地理信息系统与遥感应用

第十三讲　遥感物理量

南方科技大学 · 环境科学与工程学院

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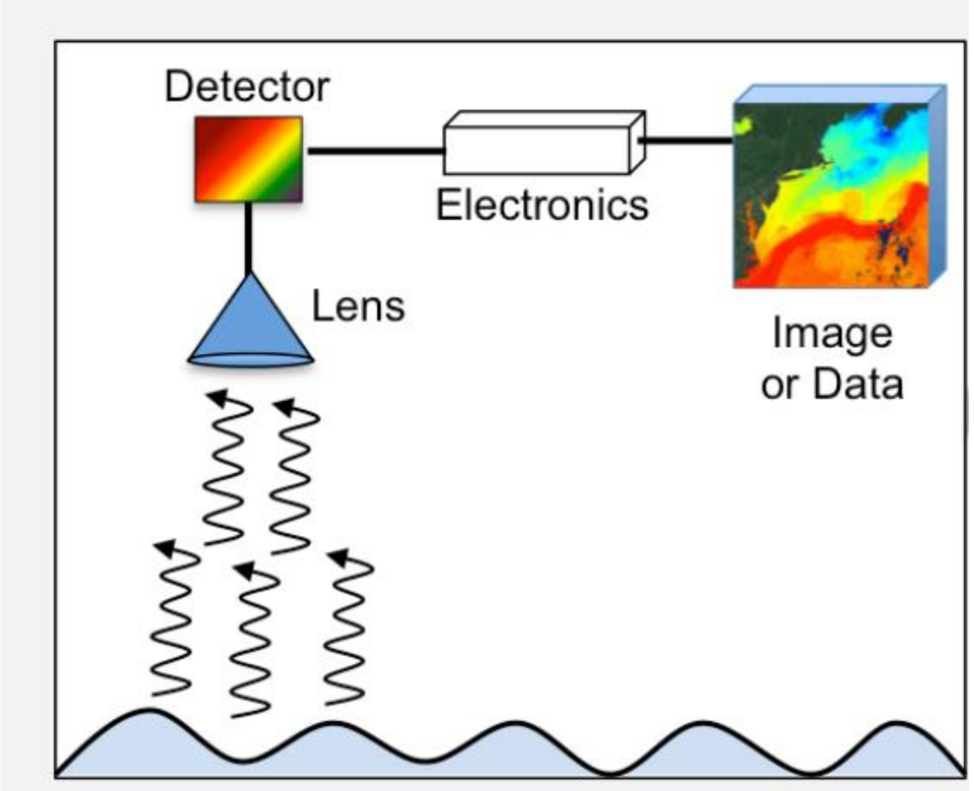
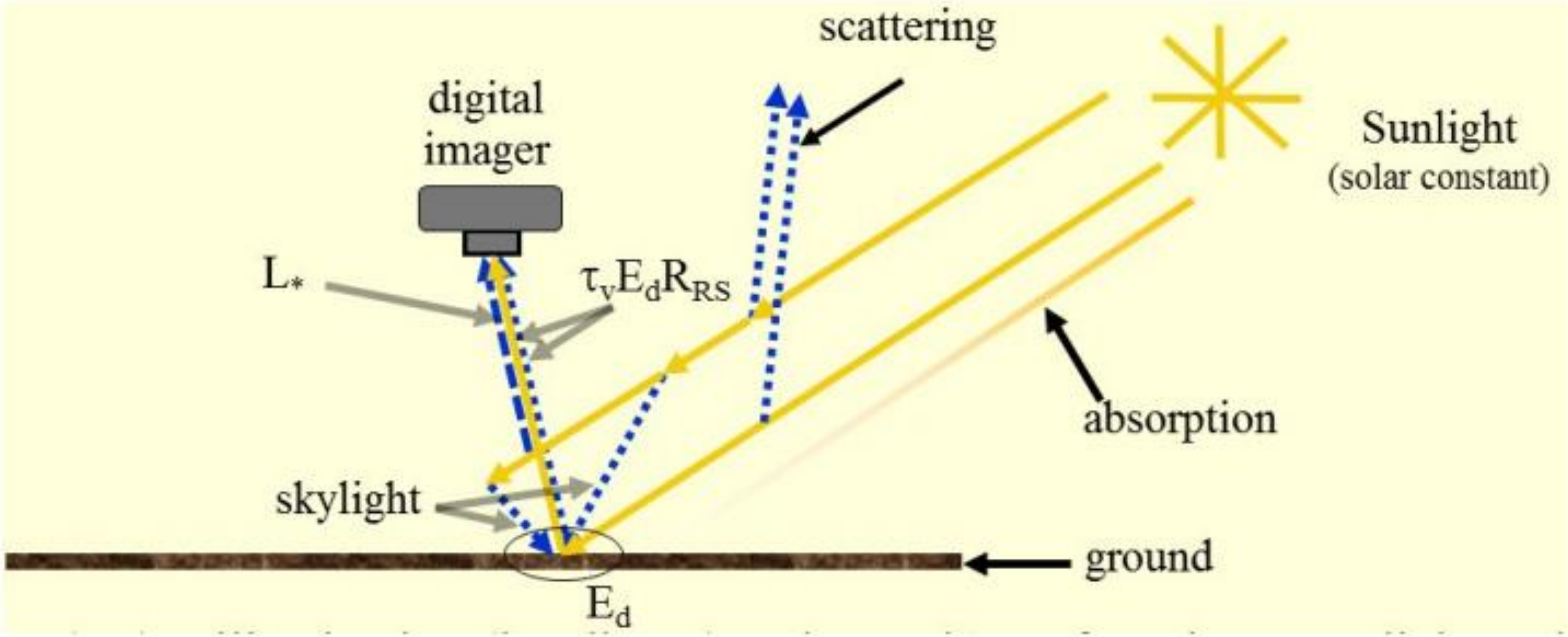
Stages in Remote Sensing

1. Emission of electromagnetic radiation, or EMR (sun)
2. Transmission of energy from the source to the surface of the earth, as well as absorption and scattering
3. Interaction of EMR with the earth's surface: reflection and emission
4. Transmission of energy from the surface to the remote sensor
5. Sensor data output



Transmission of energy



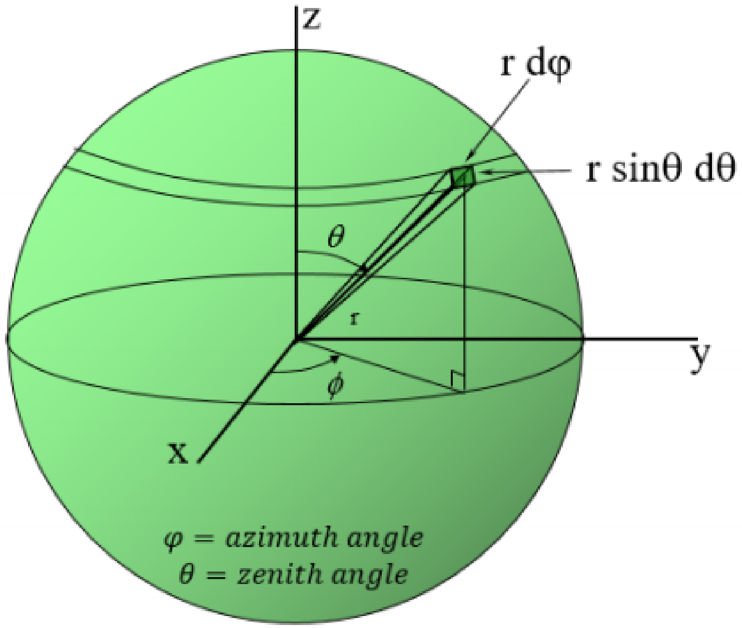
- Absorption
- Scattering
- Refraction

Solid Angles 立体角

A solid angle represents a 2-dimensional set of directions

- denoted by ω or Ω
- defined as the area on the surface of a sphere divided by the square of the radius of the sphere.
- $d\omega = (r^2 \sin\theta \, d\theta \, d\varphi) / r^2 = \sin\theta \, d\theta \, d\varphi$
- there are 4π steradians in a sphere; 2π steradians in a hemisphere

