NISGTC

The National Information, Security & Geospatial Technologies Consortium

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Lesson 2: Physical Foundations

INTRODUCTION

In this lesson you will learn about physical principles of remote sensing and how sensors collect and record data. Electromagnetic spectrum and wavelengths are explained to help you understand how sensors detect reflected data. Transmission, absorption, and reflection are concepts of energy that are defined and exhibited in the content. You will also learn about passive sensors, optical and satellite sensors and active sensors such as RADAR and LIDAR.

LESSON OBJECTIVES

By the end of this lesson, you will be able to:

1. Describe the basic physical concepts on which remote sensing are based such as the electromagnetic spectrum, reflection and absorption.

2. Explain the physical differences between active and passive remote sensing systems.

LEARNING SEQUENCE

Required Reading	Read the following: • Online Lesson Material
Resources	Review the following: • None
Assignments	Complete the following: • Quiz

INSTRUCTION

Physical Principles of Remote Sensing

Before jumping into specific sensors and digital image processing, this lesson focuses on the physical principles of remote sensing and how sensors collect and record data. Most of the remote sensors that will be used in this course will detect reflected energy from the Earth that originates from the Sun. Some sensors such as RADAR and LiDAR provide their own energy source.

Figure 1 illustrates how some of the energy from the sun is scattered or absorbed by the atmosphere. The energy that reaches the Earth's surface will have interactions with the objects it hits. In some cases the energy is absorbed by the vegetation, ground, or water. In other cases energy is transmitted through the object and passes onto another object. In still other instances this energy is reflected back through the atmosphere of which some of the energy is absorbed. The rest will pass through the atmosphere and be recorded on the remote sensor's electronics.

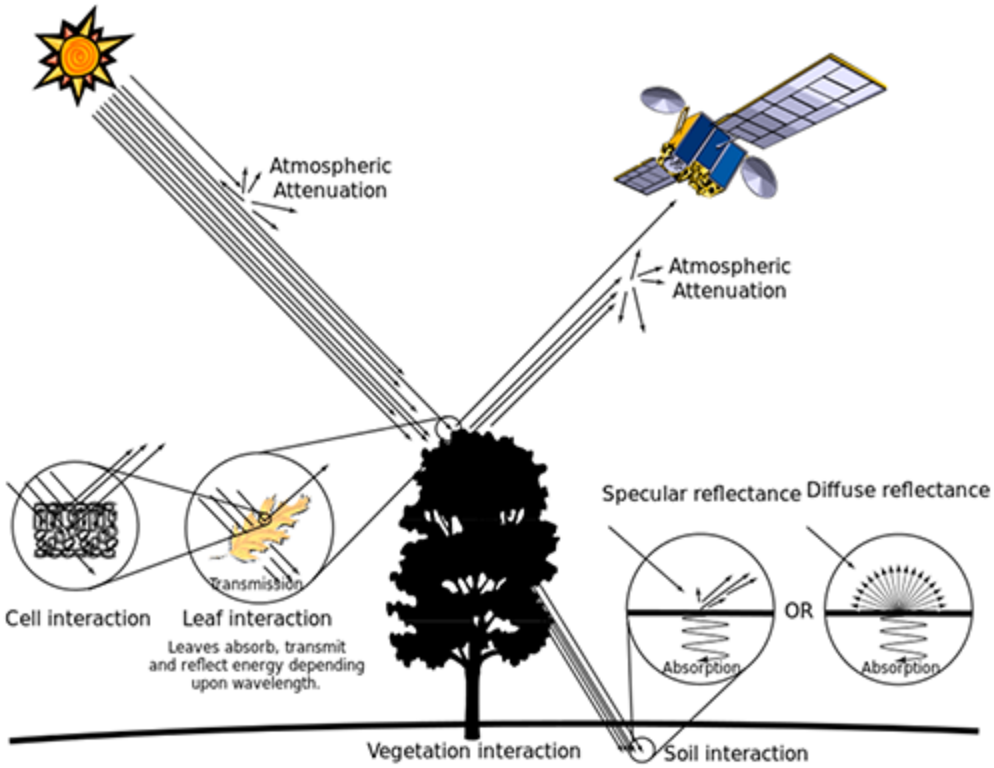

Figure 1 Sun Energy

Energy, Photons, and Wavelength

When talking about energy from the Sun, photons are quantities of energy that move at the speed of light. A relationship exists between the frequency and wavelength of a photon and the speed of light.

