a specific application.

- Image enhancement operators improve the detectability of important image details or objects by man or machine.
- Example operations include noise reduction, smoothing, contrast stretching, and edge enhancement.

- Image enhancement techniques help in improving the visibility of any portion or feature of the image suppressing the information in other portions or features.
- Information extraction techniques help in obtaining the statistical information about any particular feature or portion of the image.

- Enhancements are used to make it easier for visual interpretation and understanding of imagery.
- The advantage of digital imagery is that it allows us to manipulate the digital pixel values in an image.
- There are d/t image enhancement technics such as:

- **Contrast enhancement** involves changing the original values so that more of the available range is used, thereby increasing the contrast between targets and their backgrounds.
- The key to understanding contrast enhancements is to understand the concept of an **image histogram**.
- A histogram is a graphical representation of the brightness values that comprise an image.
- The brightness values (i.e. 0-255) are displayed along the x-axis of the graph.

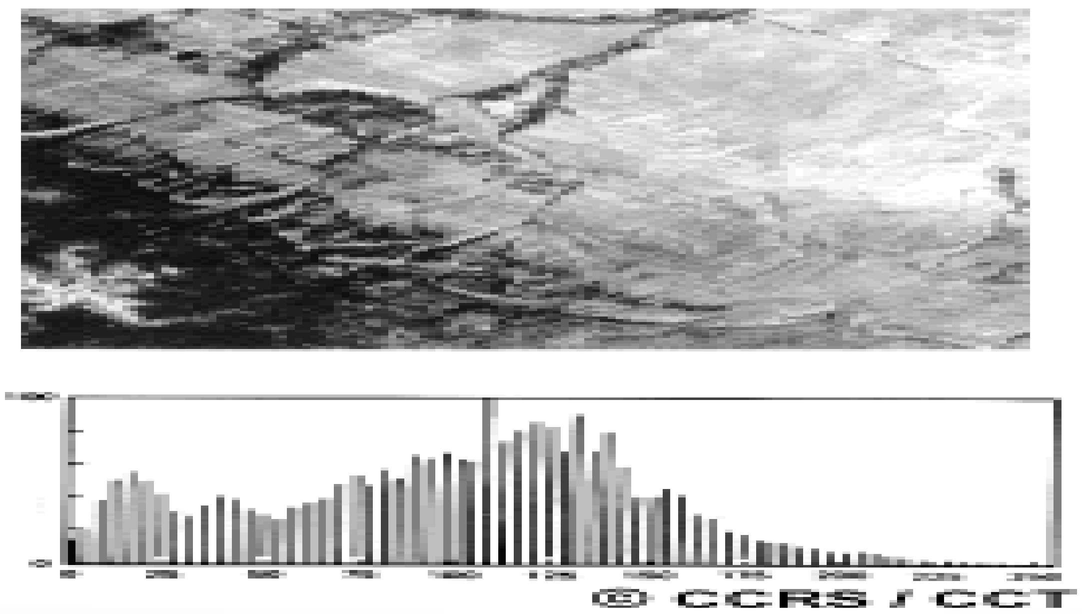


Figure: raw imagery(top) and its histogram(bottom)

- By manipulating the range of digital values in an image, graphically represented by its histogram, we can apply various enhancements to the data.
- There are many different techniques and methods of enhancing contrast and detail in an image; we will cover only a few common ones here.

✓ Linear Contrast Stretch:

This type referred a contrast stretching, linearly expands the original digital values of the remotely sensed data into a new distribution.

- By expanding the original input values of the image, the total range of sensitivity of the display device can be utilized.
- The simplest contrast by which improved contrast ratio of the image with linear contrast stretch will enhance different features on the map.
- Most of the image processing software displays an image only after linear stretching by default.

- Greatly improves the contrast of most of the original brightness values, but there is a loss of contrast at the extreme high and low end of values.

