CHAPTER 3: REMOTE SENSING

3.1 INTRODUCTION

Remote sensing is defined as the technique of deriving information about the earth using information acquired from an overhead perspective, (without actually coming in contact with it) by using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the earth's surface . Electromagnetic radiation (EMR) is generated by several mechanisms, including changes in the energy levels of electrons, acceleration of electrical charges, decay of radioactive substances and the thermal motions of atoms and molecules. Nuclear reactions within the sun are our major source of electromagnetic radiation.

Electromagnetic radiation consists of an electrical field that varies in magnitude in a direction perpendicular to the direction of propagation. In addition, a magnetic field oriented at right angles to the electric field is propagated in phase with the electric field. Electromagnetic energy displays three properties: *wavelength, frequency* and *amplitude* Wavelength is the distance from one wave crest to another and is measured in units of length like A^{o} (Angstrom units), μm (micrometers) or m (meters), frequency is the number of crests passing a fixed point in a given period and is usually measured in hertz and amplitude which is equivalent to the height of each peak and often expressed in terms of energy level per wavelength interval. The EMR ranges from very high energy radiation such as gamma rays and X rays to radio waves, through ultraviolet, visible light, infrared radiation and microwaves (Fig. 3.1). Longer wavelength radiation such as microwave radiation is often described in terms of its frequency whereas shorter wavelength radiation is described in terms of its wavelength.
Instruments which are able to measure EMR are known as sensors. There are various types of sensors, which measure incoming electromagnetic radiation in different parts of the electromagnetic spectrum. Based on their nature, sensors can be grouped under two categories active and passive sensors. *Active sensors* generate their own radiation (*e.g.* from radar and *laser)* and measure what is reflected back to the sensor whereas the *passive sensors* use sun's radiation. Acquisition of data by passive sensors is possible only in daytime

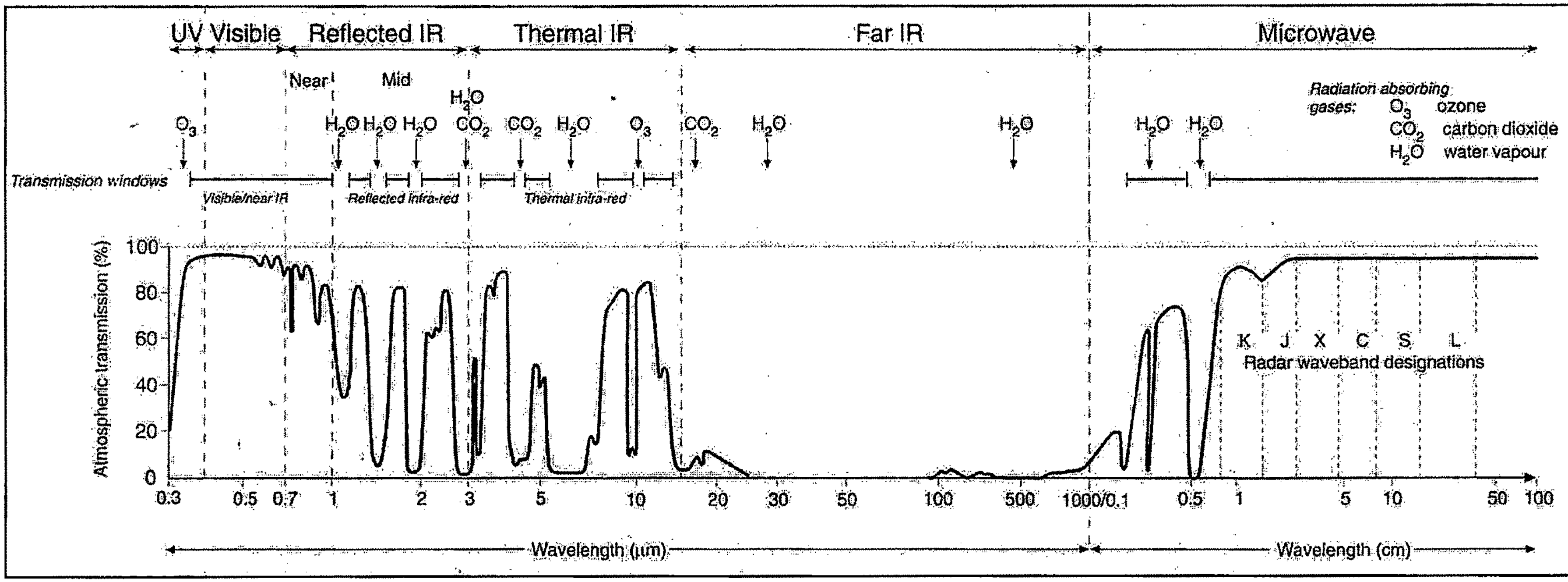

Figure 3.1 The electromagnetic spectrum from ultra-violet to microwave wavelength range. Atmospheric windows and radiation absorbing gases which block transmission at specific wavelengths are also shown. (Green *et al.* 2000).

