Remote Sensing Measurement

Orbital platform

Suborbital platform

Remote platform

Remote sensing instrument

Height above ground level (AGL)

β
instantaneous field-of-view (IFOV)
of the sensor system

Object, area, or materials within the ground-projected IFOV

diameter of the ground-projected IFOV

Figure 1-2: A remote sensing instrument collects information about an object or phenomenon within the instantaneous field-of-view (IFOV) of the sensor system without being in direct physical contact with it. The remote sensing instrument may be located just a few meters above the ground and/or onboard an aircraft or satellite platform.

Remote sensing data collection was originally performed using cameras mounted in suborbital aircraft. Photogrammetry was defined in the early editions of the Manual of Photogrammetry as:

the art or science of obtaining reliable measurement by means of photography (American Society of Photogrammetry, 1952, 1966).

Photographic interpretation is defined as:

the act of examining photographic images for the purpose of identifying objects and judging their significance (Colwell, 1960).

Remote sensing was formally defined by the American Society for Photogrammetry and Remote Sensing (ASPRS) as:

the measurement or acquisition of information of some property of an object or phenomenon, by a recording device that is not in physical or intimate contact with the object or phenomenon under study (Colwell, 1983).

In 1988, ASPRS adopted a combined definition of photogrammetry and remote sensing:

Photogrammetry and remote sensing are the art, science, and technology of obtaining reliable information about physical objects and the environment, through the process of recording, measuring and interpreting imagery and digital representations of energy patterns derived from non-contact sensor systems (Colwell, 1997).

But where did the term remote sensing come from? The actual coinage of the term goes back to an unpublished paper in the early 1960s by the staff of the Office of Naval Research Geography Branch (Pruitt, 1979; Fussell et al., 1986). Evelyn L. Pruitt was the author of the paper. She was assisted by staff member Walter H. Bailey. Aerial photo interpretation had become very important in World War II. The space age was just getting under way with the 1957 launch of Sputnik (U.S.S.R.), the 1958 launch of Explorer 1 (U.S.), and the collection of photography from the then secret CORONA program initiated in 1960 (Table 1-1). In addition, the Geography Branch of ONR was expanding its research using instruments other than cameras (e.g., scanners, radiometers) and into regions of the electromagnetic spectrum beyond the visible and near-infrared regions (e.g., thermal infrared, microwaves). Thus, in the late 1950s it had become apparent that the prefix “photo” was being stretched too far in view of the fact that the root word, photography,
literally means "to write with [visible] light" (Colwell, 1997). Evelyn Pruitt (1979) wrote:

The whole field was in flux and it was difficult for the Geography Program to know which way to move. It was finally decided in 1960 to take the problem to the Advisory Committee. Walter R. Bailey and I pondered a long time on how to present the situation and on what to call the broader field that we felt should be encompassed as a program to replace the aerial photointerpretation project. The term 'photograph' was too limited because it did not cover the region in the electromagnetic spectrum beyond the 'visible' range, and it was in these non-visible frequencies that the future of interpretation seemed to lie. 'Aerial.' was also too limited in view of the potential for seeing the Earth from space.

The term remote sensing was promoted in a series of symposia sponsored by ONR at the Willow Run Laboratories of the University of Michigan in conjunction with the National Research Council throughout the 1950s and early 1960s, and has been in use ever since (Eastes and Jensen, 1998).

Maximal/Minimal Definitions:

Numerous other definitions of remote sensing have been proposed. In fact, Colwell (1984) suggests that "one measure of the newness of a science, or of the rapidity with which it is developing is to be found in the preoccupation of its scientists with matters of terminology." Some have proposed an all-encompassing maximal definition: Remote sensing is the acquiring of data about an object without touching it.

Such a definition is short, simple, general, and memorable. Unfortunately, it excludes many from the family of remote sensing (Russell et al., 1986). It encompasses virtually all remote sensing devices, including radars, optical/mechanical sensors, linear and area arrays, lasers, radar systems, seismotomography, gravimeters, magnetometers, and circulation sensors.

Others have suggested a more focused, minimal definition of remote sensing that adds qualifier after qualifier in an attempt to make certain that only legitimate functions are included in the term's definition. For example:

Remote sensing is the noncontact recording of information from the ultraviolet, visible, infrared, and microwave regions of the electromagnetic spectrum by means of instruments such as cameras, scanners, lasers, linear arrays, and/or area arrays located on platforms such as airplanes, spacecraft, and the analysis of acquired information by means of visual and digital image processing.

Robert Green at NASA's Jet Propulsion Lab (JPL) suggests that the term remote measurement might be used instead of remote sensing because data obtained using the new hyperspectral remote sensing systems are so accurate (Robbins, 1999). Each of the definitions are correct in an appropriate context. It is useful to briefly discuss components of these remote sensing definitions.

Remote Sensing: Art and/or Science?

Science: A science is defined as a broad field of human knowledge concerned with facts held together by principles (rules), scientists discover and test facts and principles by the scientific method, an orderly system of solving problems. Scientists generally feel that any subject that humans can study by using the scientific method and other special rules of thinking may be called a science. The sciences include: 1) mathematics and logic, 2) physical sciences, such as physics and chemistry, 3) biological sciences, such as botany and zoology, and 4) the social sciences, such as geography, sociology, and anthropology (Figure 1-3). Interestingly, some persons do not consider mathematics and logic to be sciences. But the fields of knowledge associated with mathematics and logic are such valuable tools for science that we cannot ignore them. The human race's earliest questions were concerned with "how many" and "what belonged together." They struggled to count, to classify, to think systematically, and to describe exactly. In many respects, the state of development of a science is indicated by the use it makes of mathematics. A science seems to begin with simple mathematics to measure, then works toward more complex mathematics to explain.

Remote sensing is a tool or technique similar to mathematics. Using sophisticated sensors to measure the amount of electromagnetic energy emitted by an object or geographic area from a distance and then extracting valuable information from the data using mathematically and statistically based algorithms is a scientific activity (Russell et al., 1986). Remote sensing functions in harmony with other geographic information sciences (often referred to as GIScience), including cartography, surveying, and geographic information systems (GIS) (Curran, 1987; Clarke, 2001; Jensen, 2005). Dahlberg and Jensen (1996) and Fisher and Lindenberg (1989) suggested a model where there is interaction.
between remote sensing, cartography, surveying, and GIS, where no sub-discipline dominates and all are recognized as having unique yet overlapping areas of knowledge and intellectual activity as they are used in physical, biological, and social sciences (Figure 1-3).

The theory of science suggests that scientific disciplines go through four classic developmental stages. Wolfer (1979) suggested that the growth of a scientific discipline, such as remote sensing, has its own techniques, methodologies, and intellectual orientation seems to follow the sigmoid or logistic curve illustrated in Figure 1-4. The growth stages of a scientific field are: Stage 1 — a preliminary growth period with small increments of literature; Stage 2 — a period of exponential growth when the number of publications doubles at regular intervals; Stage 3 — a period when the rate of growth begins to decline but annual increments remain constant; and Stage 4 — a final period when the rate of growth approaches zero. The characteristics of a scholarly field during each of the stages may be briefly described as follows: Stage 1 — little or no social organization; Stage 2 — growth of collaborations and existence of invisible colleges, often in the form of ad hoc institutes, research units, etc.; Stage 3 — increasing specialization and increasing controversy; and Stage 4 — decline in membership in both collaborators and invisible colleges.

Using this logic, it may be suggested that remote sensing is in Stage 2 of a scientific field, experiencing exponential growth since the mid-1960s with the number of publications doubling at regular intervals (Colwell, 1983; Cracknell and Hayes, 1992; Jenson, 2005). Empirical evidence is presented in Table 1-3, including: 1) the organization of many specialized institutes and centers of excellence associated with remote sensing, 2) the organization of numerous professional societies devoted to remote sensing research, 3) the publication of numerous new scholarly remote sensing journals, 4) significant technological advancement such as improved sensor systems and methods of image analysis, and 5) intense self-examination (e.g., DeSienzo and Fritzi, 2000). We may be approaching Stage 3 with increasing specialization and theoretical controversy. However, the rate of growth of remote sensing has not begun to decline. In fact, there has been a tremendous surge in the numbers of persons specializing in remote sensing and commercial firms using remote sensing during the 1990s and early 2000s (Davis, 1999; ASPRS, 2004). Significant improvements in the spatial resolution of satellite remote sensing (e.g., more useful 1 × 1 m panchromatic data) has brought even more social science GIS practitioners into the fold. Hundreds of new peer-reviewed remote sensing research articles are published every month.

Art: The process of visual photo or image interpretation brings to bear not only scientific knowledge, but all of the background that a person has obtained through his or her (evening) such learning cannot be measured, programmed, or completely understood. The synergism of combining scientific knowledge with real-world analyst experience allows the interpreter to develop heuristic rules of thumb to extract...
valuable information from the imagery. It is a fact that some image analysts are superior to other image analysts because they: 1) understand the scientific principles better, 2) are more widely traveled and have seen many landscape objects and geographic areas, and/or 3) they can synthesize scientific principles and real-world knowledge to reach logical and correct conclusions. Thus, remote sensing image interpretation is both an art and a science.

**Information About an Object or Area**

Sensors can obtain very specific information about an object (e.g., the diameter of an oak tree crown) or the geographic extent of a phenomenon (e.g., the polygonal boundary of an entire oak forest). The electromagnetic energy emitted or reflected from an object or geographic area is used as a surrogate for the actual property under investigation. The electromagnetic energy measurements must be turned into information using visual and/or digital image processing techniques.

