CHAPTER 15

Remote Sensing

15.1 REMOTE SENSING

Remote sensing is the science of gathering information from a location that is distant from the data source. Image analysis is the science of interpreting specific criteria from a remotely sensed image. An individual may visually, or with the assistance of computer enhancement, extract information from an image, whether it is furnished in the form of an aerial photograph, a multispectral satellite scene, a radar image, a base of LIDAR data, or a thermal scan.

Remote sensing is a dynamic technical field of endeavor. Between 1995 and 2000 the number of users employed in these combined branches of knowledge rose from 0.7 to 8.1 million, and their commercial application values rose from $3 billion to $12 billion during the same time frame.

The purpose of this chapter is to acquaint the reader with the technology in order to pique his/her interest in pursuing further knowledge, because these procedures may provide sources of pertinent information for the managers and/or technicians involved in mapping or GIS projects. With this in mind, a number of web site references are sprinkled throughout this chapter to start the reader on a voyage of discovery. Most of these web sites are starting points to further guidance.

It should be noted that the remote sensing systems cited in this book do not cover the entire group of remote geospatial data collection systems that is out there waiting to help the project manager in his/her search for applicable digital information. Also, no partiality is intended for those systems and providers that are discussed herein.

This chapter will not dwell on the mechanics of sensors. Rather, it is intended to establish a passing acquaintance with the characteristics of electromagnetic energy, hopefully helpful to the reader in deciding what types of captured information will best fit a particular project needs.

15.2 SEARCHING THE INTERNET

The Internet can be an educational source of pertinent remote sensing information for the project manager to expand his/her technical knowledge.

15.2.1 Tutorials

There are remote sensing tutorials to be found on the Internet, and it may be to the reader's advantage to access a few of these web sites:

- http://hawaii.ivv.nasa.gov/space/hawaii/vfts/oahu/rem_sens_ex/rsex.spectral.1.html
- http://rst.gsfc.nasa.gov/Front/tofc.html
- http://auslig.gov.au/acres/referenc/abou_rs4.htm

The web site http://satellite.rsat.com/rsat/tutorial.html discusses and illustrates spatial analysis, spectral analysis, advanced processing, applications, three-dimensional perspectives, LANDSAT and IRS-1C data fusion, change detection, and various data resolutions.

Refer to web site http://www.ccrs.nrcan.gc.ca for an enlightening tutorial on stereoscopy, radar fundamentals, and stereointerpretation that can be off-loaded for noncommercial instructional purposes.

15.2.2 Applications Dynamics

Remote sensing, along with its entwined sibling sciences (photogrammetry, GPS, GIS), has enjoyed a dynamic upsurge during the past five years. If the reader is interested in technologies related to agriculture, disaster management, environmental monitoring, forestry, mining, transportation, or utilities distribution, he/she would do well to access the web site http://www.edu.nasa.gov/crsp-wdet/commercial/comApps.html for an extremely instructive session. For each of these technologies this Internet reference provides multipage studies of emerging applications. The Internet web site http://www.flidata.com/ is an enlightening source of information covering the availability of high technology commercial airborne hyperspectral/multispectral imaging systems, advanced remote sensing applications, and airborne data acquisition services applicable to governmental and industrial scientific fields of endeavor:

Agriculture
Defense
Environmental
Forestry
Geographic Information Systems
Mapping
Oceanographics
Research
Terrestrial

For those readers who have a specific interest in forestry applications of remote sensing, log on to http://www.airbornelasermapping.com/Features/ALMSpo01.html for an instructional glimpse at laser mapping.

An instructive Internet reference discussing the principles of remote sensing, with illustrations and images, is found at http://www.sci-ctr.edu.sg/ssc/publication/remotesense/rms1.html.

15.3 REMOTE SENSING SYSTEMS

Many contemporary mapping technologists collect information with a variety of instrumentation, collectively known as remote sensors. Even though these systems collect digital spatial data in mechanically different ways, all of the captured information is related to the electromagnetic spectrum. Although aerial photos are limited to the 0.4–1.0 μm range, there are other sensors that duplicate this range and still others that can extend their range well into the microwave sector.

The reader may want to access the following key words on the Internet to get a more comprehensive grasp of this subject:

Advanced Very High Resolution Radiometer
Agricultural Research Service Laser Profile
Agricultural Research Service Radiance Transect
Agricultural Research Service Thermal Transect
Airborne Data Acquisition and Registration
Airborne Synthetic Aperture Radar
Airborne Terrestrial Applications Scanner
Airborne Visible/Infrared Imaging Spectrometer
Digital Video Imagery
European Remote Sensing Satellite-1
Japanese Earth Resources Satellite-1
LANDSAT Multisprectral Scanner
LANDSAT Thematic Mapper
MODIS/ASTER Airborne Simulator
Systeme Pour l'Observation de la Terre
Thematic Mapper Simulator/12-Channel Daedelus Multispectral Scanner
Thermal Infrared Multispectral Scanner

These sites can open a lot of doors into the subject of remote sensing methodology and applications.

