Overview of Remote Sensing

What is Remote Sensing?

Remote sensing is the science of acquiring information about the Earth's surface without actually being in contact with it

That involves:

- Recording reflected or emitted energy
- Processing, analyzing and applying information

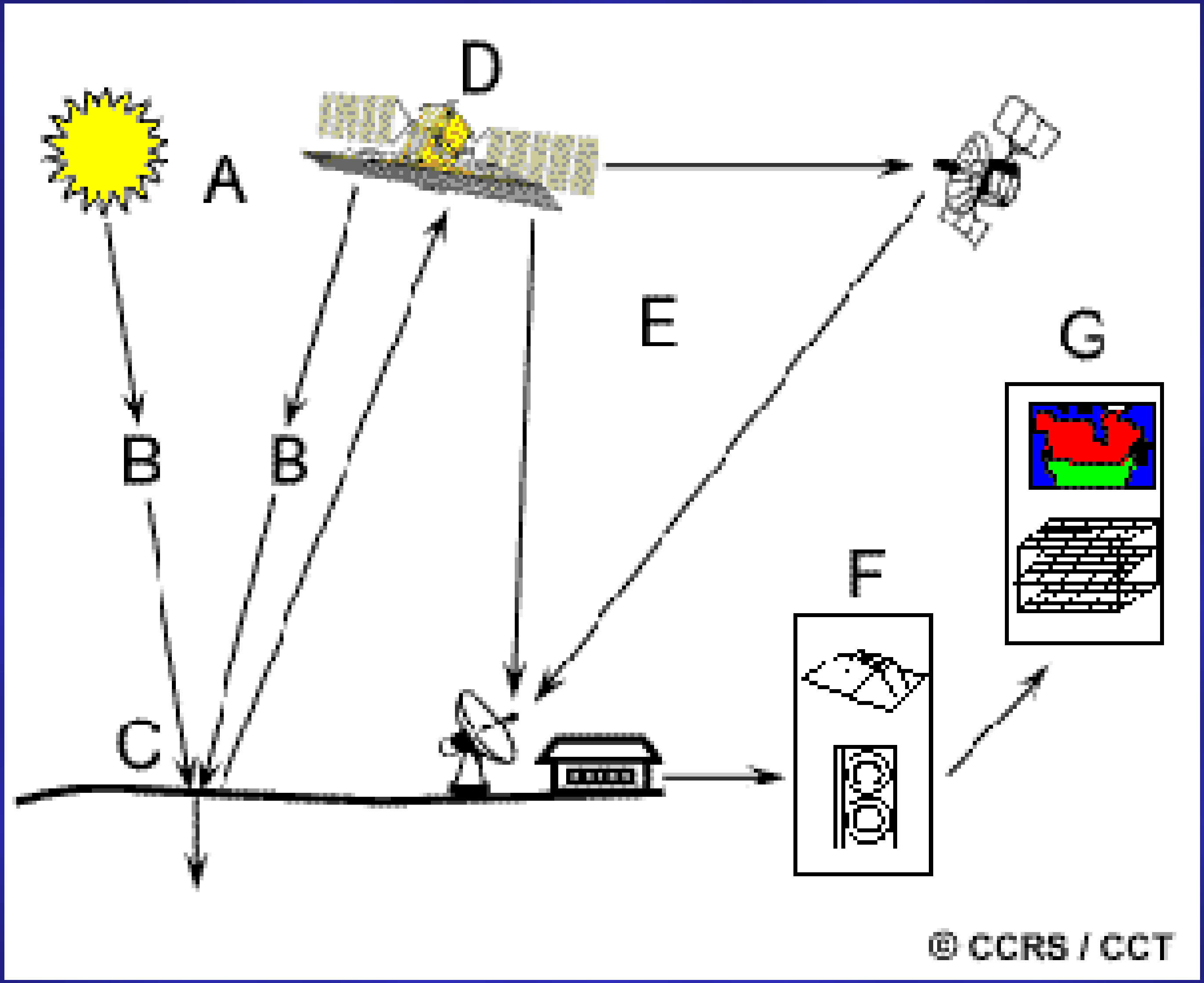
Why Remote Sensing?

- New technology for ecosystem analysis, evaluation and monitoring
- Integral part of several projects, e.g., mineral and petroleum exploration, satellite meteorology, etc.
- Synoptic view
- Multitemporal studies
- New satellite with improved spectral and spatial resolutions

Remote sensing definitions

- Instrumentation, techniques to observe the Earth surface at a distance and to interpreter the images for numerical values obtained in order to acquire meaningful information of particular objects on Earth
- Remote sensing process involves the interaction between incident radiation and the earths surface or targets of interest

Process of Remote Sensing



Process of Remote Sensing

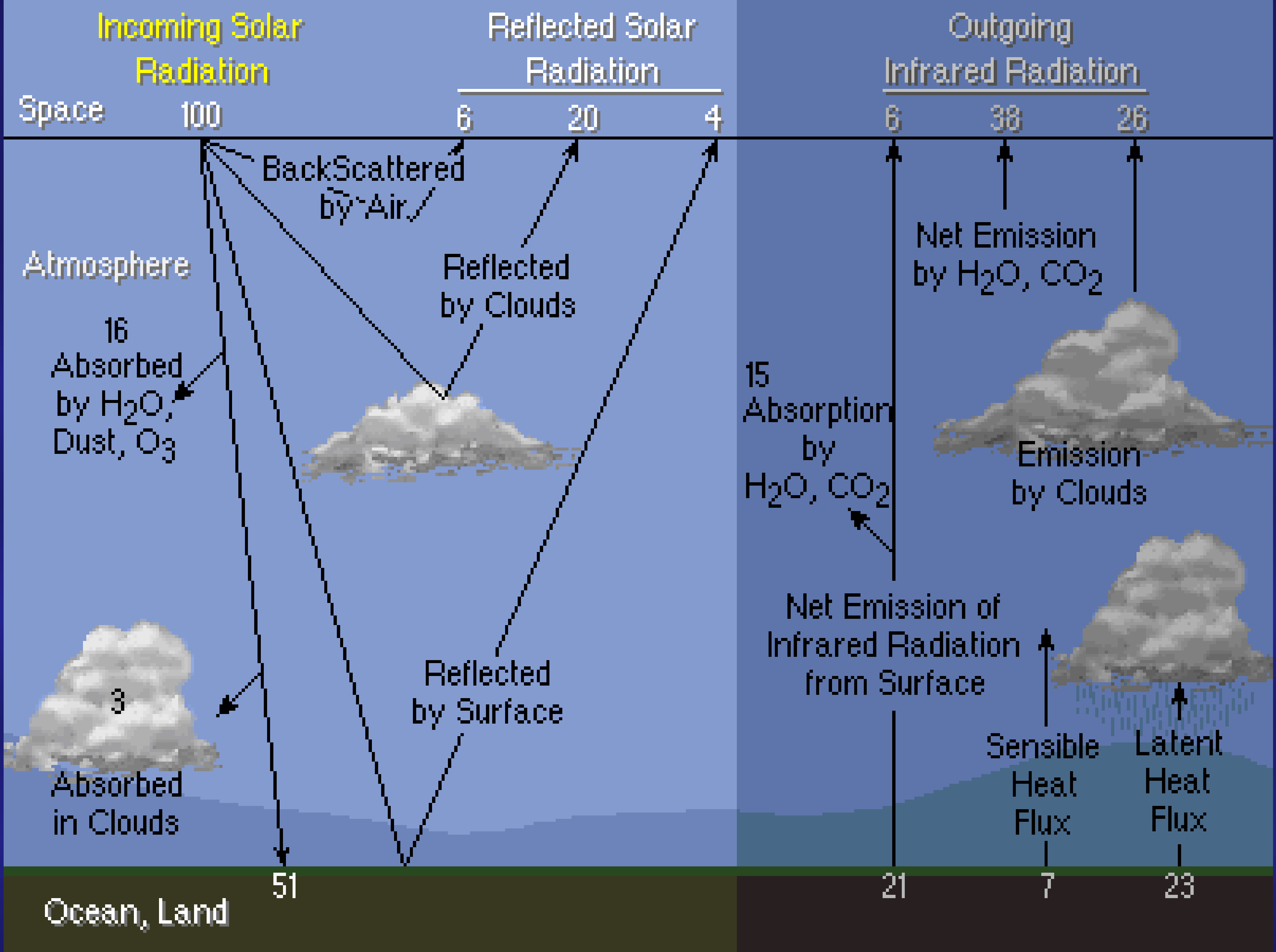
- Energy Source or Illumination (A)
  - Illuminates or provides electromagnetic energy to the target
- Propagation through the atmosphere (B)
  - The energy comes in contact with and interacts with the atmosphere it passes through
- Energy interactions with earth surfaces (target) (C)
  - Energy interacts with the target
  - Interaction depends on the characteristics of the radiation and the target

Process of Remote Sensing

- **Retransmission of energy through the atmosphere (D)**
  - **Energy interacts with the atmosphere a second time as it travels to the sensor**
- **Recording of energy by the airborne and/or spaceborne sensors (E)**
- **Transmission, reception, and processing resulting in the generation of sensor data in pictorial and/or digital form (F)**

Process of Remote Sensing

- Analysis of sensor data using viewing and interpretation devices (G)
  - Analyst obtains information on type, extent, location, and conditions of various resources
- Information compilation (H)
  - Hardcopy, digital maps, computer files that could merged with other layers (GIS)
- Presentation of information to users (I)
  - Apply it to decision-making process



Incoming Solar Radiation
Reflected Solar Radiation
Outgoing Infrared Radiation
Space
100
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BackScattered by Air
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Reflected by Clouds
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Emission by Clouds
Net Emission of Infrared Radiation from Surface
3
Absorbed in Clouds
Reflected by Surface
Sensible Heat Flux
Latent Heat Flux
51
21
7
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Ocean, Land

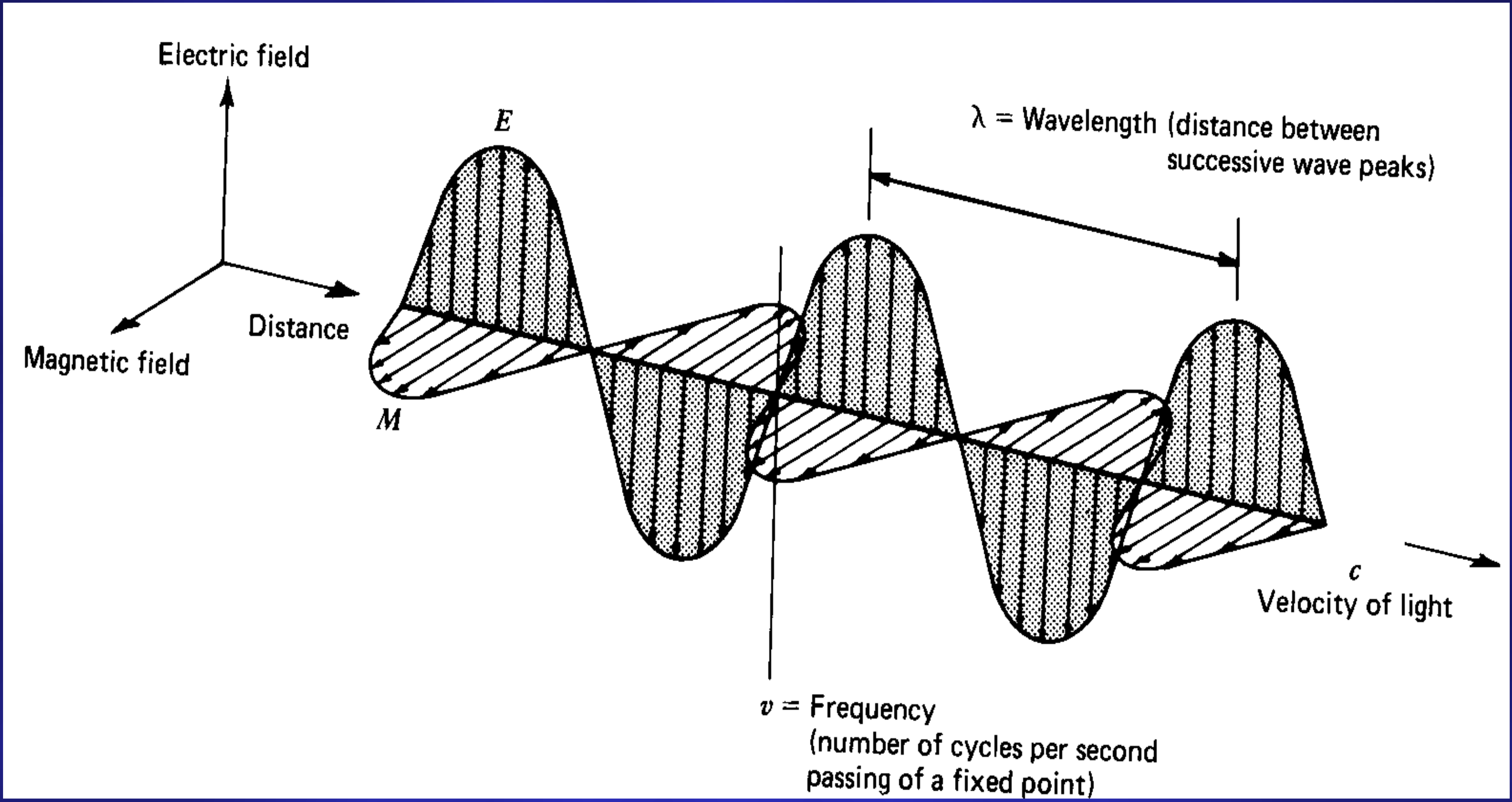
Electromagnetic energy and remote sensing

- Remote sensing relies on measurements of electromagnetic energy (EM)
- Sun is the most important source
  - Eg, visible light, heat and UV-light
- Remote sensing uses reflected and emitted sunlight from the Earth’s surface
- Basic knowledge of EM is needed to interpret remote sensing data correctly

Electromagnetic spectrum

- Can be modeled in two ways
  - Waves or by energy bearing particles called photons
- All electromagnetic radiation has fundamental properties and behaves according to the basics of wave theory
- Ranges from shorter wavelength (gamma and x-rays) to longer wavelengths (microwaves and broadcast radio waves

Electromagnetic wave



Wave equation

Wavelength and frequency are related by the wave equation

- Wave equation
    - $c = \upsilon\lambda$
    - λ=wavelength (m)
    - υ=frequency (cycles per second, Hz
    - c=speed of light ($3x10^8$ m/s)
  - Inverse relations between frequency and wavelength (µm)—the shorter the wavelength the lower the frequency

Particle theory

- Electromagnetic radiation is composed of many discrete units called photons or quanta. The energy of a quantum is given as
- Q=hv
  - Q=energy of a quantum, Joules (J)
  - h=Plank's constant, 6.626 x 10^{-34} J sec
  - v=frequency