**The Instrument (Sensor)**

Remote sensing is performed using an instrument, often referred to as a sensor. The majority of remote sensing instruments record EMR that travels at a velocity of $3 \times 10^8$ m s$^{-1}$ from the source, directly through the vacuum of space or indirectly by reflection or reradiation is the sensor. The EMR represents a very efficient high-speed communications link between the sensor and the remote phenomenon. In fact, we know of nothing that travels faster than the speed of light. Changes in the amount and properties of the EMR become, upon detection by the sensor, a valuable source of data for interpreting important properties of the phenomenon (e.g., temperature, color). Other types of force fields may be used in place of EMR, such as acoustic (sonar) waves (e.g., Durnell and Gardner, 2004). However, the majority of remotely sensed data collected for Earth resource applications is the result of sensors that record electromagnetic energy.

**Distance: How Far Is Remote?**

Remote sensing occurs at a distance from the object or area of interest. Interestingly, there is no clear distinction about how great this distance should be. The intervening distance could be 1 cm, 1 m, 100 m, or more than 1 million m from the object or area of interest. Much of astronomy is based on remote sensing. In fact, many of the most innovative remote sensing systems and visual and digital image processing methods were originally developed for remote sensing extraterrestrial landscapes such as the moon, Mars, Io, Saturn, Jupiter, etc. This text, however, is concerned primarily with remote sensing of the terrestrial Earth, using sensors that are placed on suborbital air-breathing aircraft or orbital satellite platforms placed in the vacuum of space.

Remote sensing and digital image processing techniques can also be used to analyze inner space. For example, an electron microscope can be used to obtain photographs of extremely small objects on the skin, in the eye, etc. An x-ray instrument is a remote sensing system where the skin and muscle are like the atmosphere that must be penetrated, and the interior bone or other matter is the object of interest.

**Remote Sensing Advantages and Limitations**

Remote sensing has several unique advantages as well as some limitations.

**Advantages**

Remote sensing is non-invasive if the sensor is passively recording the electromagnetic energy reflected from or emitted by the phenomenon of interest. This is a very important consideration, as passive remote sensing does not disturb the object or area of interest.

Remote sensing devices are programmed to collect data systematically, such as within a single 9 x 9 m frame of vertical aerial photography or a matrix (raster) of Landsat 5 Thematic Mapper data. This systematic data collection can remove the sampling bias introduced in some in situ investigations (e.g., Karaska et al., 2004).

Remote sensing science is also different from cartography or GIS because these sciences rely on data obtained by others. Remote sensing science can provide fundamental, new scientific information. Under controlled conditions, remote sensing can provide fundamental biophysical information, including x,y location; z elevation or depth; biomass; temperature; and moisture content. In this sense, remote sensing science is much like surveying, providing fundamental information that other sciences can use when conducting scientific investigations. However, unlike much of surveying, the remotely sensed data can be obtained systematically over very large geographic areas rather than just single-point observations. In fact, remote sensing-derived information is now critical to the successful modeling of numerous natural (e.g., water-supply estimation; eutrophication studies; non-point source pollution) and cultural (e.g., land-use conversion at the urban fringe; water-demand estimation; population estimation) processes (Walsh et al., 1999; Stow et al., 2003; Nemani et al., 2003; Karaska et al., 2004). A good
example is the digital elevation model that is so important in many spatially-distributed GIS models (Clarke, 2011). Digital elevation models are now produced from stereo-
scopic imagery, light detection and ranging (lidar) (e.g., Magoon, 2001; Hodgson et al., 2003b, 2005), radio detection and ranging (radar) (radar) measurements, or interferometric synthetic aperture radar (ifsar) imagery.

Limitations

Remote sensing science has limitations. Perhaps the greatest limitation is that it often overestimates. Remote sensing is not a panacea that will provide all the information needed to con-
duct physical, biological, or social science research. It sim-
ply provides some spatial, spectral, and temporal information of value in a manner that we hope is efficient and economical.

Human beings select the most appropriate remote sensing system to collect the data, specify the various resolutions of the remote sensor data, calibrate the sensor, select the plat-
form that will carry the sensor, determine when the data will be collected, and specify how the data are processed. Human method-produced error may be introduced as the remote sensing instrument and mission parameters are specified.

Powerful active remote sensor systems that emit their own electromagnetic radiation (e.g., lidar, radar, sonar) can be intrusive and affect the phenomenon being investig-
gated. Additional research is required to determine how intrusive these active-sensor systems can be.

Remote sensing instruments may become uncalibrated, resulting in uncalibrated remote sensor data. Finally, remote sensor data may be expensive to collect and analyze. Hope-
fully, the information extracted from the remote sensor data justifies the expense. Interestingly, the greatest expense in a typical remote sensing investigation is for well-trained image analysis, not remote sensor data.

The Remote Sensing Process

Scientists have been developing procedures for collecting and analyzing remotely sensed data for more than 150 years. The first photograph from an aerial platform (a tethered balloon) was obtained in 1858 by the Frenchman (Henriard Feli); Tourjmaison (who called himself Nadar). Significant strides in aerial photography and other remote sensing data collec-
tion took place during World War II and IF, the Korean Con-
flict, the Cuban Missile Crisis, the Vietnam War, the Gulf

War, the war in Bosnia, and the war on terrorism. Many of
the accomplishments are summarized in Table 1-1 and in
Chapter 3 (History of Aerial Photography and Aerial Plat-
forms). Basically, military contracts to commercial compa-
nies resulted in the development of sophisticated electro-
optical multispectral remote sensing systems and thermal
infrared and microwave (radar) sensor systems whose char-
acteristics are summarized in Chapters 7, 8, and 9, respec-
tively. While the majority of the remote sensing systems
may have been initially developed for military surveil-
ance applications, the systems are also heavily used for
monitoring the Earth's natural resources.

The remote sensing data—collection and analysis procedures
used for Earth resource applications are often implemented
in a systematic fashion that can be termed the remote sensing
process. The procedures in the remote sensing process are
summarized here and in Figure 1-5:

- The hypothesis to be tested is defined using a specific type of
  logic (e.g., inductive, deductive) and an appropriate
  processing model (e.g., deterministic, stochastic).

- In situ and collateral data necessary to calibrate the remote
  sensor data and/or judge its geometric, radiometric, and
  thematic characteristics are collected.

- Remote sensor data are collected passively or actively
  using analog or digital remote sensing instruments, ideally
  at the same time as the in situ data.

- In situ and remotely sensed data are processed using a
  variety of computer processing models (e.g., digital image
  processing, c, digital image processing, c, model-
  ing, and non-dimensional visualization).

- Metadata, processing lineages, and the accuracy of the
  information are provided and the results communicated
  using images, graphs, statistical tables, GIS databases,
  Spatial Decision Support Systems (SDSS), etc.

It is useful to review the characteristics of these remote sens-
ing processes procedures.

Statement of the Problem

Sometimes the general public and even children look at
aerial photography or other remote sensor data and extract
useful information. They typically do this without a formal
hypothesis in mind. More often than not, however, they
interpret the imagery incorrectly because they do not under-
stand the nature of the remote sensing system used to collect
the data or appreciate the vertical or oblique perspective of the terrain recorded in the imagery.

Scientists who use remote sensing, on the other hand, are usually trained in the scientific method—a way of thinking about problems and solving them. They use a formal plan that has at least five elements: 1) stating the problem, 2) forming the research hypothesis (i.e., a possible explanation), 3) observing and experimenting, 4) interpreting data, and 5) drawing conclusions. It is not necessary to follow this formal plan exactly.

The scientific method is normally used in conjunction with environmental models that are based on two primary types of logic:

- deductive logic
- inductive logic

Models based on deductive and/or inductive logic can be further subdivided according to whether they are processed deterministically or stochastically (Jensen, 2005). Some scientists extract new thematic information directly from remotely sensed imagery without ever explicitly using an inductive or deductive logic. They are just interested in extracting information from the imagery using appropriate methods and technology. This technological approach is not as rigorous, but it is common in applied remote sensing. The approach can also generate new knowledge.

Remote sensing is used in both scientific (inductive and deductive) and technological approaches to obtain knowledge. There is debate as to how the different types of logic used in the remote sensing process yield new scientific knowledge (e.g., Russell et al., 1986; Curran, 1987; Fisher and Lindenberg, 1989; Dobson, 1993; Skidmore, 2002).
CHAPTER 1 Remote Sensing of the Environment

Identification of In situ and Remote Sensing Data Requirements

If a hypothesis is formulated using inductive or deductive logic, a list of variables or observations are identified that will be used during the investigation. In situ observation and/or remote sensing may be used to collect information on the most important variables.

Scientists using remote sensing technology should be well trained in field and laboratory data-collection procedures. For example, if a scientist wants to map the surface temperature of a lake, it is usually necessary to collect accurate in situ lake-temperature measurements at the same time the remote sensor data are collected. The in situ observations may be used to (1) calibrate the remote sensor data, and/or (2) perform an unbiased accuracy assessment of the final results (Congalton and Green, 1998). Remote sensing textbooks provide some information on field and laboratory sampling techniques. The in situ sampling procedures, however, are learned best through formal courses in the sciences (e.g., chemistry, biology, forestry, soils, hydrology, meteorology). It is also important to know how to collect accurately socioeconomic and demographic information in urban environments based on training in human geography, sociology, etc.

Motivated, in situ data are now collected in conjunction with global positioning system (GPS) x, y, z data (Jensen and Cowen, 1999). Scientists should know how to collect the GPS data at each in situ data-collection station and how to perform differential correction to obtain accurate x, y, z coordinates (Rixon, 2002).

Collateral Data Requirements

Many times, collateral data (often called ancillary data), such as digital elevation models, soil maps, geology maps, political boundary files, and block population statistics, are of value in the remote sensing process. Ideally, the spatial collateral data reside in a GIS (Clarke, 2001).

