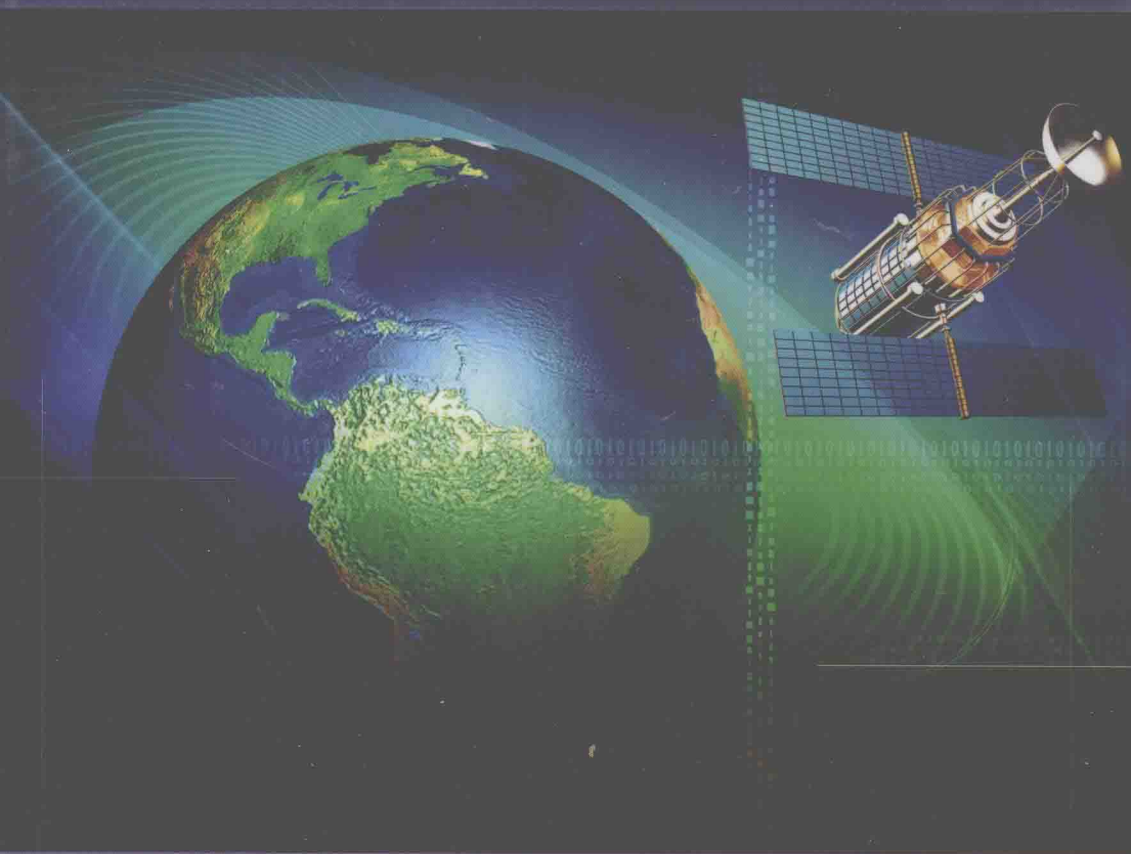


# FUNDAMENTALS OF SATELLITE REMOTE SENSING

Emilio Chuvieco *and* Alfredo Huete



CRC Press

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Emilio Chuvieco

With the collaboration of

Alfredo Huete



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# *Dedication*

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*To all mothers ...*

*Because they chose to give us life*

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# Foreword

The growing concern about the future and welfare of our planet has spurred great interest in monitoring environmental phenomena so that we may better understand how the Earth functions and how we may mitigate or adapt to future environments. Satellite remote sensing is a particularly valuable tool to collect critical information on the state and condition of the Earth. The impacts of climate change, deforestation, desertification, fire, floods, and other natural and man-caused disturbances require an up-to-date, spatially comprehensive, and global source of terrestrial data. Satellite Earth observations provide such global, recurrent, and comprehensive views of the many dynamic processes that are affecting the health, resources, and habitability of our planet. Human beings have demonstrated their capacity to dramatically alter Earth's natural systems with both beneficial and negative consequences. To make more informed decisions concerning our changing environment, a better understanding of the tools used in environmental monitoring becomes important. Watching how our planet changes from space may not be sufficient to modify our current way of living, but it will certainly help us to more wisely manage our resources and move in more sustainable directions, because access to continuous and updated information is the basis for making rational decisions.

