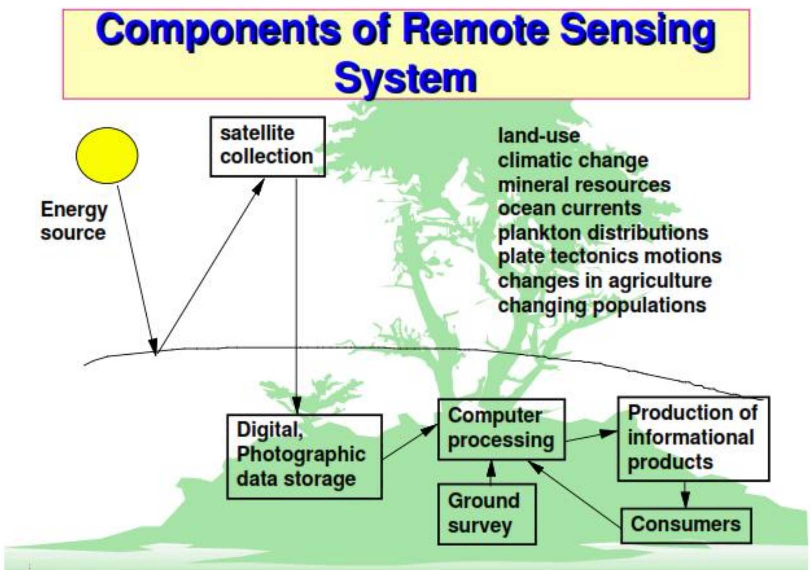
UNIT –I
EMR AND ITS INTERACTION WITH ATMOSPHERE & EARTH MATERIAL
Definition of remote sensing and its components – Electromagnetic spectrum – wavelength regions important to remote sensing – Wave theory, Particle theory, Stefan-Boltzman and Wein's Displacement Law – Atmospheric scattering, absorption – Atmospheric windows – spectral signature concepts – typical spectral reflective characteristics of water, vegetation and soil.

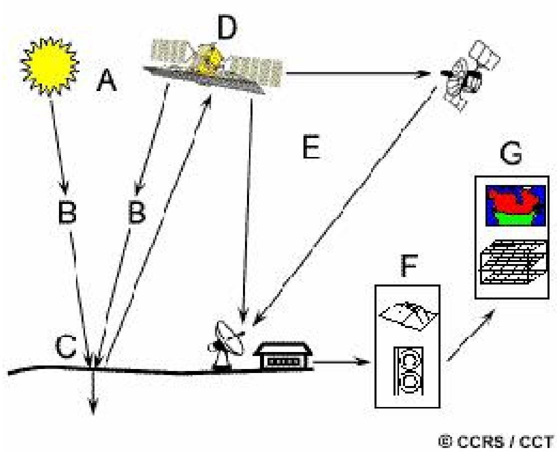
Remote Sensing

Definition:
Remote sensing is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information.

Components of Remote Sensing



Elements:
In much of remote sensing, **the process** involves an interaction between incident radiation and the targets of interest. This is exemplified by the use of imaging systems where the following seven elements are involved. Note, however that remote sensing also involves the sensing of emitted energy and the use of non-imaging sensors.

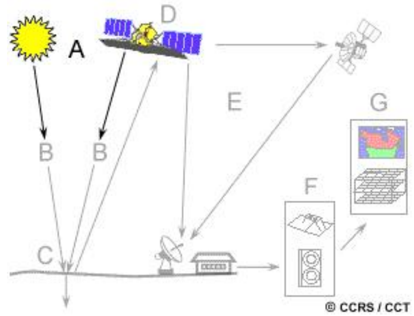


1. Energy Source or Illumination (A) - the first requirement for remote sensing is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.
2. Radiation and the Atmosphere (B) - as the energy travels from its source to the target, it will come in contact with and interact with the atmosphere it passes through. This interaction may take place a second time as the energy travels from the target to the sensor.
3. Interaction with the Target (C) - once the energy makes its way to the target through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation.
4. Recording of Energy by the Sensor (D) - after the energy has been scattered by, or emitted from the target, we require a sensor (remote **-** not in contact with the target) to collect and record the electromagnetic radiation.
5. Transmission, Reception, and Processing (E) - the energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (hardcopy and/or digital).
6. Interpretation and Analysis (F) - the processed image is interpreted, visually and/or digitally or electronically, to extract information about the target which was illuminated.
7. Application (G) - the final element of the remote sensing process is achieved when we apply the information we have been able to extract from the imagery about the target in order to better understand it, reveal some new information, or assist in solving a particular problem.

These seven elements comprise the remote sensing process from beginning to end.

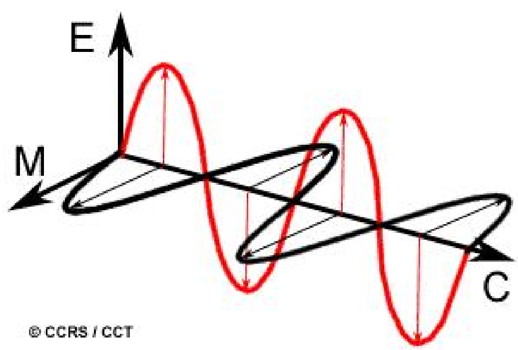
1.2 Electromagnetic Radiation

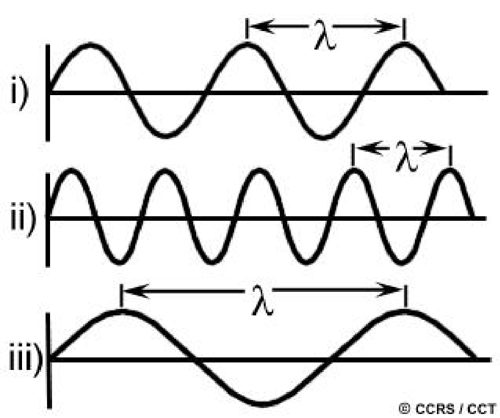
As was noted in the previous section, the first requirement for remote sensing is to have an energy source to illuminate the target (unless the sensed energy is being emitted by the target). This energy is in the form of electromagnetic radiation.



All electromagnetic radiation has fundamental properties and behaves in predictable ways according to the basics of wave theory. **Electromagnetic radiation** consists of an electrical field (E) which varies in magnitude in a direction perpendicular to the direction in which the radiation is traveling, and a magnetic field (M) oriented at right angles to the electrical field. Both these fields travel at the speed of light (c).

Two characteristics of electromagnetic radiation are particularly important for understanding remote sensing. These are the **wavelength and frequency.**





The wavelength is the length of one wave cycle, which can be measured as the distance between successive wave crests. Wavelength is usually represented by the Greek letter lambda (λ). Wavelength is measured in meters (m) or some factor of meters such as **nanometers** (nm, 10^{-9} meters), **micrometers** (μm, 10^{-6} meters) or centimeters (cm, 10 meters). Frequency refers to the number of cycles of a wave passing a fixed point per unit of time. Frequency is normally measured in **hertz** (Hz), equivalent to one cycle per second, and various multiples of hertz.