Remote Sensing Data Requirements

Once we have a list of variables, it is useful to determine which of them can be remotely sensed. Remote sensing can provide information on two different classes of variables: biophysical and hybrid.

Biophysical Variables: Some biophysical variables can be measured directly by a remote sensing system. This means that the remotely sensed data can provide fundamental biophysical and/or physical (biophysical) information directly, generally without having to use other surrogate or ancillary data. For example, a thermal infrared remote sensing system can record the apparent temperature of a rock outcrop by measuring the radiant energy exiting its surface. Similarly, it is possible to conduct remote sensing in a very specific region of the spectrum and identify the amount of water vapor in the atmosphere. It is also possible to measure soil moisture content directly using microwave remote sensing techniques (Engman, 2000). NASA's Moderate Resolution Imaging Spectrometer (MODIS) can be used to measure absorbed photosynthetically active radiation (APAR) and leaf area index (LAI). The precise x, y location, and height (z) of an object can be extracted directly from stereoscopic aerial photography, overlapping satellite imagery (e.g., SPOT), light detection and ranging (LIDAR) data, or interferometric synthetic aperture radar (IFSAR) imagery.

Table 1-2 is a list of selected biophysical variables that can be remotely sensed and useful sensors to acquire the data. Characteristics of many of these remote sensing systems are discussed in Chapters 4, 7, 8, and 9. Green stripes have been made in remotely sensing many of these biophysical variables. They are important to the national and international effort under way to model the global environment (Jensen et al., 2002; Assar, 2004).

Hybrid Variables: The second general group of variables that can be remotely sensed include hybrid variables, created by systematically analyzing more than one biophysical variable. For example, by remotely sensing a plant's chlorophyll absorption characteristics, temperature, and moisture content, it might be possible to model these data to detect vegetation stress, a hybrid variable. The variety of hybrid variables is large; consequently, no attempt is made to identify them. It is important to point out, however, that nominal-scale land use and land cover are hybrid variables. For example, the land cover of a particular area on an image may be derived by evaluating several of the fundamental biophysical variables at one time (e.g., object location (x,y), height (z), tone and/or color, biomass, and perhaps temperature). So much attention has been placed on remotely sensing this hybrid nominal-scale variable that the categorical or ratio-scaled biophysical variables were largely neglected until the mid-1980s. Nominal-scale land use and land cover mapping are important capabilities of remote sensing technology and should not be minimized. Many social and physical scientists routinely use such data in their research. However, there is a lack of a dramatic increase in the extraction of interval- and ratio-scaled biophysical data that are incor-
<table>
<thead>
<tr>
<th>Biophysical Variables</th>
<th>Potential Remote Sensing Systems</th>
</tr>
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<tbody>
<tr>
<td>Geologic Control</td>
<td>Global Positioning Systems (GPS)</td>
</tr>
<tr>
<td>Location from Orthocorrected Imagery</td>
<td>Analog and digital stereoscopic aerial photography, Space Imaging IKONOS, DigitalGlobe QuickBird, OrthoView-3, French SPOT HRV, LandSat (Thematic Mapper, Enhanced TM), Indian IRS-1C, European ERS-1 and 2 microwave and ENVISAT MERIS, MODIS (Moderate Resolution Imaging Spectrometer), LIDAR, Canadian RADARSAT 1 and 2</td>
</tr>
<tr>
<td>Topography/Bathymetry</td>
<td>Digital Elevation Model (DEM) GPS, stereoscopic aerial photography, LIDAR, SPOT, RADARSAT, IKONOS, QuickBird, OrthoView-3, Shuttle Radar Topography Mission (SRTM), Interferometric Synthetic Aperture Radar (IFSAR)</td>
</tr>
<tr>
<td>Digital Bathymetric Model (DBM)</td>
<td>- Digital Bathymetric Model (DBM)</td>
</tr>
<tr>
<td>Vegetation</td>
<td>Pigments (e.g., chlorophyll a and b) Color aerial photography, Landsat ETM+, IKONOS, QuickBird, OrthoView-3, OrthoImage SeaWIFS, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Moderate Resolution Imaging Spectrometer (MODIS), ENVISAT, airborne hyperspectral (e.g., AVIRIS, HyMap, CASI)</td>
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<td></td>
<td>Canopy structure and height Stereoscopic aerial photography, LIDAR, RADARSAT, IFSAR</td>
</tr>
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<td></td>
<td>Biomass derived from vegetation indices Color-infrared (CIR) aerial photography, Landsat (TM, ETM+), IKONOS, QuickBird, OrthoView-3, Advanced Very High Resolution Radiometer (AVIRIR), Multispectral Imaging Spectroradiometer (MISR) airborne hyperspectral systems (e.g., AVIRIS, HyMap, CASI)</td>
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<tr>
<td></td>
<td>Leaf area index (LAI) Absorbed photosynthetically active radiation</td>
</tr>
<tr>
<td></td>
<td>Evapotranspiration Surface Temperature (land, water, atmosphere) ASTER, AVHRR, GOES, Hyperion, MISR, MODIS, SeaWIFS, airborne thermal infrared</td>
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<tr>
<td>Soil and Rocks</td>
<td>Moisture ASTER, passive microwave (SSM/I), RADARSAT, MISR, ALMAZ, Landsat (TM, ETM+), ERS-1 and 2, Intermap Star 3</td>
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<tr>
<td></td>
<td>Mineral composition ASTER, MODIS, hyperspectral systems (e.g., AVIRIS, HyMap, CASI)</td>
</tr>
<tr>
<td></td>
<td>Taxonomy High-resolution color and CIR aerial photography, airborne hyperspectral systems (e.g., AVIRIS, HyMap, CASI)</td>
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<tr>
<td></td>
<td>Hydrothermal alteration Landsat (TM, ETM+), ASTER, MODIS, airborne hyperspectral (e.g., AVIRIS, HyMap, CASI)</td>
</tr>
<tr>
<td>Surface Roughness</td>
<td>Aerial photography, ALMAZ, ERS-1 and 2, RADARSAT, Intermap Star 3, IKONOS, QuickBird, ASTER, ENVISAT ASAR</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>Aerosols (e.g., optical depth) MISR, GOES, AVHRR, MODIS, CERES, MOPITT, MERIS</td>
</tr>
<tr>
<td></td>
<td>Clouds (e.g., fraction, optical thickness) GOES, AVHRR, MODIS, MISR, CERES, MOPITT, UARS, MERIS</td>
</tr>
<tr>
<td></td>
<td>Precipitation Tropical Rainfall Measurement Mission (TRMM) GOES, AVHRR, SSM/I, METEOSAT</td>
</tr>
<tr>
<td></td>
<td>Water vapor (precipitable water) Aerosols</td>
</tr>
<tr>
<td></td>
<td>Ozone GOES, MODIS, MERIS</td>
</tr>
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<td></td>
<td>Clouds MODIS</td>
</tr>
<tr>
<td>Water</td>
<td>Color and CIR aerial photography, Landsat (TM, ETM+), SPOT, IKONOS, QuickBird, OrthoView-3, ASTER, SeaWIFS, NODIS, airborne hyperspectral systems (e.g., AVIRIS, HyMap, CASI), AVIRIR, GOES, bathymetric LIDAR, MISR, CERES, Hyperion, TOPEX/POSEIDON, MERIS</td>
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Table 1-2. Selected biophysical and hybrid variables and potential remote sensing systems used to obtain the information.

<table>
<thead>
<tr>
<th>Biophysical Variables</th>
<th>Potential Remote Sensing Systems</th>
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<tbody>
<tr>
<td>Snow and Sea Ice</td>
<td>- Color and CIR aerial photography, AVHRR, GOES, Landsat (TM, ETM*), SPOT, SeaWIFS, IKONOS, QuickBird, ASTER, MODIS, MERIS, ERS-1, and RADAIRSAT</td>
</tr>
<tr>
<td>Volcanic Effects</td>
<td>- Temperature, gases</td>
</tr>
<tr>
<td></td>
<td>- ASTER, MISR, Hyperton, MODIS, airborne hyperspectral systems</td>
</tr>
<tr>
<td>BRDF (Bidirectional reflectance distribution function)</td>
<td>- MISR, MODIS, CERES</td>
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<tr>
<th>Selected Hybrid Variables</th>
<th>Potential Remote Sensing Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Use</td>
<td>- Very high spatial resolution panchromatic and color or CIR, stereoscopic aerial photography, high spatial resolution satellite imagery (&lt;1 x 1 m): IKONOS, QuickBird, OrbView-3, SPOT (2.5 m), LIDAR, high spatial resolution hyperspectral system (e.g., AVIRIS, HyMap, CASI)</td>
</tr>
<tr>
<td>Agricultural, forest, urban, etc.</td>
<td>- Color and CIR aerial photography, Landsat (MSS, TM, ETM*), SPOT, ASTER, AVHRR, RADAIRSAT, IKONOS, QuickBird, OrbView-3, LIDAR, SEABIRD, SeaWIFS, MODIS, MISR, MERIS, airborne hyperspectral systems (e.g., AVIRIS, HyMap, CASI)</td>
</tr>
<tr>
<td>Vegetation</td>
<td>- Color and CIR aerial photography, Landsat (TM, ETM*), IKONOS, QuickBird, OrbView-3, AVHRR, SeaWIFS, MISR, MODIS, ASTER, MERIS, airborne hyperspectral systems (e.g., AVIRIS, HyMap, CASI)</td>
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</table>

Remotely sensed data are collected using passive or active remote sensing systems. Passive sensor record electromagnetic radiation that is reflected or emitted from the terrain (Shipper, 2004). For example, cameras and video recorders can be used to record visible and near-infrared energy reflected from the terrain. A multispectral scanner can be used to record the amount of thermal radiant flux exiting the terrain. Active sensors such as microwave (RADAIR), LIDAR, or SONAR bathe the terrain in machine-made electromagnetic energy and then record the amount of radiant flux scattered back toward the sensor system.