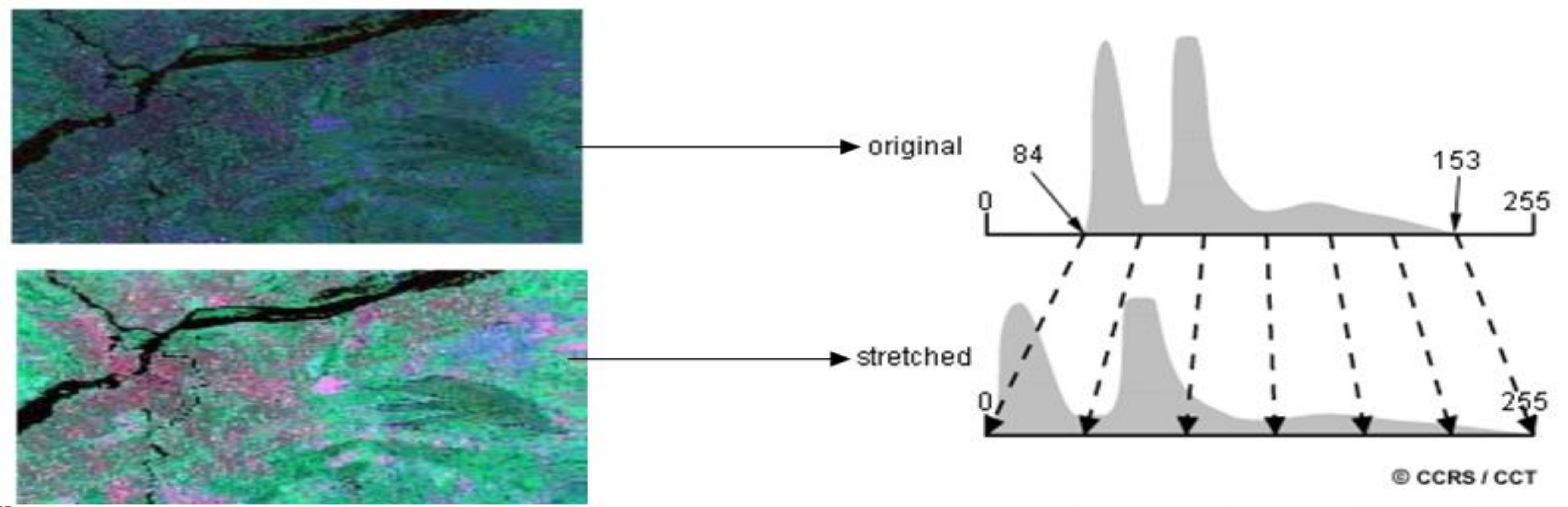


Figure: linear contrast stretch enhancement

❖ Min-Max Linear Contrast Stretch

- When using the minimum-maximum linear contrast stretch, the original minimum and maximum values of the data are assigned to a newly specified set of values that utilize the full range of available brightness values.
- Consider an image with a minimum brightness value of 45 and a maximum value of 205.

❖ Percentage Linear Contrast Stretch

- The percentage linear contrast stretch is similar to the minimum-maximum linear contrast stretch except this method uses specified minimum and maximum values that lie in a certain percentage of pixels from the mean of the histogram.
- A standard deviation from the mean is often used to push the tails of the histogram beyond the original minimum and maximum values.

Piecewise Linear Contrast Stretch

When the distribution of a histogram in an image is biortrimodal, an analyst may stretch certain values of the histogram for increased enhancement in selected areas.

- This method of contrast enhancement is called a piecewise linear contrast stretch.
- A piecewise linear contrast enhancement involves the identification of a number of linear enhancement steps that expands the brightness ranges in the modes of the histogram.

Nonlinear Contrast Stretch

- An important step in the process of contrast enhancement is for the user to inspect the original histogram and determine the elements of the scene that are of greatest interest.
- Experienced operators of image processing systems by-pass the histogram examination stage and adjust the brightness and contrast of images that are displayed on a screen.
- For some scenes a variety of stretched images are required to display fully the original data.
- It should be noted that contrast enhancement should not be done until other processing is completed, because the stretching distorts the original values of the pixels.

- Nonlinear contrast enhancement is made in different ways. Such as:
- **Uniform distribution stretch** (or **histogram equalization**)
- **Intensity, Hue and Saturation Transformations**
- **Edge Enhancement**
- **Non-directional Filters**
- **Directional Filters**
- **Adaptive histogram equalization**

Visual Image Interpretation

- Up to now, we have been dealing with acquisition of image data.
- The data acquired still needs to be interpreted (or analyzed) to extract the required information.
- Visual image interpretation is one of the methods to extract information from remote sensing image data.
- For that purpose, images need to be visualized on screen or in hardcopy.
- The human vision system is used to interpret the colours and patterns on the picture.

- Spontaneous recognition and logical inference (reasoning) are distinguished.
- Interpretation keys or guidelines are required to instruct the image interpreter.
- In such guidelines, the (seven) interpretation elements can be used to describe how to recognize certain objects.
- Guidelines also provide a classification scheme, which defines the thematic classes of interest and their (hierarchical) relationships.
- Finally, guidelines give rules on the minimum size of objects to be included in the interpretation.

- An iterative approach is then required to establish the relationship between features observed in the picture and the real world.
- In all interpretation and mapping processes the use of ground observations is essential to
  - ✓ acquire knowledge of local situation,
  - ✓ gather data for areas that cannot be mapped from the images
  - ✓ to check the result of the interpretation.
- The quality of the result of visual image interpretation depends on the experience and skills of the interpreter, the appropriateness of the image data applied and the quality of the guidelines being used.

- Digital processing and analysis may also be carried out to automatically identify targets and extract information completely based on computer without manual intervention by a human interpreter.
- Examples include automatic generation of DTMs, image classification and calculation of surface parameters.
- The most intuitive way to extract information from remote sensing images is by ***visual image interpretation,*** which is based on man's ability to relate colours and patterns in an image to real world features.

- In some situations pictures are studied to find evidence of the presence of features, for example, to study natural vegetation patterns.
- Most often the result of the interpretation is made explicit by digitizing the geometric and thematic data of relevant objects ('mapping').
- The digitizing of 2D features (points, lines and areas) is carried out using a digitizer tablet or on screen digitizing.
- 3D features interpreted in stereopairs can be digitized using stereoplotters or digital photogrammetric workstations.