By relating the wave and quantum models of electromagnetic radiation we obtain

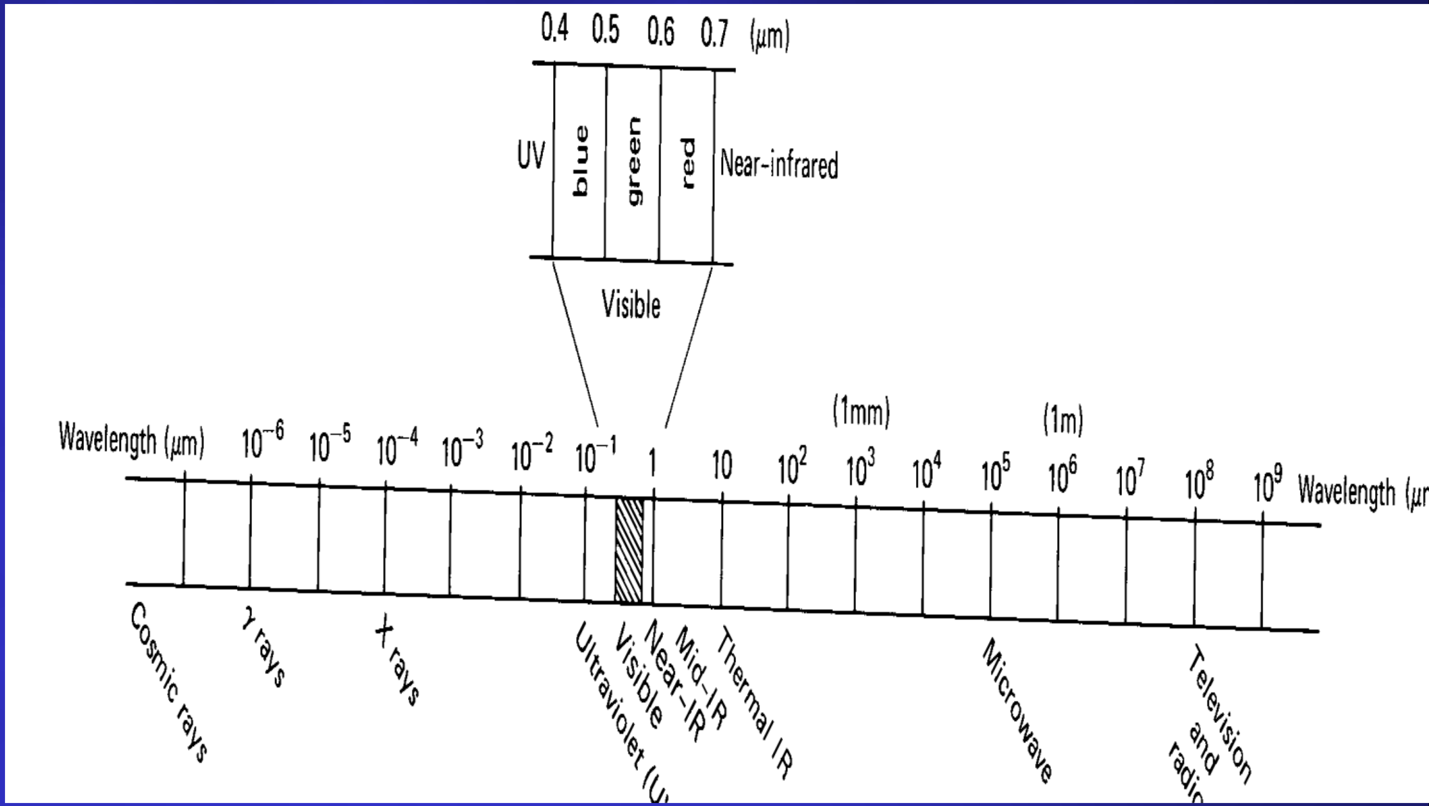
- Q=hc/ λ

Energy is inversely proportional to its wavelength

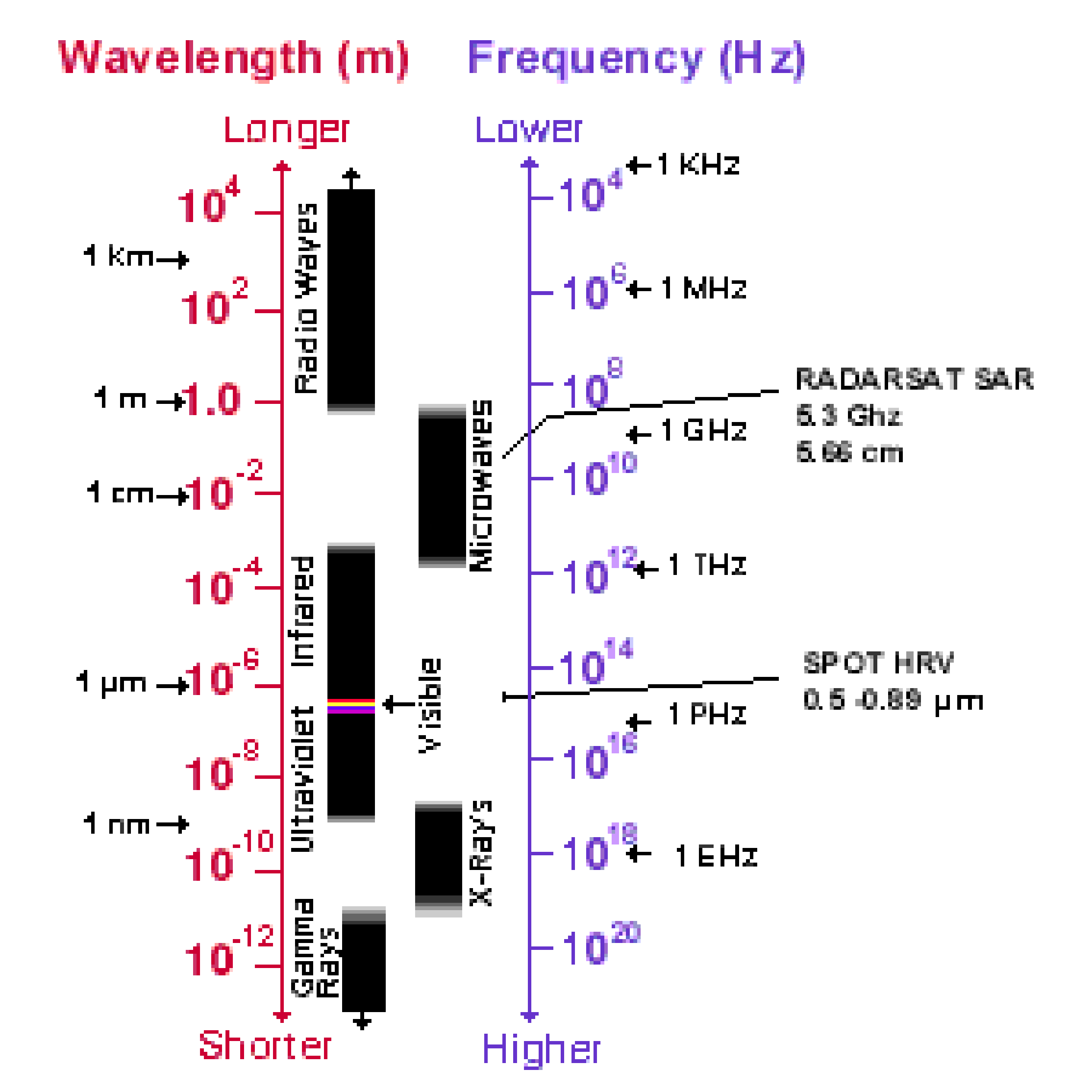
  - The longer the wavelength involved the lower its energy content

Electromagnetic spectrum

- Ranges from the shorter wavelengths (including cosmic, gamma and x-rays) to the longer wavelengths (including microwaves and broadcast radio waves)



Electromagnetic Spectrum



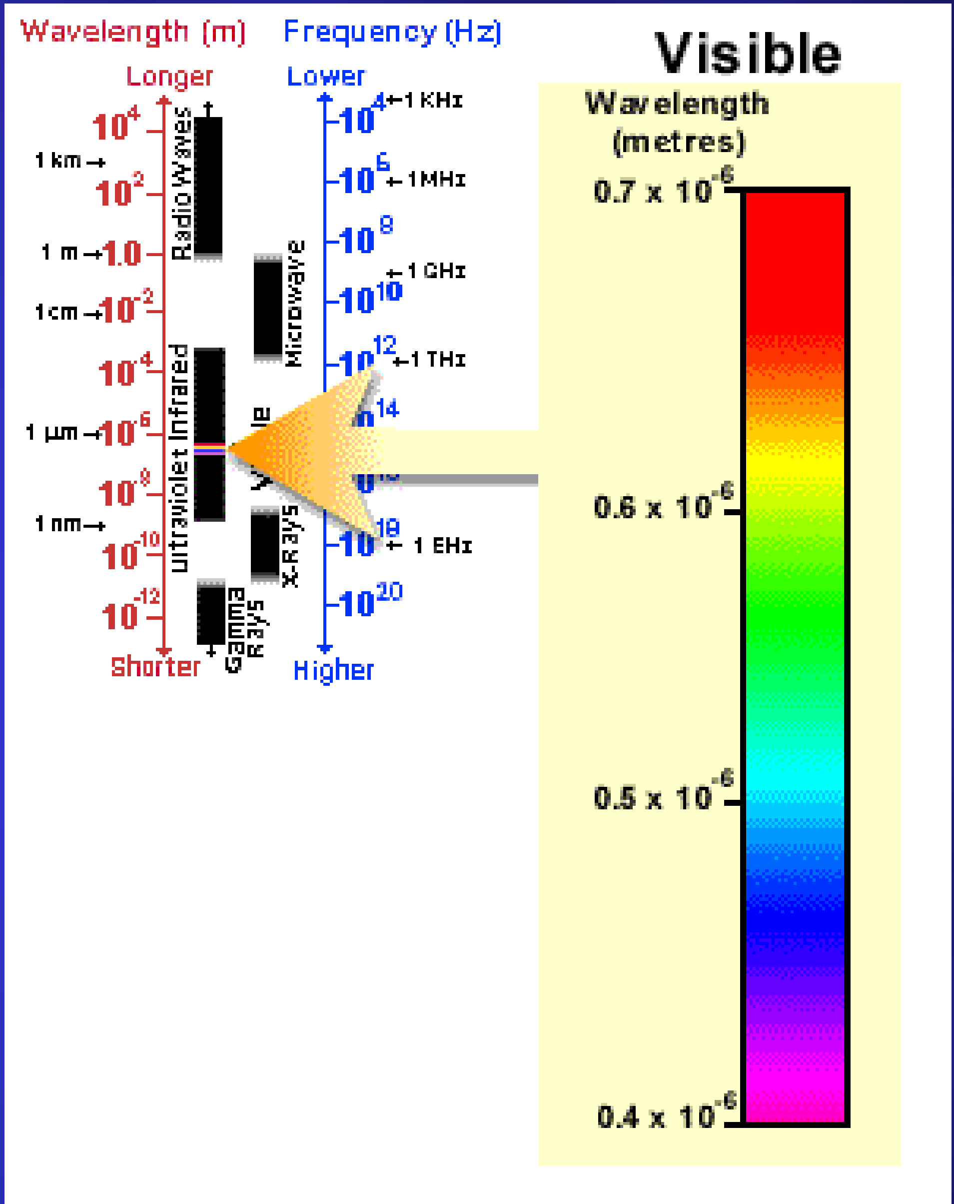
Electromagnetic spectrum

- **Comic rays**
- **γ-rays**
- **X-rays**
- **Ultraviolet rays**
- **Visible (0.4-0.7 μm)**
- **Infrared**
  - **Near-infrared (0.7-1.3 μm)**
  - **Mid-infrared (1.3-3 μm)**
  - **Thermal infrared (beyond 3 μm)**
- **Microwave (1 mm to 1m)**
- **Television and radio waves**

There is no clear-cut dividing line between regions

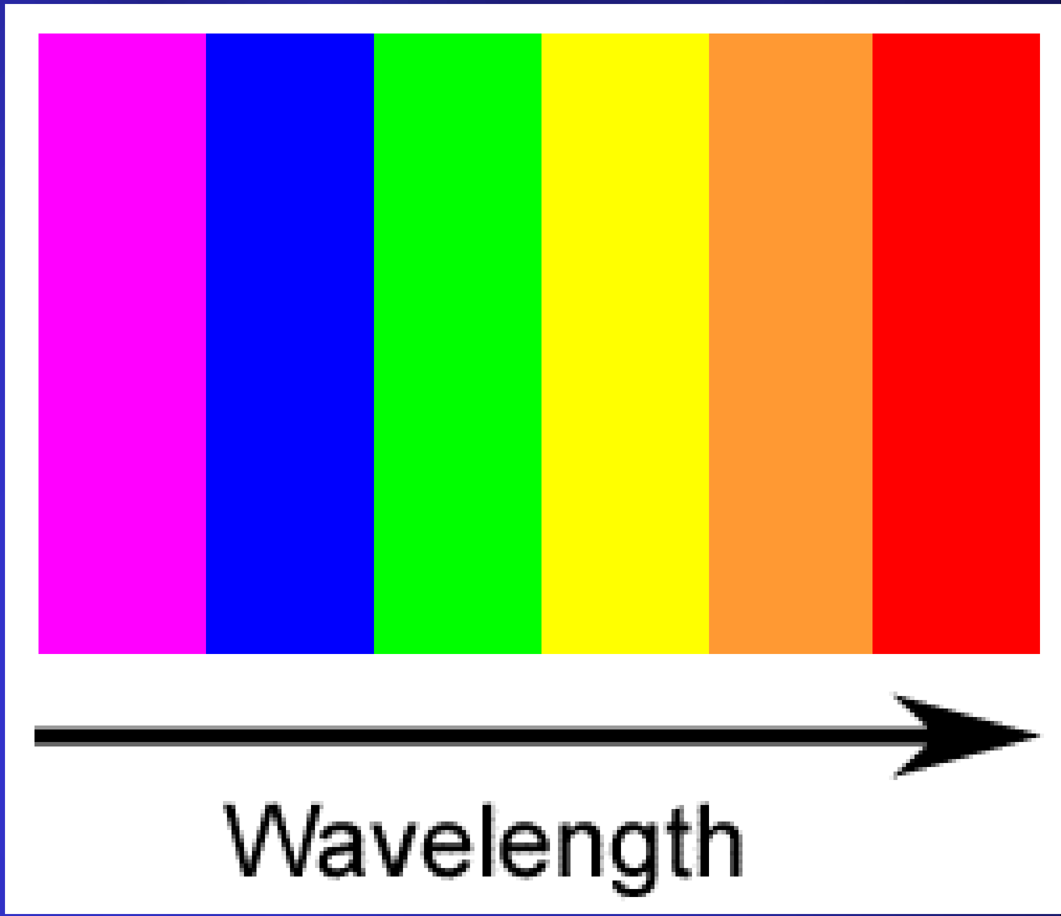
Visible region

- The light which our eyes can sense is part of the visible spectrum
- Region is small compared to the rest of the spectrum
- A lot of radiation are invisible to our eyes
- Can be detected by other remote sensing techniques and used to our advantage



Visible region

- Only portion of the spectrum associated with the concept of color
- Visible spectrum (0.4-0.7 µm) can be subdivided into
  - Violet (0.4-0.446)
  - Blue (0.446-0.5 µm)
  - Green (0.5-0.78 µm)
  - Yellow (0.578-0.592)
  - Orange (0.592-0.620)
  - Red (0.62-0.7 µm)