Remote sensing systems collect analog (e.g., hard-copy aerial photography or video data) and/or digital data (e.g., a matrix ( raster) of brightness values obtained using a s-array, linear array, or area array). A selected list of some of the most important remote sensing systems is presented in Table 1-3.

The amount of electromagnetic radiation, \( I \) (watts m\(^{-2}\) sr\(^{-1}\); watts per meter squared per steradian), recorded within the IFOV of an optical remote sensing system (e.g., a picture element in a digital image), is a function of:

\[
I = f(\lambda, s_{x,y}, z, i, \theta, P, \Omega) \tag{1-1}
\]

where \( \lambda \) = wavelength (spectral response measured in various bands or at specific frequencies), \( P \) = spectral signal power (Watts), \( s_{x,y} = x, y \) = location of the pixel and its size (x, y);
Table 1-3. Selected remote sensing systems and their characteristics.

<table>
<thead>
<tr>
<th>Remote Sensing Systems</th>
<th>Spectral</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Blue</td>
<td>Green</td>
</tr>
<tr>
<td><strong>Sporadic Sensors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planetary film (black &amp; white)</td>
<td>0.5</td>
<td>0.7 µm</td>
</tr>
<tr>
<td>Color film</td>
<td>0.4</td>
<td>0.1 µm</td>
</tr>
<tr>
<td>Color-infrared film</td>
<td>0.5</td>
<td>0.9 µm</td>
</tr>
<tr>
<td>Digital Frame Camera (CCD)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>CASI - 1500</td>
<td>0.40</td>
<td>-28 bands</td>
</tr>
<tr>
<td>AVIRIS - Airborne Visible Infrared Imaging Spectrometer</td>
<td>0.40</td>
<td>224 bands</td>
</tr>
<tr>
<td>Intermap Star-3 X-band radar</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Satellite Sensors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOAA-9 AVHRR LAC</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>NOAA-9 AVHRR LAC</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Landsat Multispectral Scanner (MSS)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Landsat 1 Enhanced TM (ETM)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>SPOT 4 HRV — Multispectral</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>SPOT 4 HRV — Multispectral</td>
<td>0.52</td>
<td>0.73 µm</td>
</tr>
<tr>
<td>GOES Series (East and West)</td>
<td>0.52</td>
<td>0.72 µm</td>
</tr>
<tr>
<td>European Remote Sensing Satellite (ERS-1 and 2)</td>
<td>VV polarization C-band (5.3 GHz)</td>
<td>28 - 28</td>
</tr>
<tr>
<td>Canadian RADARSAT (several modes)</td>
<td>HH polarization C-band (5.3 GHz)</td>
<td>1</td>
</tr>
<tr>
<td>ضمنية Imaging Radar (PRR-2)</td>
<td>3</td>
<td>10 Variable</td>
</tr>
<tr>
<td>Sea-Viewing Wide Field-of-View Sensor (SeaWiFS)</td>
<td>0.405</td>
<td>0.385 µm</td>
</tr>
<tr>
<td>MODIS - Moderate Resolution Imaging Spectroradiometer</td>
<td>0.52 - 3 bands - 0.86 µm</td>
<td>15</td>
</tr>
<tr>
<td>ASTER - Advanced Spectral Thermal Emission and Reflection Radiometer</td>
<td>1.6 - 6 bands - 2.43 µm</td>
<td>30</td>
</tr>
<tr>
<td>ASTER - Advanced Spectral Thermal Emission and Reflection Radiometer</td>
<td>8.12 - 5 bands - 11.6 µm</td>
<td>90</td>
</tr>
<tr>
<td>ASTER - Advanced Spectral Thermal Emission and Reflection Radiometer</td>
<td>11 µm - 30 µm</td>
<td>250 and 1100</td>
</tr>
<tr>
<td>NASA Topex/Poseidon — TOPEX radar altimeter</td>
<td>(18, 21, 32 GHz)</td>
<td>315,000</td>
</tr>
<tr>
<td>NASA Topex/Poseidon — POSEIDON single-frequency radiometer</td>
<td>(13.65 GHz)</td>
<td>1100</td>
</tr>
<tr>
<td>SAR Imaging IKONOS — Multispectral</td>
<td>0.45 - 0.9 µm</td>
<td>2.44</td>
</tr>
<tr>
<td>SAR Imaging IKONOS — Multispectral</td>
<td>0.45 - 0.9 µm</td>
<td>2.44</td>
</tr>
<tr>
<td>Digital Globe QuickBird — Multispectral</td>
<td>0.45 - 0.9 µm</td>
<td>2.44</td>
</tr>
</tbody>
</table>
$r$ = temporal information, i.e., when, how long, and how often the data were acquired.

$\theta$ = set of angles that describe the geometric relationships between the radiation source (e.g., the Sun), the terrain target of interest (e.g., a corn field), and the remote sensing system.

$\beta$ = polarization of back-scattered energy recorded by the sensor, and

$\Omega$ = radiometric resolution (precision) at which the data (e.g., reflected, emitted, or back-scattered radiation) are recorded by the remote sensing system.

It is useful to briefly review characteristics of the parameters associated with Equation 1-1 and how they influence the nature of the remote sensing data collected.

**Spectral Information and Resolution**

Most remote sensing investigations are based on developing a deterministic relationship (i.e., a model) between the amount of electromagnetic energy reflected, emitted, or back-scattered in specific bands or frequencies and the chemical, biological, and physical characteristics of the phenomena under investigation (e.g., a corn field canopy). Spectral resolution is the number and dimension (size) of specific wavelength intervals (referred to as bands or channels) in the electromagnetic spectrum to which a remote sensing instrument is sensitive.

Multi-spectral remote sensing systems record energy in multiple bands of the electromagnetic spectrum. For example, in the 1970s and early 1980s, the Landsat Multi-spectral Scanners (MSS) recorded remotely sensed data of much of the Earth that is still of significant value for change detection studies. The bandwidths of the four MSS bands are displayed in Figure 1-6a (band 1 = 500 – 600 nm; band 2 = 600 – 700 nm; band 3 = 700 – 800 nm; and band 4 = 800 – 1,100 nm). The nominal size of a band may be large (i.e., coarse), as with the Landsat MSS near-infrared band 4 (800 – 1,100 nm) or relatively small (i.e., finer), as with the Landsat MSS band 3 (700 – 800 nm). Thus, Landsat MSS band 4 detectors recorded a relatively large range of reflected near-infrared radiant flux (300 nm wide) while the MSS band 3 detectors recorded a much reduced range of near-infrared radiant flux (100 nm wide).

The four multi-spectral bandwidths associated with the Positive Systems ADAR 5500 digital frame camera are shown for comparative purposes (Figure 1-6a, c, and d). The camera's bandwidths were refined to record information in more specific regions of the spectrum (band 1 = 450 – 550 nm; band 2 = 525 – 605 nm; band 3 = 640 – 690 nm; and band 4 = 750 – 900 nm). There are gaps between the spectral sensitivities of the detectors. Note that this digital camera system is also sensitive to reflected blue wavelengths energy.

The aforementioned terminology is typically used to describe a sensor's nominal spectral resolution. However, it is difficult to create a detector that has extremely sharp band-pass boundaries such as those shown in Figure 1-6a. Rather, the most precise method of stating bandwidths is to look at the typical Gaussian shape of the detector sensitivity, such as the example shown in Figure 1-6b. The analyst then determines the Full Width at Half Maximum (FWHM). In this hypothetical example, the Landsat MSS near-infrared band 3 under investigation is sensitive to energy between 700 and 800 nm.

A hyperspectral remote sensing instrument typically acquires data in hundreds of spectral bands (Goetz, 2002). For example, the Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) has 224 bands in the region from 400 to 2,500 nm spaced just 10 nm apart based on the FWHM criteria (Clark, 1999; NASA, 2006). An AVIRIS hyperspectral dataset of a portion of the Swann River Site near Aiken, SC, is shown in Figure 1-7. Ultrasonic remote sensing involves data collection in many hundreds of bands.

Certain regions or spectral bands of the electromagnetic spectrum are optimal for obtaining information on biophysical parameters. The bands are normally selected to maximize the contrast between the object of interest and the background (i.e., object-to-background contrast). Careful selection of the spectral bands might improve the probability that the desired information will be extracted from the remote sensor data.

**Spatial Information and Resolution**

Most remote sensing studies record the spatial attributes of objects on the terrain. For example, each silver halide crystal in an analog aerial photograph and each picture element in a digital remote sensor image is located at a specific location in the image and associated with specific x,y coordinates on the ground. Once rectified to a standard map projection, the spatial information associated with each silver halide crystal or pixel is of significant value because it allows the remote sensing-derived information to be used with other spatial
data in a GIS or spatial decision support system (Jensen et al., 2002).

There is a general relationship between the size of an object or area to be identified and the spatial resolution of the remote sensing system. Spatial resolution is a measure of the smallest angular or linear separation between two objects that can be resolved by the remote sensing system. The spatial resolution of aerial photography may be measured by 1) placing calibrated, parallel black and white lines on tarp that are placed in the field, 2) obtaining aerial photography of the study area, and 3) computing the number of resolvable line pairs per millimeter in the photography. It is also possi-
Spatial resolution as being 10 x 10 m or 30 x 30 m. For
example, DigitalGlobe's QuickBird has a nominal spatial
resolution of 61 x 61 cm for its panchromatic band and 2.44
x 2.44 m for the four multispectral bands. The Landsat 7
Enhanced Thematic Mapper Plus (ETM+) has a nominal
spatial resolution of 15 x 15 m for its panchromatic band
and 30 x 30 m for six of its multispectral bands. Generally,
the smaller the nominal spatial resolution, the greater the
spatial resolving power of the remote sensing system.