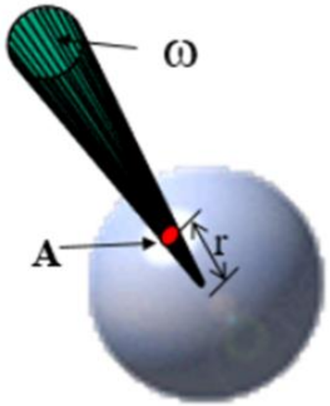
$$\Omega = \iint_S \frac{\hat{r} \cdot \hat{n} \, d\Sigma}{r^2} = \iint_S \sin\theta \, d\theta \, d\varphi$$

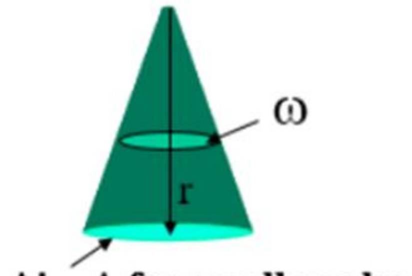


A **solid angle** is defined as an area on the surface of a sphere, divided by the square of the radius of that sphere,

$$\boldsymbol{\omega} = \boldsymbol{A/r^2 \sim A'/r^2}$$

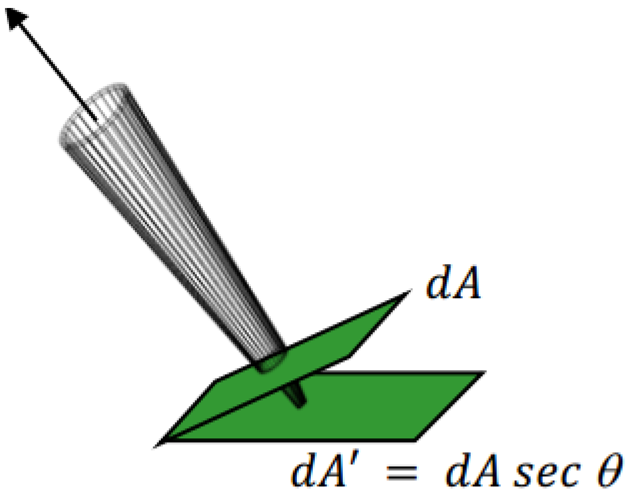
- for small angles, the area on the surface of the sphere is approximated by the area of the intersecting planar surface.





立体角是单位球面上的一块面积，这和“平面角是单位圆上的一段弧长”类似。其单位是球面度

Basic Radiative Transfer Terms



辐射通量

Power or flux, Φ [watts = Joule sec^{-1}]

- The quantity that is actually measured.
- Denoted by **Φ** (or P in older notation)
- normally measured in watts,

  milliwatts [mW] = 10^{-3} watts;

  or microwatts [μW] = 10^{-6} watts).

辐射强度

Intensity, I [watts ster^{-1}]

- Intensity is the power flowing into the solid angle dΩ, in the direction $\xi = (\theta, \varphi)$. Intensity is defined simply as: L = dΦ / dΩ

辐射亮度

Radiance, L [watts m^{-2} ster^{-1}]

- Radiance is the power falling onto a surface area, dA, from the solid angle dΩ, in the direction $\xi = (\theta, \varphi)$. If the surface is perpendicular to the incoming radiation, then the radiance may be defined simply as: $L = d\Phi / dA\, d\Omega$
- If the surface is oriented at an angle, θ, to the incoming radiation, then we must adjust the relationship accordingly: $L = d\Phi / dA'\, d\Omega = d\Phi / \sec\theta\, dA\, d\Omega$

辐射照度

Irradiance, E [watts m^{-2}]

- Irradiance describes the radiant power per unit area on a surface.
- The incident (or exitant) direction is not specified.
  (It doesn't matter where the radiation comes from or where it's going, just how much arrives.)
- The surface itself, however, is of a fixed size and has some orientation.

$$\begin{array}{c}\textit{downwelling}\\ \textit{irradiance}\\ (\textit{diffuse})\end{array} \quad E_d = \int_{\substack{\textit{upward}\\ \textit{hemisphere}}} L\cos\theta \; d\omega = \int_{\theta=0}^{\pi/2}\int_{\varphi=0}^{2\pi} L\,\cos\theta\sin\theta\, d\theta\, d\varphi$$

$$\begin{array}{c}\textit{upwelling}\\ \textit{irradiance}\\ (\textit{diffuse})\end{array} \quad E_d = \int_{\substack{\textit{downward}\\ \textit{hemisphere}}} L\cos\theta \; d\omega = \int_{\theta=\frac{\pi}{2}}^{\pi/2}\int_{\varphi=0}^{2\pi} L\,\cos\theta\sin\theta\, d\theta\, d\varphi$$

普朗克定律

- 1900年普朗克用量子理论推导出普朗克定律
- 黑体辐射通量密度与温度、波长的关系满足普朗克定律：

$$\text{Planck's Law} \qquad W(\lambda) = \frac{2\pi hc^2}{\lambda^5} \frac{1}{e^{ch/\lambda kT} - 1}$$

W(λ)—— 分谱辐射通量密度，单位W／（$cm^2 \cdot \mu m$）

λ—— 波长，单位是μm

h—— 普朗克常数($6.6256 \times 10^{-34} J \cdot s$)

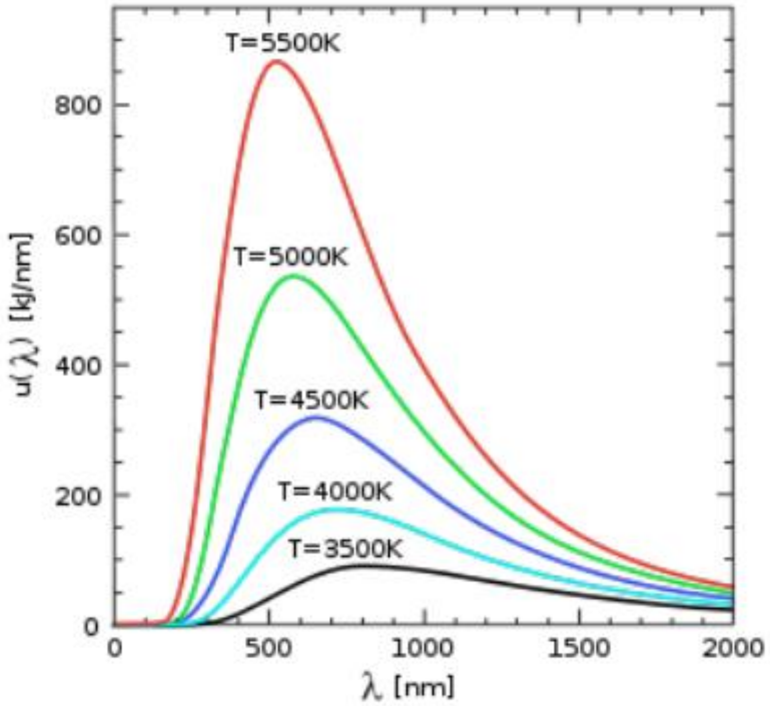
c—— 光速

k—— 玻耳兹曼常数($1.38 \times 10^{-23} J / K$)

