# Preface

*Principles and Applications of Remote Sensing* serves as a fundamental course for disciplines such as surveying, geosciences, resources, and environmental studies at the undergraduate level. Its purpose is to introduce students to the theoretical foundations, technical aspects, and practical applications of remote sensing. In some educational programs, there is a requirement to teach this course in a bilingual format. This textbook primarily functions as the textbook for the bilingual course in "Principles and Applications of Remote Sensing".

The development of remote sensing science and technology stems from the interpenetration and integration of space science, Earth science, surveying science, computer science, and other disciplines. The hallmark of multidisciplinary fusion necessitates meticulous and rational selection and synthesis of a vast body of existing knowledge in textbooks elucidating remote sensing principles. Furthermore, the rapid evolution of sensor, platform, and data processing technologies introduces new challenges in the scientific curation of this textbook.

From the perspective of output forms in remote sensing data processing, imaging remote sensing systems can be broadly divided into two categories: first, acquiring land cover information through the interpretation and analysis of remote sensing images; second, obtaining surface three-dimensional coordinate values using specialized techniques or algorithms. LiDAR, InSAR, and UAV-based photogrammetry have evolved rapidly in recent years and are widely used to acquire surface three-dimensional coordinate values. However, these topics, not the focus of this course, will be elaborated in other courses. The selected content of this textbook primarily pertains to the acquisition of the first category of output data, encompassing the interaction of solar radiation with the atmosphere and terrestrial objects, representative remote sensing platforms and sensors, imaging mechanisms in optical and microwave remote sensing, characteristics of optical and microwave remote sensing images, image display and enhancement, radiometric and geometric correction, remote sensing image transformations, image fusion, visual interpretation of remote sensing images, remote sensing image classification based on classical algorithms and deep learning, and the applications of remote sensing.

Processing remote sensing data requires a suitable software environment. Among professional software tools, ENVI is the most commonly used. This textbook uses ENVI as an example to demonstrate the convenience of performing various classic remote sensing image processes by showcasing detailed procedures and operations. Beyond relying solely on dedicated remote sensing image software, mastering remote sensing technology often involves devising individual methods to address specific problems. Therefore, there is a need for an excellent language that can swiftly translate one's ideas into concrete code. Python stands out as the most effective language for developing deep learning algorithmic code. However, MATLAB exhibits notable advantages in handling data processing problems beyond deep learning. Given this consideration, this textbook has decided to use MATLAB as the language for developing remote sensing data processing software. It provides a comprehensive description of the fundamental concepts involved in processing remote sensing images and offers corresponding operational examples.

This textbook is collectively authored by teachers from the Department of Survey Science and Engineering at Hohai University, specializing in remote sensing-related course instruction. Chapter 1, Chapter 4, Chapter 5, Chapter 6, and Chapter 10 are written by Zhou Shaoguang. Chapter 2 is authored by Su Hongjun. Chapter 3 is written by Xu Jia. Chapter 7 is contributed by Xue Zhaohui. Chapter 8 is penned by Yang Yingbao. Chapter 9 is composed by Chen Renxi. The entire manuscript is overseen by Zhou Shaoguang. Graduate students Qin Jiumei, Bao Tianyu, Wan Zihao, and Cong Qing completed the manuscript formatting work.

For non-native English-speaking teachers and students, teaching or learning in English undoubtedly presents challenges. Therefore, in this textbook, the descriptions of concepts, professional terms, and fundamental principles are presented as concisely and clearly as possible. However, aiming for clarity and simplicity in expression doesn't guarantee the absence of shortcomings or errors. We welcome readers to point out any deficiencies, and we will promptly make revisions.

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*Principles and Applications of Remote Sensing* Writing Team
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# Contents

# Chapter 1 Introduction to Fundamentals

## 1.1 The Role and Importance of Earth Observation

Earth observation involves collecting detailed information about the Earth's physical, chemical, biological, and geometrical characteristics. This process is essential for monitoring and assessing changes in both natural and built environments. Applications of Earth observation include mapping, monitoring, and forecasting.

