EARTH OBSERVATION RESEARCH

Julius-Maximilians-UNIVERSITÄT WÜRZBURG

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2 Electromagnetic Radiation, Atmospheric Interactions and Surface Interactions

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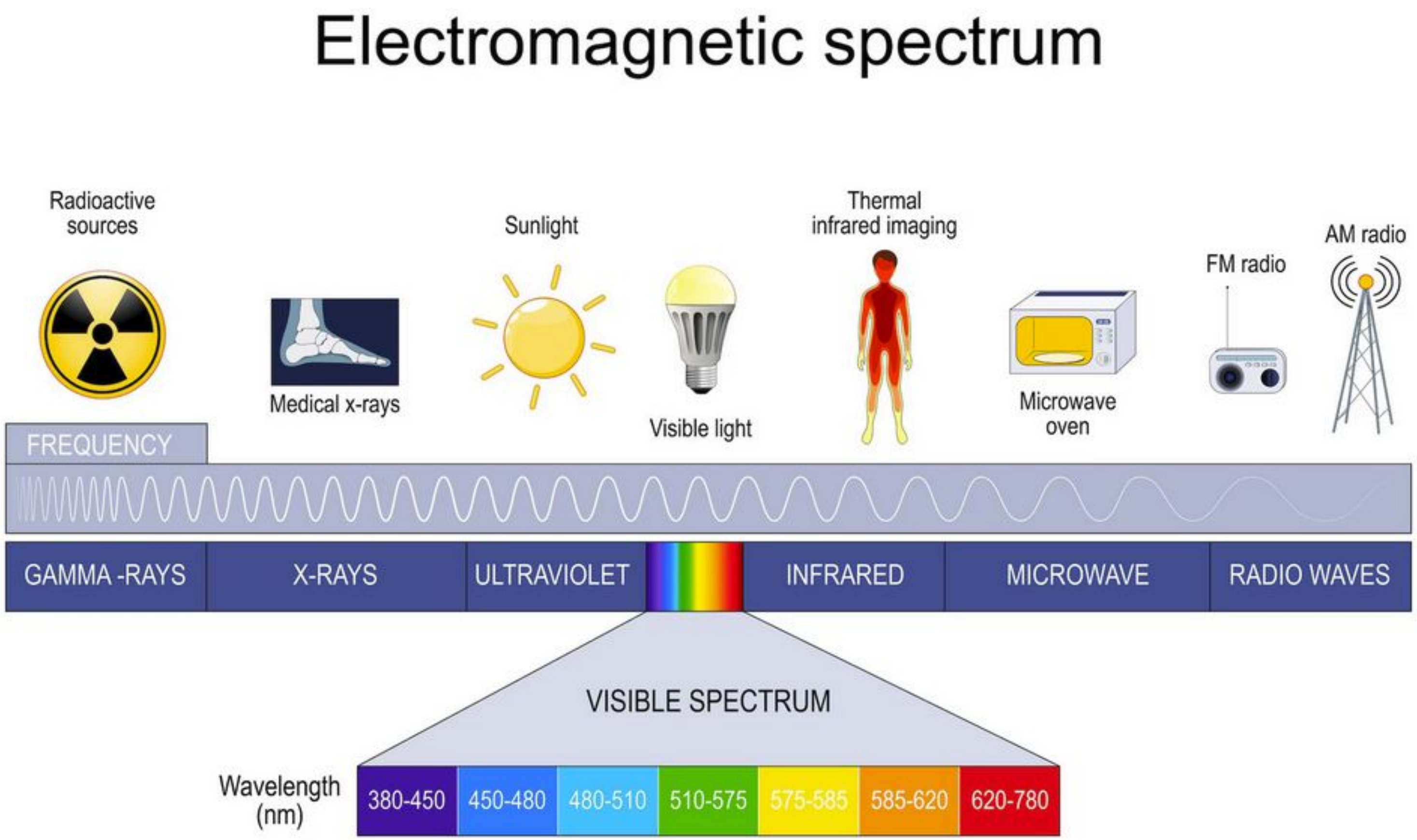
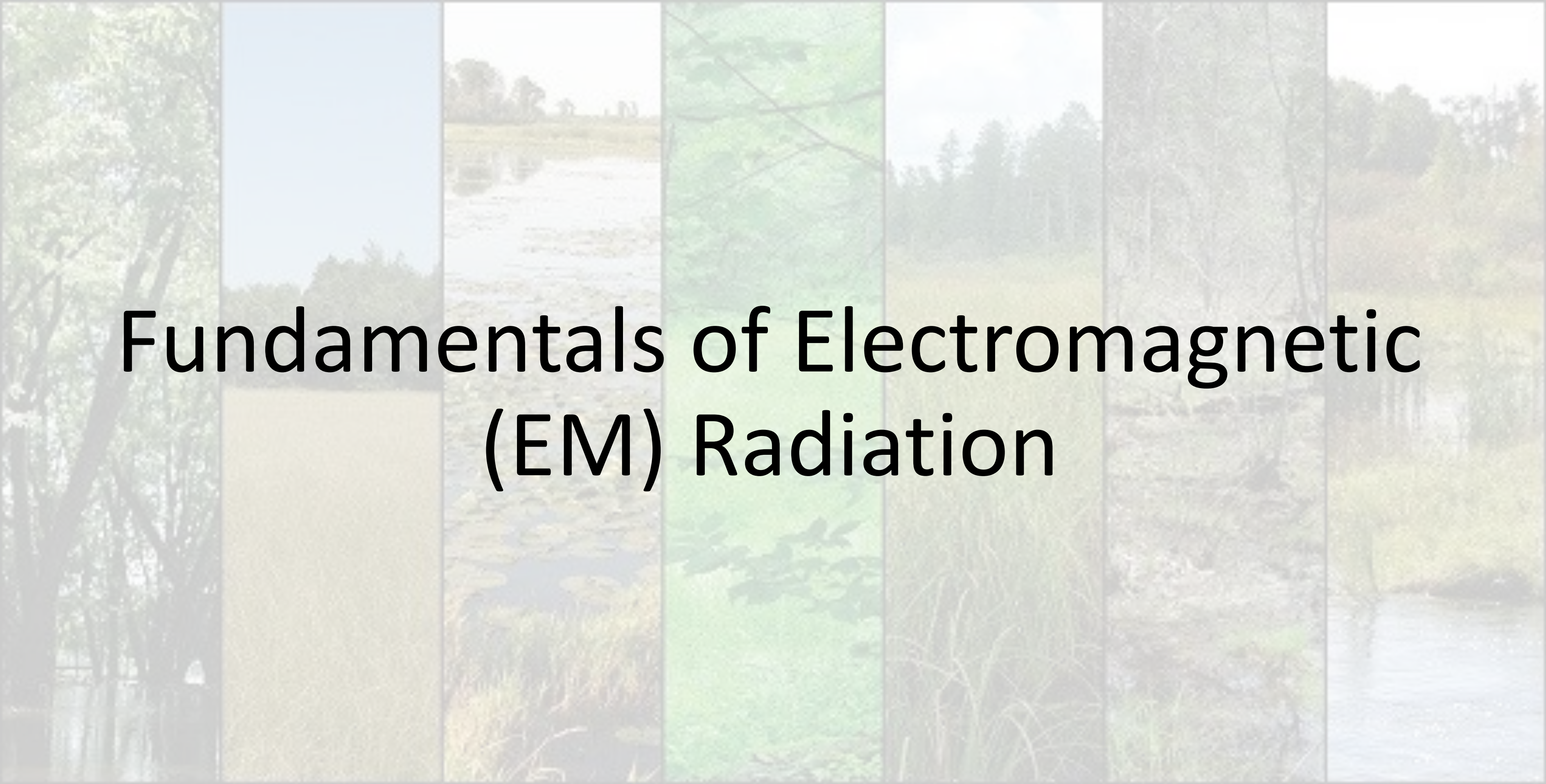
Recap

What is Remote Sensing?

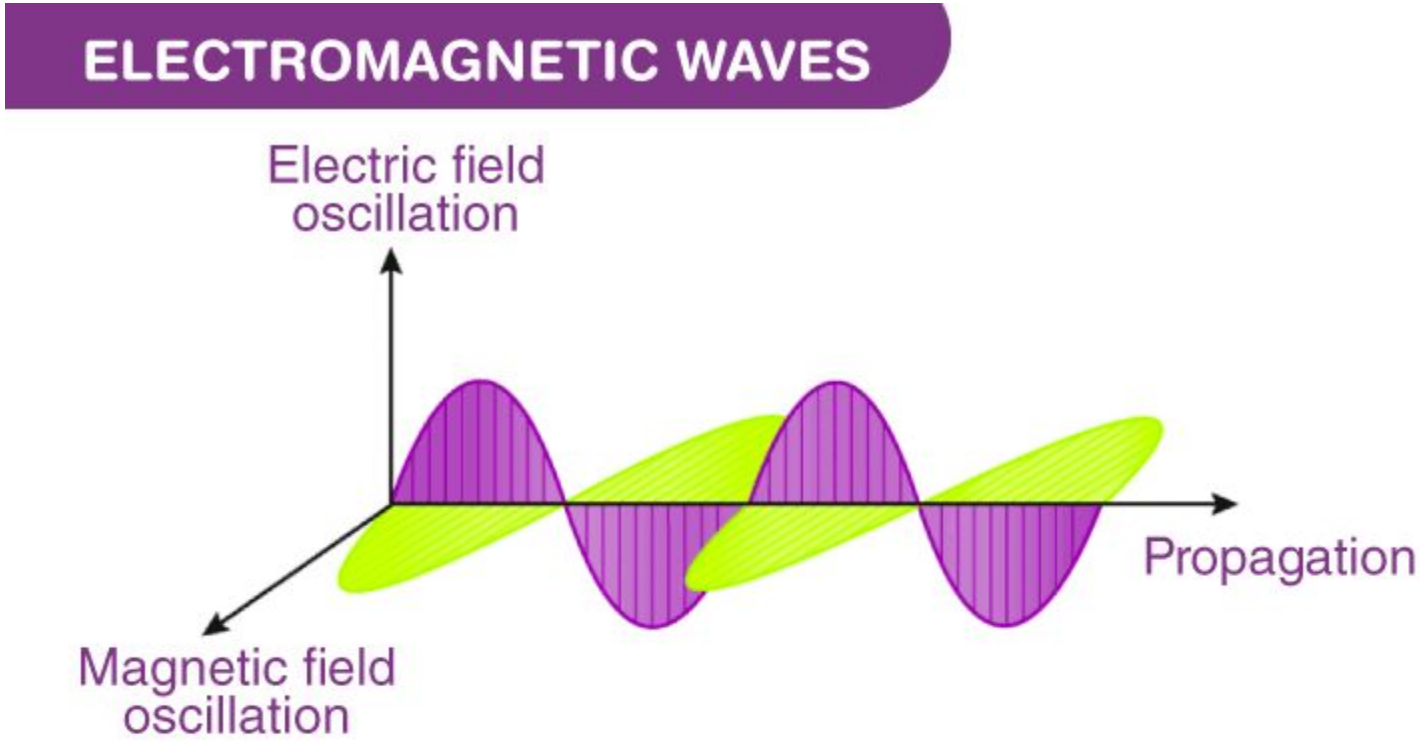


- The electromagnetic spectrum is the full range of **wave frequencies** that characterizes solar radiation.
- Although we are talking about light, most of the electromagnetic spectrum cannot be detected by the human eye.
- Even satellite detectors only capture a small portion of the entire electromagnetic spectrum.