- However, rarely is digital processing and analysis carried out as a complete replacement for visual (manual) interpretation.
- Often, it is done to supplement and assist the human analyst.
- Manual interpretation and analysis dates back to the early beginnings of remote sensing for air photo interpretation.
- Digital processing and analysis is more recent with the advent of digital recording of remote sensing data and the development of computers.

Figure: Visual and Digital interpretation strategy

- Both manual and digital techniques for interpretation of remote sensing data have their respective advantages and disadvantages.
- Generally, manual interpretation requires little, if any, specialized equipment, while digital analysis requires specialized, and often expensive, equipment.
- Manual interpretation is often limited to analyzing only a single channel of data or a single image at a time due to the difficulty in performing visual interpretation with multiple images.

- The computer environment is more amenable to handling complex images of several or many channels or from several dates.
- In this sense, digital analysis is useful for simultaneous analysis of many spectral bands and can process large data sets much faster than a human interpreter.
- Manual interpretation is a subjective process, meaning that the results will vary with different interpreters.
- Digital analysis is based on the manipulation of digital numbers in a computer and is thus more objective, generally resulting in more consistent results.

It is important to reiterate that visual and 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.
- In fact, the ultimate decision of the utility and relevance of the information extracted at the end of the analysis process still must be made by humans.

- **Image understanding and interpretation**
- **Human vision**
- *Human vision* goes a step beyond perception of colour: it deals with the ability of a person to draw conclusions from visual observations.
- In analysing a picture, typically you are somewhere between the following two situations:
- direct and spontaneous recognition or using several clues to draw conclusions by a reasoning process (logical inference).
- *Spontaneous recognition* refers to the ability of an interpreter to identify objects or phenomena at a first glance.

- An agronomist would immediately recognize the pivot irrigation systems with their circular shape.
- S/he would be able to do so because of earlier (professional) experience.
- Similarly, most people can directly relate an aerial photo to their local environment.
- The quote from people that are shown an aerial photograph for the first time "I see because I know" refers to *spontaneous recognition*.

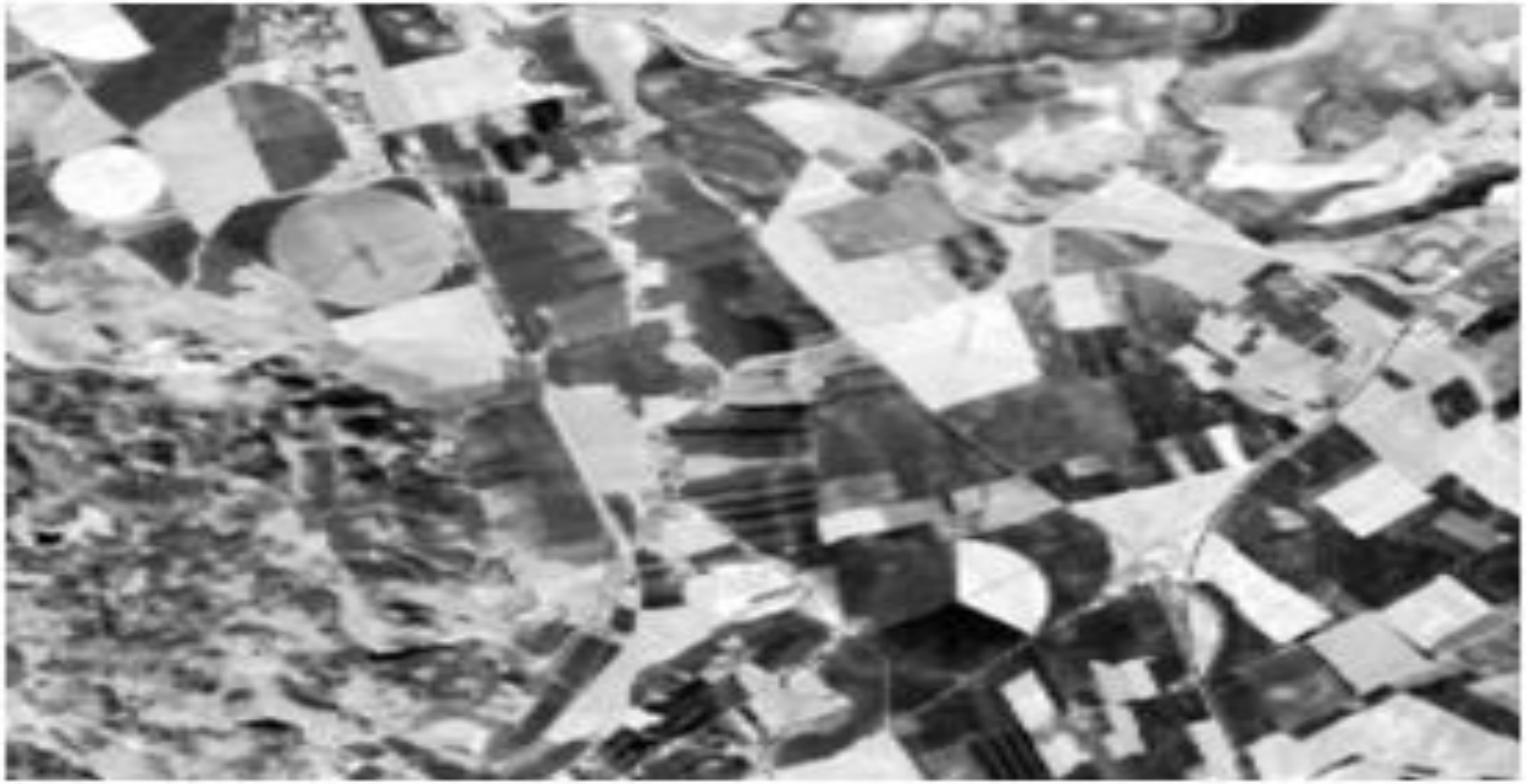


Fig. satellite image of a certain area, the circular features are pivot irrigation systems