T—— 绝对温度，单位是K

黑体辐射特性

- 与曲线下的面积成正比的总辐射通量密度W是随温度T的增加而迅速增加。总辐射通量密度W可在从零到无穷大的波长范围内。
- 对普朗克公式进行积分，可得到从1cm²面积的黑体辐射到半球空间里的总辐射通量密度的表达式为：



$$W = \int_0^\infty W(\lambda) d\lambda$$

$$W = \frac{2\pi^5 k^4}{15c^2 h^3} T^4 = \sigma T^4$$

σ为斯忒藩—玻耳兹曼常数，T为绝对黑体的绝对温度（K）

从上式可以看出：绝对黑体表面上，单位面积发出的总辐射能与绝对温度的四次方成正比，称为斯忒藩－玻耳兹曼公式。

对于一般物体来讲，传感器检测到它的辐射能后就可以用此公式概略推算出物体的总辐射能量或绝对温度。热红外遥感就是利用这一原理探测和识别目标物的

维恩位移定律

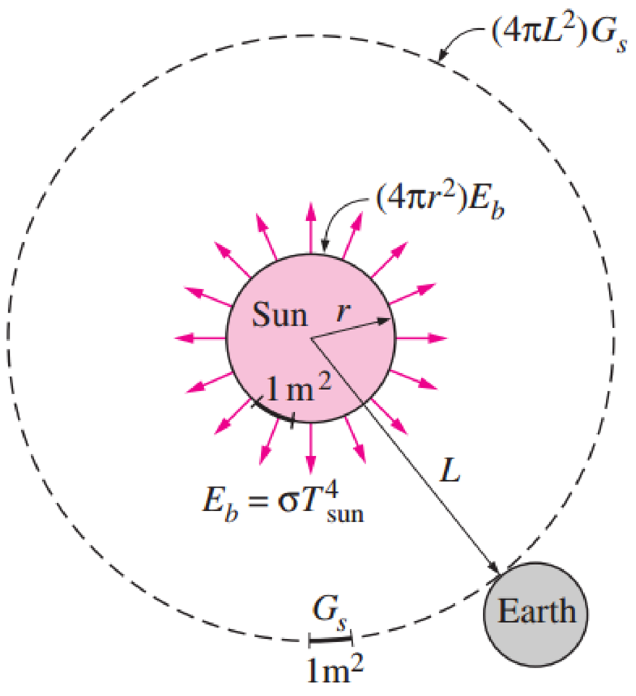
- 分谱辐射能量密度的峰值波长随温度的增加向短波方向移动。可微分普朗克公式，并求极值

$$\frac{\partial u}{\partial \lambda} = 2hc^2 \left(\frac{hc}{kT\lambda^7} \frac{e^{hc/\lambda kT}}{\left(e^{hc/\lambda kT} - 1\right)^2} - \frac{1}{\lambda^6} \frac{5}{e^{hc/\lambda kT} - 1} \right) = 0$$

$$\lambda_{\max} T = \frac{ch}{k4.96511} = 2897.8$$

此称维恩位移定律。它表明：黑体的绝对温度增高时，它的最大辐射本领向短波方向位移。若知道了某物体温度，就可以推算出它所辐射的波段。在遥感技术上，常用这种方法选择遥感器和确定对目标物进行热红外遥感的最佳波段。

根据观测，太阳辐射强度最大波长为0.475μm，根据维恩位移定律，可推算出太阳表面温度约为6100 K



The total solar energy passing through concentric spheres remains constant, but the energy falling per unit area decreases with increasing radius.

Computation of solar radiance and irradiance

Much of what has been presented in this chapter can be illustrated by considering the radiation from the sun as it illuminates the earth-moon system. To a good approximation the sun may be considered a gray body with an effective temperature of 5800K and an emissivity of $\varepsilon_{sun} = 0.99$. Thus, the sun's total radiant exitance is:

$$M_{tot} = \varepsilon\, \sigma\, T^4 = 6.35 \times 10^7 \text{ W m}^{-2}$$

which corresponds to a wavelength of maximum emission of:

$$\lambda_{max} = \frac{A}{T} = \frac{2.898 \times 10^{-3}\,\text{K m}}{5800\text{K}} = 500 \text{ nm}$$

The radiation that we see from the sun is emitted in the photosphere, the surface of which will define for us the diameter of the sun, $R_{sun} \approx 6.96 \times 10^8$ m. The total power radiated by the sun is obtained by multiplying the total radiant exitance by the total surface area of the sun:

$$\Phi_{sun} = (4\,\pi\, R_{sun}^2)\, M_{sun} = 3.87 \times 10^{26} \text{ W}$$

At the earth, a distance of $D_e \approx 1.5 \times 10^{11}$ m, this power is spread out over the surface area of a sphere of area $4\pi D_e^2$, making the irradiance at the earth (the solar constant):

$$E_{sun} = \Phi_{sun} / 4\pi D_e^2 = 1.37 \times 10^3 \text{ W m}^{-2}$$

(Measured values of E_{sun} can be found at http://www.pmodwrc.ch/pmod.php?topic=tsi/composite/SolarConstant.)

Treating the sun as a disk, the solid angle subtended by the sun as seen from the earth is

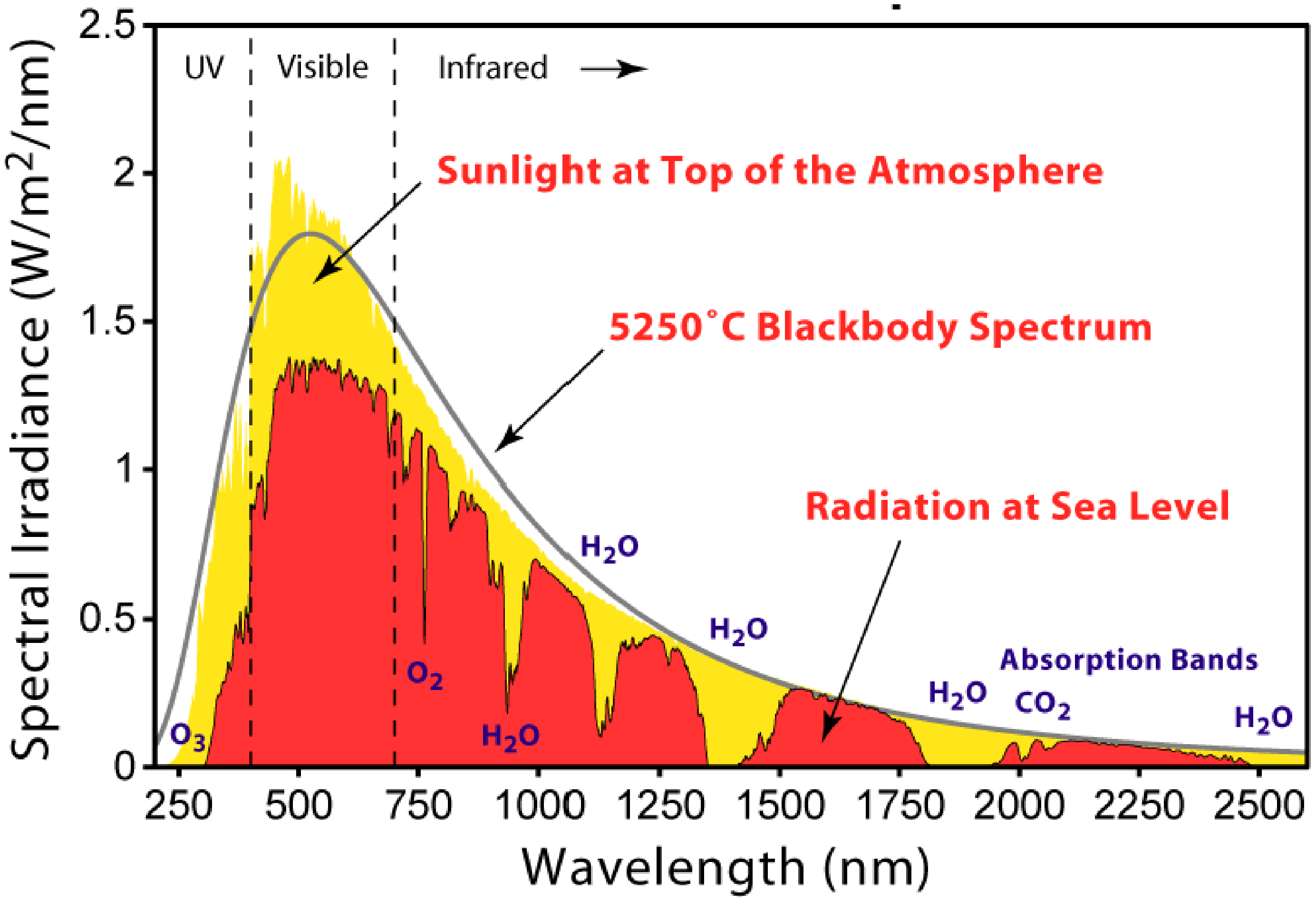
$$\Omega_{sun} = \pi\, (R_{sun})^2 / (D_e)^2 = 6.71 \times 10^{-5} \text{ sr}$$

