Unit 1
Basics of Remote Sensing

Session 2
Energy Sources

Department of Civil Engineering
The Open University of Sri Lanka

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Session 2 – Energy Sources

Introduction

Thermal radiation principles are used for interpreting thermal images. A thermal scanner is a multispectral scanner which operates only in the thermal portion of the spectrum. We need to see how thermal radiation principles are used for interpreting thermal images. An introduction is given to Blackbody Radiation, radiation from real materials, atmospheric effects on thermal images.

Aims:

- To teach the fundamentals of electromagnetic energy
- To teach about the energy interactions with the atmosphere
- To emphasise the importance of certain features in relation to image interpretation.

2.1 Energy sources and radiation principles and Electromagnetic Spectrum

Everything in nature radiates!

You and everything around you!

Radiation needs no medium to transfer energy. How powerfully something radiates will depend on its temperature. Solar radiation bathes our planet with sunlight.

Let us see what this radiation really is.

Radiation is a form of electromagnetic energy.

What are the common forms of electromagnetic energy?
Visible light is just one form. Some other forms are, radio waves, heat, ultraviolet rays, and X-rays.

The electromagnetic spectrum can be defined as follows.

> "Electromagnetic radiation is, the energy propagated through space between electric and magnetic fields. The electromagnetic spectrum is, the extent of that energy ranging from cosmic rays, gamma rays, X-rays to ultraviolet, visible and infrared radiation including microwave energy and television and radio waves."

(Source: Lillesand, T.M., & Kiefer, R.W. (1999).' Remote Sensing & Image interpretation' 4th edition University of Wisconsin-Madison.)

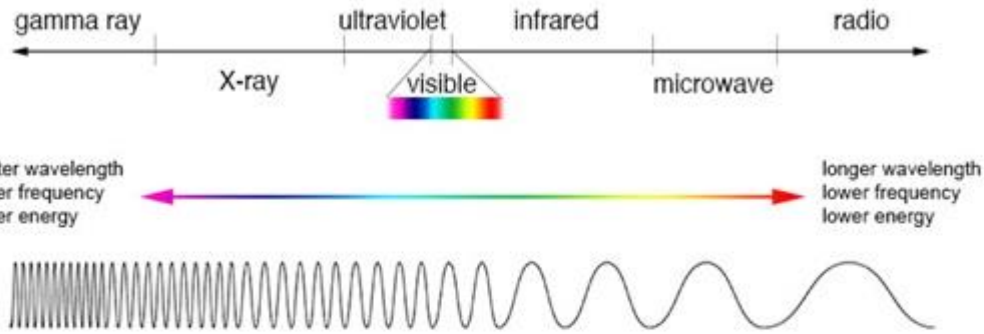

Figure 0.1: The electromagnetic spectrum

(Source: https://imagine.gsfc.nasa.gov/Images/science/EM_spectrum_compare_level1_lg.jpg)

The collection of all possible wavelengths is called the 'electromagnetic spectrum'.

You can see from the above figure that the visible portion of the spectrum is very small. The spectrum of waves is divided into sections based on wavelength (explained below). The micron is the most commonly used unit for measuring the wavelength of electromagnetic waves. The shortest and most energetic (high frequency) waves are called gamma rays. The longest and lowest energy (low frequency) waves are called radio waves, which are measured in meters or kilometers. The narrow portion of the spectrum, [0.4 microns (blue) to 0.7 microns (red)] indicates the range of visible light that is sensed by our eyes. The photographic range of wavelength extends into the near infrared and can be used to capture ultraviolet photography with highly specialized lens and film.

Sensors are the devices used to acquire images in remote sensing. In remote sensing, the sensors can acquire information that the human eye cannot normally see. This is done using radiation in other parts of the electromagnetic spectrum than in the visible portion.