- *Logical inference* means that the interpreter applies reasoning. In the reasoning the interpreter will use his/her professional knowledge and experience.
- Logical inference is, for example, concluding that a rectangular shape is swimming pool because of its location in a garden and near to a house.
- Sometimes, logical inference alone cannot help you in interpreting images and field observations are required.
- Consider the aerial photograph below. Would you be able to interpret the material and function of the white mushroom like objects?

- A field visit would be required for most of us to relate the different features to elements of a house or settlement.

Fig. Mud huts of Labbezanga near the Niger river.

❑ Elements of Visual Interpretation

- Analysis of remote sensing imagery involves the identification of various targets in an image, and
- those targets may be environmental or artificial features which consist of points, lines, or areas.
- Targets may be defined in terms of the way they reflect or emit radiation.
- Elements of the visual interpretations are: **tone, shape, size, pattern, texture, shadow, and association**.

A. Tone is defined as the relative brightness or colour of objects in an image(a black/white image).

- *Hue* refers to the colour on the image as defined in the intensity-hue-saturation (IHS) system.
- Tonal variations are an important interpretation element in an image interpretation.
- The tonal expression of objects on the image is directly related to the amount of light (energy) reflected from the surface.
- Different types of rock, soil or vegetation most likely have different tones.

- Variations in moisture conditions are also reflected as tonal differences in the image: increasing moisture content gives darker grey tones.
- Variations in hue are primarily related to the spectral characteristics of the measured area and also to the bands selected for visualization.
- The advantage of hue over tone is that the human eye has a much larger sensitivity for variations in colour.
- Variations in tone also allow the elements of shape, texture, and pattern of objects to be distinguished.