The corresponding radiance observed by a detector with a field of view filled by the sun is then,

$$L_{sun} = E_{sun} / \Omega_{sun} = \varepsilon\sigma T^4/\pi \approx 2.02 \times 10^7 \text{ W m}^{-2} \text{ sr}^{-1}$$

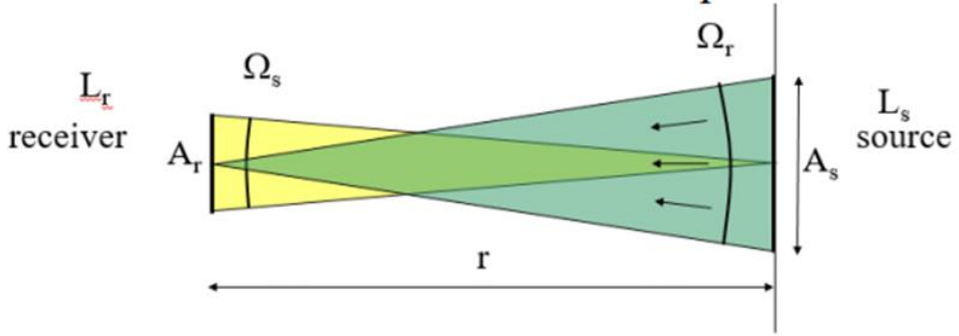
Electromagnetic Radiation

- The sun is the source of radiation for the bulk of the passive sensing systems used in remote sensing
- Radiation from the sun approximates a blackbody source at ~5800 K at its surface
- The total irradiance at the earth available from the sun, averaging over all wavelengths, is referred to as the "solar constant" with an average value of 1360 w/m^2. The actual value fluctuates by about 6.9% per year, from 1412 w/m^{2}in January to 1321 w/m^2 in July, due to the change in the earth's distance from the sun.



The solar spectrum at the earth: outside the atmosphere and at the earth surface, compared to a 5250° C (5520 K) blackbody spectrum.

Radiance invariance law – radiance is invariant over a path in a vacuum



$$L_r = \frac{\Phi_0}{A_r \Omega_r}$$

$$L_s = \frac{\Phi_0}{A_s \Omega_s}$$

$$\Omega_r = A_s / r^2$$

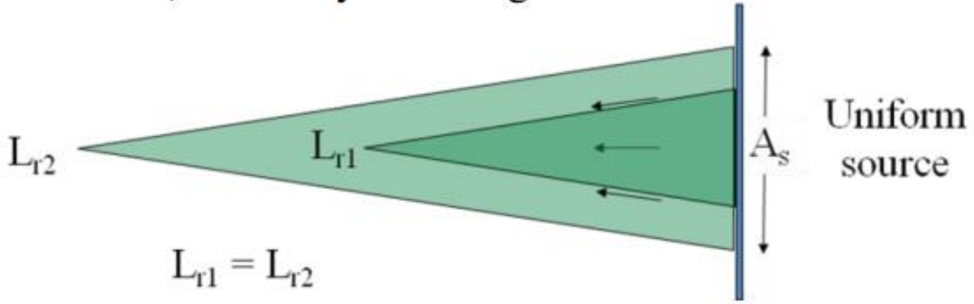
$$\Omega_s = A_r / r^2$$

$$\rightarrow A_s \Omega_s = A_r \Omega_r$$

$$\mathbf{L_r = L_s}$$

Range independence of Radiance - Radiance is independent of range for

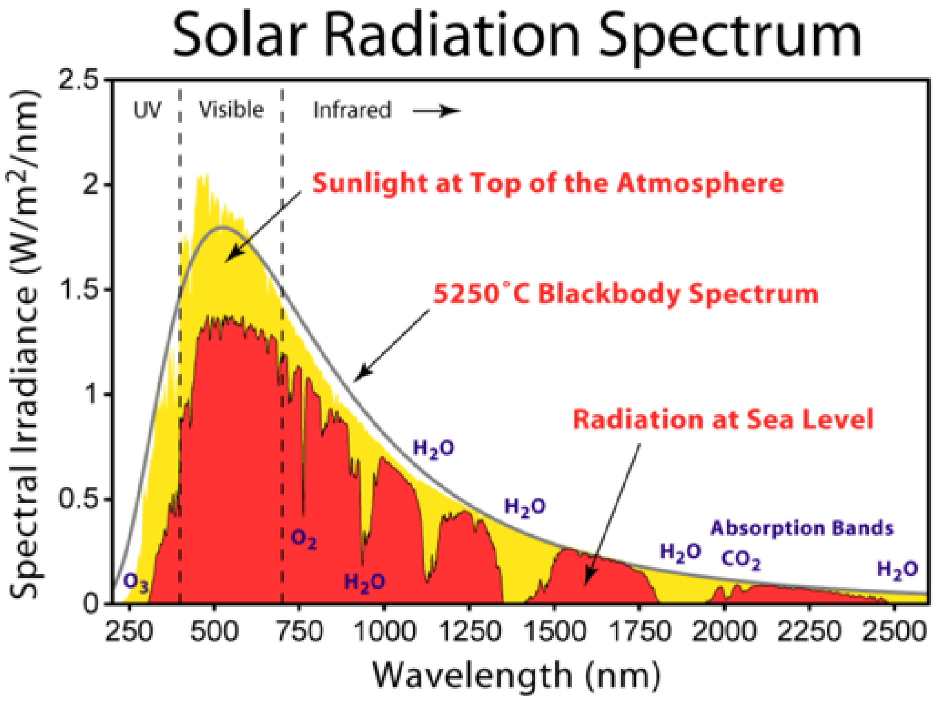
- a uniform, extended source
- a uniformly illuminated, uniformly reflecting surface that fills the detector field of vi