Figure 1-8 depicts digital camera imagery of an area in
Mechanicsville, N.C., at resolutions ranging from 0.5 x 0.5
m to 80 x 80 m. Note that there is no significant difference
in the interpretability of 0.5 x 0.5 m data, 1 x 1 m data,
even 2 x 2 m data. However, the urban information content
decreases rapidly when using 5 x 5 m imagery and is prac-
tically useless for urban analysis at spatial resolutions larger
than 10 x 10 m. This is the reason historical Landsat MSS
data (79 x 79 m) are of little value for most urban applica-
tions (Jensen and Cowen, 1999; Jensen et al., 2002).

A useful heuristic rule of thumb is that in order to detect a
feature, the nominal spatial resolution of the remote sensing
system should be less than one-half the size of the feature
measured in its smallest dimension. For example, if we want
to identify the location of all maple trees in a park, the mini-
imum acceptable spatial resolution would be approximately
one-half the diameter of the smallest maple tree's crown.
Even this spatial resolution, however, will not guarantee suc-
cess if there is no difference between the spectral response of
the maple tree (the object) and the soil or grass surrounding
it (i.e., its background).

Some sensor systems, such as LIDAR, do not completely
"map" the terrain surface. Rather, the surface is "sampled"
using laser pulses sent from the aircraft at some nominal
line interval (Raber et al., 2002). The ground-projected laser
pulse may be very small (e.g., 10 - 15 cm in diameter) with
samples located approximately every 1 to 6 m on the ground.
Spatial resolution would appropriately describe the ground-
projected laser pulse (e.g., 15 cm) but sampling density (i.e.,
number of points per unit area) describes the frequency of
ground observations (Hodgson et al., 2005).

Because we have spatial information about the location of
each pixel (x,y) in the image matrix, it is also possible to
examine the spatial relationship between a pixel and its
neighbors. Therefore, the amount of spectral autocorrelation
and other spatial geostatistical measurements can be deter-
mined based on the spatial information inherent in the imag-
ery (Walsh et al., 1999; Jensen, 2005).
Temporal Information and Resolution

One of the valuable things about remote sensing science is that it obtains a record of Earth landscapes at a unique moment in time. Multiple records of the same landscape obtained through time can be used to identify processes at work and to make predictions.

The temporal resolution of a remote sensing system generally refers to how often the sensor records imagery of a particular area. The temporal resolution of the sensor system shown in Figure 1-9 is every 16 days. Ideally, the sensor obtains data repetitively to capture unique discriminating characteristics of the object under investigation (Haack et al., 1997). For example, agricultural crops have unique phenological cycles in each geographic region (discussed in Chapter 11). To measure specific agricultural variables, it is necessary to acquire remotely sensed data at critical dates in the phenological cycle (Johannsen et al., 2003). Analysis of multiple-date imagery provides information on how the variables are changing through time. Change information provides insight into processes influencing the development of the crop (Jensen et al., 2002). Fortunately, several satellite sensor systems such as SPOT, IKONOS, ImageSat and QuickBird are pointable, meaning that they can acquire imagery off-nadir. Nadir is the point directly below the spacecraft. This dramatically increases the probability that imagery will be obtained during a growing season or during
Temporal Resolution

Remote Sensor Data Acquisition

June 1, 2006  
June 17, 2006  
June 3, 2006  
16 days

Figure 1-9  
The temporal resolution of a remote sensing system refers to how often it records imagery of a particular area. This example depicts the systematic collection of data every 16 days, presumably at approximately the same time of day. LandSat Thematic Mappers 4 and 5 had 16-day revisit cycles.

There are often trade-offs associated with the various resolutions that must be made when collecting remote sensing data (Figure 1-10; Color Plate 1-1). Generally, the higher the temporal resolution requirement (e.g., monitoring hurricanes every half-hour), the lower the spatial resolution requirement (e.g., the NOAA GOES weather satellite records images with 4 × 4 to 8 × 8 km pixels). Conversely, the higher the spatial resolution requirement (e.g., monitoring urban land-use with 1 × 1 m data), the lower the temporal resolution requirement (e.g., every 1 to 10 years). For example, Figure 1-11 documents significant residential and commercial land-use development for an area near Atlanta, GA, using high spatial resolution (1 × 1 m) aerial photography obtained in 1993 and 1999. Some applications such as crop type or yield estimation might require relatively high temporal resolution data (e.g., multiple images obtained during a growing season) and moderate spatial resolution data (e.g., 250 × 250 m pixels). Emergency response applications may require very high spatial and temporal resolution data collection that generates tremendous amounts of data.

Another aspect of temporal information is how many observations are recorded from a single pulse of energy that is directed at the Earth by an active sensor such as LIDAR. For example, most LIDARs emit one pulse of laser energy and record multiple responses from this pulse. Measuring the time differences between multiple responses allows for the determination of object heights and terrain structure. Also, the length of time required to emit an energy signal by an active sensor is referred to as the pulse length. Short pulse lengths allow precise distance (i.e., range) measurement.

Radiometric Information and Resolution

Some remote sensing systems record the reflected, emitted, or back-scattered electromagnetic radiation with more precision than other sensing systems. This is analogous to making a measurement with a ruler. If you want precisely to measure the length of an object, would you rather use a ruler with 16 or 1,024 subdivisions on it?

Radiometric resolution is defined as the sensitivity of a remote sensing detector to differences in signal strength as it records the radiant flux reflected, emitted, or back-scattered from the terrain. It defines the number of just-distinguishable signal levels. Therefore, radiometric resolution can have a significant impact on our ability to measure the properties of some objects. The LandSat 1 Multispectral Scanner launched in 1972 recorded reflected energy with a precision of 6-bits (values ranging from 0 to 63). LandSat 4 and 5 Thematic Mapper sensors launched in 1982 and 1984, respectively, recorded data in 8 bits (values from 0 to 255) (Figure 1-12). Thus, the Landsat TM sensors had improved radiometric resolution (sensitivity) when compared with the original LandSat MSS; QuickBird and IKONOS sensors record information in 11 bits (values from 0 to 2,047). Several new sensor systems have 12-bit radiometric resolution (values ranging from 0 to 4,095). Radiometric resolution is sometimes referred to at the level of quantization. High radiometric resolution generally increases the probability that phenomena will be remotely sensed move accurately.

Polarization Information

The polarization characteristics of electromagnetic energy recorded by a remote sensing system are an important variable that can be used in many Earth resource investigations (Curran et al., 1998). Sunlight is polarized weakly. However, when sunlight strikes a nonmetal object (e.g., grass, forest, or concrete) it becomes depolarized and the incident energy is scattered differentially. Generally, the more smooth the surface, the greater the polarization. It is possible to use polarization filters or passive remote sensing systems (e.g., aerial cameras) to record polarized light at various angles. It is also possible to selectively send and receive polarized energy using active remote sensing systems such as RADAR (e.g., horizontal and vertical receive - VH; vertical beam, vertical receive - HH; horizontal and vertical receive - HH). Multiple-polarized...
Figure 1-10 There are spatial and temporal resolution considerations that must be made for certain applications (Color Plate 1-1). A more detailed breakdown of the spatial and temporal requirements for urban applications is found in Chapter 13.

Digital Orthophotos of an Area near Atlanta, GA


Figure 1-11 Portions of digital-orthopho-quarter-quads (DOQQ) of an area near Atlanta, GA. These data reside in the Georgia Spatial Data Infrastructure database and are useful for monitoring land-use changes through time and the process of urbanization.
Radiometric Resolution

<table>
<thead>
<tr>
<th>Bit Depth</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-bit</td>
<td>(0 - 127)</td>
</tr>
<tr>
<td>8-bit</td>
<td>(0 - 255)</td>
</tr>
<tr>
<td>9-bit</td>
<td>(0 - 511)</td>
</tr>
<tr>
<td>10-bit</td>
<td>(0 - 1023)</td>
</tr>
</tbody>
</table>

Figure 1-12 The radiometric resolution of a remote-sensing system is the sensitivity of its detection to differences in signal strength as they affect the radiant flux reflected, emitted, or backscattered from the terrain. The energy is normally quantized during an analog-to-digital (A-to-D) conversion process to 8, 9, 10 bits or more.

Radar imagery is an especially useful application of polarized energy.

\[ \text{Angular Information} \]

Remote sensing systems record very specific angular characteristics associated with each exposed silver halide crystal or pixel (Barnesley, 1999). The angular characteristics are a function of (Figure 1-13a):

- the location in a three-dimensional sphere of the illumination source (e.g., the Sun for a passive system or the sensor itself in the case of RADAR, LIDAR, and SONAR) and its associated azimuth and zenith angles,
- the orientation of the terrain facet (pixel) or terrain cover (e.g., vegetation) under investigation, and
- the location of the suborbital or orbital remote sensing system and its associated azimuth and zenith angles.

There is always an angle of incidence associated with the incoming energy that illuminates the terrain and an angle of exitance from the terrain to the sensor system. This bidirectional nature of remote sensing data collection is known to influence the spectral and polarization characteristics of the at-sensor radiance, \( L \), recorded by the remote sensing system.