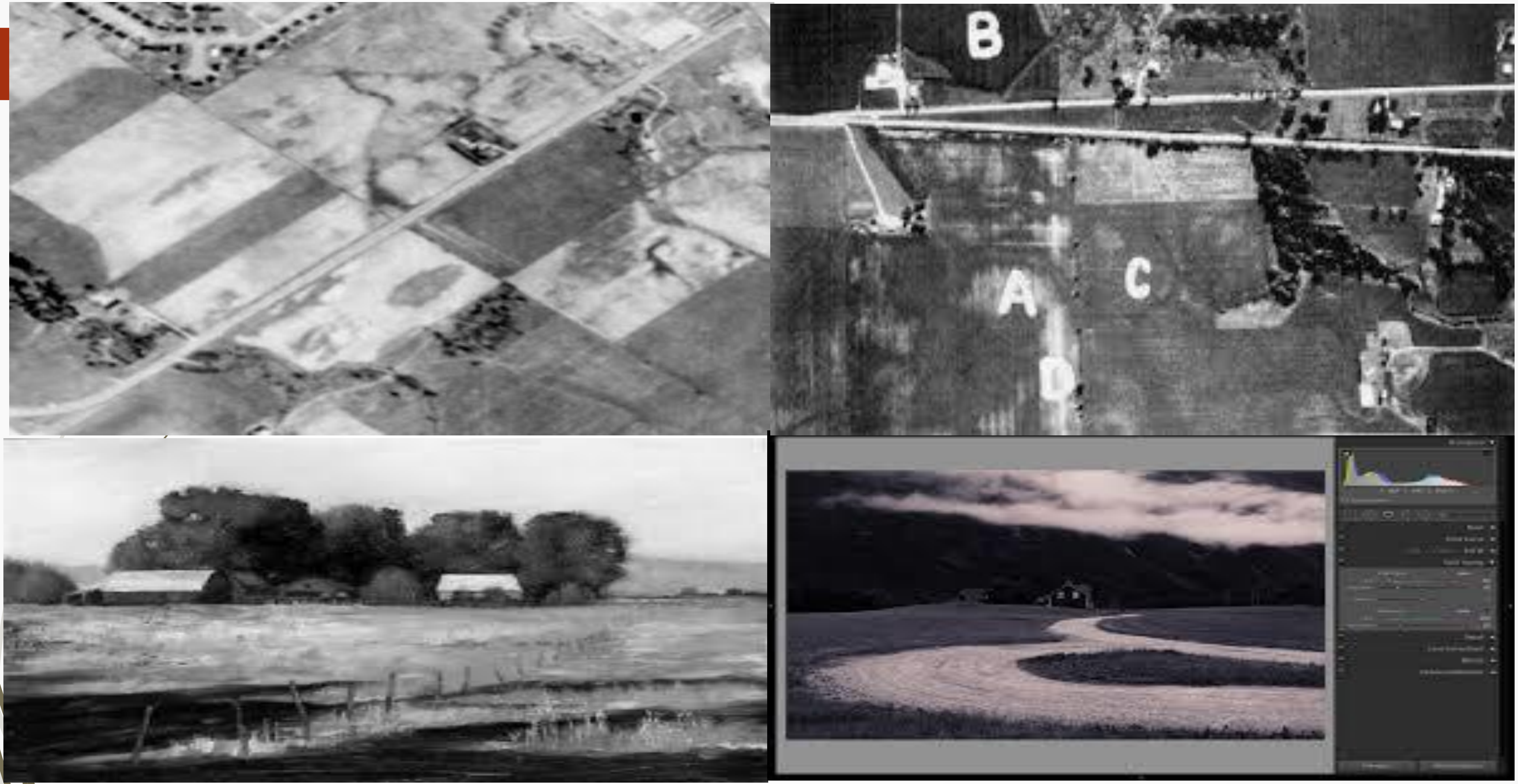


Figure: overview of variation in tone

B. **Shape** refers to the general form, structure, or outline of individual objects. Shape can be a very distinctive clue for interpretation.

- Shape also relates to (relative) height when dealing with stereo-images.
- Height differences are important to distinguish between different vegetation types and also in geomorphological mapping.
- The shape of objects often helps to determine the character of the object (built-up areas, roads and railroads, agricultural fields.

Figure: overview of different shape on the imagery

C. Size: *Size* of objects can be considered in relative or absolute sense and size of objects in an image is a function of scale.

- It is important to assess the size of a target relative to other objects in a scene, as well as the absolute size, to aid in the interpretation of that target.
- A quick approximation of target size can direct interpretation to an appropriate result more quickly.
- For example, large buildings such as factories or warehouses would suggest commercial property, whereas small buildings would indicate residential use.
- The width of a road can be estimated, for example, by comparing it to the size of the cars, which is generally known. Subsequently this width determines the road type, e.g., primary road, secondary road, *etc*.

Figure: overview of size in different feature in the imagery

D. Pattern refers to the spatial arrangement objects and implies the characteristic repetition of certain forms or relationships.

- Pattern can be described by terms such as concentric, radial, checkerboard.
- Typically an orderly repetition of similar tones and textures will produce a distinctive and ultimately recognizable pattern.
- You may think of different irrigation types but also different types of housing in the urban fringe.
- Other typical examples include the hydrological system (river with its branches) and patterns related to erosion.

▪Orchards with evenly spaced trees and urban streets with regularly spaced houses are good examples of pattern.

▪pattern of river with its branches or tributaries

Figure: overview of pattern in different surface feature

E. Texture refers to the arrangement and frequency of tonal variation in particular areas of an image.

- Texture may be described by terms as coarse or fine, smooth or rough, even or uneven, mottled, speckled, granular, linear, woolly
- Rough textures would consist of a mottled tone where the grey levels change abruptly in a small area, whereas smooth textures would have very little tonal variation.
- Smooth textures are most often the result of uniform, even surfaces, such as fields, asphalt, or grasslands.
- A target with a rough surface and irregular structure, such as a forest canopy, results in a rough textured appearance.