Wavelength and frequency are related by the following formula:

$$c = \lambda v$$

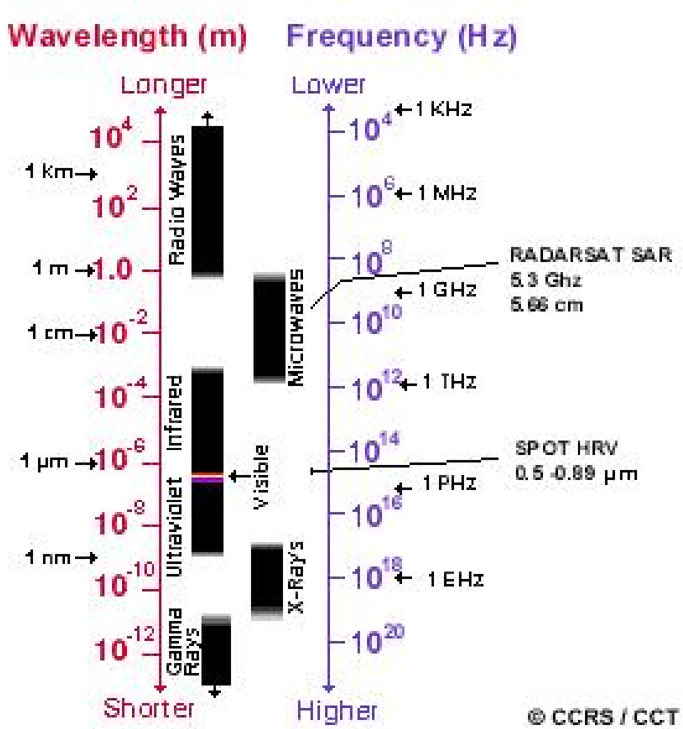
where:

λ = wavelength (m)
v = frequency (cycles per second, Hz)
c = speed of light (3×10^8 m/s)

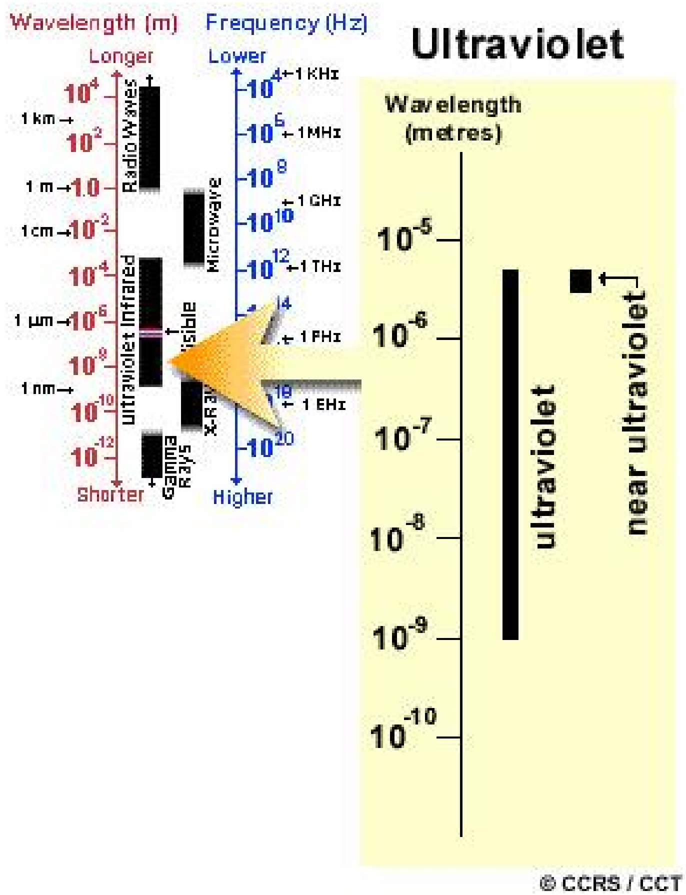
Therefore, the two are inversely related to each other. The shorter the wavelength, the higher the frequency. The longer the wavelength, the lower the frequency. Understanding the characteristics of electromagnetic radiation in terms of their wavelength and frequency is crucial to understanding the information to be extracted from remote sensing data. Next we will be examining the way in which we categorize electromagnetic radiation for just that purpose.

1.3 The Electromagnetic Spectrum

The **electromagnetic spectrum** ranges from the shorter wavelengths (including gamma and x-rays) to the longer wavelengths (including microwaves and broadcast radio waves). There are several regions of the electromagnetic spectrum which are useful for remote sensing.

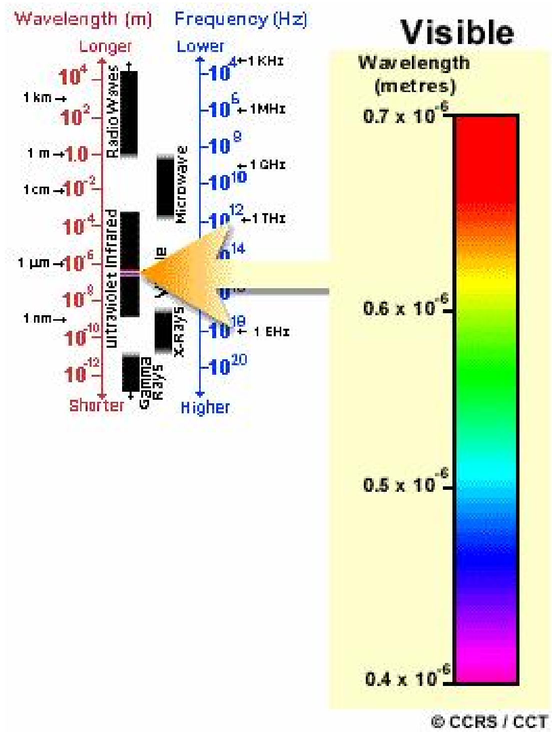


For most purposes, the **ultraviolet or UV** portion of the spectrum has the shortest wavelengths which are practical for remote sensing. This radiation is just beyond the violet portion of the visible wavelengths, hence its name. Some Earth surface materials, primarily rocks and minerals, fluoresce or emit visible light when illuminated by UV radiation.



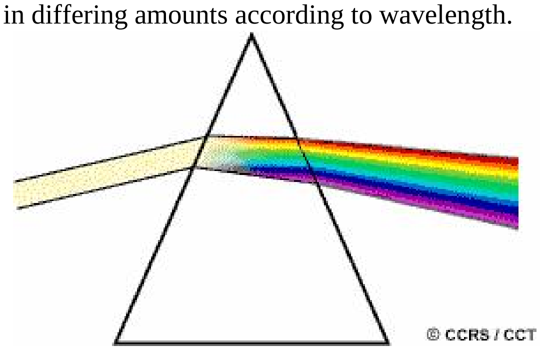
The light which our eyes - our "remote sensors" - can detect is part of the **visible spectrum**. It is important to recognize how small the visible portion is relative to the rest of the spectrum.

There is a lot of radiation around us which is "invisible" to our eyes, but can be detected by other remote sensing instruments and used to our advantage. The visible wavelengths cover a range from approximately 0.4 to 0.7 ∝m. The longest visible wavelength is red and the shortest is violet. Common wavelengths of what we perceive as particular colours from the visible portion of the spectrum are listed below. It is important to note that this is the only portion of the spectrum we can associate with the concept of **colours**.