15.3.1 Thematic Data Collection

A remote sensor is an instrument that gathers thematic information from a distance. Over the years, image analysts have employed various segments of the electromagnetic spectrum to enhance their data gathering capabilities. Commercial use of aerial photography using panchromatic film began about the time of the Civil War, but its extended utilization has come about since the World War I era. World War II saw the beginning of near infrared film and the expanded use of color film. The 1970s began the use of airborne and satellite platforms carrying electromagnetic scanners to collect data from earth. Through the 1980s and 1990s these various spatial vehicles transported scanners utilizing such electromagnetic components as

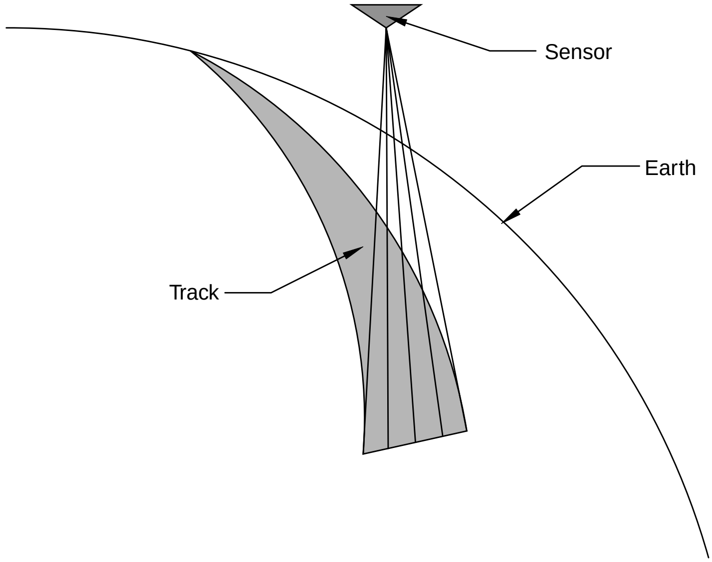

Figure 15.1 A portion of a single scan line.

visible light, near infrared, mid-range infrared, thermal, radar, and LIDAR to collect specialized information.

15.3.2 Scanners

Most scanners operate by catching either radiant rays or return signals and capture information in digital form along scan lines (tracks) forming a continuous orbital path as illustrated in Figure 15.1.

These data are furnished to the buyer as a copy of a segment (scene) of this scanned path information, either in the form of an image or as digital data as shown in Figure 15.2.

Prevailing photogrammetric planimetric and/or topographic mapping is limited to the primary colors of visible light as shown in Table 15.1, but technicians involved in GIS and specialty projects may also want to consider other regions of the electromagnetic spectrum for complementary data sources.

15.3.3 Types of Sensors

Although there are a number of remote sensing systems capable of collecting information, there are two general categories:

- Passive sensors collect natural radiant energy reflected or emitted from a targeted object.
- Active sensors transmit a signal and then receive the reflected response.

There are many different types of data sensors in use, depending upon the purpose of the collected information. Some of the more popular remote sensors currently

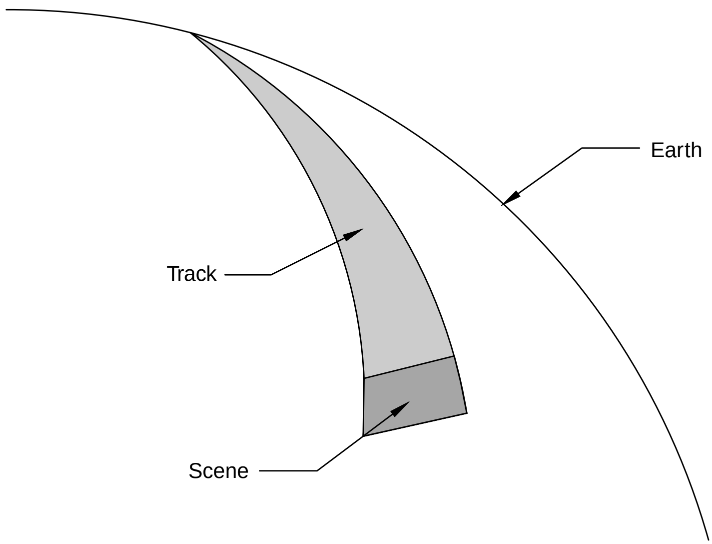

Figure 15.2 A scene from a scanner's orbital path.

Table 15.1 Spectral Bands of Primary Colors

Band	Spectral Range (μm)
Blue	0.4–0.5
Green	0.5–0.6
Red	0.6–0.7

employed in data capture are listed herein, but it is not intended that all available systems be included. Those shown represent a sampling of the different segments of the electromagnetic spectrum that are used in analyzing ground characteristics.

15.3.3.1 Aerial Camera

An aerial camera is a passive sensor that collects a direct, continuous tone pictorial image in the visible light (0.4–0.7 μm) range. Through the use of proper film, the camera can also create a photographic near infrared image composed of visible green (0.5–0.6 μm), visible red (0.6–0.7 μm), and near infrared (0.7–1.0 μm) light.