since the sun is the source of light. The passive optical sensor also has a limitation in data collection under cloudy conditions. Active sensors have advantage over the passive sensors since it can sense through cloud (using microwave) and also can acquire data during nights. They have proved to be valuable in studying the mangroves where obtaining a cloud free data is a major problem.

Various stages are involved in the remote sensing of the earth (Fig. 3.2). When the EMR falls upon the earth's surface, the energy is either absorbed, reflected or transmitted. Objects on earth's surface also naturally emit radiation, mostly in the form of heat (infrared radiation). Sensors record this reflected and emitted radiation. Since the amount of energy reflected/emitted by an object depends on the wavelength and the nature of the object, each object on the earth's surface reflect/emit specific amount of radiation resulting into their characteristic *spectral signature*. The characteristic spectral signature is used to identify and map the objects using remote sensing data.

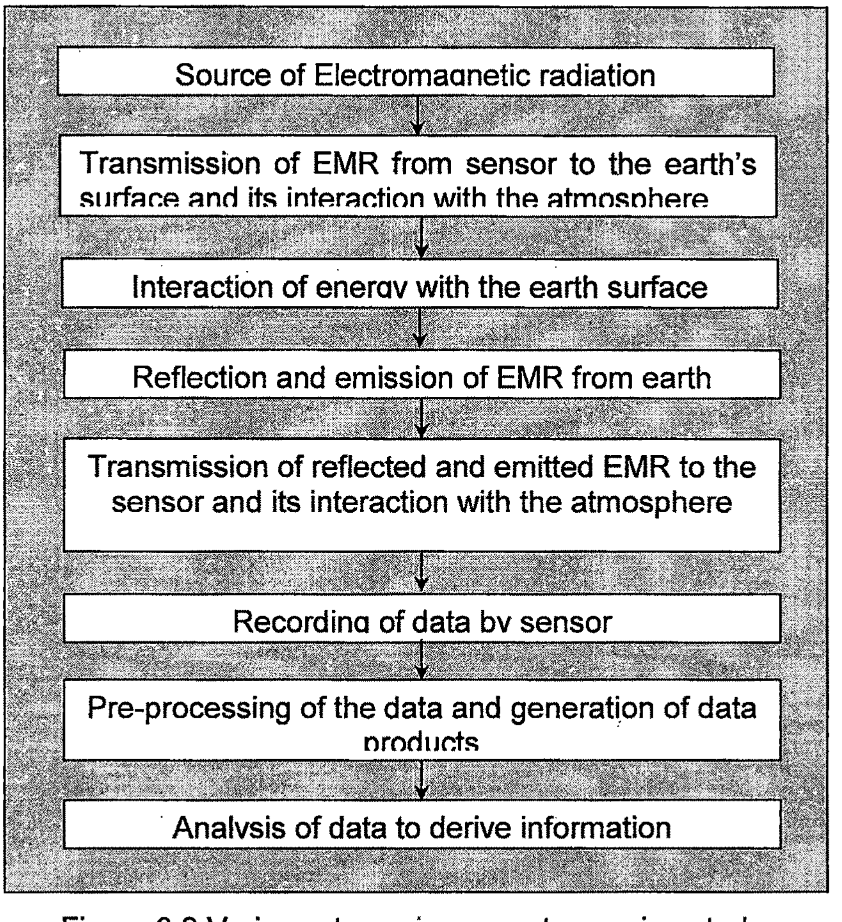

Figure 3.2 Various stages in a remote sensing study.