Fundamentals of Electromagnetic (EM) Radiation

Radiation Transfer of energy through space

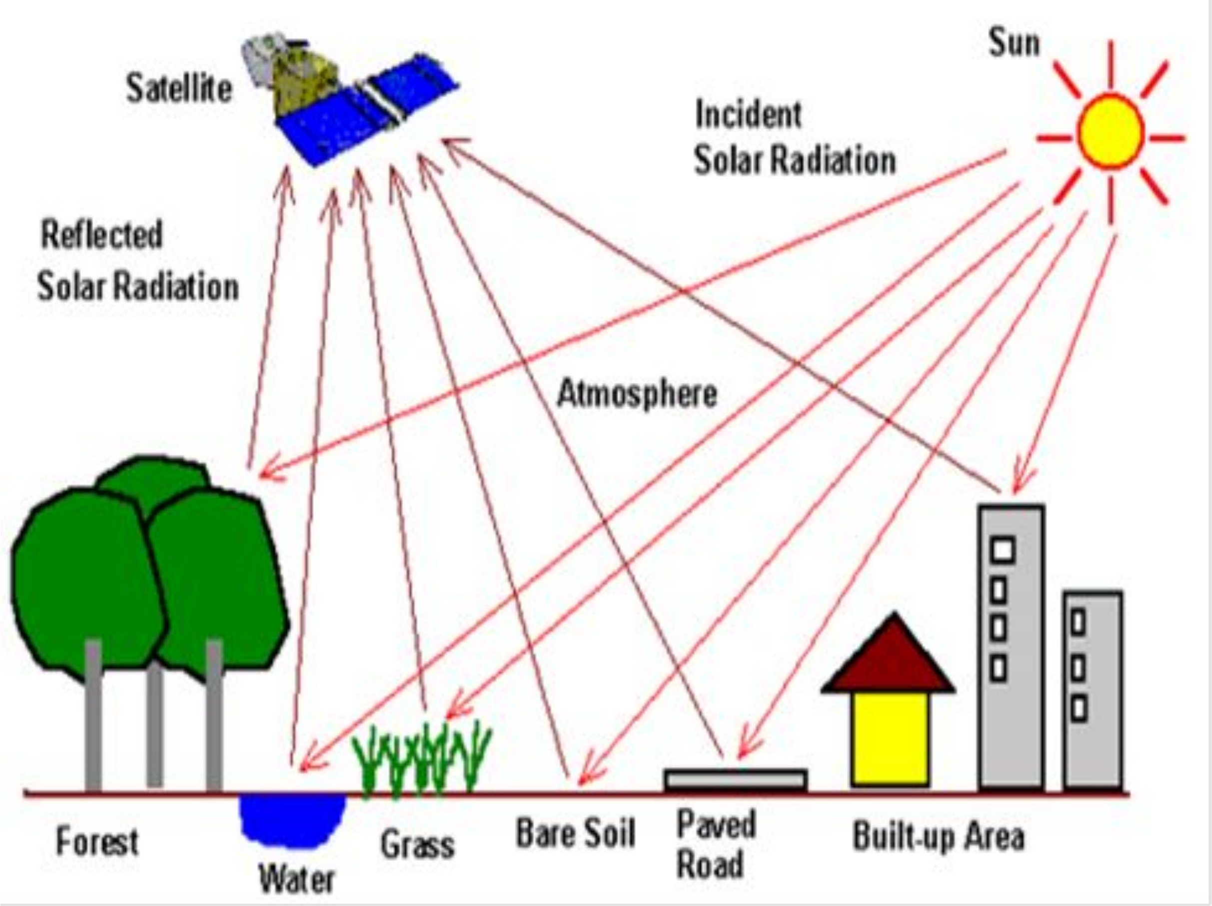


- **Radiation**: Transfer of energy through space by electromagnetic waves
- **Electromagnetic waves**: Up and down fluctuations in the energy levels of electromagnetic fields

Characteristics of EM Radiation

- All substances with a temperature above zero emit **electromagnetic radiation**
- Exception: so-called **dark matter** which has been theorized to provide the unobserved mass needed to account for observed motions of astrophysical bodies such as galaxies
- **Dark matter does not emit radiation**, so we cannot detect it directly, only by its gravitational effect
- **Electromagnetic radiation travels at the speed of light (c)** ($c_0 = 2.99792458 \times 10^8$ m s^{-1} in a vacuum, slightly slower in air)

Characteristics of EM Radiation

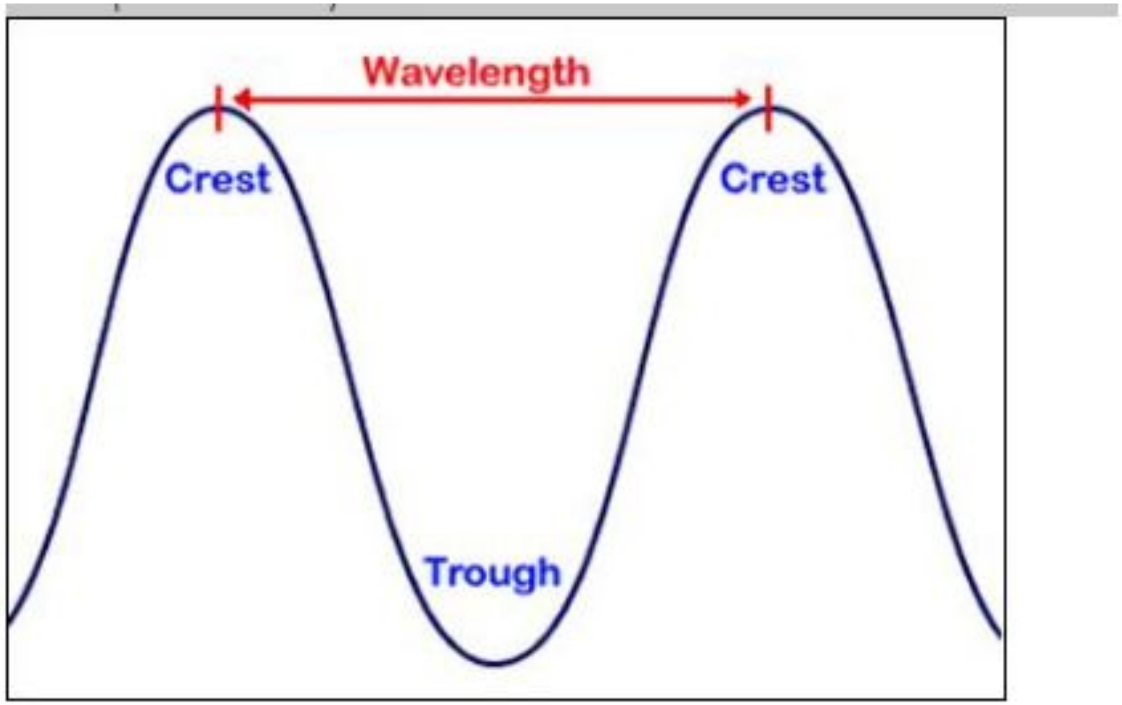


- All objects with a temperature above zero **emit** electromagnetic radiation
- Objects **reflect** electromagnetic radiation emitted by other objects

 Key basis of remote sensing because earth’s surface materials reflect light in unique ways

EM Radiation can be characterized by

- **Wavelength (λ)**: distance measured from wave crest to wave crest
- Highest point of the wave: **crest**
- Lowest point of the wave: **trough**



Units of Wavelength

- Measured in different distance units depending on the type of radiation
- Infrared (IR) usually given in micrometers
- 1 micrometer = 10^{-6} m = 1/1,000,000 m
- Microwave often given in centimeters, e.g. NEXRAD is a 10 cm radar

Frequency

- Frequency (ν): number of wave crests passing a certain point over a given period of time

- Wavelength (λ) is related to frequency by: $\lambda = \frac{c}{\nu}$

- Unit: multiple Hertz (Hz) which are cycles per second

- **Note: Wavelength is inversely proportional to frequency!**

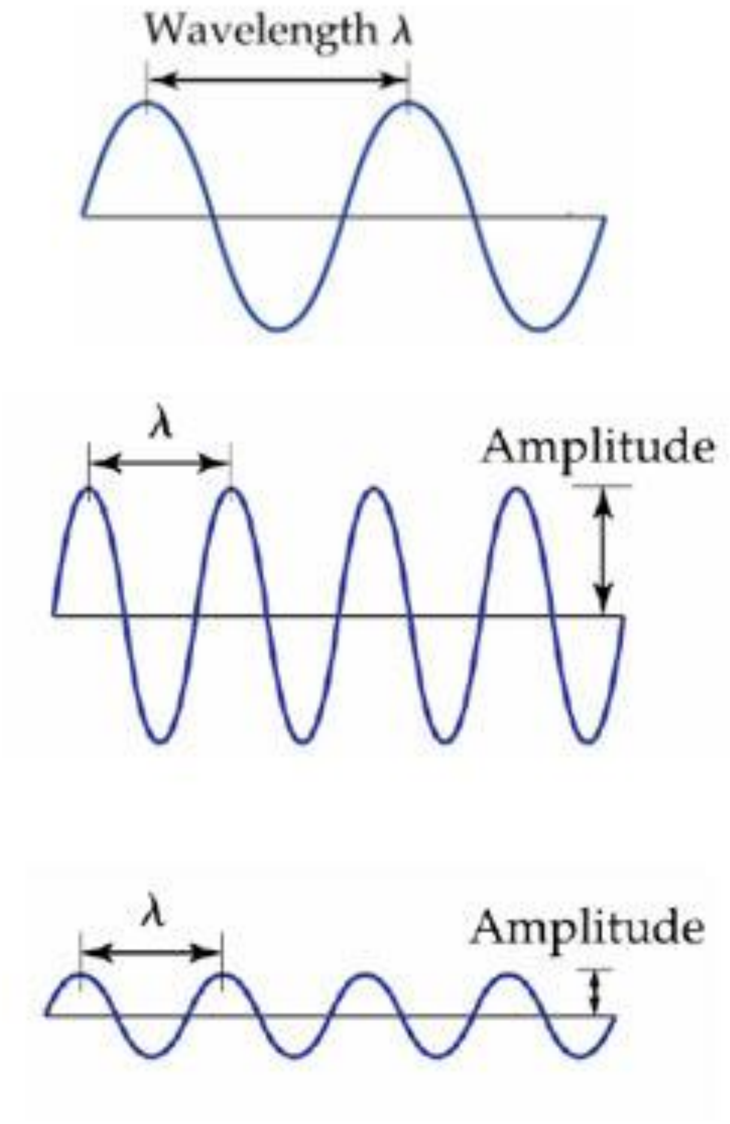
    → longer wavelength radiation has lower frequency