15.3.3.2 Video Camera

A video camera can be installed in an aircraft. This passive sensor records a continuous swath of raster data covering a moving scene of the terrain, and the videotape can be played on a graphic screen much like a video movie. Digital video systems today are often used to collect, manipulate, and analyze data in the black and white, natural color, and color infrared ranges of the spectrum. Since the video image is a raster file, it can be segmented and imported into a CADD/CAM/CAD environment.

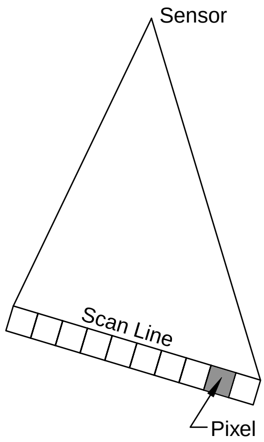

Figure 15.3 Scanned pixels.

15.3.3.3 Scanners

Scanners are passive sensors that capture the reflected or emitted energy intensity from observed objects into digital picture elements called pixels. Scanner data can be viewed as a pictorial rendition on a computer screen or generated as a hardcopy counterpart. Data gathered as groups of pixels are termed raster data. Figure 15.3 is a schematic representation of a scanned data line with a single pixel blackened.

Thematic Mapper/Multispectral Scanner

Thematic mappers (TM) and multispectral scanners (MSS) are passive scanning systems that collect raster data in several selected bandwidths simultaneously between visible light and thermal bandwidths (0.4–8.0 μm). Refer to Figure 15.4 for a schematic of a rudimentary MSS. These sensors have been deployed on several systems of earth resource satellites.

Operational scanning systems are considerably more complex than this simplistic diagram implies. A revolving mirror makes successive raster sweeps of the terrain as the carrier moves forward. Pixels of reflected and/or emitted energy wave bundles pass through the system aperture to be reflected off the surface of the rotating mirror onto a beam-splitting mirror that reflects specific wavelengths and transmits others. This grate deflects the visible portion of the spectrum, while the thermal passes on to be collected by thermal detectors. The visible waves pass through a prism where they are separated into various colors, which are collected by visible light detectors. Data are stored in groups of waveband ranges.

Thermal Scanner

A thermal scanner is a passive scanner that collects raster data in the longer infrared wavelengths (8–13 μm range) which are actual temperature radiations emitted

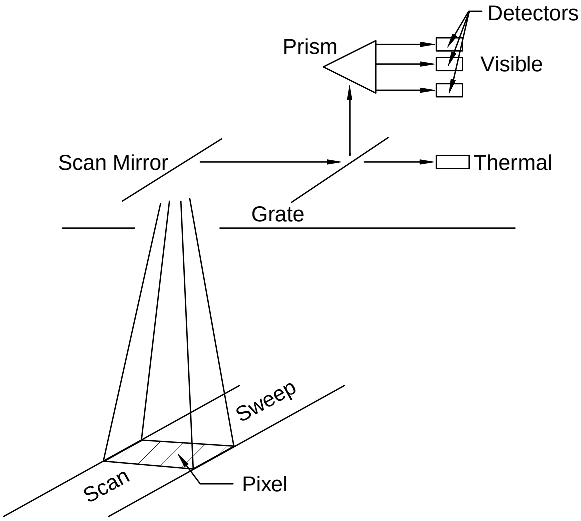

Figure 15.4 Rudimentary components of an MSS.

from an object. Since this scanner senses heat emissions, it can be employed during daylight or darkness.

Radar

The web site http://southport.jpl.nasa.gov/drsc/imagingradarv3.html presents a basic dissertation on the subject of imaging radar. Synthetic aperture radar (SAR) is an active scanner that transmits and receives its own signals in several bands within the microwave range (1 mm to 1 m range). The receiver records a continuous swath of raster data covering a moving scene, and the data tape can be played on a graphic screen much like a video movie. Radar scans can be segmented and imported into a CADD/CAM/CAD environment.

This system is capable of piercing clouds and penetrating to certain depths in the soil mantel and can be operated during daylight or darkness, which partially accounts for its increasingly wider usage. Reflected radar signals are measurable, thus enabling mappers to calculate geographic coordinate values of ground features.

Integrating radar sweep data into a DTM structure can generate interpolated contours covering designated tracts.

Radar has a number of capabilities, which makes it a valuable sensor in a variety of applications, some of which are listed in Table 15.2. The web site http://www.sandia.gov/radar/sarapps.html offers more information.

Light Detection and Ranging

LIDAR (light detection and ranging*), a relatively recent innovative technique for the collection of digital elevation data, shows great promise for terrain mapping

* Log on to the Internet with this key search phrase to open various references pertaining to LIDAR.