Prior to the launch of the series of Landsat satellites, remote sensing activities were restricted to aerial photography. The study of earth resource evaluation, ecosystem processes and their monitoring from space was initiated about three decades ago with the launch of the first Earth Resources Technology Satellite (ERTS-1, later renamed as Landsat 1) in 1972 by the United States. The utility of orbital data was demonstrated and their potential in mapping earth surface physiography, earth resource evaluation, study of various environmental processes and their long term monitoring were recognized. The technological advancement in data storage and processing techniques made the technique feasible for environmental monitoring in both time and space over large areas, and stimulated tremendous interest in technical as well as application researches. Using remote sensing technique it is possible to calibrate the digital data using a small amount of fieldwork and then extend the information over the entire data set.

The study of coastal vegetation, which is one of the major components of the coastal environment, is important to understand the coastal processes operating in an area. Remote sensing technology has proved to be of immense use to map and study the coastal features (including ecosystems such as mangroves, coral reefs, *etc.*) largely due to its synoptic and repetitive coverage. Table 3.1 presents a summary of utility of remote sensing data of various spatial resolutions for mangrove vegetation studies. Table 3.2 lists various satellites and sensors, which are useful for coastal/marine applications.

3.2 REMOTE SENSING OF VEGETATION

Approximately 70 percent of the earth's surface is covered with vegetation. Furthermore, vegetation is one of the most important components of ecosystems. Knowledge about the variations in vegetation species and community distribution patterns, alterations in vegetation phenological (growth) cycles and modifications in the plant physiology and morphology provide valuable insight into the climatic, edaphic and physiographic characteristics of an area (Jones *et al.*, 1998). Visual and digital image processing algorithms have been developed to extract important vegetation biophysical information from remotely sensed data (Jensen, 2000). Many of the remote sensing techniques are generic in nature and can be applied for a variety of vegetated landscapes including agriculture, forests, wetlands and urban vegetation.

Table 3.1 Utility of remote sensing data of various spatial resolutions for mangrove studies

Spatial resolution	Sensors	Characteristics	Applications
High (1 – 5 m)	QuickBird IKONOS, *etc.*	High spatial resolution, synoptic coverage	Density, floristics, height, phenology, human impacts, standing stock, (Numerous studies species mapping, conversion of mangrove areas)
Medium (6 – 80 m)	LISS III, SPOT (HRV), ETM+, TM, COIS	Synoptic coverage, intermediate spectral resolution, cost effective	Density, phenology, hydrological status, human impacts (Numerous studies on mapping, conversion of mangrove area and conservation.
	MSS, LISS I & II, *etc.* (30-200 m)	Synoptic coverage	Extent at regional scale. Broad Physiognomy and detection of one or two dominant sub-classes (Few regional studies)
Coarse (> 80 m)	WiFS, OCM, MODIS, MERIS, GLI, *etc.* (200-1000 m)	High temporal resolution, synoptic coverage, high spectral resolution, poor spatial resolution	Aerial extent at global scale of large mangrove areas (Few studies on continental scale)
	SeaWiFS, MERIS, AVHRR, *etc.* (> 1000 m)	High temporal resolution, synoptic global coverage, intermediate spectral resolution, poor spatial resolution	Broad approximation of large mangrove areas (Very few studies)

Table 3.2 Satellites and sensors useful in coastal/marine applications

Satellite (Launch Year)	Country / Organisation	Sensor	Temporal Resolution (Days)	Spatial Resolution (m)	Spectral Resolution (nm)
High resolution sensors (1 - 5 m)					
SPIN-2 (1993)	Russia	KRV 1000	-	2	Pan : 510-760
IKONOS (2001)	Space Imaging Inc.	PAN	-	1	Pan : 528-929
		XS	-	4	445-516, 506-595, 632-698, 757-853
QuickBird (2001)		PAN	1 - 3.5	0.61 - 0.72	Pan : 450-900
		XS	1 - 3.5	2.44 - 2.88	Band 1 = 450-520, Band 2 = 520-600 Band 3 = 630-690, Band 4 = 760-900
CARTOSAT-1 (in future)	India	PAN	5	2.5	Pan : 500-750 (Two cameras for Stereoscopic viewing)
CARTOSAT-2 (in future)	India	PAN	5	1	Pan : 500-750 (Two cameras for Stereoscopic viewing)
Medium resolution sensors (6-80 m)					
LANDSAT (1 TO 3) (1972)	USA	MSS	18	80	500-600, 600-700, 700-800, 800-1100