This book is a modest attempt to help the student and professional become more familiar with remote sensing technology. Many books have already been published on this topic, which we obviously do not try to amend. The scope of this book relies on focusing on only satellite remote sensing systems. A basic knowledge of aerial photography is assumed, and the main effort here is dedicated to digital interpretation. However, a chapter on visual analysis of satellite images is also included to offer a synergic use of visual and digital interpretation techniques. A chapter on accuracy assessment and the connection between remote sensing and geographic information systems is also provided to help the reader extend the interpretation of satellite images to a more operational, applications-oriented framework.

This book was initially published in Spanish in 1990. This version is based on the fourth Spanish edition, published in 2008, with extensive updating over the previous version. In addition to translation of all the materials, we have tried to adapt the contents to the American student by including a wide range of satellite images from the United States. More than half of the figures of this edition are new with respect to the Spanish version. Whenever sources are not given for figures, it should be assumed that they proceed from the Spanish text. Formulas are referenced by parentheses ( ) and are numbered sequentially, preceded by the number of the chapter, in the same way as the figures.

A CD is included with the book to extend the educational materials that may be useful for teaching this course. The CD includes a set of PowerPoint™ presentations and images for educational purposes.

The book underwent a relatively long history until it was finally completed. We would like to thank the publishing company for their support in the process, and the valuable suggestions of colleagues and students who have helped to shape the text in a more pedagogical way. Particular thanks to Edna Rodriguez for help in translating and to Paul Bolstad who helped to review the first chapters of the book.

Writing a textbook is really a difficult task that is highly underappreciated by current academic evaluation criteria. Our main interest in carrying out this task was to help students and colleagues discover a fascinating world, as observed from above Earth, as well as to facilitate their learning of concepts and tools so that they can make more effective use of satellite data for the benefit of humankind.

**Emilio Chuvieco**

**Alfredo Huete**

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# 1 Introduction

## 1.1 DEFINITION AND OBJECTIVES

One of the earliest dreams of humans has been to fly and observe Earth and its landscapes from above. This has been realized only recently with the advent of balloons, gliders, and airplanes. Today, as a result of rapid technological advances, we routinely survey our planet's surface from airplanes and we can now, for the first time in human history, observe the entire Earth as a planet from space. The photographs and digital images sent back from satellites have revolutionized our knowledge and understanding and have enabled new discoveries about our planet's environment and its inhabitants.

A key driving force in our quest to fly above the ground has been to find new perspectives from which to observe Earth's diverse landscapes. Our view of Earth is quite limited when we are confined to the ground. Our desire to survey entire landscapes, mountain ranges, volcanoes, hurricanes, rivers, and ice fields has been evident since the beginnings of aeronautics and now forms the foundation of space-based Earth observations.

The surveillance of Earth's terrestrial landscapes, oceans, and ice sheets constitutes the main goal of "remote sensing" techniques. The term *remote sensing* was first utilized in the early 1960s to describe any means of observing the Earth from afar, particularly as applied to aerial photography, the main sensor used at that time. In a broader context, remote sensing activities encompass a multitude of activities, including the operation of satellite systems, image data acquisition and storage, and the subsequent data processing, interpretation, and dissemination of the processed data and image products.

