MODULE – 1 LECTURE NOTES – 3

ENERGY INTERACTIONS IN THE ATMOSPHERE

1. INTRODUCTION

In many respects, remote sensing can be thought of as a reading process. Using various sensors, we remotely collect data that are analysed to obtain information about the objects, areas or phenomena being investigated. In most cases the sensors are electromagnetic sensors either air-borne or space-borne for inventorying. The sensors record the energy reflected or emitted by the target features. In remote sensing, all radiations traverse through the atmosphere for some distance to reach the sensor. As the radiation passes through the atmosphere, the gases and the particles in the atmosphere interact with them causing changes in the magnitude, wavelength, velocity, direction, and polarization.

In this lecture electromagnetic energy interactions in atmosphere are explained.

2. Composition of the atmosphere

In order to understand the interactions of the electromagnetic radiations with the atmospheric particles, basic knowledge about the composition of the atmosphere is essential.

Atmosphere is the gaseous envelop that surrounds the Earth's surface. Much of the gases are concentrated within the lower 100km of the atmosphere. Only $3x10^{-5}$ percent of the gases are found above 100 km (Gibbson, 2000).

Table 1 shows the gaseous composition of the Earth's atmosphere

Table.1. Gaseous composition of the Earth's atmosphere (from Gibbson, 2000)

Component	Percentage
Nitrogen (N_2)	78.08
Oxygen (O_2)	20.94
Argon	0.93
Carbon Dioxide (CO_2)	0.0314
Ozone (O_3)	0.00000004

Oxygen and Nitrogen are present in the ratio 1:4, and both together add to 99 percent of the total gaseous composition in the atmosphere. Ozone is present in very small quantities and is mostly concentrated in the atmosphere between 19 and 23km.

In addition to the above gases, the atmosphere also contains water vapor, methane, dust particles, pollen from vegetation, smoke particles etc. Dust particles and pollen from vegetation together form about 50 percent of the total particles present in the atmosphere. Size of these particles in the atmosphere varies from approximately 0.01μm to 100μm.

The gases and the particles present in the atmosphere cause scattering and absorption of the electromagnetic radiation passing through it.

3. Energy Interactions

The radiation from the energy source passes through some distance of atmosphere before being detected by the remote sensor as shown in Fig. 1.

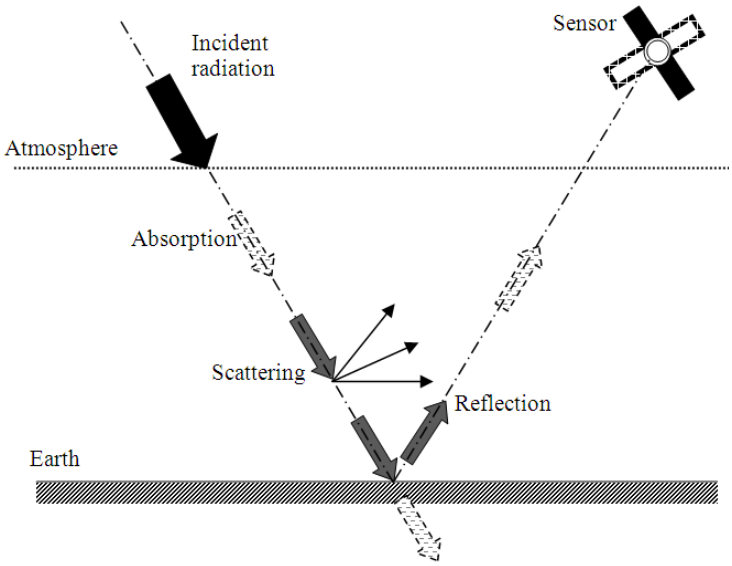

Fig. 1. Interactions in the atmosphere

The distance travelled by the radiation through the atmosphere is called the path length. The path length varies depending on the remote sensing techniques and sources.

For example, the path length is twice the thickness of the earth's atmosphere in the case of space photography which uses sunlight as its source. For airborne thermal sensors which use emitted energy from the objects on the earth, the path length is only the length of the one way distance from the Earth's surface to the sensor, and is considerably small.

The effect of atmosphere on the radiation depends on the properties of the radiation such as magnitude and wavelength, atmospheric conditions and also the path length. Intensity and spectral composition of the incident radiation are altered by the atmospheric effects. The interaction of the electromagnetic radiation with the atmospheric particles may be a surface phenomenon (e.g., scattering) or volume phenomenon (e.g., absorption). Scattering and absorption are the main processes that alter the properties of the electromagnetic radiation in the atmosphere.