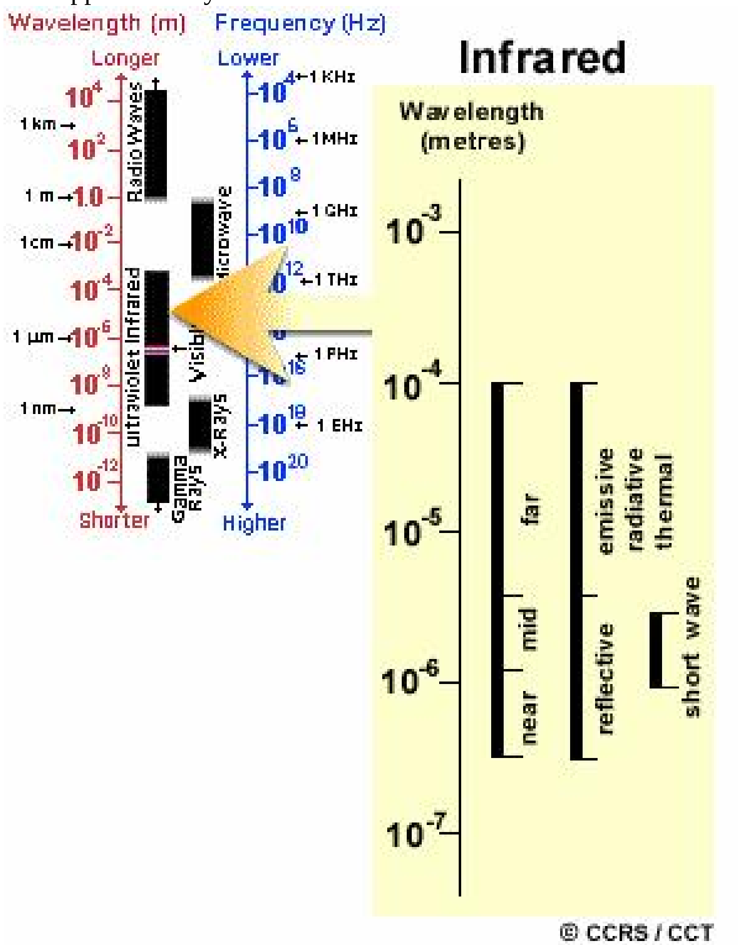


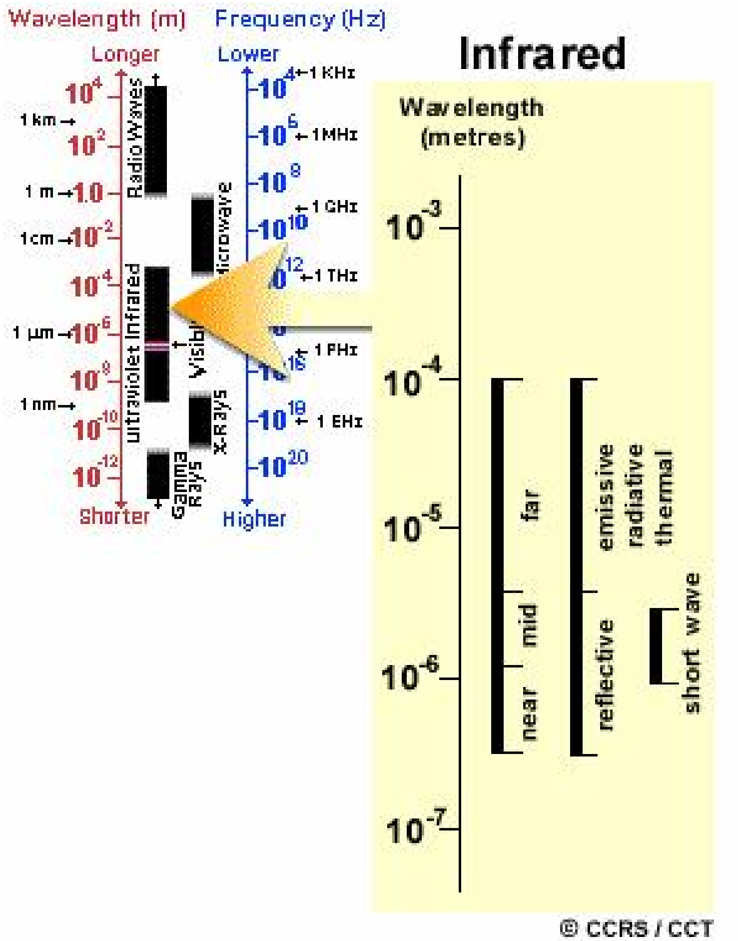
Violet: 0.4 - 0.446 ∝m
Blue: 0.446 - 0.500 ∝m
Green: 0.500 - 0.578 ∝m
Yellow: 0.578 - 0.592 ∝m
Orange: 0.592 - 0.620 ∝m
Red: 0.620 - 0.7 ∝m

Blue, **green**, and **red** are the **primary colours** or wavelengths of the visible spectrum. They are defined as such because no single primary colour can be created from the other two, but all other colours can be formed by combining blue, green, and red in various proportions.
Although we see sunlight as a uniform or homogeneous colour, it is actually composed of various wavelengths of radiation in primarily the ultraviolet, visible and infrared portions of the spectrum. The visible portion of this radiation can be shown in its component colours when sunlight is passed through a **prism**, which bends the light in differing amounts according to wavelength.

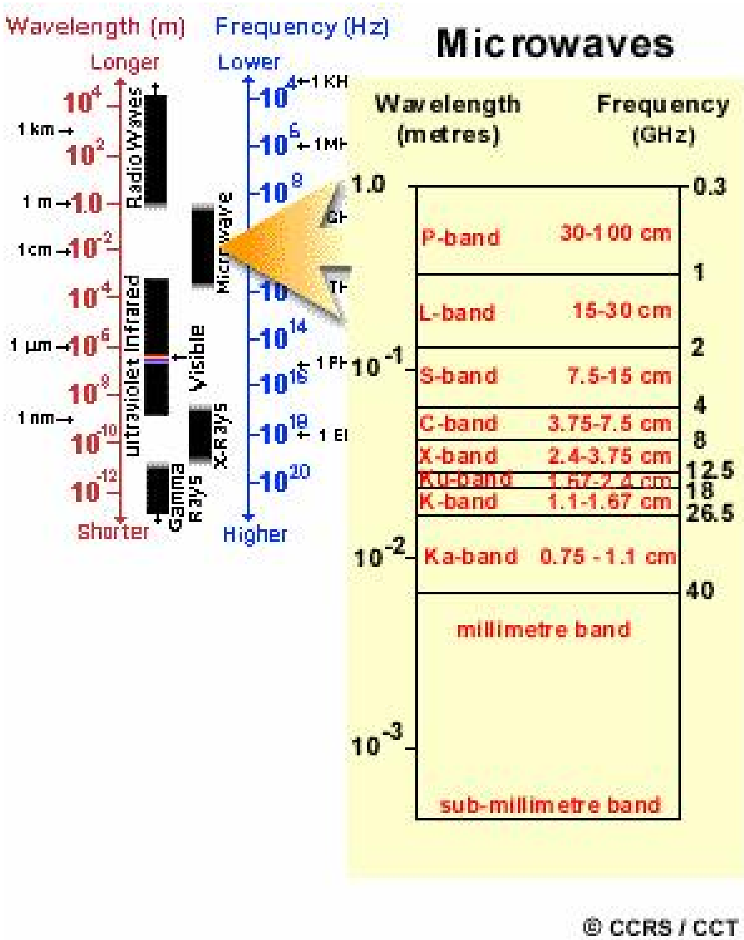


The next portion of the spectrum of interest is the infrared (IR) region which covers the wavelength range from approximately 0.7 ∝m to 100 ∝m - more than 100 times as wide as the visible portion! The infrared region can be divided into two categories based on their radiation properties - the **reflected 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 IR covers wavelengths from approximately 0.7 ∝m to 3.0∝m. The thermal IR region is quite different than the visible and reflected IR portions, as this energy is essentially the radiation that is emitted from the Earth's surface in the form of heat. The thermal IR covers wavelengths from approximately 3.0 ∝m to 100 ∝m.





The portion of the spectrum of more recent interest to remote sensing is the **microwave region** from about 1 mm to 1 m. This covers the longest wavelengths used for remote sensing. The shorter wavelengths have properties similar to the thermal infrared region while the longer wavelengths approach the wavelengths used for radio broadcasts. Because of the special nature of this region and its importance to remote sensing in Canada, an entire chapter



Planck Radiation Law

The primary law governing blackbody radiation is the *Planck Radiation Law*, which governs the intensity of radiation emitted by unit surface area into a fixed direction (solid angle) from the blackbody as a function of wavelength for a fixed temperature. The Planck Law can be expressed through the following equation.

$$E(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}$$

$$h = 6.625 \times 10^{-27} \text{ erg- sec} \quad \text{(Planck Constant)}$$

$$k = 1.38 \times 10^{-16} \text{ erg/ K} \quad \text{(Boltzmann Constant)}$$

$$c = 3 \times 10^{10} \text{ cm/sec} \quad \text{(Speed of Light)}$$

The behavior is illustrated in the figure shown above. The Planck Law gives a distribution that peaks at a certain wavelength, the peak shifts to shorter wavelengths for higher temperatures, and the area under the curve grows rapidly with increasing temperature.