Table 15.2 General Applications of SAR

Military	Reconnaissance
	Surveillance
	Targeting
	Buried arms caches and mines
	Underground bunkers
Treaty verification	Weapons nonproliferation
Guidance	All-weather navigation
Penetration	Foliage
	Soil
	Underground utilities
Environmental	Crop characteristics
	Deforestation
	Ice flows
	Oil spills
	Oil seepage

applications. LIDAR is capable of producing a mass of spatial points that may be used as basic elevation data for production of surface models such as DEMs, DTMs, and computer software-generated contours. Additional ancillary products may be developed from LIDAR elevation data sets with the use of specific software techniques. The light energy that is emitted by the laser strikes a terrain surface. A portion of the energy is absorbed by the surface. The amount of absorption is partially dependent upon the type of surface that the light strikes. The remaining energy reflects off the terrain surface and is captured by the sensor. Intensity images are software-produced images created by assigning colors or shades of gray to the amount of energy returned to the sensor from laser light pulses. Intensity images can provide a crude pictorial of the earth surface that may have use as a reconnaissance or planning tool. The project manager should remember that LIDAR data are simply elevation data used in the preparation of elevation products. Raw LIDAR data is not an end product itself, and in fact in most cases is of little use in photogrammetric mapping. It is important for project managers to understand that LIDAR is only one of several posible tools that can be used to collect elevation data. The web site http://lidar.woolpert.com discusses benefits, system components, specifications, accuracy, flight layout, post processing, and quality control as they pertain to LIDAR operations.

The airborne LIDAR system is composed of multiple interfaced systems, which may consist of the following:

1. An infrared laser discharging a stream of focused pulses at a rotating mirror, which scatters them across a swath on the ground. When the receiver unit recaptures the reflected rays, a discriminator and a time interval meter measure the elapsed time between the transmitted signal and the reflected echo.
2. As the flight is in progress an inertial reference system (IRS) automatically maintains a constant record of the pitch, roll, and heading of the aircraft.
3. Throughout the flight, a kinematic ABGPS locks onto at least four navigation satellites, thereby constantly documenting the spatial position of the aircraft.

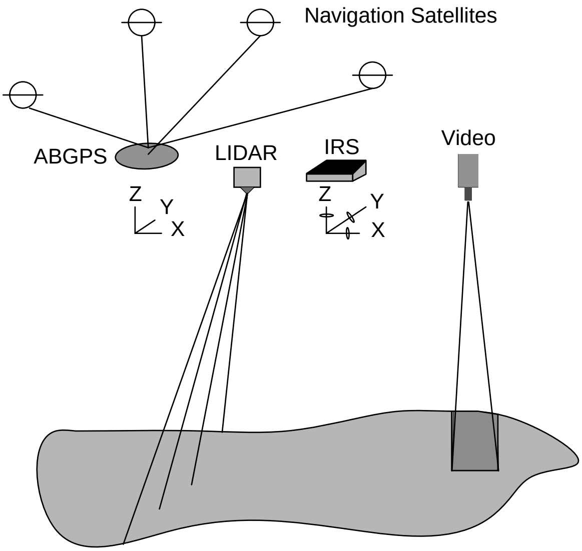

Figure 15.5 Schematic of the components of an airborne LIDAR system.

4. An imagery collection system (analog camera, digital camera system or color video camera) records the terrain along the track of the LIDAR scan. Imagery may be required for quality control of final processing of the data and planimetric feature collection. Many projects may not require the collection of this type data or may be able to make use of existing imagery.

Figure 15.5 illustrates the concept of how the separate airborne components are linked in an operational mode.

During the mission one or more ground GPS stations are linked into the system to assure dependable referencing of the airborne package to the earth. Once the flight data are recorded, appropriate software manipulates the combined data and creates a spatial coordinate at each ray point. The accumulated digital points are stored in a massive database of ground stations. LIDAR projects that are designed properly can economically generate digital terrain models with vertical accuracies as close as 6 in. or less, and horizontal accuracies within 1/1000 of the flight height.

LIDAR offers some advantages over aerial photography in creating topographic maps:

- Overflights can be scheduled at almost any time because LIDAR is uninhibited by the time of day, sun angle, certain types of vegetation, or less than ideal weather conditions. Rain, and flights that require an altitude in or above cloud cover, are unsuitable conditions for LIDAR collection.
- Foliage penetration is possible. Penetration of foliage may vary depending upon many factors, including the specifications for the laser to be used, type of foliage, swath width, and flight height. Penetration of foliage is one of the most important features of a LIDAR terrain data collection project. Many LIDAR projects have as final

products a model of the earth's surface without trees, foliage, and planimetric features. The LIDAR industry is constantly improving collection and processing systems for penetration of foliage and the accurate removal of trees and planimetric features.

- Terrain data may be collected and processed in an expeditious manner, thus possibly reducing project completion time.
- Flights are not inhibited by restricted right of entry or remote sites.

Since the rays are measured to a point where they are reflected by an object — foliage, structures, ground — editing of the LIDAR data must be done in a highly adept manner. Contractor LIDAR data processing techniques are often unique. The speed and accuracy of these techniques are critical to the success of a LIDAR elevation data collection and final product generation process.

Forward Looking Infrared

Forward looking infrared (FLIR) is a passive scanner which converts incident thermal (heat) rays into real-time video signals. This system may be brought into play during daylight or darkness and can utilize airplanes, helicopters, or ground vehicles as carriers employed in police work, search and rescue missions, wild game census, and environmental studies where differential shades of temperature values segregate primary interest objects from a cluttered background. Consult the web site http://www.flir.com/resources/InfraredEverywhere.htm for further information about this system.