    → shorter wavelength radiation has higher frequency

Amplitude

- **Amplitude**: magnitude of the wave, i.e., maximum displacement from the zero-energy level to the peak-energy level

- Measure of the intensity (= strength) of the electromagnetic radiation



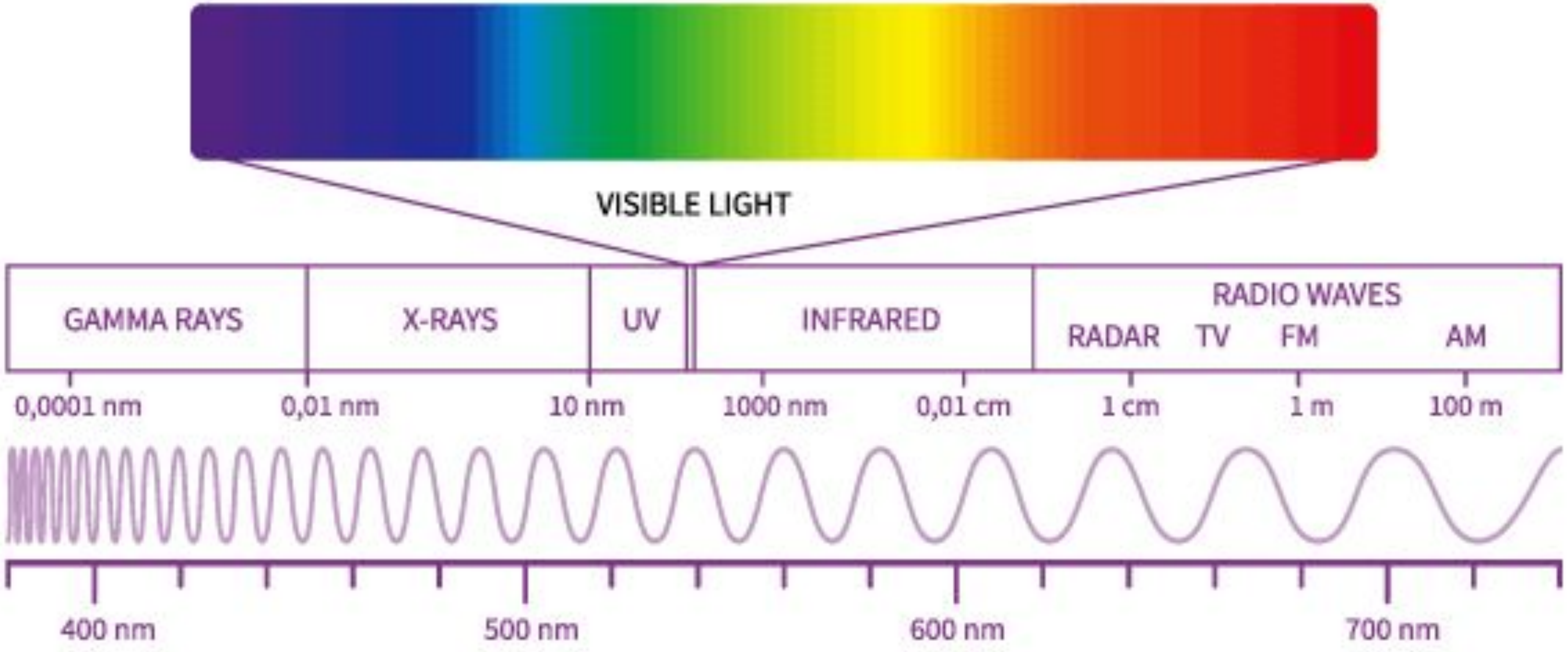
Wavenumber

- An additional way of characterizing EM radiation is the wavenumber
- It is the number of wave crests per unit distance
- Often given in units of cm^{-1}, i.e., number of wave crests per centimeter

Electromagnetic Spectrum

- All the different wavelengths of observed radiation from very short to very long.

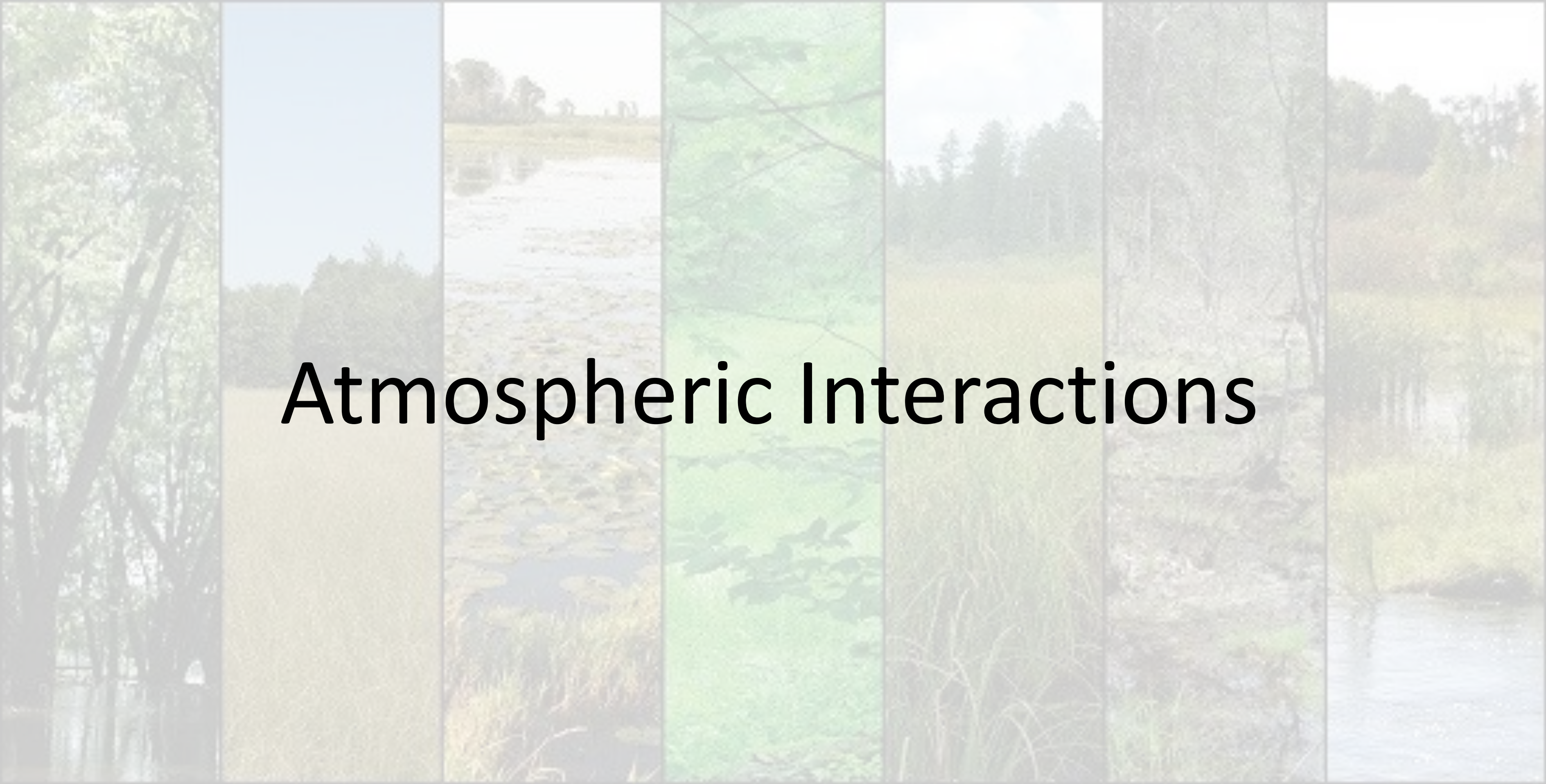
Electromagnetic Spectrum



Electromagnetic Spectrum

- The shorter the wavelength of the radiation, the higher is its energy level per wave. Thus X-rays carry more energy than microwaves
- Visible light is the portion of the spectrum of wavelengths from 0.1 to 0.4 micrometers
- Near Infrared (IR) is 0.7 to 4.0 micrometers
- IR is roughly 4.0 to 1000 micrometers
- For weather satellites we will be mainly concerned with the visible and IR portions of the spectrum up to 20 micrometers
- For weather radar we will be concerned with the microwave part of the spectrum at wavelengths 3 to 10 cm

Atmospheric Interactions



Radiation Concepts and Definitions

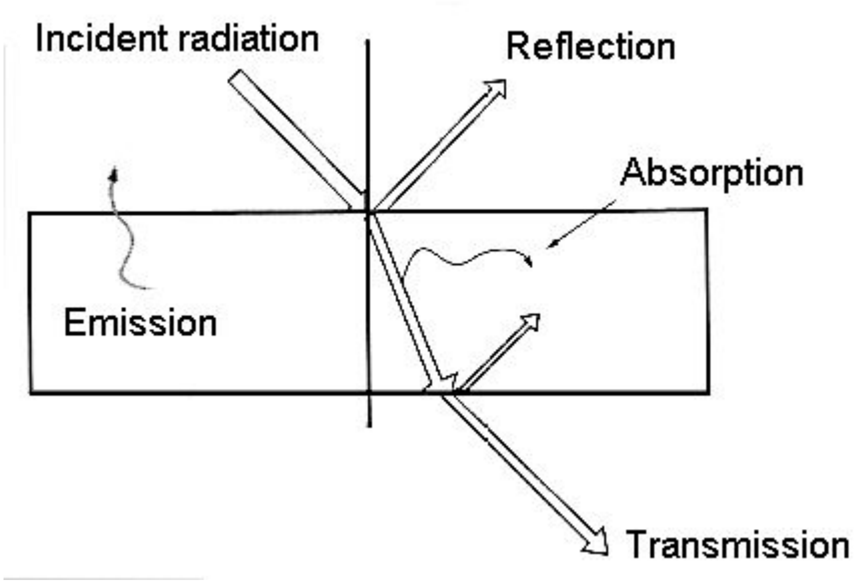
- Consider what can happen to a beam of radiation as it traverses a medium or encounters an object.
- Absorption, transmission and scattering