4. Scattering

Atmospheric scattering is the process by which small particles in the atmosphere diffuse a portion of the incident radiation in all directions. There is no energy transformation while scattering. But the spatial distribution of the energy is altered during scattering.

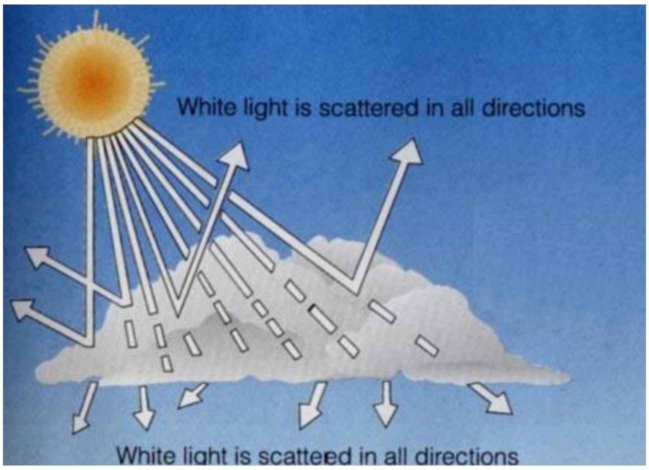

Fig. 2. Scattering of the electromagnetic radiation in the atmosphere
http://www.geog.ucsb.edu/~joel/g110_w08/lecture_notes/radiation_atmosphere/radiation_atmosphere.html

There are three different types of scattering:

- Rayleigh scattering
- Mie scattering
- Non-selective scattering

3.1 Rayleigh scattering

Rayleigh scattering mainly consists of scattering caused by atmospheric molecules and other tiny particles. This occurs when the particles causing the scattering are much smaller in diameter (less than one tenth) than the wavelengths of radiation interacting with them.

Smaller particles present in the atmosphere scatter the shorter wavelengths more compared to the longer wavelengths.

The scattering effect or the intensity of the scattered light is inversely proportional to the fourth power of wavelength for Rayleigh scattering. Hence, the shorter wavelengths are scattered more than longer wavelengths.

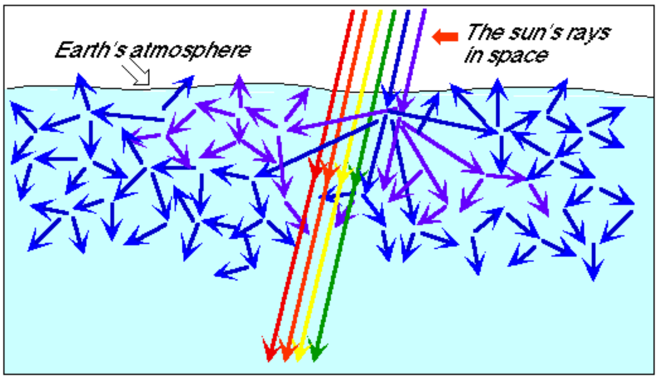

Fig. 3. Rayleigh scattering
http://home.comcast.net/~vinelandrobotics/

Rayleigh scattering is also known as selective scattering or molecular scattering.

Molecules of Oxygen and Nitrogen (which are dominant in the atmosphere) cause this type of scattering of the visible part of the electromagnetic radiation. Within the visible range, smaller wavelength blue light is scattered more compared to the green or red. A "blue" sky is thus a manifestation of Rayleigh scatter. The blue light is scattered around 4 times and UV light is scattered about 16 times as much as red light. This consequently results in a blue sky. However, at sunrise and sunset, the sun's rays have to travel a longer path, causing complete scattering (and absorption) of shorter wavelength radiations. As a result, only the longer wavelength portions (orange and red) which are less scattered will be visible.

The haze in imagery and the bluish-grey cast in a color image when taken from high altitude are mainly due to Rayleigh scatter.

3.2 Mie Scattering

Another type of scattering is Mie scattering, which occurs when the wavelengths of the energy is almost equal to the diameter of the atmospheric particles. In this type of scattering longer wavelengths also get scattered compared to Rayleigh scatter (Fig. 4).