15.4 AERIAL PHOTO IMAGE SCANNING

Although there is a growing popularity for digital cameras in aerial photography projects, most aerial photography is accomplished with an analytical camera. Spurred by the transition toward softcopy systems, there is a growing trend to scan aerial photographs with which to superimpose raster images on vector mapping information either on the computer monitor or hardcopy data plots. Photogrammetric mapping projects require high-resolution scanning with generally between 800 and 1600 points per inch. Scanning at these resolutions requires large quantities of hard disk storage. Photogrammetric mapping projects typically require a significant number of photographic images. Photogrammetric workstations that require the incorporation of scanned imagery will necessarily mandate significant processing and digital data storage capacity.

A series of simple formulae calculate the amount of disk storage for photo scanning. Equation 15.1 determines the number of raster points per line, based upon pixel resolution.

$$p_l = p_i * L \tag{15.1}$$

where:

p_l = points per line
p_i = resolution (points per inch)
L = length of image (inches) in line of flight

The number of scan lines is reckoned with Equation 15.2, dependent upon raster resolution and width of the image frame.

$$d_l = p_i * W \tag{15.2}$$

where:
d_l = lines of data
p_i = resolution (points per inch)
W = width of image (inches) perpendicular to flight

The total bytes of scanned data are calculated with Equation 15.3, based upon points per line and number of lines.

$$d_b = p_l * d_l \tag{15.3}$$

where:
d_b = total bytes of scanned data
p_l = points per line
d_l = number of lines of data

As an example, a total panchromatic aerial photo is to be scanned at a resolution of 200 points per inch. A photo encompasses a 9-in. square area.

$p_l = p_i * L = 200 \times 9 = 1800$ points
$d_l = p_i * W = 200 \times 9 = 1800$ lines
$d_b = p_l * d_l = 1800 \times 1800 = 3{,}240{,}000$ bytes

Each point requires 1 byte of storage, so disk space for this single panchromatic photo requires 3.24 megabytes at a resolution of 200 points per inch.

It is not always necessary to scan the entire photo, which would lessen storage requirements, but sometimes multiple photos are necessarily scanned to form mosaics. This technique adds to the storage. Color photos require a separate scan for each primary color of red, green, and blue. Therefore, color storage requires three times as much disk space as panchromatic.

15.5 SATELLITE IMAGERY*

Every portion of the surface on the earth receives solar radiation that is reflected or absorbed and emitted in specific wavelengths, some of which are invisible to the human eye. A surface's characteristic spectral signature is made up of those specific wavelengths that can be recorded by satellite-mounted sensors. The recorded spectral signatures are subsequently processed into photograph-like images.

* Log on to the Internet key phrase "satellite remote sensing systems" which opens numerous informative web sites on this subject.

15.5.1 Data Format

Satellite images are collected in raster format, which is a matrix of thousands of individual picture elements called pixels. The ground area covered by each pixel determines the resolution of the pixel. For instance, if the image resolution is 30 m, each picture element is restricted to an area on the ground covering 30 m, about 100 ft, square.

Each pixel contains a single unit of information which represents the dominant spectral signature for the corresponding area on the earth's surface. The information content of an individual pixel is in digital form, usually 8-bit, so that it can be analyzed by a computer or converted to photographs for visual analysis. The information set captured by a pixel is composed of its XY position and the brightness value.

15.5.2 Spectral Bands

Satellites collect data in groups of spectral bands. In a natural color image there would be three bands of data (red, green, and blue), each showing various intensities of the pertinent color. By the same token, a false color photographic image would also contain three bands of data (near infrared, red, and green), each showing various radiances for the pertinent layer.

15.5.3 Georeferencing Satellite Data

Satellite data are subject to a number of errors, but vendors process the raw data through standard algorithms and cleanse the information prior to delivery. Satellite images can be georeferenced to earth coordinates. Once the image is georeferenced to the ground, these causal errors are normally not significant at the mapping scales involved. In many situations this can be a "rubbersheet" scaling process rather than a true displacement rectification, whereby the image is best fit to several ground control points. In other situations, some processes that use orthophoto generation of the image produce a truly scale rectified image.

15.5.3.1 Advantages of Satellite Scenes

Presuming that the inherent accuracy of satellite data conforms to the mapping specification demands, satellite data can be a valuable tool in many ways.

15.5.3.2 Pictorial Image

Satellite raster imagery provides a pictorial simulation that can be overlaid on GIS/LIS vector themes so that the viewer can see the image and line drawing simultaneously. Hardcopy plots of the image data can be created.

15.5.3.3 Change Detection

Historical satellite imagery for different passes over the same site is available for purchase. Change detection information can be gleaned from these time-lapse scenes.

15.5.3.4 Perspective Views

Three-dimensional perspective maps can be generated, looking at the data scene from any angle, with a spatial image or a GIS file draped over it.

15.5.3.5 Screen Digitizing

After an image is registered on the screen data can be digitized from it, thus creating polygonal thematic layers.