The Wien and Stefan-Boltzmann Laws

The behavior of blackbody radiation is described by the Planck Law, but we can derive from the Planck Law two other radiation laws that are very useful. The Wien Displacement Law, and the Stefan-Boltzmann Law are illustrated in the following equations.

Steffan - Boltzmann Law: $$\boxed{E = \sigma T^4}$$

$$\sigma = 5.6705 \times 10^{-5} \text{ erg - cm}^{-2} \text{ - K}^{-4} \text{- sec}^{-1}$$

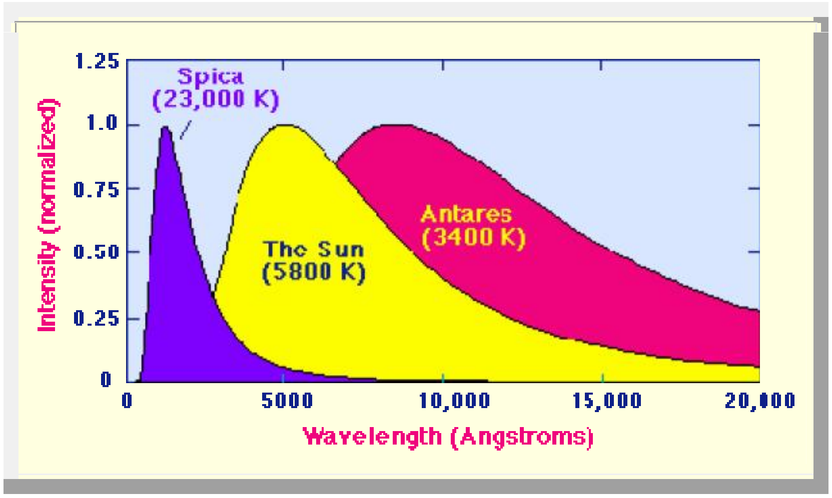
(Steffan - Boltzmann Constant)

Wien Displacement Law: $$\boxed{\lambda_{Max} = \frac{3 \times 10^7}{T}}$$

(λ in Angstroms T in Kelvin)

The Wien Law gives the wavelength of the peak of the radiation distribution, while the Stefan-Boltzmann Law gives the total energy being emitted at all wavelengths by the blackbody (which is the area under the Planck Law curve). Thus, the Wien Law explains the shift of the peak to shorter wavelengths as the temperature increases, while the Stefan-Boltzmann Law explains the growth in the height of the curve as the temperature increases. Notice that this growth is very abrupt, since it varies as the fourth power of the temperature.

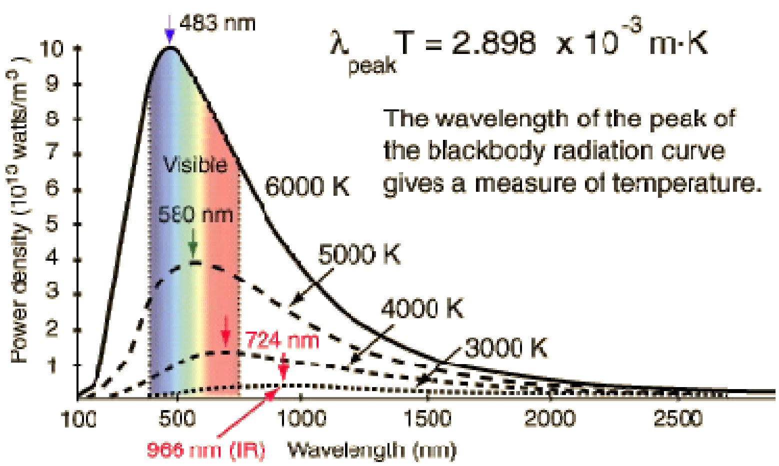
The following figure illustrates the Wien law in action for three different stars of quite different surface temperature. The strong shift of the spectrum to shorter wavelengths with increasing temperatures is apparent in this illustration.



For convenience in plotting these distributions have been normalized to unity at the respective peaks; by the Stefan-Boltzmann Law, the area under the peak for the hot star Spica is in reality 2094 times the area under the peak for the cool star Antares.

Wien's Displacement Law

When the temperature of a blackbody radiator increases, the overall radiated energy increases and the peak of the radiation curve moves to shorter wavelengths. When the maximum is evaluated from the Planck radiation formula, the product of the peak wavelength and the temperature is found to be a constant.



$$\lambda_{peak} T = 2.898 \times 10^{-3} \, m \cdot K$$ Calculation

This relationship is called Wien's displacement law and is useful for the determining the temperatures of hot radiant objects such as stars, and indeed for a determination of the temperature of any radiant object whose temperature is far above that of its surroundings.

It should be noted that the peak of the radiation curve in the Wien relationship is the peak only because the intensity is plotted as a function of wavelength. If frequency or some other variable is used on the horizontal axis, the peak will be at a different wavelength.

A. Stefan-Boltzmann Law

Blackbody radiation is emitted as a broad spectrum of wavelengths, as shown in figure 1. The shape of this curve is modeled by Planck's law of blackbody radiation[3], which states that for any given temperature T, the intensity I for frequency f is given by

$$I = \frac{2h}{c^3} \frac{f^3}{e^{hf/kT} - 1}. \qquad (1)$$

Here h, k, and c are respectively Planck's constant, Boltzmann's constant, and the speed of light.

The wavelength with the maximum luminosity in figure 1 is given by the Wien Displacement law[4]. Formally, this law states that for some temperature T (in Kelvin), the most intense wavelength λ_{max} will be

$$\lambda_{max} \approx \frac{3 \times 10^7}{T} \text{ Å}\text{K}^{-1}. \qquad (2)$$

From this, we can make the simplification

$$\lambda_{max} \propto \frac{1}{T}. \qquad (3)$$

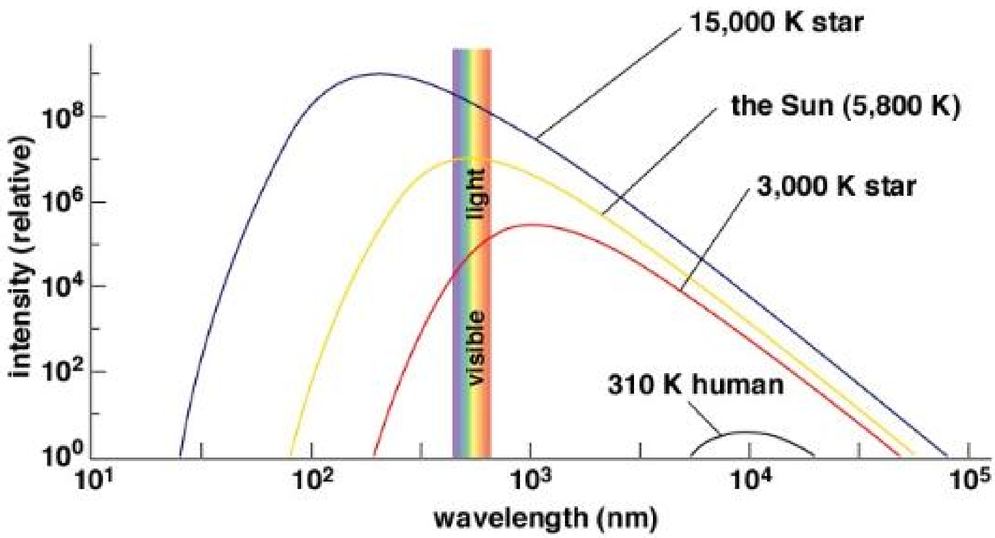


FIG. 2: The thermal radiation emitted by several reference objects[5]. The hotter objects have smaller peak wavelengths and sharper curves. Note that much of the energy is not emitted as visible light.