It should be clear now that remote sensing involves many types of radiation in the electromagnetic spectrum. Since the human eye can only perceive radiation within a limited interval of the electromagnetic spectrum, instruments for remote sensing outside the visible wavelengths, represent an extension of our visual field. They give access to additional information about the physical reality surrounding us.

All objects reflect some of the light that reaches them. In other words, the energy reflected from the surface of a feature is part of the energy incident on that feature. It is this part which gets reflected that 'gives' the objects their colour. For example, if you see that a plant is green, it is because the plant reflects part of the light that the eye sees as green. In the same way, an apple is red because it reflects part of the light that corresponds to red.

Some objects not only reflect light that reaches them, but also emit 'radiation'. This emitted radiation can be in the form of light or it can be in another form such as heat. A fire emits warmth and light, so even when it is dark you can see the fire. By comparison, when it is dark, you cannot see an apple. This is because an apple only reflects light whereas fire also emits light. Think of a case where an object may emit warmth but not light. This object will not be visible in the dark but still it will emit 'thermal radiation'.

Think of other examples of objects that 'emit' radiation and objects that only 'reflect' radiation. The light and warmth that is emitted and reflected by objects is 'radiation'. Radiation is a group of electrically charged particles in movement. The movement in this case is a 'wave'. Therefore, to measure radiation emitted or reflected by objects, it is necessary to measure their wavelength and their strength, which is given by the amplitude (see 'Wave theory' described below). By measuring the wavelength of many different objects, it has been realised that some objects reflect wavelengths that cannot be seen by the human eye (example infrared rays).

Electromagnetic radiation from a surface is either a reflection (reflected light) or an emission (radiation emitted from the surface itself). Reflected sunlight can be measured only in daylight, whereas emission can be measured at all times.

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When electromagnetic radiation encounters any feature, radiation can get reflected off the object, be absorbed by it, or it could be transmitted through because the energy manifested by electromagnetic waves can behave both like a particle (the photon) and like a wave (oscillating electric/magnetic fields). Incident radiation refers to the total amount of radiation that strikes an object.

incident radiation = reflected radiation + absorbed radiation + transmitted radiation

In addition to the above, we have seen that there is also radiation that is 'emitted' by some objects.

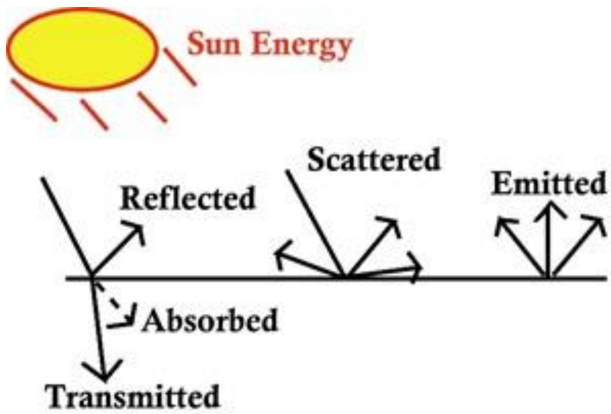

Figure 2.2: Energy interactions

In remote sensing, we are largely concerned with 'reflected radiation' and almost as much with thermal radiation, which is radiation 'emitted' by objects.

Let us now consider the reflected radiation.

The reflected radiation consists of a continuum of wavelengths.
A sensor will respond differently to each wavelength of different magnitude. The magnitude of the wavelengths will depend on what type of surface is reflecting them. This leads to what is called 'spectral signatures'. The spectral signature of a feature is something that should be unique to a feature and is independent of the sensor that measures it. But as we shall see later, it is not unique in reality! We shall discuss this later in 'spectral response patterns'.