The equation shown indicates that the speed of light is a combination of the specific wavelength of light and its frequency.

Speed of Light *= Frequency of photon X wavelength of photon*

The next equation shows that by arranging the first equation, wavelength can be measured by taking the speed of light and dividing it by its frequency. Since the speed of light is a constant value of 300,000 km/hr (or 186,000 mi/hr) different kinds of light energy can be measured by its wavelength.

Wavelength = Speed of Light

Electromagnetic Waves

The energy that hits the Earth is considered electromagnetic radiation because the energy consists of two components of both electrical and magnetic waves. These different wave patterns form when an electron accelerates at a certain frequency. For a given wavelength of light, the frequency is the number of wave crests that pass the same point in one second. Because there is a continuum of electromagnetic radiation, different kinds of electromagnetic waves have different frequencies.

Electromagnetic waves that have higher energy states will have shorter wavelengths and higher frequencies. Electromagnetic waves that have lower states of energy will have longer wavelengths and shorter frequencies. For example, X-rays such as those that humans are exposed to when they are at the dentist or doctor’s office have shorter wavelengths. Radio waves, on the other hand, have longer wavelengths and provide the means for us humans to listen to the radio.

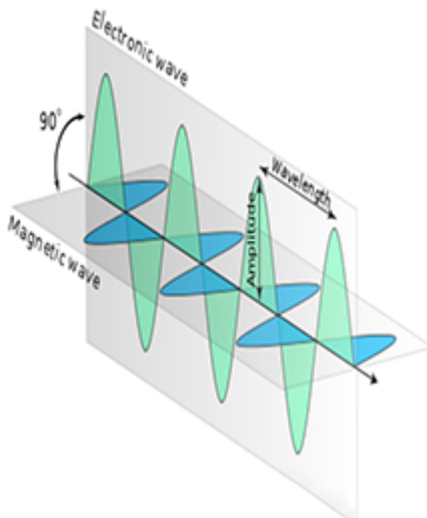

Figure 2 Electromagnetic Waves

Electromagnetic Spectrum

Figure 3 is a graph of the electromagnetic spectrum, the continuum of electromagnetic radiation. The portions of the electromagnetic spectrum highlighted are those that are detected by many of the remote sensors that will be discussed in this course.

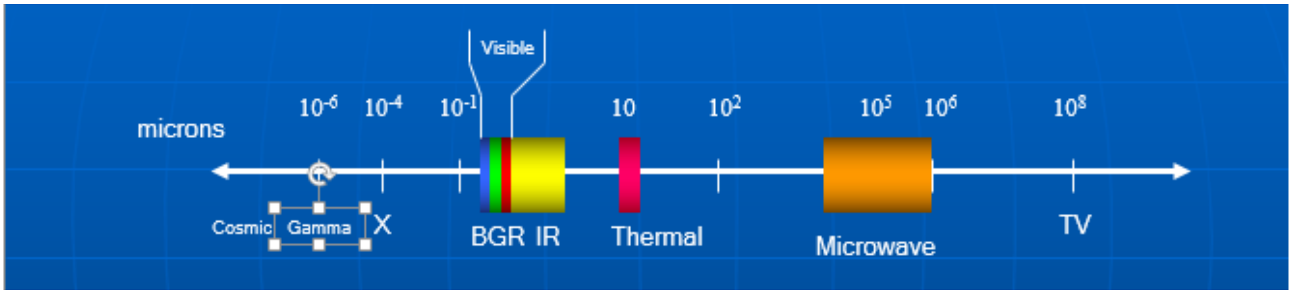

Figure 3 Electromagnetic Spectrum

The true color portion of the spectrum is detected and makes it convenient for humans to relate to the information being detected by the sensor.