15.5.4 Restrictions

Two restrictions must be realized when using satellite imagery:

- These operations require tremendous amounts of RAM and hard disk storage.
- Data compatibility is only as good as the most inaccurate information.

15.6 SATELLITE SYSTEMS

Currently, a number of major earth resource satellite systems revolve around the world in sun-synchronous paths. It should be noted that those discussed herein are not the total collection of orbiting satellites, but are intended to inform the reader about the different types of electromagnetic information that is available to the public.

15.6.1 LANDSAT

For further information about the LANDSAT satellite umbrella, refer to:

http://www.friends-partners.org/~jgreen/landsat.html
http://geo.arc.nasa.gov/sge/landsat/lpsum.html
http://www.fes.uwaterloo.ca/crs/geog376/Satellites/Landsat.html

In 1972 the United States launched LANDSAT 1, an optical satellite, the first of what would become a series of earth resources satellites. Since then six other satellites in this series were put into service, so at times multiple sensing systems were in orbit simultaneously. Figure 15.6 indicates the launch intervals of LANDSAT vehicles 1–7 and follows their operational longevity. LANDSAT 8 is scheduled for flight in about 2004.

These satellites fly in generally a north/south orbit over the sunlit portion of the earth while collecting electromagnetic data along a scan line. Data from the LANDSAT vehicles are transferred to earth stations for processing and distribution.

Table 15.3 indicates the payloads carried by each of the satellites in the LANDSAT series. The data collection instruments referenced in the table are:

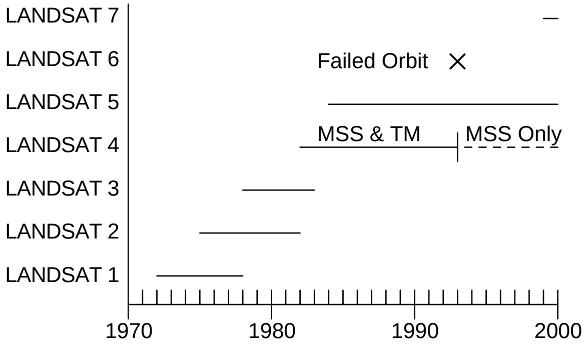

Figure 15.6 Launch years and longevity of the LANDSAT series.

Table 15.3 Sensor Payload Aboard Each of the Vehicles in the LANDSAT Series

System	RBV	MSS	TM	ETM	ETM+
LANDSAT 1	√	√			
LANDSAT 2	√	√			
LANDSAT 3	√	√			
LANDSAT 4		√	√		
LANDSAT 5		√	√		
LANDSAT 6				√	
LANDSAT 7					√

RBV (Return Beam Vidicon)
MSS (Multispectral Scanner)
TM (Thematic Mapper)
ETM (Enhanced Thematic Mapper)
ETM+ (Enhanced Thematic Mapper Plus)

Table 15.4 cites the resolution of the sensory systems of the various LANDSAT series. The resolution discriminates between data collected in panchromatic (pan) and multispectral (ms). LANDSAT 1 through LANDSAT 5 provide data in both panchromatic and multispectral mode at the same resolution.

The spectral characteristics of each vehicle in the LANDSAT constellation can be found at the web site http://www.ccrs.nrcan.gc.ca/ccrs/tekrd/satsens/landsate.html.

The orbital altitude and revisit* schedule of the LANDSAT series can be found in Table 15.5.

Some applications that have been used or might be considered for use with LANDSAT imagery are listed in Table 15.6.

A USGS guide to LANDSAT coverage can be found by referencing "Thematic Mapper LANDSAT Data: Search Criteria" at http://edcwww.cr.usgs.gov/Webglis/glis-bin/search.plLANDSAT_TM on the Internet.

* Revisit is the time interval between successive data captures of the same scene.

Table 15.4 Resolution of Instrument Packages in the LANDSAT Series

System	Instrument	Resolution (meters)
LANDSAT 1	RBV	80
	MSS	80
LANDSAT 2	RBV	80
	MSS	80
LANDSAT 3	RBV	30
	MSS	80
LANDSAT 4	MSS	80
	TM	30
LANDSAT 5	MSS	80
	TM	30
LANDSAT 6	ETM	15 (pan)
	ETM	30 (ms)
LANDSAT 7	ETM+	15 (pan)
	ETM+	30 (ms)

Table 15.5 Altitude Above the Earth's Surface and Revisit Interval of Each of the LANDSAT Series

Series	Altitude	Revisit
LANDSAT 1	917 km	18 days
LANDSAT 2	917 km	18 days
LANDSAT 3	917 km	18 days
LANDSAT 4	705 km	16 days
LANDSAT 5	705 km	16 days
LANDSAT 6	Inoperable	Inoperable
LANDSAT 7	705 km	16 days

15.6.2 SPOT

The French-based SPOT (Systeme Pour l'Observation de la Terre) has launched a constellation of four optical earth resources satellites into orbit. Refer to the SPOT web pages http://www.spot.com, http://edcwww.cr.usgs.gov/glis/hyper/guide/spot or http://version0.neonet.nl/ceos-idn/sources/SPOT_3.html for information about this earth observation system. Refer to Figure 15.7 for the launch and decommission dates of the SPOT series.