In this book, we will deal with Earth observation from space-borne imaging sensors, encompassing sensors mounted on and imagery obtained from orbiting satellites. There is also a multitude of airborne sensing systems (aerial photography, videography, and radar systems) that also play an important role in remote sensing of the Earth's surface. Airborne remote sensing is particularly valuable in research, development, and validation of new sensor systems and in assessing science applications of satellite observation data. We assume the reader is familiar with basic, visual photo-interpretation techniques and focus here on the principles of satellite remote sensing systems and their applications in environmental studies, particularly as they relate to topics of interest among environmental scientists, including biologists, geologists, ecologists, geographers, foresters, agronomists, pedologists, oceanographers, and cartographers.

Remote sensing may be more formally defined as the acquisition of information about the state and condition of an object through sensors that are not in physical contact with it. A remote observation requires some kind of energy interaction

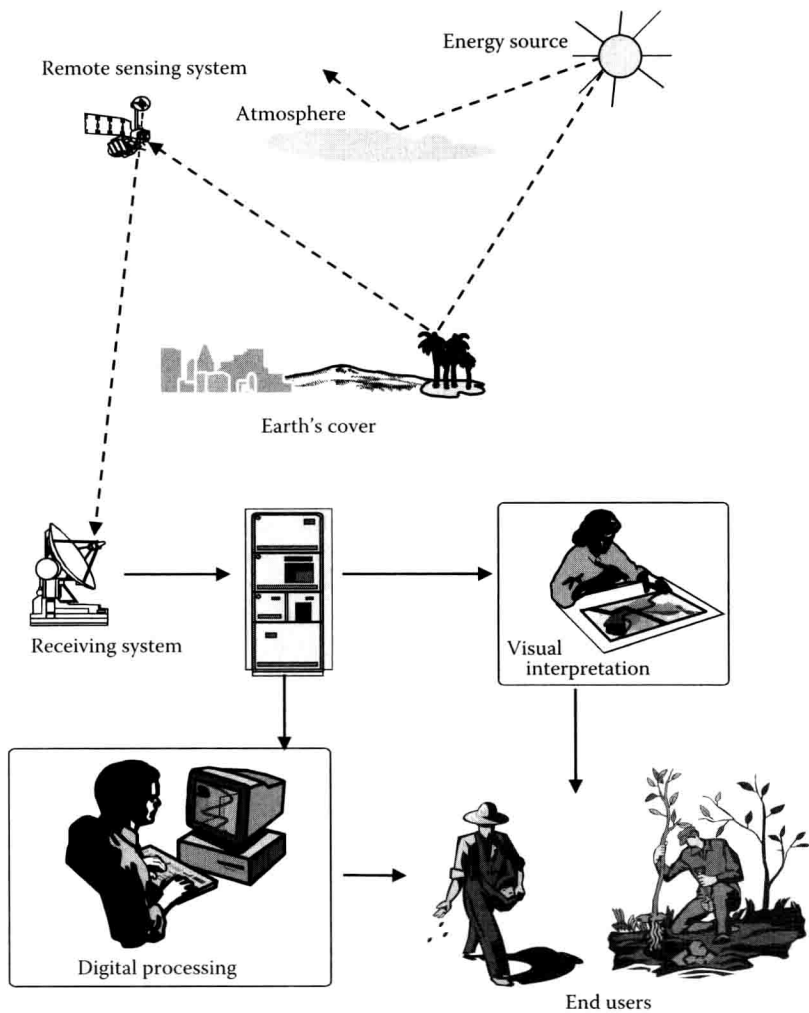
between the target and the sensor. The sensor-detected signal may be solar energy (from the Sun) that is reflected from the Earth's surface or it may be self-emitted energy from Earth itself. We can also build sensors that produce their own energy source, which is then measured after interacting with the Earth's surface. The radiant energy signal that is detected and measured by the satellite sensor is then either stored in memory on board the satellite or transmitted to a ground receiving station for later interpretation.

Remote sensing also includes the analysis and interpretation of the acquired data and imagery. For environmental scientists this is the most important aspect of remote sensing, since the main value of this technique is to provide relevant information for monitoring Earth resources. For this reason, this book will focus on the interpretation and analysis of remote sensing images for improving our understanding of environmental processes and their interaction with human activities.