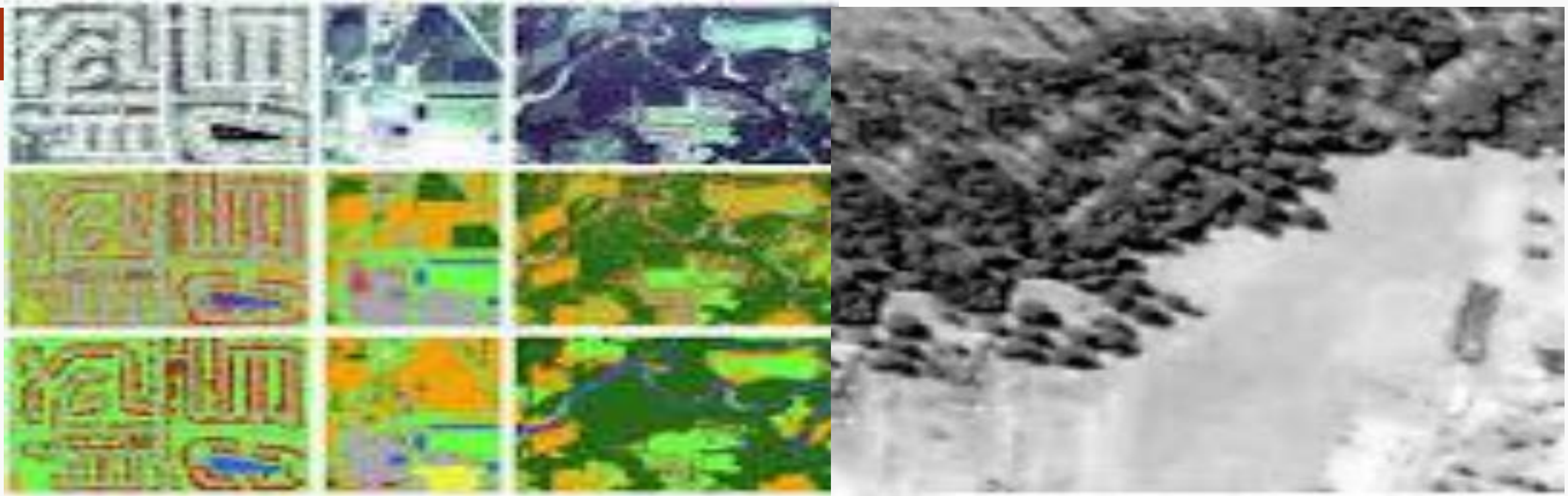


Figure: overview of texture of different surface cover

F. Site relates to the topographic or geographic location.

- A typical example of this interpretation element is that back swamps can be found in a floodplain but not in the centre of a city area.
- Similarly, a large building at the end of a number of converging railroads is likely to be a railway station we do not expect a hospital at this site.

G. Association takes into account the relationship between other recognizable objects or features in proximity to the target of interest.

- The identification of features that one would expect to associate with other features may provide information to facilitate identification.
- In the example given above, commercial properties may be associated with proximity to major transportation routes, whereas residential areas would be associated with schools, playgrounds, and sports fields.
- In our example, a lake is associated with boats, a marina, and adjacent recreational land.

Figure: Overview of association between different surface features

Digital Image Classification

- Digital image classification is a technique to derive thematic classes from image data.
- Input are multi-band image data; output is a raster file containing thematic (nominal) classes.
- In the process of image classification the role of the operator and additional (field) data is significant.
- The operator needs to provide the computer with training data and select the appropriate classification algorithm.
- The training data are defined based on knowledge (derived by field work, or from secondary sources) of the area being processed.

- Based on the similarity between pixel values (feature vector) and the training classes a pixel is assigned to one of the classes defined by the training data.
- Classes to be distinguished in an image classification need to have different spectral characteristics.
- This can, for example, be analyzed by comparing spectral reflectance curves.
- If classes do not have distinct clusters in the feature space, image classification can only give results to a certain level of reliability.
- Comparison of the individual pixels with the clusters takes place using *classifier algorithms.*

- Digital image classification uses the reflectance statistics for individual pixels.
- It categorizes the pixels in an image into land cover classes.
- The output image with a number of feature classes with varying shades of grey or varying colors representing a continuous range of spectral reflectance.
- The range of digital numbers (DN) in different bands for particular features is known as ***spectral pattern*** or ***spectral signature***

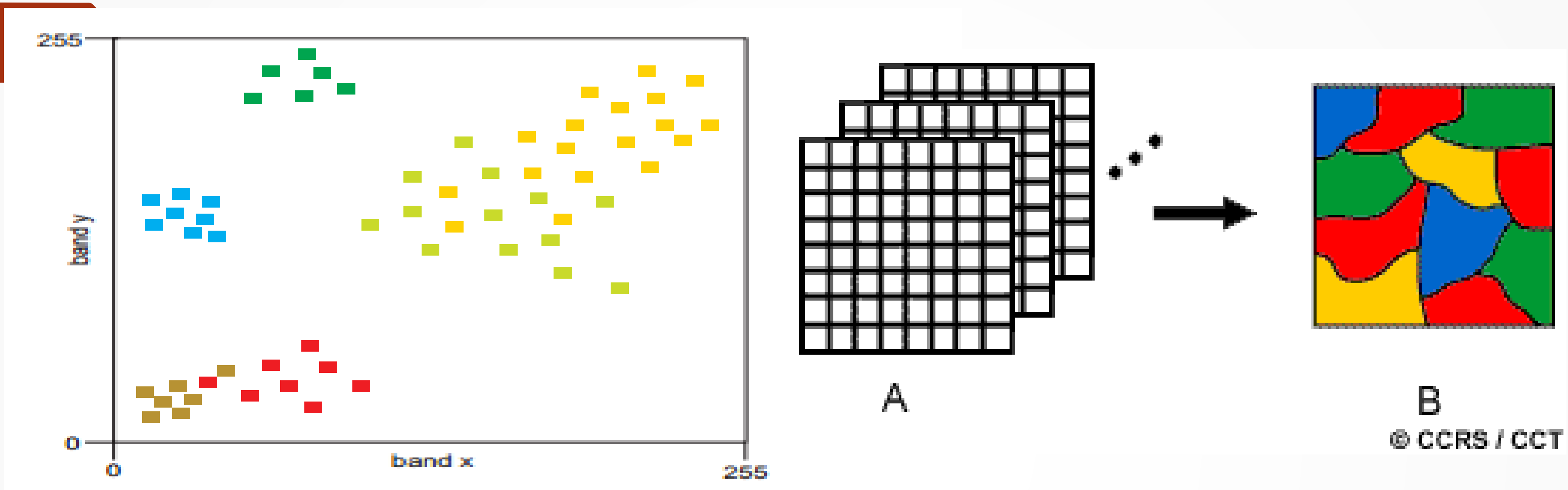


Figure: feature space showing the respective cluster of six classes; note that each class occupies a limited area in the feature space.