$L_{r1} = L_{r2}$

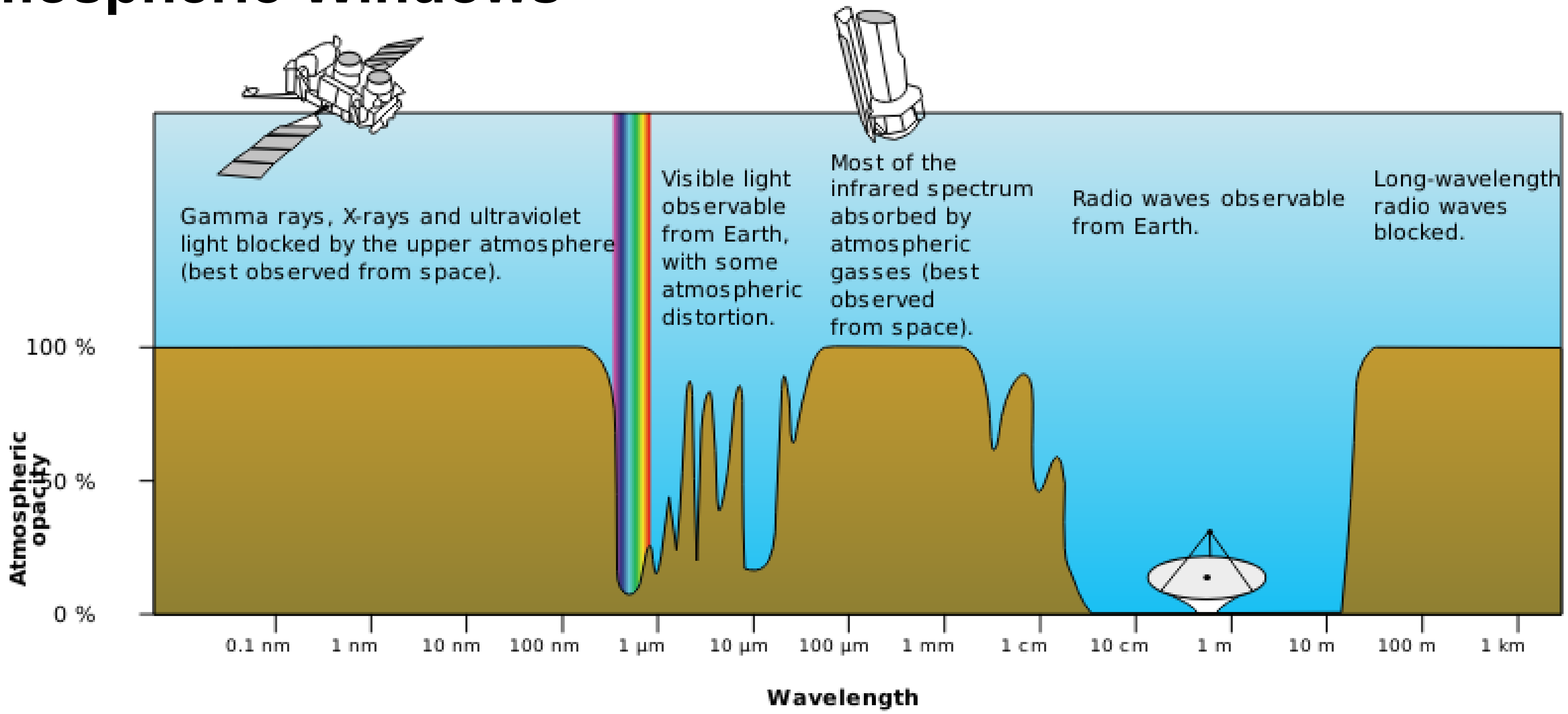
Absorption

- The general atmospheric transmittance across the whole spectrum of wavelengths is shown in the Figure. The atmosphere selectively transmits energy of certain wavelengths.
- The spectral bands for which the atmosphere is
- relatively transparent are known as **atmospheric windows**.



- 大气主要气体及相应吸收带
  - 水汽吸收带：对太阳辐射的吸收作用最为显著，范围很广，但集中在红外波段，其中0.7-3.0um波段是强吸收带
  - 氧和臭氧吸收带：氧的吸收带主要在0.176-0.202um和0.242-0.260um，在0.69-0.76um也有一狭小的吸收带。臭氧对0.28um以下的短波光能全部吸收。
  - 二氧化碳吸收带：主要发生在大于2um的红外区内。
  - 水滴和尘埃：吸收的范围较宽，但主要吸收0.7-3um的红外线。

Atmospheric Windows



- 0.30 ~ 1.15μm大气窗口：这个窗口包括全部可见光波段、部分紫外波段和部分近红外波段，是遥感技术应用最主要的窗口之一
- 1.3~2.5μm大气窗口：属于近红外波段
- 3.5~5.0μm大气窗口：属于中红外波段
- 8~14μm热红外窗口：属于地物的发射波谱
- 1.0mm~1m微波窗口

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Atmospheric Scattering

- Scattering is the redirection of EMR by particles suspended in the atmosphere or by large molecules of atmospheric gases. Scattering not only reduces the image contrast but also changes the spectral signature of ground objects as seen by the sensor. The amount of scattering depends upon the size of the particles, their abundance, the wavelength of radiation, depth of the atmosphere through which the energy is traveling and the concentration of the particles.

散射强度与波长的关系

$$I \propto E_s'^2 \propto \frac{\sin^2\theta}{\lambda^4}$$

蓝光散射较强

红光散射较弱

	Scattering process	Wavelength	Approximate dependence particle size	Kinds of particles
	Selective			
瑞利散射	• Rayleigh	λ^{-4}	< 1 µm	Air molecules
米氏散射	• Mie	λ^{0} to λ^{-4}	0.1 to 10 µm	Smoke, haze
均匀散射	• Non-selective	λ^{0}	> 10 µm	Dust, fog, clouds

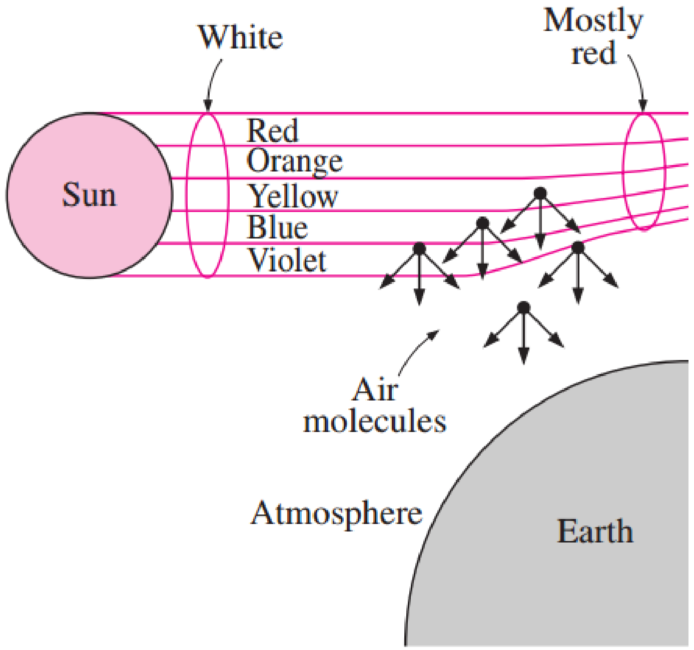


FIGURE 11–41

Air molecules scatter blue light much more than they do red light. At sunset, the light travels through a thicker layer of atmosphere, which removes much of the blue from the natural light, allowing the red to dominate.






″朝霞不出门，晚霞行千里″

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.
- The reflection intensity depends on the surface refractive index, absorption coefficient and the angles of incidence and reflection

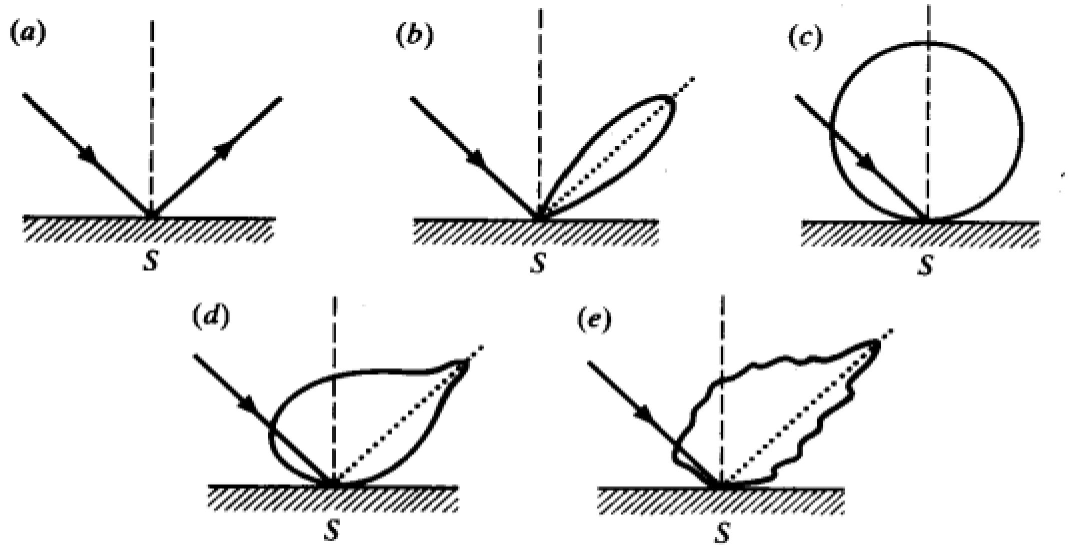


Figure 4. Different types of scattering surfaces (a) Perfect specular reflector (b) Near perfect specular reflector (c) Lambertain (d) Quasi-Lambertian (e) Complex.