Satellite (Launch Year)	Country / Organisation	Sensor	Temporal Resolution (Days)	Spatial Resolution (m)	Spectral Resolution (nm)
MOS **(1987)**	Japan	MESSR	17	50	510-590, 610-690, 730-800, 800-1100
IRS 1A (1989)	India	LISS 1	22	72.5	450-520, 520-590, 620-680, 770-860
IRS 1B **(1991)**	India	LISS II	22	36.4	450-520, 520-590, 620-680, 770-860
LANDSAT (4 & 5) (1982)	USA	MSS	18	80	500-600, 600-700, 700-800, 800-1100
		TM	18	30	450-520, 520-600, 600-690, 760-900, 1550-1750, 10,400-12,500, 2080-2350
SPOT (1 –3) (1986)	France	HRV- XP	26	10	PAN : 510-730
		HRV – XS	26	20	500-590, 610-680, 790-890
ERS (1991)	ESA	*SAR	3	25	Single band at 5.6 cm (5.3 Ghz.)
JERS-1 (1992)	Japan	OPS	44	18.3	520-600, 630-690, 760-860, 760-860 1600-1710, 2010-2120, 2130-2250, 2270-2400
RADARSAT (1995)	Canada	*SAR	Varialble	10-100	Single band at 5.6 cm (5.3 Ghz.)
IRS 1C/ 1D (1995/97)	India	PAN	24	5.8	PAN : 500-900
		LISS III	24	23.5	520-590, 620-680, 770-860, 1550-1700

Satellite (Launch Year)	Country / Organisation	Sensor	Temporal Resolution (Days)	Spatial Resolution (m)	Spectral Resolution (nm)
SPOT 4 (1998)	France	HRVIR- XP	26	10	PAN : 510-730
		HRVIR – XS	26	20	430-470, 610-680, 780-890, 1580-1750
LANDSAT 7 (1999)	USA	ETM+	18	30 (Band 8 = 15 m)	450-520, 520-600, 600-690, 760-900 1550-1750, 10,400-12,500, 2080-2350, 600-900
ARIES (2000)	Australia	#ARIES	2000	30	105 Bands at 16 nm Bandwidth
NEMO (2000)	USA	#COIS	-	30- 60	210 BANDS WITH 16 NM BANDWITH
RESOURCESAT (2003)	India	LISS III	24	23.5	520-590, 620-680, 770-860, 1550-1700
		LISS IV	24	5.8	520-590, 620-680, 770-860
		AWiFS	5	56	520-590, 620-680, 770-860, 1550-1700
Coarse resolution sensors (> 80 m)					
Nimbus 7 (1978)	USA	CZCS	6	825	433-453, 510-530, 540-560, 660-680 700-800, 10,500-12,500
EOS-AM (1988)	USA	MODIS	2	250-1000	400-14,400 (36 Bands) 250 m (2 bands), 500 m (5 bands), 1000m (29 bands)
NOAA (9-12) 1984	USA	AVHRR	12 hrs.	1100-4000	580-680, 725-1100, 3550-3930, 10.3-11.3μm (NOAA-10, 10.5-11.5 μm), 11.4-12.4 μm

Satellite (Launch Year)	Country / Organisation	Sensor	Temporal Resolution (Days)	Spatial Resolution (m)	Spectral Resolution (nm)
ADEOS I (1996)	Japan	OCTS	3	700	402-422, 433-453, 480-500, 510-530, 555-575, 655-675, 745-785, 845-885, 3550-3880, 8250-8800, 10,300-11,400 11,400-12,500
IRS 1C/ 1D (1995/97)	India	WiFS	5	188	620-680, 770-860
SeaStar (1997)	USA	SeaWiFS	12 hrs	1100-4000	402-422, 433-453, 480-500, 500-520 545-565, 600-680, 745-785, 845-885
ADEOS (1999)	Japan	OCTS	3	700	402-422, 433-453, 480-500, 510-530 555-575, 655-675, 745-785, 845-885 3550-3880, 8250-8800, 10,300-11,400 11,400-12,500
IRS-P4 (1999)	India	OCM	2	360	402-422, 433-453, 480-500, 500-520 545-565, 600-680, 745-785, 845-885
ENVISAT (1999)	ESA	MERIS	35	300	15 bands, Programmable in Width and Position (Only Visible and Infra-red)
ERS-1 (1999)	ESA	ASTR	3	1000	1580-1640, 3350-3930, 10,400-11,300, 11,500-12,500
EOS-PM (2000)	ESA	MODIS	2	250-1000	400-14,400 (36 Bands) 250 m (2 bands), 500 m (5 bands), 1000m (29 bands)