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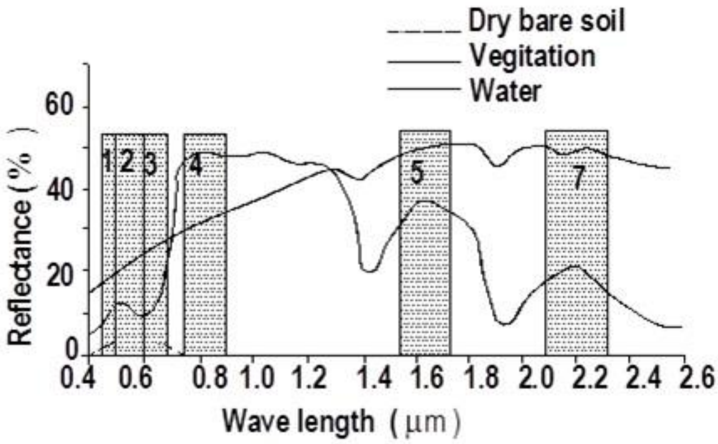

Figure 2.3: Wavelength vs Intensity graph for a sensor responding to different spectral signatures.

2.1.1 Wave theory and Particle theory

Electromagnetic radiation is most easily described by 'wave theory'. But the 'particle theory' gives useful information on how electromagnetic energy interacts with matter. We shall discuss each of these theories in brief.

Wave theory

Electromagnetic waves travel in a harmonic, sinusoidal fashion at the 'velocity of light'. Electromagnetic waves are classified by frequency or wavelength. The 'wavelength λ' refers to the distance from one wave peak to the next. The 'wave frequency' λ refers to the number of peaks passing a fixed point in space per unit time. The 'amplitude' refers to the peak of the wavelength.

From basic physics, waves obey the general equation:

$$\boxed{C=v\lambda} \qquad \text{Equation 2.1}$$

where 'C' is a constant (the speed of light).

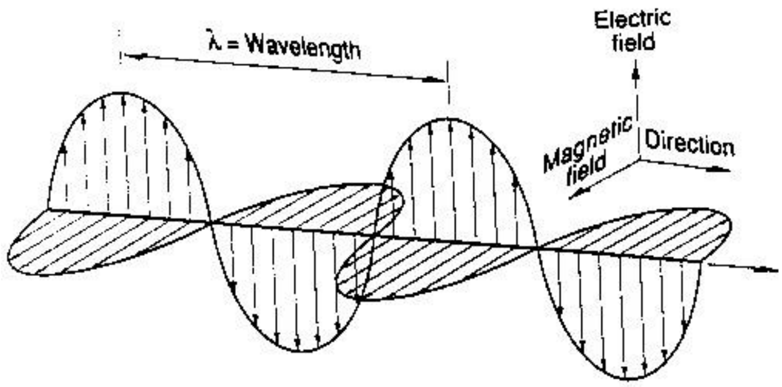

Figure 2.4: Figure of electromagnetic wave giving the components

(Source: http://www.edinformatics.com/math_science/e_mag_nasa_image.gif)

The electric field and the magnetic field are important concepts that can be used to mathematically describe the physical nature of electromagnetic waves (light). The electric field vibrates transverse (perpendicular) to the direction in which the electromagnetic wave is travelling. The magnetic field vibrates in a direction transverse to the direction the electromagnetic wave is travelling and transverse to the electric field. These two fields oscillate in a consistent manner so that the wave moves forward at a constant rate, at the speed of light (c). The electromagnetic spectrum is a continuum of electromagnetic waves.

Particle theory

The particle theory suggests that electromagnetic radiation is composed of many discrete units called 'photons 'or 'quanta'.

The energy of a quantum is given as,

$$\boxed{\mathbf{Q = hv}} \qquad \text{Equation 2.2}$$

Where, Q = energy of a quantum (J)

h = Planck's constant (J sec)

v = frequency

By relating to the wave theory equation, we have,

$$Q = hc/ \lambda$$

Hence, we see that the energy of a quantum is inversely proportional to its wavelength. The longer the wavelength involved, the lower the energy content. This means that, the longer the wavelength, the more difficult it becomes to sense the energy signal.

This phenomenon is important in remote sensing.