Spectral Reflection

Spectral Signature (反射波谱)

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

- Spectral reflectance, [ρ(λ)], 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

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:

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

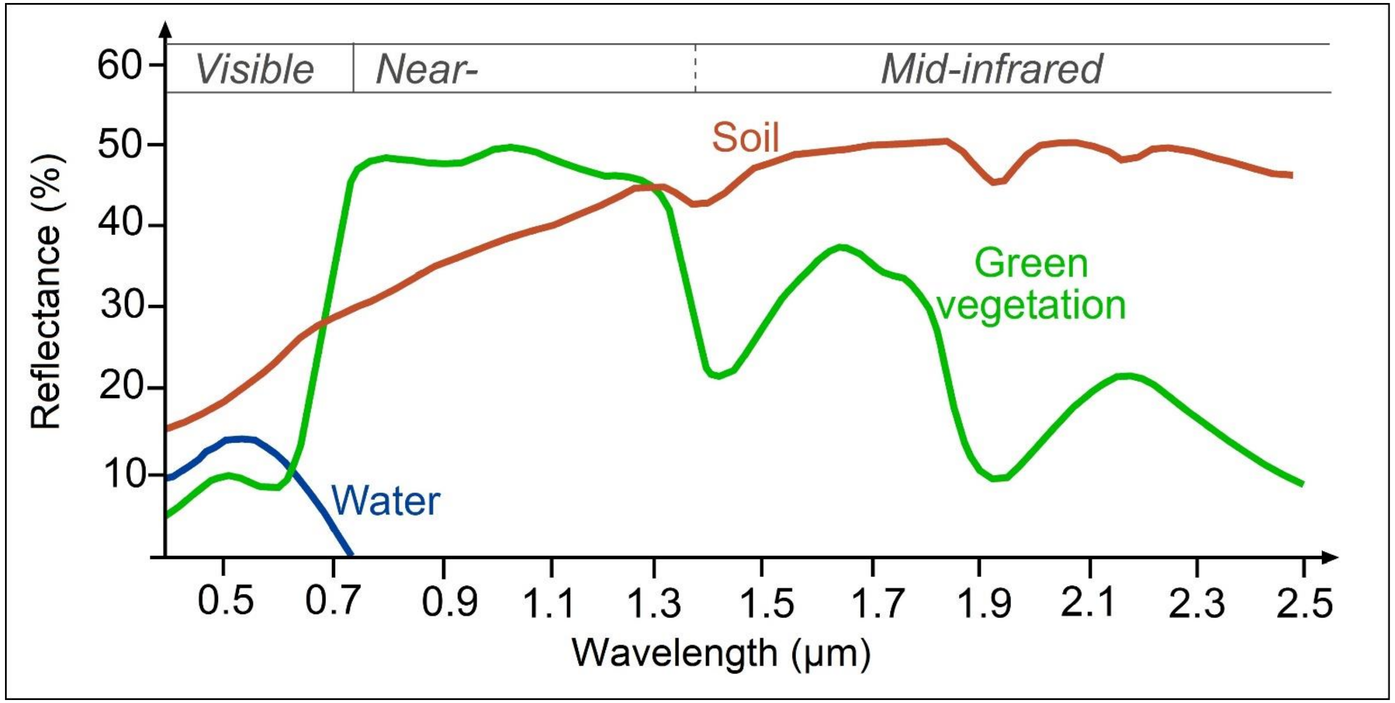
Where,

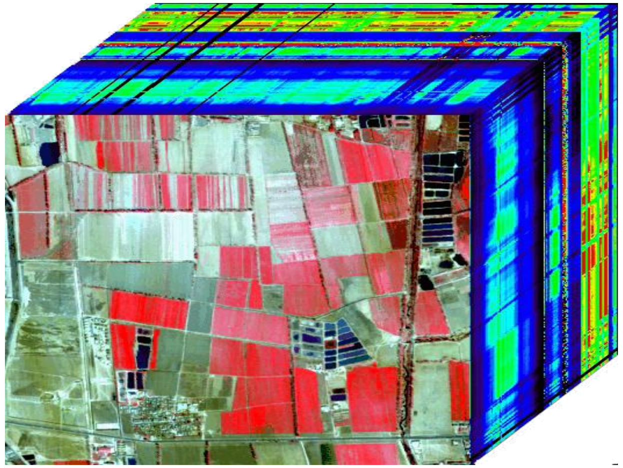
$\rho(\lambda)$ = Spectral reflectance (reflectivity) at a particular wavelength.

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

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

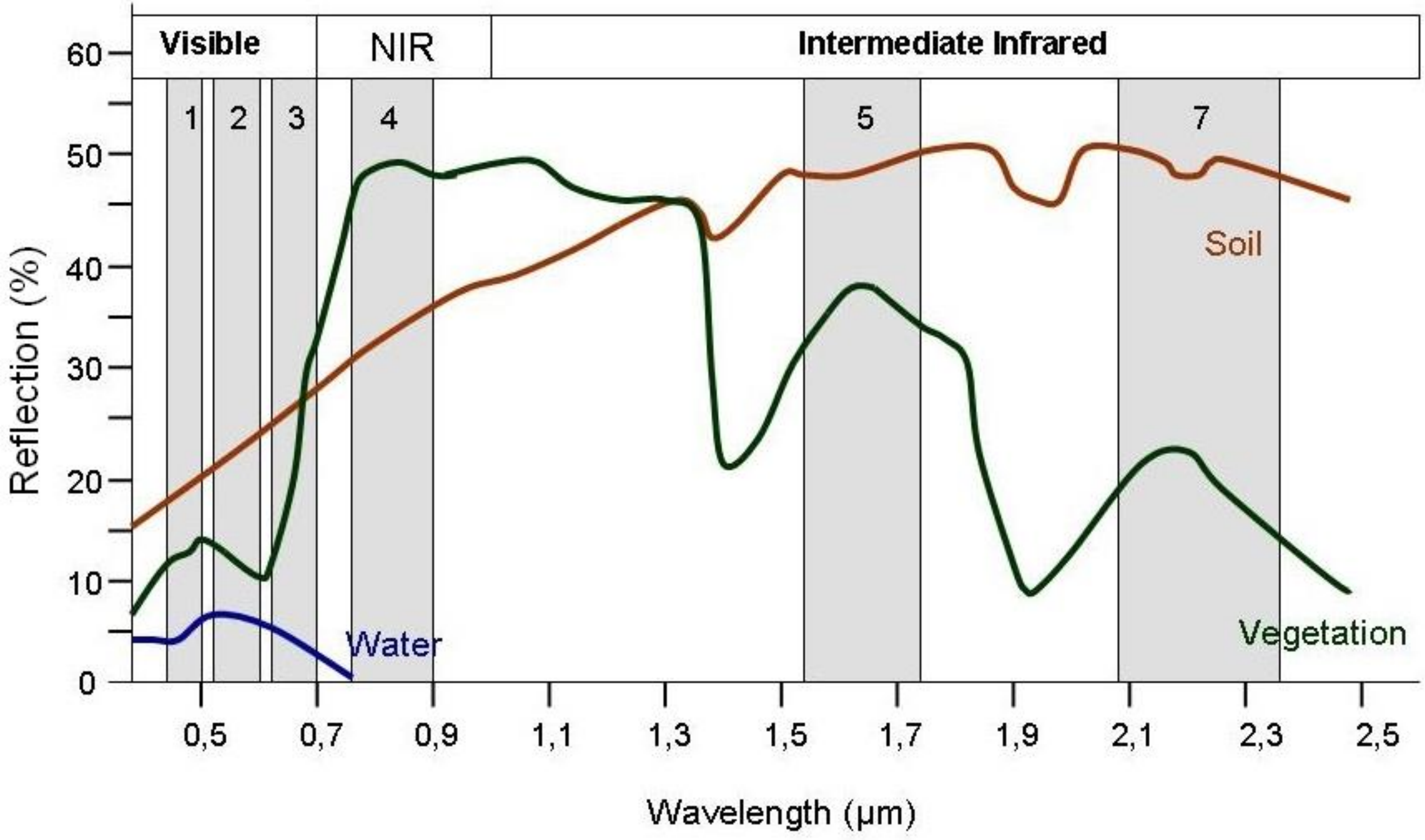
The plot between ρ(λ) and λ is called a spectral reflectance curve. This varies with the variation in the chemical composition and physical conditions of the feature, which results in a range of values.