Hyper spectral Sensors, *Microwave sensors

Acronyms used in the tables

Acronym	Explanation
ADEOS	Advanced Earth Observing Satellite
ARIES	Australian Resource Information and Environmental Satellite
ASAR	Advanced Synthetic Aperture Radar
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
AWiFS	Advanced Wide Field-of-view Sensor
CARTOSAT	Cartographic Satellite
COIS	Coastal Ocean Imaging Spectrometer
CZCS	Coastal Zone Color Scanner
ENVISAT	Environmental Research Satellite
EOS	Earth Observing Satellite
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ETM	Enhanced Thematic Mapper
FIR	Far Infra red
GLI	Global Imager
HRV	High Resolution Visible
HRVIR	High Resolution Visible and Infra-Red
IRS	Indian Remote Sensing Satellite
JERS	Japanese Earth Resources Satellite
LANDSAT	Land Remote Sensing Satellite
LISS	Linear Imaging Self -scanning Sensor
MERIS	Medium Resolution Imaging Spectrometer
MESSR	Multispectral Electronic Self-Scanning Radiometer
MIR	Middle Infra red
MODIS	Moderate Resolution Imaging Spectroradiometer
MOS	Marine Observations Systems
MSS	Multispectral Scanner
MW	Microwave
NEMO	Naval EarthMap Observer
NOAA	National Oceanic and Atmospheric Administration
NIR	Near Infra Red
OCM	Ocean Colour Monitor
OCTS	Ocean Colour and Temperature Scanner
OPS	Optical Sensor
OrbView	Orbital Viewer
PAN	Panchromatic
RADARSAT	Radar Satellite
RESOURCESAT	Resource Satellite
SAR	Synthetic Aperture Radar
SeaWiFS	Sea-Viewing Wide Field-of-view Sensor
SPOT	Satellite pour l'Observation de la Terre
SWIR	Short Wave Infra Red
TM	Thematic Mapper
USA	United States of America
VIS	Visible
WiFS	Wide Field-of-view Sensor
XS	Multi-Spectral

3.3 SPECTRAL CHARACTERISTICS OF VEGETATION

Photosynthesis is the process by which green plants use sunlight to produce carbohydrates such as glucose, other nutrients, and oxygen from simple compounds such as water and carbon dioxide. In energy terms, photosynthesis converts solar energy into chemical potential energy that is in carbohydrates. Plants have adapted their internal and external structures to perform photosynthesis. Leaves and canopies impart signature to a plant that is viewed by a remote platform.

A healthy green leaf intercepts incident radiant flux (Φ_i) directly from the sun or from diffuse skylight scattered onto the leaf. This incident electromagnetic energy interacts with the pigments, water and intercellular spaces within the plant leaf. The amount of radiant flux reflected from the leaf (Φ_r), the radiant flux absorbed by the leaf (Φ_α) and the amount of radiant flux transmitted through the leaf (Φ_τ) can be carefully measured as we apply the energy balance equation and attempt to keep track of what happens to all the incident energy. The general equation for the interaction of spectral (λ) radiant flux on and within the leaf is

$$\Phi_{i_\lambda} = \Phi_{r_\lambda} + \Phi_{\alpha_\lambda} + \Phi_{\tau_\lambda}$$

Most remote sensing systems function in the 0.35 – 3.0 μm region measuring primarily reflected energy. So the above relationship can be shown as

$$i_\lambda = r_\lambda - \alpha_\lambda + \tau_\lambda$$

where the energy reflected from the plant leaf surface is equal to the incident energy minus the energy absorbed directly by the plant for photosynthetic or other purposes and the amount of energy transmitted directly through the leaf onto other leaves or the ground beneath the canopy.