A critical aspect of Earth observation is the acquisition of geospatial data. Geospatial data is time-specific and linked to precise locations on the Earth's surface. It is instrumental in advancing social well-being, promoting sustainable economic development, and protecting the environment. Timely and accurate information is crucial for effective decision-making. Worldwide, there is increasing recognition of the importance of accessible, reliable, and affordable geospatial data. Moreover, rapid advancements in information and communication technology are enhancing the methods for acquiring and providing this data.

Earth observation utilizes both remote-sensing technologies and ground-based techniques to gather geospatial data. This data underpins a continuous cycle of observing, analyzing, designing, planning, constructing, and re-observing. Typical products derived from geospatial data include orthophoto maps, satellite image maps, topographic maps, and thematic maps, such as those illustrating land use and land use changes.

## 1.2 The Science and Process of Remote Sensing

Remote sensing (RS) involves acquiring information about the Earth's surface without direct contact. This is achieved by sensing and recording reflected or emitted energy, followed by processing, analyzing, and applying the data. **Throughout this textbook, "RS" will refer to "remote sensing".**

The remote sensing process typically includes an interaction between incident radiation and the target objects. This is especially evident in imaging systems, which involve some key elements. It's important to note that remote sensing can also involve detecting emitted energy and using non-imaging sensors.

(1) The initial requirement for remote sensing is an energy source that illuminates or provides electromagnetic energy to the target.

(2) As energy travels from its source to the target, it interacts with the atmosphere. This interaction may occur again as the energy travels from the target to the sensor.

(3) When energy reaches the target, it interacts based on the properties of both the target and the radiation.

(4) After the energy is scattered by or emitted from the target, a remote sensor collects and records the electromagnetic radiation.

(5) The data recorded by the sensor, often in electronic form, is sent to a receiving and processing station, where it is converted into an image (either hard copy or digital image).

(6) The processed image is then interpreted visually or digitally to extract information about the illuminated target.

(7) The final stage of remote sensing is applying the extracted information to better understand the target, uncover new information, or solve specific problems.

## 1.3 Fundamental Concepts of Electromagnetic Radiation in Remote Sensing

As discussed earlier, the initial requirement for remote sensing is an energy source to illuminate the target, unless the energy is emitted by the target itself. This energy takes the form of electromagnetic radiation.

Electromagnetic radiation has fundamental properties and behaves predictably according to wave theory principles (Figure 1.1). It consists of an electric field ($E$), which varies in magnitude in a direction perpendicular to the direction of radiation travel, and a magnetic field ($B$), oriented at right angles to the electric field. Both fields move at the speed of light ($c$).

Two key characteristics of electromagnetic radiation are essential for remote sensing: wavelength and frequency.

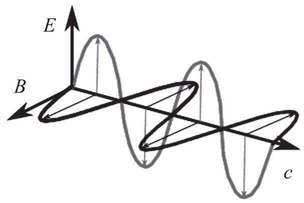


Figure 1.1 Electromagnetic radiation

**Wavelength**: This is the length of one wave cycle, measured as the distance between successive wave crests. Wavelength is usually represented by $\lambda$. 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, $10^{-2}$ meters).

**Frequency**: This refers to the number of wave cycles passing a fixed point per unit time, usually measured in hertz (Hz), where one Hz equals one cycle per second.

Wavelength and frequency are related by the following formula:

$$c = \lambda \nu \tag{1.1}$$

Where $\lambda$ is the wavelength (m); $\nu$ is the frequency (Hz); and $c$ is the speed of light ($3\times10^8$ m/s).

Wavelength and frequency are inversely related: shorter wavelengths correspond to higher frequencies, while longer wavelengths correspond to lower frequencies. Understanding these characteristics is crucial for interpreting remote sensing data. Next, we will explore how electromagnetic radiation is categorized for remote sensing purposes.

## 1.4 Electromagnetic Energy in Remote Sensing

While the sun is the primary source of electromagnetic (EM) energy, it is not the only one. All matter with a temperature above absolute zero emits EM energy due to molecular activity. Thermodynamic temperature, measured in kelvins (K), uses Celsius-scaled increments. At absolute zero (0 K = –273.15℃), molecular motion stops. The Earth's surface temperature averages 288 K, with minimal variation over time, causing the Earth's features to emit EM energy, replenished by solar radiation. The sun, at approximately 6000 K, emits 44% of its energy as visible light and 48% as infrared radiation.