In addition, a larger range of Infrared radiation is also detected. Although the human eye is not capable of "sensing" this part of the electromagnetic spectrum, it is very import to remote sensing, since much of the valuable information content can be sensed and recorded on remote sensor devices.

The microwave portion of the electromagnetic spectrum is indicated which ranges from approximately 1 centimeter to 1 meter. RADAR sensors operate in this portion of the spectrum.

When analyzing and processing remotely sensed imagery, it is important to know which wavelengths the remote sensor is able to detect and record.

The wavelengths for the respective portions of the electromagnetic spectrum shown in the graph are noted on the slide. The unit of measure for these wavelengths is either nanometers or microns (also known as micrometers).

- Blue is 0.4 to 0.5 microns (or 400 to 500 nanometers)
- Green is 0.5 to 0.6 microns (or 500 to 600 nanometers)
- Red is 0.6 to 0.7 microns (or 600 to 700 nanometers)
- Near Infrared is 0.7 to 0.9 microns (or 700 to 900 nanometers)

Depending on the sensor, other portions of the infrared part of the electromagnetic spectrum will be detected at approximately 1.6-1.8 microns and at approximately 2.1 to 2.4 microns. These sections of the electromagnetic spectrum are sometimes referred to the short wave infrared.

On some remote sensors, such as Landsat, the wavelengths between 8 and 14 microns are detected and recorded. This section of the electromagnetic spectrum represents the thermal wavelengths. This section is sometimes called the "heat" band(s), since these wavelengths represent objects that emit thermal radiation such as cooling towers at power plants. Some handheld thermal sensors can pick up body heat.

Transmission, Absorption and Reflectivity

The previous segment introduced electromagnetic radiation, the electromagnetic spectrum, and wavelengths. This section will extend this discussion by showing how these sensors are capable of detecting these wavelengths.

- Specific remote sensors are tuned to specific portions of the electromagnetic spectrum. This allows data to be collected and the imagery created from these sensors will provide useful information to remote sensing analysts who need to study earth phenomena across different geographical extents.
- Since satellite-based remote sensors orbit the earth above the Earth's atmosphere, not all wavelengths can be detected by the system.
- Electromagnetic radiation can be transmitted, absorbed, or reflected. The brown section of the figure provided indicates that energy passing through the atmosphere cannot easily be detected by a space or airborne remote sensors. In these cases the atmosphere may absorb or scatter energy and thus not being detected by the sensor.
- The portions of the spectrum that have a small atmospheric opacity influence indicate that most of these wavelengths will make it to the Earth's surface and back to the remote sensor and not be too affected by the Earth's atmosphere.

Transmission, Absorption, and Reflection

Atmosphere allows for electromagnetic radiation to be transmitted, absorbed, or reflected. Please review the definitions and the example image provided.

Transmission

Transmission indicates that energy from the sun will pass through the atmosphere and in some cases will pass through the object being sensed (such as leaves).

Absorption

Absorption refers to energy that is absorbed by the object and may be transformed into another form of energy (such as heat or chemical energy. For example the Sun's energy is absorbed by plant material and converted into chemical energy when photosynthesis occurs).

Reflection

Reflected energy occurs when the energy from the sun (or sensor) hits an object and is returned to the sensor. Energy can be reflected from atmospheric gases or dust particles, but the energy that is reflected from the Earth's surface and actually hits the remote sensor is recorded. This recorded reflected energy ultimately is stored in pixels (picture elements) that make up the digital image. The human eye detects electromagnetic radiation in the blue, green, and red part of the spectrum. Many remote sensors do this too, but they are also capable of recording reflected energy that our eyes cannot see such as the infrared part of the electromagnetic spectrum. Being able to detect the infrared part of the electromagnetic spectrum is important to many remote sensing applications.