Fig. 3.3 shows the reflectance, absorptance and transmittance of vegetation over the wavelength 0.4 – 2.7 μm. This shows that the reflectance and transmittance are almost mirror images over the wavelength region shown. The dominant factors controlling leaf reflectance have been explained below

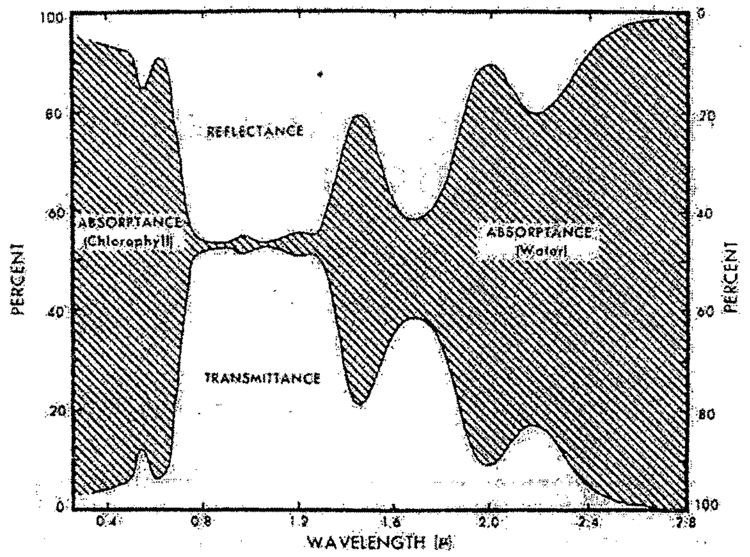

Fig 3.3 Reflectance, absorptance and transmittance spectra of vegetation (from Knipling, 1970)

Poineering work by Gates *et al.* (1965), Gausmann *et al.* (1969), Mayers (1970) and others demonstrated the importance of understanding how leaf pigments, internal scattering and leaf water content affect the reflectance and transmittance properties of leaves (Peterson and Running, 1989). Dominant factors controlling leaf reflectance in the region 0.35 – 2.6 μm are summarized in the figure 3.4

The leaf is the primary photosynthesizing organ. A cross section of a typical green leaf is shown in Fig 3.5. The cell structure of leaves is highly variable depending upon species and environmental conditions during growth.
The top layer of leaf, the upper epidermis, has a cuticular surface that diffuses but reflects very little light (Knipling, 1970). Much of the visible and near-infrared wavelength energy is transmitted through the cuticle and upper epidermis to the palisade parenchyma mesophyll cells and spongy parenchyma mesophyll cells below. Photosynthesis occurs inside the typical green leaf in the mesophyll cells. Molecules in a typical green plant have evolved to absorb wavelengths of light in the visible region of the spectrum very well and are called pigments. An

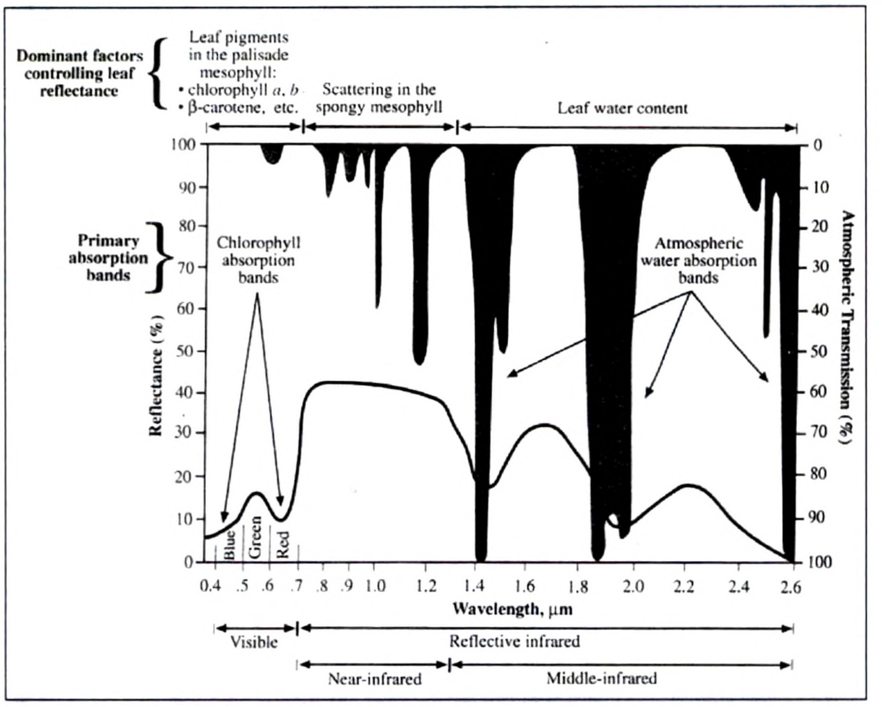

Figure 3.4 The dominant factors controlling leaf reflectance for the wavelength range 0.4-2.6 µm. (from Jensen, 2000)

absorption spectrum for a particular pigment describes the wavelength at which it can absorb light and enter into an excited state. The figure 3.6 presents the absorption spectrum of pure chlorophyll pigments in solution. Chlorophyll a and b