The sun and stars behave like approximate black bodies, theoretical objects that absorb all incident radiation without reflection, appearing perfectly black. A black body re-emits all absorbed energy and has an emissivity of 1. Black bodies emit energy across all wavelengths, known as black body radiation, with the dominant wavelength determined by temperature. At room temperature, black bodies emit mainly infrared energy. As temperatures rise above 1273 K (1000℃), visible light emission becomes prominent, progressing through red, orange, yellow, white (at 6000 K), and eventually blue, with increasing ultraviolet radiation. The behavior of heated black bodies, like hot iron or a candle flame, demonstrates these principles. A candle flame's outer core appears light-blue at 1670 K, while the center appears orange at 1070 K. Flame colors, influenced by burning material, surrounding temperature, and oxygen levels, indicate different temperatures, ranging from 600℃ to 1400℃. By observing color, we can estimate temperatures, such as those of lava flows, from a safe distance. Remote sensing (RS) can use sensors to detect and quantify EM energy at various wavelengths, enabling temperature estimation of objects. Black body radiation curves show intensity increasing with temperature, with total radiant emittance represented by the area under the curve (Figure 1.2).

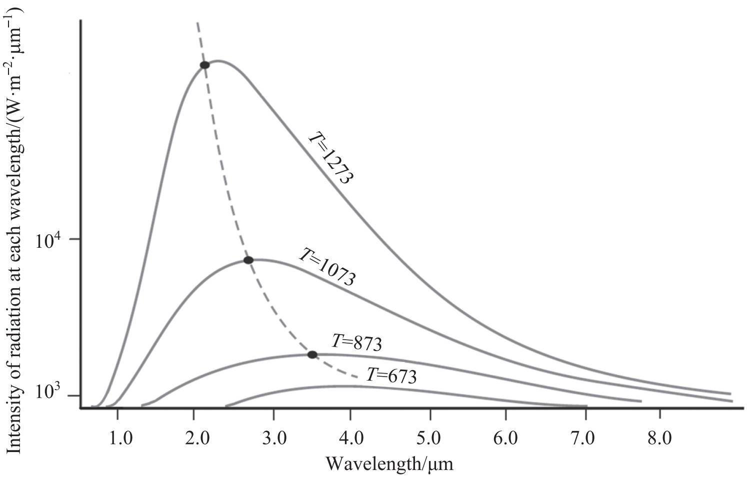


Figure 1.2 Black body radiation curves (with temperatures, $T$, in K)

Energy can be quantified in various ways. The total energy amount is commonly expressed in joules. Radiant power, the energy per unit time, is measured in watts (1 W = 1 $J \cdot s^{-1}$). Radiant emittance, the power emitted from a surface, is measured in watts per square meter ($W \cdot m^{-2}$). Spectral radiant emittance, the emittance per wavelength, is measured in $W \cdot m^{-2} \cdot \mu m^{-1}$, as shown in black body radiation curves. Radiance, another key measure in RS, describes the energy emitted or reflected from an area per unit solid angle and time, expressed in $W \cdot m^{-2} \cdot sr^{-1}$. Irradiance is the incident energy on a surface per unit area and time, also measured in $W \cdot m^{-2}$.

Real objects approximate black bodies, re-emitting about 80%–98% of received energy. Emissivity, a dimensionless ratio between 0 and 1, expresses the emitting ability of real materials compared to a black body. A material's spectral emissivity depends on factors such as temperature, emission angle, and wavelength. Understanding emissivity is crucial for modeling phenomena such as global warming.

## 1.5 Exploring the Electromagnetic Spectrum for Remote Sensing

The electromagnetic spectrum spans from short wavelengths, such as gamma and X-rays, to long wavelengths, including microwaves and broadcast radio waves. Various regions of the spectrum are valuable for remote sensing applications.