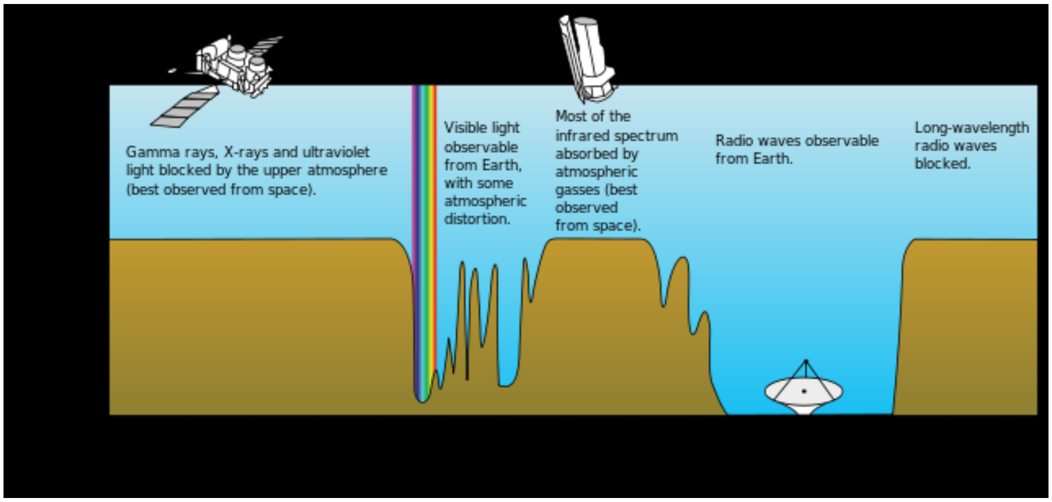

Figure 4 Illustration: Reflection as described in the above paragraph

Material Reflectivity and Wavelengths

Figure 5 is an example of an electromagnetic spectrum that includes the range from the true color (Blue, Green, and Red) to the infrared portion near 2.4 microns.

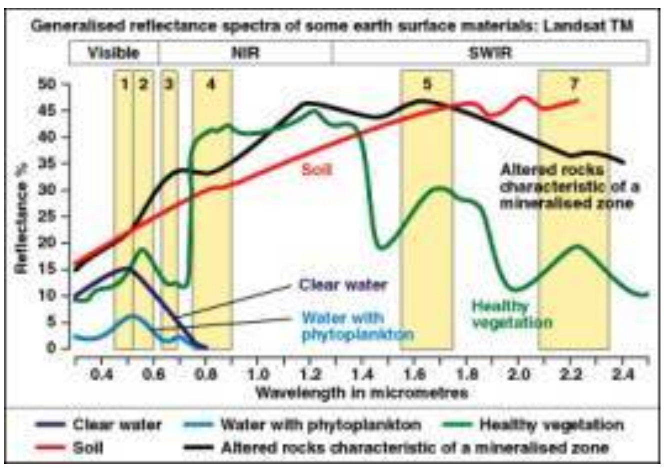

Figure 5 Electromagnetic Spectrum with True Color

- The yellow vertical bars represent the wavelength sensitivity of the Landsat Thematic Mapper satellite. The numbers represent the individual band numbers on the sensor. You will note that bands 1, 2, and 3 refer to the Blue, Green, and Red part of the electromagnetic spectrum. Bands 4, 5, and 7 represent different portions of the infrared part of the spectrum. Band 6 is not shown, but refers to the thermal portion of the spectrum which is beyond the extent of this graph.
- The vertical axis represents the percent reflectance. The different colored curves represent different general land cover types.
- Note the blue curves represent water and for the most part, water is not very reflective. There is a peak between the blue and green wavelengths and this

contributes to the color we often see in true color aerial photos or satellite imagery. Note that in the infrared part of the electromagnetic spectrum that there is almost no reflectance. This is because the infrared energy is absorbed by water.