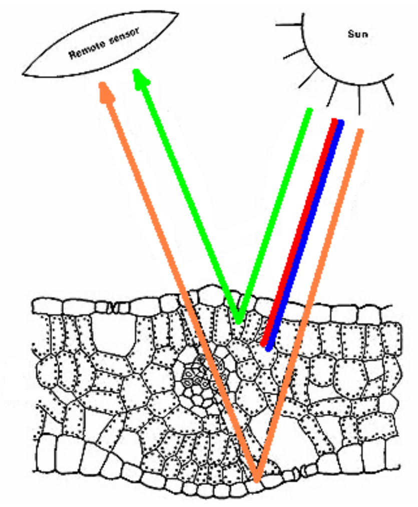
Landsat 4-5 Thematic Mapper (TM)	Bands	Wavelength (micrometers)	Resolution (meters)
	Band 1 - Blue	0.45-0.52	30
	Band 2 - Green	0.52-0.60	30
	Band 3 - Red	0.63-0.69	30
	Band 4 - Near Infrared (NIR)	0.76-0.90	30
	Band 5 - Shortwave Infrared (SWIR) 1	1.55-1.75	30
	Band 6 - Thermal	10.40-12.50	120* (30)
	Band 7 - Shortwave Infrared (SWIR) 2	2.08-2.35	30

Landsat 7 Enhanced Thematic Mapper Plus (ETM+)	Bands	Wavelength (micrometers)	Resolution (meters)
	Band 1 - Blue	0.45-0.52	30
	Band 2 - Green	0.52-0.60	30
	Band 3 - Red	0.63-0.69	30
	Band 4 - Near Infrared (NIR)	0.77-0.90	30
	Band 5 - Shortwave Infrared (SWIR) 1	1.55-1.75	30
	Band 6 - Thermal	10.40-12.50	60 * (30)
	Band 7 - Shortwave Infrared (SWIR) 2	2.09-2.35	30
	Band 8 - Panchromatic	.52-.90	15

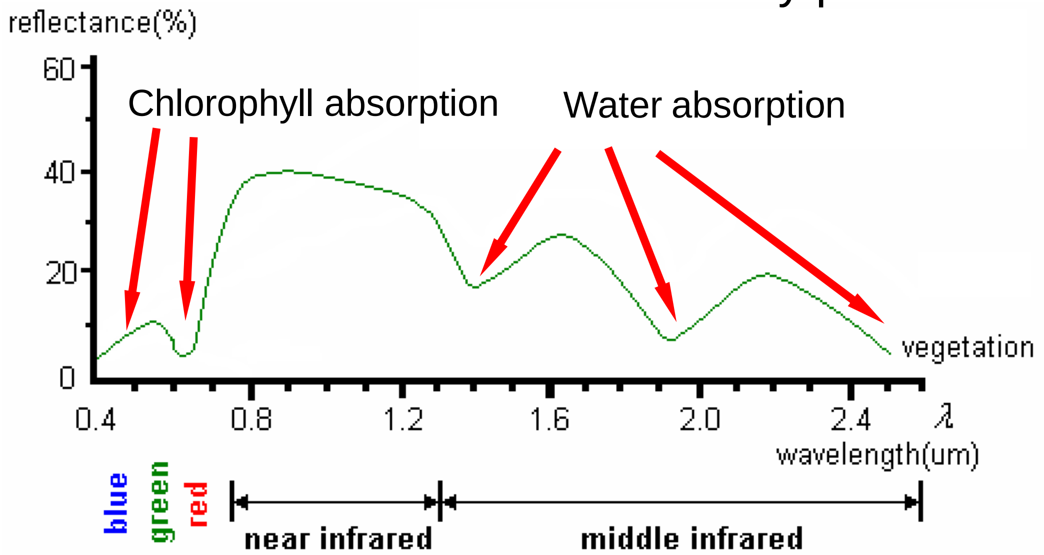


Spectral signatures of soil, vegetation and water, and spectral bands of LANDSAT 7.

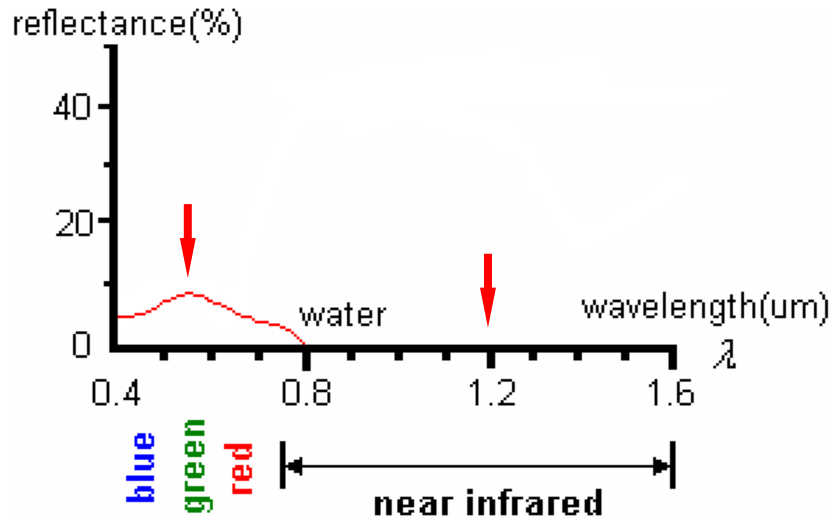
Vegetation



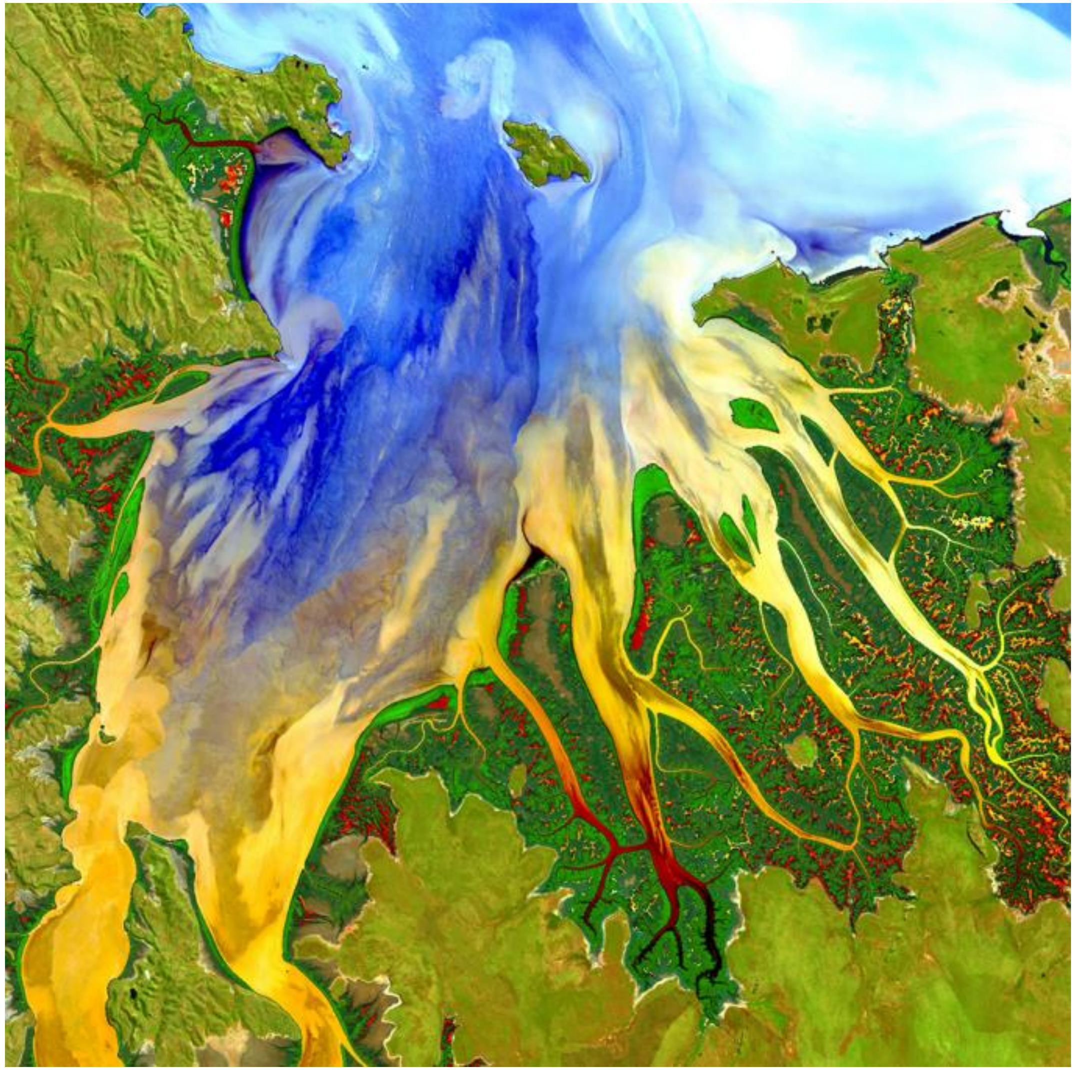
- Plant pigment in leaves called chlorophyll strongly absorbs radiation in the red and blue wavelengths but reflects green wavelength.
- Near infrared light is reflected very effectively as it is of no use to the plant
- The internal structure of healthy leaves acts as diffuse reflector of near infrared wavelengths. Measuring and monitoring the near infrared reflectance is one way that scientists determine how healthy particular vegetation may be