For most remote sensing purposes, the ultraviolet (UV) portion of the spectrum, which has the shortest practical wavelengths, is essential (Figure 1.3). UV radiation is just beyond the violet part of the visible spectrum. Certain earth materials, especially rocks and minerals, can fluoresce or emit visible light when exposed to UV radiation.

The visible spectrum, which our eyes can detect, is only a small part of the electromagnetic spectrum (Figure 1.4). Visible wavelengths range from approximately 0.4 μm to 0.7 μm, with red at the longest wavelength and violet at the shortest. This is the only part of the spectrum we can associate with colors. Blue, green, and red are the primary colors in the visible spectrum. They cannot be created from each other but can combine in various proportions to form other colors. Although sunlight appears uniform, it comprises multiple wavelengths primarily in the ultraviolet, visible, and infrared regions. Passing sunlight through a prism reveals its component colors by bending light according to wavelength[1].

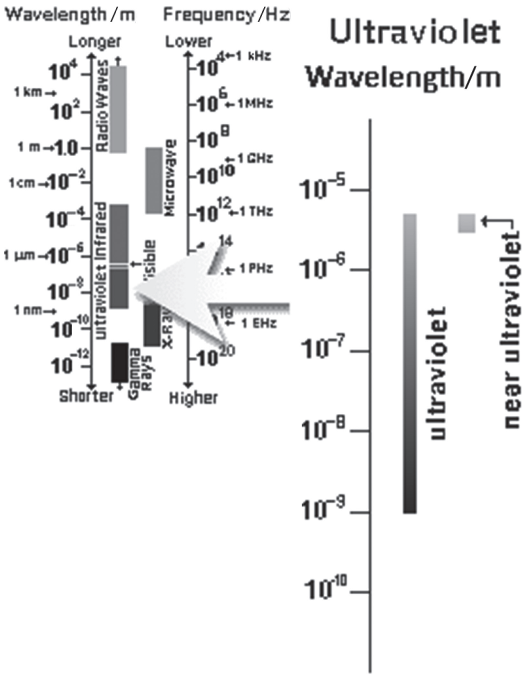


Figure 1.3 The ultraviolet or UV portion of the spectrum

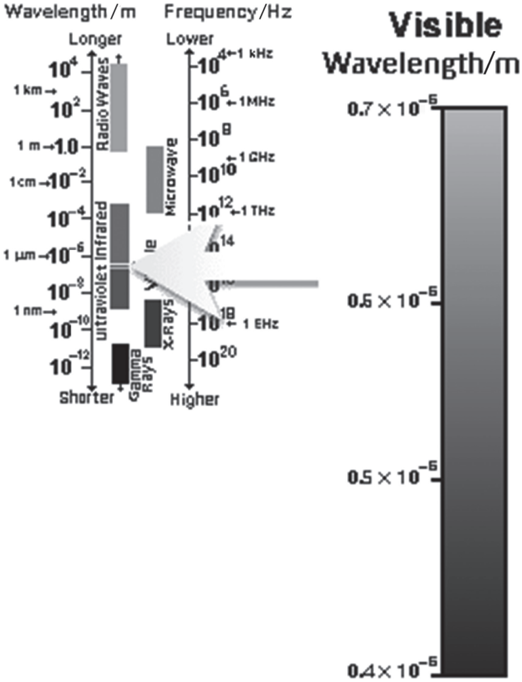


Figure 1.4 The visible spectrum

- **Violet**: 0.4–0.446 μm
- **Blue**: 0.446–0.500 μm
- **Green**: 0.500–0.578 μm
- **Yellow**: 0.578–0.592 μm
- **Orange**: 0.592–0.620 μm
- **Red**: 0.620–0.7 μm

The infrared (IR) region of the spectrum, ranging from approximately 0.7 μm to 100 μm, is more than 100 times wider than the visible portion (Figure 1.5). The IR region divides into two categories based on radiation properties: reflected IR and emitted (thermal) IR. The reflected IR, spanning wavelengths from about 0.7 μm to 3.0 μm, is used similarly to visible radiation in remote sensing. In contrast, the thermal IR, covering wavelengths from approximately 3.0 μm to 100 μm, consists of radiation emitted as heat from the Earth's surface.