Let us see how we can relate this to Earth Observation.

Naturally emitted long wavelength radiation, such as microwave emission from terrain features, is more difficult to sense than radiation of shorter wavelengths, such as emitted thermal IR energy. Long wave length radiation has low energy content. Hence large areas need to be 'viewed' by systems operating at long wave lengths to obtain an energy signal which can be detected.

2.2 Surface temperature and radiation

The sun is the main source of electromagnetic radiation for remote sensing. But all matter at temperatures above absolute zero (0K or –273 ^{0}C), radiate electromagnetic energy of varying wavelengths according to their temperature. Absolute zero (0 degrees Kelvin) is a theoretical temperature that describes no molecular motion.

The energy emitted from an object in the form of radiation, is primarily a function of its temperature.

Let us see how the temperature affects the emission when considering the sun and the earth. The sun has a surface temperature of 6000K and maximum emission in the visible range (wavelength 0.483µm).

The earth has a surface temperature of about 290K and maximum emission in the thermal infrared range (wavelength 14µm).

A surface with a temperature of about 1000K (a fire) will have its maximum emission in the middle infrared spectrum (wavelength 3µm).

There is a direct correlation between surface temperature of an object and the degree of emission of radiation at a given wavelength. The surface temperature can be calculated by remote sensing of the thermal infrared emission.

It is possible to 'see' the surface of the Earth at all only because it reflects visible light from the sun. Sun rays hitting the earth can either be absorbed and thus contribute to

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the heating of the earth or be reflected and seen by the human eye or sensed by a satellite.

The albedo value of a surface indicates how large a percentage of the sunlight is reflected from that surface.
This can be related to what is called the 'black body'

What is a black body?

A black body is a hypothetical ideal radiator that totally absorbs and reemits all energy incident upon it. The following conditions hold true for a black body.

1. The total energy emitted from an object increases very rapidly with increases in temperature.
2. The wavelength at which the maximum spectral radiant exitance occurs, varies inversely with the black body's temperature.

Figure below shows the spectral distribution of energy radiated from the sun and the earth considering them as black bodies.

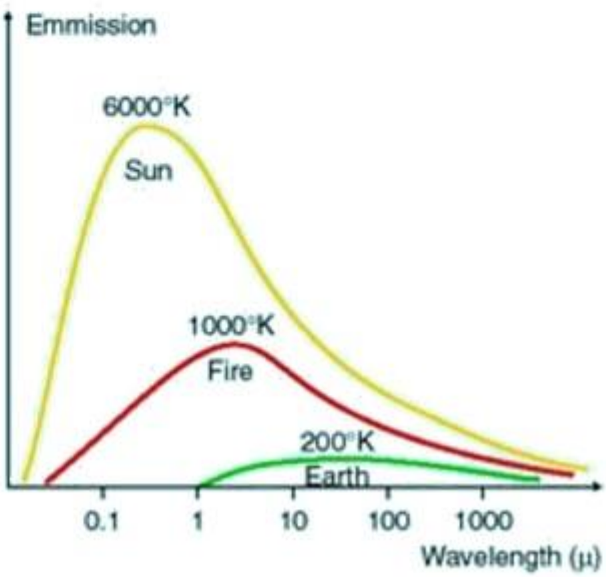

Figure 2.5: 'Black body' emission spectrum for the sun, a fire and the earth.
(Source: http://www.esa.int/images/03_400.jpg)

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Activity 2.1

1. For a black body, the wavelength at which the maximum spectral radiance occurs varies inversely with the black body's temperature as seen from the graph given in the session. To observe this phenomenon, heat a metal body such as a piece of iron. As the object becomes hotter, it begins to glow and its colour changes successively to shorter wavelengths, from dull red to orange then to yellow and eventually to white.