❖ Image classification process

The process of image classification typically involves five steps:

1. Selection and preparation of the image data. Depending on the cover types to be classified, the most appropriate sensor, the most appropriate date(s) of acquisition and the most appropriate wavelength bands should be selected.

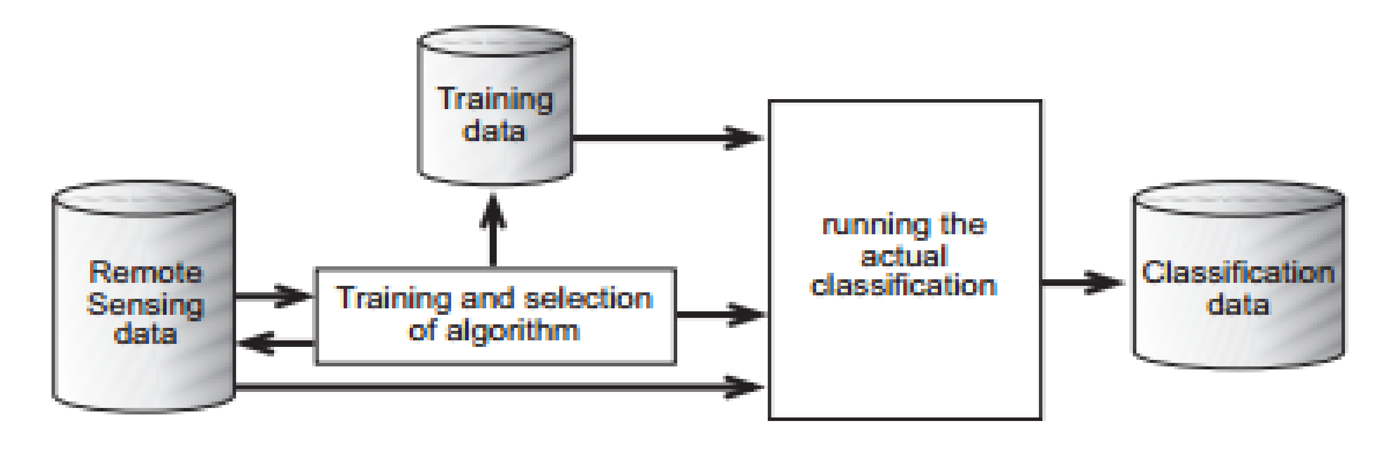


Figure : The classification process; most important component is the training in combination with selection of the algorithm.

2. Definition of the clusters in the feature space. Here two approaches are possible: *supervised classification* and *unsupervised classification*.

- In a supervised classification, the operator defines the clusters during the training process.
- In an unsupervised classification a clustering algorithm automatically finds and defines a number of clusters in the feature space.

3. Selection of classification algorithm. Once the spectral classes have been defined in the feature space,

- the operator needs to decide on how the pixels (based on their DN-values) are assigned to the classes. The assignment can be based on different criteria or algorism.

4. Running the actual classification. Once the training data have been established and the classifier algorithm selected, the actual classification can be carried out.

- This means that, based on its DN-values, each individual pixel in the image is assigned to one of the defined classes.

5. Validation of the result. Once the classified image has been produced its quality is assessed by comparing it to reference data (ground truth).

- This requires selection of a sampling technique, generation of an error matrix, and the calculation of error parameters.