To illustrate this relationship between temperature and thermal radiation, the blackbody radiation spectrum for several reference objects is shown in figure 2. As expected, the hotter objects have smaller peak wavelengths.

To find the total amount of energy being radiated by an object, we merely need to find the area under the curve, which is equivalent to the integral of equation 1 over all wavelengths. This integration results in the Stefan-Boltzmann law, which states[6] that for an object of temperature T, the radiated power P will be

$$P_{rad} = \epsilon \sigma A_s T^4. \qquad (4)$$

ATMOSPHERIC Scattering and Absorption

- **Extinction of radiation passing through atmosphere**
  - **Consider beam of radiation passing through thin layer of atmosphere**
  - **Scattering and absorption reduce intensity of radiation**
  - **Rate depends linearly on:**
    - **Local intensity of radiation**
    - **Local concentration of molecules/particles**
    - **Scattering and absorbing efficiencies of molecules/particles**
  - **For each scattering and absorbing material:**
    - $dI_\lambda = -I_\lambda K_\lambda N \sigma ds$
    - **N is number of particles,** K_λ **is scattering or absorbing efficiency,** σ **is areal cross section of particles**
    - $K_\lambda N \sigma$ **is scattering or absorption cross section**
  - **For atmospheric gases, can be easier to work with scattering or absorption using continuum approach:**

- $dI_\lambda = -I_\lambda \rho r k_\lambda ds$
- ρ **is density, r is mass of scattering gas per mass of air, and** k_λ **is mass scattering efficiency**

o **Absorption and scattering amounts combined determine extinction:**

- $K_\lambda(\text{extinction}) = K_\lambda(\text{scattering}) + K_\lambda(\text{absorption})$

- **Scattering**
  - o **Change in direction of electromagnetic waves**
  - o **Scattering efficiency and behavior depends on size of scatterers relative to wavelengths of radiation**
    - **Define size parameter as ratio of characteristic particle diameter to wavelength**
      - $x = \dfrac{2\pi r}{\lambda}$
      - **Treats particles as identical spheres**
    - **Define complex index of refraction as:**
      - $\mathbf{m} = m_r + i m_i$
      - **Real part is change in speed of light passing through particle**
      - **Imaginary part is absorption index**
    - **Size parameter ranges widely for different common atmospheric constituents**
      - **Much less than 1 for gas molecules**
      - **About 1 for haze and smoke particles**
      - **Much larger than one for raindrops and ice crystals**
  - o **Rayleigh scattering by very small particles (e.g. gas molecules): x << 1**
    - **Scattering efficiency relatively low**
    - **Strong wavelength dependence:** $K_\lambda \propto \lambda^{-4}$
    - **Nearly equal scattering in forward and backward direction**
    - **Exercise 4.9**
      - **Estimate relative efficiencies of scattering red and blue light by air molecules**
      - $\lambda(red) \simeq 0.64\mu m,\ \lambda(blue) \simeq 0.47\mu m$
      - $\dfrac{K(blue)}{k(red)} = \left(\dfrac{0.64}{0.47}\right)^4 = 3.45$
      - **So violet and blue light scattered more effectively than red**
  - o **Mie scattering by particles similar in size to wavelengths of radiation: 0.1 <= x <= 50**
    - **Efficiency relatively high and independent of wavelength**
    - **Scattering in forward direction becomes more pronounced with increasing size**
  - o **Large particles (e.g. raindrops, ice crystals) scatter according to laws of geometric optics**

- Rainbows produced by scattering by raindrops
- Involve two refractions and one reflection
- Bright halos produced by forward scattering from ice crystals
- Hexagonal structure of crystals concentrates light at 22° and 46°

- **Absorption**
  - **Radiant energy comes in discrete packets, photons**
    - **Energy in a photon inversely proportional to wavelength**
      - $$E = \frac{hc^*}{\lambda} = h\bar{\nu}$$
      - **h = 6.626 X 10^{-34}J/s (Planck's constant)**
  - **Absorption continua**
    - **High energy, short wavelength radiation**
    - **Wavelengths < 0.1 micron strip electrons from atoms in - photoionization - in the ionosphere**
    - **Wavelengths < 0.24 microns breaks oxygen molecules apart - photodissociation**
    - **Wavelengths up to 0.31 microns dissociate ozone molecules**
    - **All wavelengths in range absorbed, with excess energy heating absorbers**
    - Processes remove nearly all wavelengths < 0.31 microns in upper atmosphere
  - **Absorption lines**
    - **Absorption of lower energy, longer wavelength radiation changes in energy in molecules**
    - **Total molecular energy is:**
      - $$E = E_o + E_v + E_r + E_t$$
      - **Energy = electron orbit + vibrational + rotational + translational**
    - **All but translational energy are quantized**
    - **Only photons with proper amount of energy to move molecule from one state to another absorbed or emitted**
    - **Creates absorption spectra of discrete lines**
    - **Orbital changes require highest energy, shortest wavelengths - ultraviolet and visible**
    - **Vibrational changes require medium energy - infrared**
    - **Rotational changes lowest energy, longest wavelengths - microwave**
    - **Primary atmospheric gases, N_2 and O_2, have no vibrational absorption bands**
    - **Greenhouse gases have many vibrational modes, so absorb strongly in infrared**
  - **Line broadening**
    - **Motion and collisions of molecules spread out theoretical absorption lines**
    - **Molecular motions cause Doppler shifting of absorption wavelengths**
    - **Pressure broadening caused by molecular collisions**
    - Pressure broadening curve has heavier tails

Table 1.12.1 Atmospheric effects

Effects	Mechanism	Wavelength	Related physical variables
Multiplitive (Extinction)	Absorption	All region	Absorption coefficient, Absorber amount, Temperature Pressure
	Scattering	Visible & near IR	Scattering coefficient, Scatterer amount, Phase function
Additive (Emission)	Thermal radiation	Thermal IR	Absorption coefficient, Absorber amount, Temperature Pressure
	Scattering	Visible & near IR	Scattering coefficient, Scatterer amount, Phase function

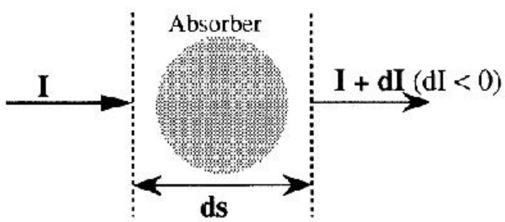


Figure 1.12.1 Absorption (extinction)

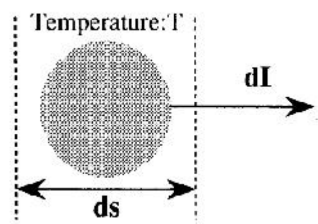


Figure 1.12.3 Thermal radiation (emission)

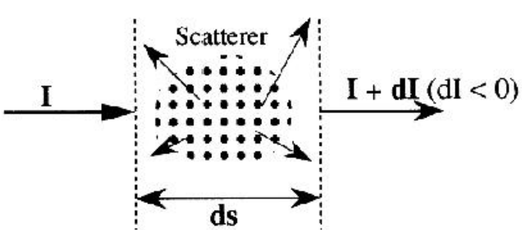


Figure 1.12.2 Scattering (extinction)

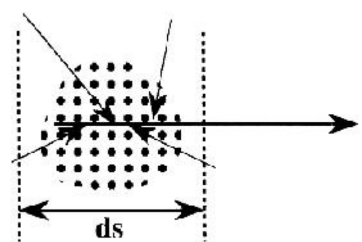


Figure 1.12.4 Scattering (emission)

Definition of extinction coefficient K

$$\boxed{dI = \rho \cdot K \cdot I \cdot ds}$$

I : Incident radiance
dI : Increment of radiance
ρ : Absorber / Scatterer density
ds : Path length