2.2.1 Active and passive remote sensing systems

We have so far understood that a remote sensing system will 'sense' the energy reflected or emitted from features of interest. But are these features always reflecting or emitting energy for us to record it? Even if we assume that they do so, what are the chances of the signal being received by the sensor? Cannot the energy path be obstructed on the way to the sensor?

What do you think?

There are many instances where the energy that is reflected or emitted cannot be detected by the normal type of remote sensor. One is, when the sky is cloudy. Naturally available radiation does not penetrate clouds and we cannot detect signals over areas overcast by clouds. Snow and smoke can also obstruct natural radiation. We shall discuss other instances in later sessions.

How do we get over this situation?
We use energy in the microwave portion of the electromagnetic spectrum for recording the spectral content, in such instances. We will try to get an idea on how this is done.

We now get down to the topic of this sub section, which is 'Active and Passive' remote sensing systems.

Passive remote sensing systems only sense naturally available energy on features of interest. A simple example is a camera used in sunlight. Here, the camera senses the energy of the sun reflected off the object that is photographed. Since the naturally occurring radiation is easily obstructed as mentioned above, the atmosphere has a significant effect on the intensity and spectral composition of the energy recorded in passive remote sensing systems. We shall read about this in detail, later.

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In contrast, active remote sensing systems, supply their own source of energy to illuminate features of interest. Radar was developed as a means of using radio waves to detect the presence of objects and their distance. This is used by remote sensing systems to overcome the obstacles, which are opaque to radiation. What is done in this case is that the sensor emits short bursts or pulses of microwave energy in the direction of interest. The 'echoes' or 'reflections' received from the objects are then recorded. We shall deal with the subject of 'Microwave Sensing' in a later session. A simple example of an active remote sensing system can be demonstrated by using a camera, which will utilize a flash. The flash is used since the natural radiation is not sufficient for detection by the camera, which is the sensor in this case.

Activity 2.2

1. Can you now list out what one must consider when selecting a sensor to be used in any given remote sensing task, as set out in this session?
2. There are special viewers that enable wearers to see in the dark. These devices are made to 'see' objects in the dark by emitting infrared radiation. Can you give other examples of objects designed by humans, to emit radiation?
3. Can you give examples of objects and the type of radiation they produce, where the radiation cannot be seen by the naked eye?

2.3 Energy interactions in the atmosphere and Atmospheric interference

The radiation from the sun and the reflection from the surface of the earth pass through the atmosphere before they reach the satellite sensor.

Let us see what happens to the radiation on its way to the sensor.

When taking images created by only the reflected energy, from satellites in space, the sunlight has passed through the full thickness of the earth's atmosphere twice on its journey from the source to the sensor. The source is the sun and the sensor is in the satellite. Another case is an airborne *thermal sensor,* which will detect *thermal energy* emitted directly from objects on the earth. Here it is a single atmospheric path length that is involved.

What are the effects of the atmosphere on this radiation as it travels to and from?
The net effect of the atmosphere on the 'intensity' and 'spectral composition' of radiation varies with the following;

Difference in path length, magnitude of the energy signal being sensed, the atmospheric conditions present and the wavelengths involved. Scattering and Absorption are two main things to be considered when measuring radiation.

2.3.1 Scattering

Diffusion of radiation by particles in the atmosphere is called scattering. There are several types of scattering.

Rayleigh scatter is an occurrence where short wave lengths have a much larger tendency to get scattered than longer wavelengths.

Why does the sky appear blue?

Let us try to explain this using the concept of Rayleigh scatter.
As the sun interacts with the earth's atmosphere, shorter (blue) wavelengths gets scattered more than the other visible wavelengths. Hence the sky appears blue.

Rayleigh scatter is also causes 'haze' in imagery.
Another type of scatter called 'Mie scatter' can occur due to, Water vapour and dust. Unlike Rayleigh scatter, Mie scatter tends to influence longer wavelengths.

There is also another type of scatter caused by water droplets.

Why do clouds appear white?