Radiation Emission

- **Emission**: Radiant energy emanating from an object
- At a given wavelength we represent emission by

  $\mathbf{E_\lambda}$

- Where the lambda subscript denotes a single wavelength

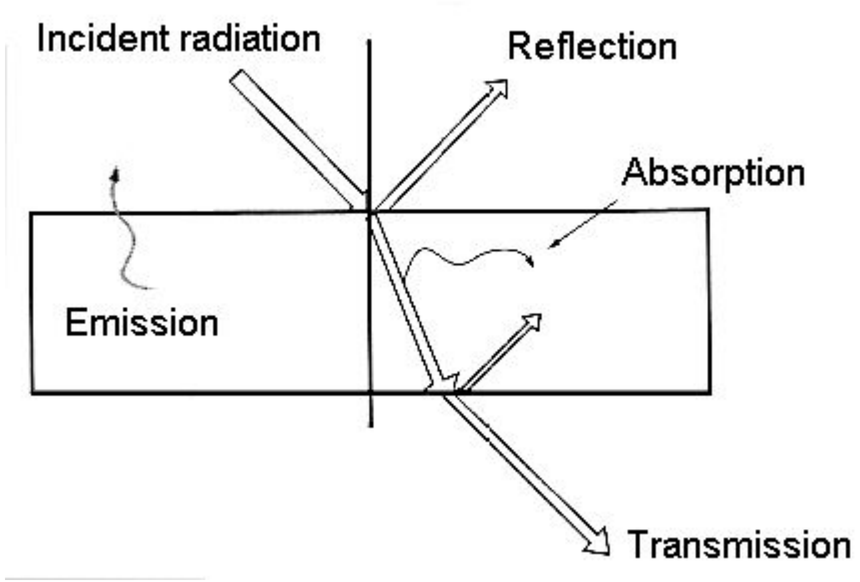


Absorption

- Removal of radiant energy from a beam incident on an object and conversion into internal energy (heat) of the absorbing object, where

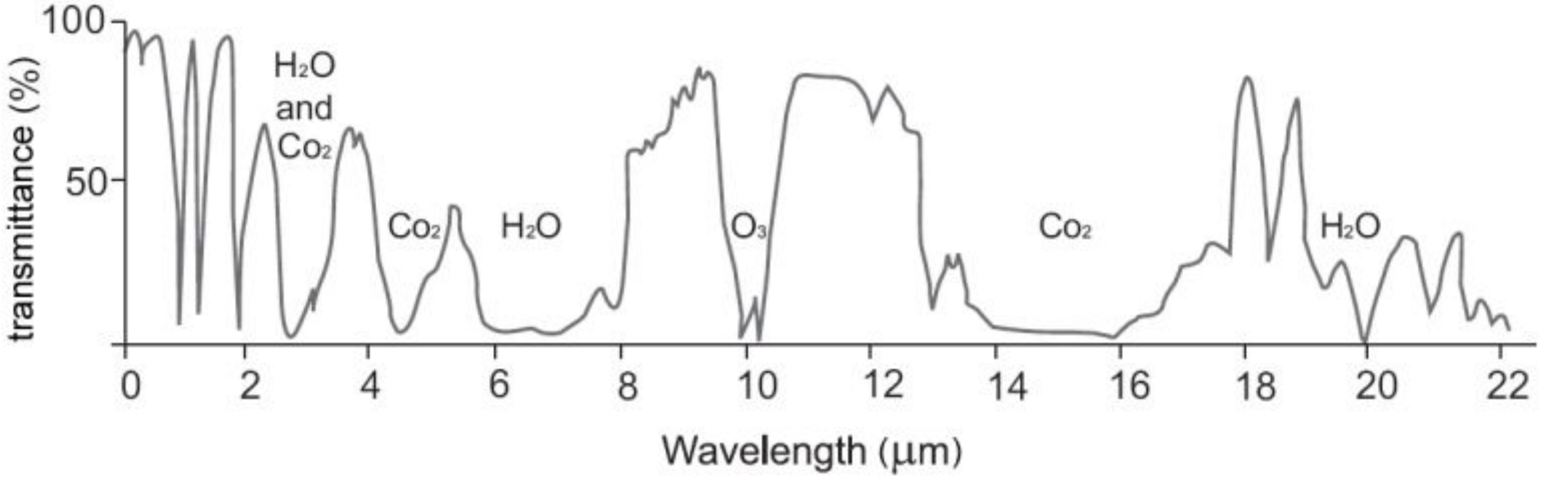
$$\alpha = \frac{Absorbed\ radiation}{Incident\ radiation} = \frac{G_{abs}}{G},\ 0 \leq \alpha \leq 1$$

- is the absorptivity, or fractional amount of the incident radiation that is absorbed.



Atmospheric Absorption

- Electromagnetic energy traveling through the atmosphere is partly absorbed by various molecules
- Most efficient absorbers of solar radiation in the atmosphere are ozone (O_3), water vapor (H_2O), And carbon dioxide (CO_2)



Tempfli et al. 2009

- Many wavelengths are **NOT useful** for remote sensing of the Earth‘s surface
- The **useful ranges** are referred to as the **atmospheric transmission windows**

Atmospheric Absorption

The **useful ranges** are referred to as the **atmospheric transmission windows:**

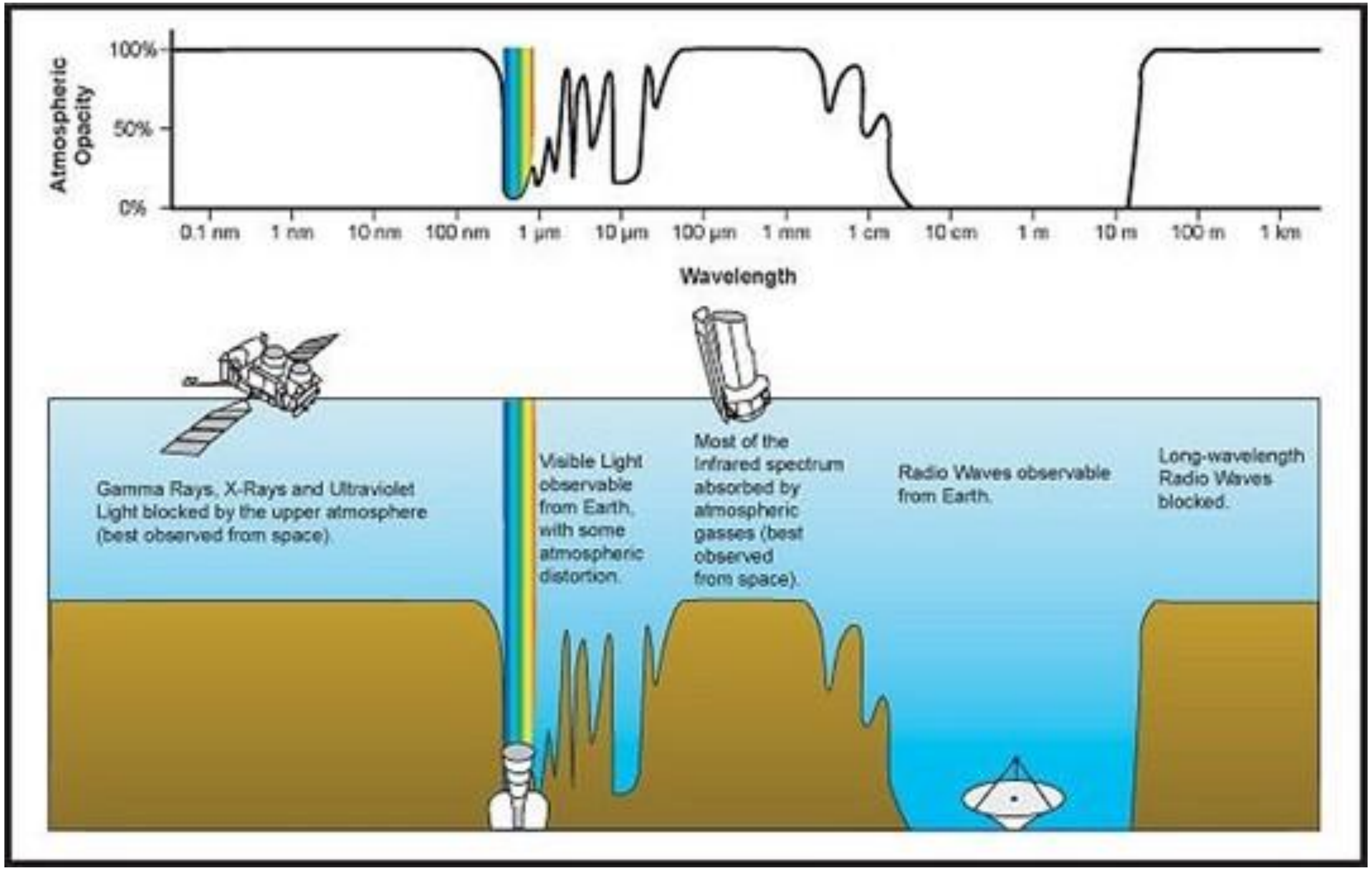
- The window from 0.4 to 2 μm
  - ➢ radiation range of visible, NIR, SWIR
  - ➢ range optical remote sensing

- Three windows in the TIR range, namely two narrow windows around 3 and 45 μm, and a third, relatively broad window extending from 8 to 14 μm