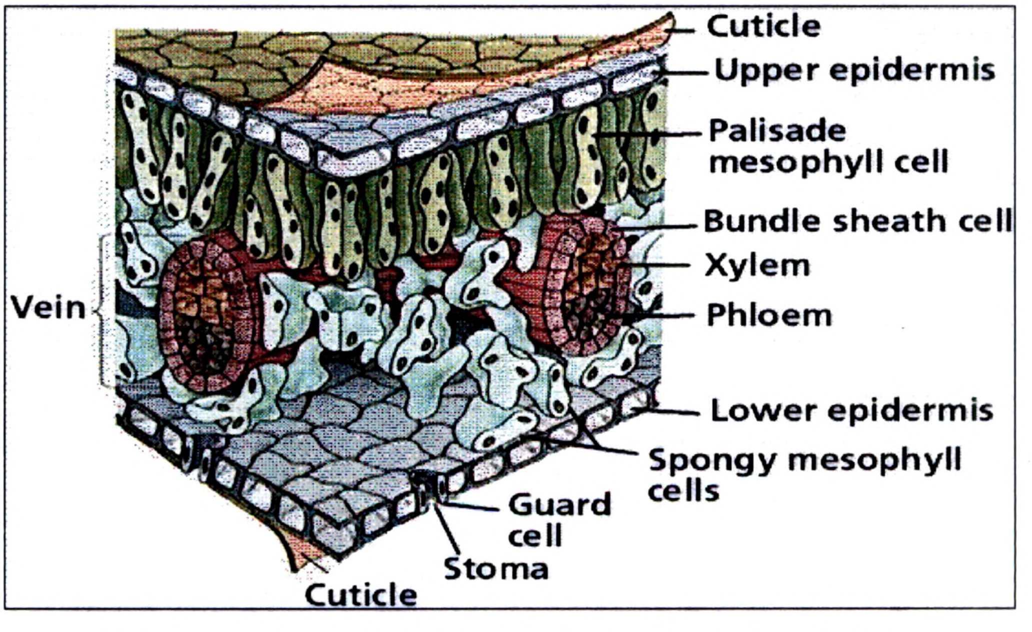

Fig 3.5 Cross section of typical dicot leaf (from Farabee, 2001)

are the most important plant pigments absorbing blue and red light: chlorophyll a at wavelengths of 0.43 and 0.66 μm and chlorophyll b at wavelengths of 0.45 and 0.65 μm (Curran, 1983; Farabee, 1997). A relative lack of absorption in the wavelengths between the two chlorophyll absorption bands produces a trough in the absorption at approximately 0.54 μm in the green portion of the electromagnetic spectrum. It is the relatively lower absorption of green wavelength light (compared to blue and red light) by the leaf that causes healthy green foliage to appear green to our eyes.