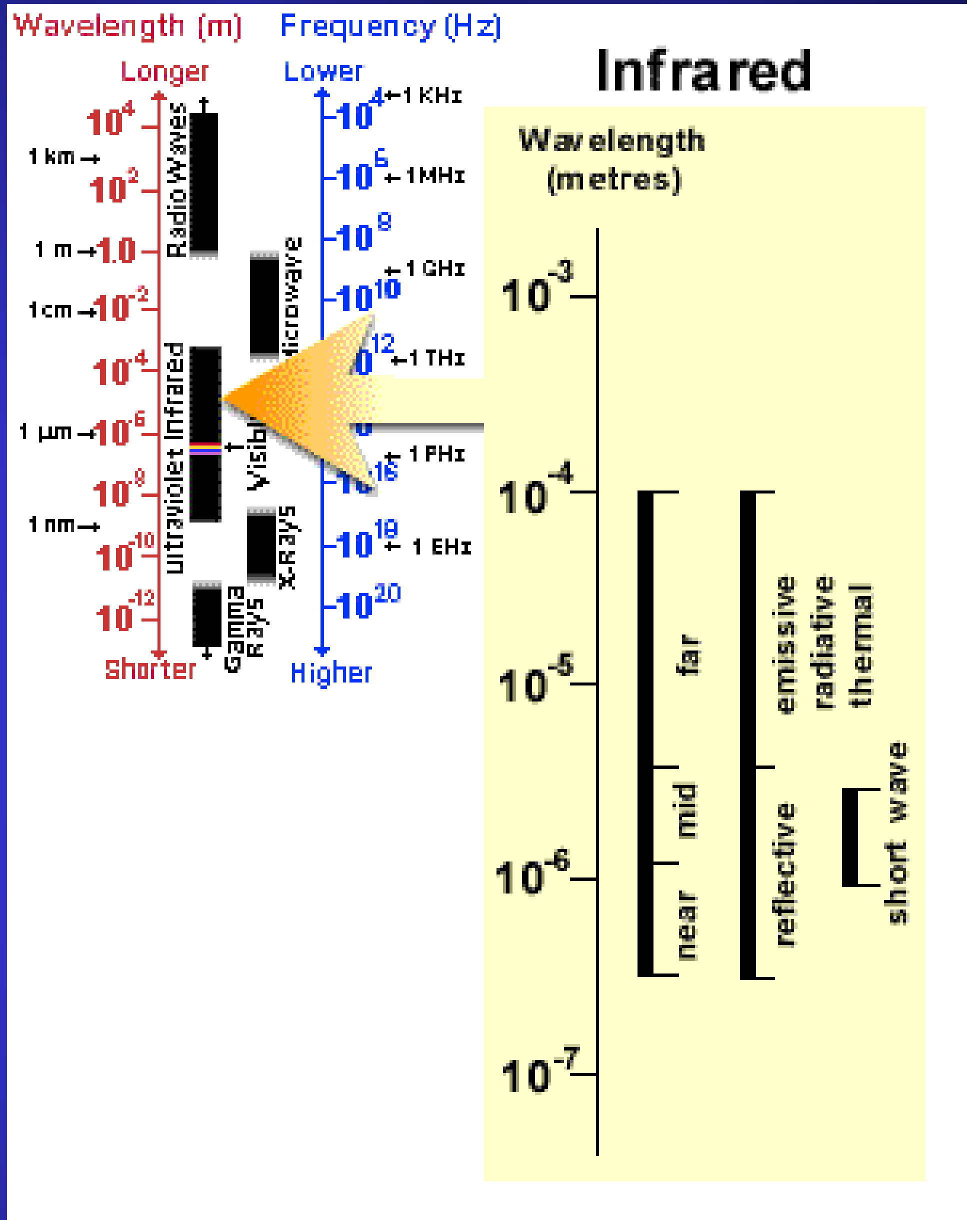


Visible region

- Blue, green, and red are the primary colors
- No single primary color can be created from the other two
- Other colors can be created by combining any of the primary colors
  - Blue (0.4-0.5 µm
  - Green (0.5-0.6 µm
  - Red (0.6-0.7 µm)

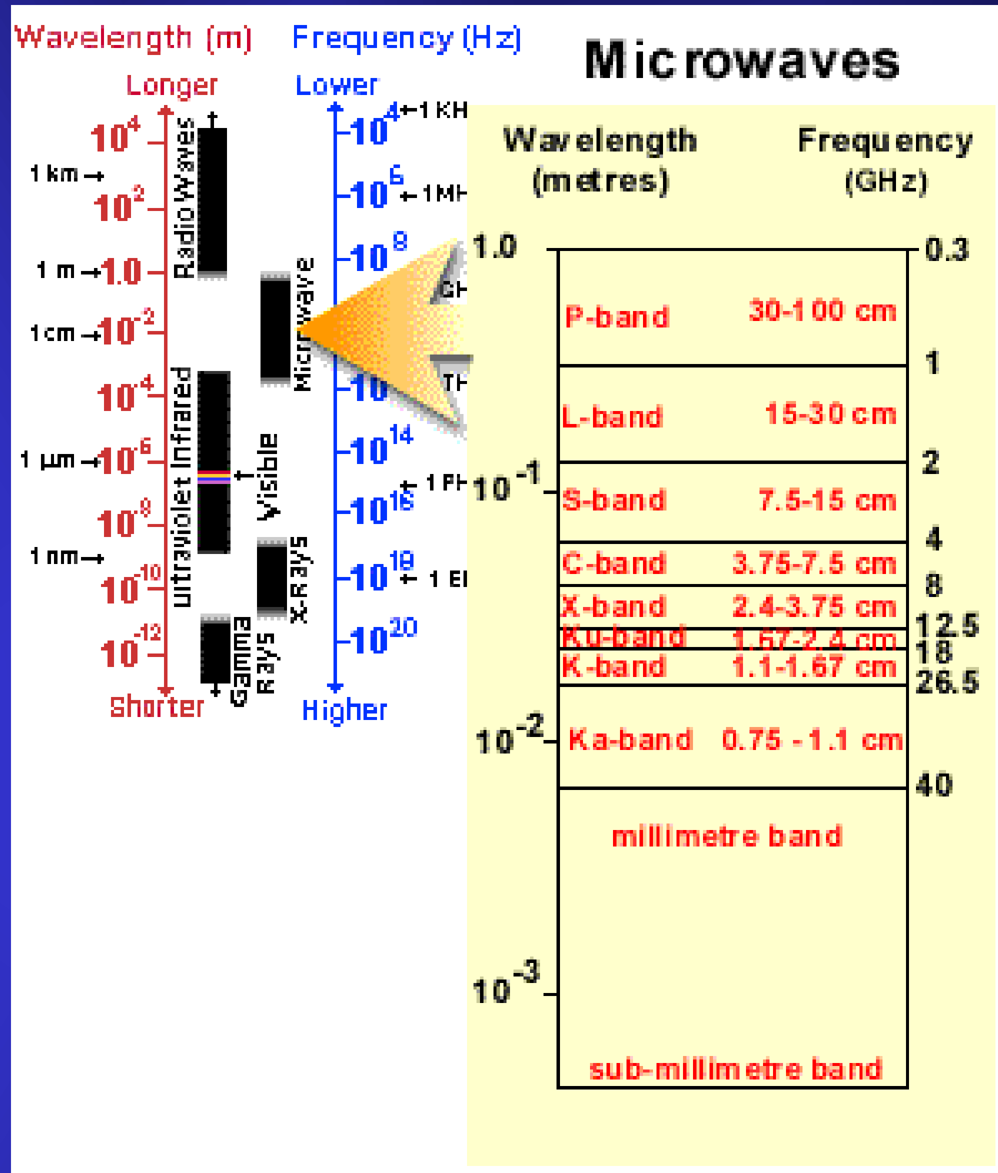
Infrared (IR)

- Infrared region can be subdivided into 3 groups
  - Near-infrared (0.7-1.3 µm)
  - Mid-infrared (1.3-3 µm)
  - Thermal infrared (beyond 3 µm)
- Groups behave differently



Microwave region

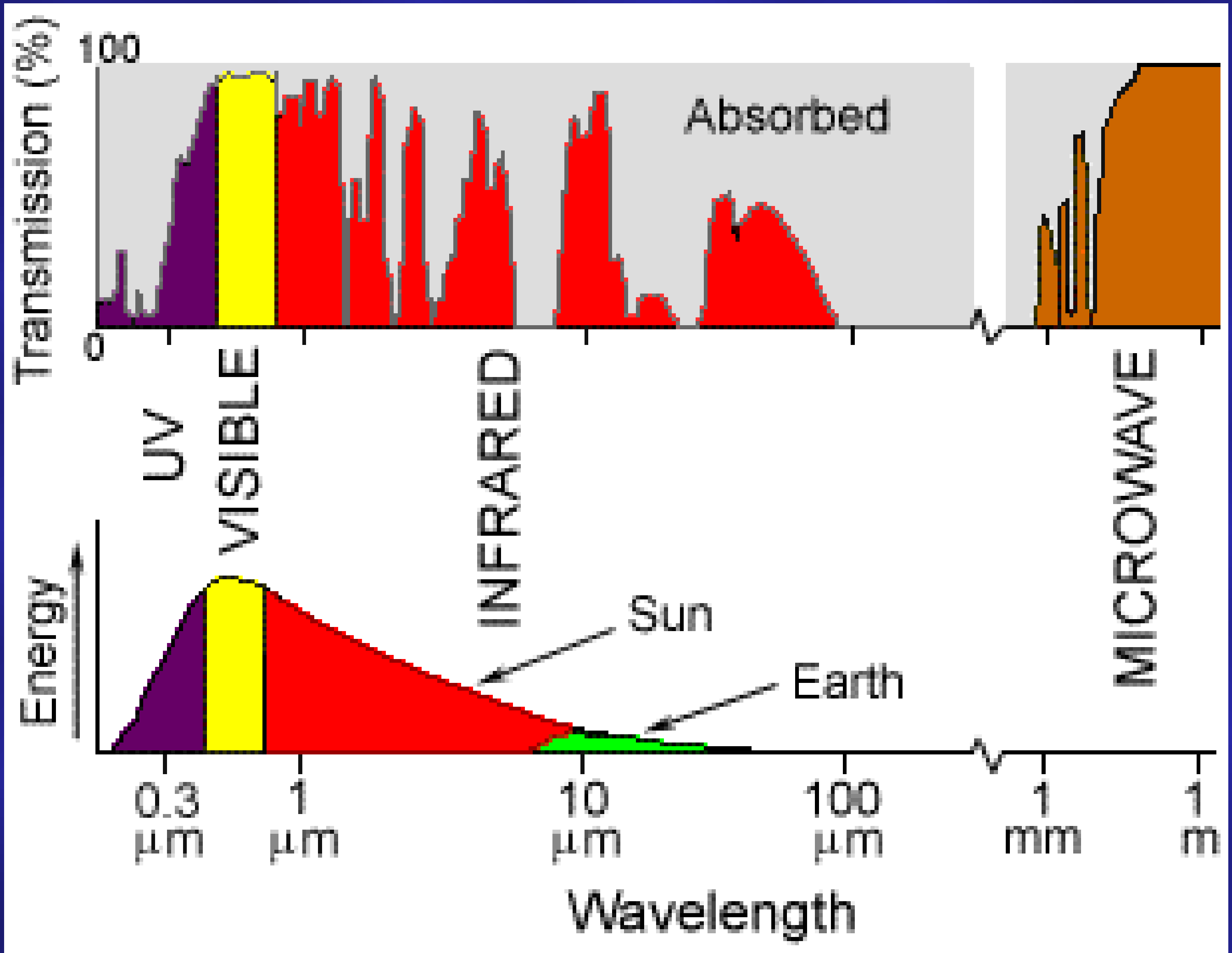
- Microwave region covers the longest wavelengths used for remote sensing (1 mm to 1 m)
- Subdivided into several regions
  - P-band (75 to 133 cm)
  - L-band (15 to 30 cm)
  - S-band (7.5 to 15 cm)
  - C-band (3.8 to 7.5 cm)
  - X-band (2.4 to 3.8 cm)
  - K-band (0.75 to 2.4 cm)



Remote sensing operates in

- Visible (blue 0.4-0.5 µm, green 0.5-0.6 µm and red 0.6-0.7 µm)
- Infrared
  - Near-infrared (0.7-1.3 µm)
    - Reflective
  - Mid-infrared (1.3-3 µm)
  - Reflective
  - Thermal infrared (3-14 µm)
    - Related to sensation of heat-- emissive
- Microwave (1 mm -1 m)

Wavelengths used in remote sensing



- **Sun is principal source of electromagnetic radiation for remote sensing**
- **However, all matter at temperatures above absolute zero (0K, -273 ºC) emits electromagnetic radiation**
- **Terrestrial objects are sources of radiation which is considerably different in spectral composition and magnitude from the sun**

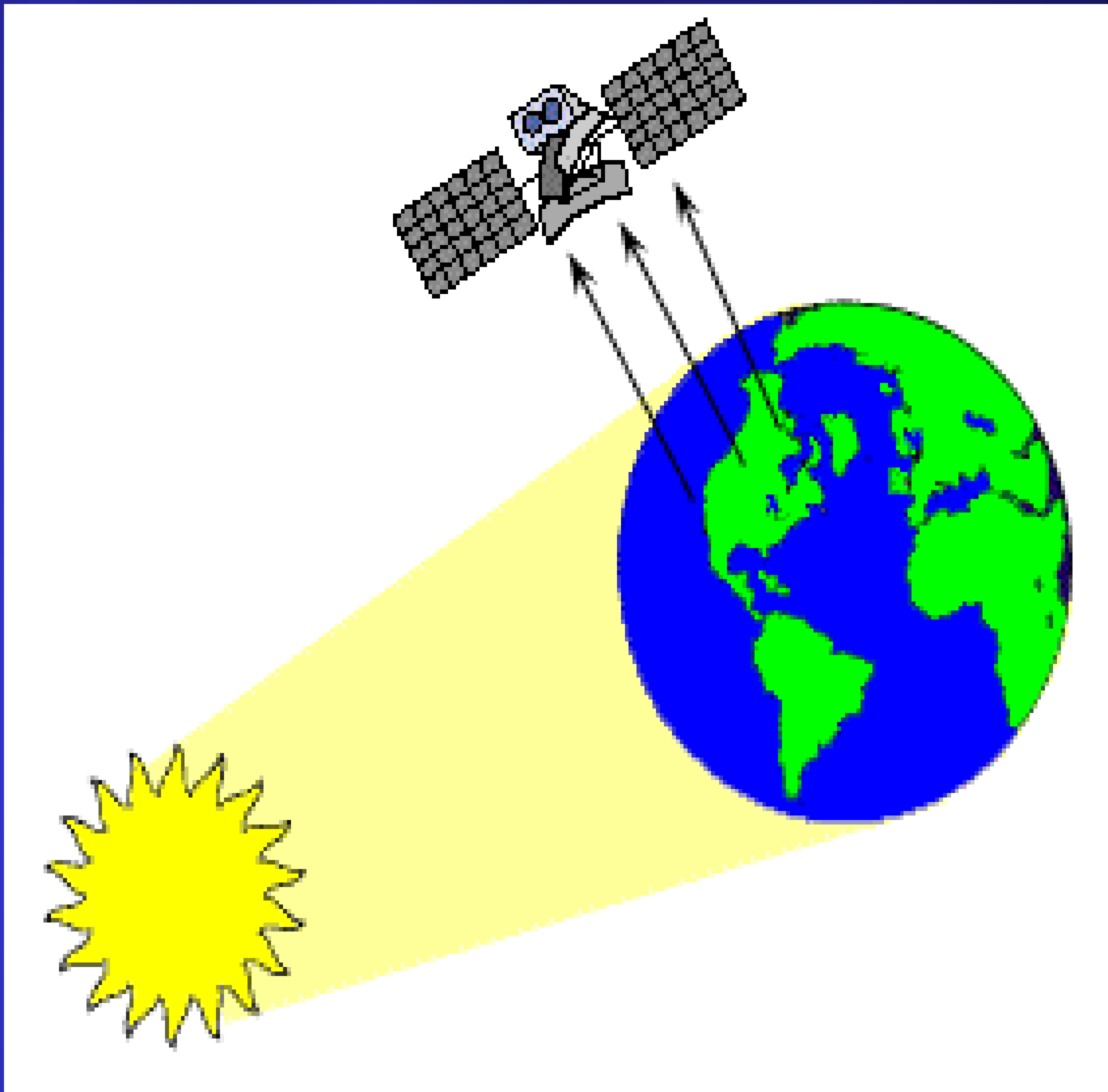
Stefan-Boltzmann law

- Stefan-Boltzmann law states that
  - $M=\alpha T^4$
    - M=total radiance from the surface of a material
    - α=Stefan-Boltzmann constant
    - T= absolute temperature of the emitted material
  - Total energy emitted varies at T^4 --blackbody
- The energy emitted from an object is a function of its temperature