Definition of emission coefficient j

$$\boxed{dI = \rho \cdot j \cdot ds}$$

(1) Thermal radiation

$$\boxed{j = \rho \cdot B(T)}$$

ρ : Absorber density
B : Planck function
T : Temperature [K]

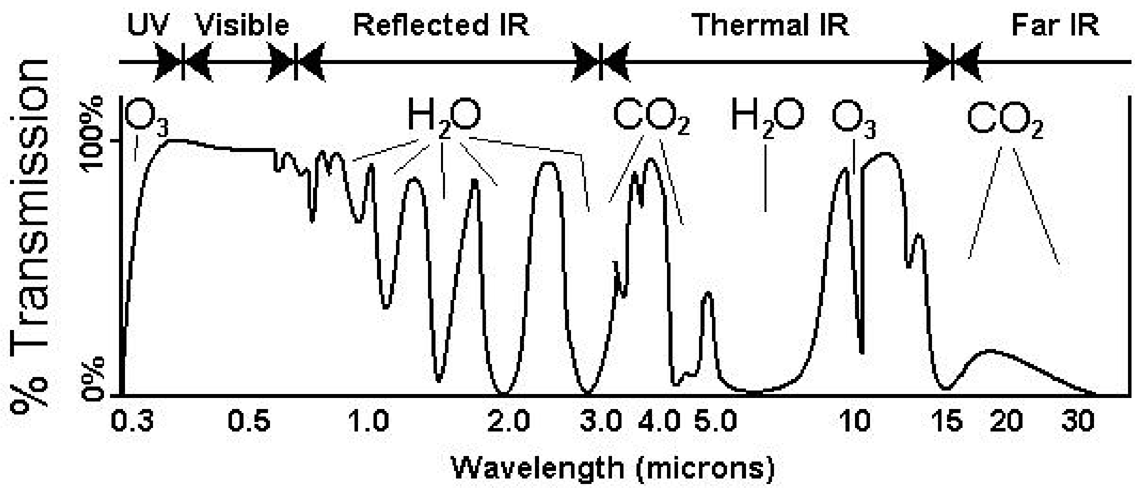
(2) Scattering

$$\boxed{j = \omega_0 \frac{K}{4\pi} \rho \int_{\Omega} P(\Omega, \Omega)\, I\,(\Omega')\, d\Omega}$$

ω_0 : Albedo for single scattering
ρ : Scatterer density
P : Phase function
Ω : Solid angle of incidence
Ω' : Solid angle of scattering
K : Extinction coefficient

Atmospheric windows

Some wavelengths cannot be used in remote sensing because our atmosphere absorbs essentially all the photons at these wavelengths that are produced by the sun. In particular, the molecules of water, carbon dioxide, oxygen, and ozone in our atmosphere block solar radiation. The wavelength ranges in which the atmosphere is transparent are called atmospheric windows. Remote sensing projects must be conducted in wavelengths that occur within atmospheric windows. Outside of these windows, there is simply no radiation from the sun to detect--the atmosphere has blocked it.



The figure above shows the percentage of light transmitted at various wavelengths from the near ultraviolet to the far infrared, and the sources of atmospheric opacity are also given. You can see that there is plenty of atmospheric transmission of radiation at 0.5 microns, 2.5 microns, and 3.5 microns, but in contrast there is a great deal of atmospheric absorption at 2.0, 3.0, and about 7.0 microns. Both passive and active remote sensing technologies do best if they operate within the atmospheric windows.

Spectral Signatures

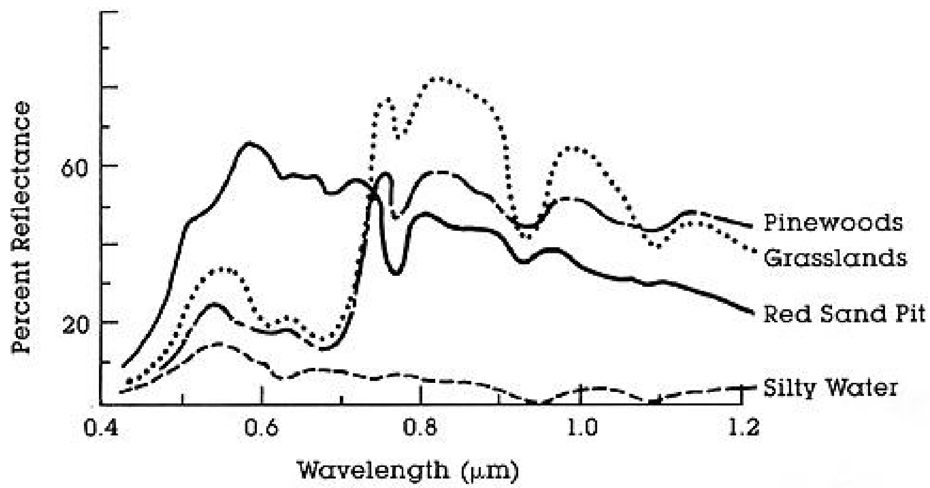
Spectral signatures are the specific combination of emitted, reflected or absorbed electromagnetic radiation (EM) at varying wavelengths which can uniquely identify an object. The spectral signature of stars indicates the composition of the stellar atmosphere. The spectral signature of an object is a function of the incidental EM wavelength and material interaction with that section of the electromagnetic spectrum.

The measurements can be made with various instruments, including a task specific spectrometer, although the most common method is separation of the red, green, blue and near infrared portion of the EM spectrum as acquired by digital cameras. Calibrating spectral signatures under specific illumination are collected in order to apply an empirical correction to airborne or satellite imagery digital images.

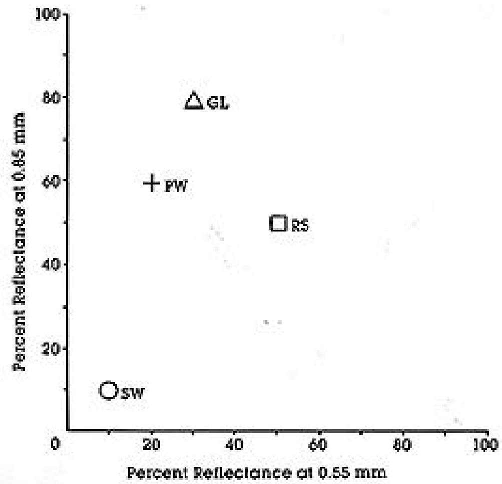
The user of one kind of spectroscope looks through it at a tube of ionized gas. The user sees specific lines of colour falling on a graduated scale. Each substance will have its own unique pattern of spectral lines.

Most remote sensing applications process digital images to extract spectral signatures at each pixel and use them to divide the image in groups of similar pixels (segmentation) using different approaches. As a last step, they assign a class to each group (classification) by comparing with known spectral signatures. Depending on pixel resolution, a pixel can represent many spectral signature "mixed" together - that is why much remote sensing analysis is done to "unmix mixtures". Ultimately correct matching of spectral signature recorded by image pixel with spectral signature of existing elements leads to accurate classification in remote sensing.

For any given material, the amount of solar radiation that reflects, absorbs, or transmits varies with wavelength. This important property of matter makes it possible to identify different substances or classes and separate them by their spectral signatures (spectral curves), as shown in the figure below. *



For example, at some wavelengths, sand reflects more energy than green vegetation but at other wavelengths it absorbs more (reflects less) than does the vegetation. In principle, we can recognize various kinds of surface materials and distinguish them from each other by these differences in reflectance. Of course, there must be some suitable method for measuring these differences as a function of wavelength and intensity (as a fraction of the amount of irradiating radiation). Using reflectance differences, we can distinguish the four common surface materials (GL = grasslands; PW = pinewoods; RS = red sand; SW = silty water), shown in the next figure. Please note the positions of points for each plot as a reflectance percentage for just two wavelengths (refer to figure below).



When we use more than two wavelengths, the plots in multi-dimensional space tend to show more separation among the materials. This improved ability to distinguish materials due to extra wavelengths is the basis for multispectral remote sensing (discussed on the following page).