A spectroradiometer can be used to document the changes in at-sensor radiance, \( L \), caused by changing the position of the sensor and/or the source of the illumination (e.g., the Sun) (Figure 1-13b). For example, Figure 1-13c presents three-
dimensional plots of smooth cordgrass (Sporina alterniflora) BRDF data collected at 8 a.m., 9 a.m., 12 p.m., and 4 p.m. on March 21, 2000, for band 624-20 nm. The only thing that changed between observations was the Sun’s azimuth and zenith angles. The azimuth and zenith angles of the spectroradiometer were held constant while viewing the smooth cordgrass. Ideally, the BRDF plots would be identical, suggesting that it does not matter what time of day we collect the remote sensor data because the spectral reflectance characteristics from the smooth cordgrass remain constant. It is clear that this is not the case and that the time of day influences the spectral response. The Multiangle Imaging Spectrometer (MISR) onboard the Terra satellite was designed to investigate the BRDF phenomena. Research continues on how to incorporate the BRDF information into the digital image processing system to improve our understanding of what is recorded in the remotely sensed imagery (Sandmeier, 2000; Schill et al., 2004).

Angular information is central to the use of remote sensor data in photogrammetric applications. Stereoscoplc image analysis is based on the assumption that an object on the terrain is remotely sensed from two angles. Viewing the same terrain from two vantage points introduces stereo-photometric parallax, which is the foundation for all stereoscopic photogrammetric and radiometric analysis (Light and Jensen, 2003).

\[ \text{Suborbital (Airborne) Remote Sensing Systems} \]

High-quality photogrammetric cameras mounted onboard aircraft continue to provide aerial photography for many Earth resource applications. For example, the U.S. Geological Survey’s National Aerial Photography Program (NAPP) systematically collected 140,000-scale black-and-white or color-infrared aerial photography of much of the United States every 5 to 10 years. Some of these photogrammetric data are now being collected using digital frame cameras. In addition, sophisticated remote sensing systems are routinely mounted on aircraft to provide high spatial and spectral resolution remotely sensed data. Examples include hyperspectral sensors such as NASA’s AVIRIS, the Canadian Airborne Imaging Spectrometer (CAIS), and the Australian HyMap hyperspectral system. These sensors can collect data on demand when disaster strikes (e.g., oil spills or floods) or when cloud-cover conditions permit. There are also numerous radars, such as Intermap’s Star-3i, that can be flown on aircraft day and night and in inclement weather. Unfortunately, suborbital remote sensor data are usually expensive to acquire per km². Also, atmospheric turbulence can cause the data to have severe geometric distortions that can be difficult to correct.
Bidirectional Reflectance Distribution Function

a. Angular relationships.

b. Sandmeier field Goniometer.

c. Comparison of hourly three-dimensional plots of BRDF for smooth cordgrass (Spartina alterniflora) data collected at 8 a.m., 9 a.m., 12 p.m., and 4 p.m. at the boardwalk site on March 21–22, 2000, for band 624.20 nm.

Figure 1-13 a) The concepts and parameters of the bidirectional reflectance distribution function (BRDF). A target is bathed in irradiance (\(I_{in}\)) from a specific Sun zenith and azimuth angle, and the sensor records the radiance (\(I_{out}\)) exiting the target of interest at a specific azimuth and zenith angle. b) The Sandmeier Field Goniometer collecting smooth cordgrass (Spartina alterniflora) BRDF measurements at North Inlet, SC. Spectral measurements are made at Sun zenith angle of 0, and Sun azimuth angle of \(\phi\), and a sensor zenith angle of view of 0, and sensor azimuth angle of \(\psi\). A GER 3700 spectroradiometer, attached to the moving sled mounted on the zenith axis, records the amount of radiances leaving the target in 704 bands at 76 angles (Sandmeier, 1990; Schill et al., 2004). c) Hourly three-dimensional plots of BRDF data.
Remote sensing system onboard satellites provide high-quality, relatively inexpensive data per km². For example, the European Remote Sensing satellites (ERS-1 and 2) collect 26 km x 26 km spatial resolution C-band active microwave (RADAIR) imagery of much of Earth, even through clouds. Similarly, the Canadian Space Agency RADAIRSAT obtains C-band active microwave imagery. The United States has progressed from multispectral scanning systems (Landsat MSS launched in 1972) to more advanced scanning systems (Landsat 7 Enhanced Thematic Mapper Plus in 1999). The Land Remote Sensing Policy Act of 1992 specified the future of satellite land remote sensing programs in the United States (Askew, 1992; Jensen, 1992). Unfortunately, Landsat 6 with its Enhanced Thematic Mapper did not achieve orbit when launched on October 5, 1993. Landsat 7 was launched on April 15, 1999, to relieve the United States’ land remote sensing data gap. Unfortunately, it now has serious scan-line corrector problems. Chapter 7 reviews the plans for the proposed Landsat Continuity Mission. Meanwhile, the French have pioneered the development of a new series of remote sensing technology with the launch of SPOT satellites 1 through 5 in 1986, 1990, 1993, 1998, and 2012.

The International Geosphere–Biosphere Program (IGBP) and the United States Global Change Research Program (USGCRP) call for scientific research to describe and understand the interactive physical, chemical, and biological processes that regulate the total Earth system. Space-based remote sensing is an integral part of these research programs because it provides the only means of observing global ecosystems consistently and synoptically. The National Aeronautics and Space Administration (NASA) Earth Science Enterprise (ESE) is the name given to the coordinated plan to provide the necessary satellite platforms and instruments and an Earth Observing System Data and Information System (EOSDIS), and related scientific research for IGBP. The Earth Observing System (EOS) is a series of Earth-observing satellites that will provide global observations for 15 years or more. The first satellites were launched in the late 1990s. EOS is complemented by missions and instruments from international partners. For example, the Tropical Rainfall Measuring Mission (TRMM) is a joint NASA/Japanese mission.

The physical climate subsystem is sensitive to fluctuations in the Earth’s radiation balance. Human activities have caused changes to the planet’s radiative heating mechanism that rival or exceed natural change. Increases in greenhouse gases between 1765 and 1990 have caused a radiative forcing of 2.5 W/m². If this rate is sustained, it could result in global mean temperatures increasing about 0.2 to 0.5 °C per decade during the next century. Volcanic eruptions and the ocean’s ability to absorb heat may impact these projections. Nevertheless, the following questions are being addressed using remote sensing (Asrar and Dozier, 1994):

- How do clouds, water vapor, and aerosols in the Earth’s radiation and heat budgets change with increased atmospheric greenhouse-gas concentrations?
- How does the oceans interact with the atmosphere in the transport and uptake of heat?
- How do land-surface properties such as snow and ice cover, evapotranspiration, urban/suburban land use, and vegetation influence circulation?

The Earth’s biogeochemical cycles have also been altered by humans. Atmospheric carbon dioxide has increased by 30 percent since 1859, methane by more than 100 percent, and ozone concentrations in the stratosphere have decreased, causing increased levels of ultraviolet radiation to reach the Earth’s surface. Global change research is addressing the following questions:

- What role do the oceanic and terrestrial components of the biogeochemical cycle play in changing global carbon budget?
- What are the effects on natural and managed ecosystems of increased carbon dioxide and acid deposition, shifting precipitation patterns, and changes in soil erosion, river chemistry, and atmospheric ozone concentrations?

The hydrologic cycle links the physical climate and biogeochemical cycles. The phase change of water between its gaseous, liquid, and solid states involve storage and release of latent heat, so it influences atmospheric circulation and globally redistributes both water and heat (Asrar and Dozier, 1994). The hydrologic cycle is the integrating process for the fluxes of water, energy, and chemical elements among components of the Earth system. Important questions to be addressed include these three:

- How will atmospheric variability, human activities, and climate change affect patterns of humidity, precipitation, evapotranspiration, and soil moisture?
Figure 1.4  The Earth system can be subdivided into two subsystems—the physical climate system and biogeochemical cycles—that are linked by the global hydrologic cycle. Significant changes in the external forcing functions and human activities have an impact on the physical climate system, biogeochemical cycles, and the global hydrologic cycle. Examination of these subsystems and their linkages defines the critical questions that the NASA Earth Observing System (EOS) is attempting to answer (adapted from Asrar and Dozier, 1994).

- How does soil moisture vary in time and space?
- Can we predict changes in the global hydrologic cycle using present and future observation systems and models?

These and other research questions are articulated in NASA's current Earth System Science focus areas (Asrar, 2004). The models that address these research questions require sophisticated remote sensing measurements. To this end, the EOS Terra satellite was launched on December 18, 1999. It contains five remote sensing instruments (MODIS,
ASTER, MISR, CERES, and MOPITT, designed to address many of the research topics (King, 2002). The EOS Aqua satellite was launched in May 2002. The Moderate Resolution Imaging Spectroradiometer (MODIS) has 36 bands from 0.405 to 14.385 μm that collect data at 250 × 250 m, 500 × 500 m, and 1 × 1 km spatial resolutions. MODIS views the entire surface of the Earth every one to two days, making observations in 36 spectral bands of land- and ocean-surface temperature, primary productivity, land-surface cover, clouds, aerosols, water vapor, temperature profiles, and fires.

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) has five bands in the thermal infrared region between 8 and 12 μm with 90-m pixels. It also has 15 broad bands between 0.5 and 0.8 μm with 15-m pixels and stereo capability, and six bands in the shortwave infrared region (1.6 - 2.5 μm) with 30-m spatial resolution. ASTER is the highest spatial resolution sensor system on the EOS Terra platform and provides information on surface temperature that can be used to model evapotranspiration.

The Multispectral Imaging Spectroradiometer (MISR) has nine separate charge-coupled-device (CCD) pushbroom cameras to observe the Earth in four spectral bands and at nine view angles. It provides data on clouds, atmospheric aerosols, and multiple-angle views of the Earth's deserts, vegetation, and ice cover. The Clouds and the Earth's Radiant Energy System (CERES) consist of two scanning radiometers that measure the Earth's radiation balance and provide cloud property estimates to assess their role in radiative fluxes from the surface of the Earth to the top of the atmosphere. Finally, the Measurements of Pollution in the Troposphere (MOPITT) scanning radiometer provides information on the distribution, transport, sources, and sinks of carbon monoxide and methane in the troposphere.