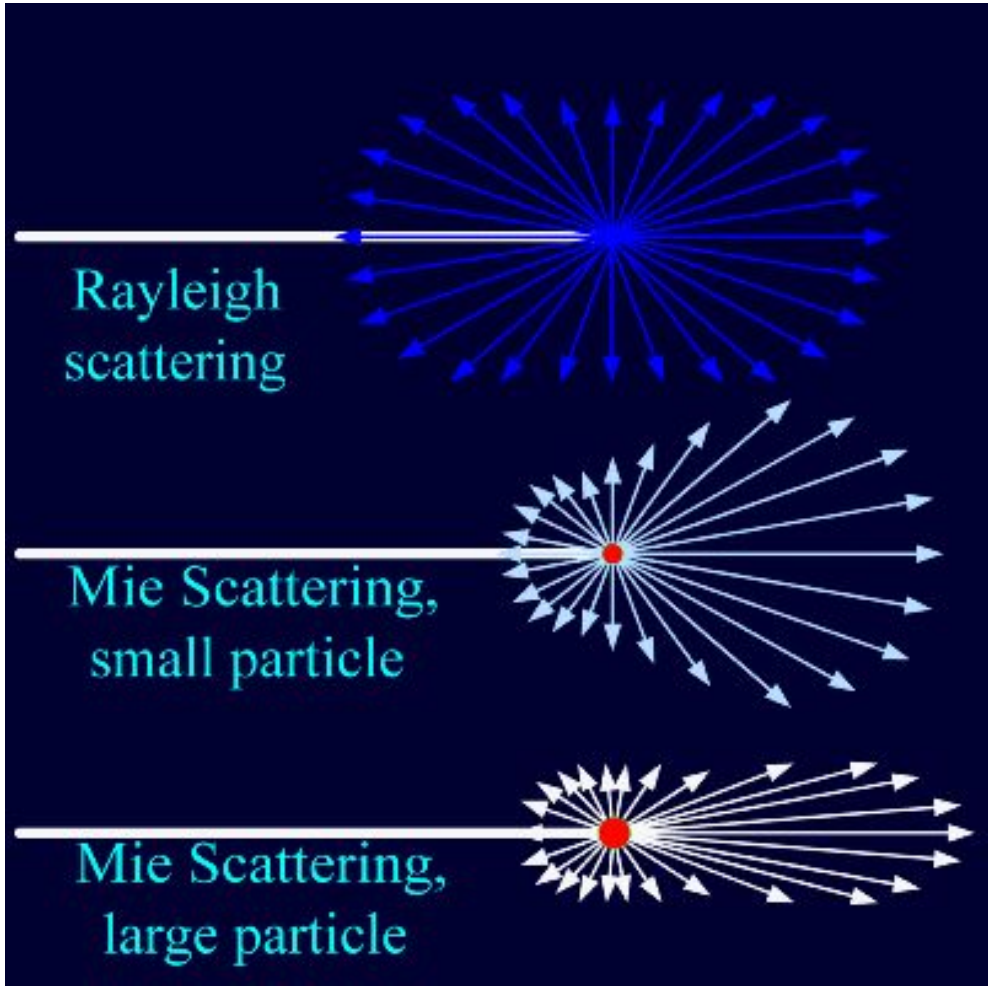
- Because of the presence of atmospheric moisture, strong absorption is occurring at longer wavelengths. There is hardly any transmission energy in the range from 22 μm to 1 mm.

- The more or less „transparent“ range beyond 1 mm is the microwave range

Atmospheric Absorption



Scattering

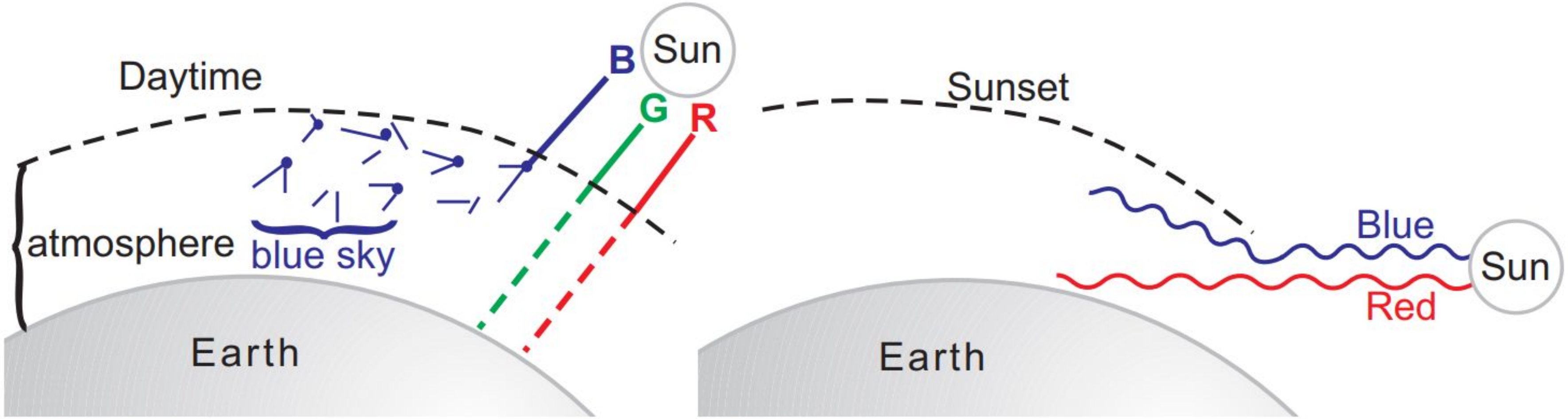


- Continuous removal of energy from a beam of radiation incident on an object and reradiation of that energy in all directions

Scattering

In the absence of particles and scattering the sky would appear black.

- At sunrise and sunset, the sunlight travels a longer distance through the atmosphere
- All the radiation of shorter wavelengths is scattered after some distance and only the longer wavelengths reach the Earth‘s surface
- As a result we do not see a blue but an orange or red sky



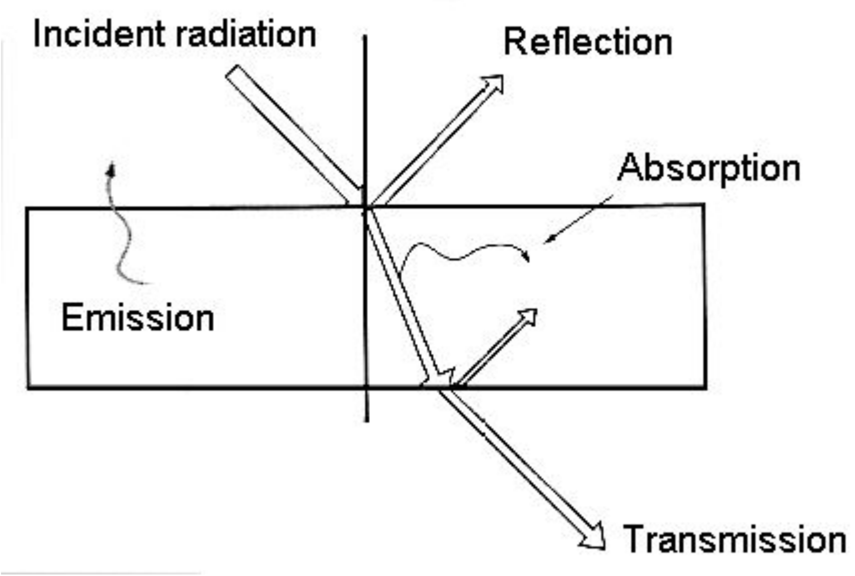
Tempfli et al. 2009

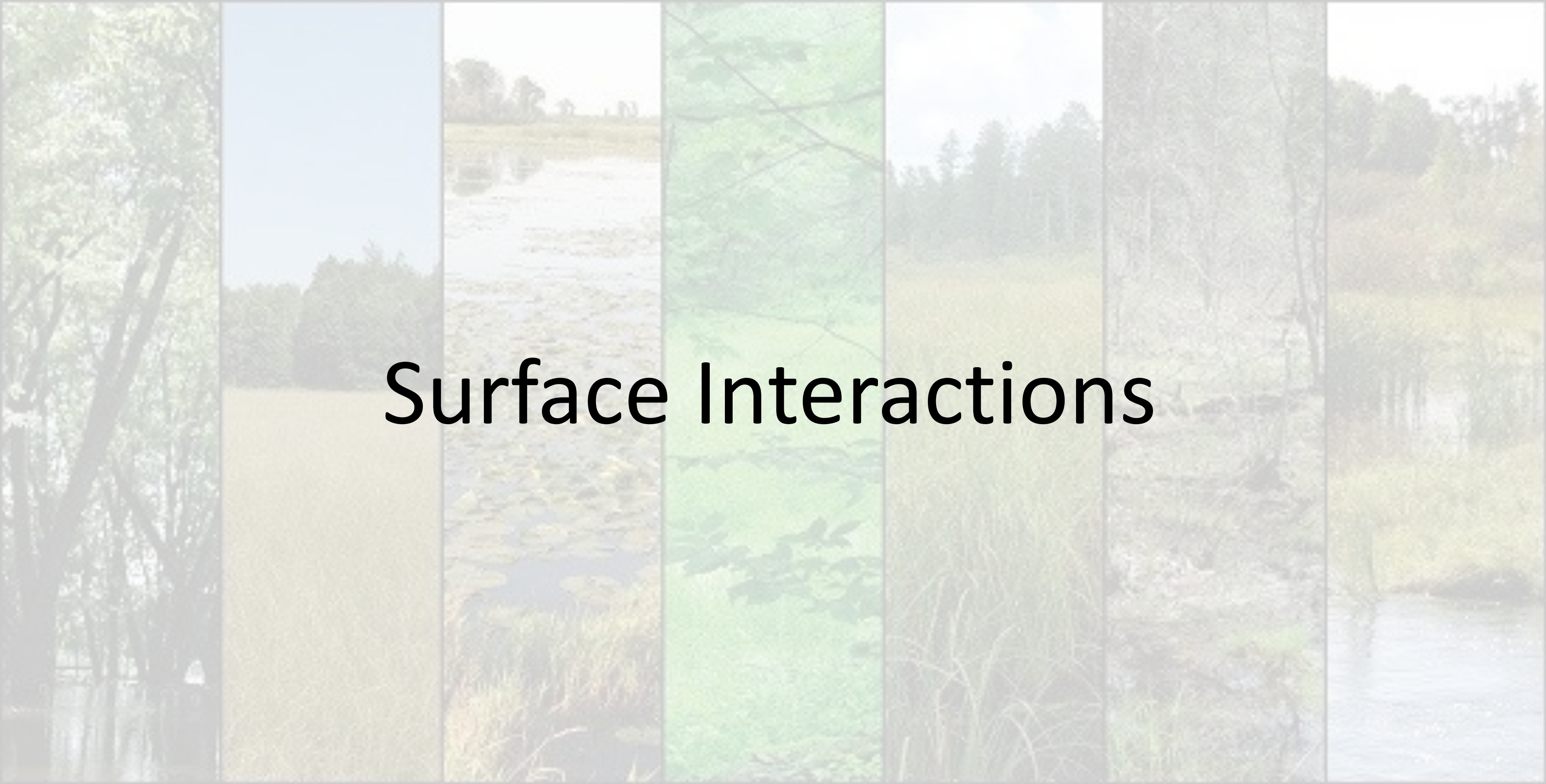
Transmission

- Is that portion of a radiation beam that is neither absorbed nor scattered and continues unimpeded through a translucent medium, where

$$t = \frac{Transmitted\ radiation}{Incident\ radiation}$$

- is the transmissivity of fractional amount of the incident radiation that is transmitted.