The payload on each satellite consists of two high-resolution sensor systems. Working independently of one another, these systems add a high degree of flexibility for customized three-dimensional data collection. Characteristics of the SPOT series can be located by logging on to the web site http://www.ccrs.nrcan.gc.ca/ccrs/tekrd/satsens/sats/spote.html.

15.6.2.1 Off-Nadir Viewing

Initially, this series of data collection satellite systems gathered continuous monoscopic raster vertical image information. Once the SPOT satellite was launched,

Table 15.6 Some Applications that Have Been Used or Might Be Considered for Use with LANDSAT Imagery

Hydrology	Agriculture
Watershed modeling	Crop assessment
Wetland conditions	Crop location
Snow pack conditions	Crop damage
Lake ice	Yield estimates
River ice	Temporal change
Sea ice	Compliance Monitoring
	Farming activity
Forestry	Soil Condition Monitoring
Mapping	Tillage practice
Forest inventory	
Forest cover typing	Disaster Management
Clearing location	Flood mapping
Pathogen location	Extent
	Damage
Engineering	Oil spill monitoring
Route location	Detection
Pipelines	Mapping
Power lines	Forest fires
Roads	Burn delineation
Utilities	Damage assessment
Geology	Land Use/Land Cover
Mapping	Land use monitoring
Structure mapping	Use/cover patterns
Surfacial bedrock mapping	Temporal change
Lineament identification	Land cover delineation
Landform delineation	Vegetation
Surfacial material	Cover types
Geological Hazard	Base mapping
Landslide hazard	Land use
Coastal erosion	Land cover
	Cultural features

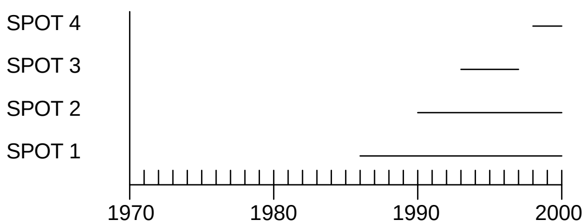

Figure 15.7 Launch years and longevity of the SPOT series.

this capability changed. Aside from amassing vertical imagery, this system can also be directed to collect side-looking information in an area covered by a previous pass.

Data collected by SPOT satellites, when in normal operational mode, are monoscopic. Unlike LANDSAT (nadir viewing only), SPOT can view both nadir (vertical) and off-nadir (oblique). Upon specific request this allows the sensor system to capture the same scene on several different passes, with the number varying from seven on the equator to eleven at 45° latitude, which allows for stereoscopic coverage. Presented with this stereoscopic faculty, mappers can compile planimetric and/or topographic maps from spatial platforms soaring 400–500 mi above the ground. Granted, this ability is limited to relatively small-scale mapping, but there are still inaccessible areas in the world that demand a use for this potential.

15.6.2.2 Applications

As noted above, Table 15.6 lists some specific applications to which LANDSAT imagery has been used or might be considered applicable. By the same token, Table 15.7 lists some specific applications to which SPOT imagery has been used or might be considered applicable. Some other applications may be in the general fields of cadastral mapping, land cover mapping, telecommunications, surveillance, natural hazard assessment, or many others requiring a view from above. A SPOT

Table 15.7 Some Applications that Have Been Used or Might Be Considered for Use with SPOT Imagery

Technology	Application
Agriculture	Crop forecasting
	Productivity monitoring
	Soil moisture assessments
	Crop damage assessments
Cartography	Topographic mapping
	Terrain simulations
	Terrain modeling
	Thematic mapping
	Map updating
Forestry	Harvest logistics
	Stand density
	Yield estimate verification
	Disease assessment
	Fire damage assessment
Geology	Oil and gas exploration
	Structural mapping
	Engineering studies
	Hazards analysis
	Tectonic studies
Urban planning	Land use mapping
	Impervious surface modeling
	Siting studies
	Demographic change detection
	Cultural change detection
Water and environment	Wetlands mapping
	Habitat mapping
	Pollution monitoring
	Resource assessment
	Hydrological studies
	Coastal studies

scene can be transformed into a three-dimensional view if integrated with corresponding DEM information.

SPOT 5, scheduled for a 2002 launch, will offer several innovative features:

- 60 × 60 km imagery scenes
- 2.5-, 5-, 10-, and 20-m resolution
- Daily global coverage at 1-km resolution
- Worldwide DTMs

SPOT's panchromatic 15-m resolution permits the imagery to be used for the production of thematic mapping with detail location accuracy comparable to map scales of cartographic work at 1:100,000 scale and map updating at 1:50,000 scale. SPOT's side-looking capability permits stereoscopic imagery and allows three-dimensional viewing and interpretation of terrain and cultural features from any location on the earth. This stereoscopic imagery is being used to produce topographic maps with contour intervals as low as 10 and 20 meters. It is also used in digital terrain modeling and the production of three-dimensional perspective views for terrain simulation, strategic planning, and impact assessments. When there is an interest in using only specific areas of satellite scenes, relevant areas can be cut out of the total scene.