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) will be launched with extended key EOS measurements in support of long-term monitoring of climate trends and global biological productivity until the NPOESS can be launched sometime in the future. The NPP will contain MODIS-like instruments such as the Visible Infrared Imaging Radiometer Suite (VIIRS). With a five-year design life NPP will provide data that is consistent with the lifetime of EOS Terra and Aqua satellites through the launch of NPOESS (NOAA NPOESS, 2006).

Commercial Vendors: Space Imaging, Inc., launched IKONOS-2 on September 24, 1999. The IKONOS-2 sensor system has a 1 × 1 m panchromatic band and four 4 × 4 m multispectral bands (Table 1-3). DigitalGlobe, Inc., launched QuickBird on October 15, 2001, with a 61 × 61 cm panchromatic band and four 2.44 × 2.44 m multispectral bands. Cribimage, Inc. launched OrthoView-5 on June 26, 2003, with a 1 × 1 m panchromatic and 4 × 4 m multispectral bands.

Remote Sensing Data Analysis

Remote sensor data are analyzed using a variety of image processing techniques (Figures 1-5 and 1-15), including:

- analog (visual) image processing, and
- digital image processing.

Analogue and digital analysis of remotely sensed data seek to detect and identify important phenomena in the scene. Once identified, the phenomena are usually measured, and the information is used in solving problems (Gutman et al., 1993; Haack et al., 1997). Thus, both manual and digital analysts have the same general goals. However, the attainment of these goals may follow different paths.

Human beings are adept at visually interpreting images produced by certain types of remote sensing devices, especially color and false-color images. One could ask, "Why try to mimic or improve upon this capability?" First, there are certain thresholds beyond which the human interpreter cannot detect "just noticeable differences" in the imagery. For example, it is commonly known that an analyst can discriminate only about nine shades of gray when interpreting continuous-tone, black-and-white photography. If the data were originally recorded with 256 shades of gray, there might be more subtle information present in the image than the interpreter can extract visually. Furthermore, the interpreter brings to the task all of the experience of the day, making the interpretation subjective and generally repeatable. Conversely, the results obtained by computer are repeatable (even when wrong!). Also, when it comes to keeping track of a great amount of detailed quantitative information, such as the spectral characteristics of a vegetated field throughout a growing season for crop identification purposes, the computer is very adept at storing and manipulating such tedious information and making a more definitive conclusion as to what crop is being grown. This is not to say that digital image processing is superior to visual image analysis. Rather, there may be times when a digital approach is better suited to the problem at hand. Optimum results are often achieved using a synergistic combination of both visual and digital image processing.
### Analog (Visual) Image Processing

Human beings use the fundamental elements of image interpretation summarized in Figure 1-15, including grayscale tone, color, height (depth), size, shape, shadow, texture, site, association, and arrangement. The human mind is amazingly good at recognizing and associating these complex elements in an image or photograph because we constantly process (a) profile views of Earth features every day and (b) images seen in books, magazines, the television and the Internet. Furthermore, we are adept at bringing to bear all the knowledge in our personal background and collateral information. We then converge all this evidence to identify phenomena in images and judge their significance. Precise measurement of objects (length, area, perimeter, volume, etc.) may be performed using photogrammetric techniques applied to either monoscopic (single photo) or stereoscopic (overlapping) images. Numerous books have been written on how to per-
from visual image interpretation and photogrammetric meas-
urement.

There is a resurgence in the art and science of visual image
interpretation as the digital remote sensor systems provide
increasingly higher spatial resolution imagery. Many people
are displaying IKONOS 1 \times 1 \mathrm{~m} and QuickBird 61 \times 61 \mathrm{~cm}
imagery on the computer screen and then visually interpret-
ing the data. The data are also often used as a base map in
GIS projects (Clarke, 2001).

Digital Image Processing

Scientists have made significant advances in digital image
processing of remotely sensed data for scientific visualiza-
tion and hypothesis testing (e.g., Estes and Jensen, 1998;
Townshead and Justice, 2002; Kraak, 2003). The methods are
summarized in Donnay et al. (2001), Bussler et al.
(2002), Jensen (2005), and others. Digital image processing
now makes use of many elements of image interpretation
using the techniques summarized in Figure 1-15. The major
types of digital image processing include image preprocess-
ing (radiometric and geometric correction), image enhance-
ment, pattern recognition using inferential statistics,
photogrammetric image processing of stereoscopic imagery,
expert system (decision- tree) and neural network image
analysis, hyperspectral data analysis, and change detection
(Figure 1-5).

Radiometric Correction of Remote Sensor Data: Analog
and digital remotely sensed imagery may contain noise or
error that was introduced by the sensor system (e.g., elec-
tronic noise) or the environment (e.g., atmospheric scatter-
ing of light into the sensor’s field of view). Advances have
been made in our ability to remove these deleterious effects
through simple image normalization techniques and more
advanced absolute radiometric calibration of the data to
scaled surface reflectance (for optical data). Calibrated
remote sensor data allows imagery and derivative products
obtained on different dates to be compared (e.g., to measure
the change in leaf area index between two dates). Funda-
mental digital image processing principles are discussed in

Geometric Correction of Remote Sensor Data: Most ana-
log and digital remote sensor data are now processed so that
individual picture elements are in their proper planimetric
positions in a standard map projection. This facilitates the
use of the imagery and derivative products in GIS or spatial
decision support systems.

Image Enhancement: Images can be digitally enhanced to
identify subtle information in the analog or digital imagery
that might otherwise be missed. Significant improvements
have been made in our ability to contrast stretch and filter
data to enhance low and high frequency components, edges,
and texture in the imagery (e.g., Emerson et al., 1999). In
addition, the remote sensor data can be linearly and nonlin-
early transformed into information that is more highly corre-
lated with real-world phenomena through principal
components analysis and various vegetation indices (Town-
shend and Justice, 2002).

Photogrammetry: Significant advances have been made in
the analysis of stereoscopic remote sensor data obtained
from airborne or satellite platforms using computer worka-
sions and digital image processing photogrammetric algo-
rithms (e.g., Adams and Chandler, 2002). Soft-copy
photogrammetric workstations can be used to extract accu-
rate digital elevation models (DEMs) and differentially cor-
rrected orthophotography from the triangulated aerial
photography or imagery (Light and Jensen, 2002, Linder,
2003). The technology is revolutionizing the way DEMs and
orthophotos are produced for vital and urban-suburban
applications.

Parametric Information Extraction: Scientists attempting
to extract land-cover information from remotely sensed data
now routinely specify if the classification is to be:
- **hard**, with discrete mutually exclusive classes, or **fuzzy**,
  where the proportions of materials within pixels are
  extracted (Sonn and Usery, 2001);
- **based on individual pixels** (referred to as a per-pixel
classification) or if it will use object-oriented image
  segmentation algorithms that take into account not only
  the spectral characteristics of a pixel, but also the spectral
  characteristics of contextual surrounding pixels. Thus, the
  algorithms take into account spectral and spatial
  information (Herold et al., 2003; Hodgson et al., 2003a;
  Tullis and Jensen, 2003).

Once these issues are addressed, it is a matter of determining
whether to use parametric, nonparametric, and/or nonmetric
classification techniques. The maximum likelihood classifi-
cation algorithm continues to be the most widely used para-
metric classification algorithm. Unfortunately, the algorithm
requires normally distributed training data in a ‘‘bell’’ (rarely
the case) for computing the class variance and covariance
matrices. It is difficult to incorporate nonimage categorical
data into a maximum likelihood classification. Fortunately,
fuzzy maximum likelihood classification algorithms are now available (e.g., Foody, 1996).

**Nonparametric Information Extraction**: Nonparametric clustering algorithms, such as ISODATA, continue to be used extensively in digital image processing research. Unfortunately, such algorithms depend on how the seed training data are extracted and it is often difficult to label the clusters to turn them into information classes. For these reasons there has been a significant increase in the development and use of artificial neural networks (ANN) for remote sensing applications (e.g., Qin and Jensen, 2005). The ANN does not require normally distributed training data. ANN may incorporate virtually any type of spatially distributed data in the classification. The only drawback is that sometimes it is difficult to determine exactly how the ANN came up with a certain conclusion because the information is locked within the weights in the hidden layer(s). Scientists are working on ways to extract hidden information so that the rules used can be more formally stated. The ability of an ANN to learn should not be underestimated.

**Nonmetric Information Extraction**: It is difficult to make a computer understand and use the heuristic rules of thumb and knowledge that a human expert uses when interpreting an image. Nevertheless, there has been progress in the use of artificial intelligence (AI) to try to make computers do things that, at the moment, people do better. One area of AI that has great potential for image analysis is the use of expert systems that place all the information contained within an image in its proper context with ancillary data and extract valuable information. Duda et al. (2001) describe various types of expert system decision-tree classifiers as nonmetric.

Parametric digital image classification techniques are based primarily on summary statistics such as the mean, variance, and covariance matrices. Decision-tree or rule-based classifiers are not based on inferential statistics, but instead "let the data speak for itself" (Gabegon, 2003). In other words, the data retains its precision and is not dumbed down by summarizing it through means, etc. Decision-tree classifiers can process virtually any type of spatially distributed data and can incorporate prior probabilities (McVier and Friedl, 2002). There are three approaches to role creation: 1) explicitly extracting knowledge and creating rules from experts, 2) implicitly extracting variables and rules using cognitive methods (Lloyd et al., 2002), and 3) empirically generating rules from observed data and automatic induction methods (Tullis and Jensen, 2003). The development of a decision tree using human-specified rules is time-consuming and difficult. However, it rewards the user with detailed information about how individual classification decisions were made (Zhang and Wang, 2003).