- Now look at the green curve. This curve represents healthy green vegetation. Note that in the true color part of the spectrum that healthy green vegetation is only a little more reflective than water. There is a peak in the green wavelength and we expect this in true color imagery, since healthy green vegetation is "green."
- In the different portions of the infrared wavelengths there is a dramatic change in the percent reflectance of energy. Note that in the near infrared part of the spectrum that healthy green vegetation has a very high curve which indicates that healthy green vegetation is highly reflective in near infrared wavelengths. In the green wavelengths, healthy green vegetation is approximately 20% reflective. In the near infrared wavelengths, the same healthy green vegetation is approximately 40-45% reflective.
- In addition, healthy green vegetation has a couple of other portions of the electromagnetic spectrum where it has higher reflectivity than the green wavelength. Note that with the Landsat satellite these portions of the electromagnetic spectrum can detect this reflected energy.
- The red curve on the graph represents the reflectivity of soil. In the true color part of the spectrum soil is a little more reflective than healthy green vegetation and has a positive reflectance trend from the blue, to green, to red wavelengths. As we look at the infrared portions of the electromagnetic spectrum, soil continues this upward trend. Soil surpasses the percent reflectance in the shortwave portions of the spectrum.
- The black curve on the graph shows the reflectance curve of rocks. Rocks have a similar reflectance pattern as soil for the blue wavelength and then have a higher percent reflectance for the green and red wavelengths. This trend extends into the near and shortwave infrared portions of the electromagnetic spectrum.

Overall, it is clear that the infrared wavelengths provide a much richer source of reflected energy for different kinds of land cover types than the true color portions of the spectrum. This will become apparent when developing processes and sample areas for land cover classification activities and feature identification tasks.

Regarding vegetation, healthy green vegetation has lower reflectance in the true color portions of the spectrum, but much higher reflectance in the infrared portion of the spectrum. Water has relatively low reflectance and tends to absorb almost all of the infrared wavelengths. For vegetation analysis, infrared wavelengths are important and will assist the image analyst to identify and discriminate different vegetation cover types that have similar reflectance values and curves in the true color part of the electromagnetic spectrum.

Spectral Response of Subalpine Fir

Figure 6 is of the spectral response across the true color and near infrared portions of the electromagnetic spectrum for subalpine fir. The green line indicates the spectral response for a non-infested fir. The red curve indicates the spectral curve for fir trees that have been infested with a beetle.

It is important to note that for the true color portion of the electromagnetic spectrum that there is little difference between the spectral response for non-infested and infested trees. However, in the near infrared portion of the spectrum notice that the differences are much greater and so with a sensor that can record reflectance in the near infrared portion of the spectrum, there is a good chance that trees that are infested with the beetle can be detected and mapped across the forest. Knowing this, forest managers can make decisions on the types of treatments to apply to the forest to manage or eradicate the beetle infestation.

This ability for remote sensors to discriminate vegetation differences in the infrared portions of the electromagnetic spectrum is very important for many natural resource management applications.

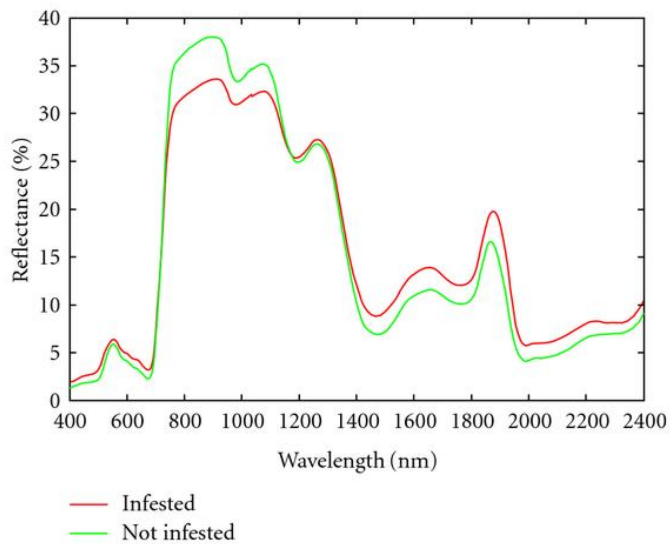

Figure 6 Spectral Response of Subalpine Fir

Passive and Active Sensors

The section on Physical Foundations showed that the primary source of energy for remote sensing comes from the sun. In greater detail, passive and active sensors are defined.

Passive Sensors

A sensor that images this reflected energy is considered to be passive. Passive sensors include all of the optical aerial and satellite sensors. Optical sensors refers to those that contain lenses that help resolve the features at are being sensed.