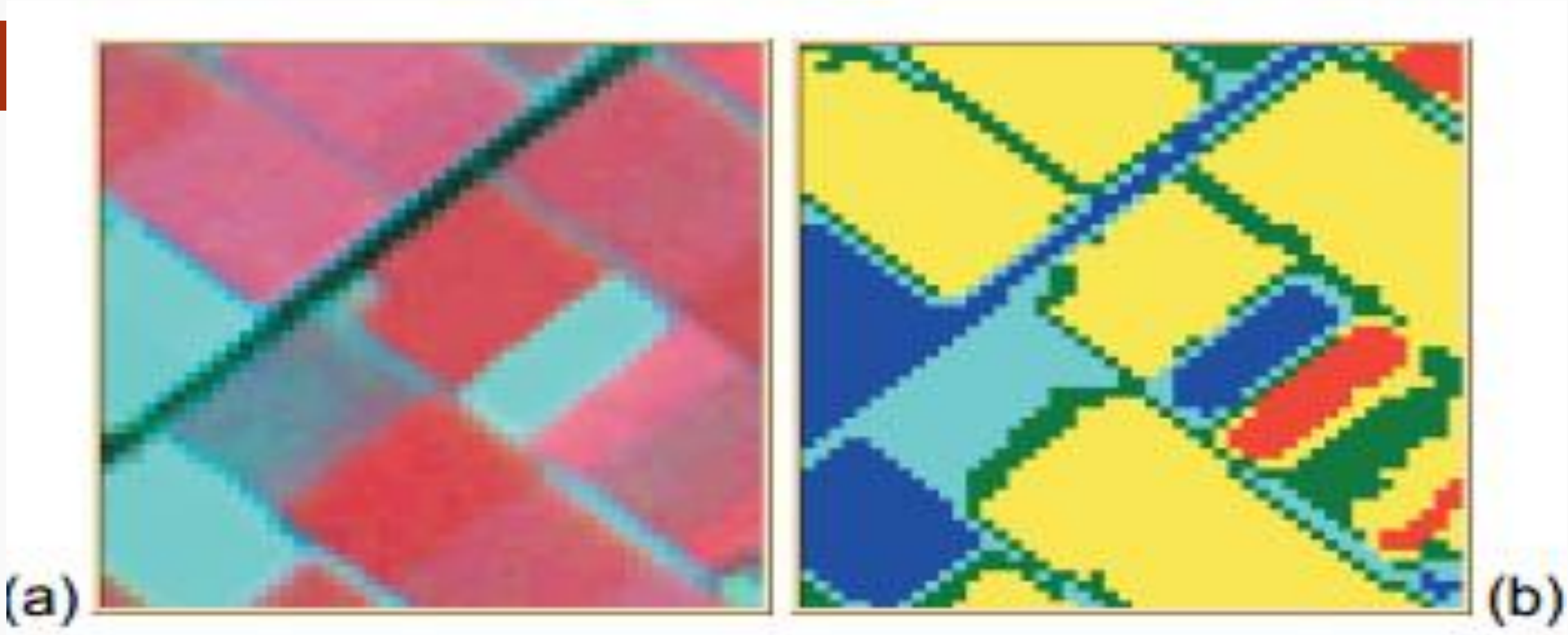


Figure: The result of classification of a multispectral image (a) is a raster in which each cell is assigned to some thematic class (b).

- **Supervised image classification**
- One of the main steps in image classification is the 'Separating' of the feature space.
- In *supervised classification* this is realized by an operator who defines the spectral characteristics of the classes by identifying sample areas (training areas).
- Supervised classification requires that the operator be familiar with the area of interest.
- The operator needs to know where to find the classes of interest in the area covered by the image.
- This information can be derived from 'general area knowledge' or from dedicated field observations.

- A sample of a specific class, comprising of a number of training pixels, forms a cluster in the feature space. The clusters, as selected by the operator:
- should form a representative data set for a given class; this means that the variability of a class within the image should be taken into account.
- Also, in absolute sense, a minimum number of observations per cluster is required.
- should not or limitedly overlap with the other clusters, otherwise, a reliable separation is not possible.
- Using a specific data set, some classes may have significant spectral overlap, which, in principle, means that these classes cannot be discriminated by image classification.
- Solutions are to add other spectral bands, and/or, add image data acquired at other moments.

Unsupervised image classification

- Supervised classification requires knowledge of the area at hand.
- If this knowledge is not sufficient available or the classes of interest are not yet defined, an unsupervised classification can be applied.
- In an *unsupervised classification*, clustering algorithms are used to partition the feature space into a number of clusters.
- Several methods of unsupervised classification system exist, their main purpose being to produce spectral groupings based on certain similarities.

- In one of the most common approaches, the user has to define the maximum number of clusters in a data set.
- Based on this, the computer locates arbitrary mean vectors as the centre points of the clusters.
- Each pixel is then assigned to a cluster by the minimum distance to cluster centroid decision rule.
- Once all the pixels have been labelled, recalculation of the cluster centre takes place and the process is repeated until the proper cluster centers are found and the pixels are labelled accordingly.
- The derived cluster statistics are then used to classify the complete image using a selected classification algorithm (similar to the supervised approach).

Comparison .....

Unsupervised	Supervised
The computer develops spectral classes then the analyst associates the spectral classes with land cover types	The analyst defines land cover types and then that can be used by the computer to identify those pixels that are numbers of each class
Does not start with a pre-determined set of classes.	The analyst knows the priori through personal experience and supervises the categorization of a set of specific classes.

Unsupervised	Supervised
The image analyst does not design the classification scheme nor develop training classes to the computer	The numerical information in all spectral bands for the pixels comprising the areas are used to "train" the computer to recognize spectrally similar areas for each class.
The computer uses a program "**clustering algorism**" that aggregates similar pixels into classes based on their similarity and dissimilarity	The computer uses a special program or algorithm to determine the numerical "signatures" for each training class.

Advantage & disadvantage of supervised & unsupervised techniques

Unsupervised

- **Advantages**
  - Requires no prior knowledge of the region
  - Human error is minimized
  - Unique classes are recognized as distinct units
  - Relatively fast and easy to perform

- **Disadvantages**
  - Limited control of classes and identities
  - Spectral properties of classes can change with time

Supervised

- **Advantages**
  - Analyst has control over the selected classes
  - Has specific classes of known identity
  - Can detect serious errors in the classification

- **Disadvantages**
  - Analyst imposes a classification (may not be natural)
  - Training data are usually tied to informational categories and not spectral properties

Classification algorithms

- After the training sample sets have been defined, classification of the image can be carried out by applying a classification algorithm.
- Several classification algorithms exist. The choice of the algorithm depends on the purpose of the classification and the characteristics of the image and training data.
- The operator needs to decide if a 'reject' or 'unknown' class is allowed. There are three classifier algorithms, these are:
- *box classifier, Minimum Distance to Mean and the Maximum Likelihood classifiers are used.*

- For detailed understanding about digital image classification it is better to discuss the ff points:
- the type of classification algorithms
- validation of the result
- Problems in image classification

THE END
THANK U!