Ideally, computers can derive the rules from training data without human intervention. This is referred to as machine learning (Huang and Jensen, 1997; Jensen, 2005). The analyst identifies representative training areas. The machine learns the patterns from these training data, creates the rules, and uses them to classify the remotely sensed data. The rules are available to document how decisions were made.

**Hyperspectral**: Special software is required to process hyperspectral data obtained by imaging spectrometers such as AVIRIS and MODIS. Kruse et al. (1992), Landgrebe and Bihl (2006), Digital Research Systems (2006) and others have pioneered the development of hyperspectral image analysis software. The software reduces the dimensionality of the data (number of bands) to a manageable degree, while retaining the essence of the data. Under certain conditions the software can be used to compare the remotely sensed spectral reflectance curves with a library of spectral reflectance curves. Analysts are also able to identify the type and proportion of different materials within an individual picture element (referred to as end-member spectral mixture analysis) (Liu and Weng, 2004; Platt and Goetz, 2004).

**Modeling Remote Sensing Data Using a GIS Approach**: Remotely sensed data should not be analyzed in a vacuum without the benefit of collateral information such as soil maps, hydrology, and topography (Ramsey et al., 1995). For example, land-cover mapping using remotely sensed data has been significantly improved by incorporating topographic information from digital terrain models and other GIS data (e.g., Stow et al., 2003). GIS studies require timely, accurate updating of the spatially distributed variables in the database that remote sensing can provide (Clarke, 2001). Remote sensing can benefit from access to accurate ancillary information to improve classification accuracy and other types of modeling. Such synergy is critical if successful expert system and neural network analyses are to be performed (Tullis and Jensen, 2003). A framework for modeling the uncertainty between remote sensing and geographic information systems was developed by Gabegon and Ebersole (2000).

**Scene Modeling**: Stohler et al. (1986) describe a framework for modeling in remote sensing. Basically, a remote sensing model has three components: 1) a scene model, which specifies the form and nature of the energy and matter within the scene and their spatial and temporal order; 2) an atmospheric model, which describes the interaction between the atmosphere and the energy entering and being emitted.
from the scene; and 3) a sensor model, which describes the behavior of the sensor in responding to the energy fluxes incident on it and in producing the measurements that constitute the image. They suggest that the problem of scene inference, then, becomes a problem of model inversion in which the scene is reconstructed from the image and the remote sensing model. For example, Woodcock et al. (1997) inverted the Li-Strohler Canopy Reflectance Model for mapping forest structure.

Basically, successful remote sensing modeling predicts how much radiant flux in certain wavelengths should exit a particular object (e.g., a conifer canopy) even without actually sensing the object. When the model's prediction is the same as the sensor's measurement, the relationship has been modeled correctly. The scientist then has a greater appreciation for energy-matter interactions in the scene and may be able to extend the logic to other regions or applications with confidence. The remote sensor data can then be used more effectively in physical deterministic models (e.g., watershed runoff, net primary productivity, and evapotranspiration models) that are so important for large ecosystem modeling. Recent work allows one to model the utility of sensors with different spatial resolutions for particular applications, such as urban analysis (Collins and Woodcock, 1999).

Change Detection: Remotely sensed data obtained on multiple dates can be used to identify the type and spatial distribution of changes taking place in the landscape (Friedl et al., 2002; Zhao et al., 2002). The change information provides valuable insight into the processes at work (Alberti et al., 2004; Aube et al., 2004). Change detection algorithms can be used on per-pixel and object-oriented (polygon) classifications. Unfortunately, there is still no universally accepted method of detecting change or of assessing the accuracy of change detection map products. Digital image processing change detection principles are discussed in Jensen (2005).

Information Presentation

Information derived from remote sensor data are usually summarized as an enhanced image, image map, orthophoto map, thematic map, spatial database file, statistic, or graph (Figure 1-5). Thus, the final output products often require knowledge of remote sensing, cartography, GIS, and spatial statistics as well as the systematic science being investigated (e.g., soils, agriculture, urban studies). Scientists who understand the rules and synergetic relationships of the technologies can produce output products that communicate effectively. Those who violate fundamental rules (e.g., cartographic theory or database topology design) often produce poor output products that do not communicate effectively.

Image maps offer scientists an alternative to line maps for many cartographic applications. Thousands of satellite image maps have been produced from Landsat MSS (1:250,000 and 1:500,000 scale), TM (1:100,000 scale) and AVHRR, and MODIS data. Image maps at scales >1:24,000 are possible using imagery with a spatial resolution of ≤ 1 m (Light and Jensen, 2002). Because image map products can be produced for a fraction of the cost of conventional line maps, they provide the basis for a national map series oriented toward the exploration and economic development of the less-developed areas of the world, most of which have not been mapped at scales of 1:100,000 or larger.

Remote sensor data that have been geometrically rectified to a standard map projection are becoming indispensable in most sophisticated GIS databases. This is especially true of orthophotomaps, which have the metric qualities of a line map and the information content of an aerial photograph or other type of image.

Unfortunately, error is introduced in the remote sensing process and must be identified and corrected. Improvements in error reduction include: 1) recording the lineage of the operations applied to the original remote sensor data, 2) documenting the geometric (spatial) error and thematic (attribute) error of the source materials, 3) improving legend design, especially for change detection map products derived from remote sensing, and 4) improving accuracy assessment. The remote sensing and GIS community should incorporate technologies that track all error in final map and image products.

This will result in more accurate information being used in the decision-making process.

Earth Observation Economics

The National Research Council recognized that there is an economic system at play when remote sensor data are used for earth resource management applications (Figure 1-6) (Miller et al., 2001). It consists of an information delivery system with three components: data collection, image processing, and information consumer (user).

The data collection system is composed of commercial vendors and public agencies that operate remote sensing systems. Private industry provides information at market value. Public agencies generally provide remote sensor data at the cost of fulfilling a user request (COPUR). Remote sensing
has been around since the 1960s. There is an increasing number of experts that can use analog and/or digital image processing techniques to extract information from the imagery. Finally, there is the information consumer (user) of the remote sensing–derived information. The user generally needs information of economic, social, strategic, environmental and/or political value (Liveman et al., 1998).

In order for the revenues generated by the information delivery system to be sufficient to support the capital and operating costs of the system, there must be a balance (equilibrium) between the value of the information, as perceived by the user (consumer), and the revenue necessary to support the system (Miller et al., 2001, 2003). The equilibrium has been achieved for airborne photogrammetric and LIDAR mapping applications for several decades. Time will tell if the balance between perceived value and cost can be maintained in the spaceborne case. Mergers are occurring. On January 12, 2006, ORBIMAGE acquired Space Imaging’s assets and now functions as GeoEye, Inc., providing IKONOS, OrbView-2 and Orbview-3 image products. GeoEye plans to launch a new sensor in 2007 with a spatial resolution of 0.41 x 0.41 m (GeoEye, 2006).

The equilibrium can also be impacted by remote sensing technology experts that do not have a good understanding of the user information requirements. In fact, some remote sensing experts are often baffled as to why the consumers don’t embrace the remote sensing–derived information. What they fail to consider is that the consumers generally have no motivation to switch to remote sensing–derived information on economic, social, environmental, strategic, or political attributes simply because it is based on new technology. Furthermore, the consumers on the right side of the diagram often have little knowledge of remote sensing technology or of how it is used to derive information.

Miller et al. (2001; 2003) suggest that this situation creates a knowledge gap between the remote sensing experts and the information consumers (user) (Figure 1-16). Bridging the
Figure 1-7: Book organization.
Figure 1-17 Book organization (continued).

Remote sensing is used for numerous applications such as medical image analysis (e.g., x-ray imaging of a broken arm), non-destructive evaluation of products on an assembly line, and analysis of Earth resources. This book focuses on the art and science of applying remote sensing for the extraction of useful Earth resource information (Figure 1-17). Earth resource information is defined as any information concerning terrestrial vegetation, soils, minerals, rocks, water, and urban infrastructure as well as certain atmospheric characteristics. Such information may be useful for modeling the global carbon cycle, the biology and biochemistry of ecosystems, aspects of the global water and energy cycle, climate variability and prediction, atmospheric chemistry, characteristics of the solid Earth, population estimation, and monitoring land-use change and natural hazards (Johansen et al., 2003).
This chapter defined terms and provided a perspective on how remote sensing science can be useful for Earth resource investigations (Figure 1-17). Chapter 2 introduces principles of electromagnetic radiation and how it is used to perform remote sensing of the environment. Chapter 3 reviews the history of photography, and serial and satellite platforms. Chapter 4 introduces aerial photography, filtration, and film. Chapter 5 presents the elements of image interpretation. Chapter 6 reviews principles of photogrammetry used to extract quantitative information from serial photography. Chapter 7 reviews optical-mechanical remote sensing systems. Chapter 8 introduces thermal infrared remote sensing. Chapter 9 reviews active (RADAR) and passive microwave remote sensing. Chapter 10 introduces remote sensing using light detection and ranging (LIDAR) technology. Chapter 11 describes how remote sensing is used to extract biophysical characteristics of terrestrial and aquatic vegetation. Chapter 12 provides insight into remote sensing of water, ice, and snow as well as atmospheric water vapor and temperature. Chapter 13 demonstrates how remote sensing can provide unique urban/suburban infrastructure information. Chapter 14 describes how selected soil and mineral characteristics may be remotely sensed and how major geomorphic features on the surface of the Earth may be identified. Chapter 15 describes how in situ spectral reflectance measurements are obtained.

References


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