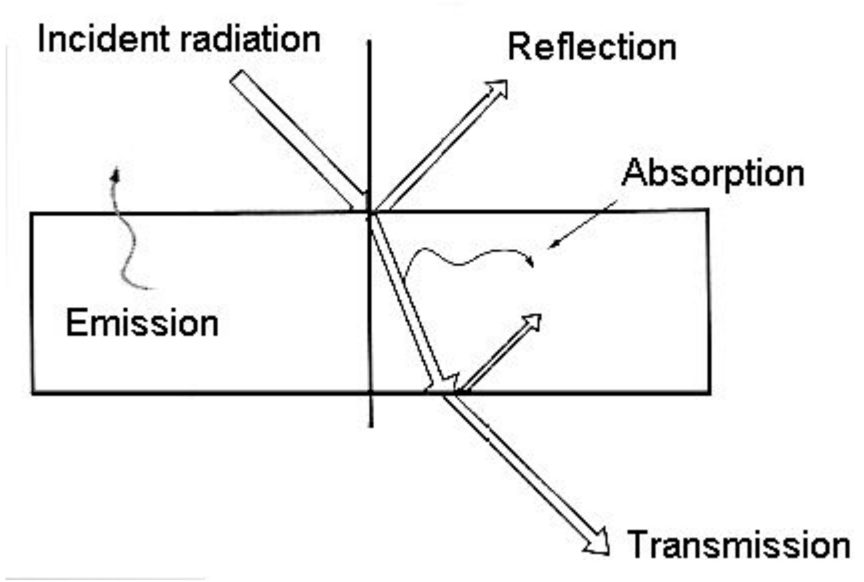
Surface Interactions

Reflection

- Reflection (backscattering) occurs with that portion of an incident beam of radiation that is turned back rather than continuing in a forward direction, where

$$\rho = \frac{Reflected\ radiation}{Incident\ radiation} = \frac{G\ ref}{G},\ 0 \leq \rho \leq 1$$

- is the reflectivity of fractional amount of the incident radiation that is reflected.



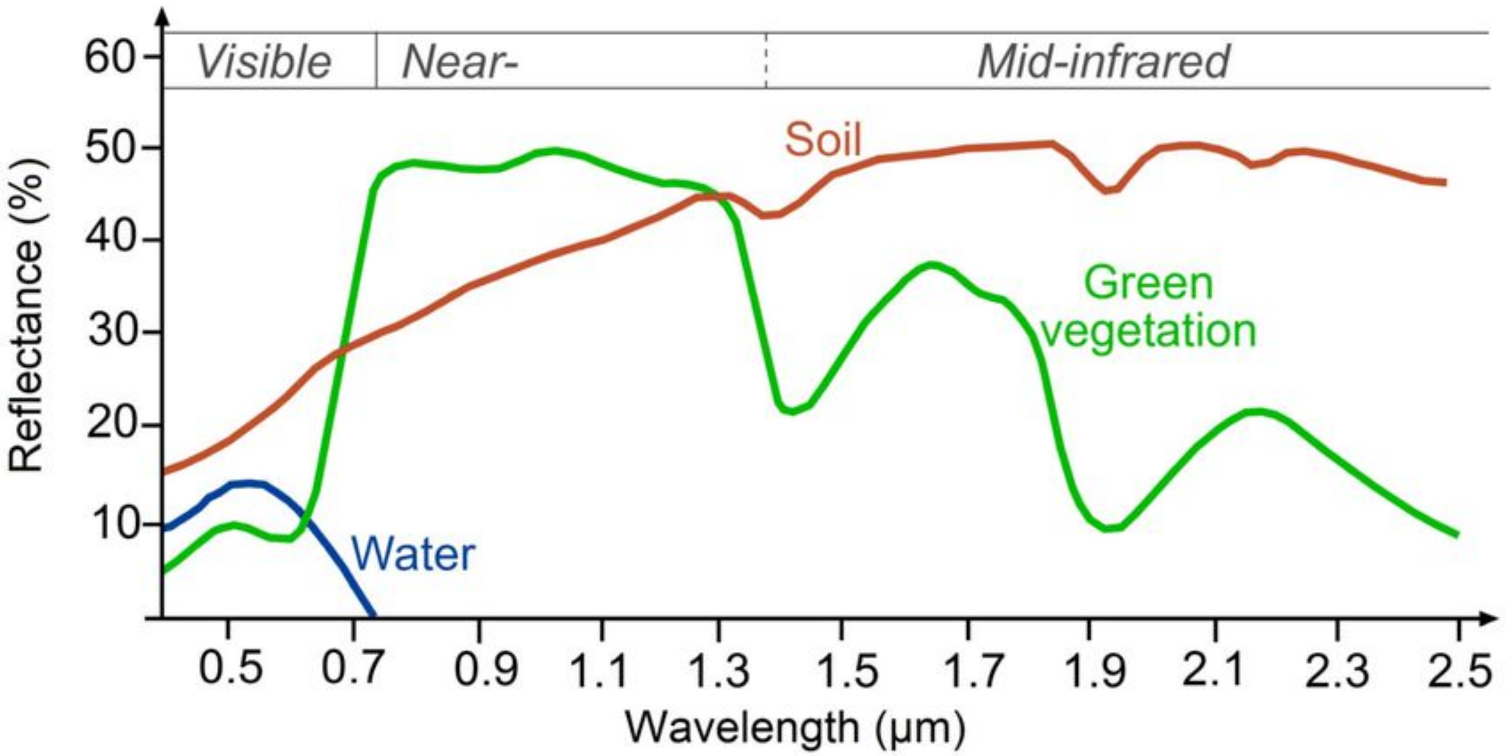
Spectral Reflectance curves

For each material type of interest a reflectance curve can be established.

- Such a curve shows the proportion of the incident energy that is reflected as a function of wavelength
- Remote sensors a sensitive to (narrow) ranges of wavelengths
- The spectral reflectance curve can be used to estimate the overall reflectance in such bands by calculating the mean of reflectance measurements in the respective ranges

 In the following, we will have a closer look at the reflectance characteristics of some common land cover types.

Spectral Reflectance curves



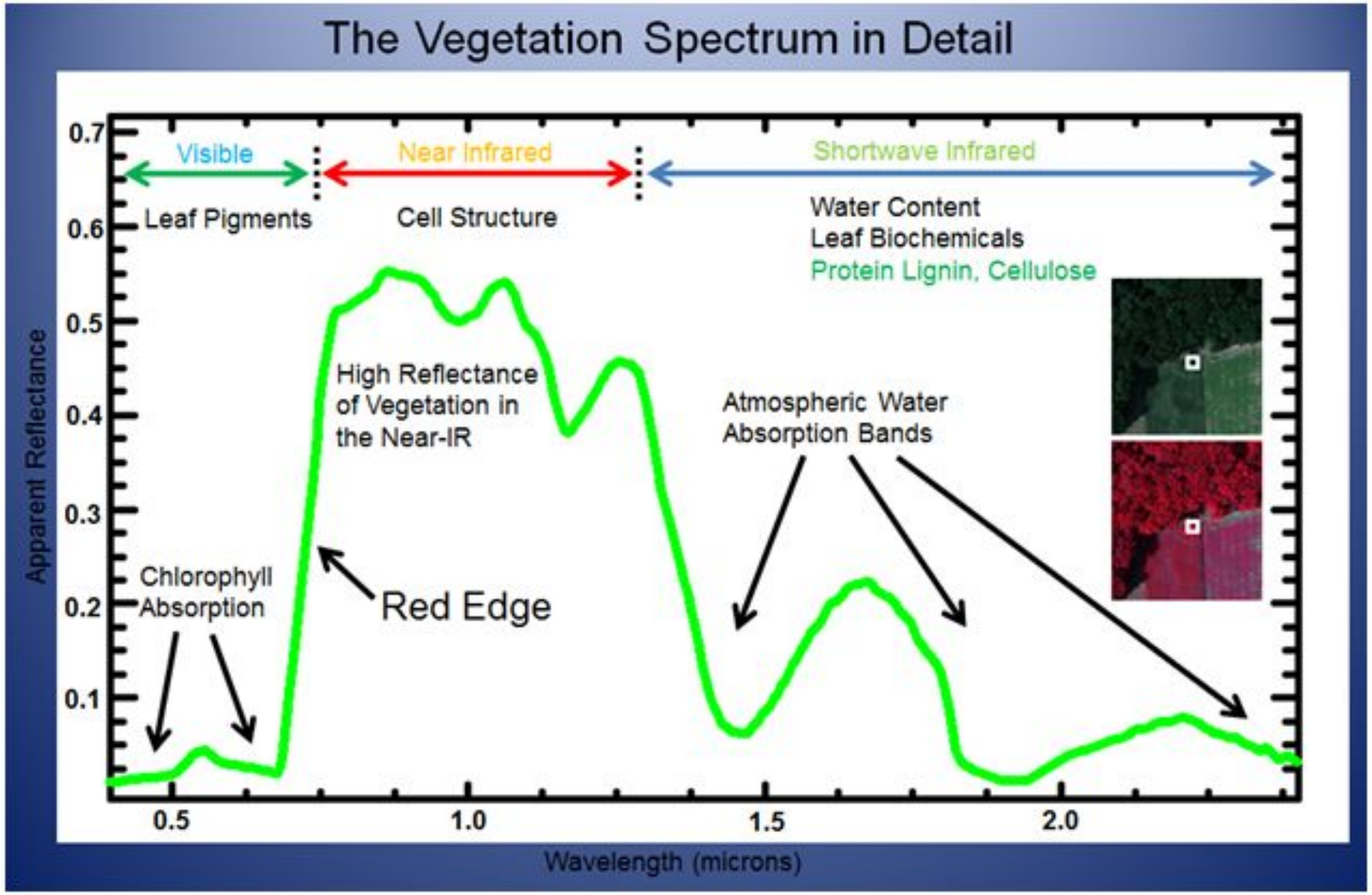
- Different materials reflect and absorb different wavelengths of electromagnetic radiation.
- You can look at the reflected wavelengths detected by a sensor and determine the type of material it reflected from. This is known as a spectral signature.