- The sun provides a very convenient source of energy for remote sensing
- Sun’s energy is either
  - Reflected (e.g., visible wavelengths) or
  - Absorbed and then re-emitted (e.g. thermal infrared)
- Remote sensing systems which measure energy that is naturally available are called passive sensors

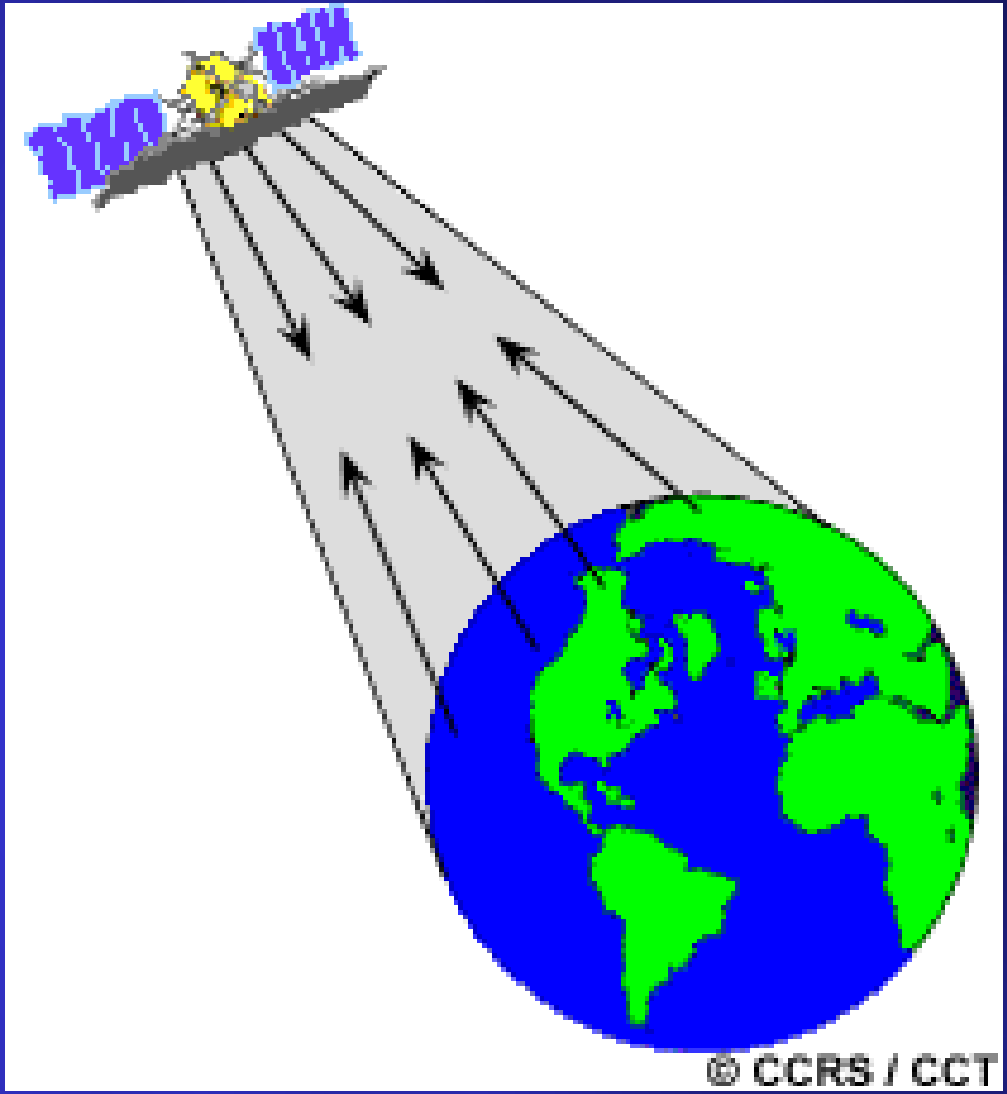
Passive sensor

- Detects energy only during the day when the sun is illuminating the Earth
- However, emitted energy such as thermal infrared can be detected day or night
- Energy must be large enough to be recorded



Active sensor

- Provide their own energy source for illumination
- Sensor emits radiation which is directed toward the target to be investigated
- Radiation reflected from that target is detected and measured by sensor

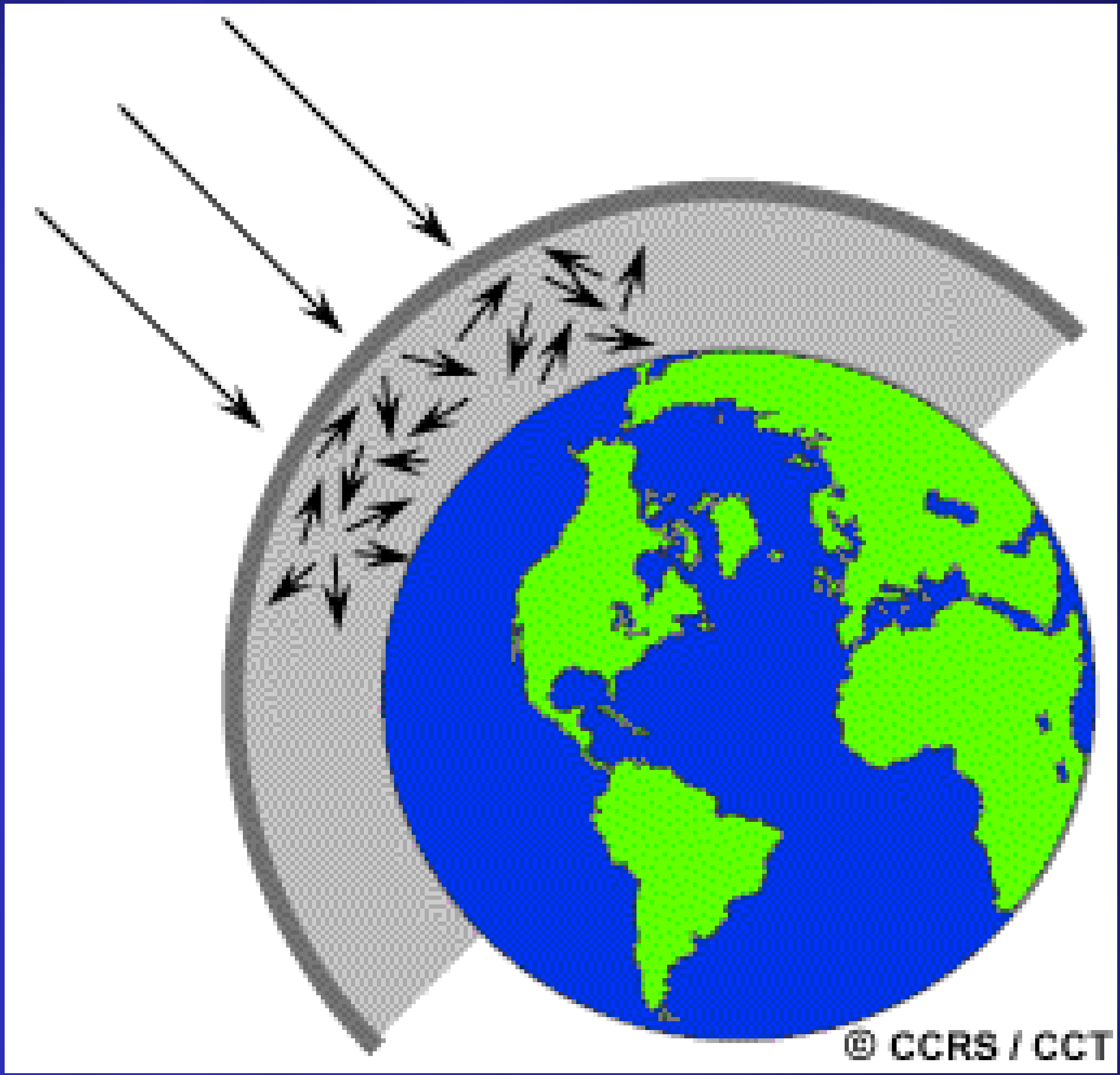


Energy Interactions With Earth Systems

- **Before radiation used for remote sensing reaches the Earth's surface it passes through the Earth's atmosphere.**
- **Particles and gasses in the atmosphere can have a profound effect on energy being transmitted through it.**
- **The principal mechanisms of atmospheric interactions are**
  - **Scattering**
  - **Absorption**

Scattering

Scattering occurs when particles or large gas molecules present in the atmosphere interact and cause the electromagnetic radiation to be redirected from its original path



Scattering

- **Unpredictable diffusion of radiation by particles and involves the redirection of electromagnetic radiation from their original path**
- **Amount of scattering depends upon**
  - **Wavelength**
  - **Abundance of particles or gasses**
  - **Distance of the radiation travels through space**

Scattering

There are three types: (1) Rayleigh scattering (2) Mie scattering, and (3) Non-selective scattering

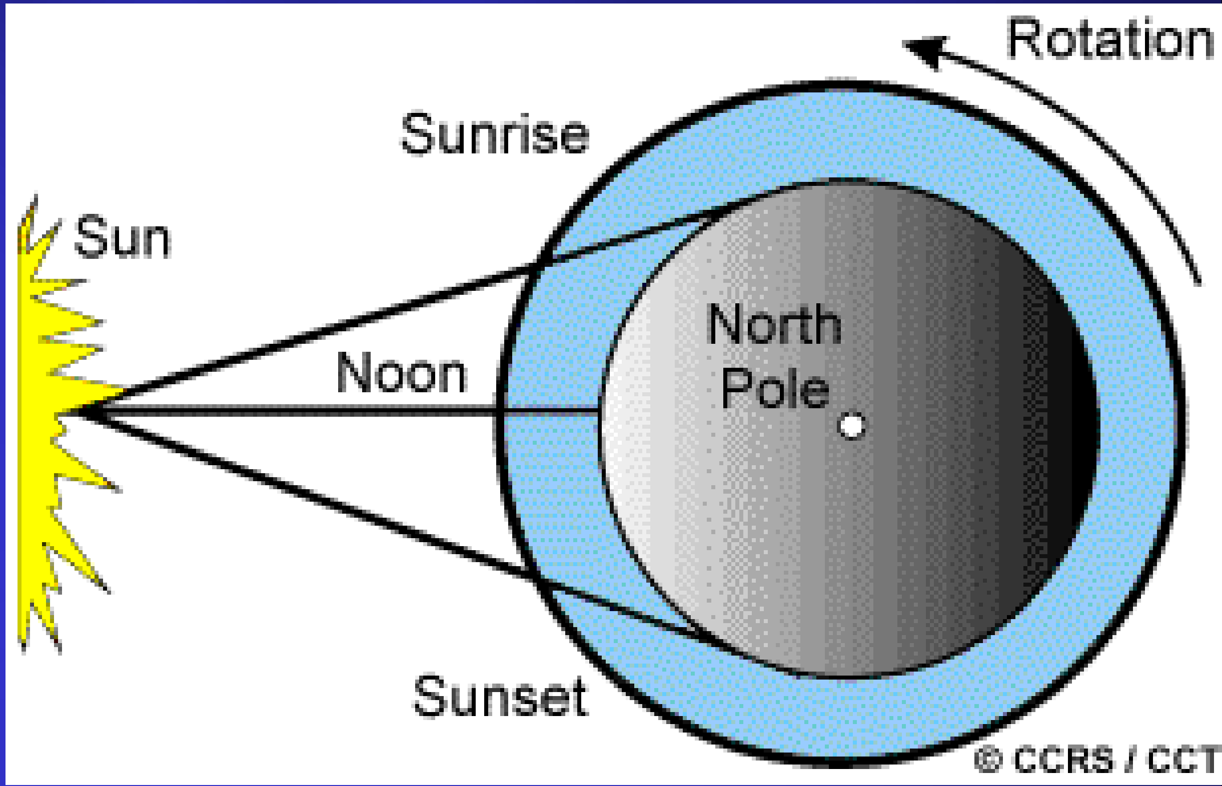
- **Rayleigh scattering occurs when**

Particles are very small compared to the wavelength of the interacting radiation, e.g., specks of dust or nitrogen and oxygen molecules

  - **Causes shorter wavelengths of energy to scattered much more than longer wavelength**
  - **Blue sky– due to stronger scattering of blue than other wavelengths**
  - **Primary cause of haze in imagery**
  - **Haze diminishes the contrast of an image**

Rayleigh Scatter

- As light passes through the atmosphere the shorter wavelengths (blue) are scattered more than the other longer visible wavelengths
- At sunrise and sunset light travels farther through the atmosphere than midday and scattering of the short wavelength is much more complete
- That leaves a greater proportion of the longer wavelengths to penetrate the atmosphere
- Sky appears orange or red



Rayleigh scattering and remote sensing

- Most important type of scattering
- It distorts the spectral characteristics of reflected light, compared to ground measurements
- Shorter wavelength (blue, green, red) are overestimated
- It accounts for the blueness of color photos taken from high altitude
- In general, it diminishes the contrast in the photo and thus negative effect on possibilities of interpretation
- Effect can be removed in digital image data

Scattering

- Mie scattering occurs when
  - Particles are about the same size as wavelength of radiation
  - Water vapor dust, pollen, smoke common causes of Mie scatter
  - Tends to influence longer wavelength compared to Rayleigh scatter
  - Occurs mostly in the lower portion of the atmosphere where larger particles are more abundant
  - Dominates when cloud conditions are overcast

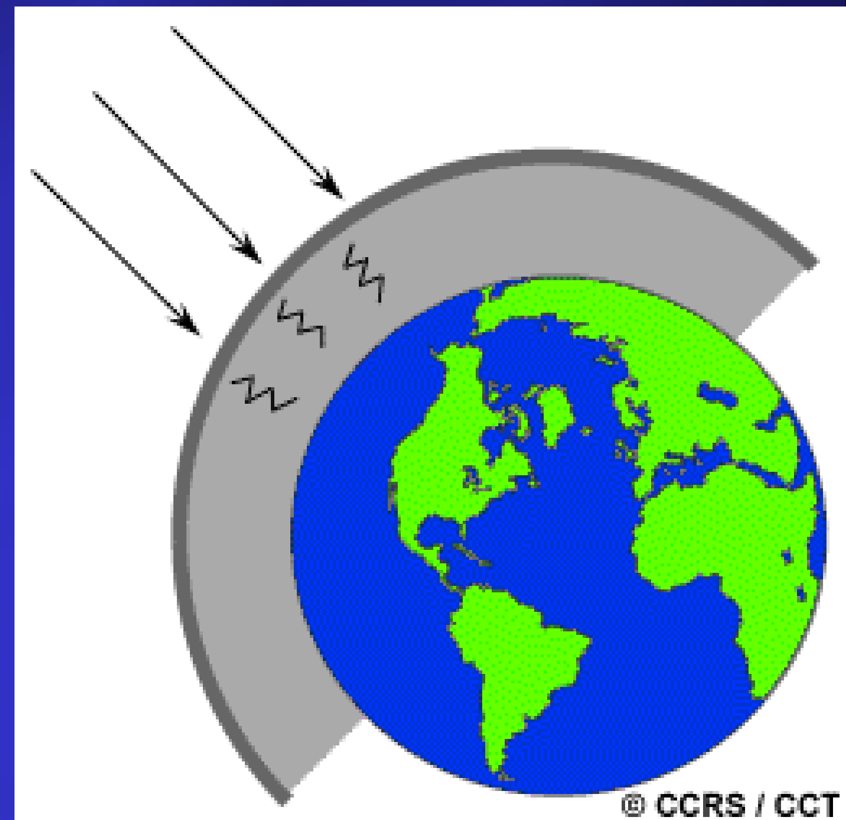
Scattering

- Nonselective scatter occurs when
  - Diameter of particles are larger than the wavelength of the radiation
  - Water droplets and large dust particles can cause this type of scattering
  - Causes all wavelengths (visible, near and mid-infrared) to be scattered about equally
  - Causes fog and clouds to appear as white because blue, green and red are scattered in approximately the same quantities (blue + green + red light = white light)