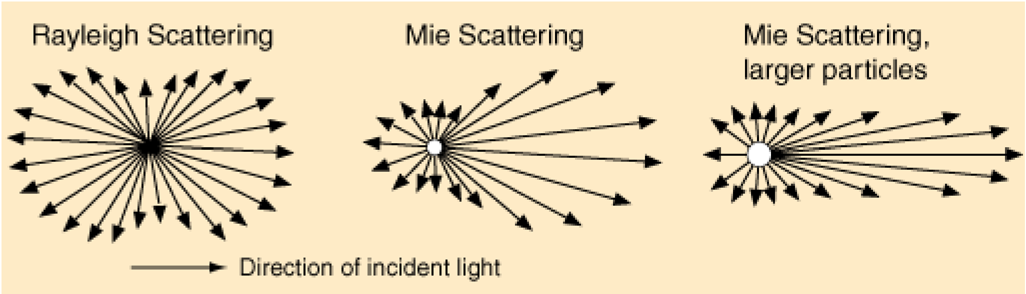

Fig.4 Rayleigh and Mie scattering

http://hyperphysics.phy-astr.gsu.edu

In Mie scattering, intensity of the scattered light varies approximately as the inverse of the wavelength.

Mie scattering is usually caused by the aerosol particles such as dust, smoke and pollen. Gas molecules in the atmosphere are too small to cause Mie scattering of the radiation commonly used for remote sensing.

3.3 Non-selective scattering

A third type of scattering is nonselective scatter, which occurs when the diameters of the atmospheric particles are much larger (approximately 10 times) than the wavelengths being sensed. Particles such as pollen, cloud droplets, ice crystals and raindrops can cause non-selective scattering of the visible light.

For visible light (of wavelength 0.4-0.7μm), non-selective scattering is generally caused by water droplets which is having diameter commonly in the range of 5 to 100 μm. This scattering is nonselective with respect to wavelength since all visible and IR wavelengths get scattered equally giving white or even grey color to the clouds.

4. Absorption

Absorption is the process in which incident energy is retained by particles in the atmosphere at a given wavelength. Unlike scattering, atmospheric absorption causes an effective loss of energy to atmospheric constituents.

The absorbing medium will not only absorb a portion of the total energy, but will also reflect, refract or scatter the energy. The absorbed energy may also be transmitted back to the atmosphere.

The most efficient absorbers of solar radiation are water vapour, carbon dioxide, and ozone. Gaseous components of the atmosphere are selective absorbers of the electromagnetic radiation, i.e., these gases absorb electromagnetic energy in specific wavelength bands. Arrangement of the gaseous molecules and their energy levels determine the wavelengths that are absorbed.

Since the atmosphere contains many different gases and particles, it absorbs and transmits many different wavelengths of electromagnetic radiation. Even though all the wavelengths from the Sun reach the top of the atmosphere, due to the atmospheric absorption, only limited wavelengths can pass through the atmosphere. The ranges of wavelength that are partially or wholly transmitted through the atmosphere are known as "atmospheric windows." Remote sensing data acquisition is limited through these atmospheric windows. The atmospheric windows and the absorption characteristics are shown in Fig.5.