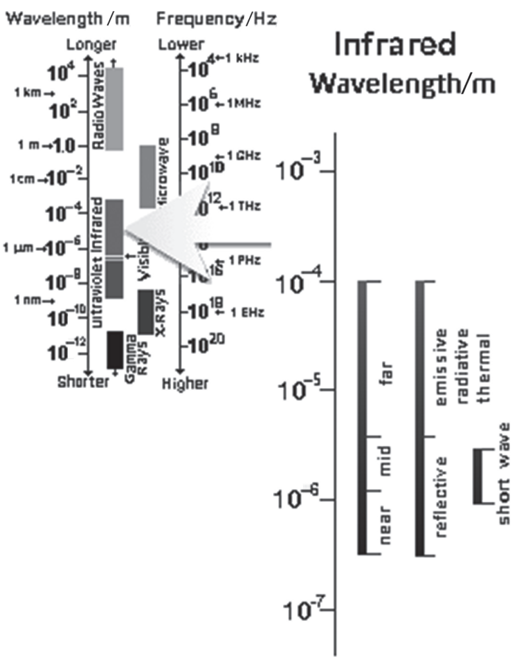


Figure 1.5 The infrared (IR) region of the spectrum

The microwave region has become increasingly significant in remote sensing (Figure 1.6). This region includes the longest wavelengths used for remote sensing. The shorter microwave wavelengths share properties with the thermal IR region, while the longer wavelengths are akin to those used in radio broadcasts.

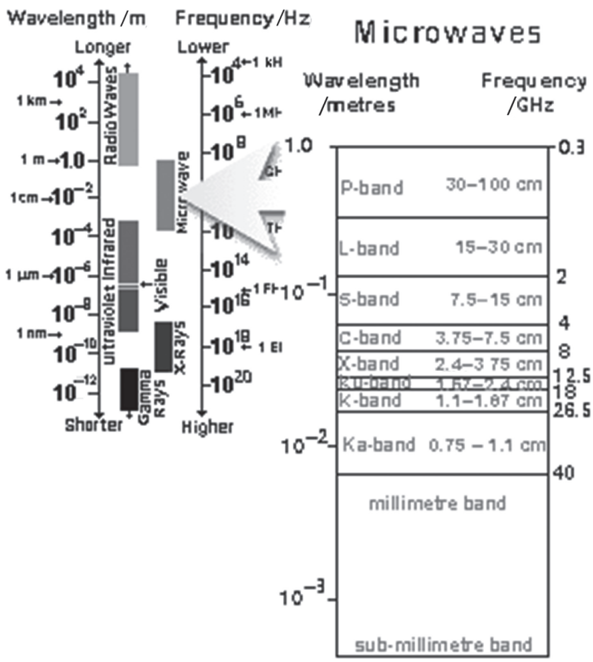


Figure 1.6 The microwave region of the spectrum

## 1.6 Atmospheric Radiation Dynamics

Before radiation used for remote sensing reaches the Earth's surface, it must travel through the Earth's atmosphere. Particles and gases in the atmosphere can affect incoming light and radiation through scattering and absorption.

Scattering (Figure 1.7) occurs when atmospheric particles or large gas molecules redirect electromagnetic radiation from its original path. The extent of scattering depends on the radiation's wavelength, the abundance of atmospheric particles or gases, and the distance traveled. There are three types of scattering: Rayleigh scattering, Mie scattering, and nonselective scattering.

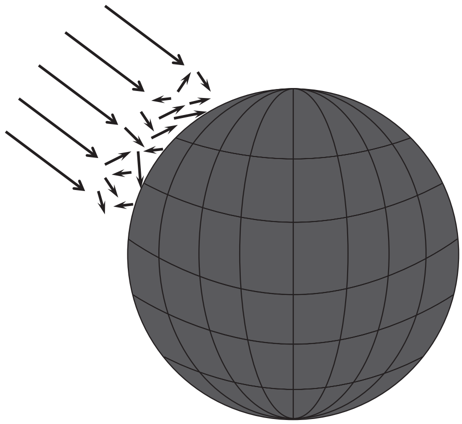

Figure 1.7 Illustration of scattering

**Rayleigh scattering:** This occurs when particles are much smaller than the wavelength of the radiation, such as dust specks or nitrogen and oxygen molecules (Figure 1.8). Rayleigh scattering predominantly affects shorter wavelengths, causing the blue sky phenomenon. At sunrise and sunset, light travels further through the atmosphere, scattering shorter wavelengths more completely, leaving longer wavelengths like red and orange more visible.