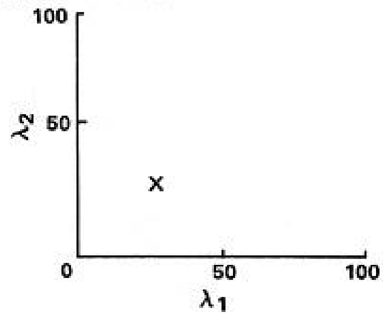
I-11: Referring to the above spectral plots, which region of the spectrum (stated in wavelength interval) shows the greatest reflectance for a) grasslands; b) pinewoods; c) red sand; d) silty water. At 0.6 micrometers, are these four classes distinguishable? ANSWER

I-12: Which material in these plots is brightest at 0.6 micrometers; which at 1.2 micrometers? ANSWER

I-13 Using these curves, estimate the approximate values of % Reflectance for rock (sand), water, and vegetation (choose grasslands) at two wavelengths: 0.5 and 1.1 micrometers, putting their values in the table provided below. Then plot them as instructed on the lower diagram. Which class is the point at X in this diagram most likely to belong? (Note: you may find it easier to make a copy of the diagram on tracing paper.) ANSWER

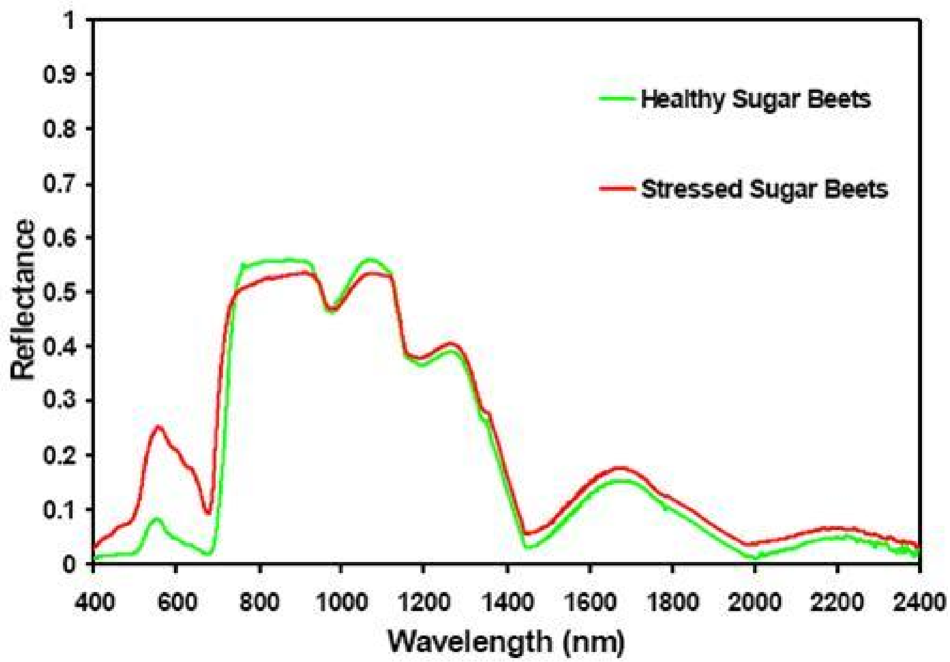
	Reflectance (%) (Class)		
	○ Water	▲ Rock	+ Vegetation
$\lambda_1 = 0.5\ \mu m$			
$\lambda_2 = 1.1\ \mu m$			

Plot these values on the diagram below, in which the 0.5 μm values are plotted on the X-axis and 1.1 values on the Y-axis.



Spectral signature in remote sensing

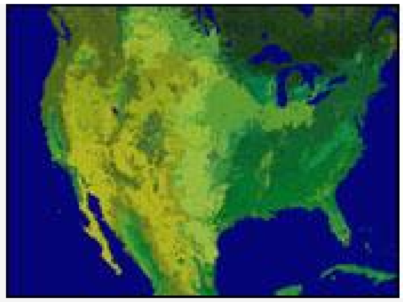
Features on the Earth reflect, absorb, transmit, and emit electromagnetic energy from the sun. Special digital sensors have been developed to measure all types of electromagnetic energy as it interacts with objects in all of the ways listed above. The ability of sensors to measure these interactions allows us to use remote sensing to measure features and changes on the Earth and in our atmosphere. A measurement of energy commonly used in remote sensing of the Earth is reflected energy (e.g., visible light, near-infrared, etc.) coming from land and water surfaces. The amount of energy reflected from these surfaces is usually expressed as a percentage of the amount of energy striking the objects. Reflectance is 100% if all of the light striking and object bounces off and is detected by the sensor. If none of the light returns from the surface, reflectance is said to be 0%. In most cases, the reflectance value of each object for each area of the electromagnetic spectrum is somewhere between these two extremes. Across any range of wavelengths, the percent reflectance values for landscape features such as water, sand, roads, forests, etc. can be plotted and compared. Such plots are called "spectral response curves" or "spectral signatures." Differences among spectral signatures are used to help classify remotely sensed images into classes of landscape features since the spectral signatures of like features have similar shapes. The figure below shows differences in the spectral response curves for healthy versus stressed sugar beet



plants. The more detailed the spectral information recorded by a sensor, the more information that can be extracted from the spectral signatures. Hyperspectral sensors have much more detailed signatures than multispectral sensors and thus provide the ability to detect more subtle differences in aquatic and terrestrial features.

Spectral Signatures

A primary use of remote sensing data is in classifying the myriad features in a scene (usually pres image) into meaningful categories or classes. The image then becomes a thematic map (th selectable e.g., land use, geology, vegetation types, rainfall). A farmer may use thematic maps to health of his crops without going out to the field. A geologist may use the images to study t minerals or rock structure found in a certain area. A biologist may want to study the variety of certain location.



For example, at certain wavelengths, sand reflects more energy than green vegetation while at wavelengths it absorbs more (reflects less) energy. Therefore, in principle, various kinds of su materials can be distinguished from each other by these differences in reflectance. Of course, must be some suitable method for measuring these differences as a function of wavelength and inte (as a fraction of the amount of radiation reaching the surface). Using reflectance differences, the most common surface materials (GL = grasslands; PW = pinewoods; RS = red sand; SW = silty w can be easily distinguished, as shown in the next figure.

When more than two wavelengths are used, the resulting images tend to show more separation objects. Imagine looking at different objects through red lenses, or only blue or green lenses. I manner, certain satellite sensors can record reflected energy in the red, green, blue, or infrared b spectrum, a process called multispectral remote sensing. The improved ability of multispect provides a basic remote sensing data resource for quantitative thematic information, such as the t cover. Resource managers use information from multispectral data to monitor fragile lands and ot resources, including vegetated areas, wetlands, and forests. These data provide unique id characteristics leading to a quantitative assessment of the Earth's features.

Electromagnetic Spectrum

- Energy transfer from one body to another in the form of electromagnetic waves
- A fundamental characteristic of radiation is the wavelength ( ) of propagation

1.9 Spectral Reflectance of Land Covers

Spectral reflectance is assumed to be different with respect to the type of land cover, as explained in 1.3 and 1.8. This is the principle that in many cases allows the identification of land covers with remote sensing by observing the spectral reflectance or spectral radiance from a distance far removed from the surface.

Figure 1.9.1 shows three curves of spectral reflectance for typical land covers; vegetation, soil and water. As seen in the figure, vegetation has a very high reflectance in the near infrared region, though there are three low minima due to absorption.

Soil has rather higher values for almost all spectral regions. Water has almost no reflectance in the infrared region.

Figure 1.9.2 shows two detailed curves of leaf reflectance and water absorption. Chlorophyll, contained in a leaf, has strong absorption at 0.45 µm and 0.67 µm, and high reflectance at near infrared (0.7-0.9 µm). This results in a small peak at 0.5-0.6 (green color band), which makes vegetation green to the human observer.