Active Sensors

Another kind of sensor that is used for remote sensing is considered active. Active sensors are those that have an energy source on board the instrument. RADAR and LiDAR are active sensors.

- RADAR emits radio wave from the sensor to sense objects on the ground
- LiDAR emits a fast moving laser beam from the sensor to capture information about elevation and heights of objects

RADAR and LiDAR will be discussed in more detail in the lesson, *Sensor Platforms, Image Processing Basics, Band Ratios, and Transformations*.

Figure 7 illustrates the differences between Passive Sensor (e.g. Landsat) vs. Active Sensor (e.g. RADARSAT): The illustration on the left shows the Sun's energy reflecting off of objects and getting recorded on the remote sensor. Some of the sun's energy is reflected or absorbed by the Earth's atmosphere. The illustration on the right shows an active RADAR sensor that emits radio waves that hit objects on the ground. The energy is reflected back to the sensor and recorded. RADAR waves are capable of passing through the Earth's atmosphere and so can collect information when it is cloudy or when it is dark.

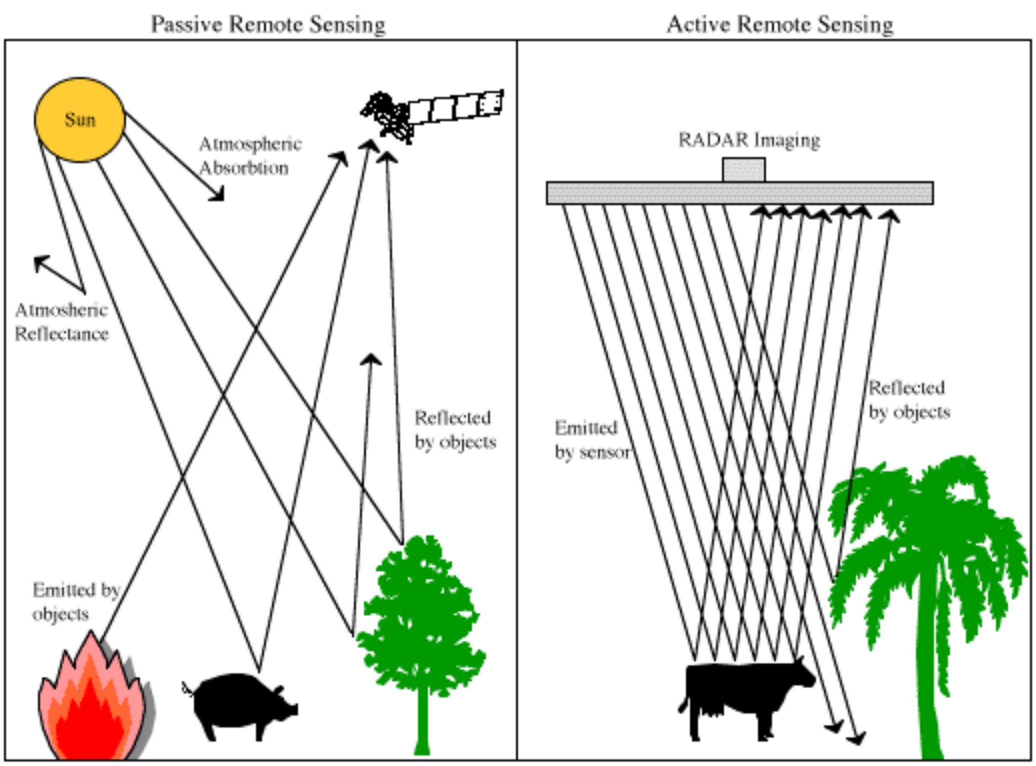

Figure 7 Passive Sensor (e.g. Landsat) vs. Active Sensor (e.g. RADARSAT)

SUMMARY

In this lesson you learned about physical foundations. Electromagnetic spectrum and wavelengths were explained to help you understand how sensors detect reflected data. Transmission, absorption, and reflection are concepts of energy that were defined and exhibited in the content. You also learned about passive sensors, optical and satellite sensors, and active sensors such as RADAR and LIDAR.

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ASSIGNMENTS

1. Quiz