In summary, remote sensing, as treated in this book, includes the following six components (Figure 1.1):

1. An energy source, or source of the electromagnetic radiation to be detected by the sensor. The most important source of energy is the Sun, as it illuminates and heats the Earth.
2. Earth's surface, consisting of vegetation, soils, water, rocks, snow, and human structures. These surfaces receive the incident energy from the source (1) and, as a result of physical and chemical interaction with the incoming energy, reflect and emit a part of that energy back toward the satellite sensor.
3. The sensor instruments and their platform. The instruments' main role is to measure and record the energy leaving the surface. The platform provides the major services for the satellite and payload operation, such as attitude and orbit control, power supply, instrument monitoring, and control of telecommunications with ground receiving stations. The energy measured and recorded is transmitted to the ground receiving station through digital telemetry.
4. The receiving station, which collects the raw digital data measured by the sensor and converts it into an appropriate format. Some basic pre-processing procedures and corrections are generally performed prior to the distribution of the imagery.
5. The analyst, who converts the processed image data into thematic information of interest, using visual and/or digital techniques.
6. The user community, which utilizes the thematic products for a wide variety of applications.

We can illustrate the six components by using the human eye as an example. The eye is a sensor (3) that "sees" the reflected sunlight (1) from the various objects observed (2). The received electromagnetic signal is transmitted to the brain (4), which then generates an image of what was observed. The observer (5) further analyzes and interprets the image and, as the end user (6), applies this knowledge



**FIGURE 1.1** Illustration of the main components associated with remote sensing activities.

toward making appropriate decisions concerning his or her own behavior. Human vision is a sophisticated and complete remote sensing system, allowing us to characterize and use what we observe in great detail.

Despite the sophisticated nature of human eyesight, our personal remote sensing capabilities have several important limitations. Our eyes are restricted to a narrow portion of the electromagnetic spectrum, known as the “visible region.” Other forms of electromagnetic energy, such as infrared, microwave, and ultra-violet radiation, cannot be seen with our eyes. In addition, our eyes are dependent on a source of external energy (the Sun or artificial light), as we are unable to “see” in total darkness. Also, human vision is constrained by our own height,

which restricts our observing capabilities to a limited, and often oblique, view of our surroundings. These factors hinder our ability to observe wide-view environmental phenomena, such as droughts and floods, deforestation and desertification processes, rendering our visual appraisals highly qualitative and narrow in scope.

Remote sensing allows us to overcome these limitations through the use of detectors (“artificial eyes”) that permit us to broaden our perception and awareness of our environment beyond the visible portion of the spectrum. These sensors are mounted on board platforms that can view Earth’s surface synoptically at multiple scales and altitudes. Remote sensing is thus an extension of our eyes in two respects: (1) We are able to raise our “eyes” above the surface for synoptic viewing, and (2) we are able to extend these “eyes” into different parts of the spectrum where we are able to “see” through clouds and “see” at night. These new capabilities of Earth observation have not only greatly expanded our knowledge about the environment, but also facilitated the visualization and interpretation of the numerous processes acting on our planet.

Today, there are an increasing number of satellite sensor systems being used to observe and monitor Earth (and neighboring celestial bodies). These sensors generate an enormous quantity of data and a variety of new ways to study the complex dynamics of Earth’s surface. Remote sensing, in conjunction with parallel developments in geographical information systems (GIS), global positioning systems (GPS) and other ground data collection systems, now provides vast amounts of information about the land surface, to improve our understanding of the Earth system and better contribute to preserving it.

The effective utilization of such enormous quantities of data is accomplished with the use of computers, which perform the tedious and time-consuming tasks of data handling and processing to enable quick and efficient user interpretations and problem solving. Computers also facilitate our capability to perform integrated analysis of spatial data, a difficult task using traditional visual interpretation methods. By enhancing our analytical capacity, we are able to focus more on data interpretation, problem solving, and making appropriate management decisions, tasks in which human intelligence is irreplaceable.