Absorption

Absorption causes molecules in the atmosphere to absorb energy at various wavelengths

- Results in the effective loss of energy to atmosphere
- The three main constituent which absorb radiation are
  - Ozone
  - Carbon dioxide
  - Water vapor



Absorption

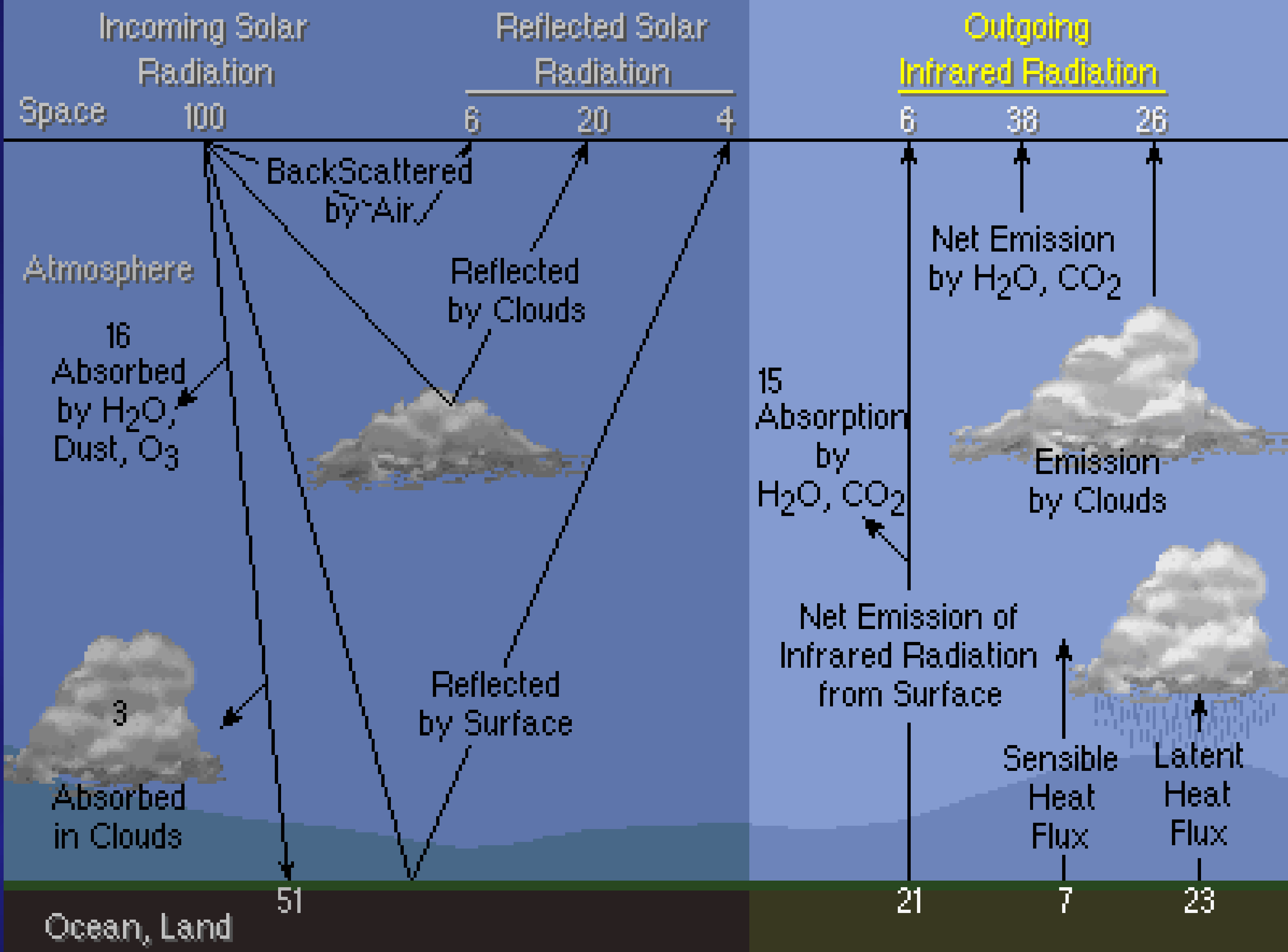
- **Ozone**
  - **Absorb the harmful (to most living things) ultraviolet radiation from the sun**
  - **Without this protection in the atmosphere the skin will burn when exposed to sunlight**

- Carbon dioxide
  - Also referred to as greenhouse gas
  - Tend to absorb radiation in the far infrared – that area associated with thermal heating– which serves to trap this heat inside the atmosphere

- Water vapor
  - Absorbs much of the incoming longwave infrared and shortwave microwave radiation (between 22 mm and 1 mm)
  - Presence of water in lower atmosphere varies greatly from one location to another and at different times of the year
  - For example air mass over a desert area would have little water vapor to absorb energy compared to the tropics with high concentration of water vapor (i.e., high humidity)

Incoming radiation

- **Only 24% of the incoming shortwave radiation hit the Earth directly**
  - **3% is promptly reflected back to space**
- **Rest of the incoming shortwave radiation is caught up in the Earth atmosphere**
  - **25% is scattered back to space**
  - **26% is deflected to the surface**
  - **25% is absorbed**


Incoming Solar Radiation
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Emission by Clouds
Net Emission of Infrared Radiation from Surface
3 Absorbed in Clouds
Reflected by Surface
Sensible Heat Flux
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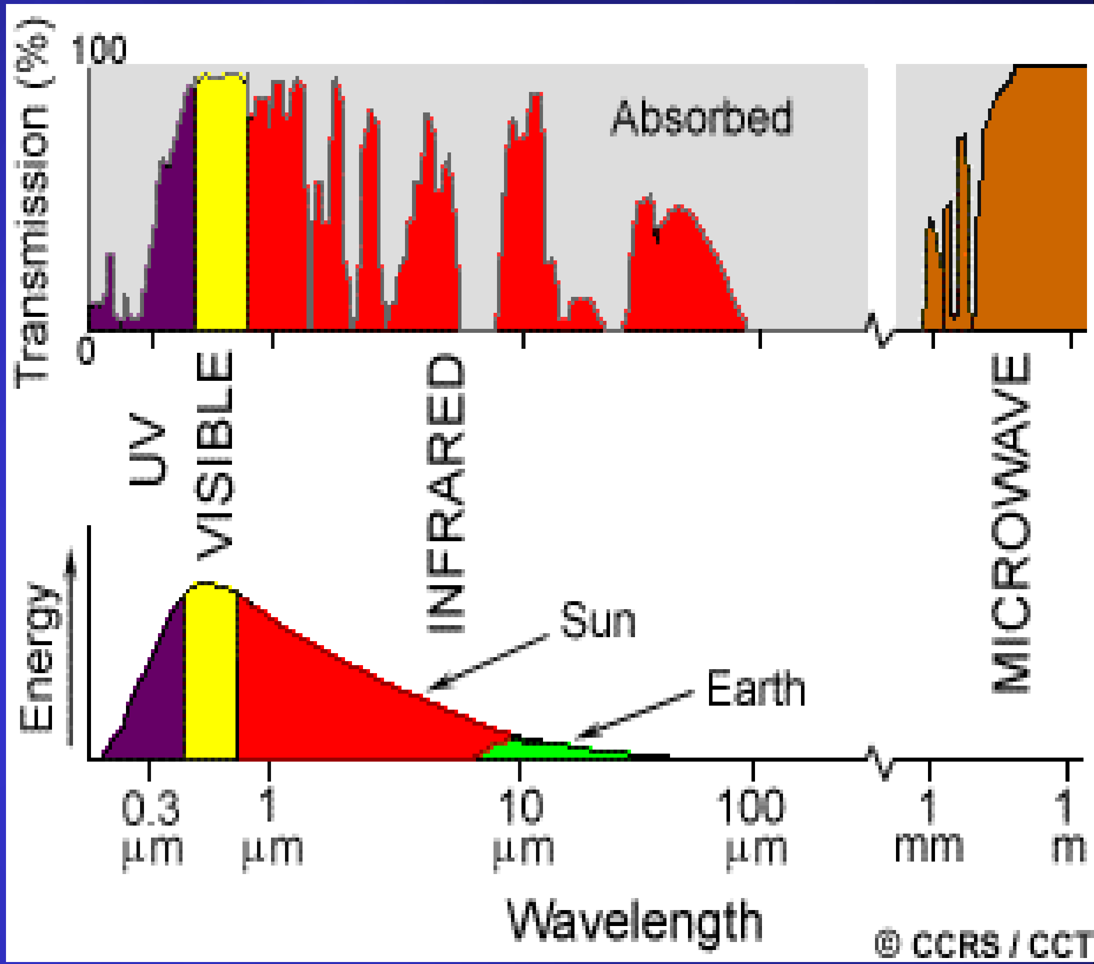
Atmospheric windows

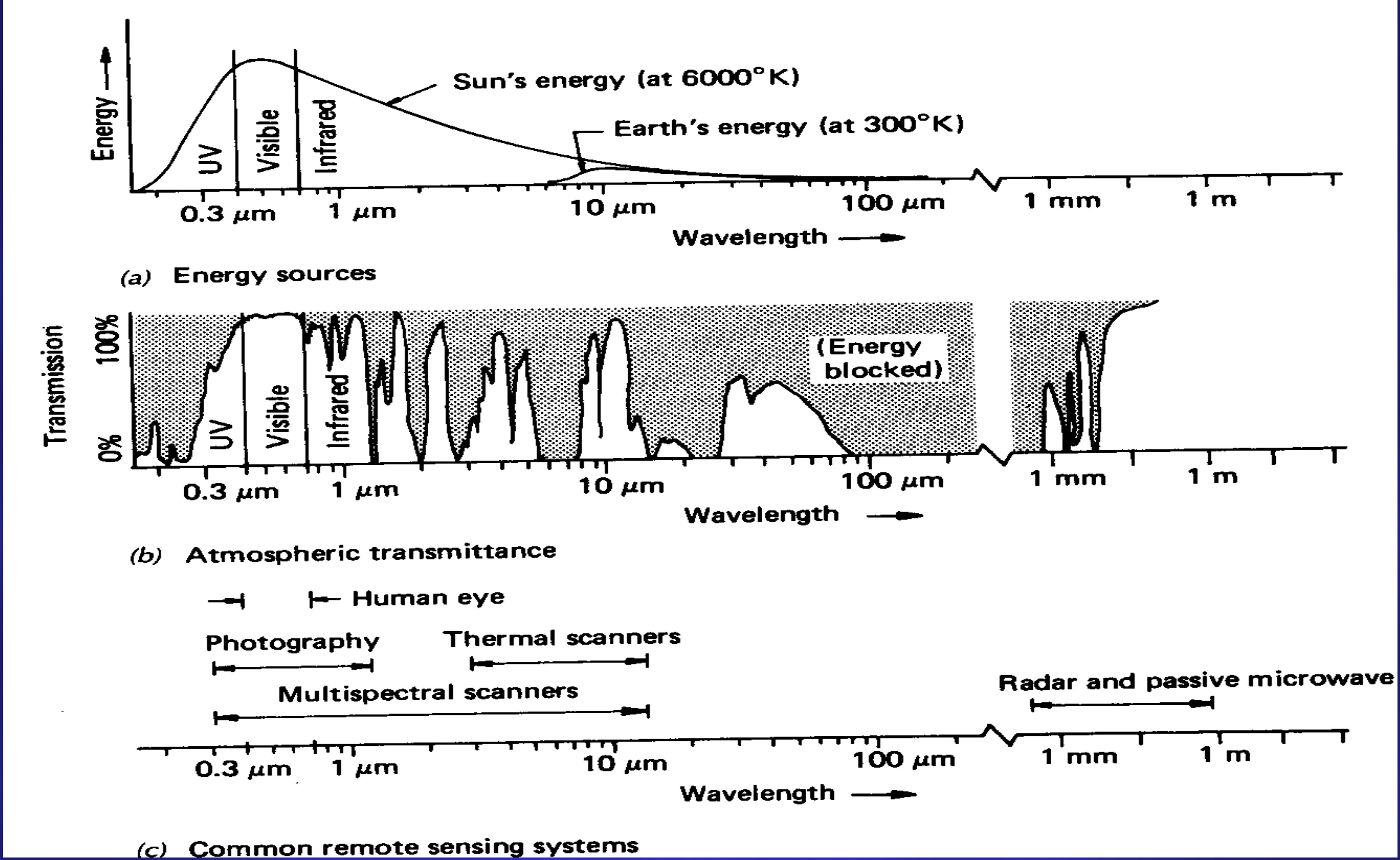
- **Certain gases absorb electromagnetic energy in very specific regions of the spectrum**
- **they influence where (in the spectrum) we can "look" for remote sensing purposes**
- **Atmospheric windows are not severely influence by the atmospheric absorption**

Atmospheric windows

- By comparing the characteristics of energy from the sun and Earth with atmospheric windows the regions that are most effective for remote sensing is defined
  - Visible region correspond to both atmospheric window and the peak energy of the sun
  - Heat energy emitted by the Earth corresponds to a window around 10 µm in the thermal infrared region
  - Microwave region approximately 1 mm



Atmospheric windows and common remote sensing systems



Criteria for remote sensing sensors

The following criteria must be considered before selecting sensors for remote sensing

- Spectral sensitivity of the sensors available
- Presence or absence of atmospheric windows in the spectral range(s) of interest
- Source, magnitude, and spectral composition of energy in the selected range

Energy interactions with Earth surface features

Radiation not absorbed or scattered in the atmosphere can reach and interact with the Earth's surface

- Three fundamental energy reactions when electromagnetic energy is incident on any given earth surface are
  - Reflection
  - Absorption
  - Transmission

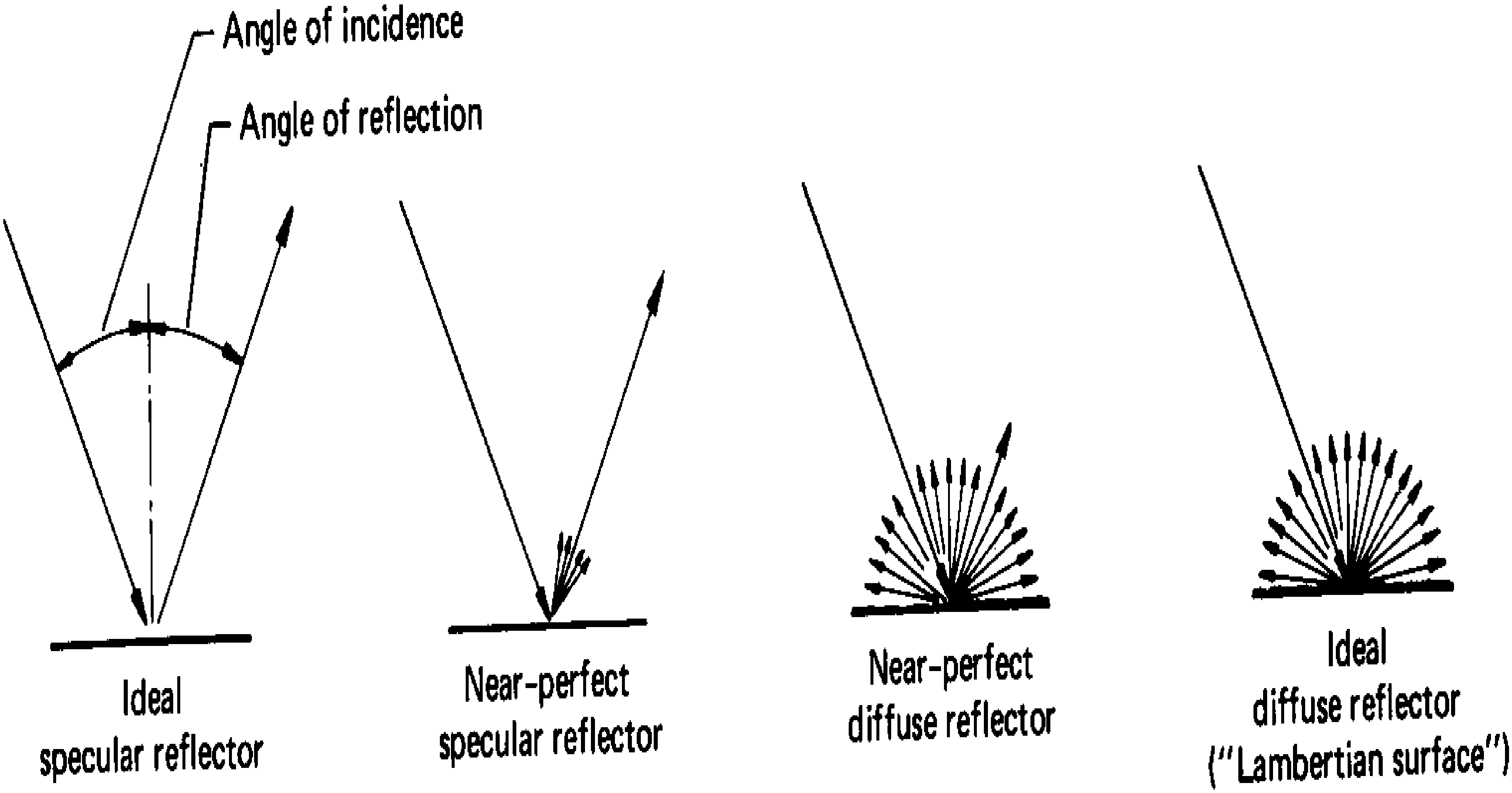
- **Incident radiation (I) strikes a surface**
- **Absorption (A) occurs when radiation is absorbed in the target**
- **Transmission (T) occurs when radiation passes through a target**
- **Reflection occurs when radiation bounces of the target and is redirected**