Water

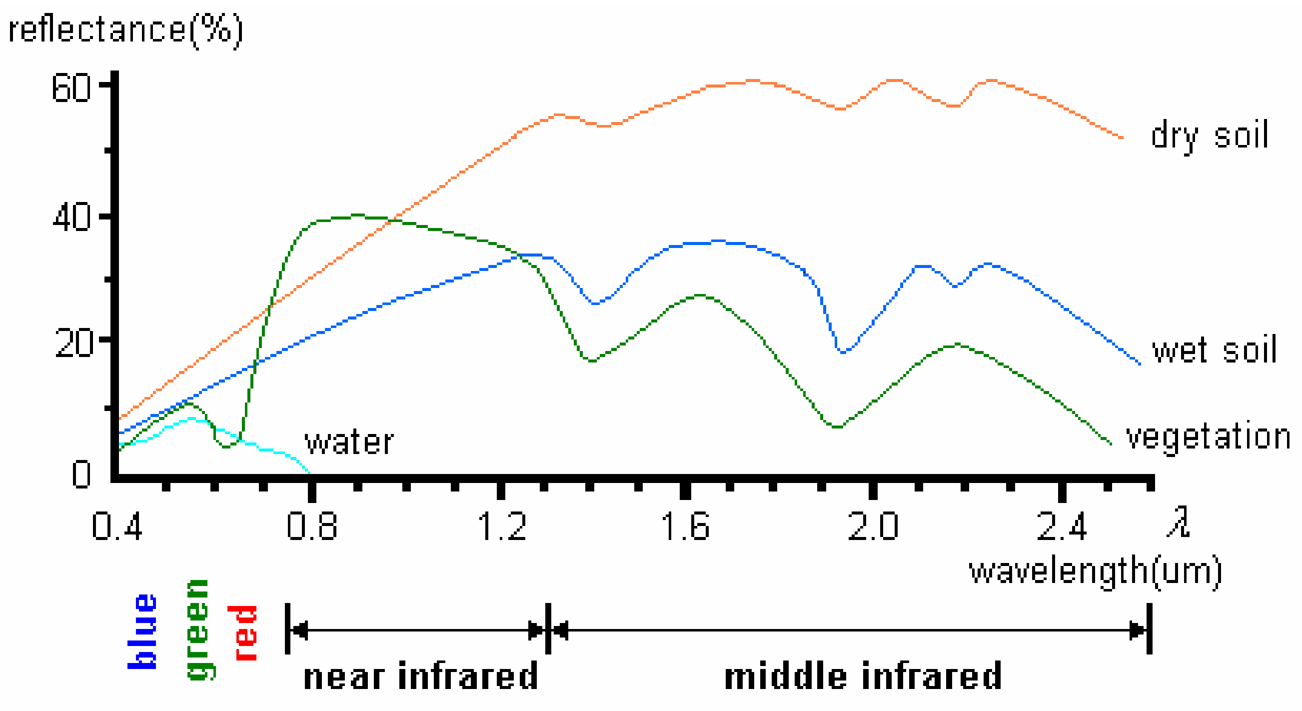


The **water curve** is characterized by a high absorption at near infrared wavelengths range and beyond. Because of this absorption property, water bodies as well as features containing water can easily be detected, located and delineated with remote sensing data. Turbid water has a higher reflectance in the visible region than clear water. This is also true for waters containing high chlorophyll concentrations. These reflectance patterns are used to **detect algae colonies** as well as contaminations such as **oil spills** or industrial waste water (more about different reflections in water can be found in the tutorial



Soil

The **spectral reflectance curve of** **bare soil** is considerably less variable.



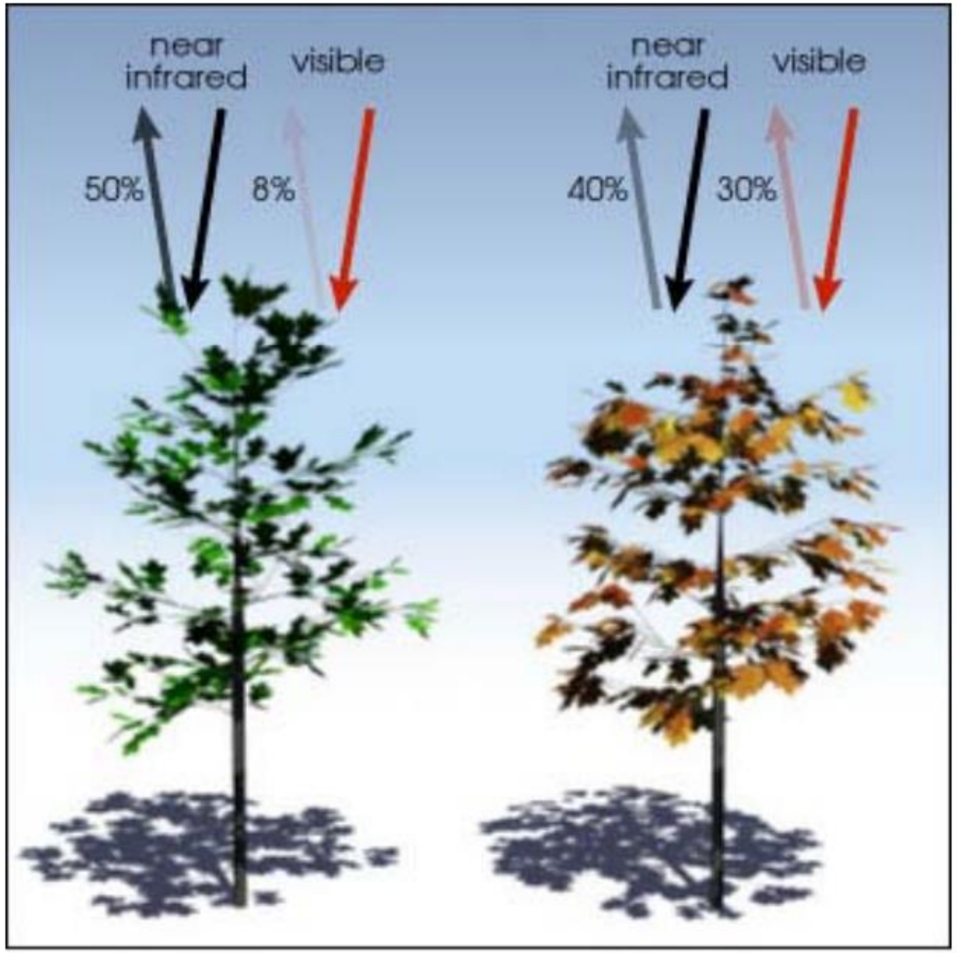
Factors affecting soil reflectance

- Moisture content
- Soil texture (proportion of sand, silt, and clay)
- Surface roughness (reduces reflectance)
- Iron oxide (reduces reflectance)
- Organic matter content (reduces reflectance)

Normalized Difference Vegetation Index NDVI

The generic normalized difference vegetation index (NDVI) has provided a method of estimating net primary production over varying biome types (e.g. Lenney et al., 1996), identifying ecoregions (Ramsey et al., 1995), monitoring phenological patterns of the earth's vegetative surface, and of assessing the length of the growing season and dry-down periods (Huete and Liu, 1994).

$$NDVI = \frac{NIR - red}{NIR + red}$$



$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$