Water droplets causing scatter have particle diameters in the range of 5 to 100 micrometres and scatter all visible and near to mid IR wavelengths, equally. Hence this scattering is 'non-selective' with respect to wavelength. Equal quantities of blue, green and red light are scattered in the visible wavelengths, which results in the clouds appearing as white.

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2.3.2 Absorption

Atmospheric absorption is a result of absorption of energy at given wavelengths to atmospheric constituents. The constituents which absorb solar radiation the most are, water vapour, carbon dioxide and ozone. These gases tend to absorb electromagnetic energy in specific wavelength bands. This phenomenon strongly influences 'where we look' spectrally with any given remote sensing system. The wavelength ranges in which the atmosphere is translucent and therefore transmissive of energy are referred to as 'atmospheric windows'.

In the spectral distribution of the energy emitted by the sun and by earth features, there can be spectral regions in which the atmosphere blocks energy. Remote sensing data acquisition which is limited to the non-blocked spectral regions are the 'atmospheric windows'.

The visible range coincides with both an atmospheric window and the peak level of energy from the sun. The wavelengths where the greater part of the radiation pass through the atmosphere are called 'Atmospheric Windows'. The atmosphere is 'translucent' and emission and reflection pass through almost unhindered. At other wavelengths the radiation is absorbed by various greenhouse gases.

A greater part of a visible light passes through the atmosphere and that is why we have day light. In certain ranges of the near infrared spectrum satellite observation is possible. There is a minimum atmospheric distortion in these ranges. Surface temperatures of the ground, water and clouds is measured using thermal infrared range from 10-12μm.

Review Questions

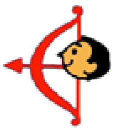
Answer the questions set out below.

1. What will be a very simple answer to the question, 'What is radiation?'
2. Draw a diagram of the electromagnetic spectrum indicating on it the range of wavelengths for various electronic rays? What is the visible range?
3. Explain how an object gets its 'colour'? How is it that only some objects can be seen in the dark and not others? Explain giving examples not in the session.
4. Explain the pattern of movement and the method of measurement of the particles of radiation.

5. Explain in simple terms the connection between ‘radiation’ and ‘remote sensing’.
6. What is the ‘speed’ of radiation?
7. How can you explain the fact that the ‘energy content’ is lower when long wavelengths are involved? Explain the theory behind this phenomena and why large areas need to be viewed in order to detect a signal from microwave emission.
8. What can you say about the ‘total energy emitted by an object’ and the ‘spectral distribution of the emitted energy’ with respect to the temperature of the object? Explain using the blackbody radiation curves of the sun and the earth as examples.
9. Particles in the atmosphere can cause the radiation to get diffused. Explain this phenomena with examples.
10. Explain the term ‘atmospheric windows’ indicating on a diagram the areas which are not blocked to radiation, and the sensors that can be used in each area.

Summary

Thermal scanner imagery interpretation is briefly described. Radiant temperature differences are used to analyses daytime and night time images. Important applications of thermal imagery are described while emphasizing the importance of radiometric calibration for achieving accurate radiometric information.



Learning Outcomes

At the end of this session you will be able to briefly explain:

- energy sources and the components of the electromagnetic spectrum.
- surface temperature and radiation
- active and passive remote sensing systems
- the theories that describe the characteristics of electromagnetic radiation
- energy interactions in the atmosphere, scattering and absorption of energy in the atmosphere and ‘atmospheric windows’.

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Course Team

Authors
Mrs. M. N. Tantirimudalige
(The Open University of Sri Lanka)

Content Editors
Dr. Juerg Lichtenegger
(European Space Agency)

Word Processing
Mrs. M. N. Tantirimudalige

Graphics
Miss. S. S. Wijiayalath
Mrs. M. S. S. Fernando

Desktop Publishing
Prof. (Mrs) B. C. Liyanage Athapattu

Web Content Developer
Mrs. H. M. Ranasinghe
Mrs. M. S. S. Fernando

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