- Proportion of energy Reflected, Absorbed, and Transmitted will vary for different targets depending upon the material type and condition
  - That form the basis for distinguish different features in an image

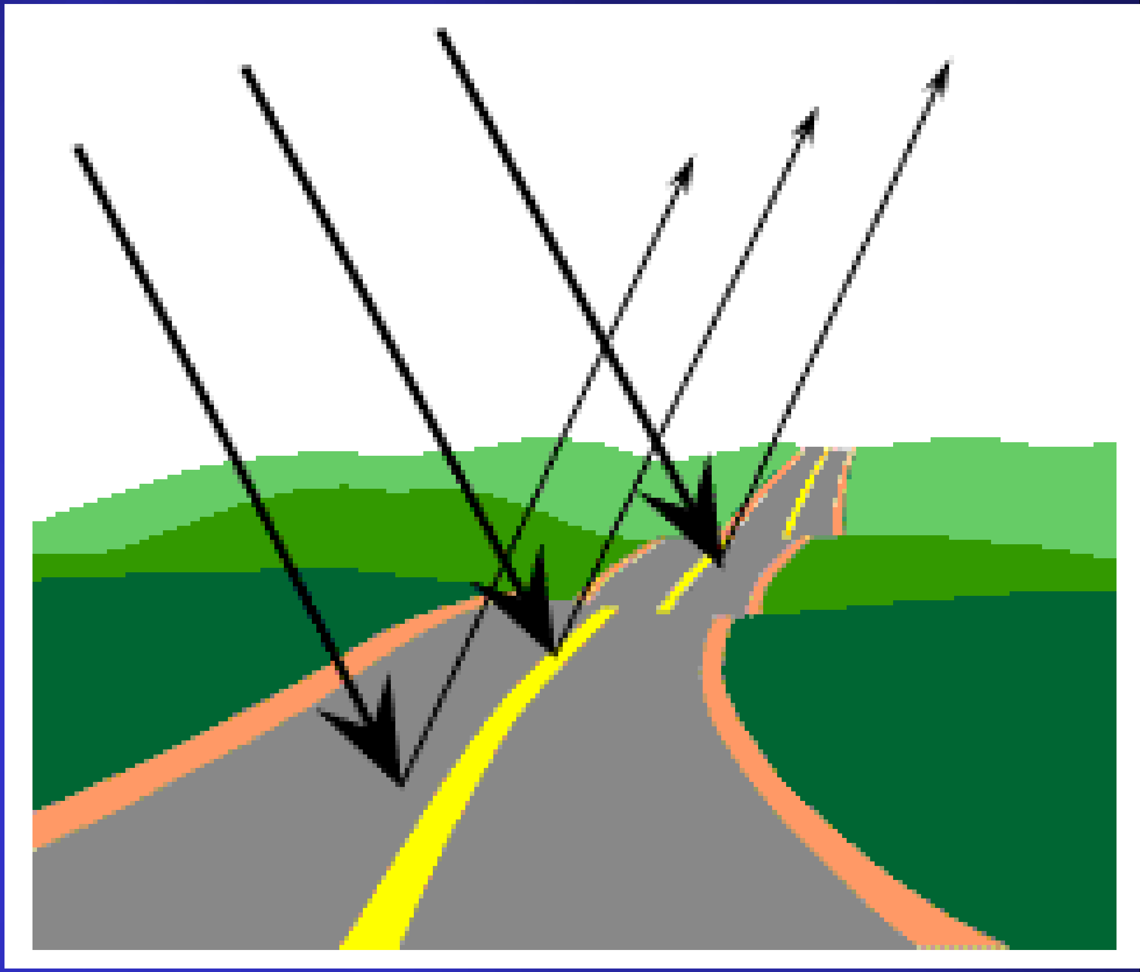
- Wavelength dependency means that Reflection, Absorption and Transmission will vary at different wavelengths
  - Two features may be indistinguishable in one spectral range but may be different in another wavelength band
  - For example., green material reflect high in green and blue material reflect high in blue

- Geometric manner for reflection is a primary function of surface roughness
  - Specular reflection—flat mirror-like reflections where the angle of reflection equals the angle of incidence
  - Diffuse (or Lambertian)—reflectors are rough surfaces that reflect uniformly in all directions
  - Most earth surfaces are in between the two extremes

Specular versus diffuse reflectance

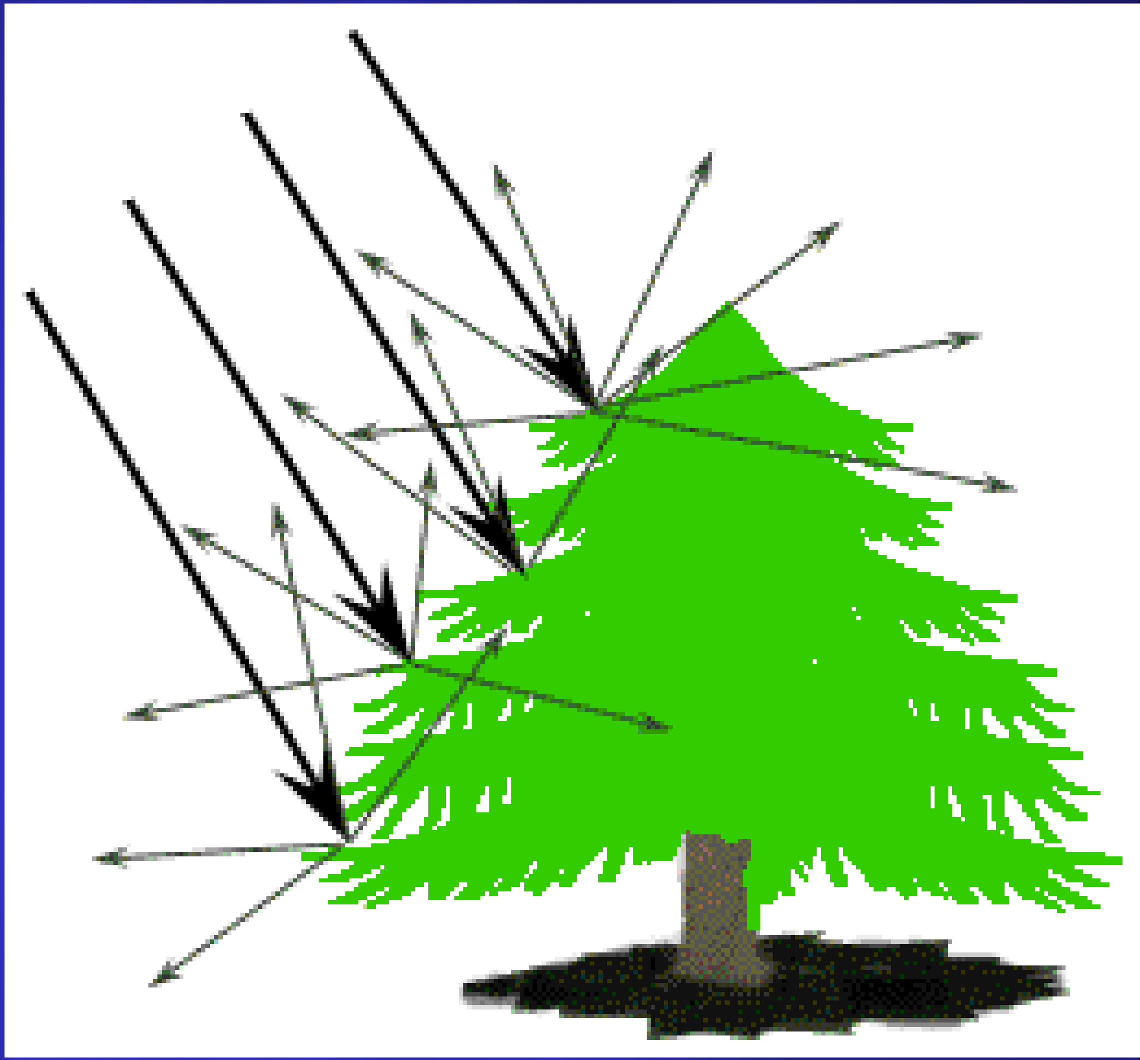


- Specular or mirror-like reflection– all energy is directed away from the surface in a single direction
- Occurs when a surface is smooth
- Most likely to occur when the Sun is high in the sky
- Specular reflection can be caused by water surface or a glasshouse roof



Diffuse reflection

- **Diffuse reflection occurs when the surface is rough an the energy is reflected almost in all directions**
- **Contain spectral information on the 'color' of the reflecting surface, but specular reflections do not**
- **Remote sensing most often uses diffuse reflectance properties of terrain features**

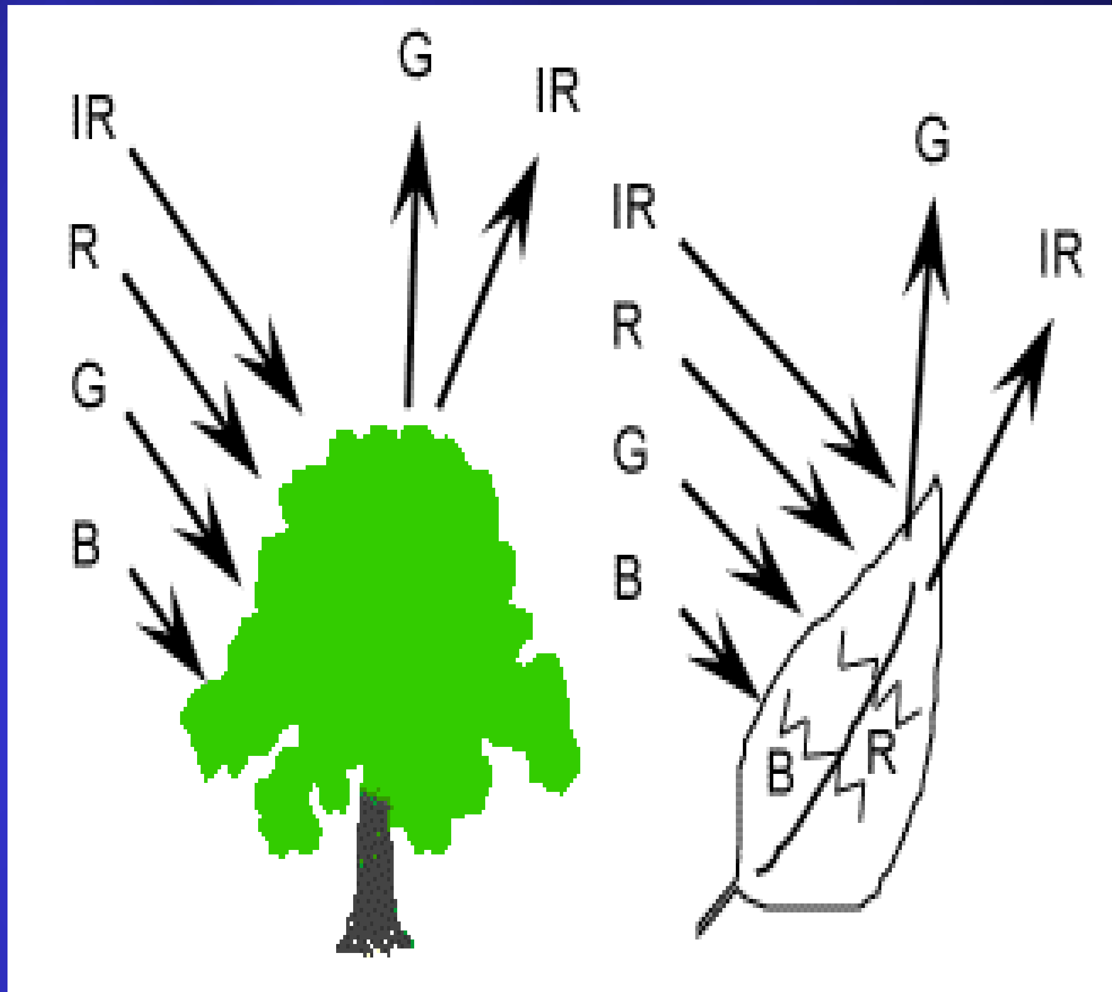


Vegetation

- Reflectance of vegetation depends on
  - Orientation
  - Structure of leave canopy
- The proportion of the radiation reflected in the different parts of the spectrum depends on
  - Leaf pigmentation
  - Leaf thickness
  - Composition (cell structure)
  - Amount of water in the leaf tissue