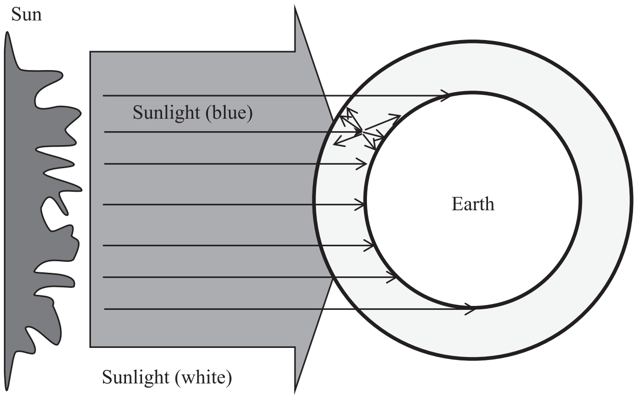


Figure 1.8 The effects of Rayleigh scattering

**Mie scattering:** This occurs when particles are about the same size as the wavelength, such as dust, pollen, smoke, and water vapor. Mie scattering primarily affects longer wavelengths and is more prevalent in the lower atmosphere, particularly under overcast conditions.

**Nonselective scattering:** This occurs when particles are much larger than the wavelength of the radiation, such as water droplets and large dust particles. Nonselective scattering affects all wavelengths equally, causing fog and clouds to appear white as blue, green, and red light are scattered equally (blue light+green light +red light = white light).

**Absorption:** It is another key mechanism, where atmospheric molecules absorb energy at various wavelengths. The main atmospheric constituents responsible for absorption are ozone, carbon dioxide, and water vapor.

**Ozone:** Absorbs harmful ultraviolet radiation from the sun, protecting living organisms from sunburn and other damage.

**Carbon dioxide:** Known as a greenhouse gas, it absorbs strongly in the far infrared portion of the spectrum, trapping heat in the atmosphere.

**Water vapor:** Absorbs longwave infrared and shortwave microwave radiation. The concentration of water vapor varies greatly by location and season, with deserts having little water vapor and tropical regions having high humidity.

The selective absorption by these gases creates regions in the spectrum where remote sensing is less effective. However, certain regions, known as atmospheric windows (Figure 1.9), are less affected by absorption and are ideal for remote sensing.

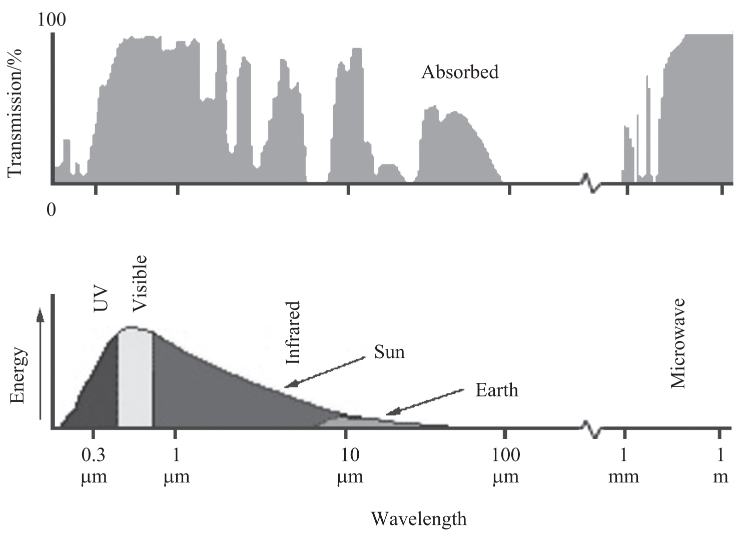


Figure 1.9 Examples of atmospheric windows