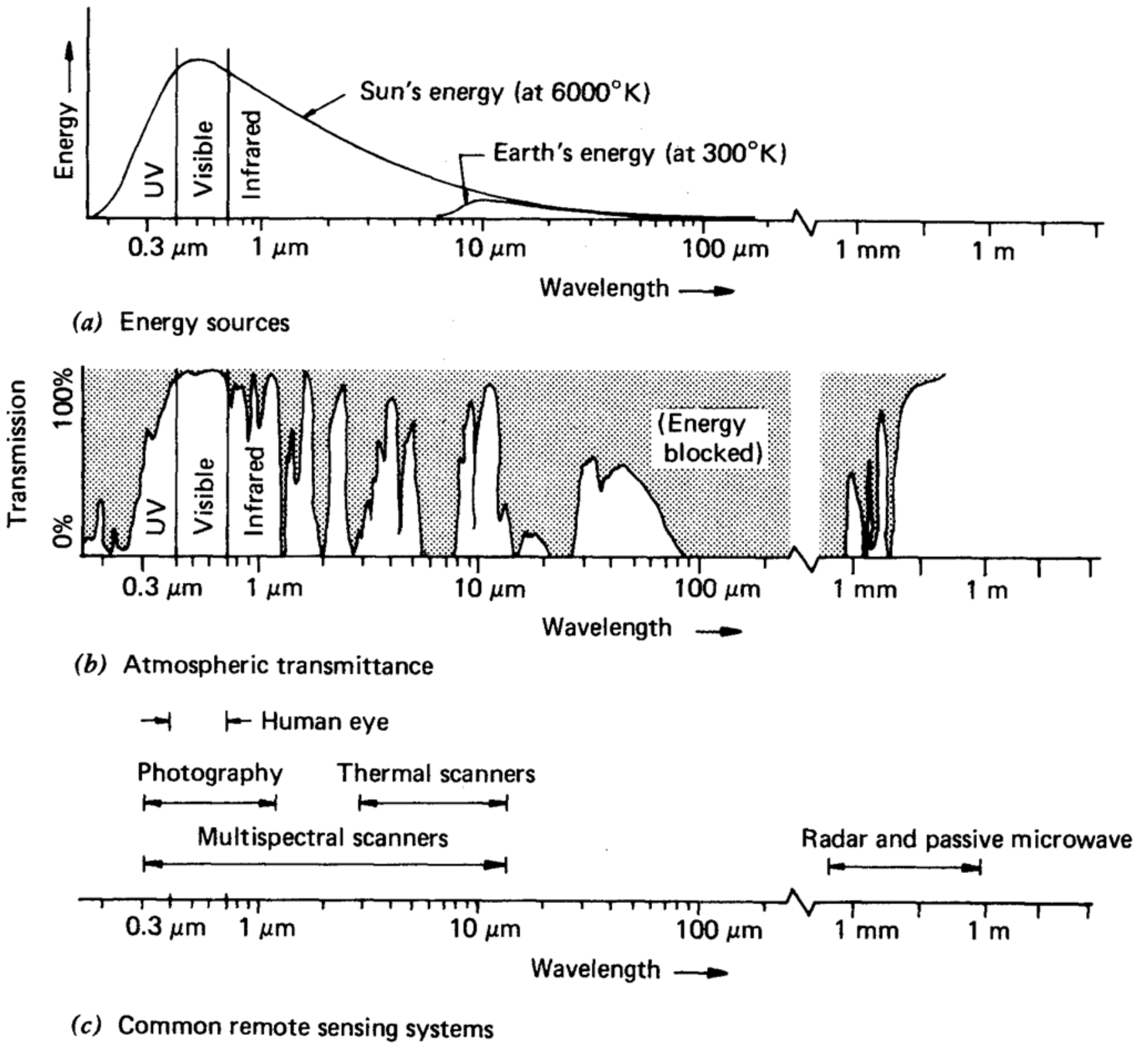

Fig. 5. (a) Spectral characteristics of main energy sources (b) Atmospheric windows and (c) Common remote sensing systems at different wavelengths (Source: Lillesand et al., 2004)

From Fig.5 it can be observed that electromagnetic radiation at different wavelengths is completely absorbed, partially absorbed or totally transmitted through the atmosphere. Nitrogen and other gaseous components in the atmosphere cause absorption of wavelengths shorter than 0.1 μm. Wavelengths shorter than 0.3μm (X-rays, Gamma rays and part of ultraviolet rays) are mostly absorbed in the atmosphere. This is caused by the ozone (O_3) present in the upper atmosphere. Oxygen in the atmosphere causes absorption centered at 6.3μm.

In the visible part of the spectrum, little absorption occurs.

Infrared (IR) radiation is mainly absorbed due to the rotational and vibrational transitions of the molecules. The main atmospheric constituents responsible for infrared absorption are water vapour (H_2O) and carbon dioxide (CO_2) molecules. Most of the radiation in the far infrared region is also absorbed by the atmosphere. However, absorption is almost nil in the microwave region.

The most common sources of energy are the incident solar energy and the radiation from the Earth. The wavelength at which the Sun's energy reaches its maximum coincides with the visible band range. The energy radiated from the Earth is sensed through the windows at 3 to 5μm and 8 to 14μm using devices like thermal scanners.

Radar and Passive microwave systems operate through a window in the 1 mm to 1 m region

Major atmospheric windows used for remote sensing are given n Table 2.

Table 2. Major atmospheric windows used in remote sensing and their characteristics

Atmospheric window	Wavelength band μm	Characteristics
Upper ultraviolet, Visible and photographic IR	0.3-1 apprx.	95% transmission
Reflected infrared	1.3, 1.6, 2.2	Three narrow bands
Thermal infrared	3.0-5.0 8.0-14.0	Two broad bands
Microwave	> 5000	Atmosphere is mostly transparent

5. Sensor selection for remote sensing

While selecting a sensor the following factors should be considered:

i. The spectral sensitivity of the available sensors
ii. The available atmospheric windows in the spectral range(s) considered. The spectral range of the sensor is selected by considering the energy interactions with the features under investigation.
iii. The source, magnitude, and spectral composition of the energy available in the particular range.
iv. Multi Spectral Sensors sense simultaneously through multiple, narrow wavelength ranges that can be located at various points in visible through the thermal spectral regions

Bibliography / Further Readings

1. Gibson, P. J., 2000.Introductory Remote Sensing- Principles and Concepts, Routledge, London.
2. Lillesand, T. M., Kiefer, R. W., Chipman, J. W., 2004. Remote sensing and image interpretation. Wiley India (P). Ltd., New Delhi.