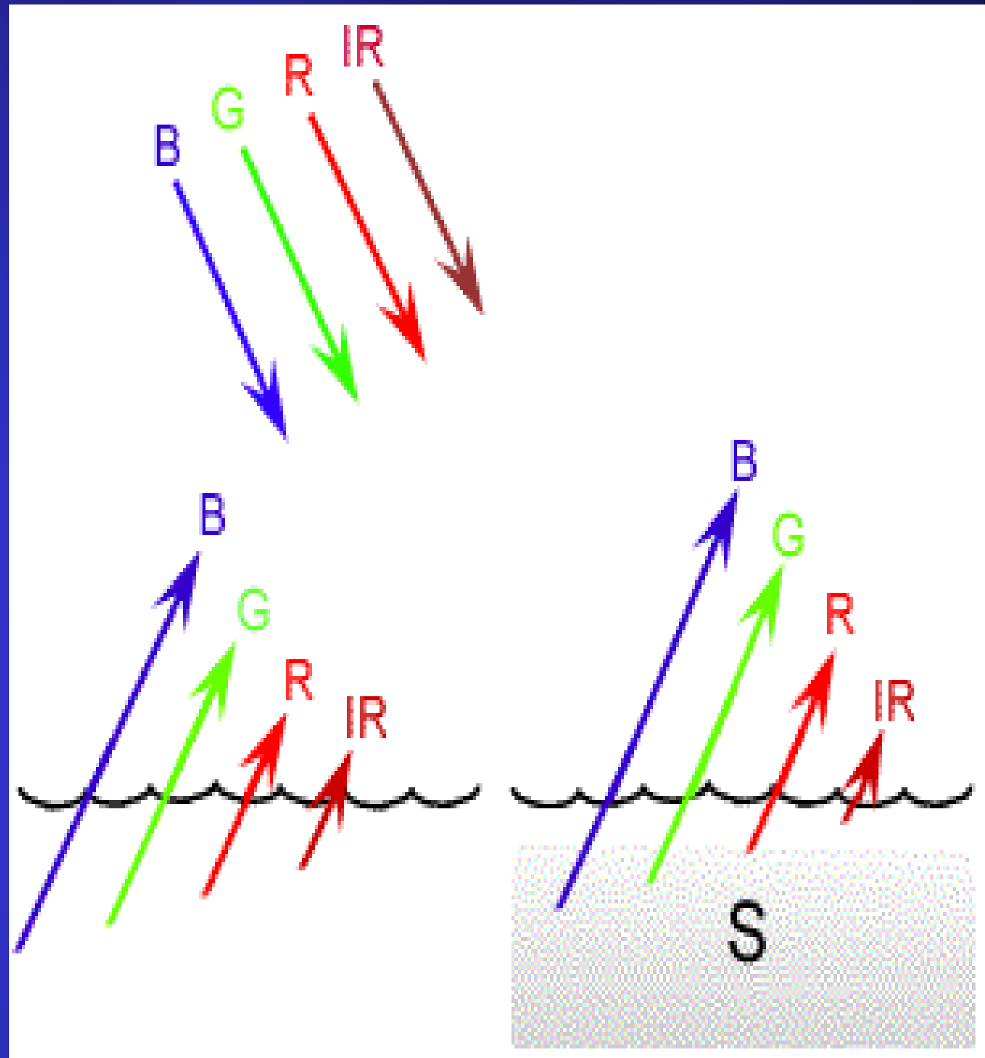
Energy interaction with leaves

- Chlorophyll– a chemical compound in leaves– strongly absorbs radiation in the red and blue wavelengths
- Healthy leaves appear 'greenest' maximum chlorophyll
- Leaves with less chlorophyll have relatively less absorption and more reflection of red making the leaves appear yellow (green + red)
- Leave have more reflection in the infrared which is not visible to our eyes



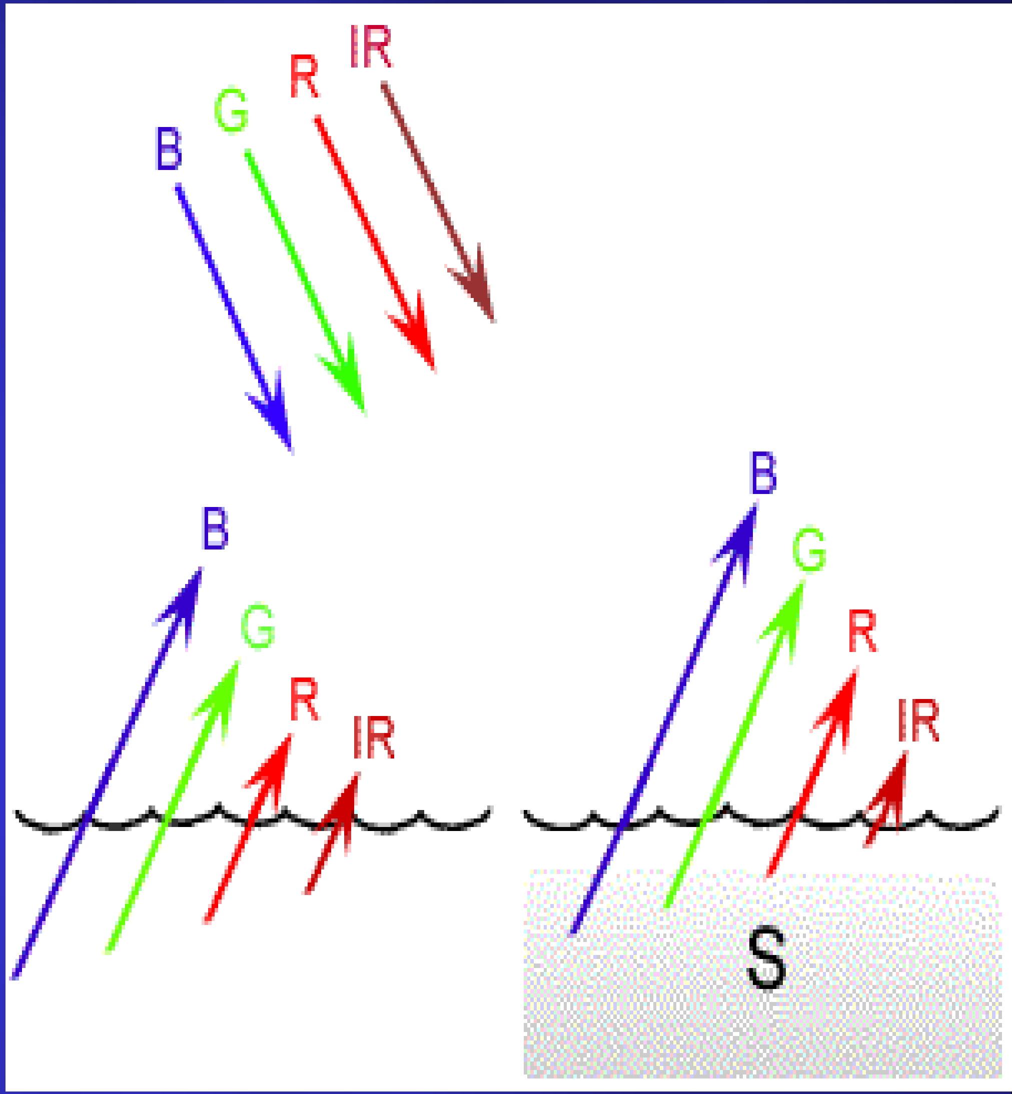
Energy interaction with water

- Longer wavelength visible and near infrared radiation is absorbed more by water than shorter wavelengths
- Water typically looks blue or blue-green due to stronger reflectance at these shorter wavelengths
- The presence of suspended sediments show a slight shift to longer wavelengths (S)
- Chlorophyll in algae absorbs more of the blue and reflects the green making the water appear more green when there is algae



Energy interaction with water

- **Topography of the water surface (rough, smooth, floating material, etc.) can complicate the water-related interpretations**
- **Water is absorbed in the infrared**



Spectral reflectance curves

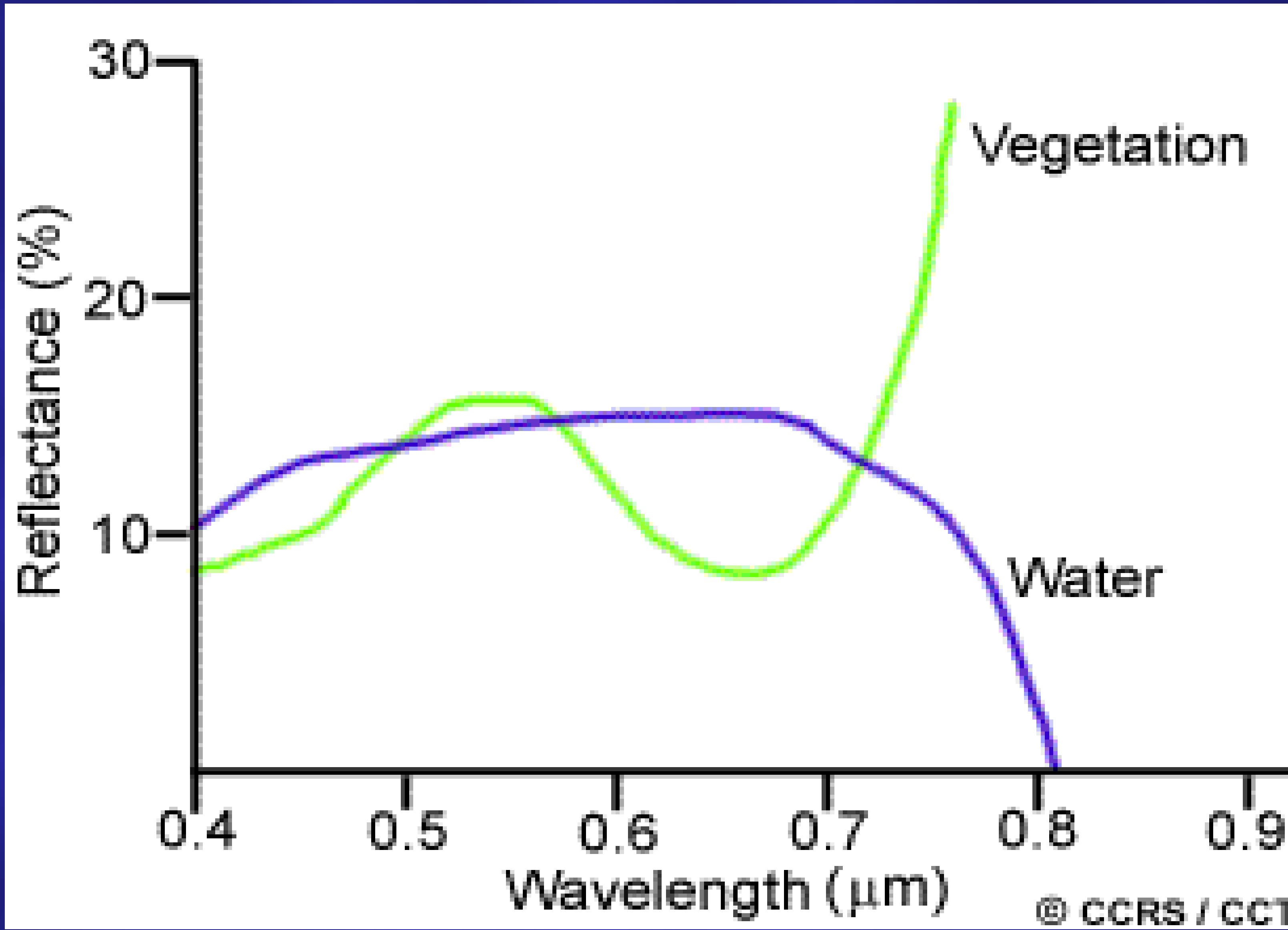
- The energy reaching the surface of a certain material is *irradiance*
- *Radiance* is the energy reflected the surface (W/m^2)

Spectral reflectance curves

By measuring the energy that is reflected or emitted by targets over a variety of different wavelengths we can build a spectral reflectance curves

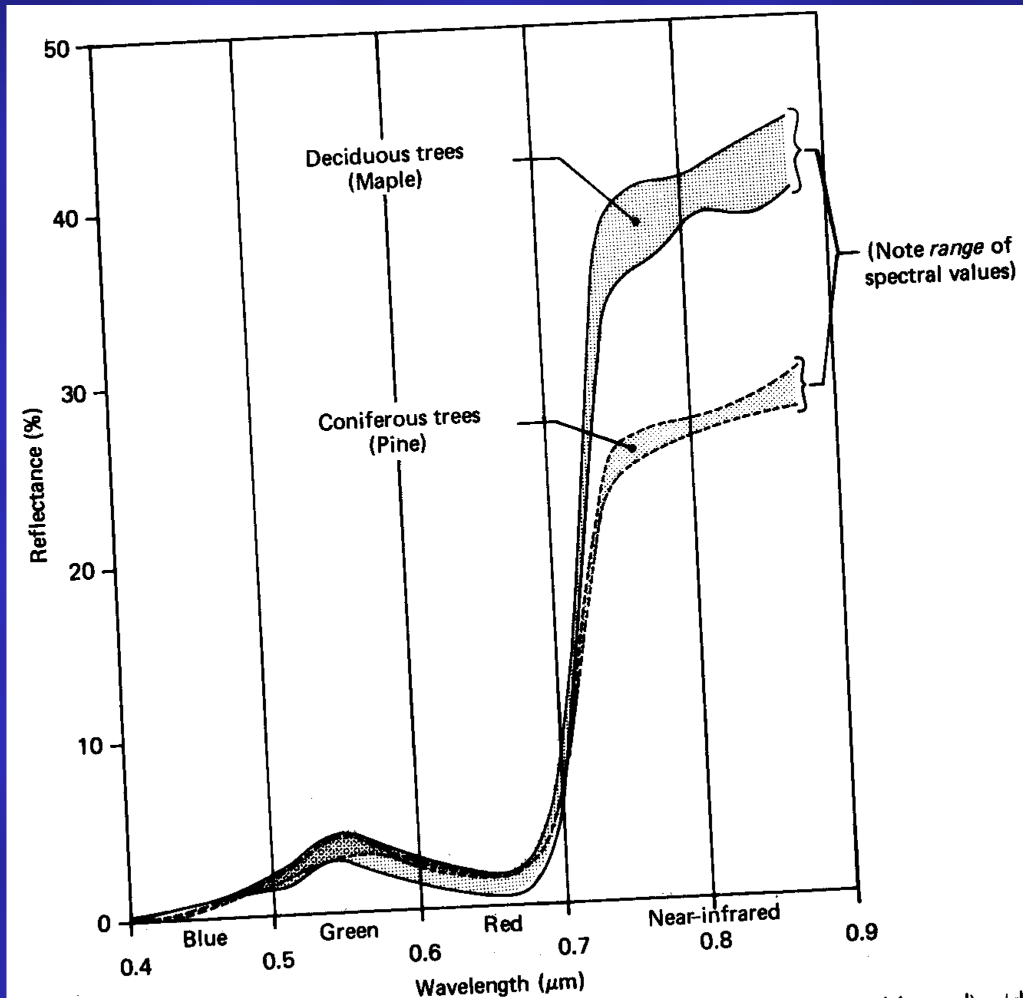
- Curves show the fraction of incident radiation that is reflected as a function of wavelength
- Reflectance curves are made for the optical part of the electromagnetic spectrum (0.4 to 2.5 microns)
- Most remote sensing sensors are sensitive to broad wavelength band, e.g., .4 to .48 microns (10^{-6})
- Has strong influence on the choice of wavelength regions in which remote sensing data are acquired for a particular application
- By comparing the spectral reflectance patterns we may be able to distinguish between them

Generalized reflectance curves for water and vegetation



Distinguishing between Deciduous (broad-leaved) and coniferous (needle-bearing) trees