Spectral Reflectance curves – **Vegetation**

- The reflectance characteristics of vegetation depends on
  - the properties of the leaves
  - the orientation and the structure of the leaf canopy

- The amount of energy reflected for a particular wavelength depends on
  - leaf pigmentation,
  - leaf thickness and composition (cell structure)
  - the amount of water in the leaf tissue

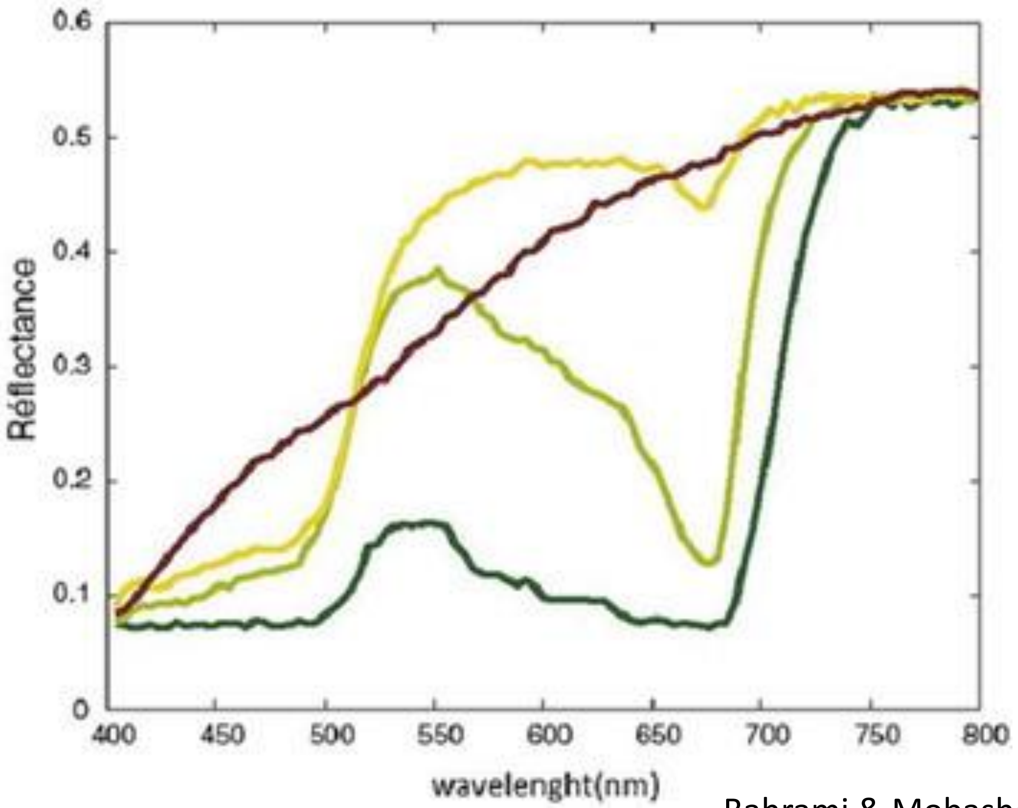
Spectral Reflectance curves - **Vegetation**



- Certain pigments in plant leaves strongly absorb wavelengths of visible (red) light.
- The leaves themselves strongly reflect wavelengths of near-infrared light, which is invisible to human eyes.
- As a plant canopy changes from early growth to late-season maturity and senescence, these reflectance properties also change.
- Since we can't see infrared radiation, we see healthy vegetation as green.

Spectral Reflectance curves - **Vegetation**

- As plants stops or reduces chlorophyll production, it absorbs less in the red bands (therefore reflects more red) and starts producing more yellow color of “dying” vegetation
- Red color of some leaves produced by carotenoids which are always present but are usually masked by chlorophyll.



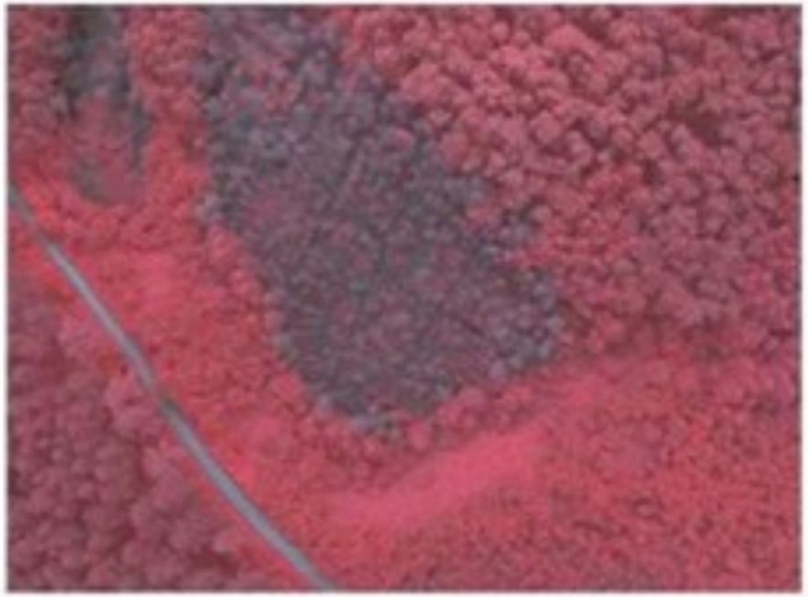
Bahrami & Mobasheri, 2020

Spectral Reflectance curves - **Vegetation**

Remote sensed images can be used to detected stressed or diseased plants.

- High NIR reflectance / low visible reflectance = healthy
- Low NIR reflectance / high visible reflectance = unhealthy

True Color RGB



False Color InfraRed

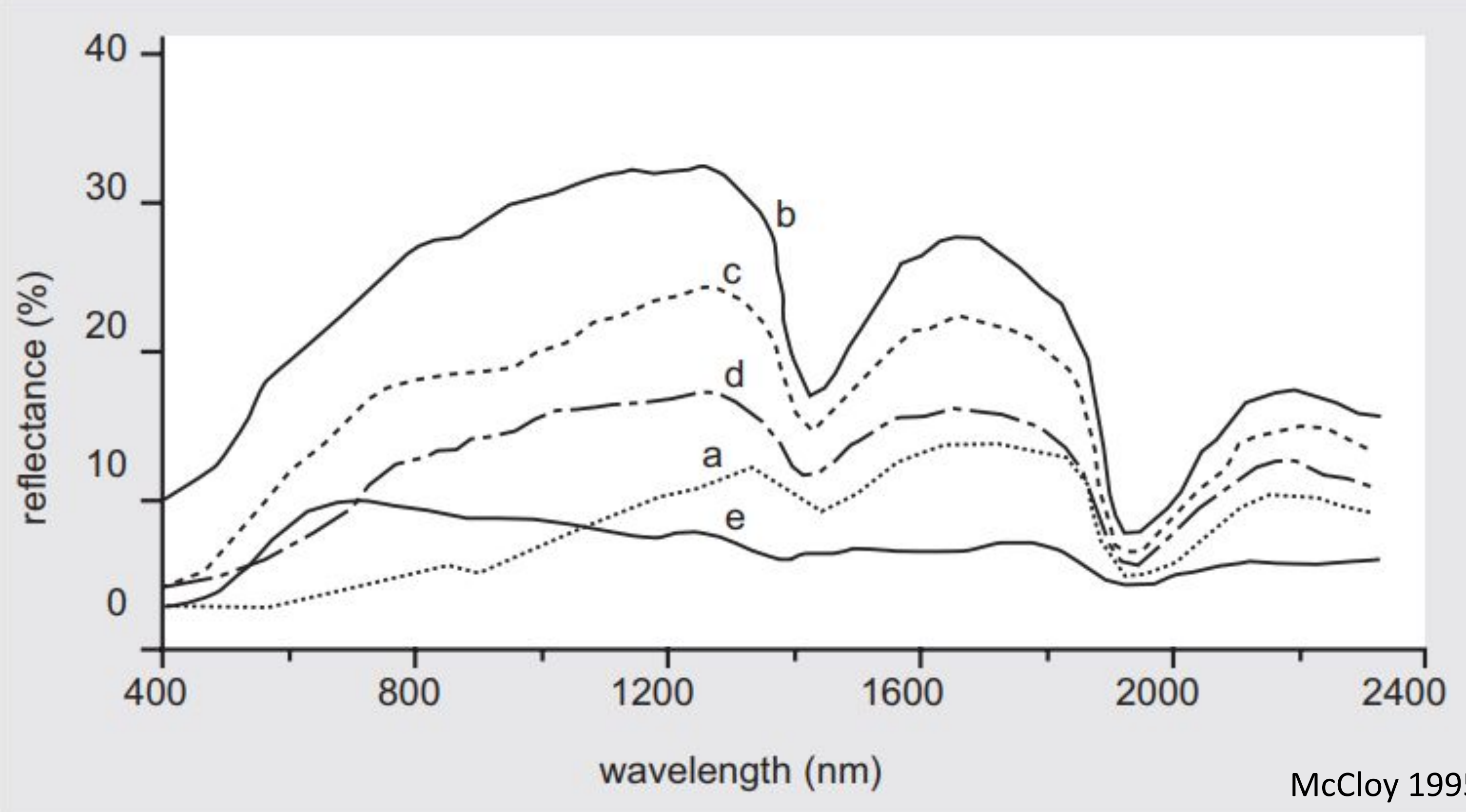
Spectral Reflectance curves – **Bare soil**

Reflection from bare soil depends on so many factors that it is difficult to give one typical soil reflectance curve.

The main factors influencing the reflectance are:

- Soil color
- Moisture content
- Presence of carbonates
- Iron oxide content

Spectral Reflectance curves – **Bare soil**

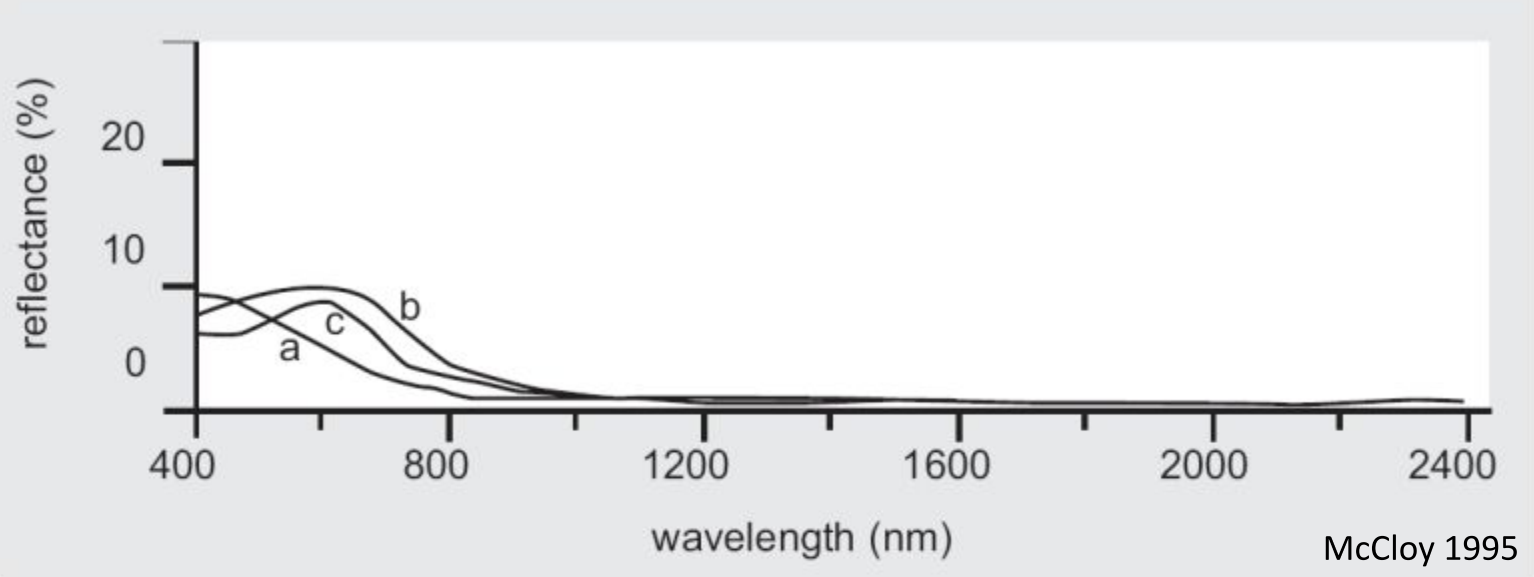


McCloy 1995

Spectral reflectance of five mineral soils, (a) organic dominated, (b) minimally altered, (c) iron altered, (d) organic affected and (e) iron dominated.