Near infrared is very useful for vegetation surveys and mapping because such a steep gradient at 0.7-0.9 µm is produced only by vegetation.

Because of the water content in a leaf, there are two absorption bands at about 1.5 µm and 1.9 µm. This is also used for surveying vegetation vigor.

Figure 1.9.3 shows a comparison of spectral reflectance among different species of vegetation.

Figure 1.9.4 shows various patterns of spectral reflectance with respect to different rock types in the short wave infrared (1.3-3.0 µm). In order to classify such rock types with different narrow bands of absorption, a multi-band sensor with a narrow wavelength interval is to be developed. Imaging spectrometers (see 2.12) have been developed for rock type classification and ocean color mapping.

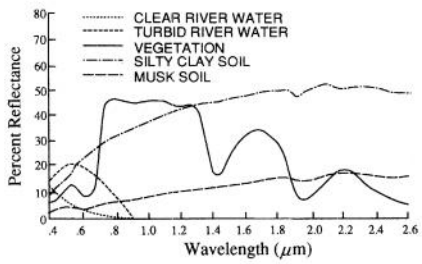


Figure 1.9.1 Spectral reflectance of vegetation, soil and water

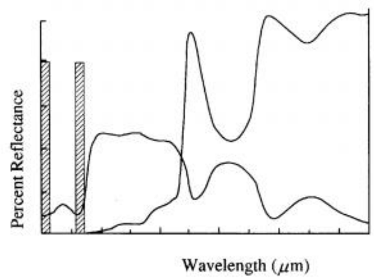


Figure 1.9.2 Spectral reflectance of a green leaf

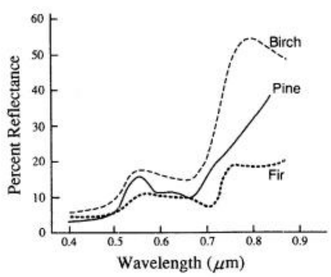


Figure 1.9.3 Spectral reflectance of different kind of plants

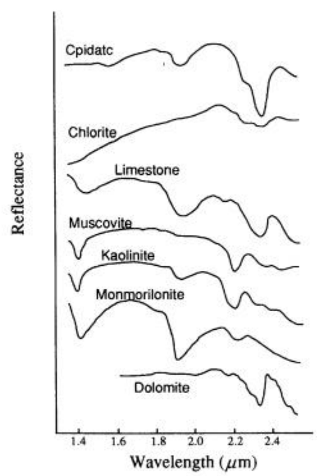


Figure 1.9.3 Spectral reflectance of rocks and minerals

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1.10 Spectral Characteristics of Solar Radiation

The sun is the energy source used to detect reflective energy of ground surfaces in the visible and near infrared regions.

Sunlight will be absorbed and scattered by ozone, dust, aerosols, etc., during the transmission from outer space to the earths surface (see 1.11 and 1.12). Therefore, one has to study the basic characteristics of solar radiation.

The sun is considered as a black body with a temperature of 5,900°K. If the annual average of solar spectral irradiance is given by $Fe0(\lambda)$, then the solar spectral irradiance $Fe(\lambda)$ in outer space at Julian day D, is given by the following formula.

$$Fe(\lambda) = Fe0(\lambda)\{1 + \cos \varepsilon\,(2\pi\,(D-3)/365)\}^2$$

where ε : 0.167 (eccentricity of the Earth orbit) λ : wavelength
D-3: shift due to January 3 as apogee and July 2 as perigee

The **sun constant** that is obtained by integrating the spectral irradiance for all wavelength regions is normally taken as $1.37\mathrm{Wm}^{-2}$. Figure 1.10.1 shows four observation records of solar spectral irradiance. The values of the curves correspond to the value at the surface perpendicular to the normal direction of the sun light. To convert to the spectral irradiance per m^2 on the Earth surface with a latitude of ϕ, multiply the following coefficient by the observed values in Figure 1.10.1.

$$\alpha = (L_0 / L)^2 \cos z \qquad \cos z = \sin\varphi\ \sin\delta + \cos\varphi\ \cos\delta\ \cos h$$

where z : solar zenith angle δ : declination h : hour angle,
L : real distance between the sun and the earth
L_0: average distance between the sun and the earth

The incident solar radiation at the earth's surface is very different to that at the top of the atmosphere due to atmospheric effects, as shown in 1.10.2, which compares the solar spectral irradiance at the earth's surface to black body irradiance from a surface of temperature 5900°K.

The solar spectral irradiance at the earth's surface is influenced by the atmospheric conditions and the zenith angle of the sun. Figure 1.10.3 shows several different curves of solar spectral irradiance on the surface with respect to different angles, with the curve, m = 0, showing the solar spectral irradiance in outer space.(ie. above the atmosphere)

Beside the direct sunlight falling on a surface, there is another light source called sky radiation, diffuse radiation or skylight, which is produced by the scattering of the sunlight by atmospheric molecules and aerosols.

The skylight is about 10 percent of the direct sunlight when the sky is clear and the sun's elevation angle is about 50 degree. The skylight has a peak in its spectral characteristic curve at a wavelength of 0.45 μm.

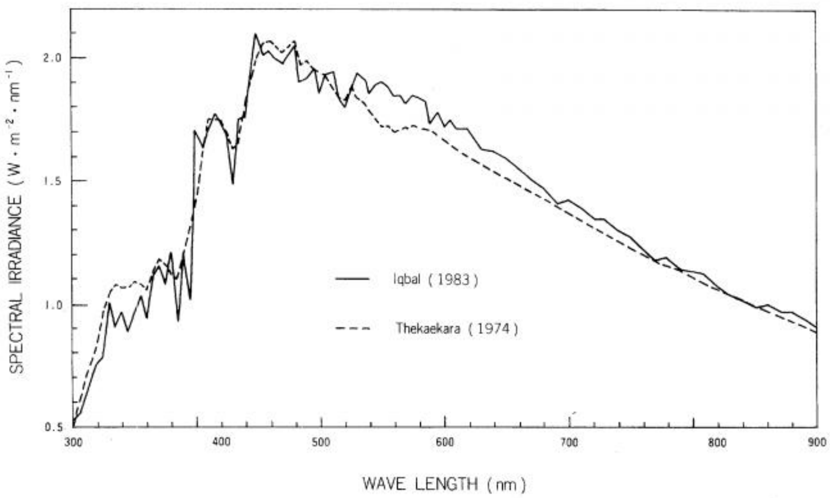

Figure 1.10.1 Solar irradiance at the top of atmosphere (annual mean)

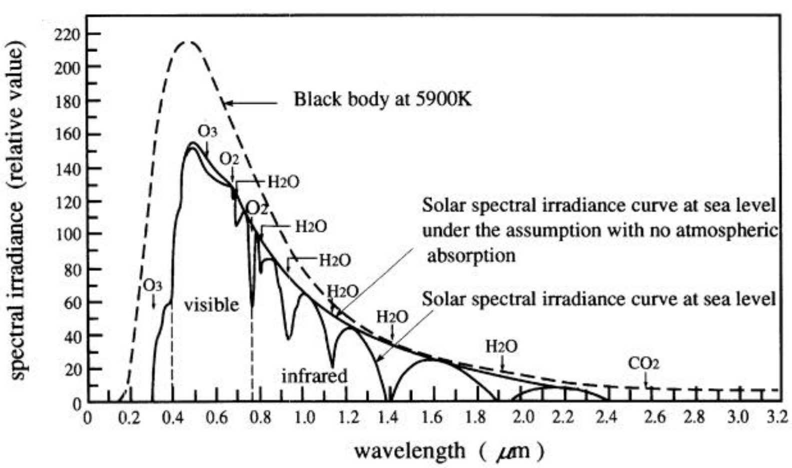

Figure 1.10.2 Comparison of spectral irradiance of solar light at sea level with black body radiation