Generalize spectral reflectance curves for deciduous and coniferous trees



Aerial photos Illustrating deciduous versus coniferous

(a) Panchromatic

(b) Black and white infrared

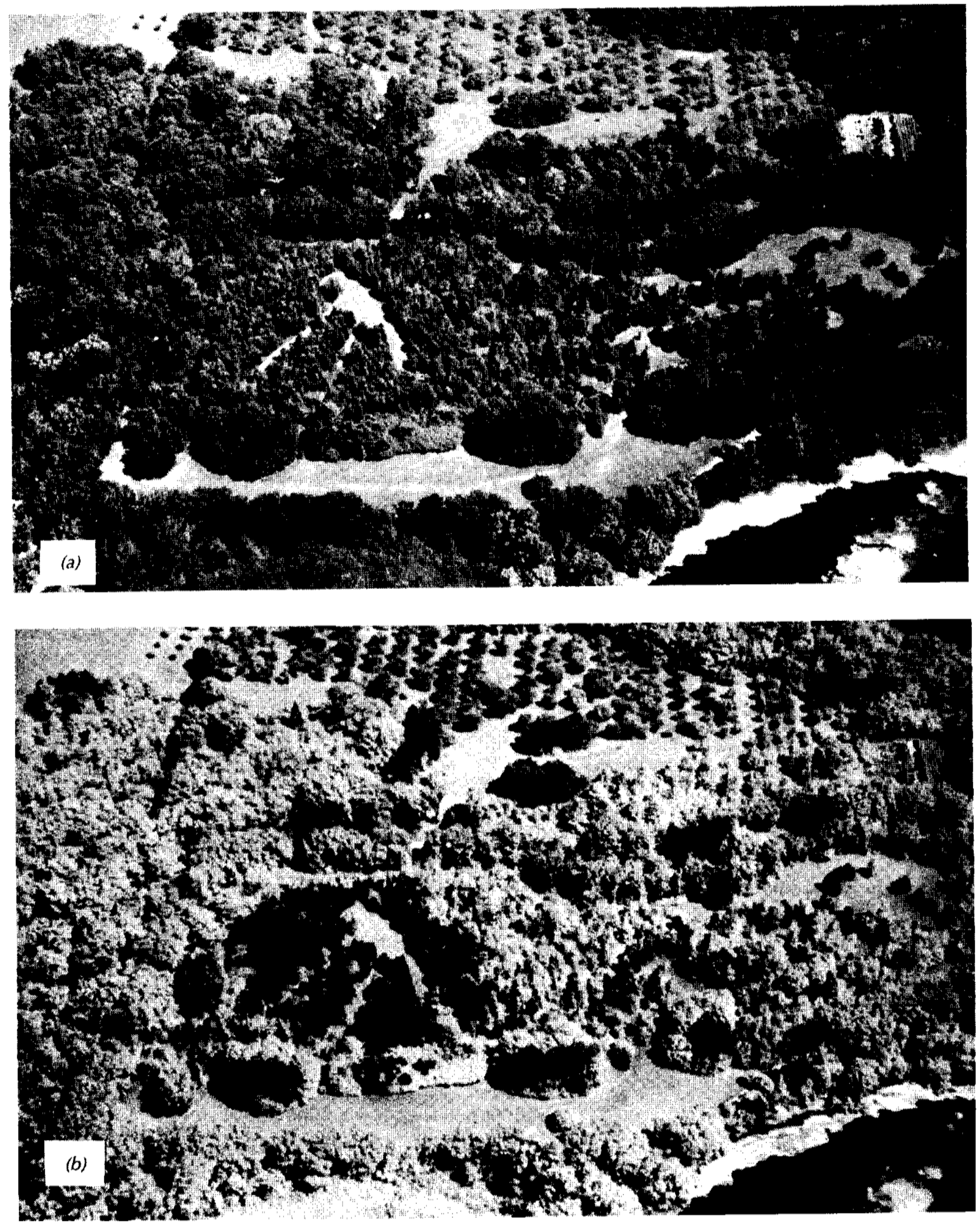
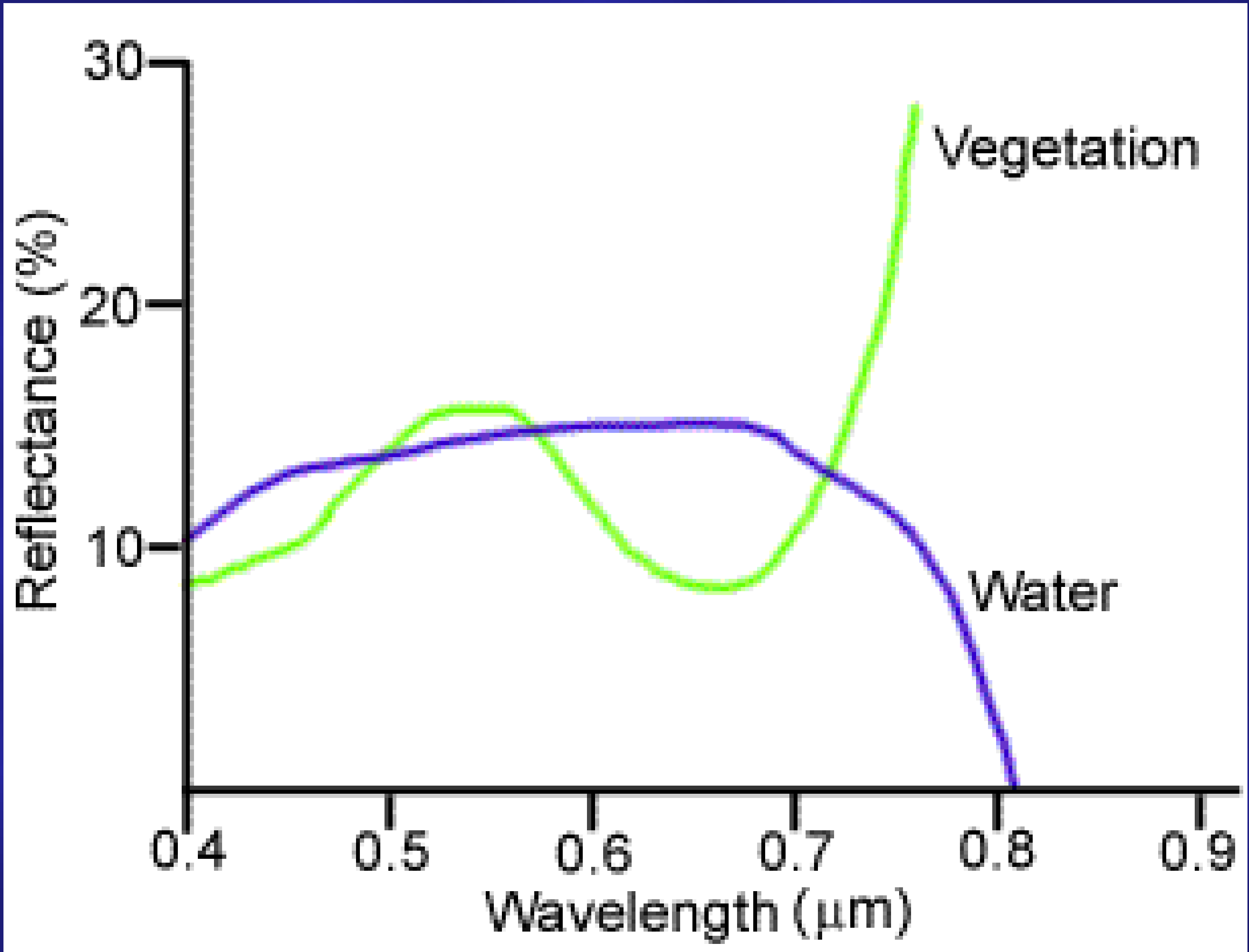


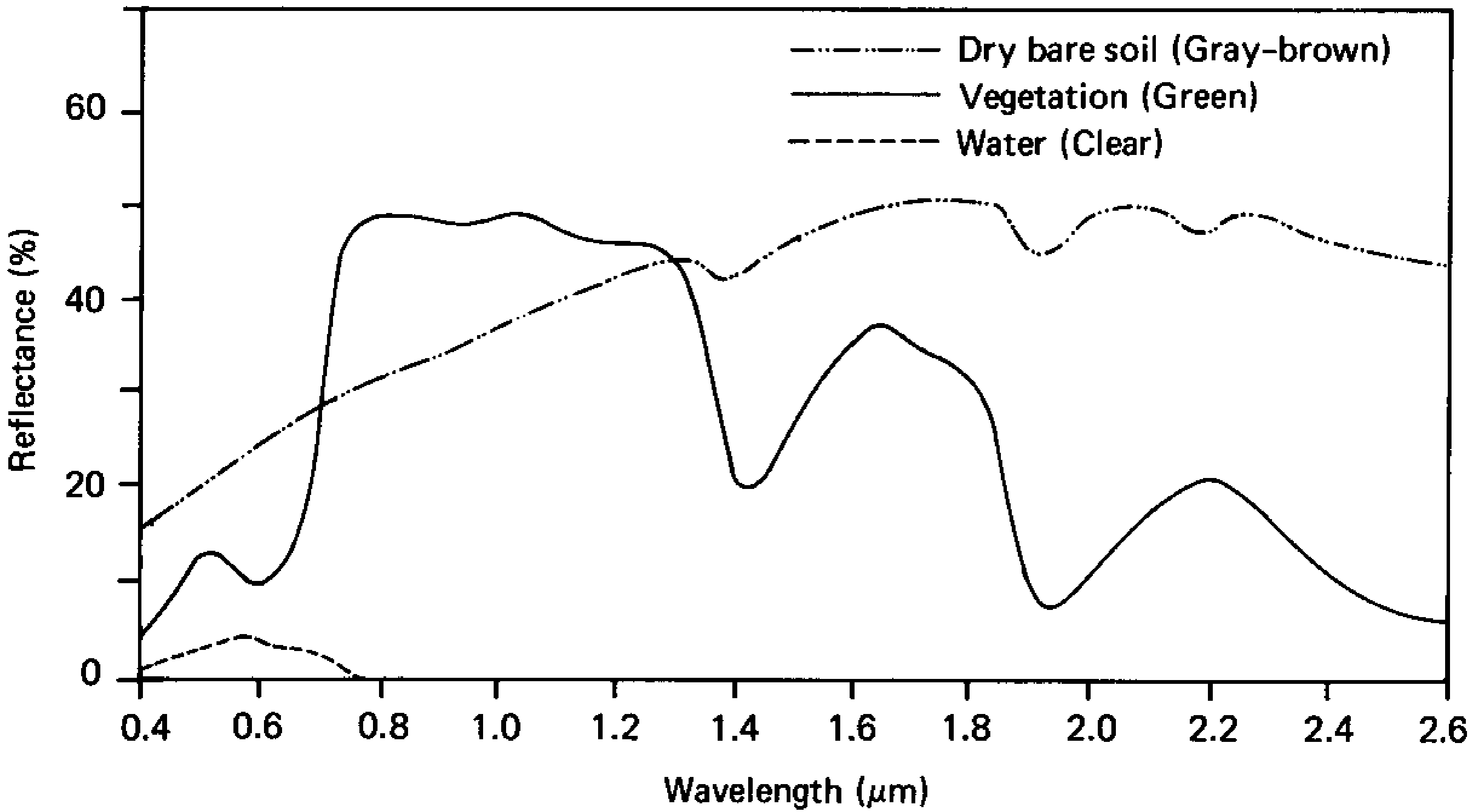
Figure 1.9 Low altitude oblique aerial photographs illustrating deciduous versus coniferous trees. (*a*) Panchromatic photograph recording reflected sunlight over the wavelength band 0.4 to 0.7 µm. (*b*) Black and white infrared photograph recording reflected sunlight over 0.7 to 0.9 µm wavelength band.

Spectral Reflectance of Vegetation, Soil, Water and Rocks

Spectral response pattern



- Spectral reflectance curves for healthy vegetation manifest the ‘peak-and-valley’ configuration in response to the absorption and reflection characteristics of chlorophyll
- Our eyes see healthy vegetation as green color because of the high absorption of blue and red energy by plant leaves and the very high reflection of green energy
- Reflectance of healthy vegetation increases dramatically in the near infrared at 0.7 µm
- Dips in reflectance occur at 1.4, 1.9 and 2.7 µm because water in the leaf absorbs strongly at these wavelengths (water absorption bands)


Dry bare soil (Gray-brown)
Vegetation (Green)
Water (Clear)
Reflectance (%)
60
40
20
0
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
Wavelength (μm)

- Dry leaves may change color to yellow due to lack of photosynthesis causing the red part of the electromagnetic spectrum to be higher
- Dry leaves will result in higher reflectance in the middle infrared and a decrease in the near-infrared
- Optical remote sensing provide information about the type of plant and well as its health conditions

Bare soil

- Depends on so many factors that it is difficult to give one typical soil reflectance curve
- Main factor influencing soil reflectance are
  - Soil color
  - Moisture content
  - Presence of carbonates
  - Presence of oxides
- Spectral reflectance for soil show less peak-and-valley variation
- Dips at 1.45 and 1.95 microns (water absorption bands) are caused by water

Water

- Water has low reflectance compared to vegetation and soils
- Vegetation may reflect up to 50%, soils up to 30-40% while water reflects at most 10% of the incoming radiation
- Water reflects EM in the visible up to near-infrared
- Water is completely absorbed beyond 1.2 microns
- High reflectances are given by
  - turbid (silt)
  - Water containing plants with chlorophyll (green algae)

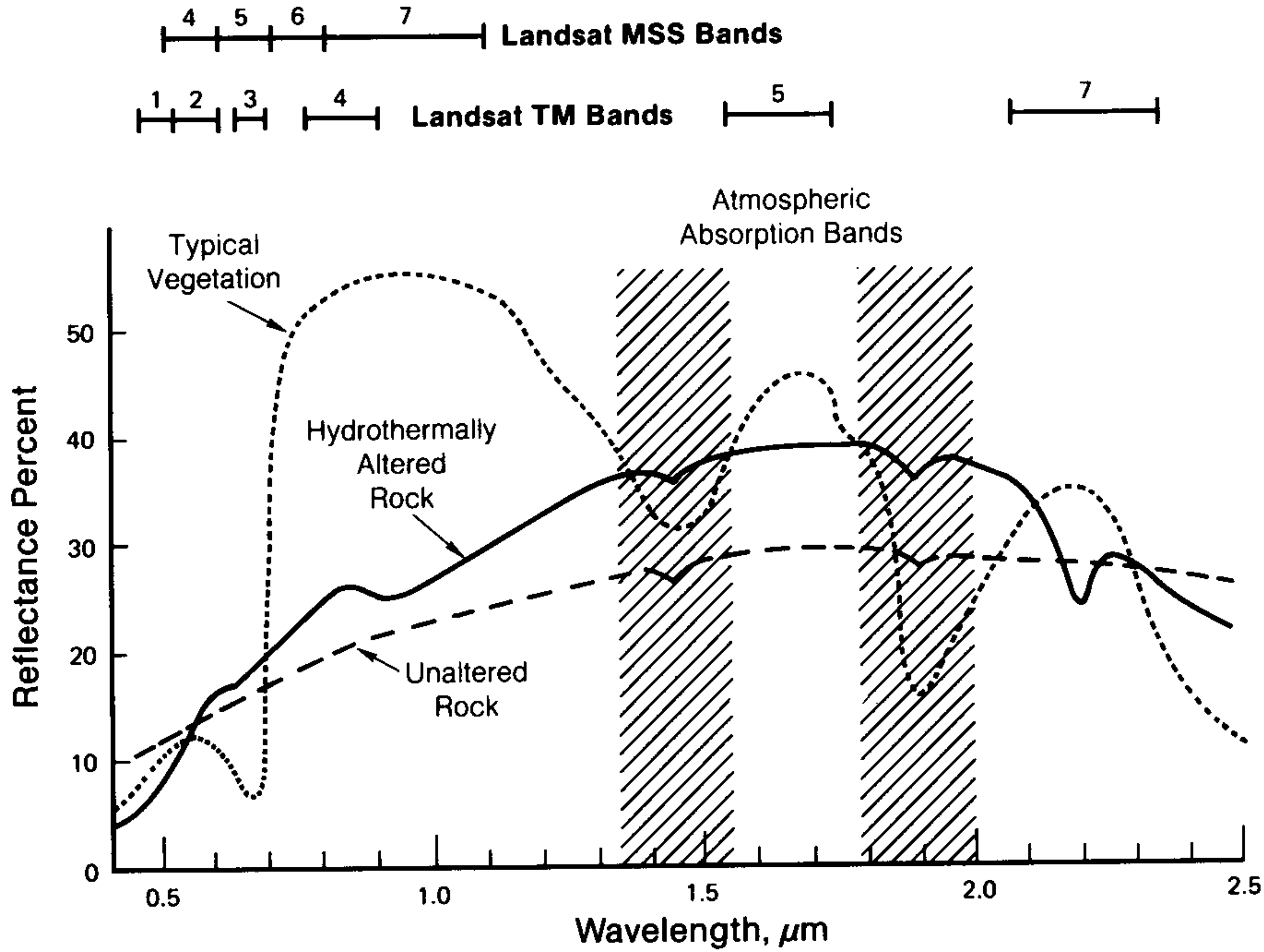


FIGURE 4.14 Spectral bands for TM and MSS systems. Reflectance curves for vegetation, unaltered rocks, and hydrothermally altered rocks. From Sabins (1983, Figure C-5).