Spectral Reflectance curves – **Water**

- Compared to vegetation and soils, water has a lower reflectance
- Vegetation may reflect up to 50 %, soils up to 30 – 40 %, while water reflects at most 10 % of the incident energy
- Water reflects EM energy in the visible range and a little in the NIR range
- Beyond 1.2 μm all energy is absorbed



McCloy 1995

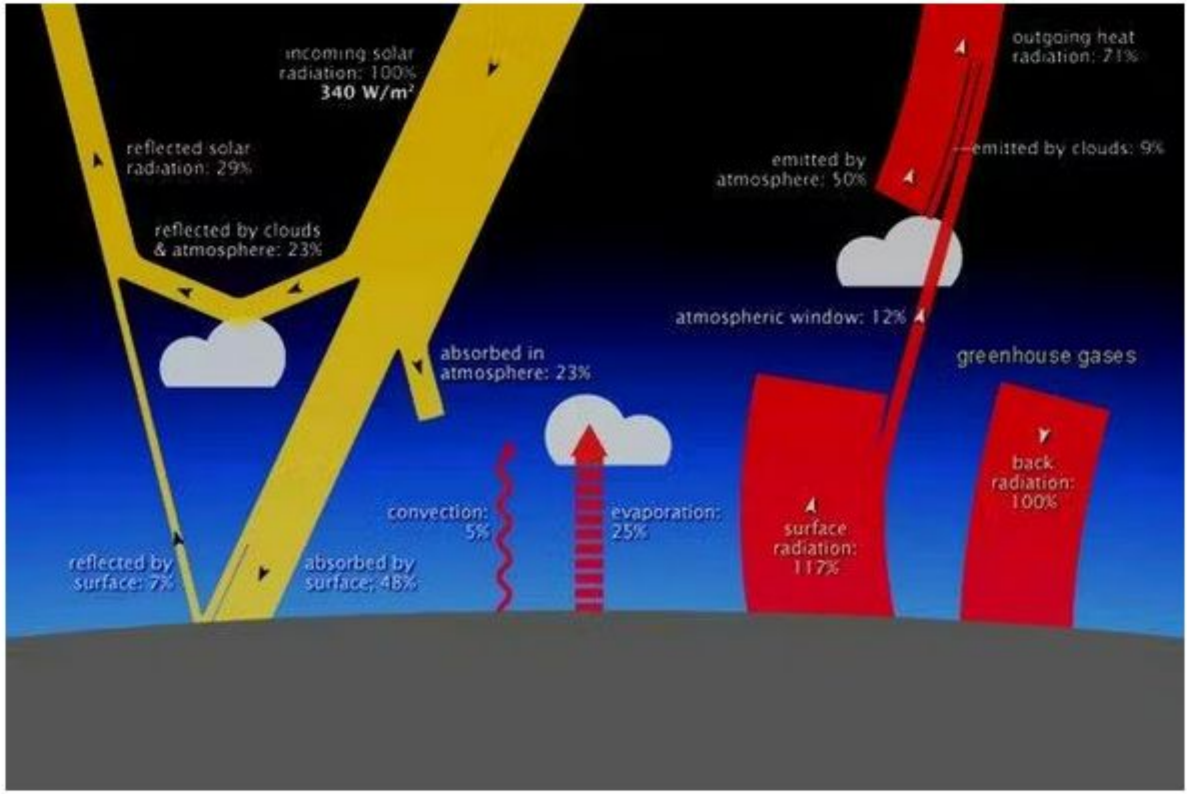
Typical effects of chlorophyll and sediments on water reflectance: (a) ocean water, (b) turbid water, (c) water with chlorophyll.

Spectral Reflectance curves – **Water**

- Longer visible wavelengths (green and red) and near-infrared radiation are absorbed more by water than shorter visible wavelengths (blue) – so water usually looks blue or blue-green.
- Satellites provide the capability to map optically active components of upper water column in inland and near-shore waters.

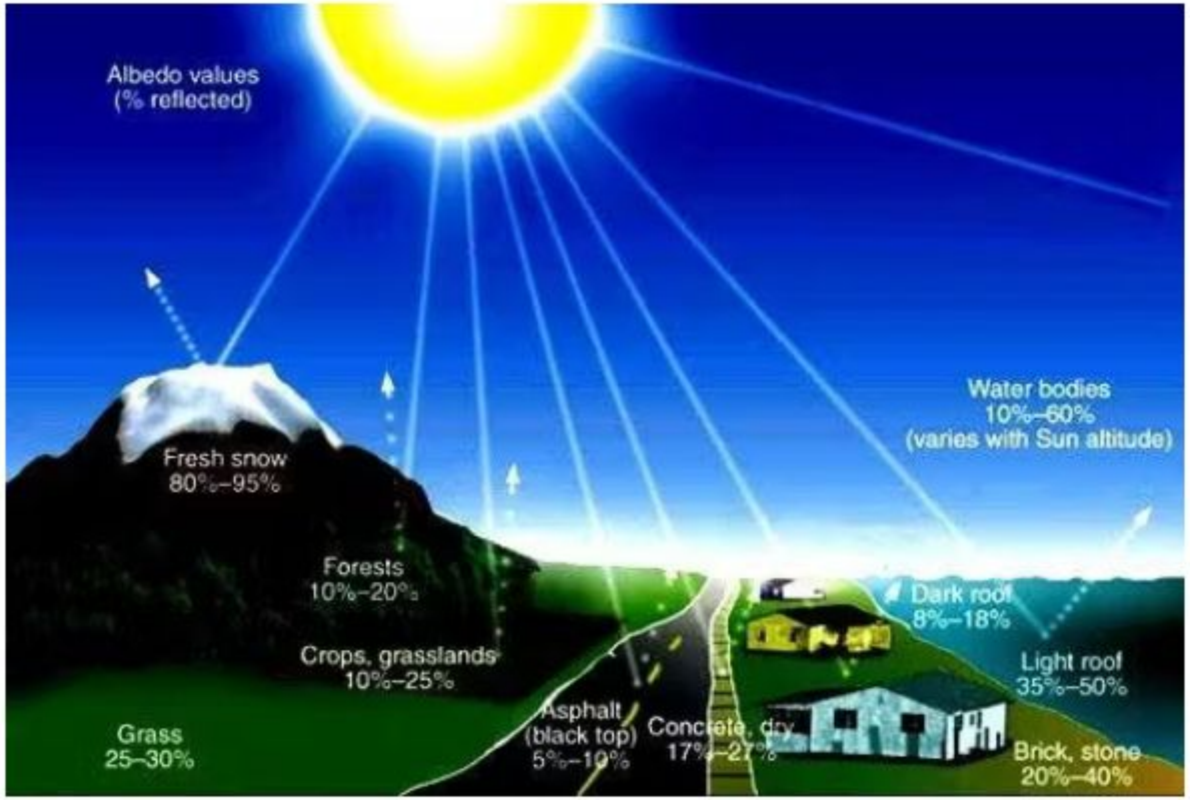
Albedo

Ratio of the total reflected to total incoming solar radiation averaged across all the solar wavelengths.



Albedo

Various land cover parameters show a different albedo:



Blackbody

- An object that absorbs and emits the maximum possible radiation at its given temperature across all wavelength bands
- It is theoretical concept, but does not actually occur in nature
- However the radiative behavior of many objects approaches that of a blackbody
- For example, the sun emits radiation with nearly 100 % efficiency for its temperature. The earth‘s surface emits with nearly 100 % efficiency for its temperature.

Aerosol effects

- Aerosols are small liquid droplets and solid particles in the atmosphere, which cause a net cooling effect by reflecting the sun's energy back out into space.
- Inversely, black aerosols such as coal smoke have the opposite effect, heating the atmosphere by absorbing solar heat.
- It's estimated that, during the Industrial Age, aerosols (light-colored smoke) reduced global warming by up to 1 °C. Still, because of the harmful health effects of this form of smoke pollution, it's desirable to eliminate it.

Albedo manipulation – **reducing the hurricane damage**

- Albedo manipulation can be applied for specific purposes
- The potential hasn’t been tested yet.
- Increase albedo to reduce hurricane damage.
    - This concept is based on the fact that hurricanes are exacerbated by increasing surface temperatures of the ocean surface below them. So, if we reduce that surface temperature, the strength of hurricanes will decrease.

Albedo manipulation – **reducing the hurricane damage**

- Water absorbs about 93% of ambient solar radiation and reflects it back into space, only about 7% (its albedo is 0.07) of that albedo is increased, so the surface gets cooler.

- The albedo of white water is three times higher (about 0.22) than regular water.

- Increasing the albedo (from 0.07 to 0.22) would reduce the temperature of white water surfaces and reduce the "fuel supply" of hurricanes.

- Turning the water surfaces in front of the path of the slow-moving tropical depression or hurricane into whitewater reduces the damage caused by hurricanes.

Albedo manipulation – **reducing the hurricane damage**

- The cost of forming whitewater is insignificant compared to the damage caused by hurricanes.

- Whitewater surfaces can be created by generating microbubbles (also called sea foam) on the surface of the ocean.

- This method of protection against hurricane damage has not yet been assessed, nor have the many other local albedo manipulation techniques that could turn out to be faster and cheaper to implement than presently contemplated ones.

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Thank you for your attention!

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