In this book, we organize our study of remote sensing systems around the six components described earlier: energy sources and interactions with terrestrial surfaces, sensing and receiving systems, analysis of the acquired data, and connection to end-users. In the first part of this book, we cover the basic processes that allow for the acquisition of space-borne imagery, including the physical principles of energy transmission and image acquisition; optical, thermal, and microwave radiant energy interactions with Earth’s surface (Chapter 2); and an overview of some of the main satellite observation systems (Chapter 3). The remaining chapters focus on visual and digital image analysis and interpretation techniques and their applications to science and management (Chapters 4 through 8). The final chapter is devoted to the integration of remote sensing with GIS for environmental analysis (Chapter 9). This first chapter also presents an overview of remote sensing with discussion on its foreseeable developments and some remarks on legal issues and international debate concerning Earth observation across national boundaries.



1.2 HISTORICAL BACKGROUND

Remote sensing, as an applied tool and methodology, has evolved historically in parallel with other technological advancements, such as the improvements in optics, sensor electronics, satellite platforms, transmission systems, and computer data processing. These developments have resulted in enormous progress in the quantity, quality, and diversity of data available to the scientific community. A summary of milestones in remote sensing observation is included in Figure 1.2.

Some of the earliest remote sensing events can be traced back to the mid-1800s, simultaneous with the development of photography. In 1839, the first ever photos were taken in France by Daguerre, Talbot, and Niepce, and by 1840 the French began using photos to produce topographic maps. In 1858, the first aerial photos were taken from a height of 80 m over Bievre, France, by Gaspard Félix Tournachon using cameras mounted on a hot air balloon. Balloon photography rapidly became commonplace, and by 1860, James Wallace Black used this methodology over the city of Boston to aid in urban planning. There are also some claims that aerial reconnaissance was used during the American Civil War with hot-air-balloon-mounted cameras. In the 1880s, the British used kites to obtain aerial photography, and in the early 1900s, carrier pigeons were able to fly as more advanced, smaller, and lighter cameras were developed. The great San Francisco earthquake of 1906 was captured on film using a panoramic camera mounted 600 m above San Francisco Bay and supported by a string of kites.

The next major milestone in remote sensing occurred in 1909, when Wilbur Wright shot the first photographs over Italy from an airplane, establishing a new era of observations from airborne platforms. By 1915 and during World War I, the British Royal Air Force was collecting aerial reconnaissance photos with cameras designed specifically for aircraft (Brookes 1975). By the early 1930s, many developments in photo acquisition and processing techniques were taking place. In 1930, the first aerial multispectral photographs were collected by Krinov and

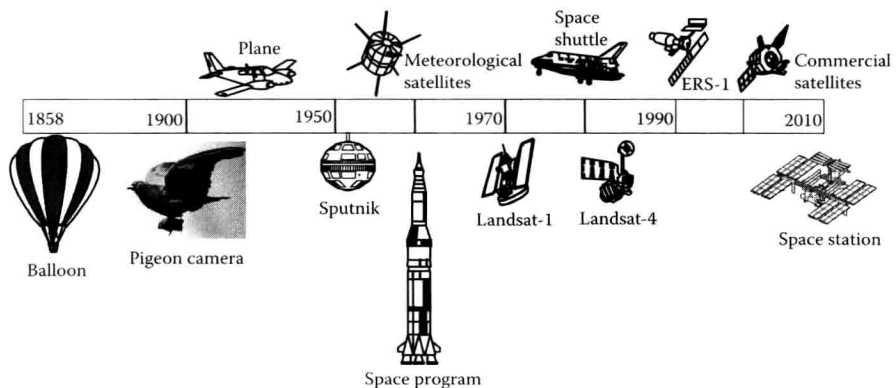


FIGURE 1.2 Historical development of remote sensing systems.