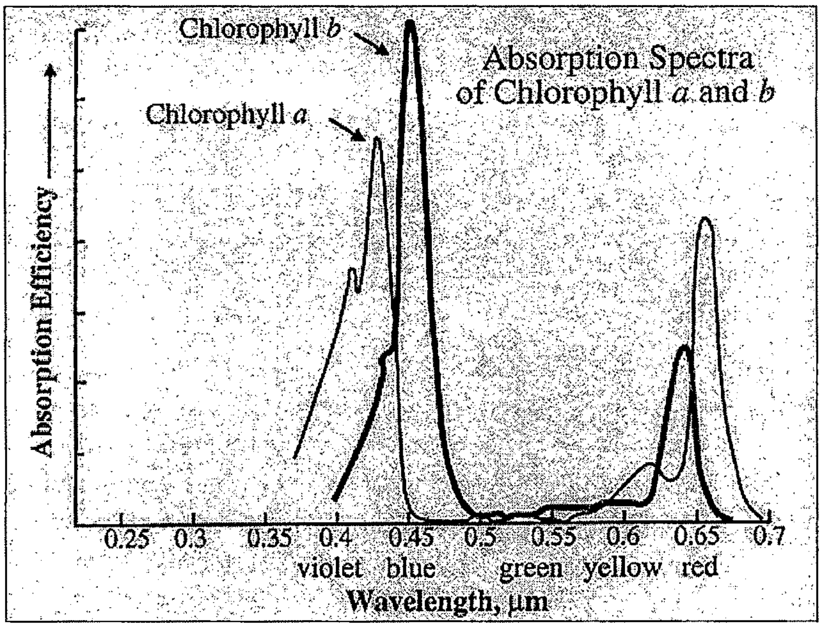

Fig 3.6 Absorption spectra of Chlorophyll a and b

There are other pigments present in the palisade mesophyll cells that are usually masked by the abundance of chlorophyll pigments. When a plant undergoes senescence in the fall or encounters stress, the chlorophyll pigment may disappear, allowing the carotenes and other pigments to become dominant.

The two dominant spectral regions for sensing the chlorophyll absorption characteristics of a leaf are believed to be 0.45 – 0.52 μm and 0.63 – 0.69 μm. The former region is characterized by strong absorption by chlorophylls and carotenes while the latter is characterized by strong chlorophyll absorption.

In a typically healthy green leaf, the near-infrared reflectance increases dramatically in the region from 700 – 1200 nm. Healthy green leaves absorb radiant energy very efficiently in the blue and red portions of the spectrum where incident light is required for photosynthesis, But immediately to the long wavelength side of red chlorophyll absorption band, the reflectance and transmittance of plant leaves increases dramatically. This condition occurs through out the near-infrared wavelength range where the direct sunlight incident on the plants has the bulk of its energy. If plants absorbed this energy with the same efficiency as they do in the visible region, they could become much too warm and the proteins would be irreversibly denatured. As a result plants have adapted so they do not use this massive amount of near-infrared energy and simply reflect it or transmit it through to underlying leaves or the ground (Jensen, 2000).

The spongy mesophyll layer in a green leaf controls the amount of near-infrared energy that is reflected. The spongy mesophyll layer typically lies below the palisade mesophyll layer and is composed of many cells and intercellular spaces. A healthy green leaf's reflectance and transmittance spectra through out the visible and near-infrared portion of the spectrum are almost mirror images of one another (Knipling, 1970)

The high diffuse reflectance of the near-infrared (0.7 – 1.2 μm) energy from plant leaves is due to the internal scattering of the cell wall – air interfaces within the leaf (Gausmann *et al.*, 1969; Peterson and Running, 1989). A water vapor absorption band exists at 0.92 – 0.98 μm; consequently the optimum spectral region for sensing in the near-infrared region is believed to be 0.74 – 0.90 μm (Tucker, 1978)

The main reasons why healthy plant canopies reflect so much near-infrared energy are

- the leaf already reflects 40 – 60 percent of the incident near-infrared energy from the spongy mesophyll
- the remaining 45 – 50 percent of the energy penetrates (i.e. is transmitted) through the leaf and can be reflected once again by leaves below it.

This is called **additive reflectance**. Greater the number of leaf layers in a healthy mature canopy, theoretically the greater the infrared reflectance.

Liquid water in the atmosphere creates five major absorption bands in the near-infrared through middle-infrared portions of the electromagnetic spectrum at 0.97, 1.19, 1.45, 1.94,and 2.7 μm. The fundamental vibrational water-absorption band at 2.7 μm is the strongest in this part of the spectrum. There is also a strong relationship between the reflectance in the middle-infrared region from 1.3 – 2.5 μm and the amount of water present in leaves of a plant canopy. Water in plants absorbs incident energy between the absorption bands with increasing strength at lower wavelengths. In these middle-infrared wavelengths, vegetation reflectance peaks occur at about 1.6 and 2.2 μm, between the major atmospheric water absorption bands.

Water is a good absorber of middle-infrared energy, so the greater the turgidity of the leaves, the lower the middle-infrared reflectance. The middle-infrared wavelength intervals from about 1.5 – 1.8 μm and 2.1 – 2.3 μm are more sensitive to changes in the moisture content of the plants than the visible or near-infrared portions of the spectrum. According to Carter (1991) the degree to which incident solar energy in the middle-infrared region is absorbed by vegetation is a function of the total amount of water present in the leaf and the leaf thickness.