15.6.2.3 National Oceanic and Atmospheric Agency

Log on to the web site http://www.publicaffairs.noaa.gov for greater in-depth information about the National Oceanic and Atmospheric Agency (NOAA) sensing system. This meteorological satellite system launched by the NOAA carries a pair of advanced very high resolution radiometers (AVHRR) with resolutions of 1.1 and 4.0 km. Sensitivity ranges are visible, near infrared, and three thermal bands. Refer to the web site http://www.ccrs.nrcan.gc.ca/ccrs/tekrd/satsens/sats/noaae.html for the visible, near infrared, and infrared characteristics of the NOAA series.

The NOAA sensing system revisits the same scene twice daily and produces a continuous east/west swath 1490 mi (2400 km) wide from an altitude of 900 mi (1450 km) above the earth. Imagery from these satellites is compatible only with ultra small-scale mapping. To get information concerning the systems or to order data, contact:

NOAA, Satellite Data Services Division
5627 Allentown Road
Camp Springs, MD 20746

15.6.2.4 Indian Remote Sensing

Having had encouraging success in testing demonstration resource satellites, Bhaskara 1 in 1979 and Bhaskara 2 in 1981, the India Department of Space set into motion the Indian Remote Sensing (IRS) Satellite program with the implementation of the National Natural Resources Management System. With the goal of boosting the national economy, this remote sensing system was designed to furnish informative

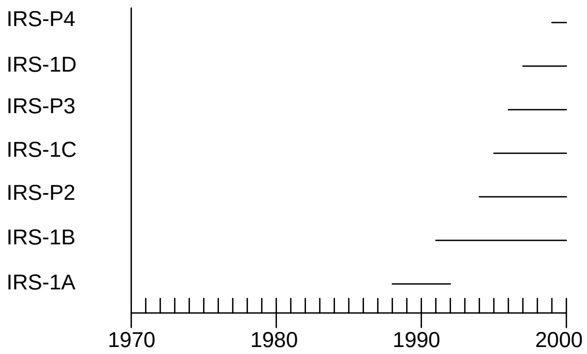

Figure 15.8 Launch years and longevity dates of the IRS series.

Table 15.8 Payloads of Those IRS Remote Sensor Satellites Operating at the Beginning of 2000

	LISS-I	LISS-II	LISS-III	PAN	WIFS	MOS	OCM	MSMR
IRS-1B	●	●						
IRS-P2		●						
IRS-1C			●	●	●			
IRS-P3					●	●		
IRS-1D			●	●	●			
IRS-P4							●	●

electromagnetic data to scientists in such ventures as agriculture, forestry, ecology, geology, watersheds, marine fisheries, and coastal management.

Since 1988 the Indian Space Research Organization has launched a constellation of seven satellites, with two more planned by 2004. Figure 15.8 indicates the launch years and longevity of the IRS series. The IRS satellites carry three instruments in four bands, covering visible and near infrared. One device on the early series covers a ground swath 93 mi (148 km) wide with a resolution of 72.5 m, and the other two devices cover parallel swaths 46 mi (74 km) wide with a 1.5-km overlap at a resolution of 36.25 m. The latest models (IRS-1C and IRS 1-D) produce panchromatic image data at less than 6-m resolution and multispectral image data ranging from 25 to 200 m. Table 15.8 notes the payloads of those IRS remote sensor satellites operating at the beginning of 2000. The system acronyms are:

- LISS — Linear imaging self-scanning
- PAN — Panchromatic
- WIFS — Wide field sensor
- MOS — Modular optoelectronic sensor
- OCM — Ocean color monitor
- MSMR — Multifrequency scanning microwave radiometer

With the subsequent successful operation of this series of satellites, the worth of their captured information has blossomed into numerous rational applications, such as:

- Crop acreage measurement
- Crop yield estimation
- Agro-climatic planning
- Drought warning and assessment
- Flood control, risk zones, and damage assessment
- Watershed management
- Water resources management
- Prediction of snowmelt runoff
- Irrigation management
- Wetland mapping
- Land use/land cover mapping
- Wasteland management
- Fisheries management
- Mineral prospecting
- Forest resource surveys
- Urban planning
- Environmental impact

IRS-1B

Refer to http://csre.iitb.ernet.in/isro/irs-1b.html on the Internet for the characteristics of IRS-1B sensors.

IRS-P2

Refer to http://csre.iitb.ernet.in/isro/irs-p2.html on the Internet for the characteristics of IRS-P2 sensors.

IRS-1C

Refer to http://csre.iitb.ernet.in/isro/irs-1c.html on the Internet for the characteristics of IRS-1C sensors.

IRS-P3

Refer to http://csre.iitb.ernet.in/isro/irs-p3.html on the Internet for the characteristics of IRS-P3 sensors.

IRS-1D

Refer to http://csre.iitb.ernet.in/isro/irs-1d.html on the Internet for the characteristics of IRS-1D sensors.

IRS-P4

Oceansat-1 measures physical and biological ocean criteria on eight spectral bands on the OCM. Refer to http://csre.iitb.ernet.in/isro/irs-p4.html on the Internet for the characteristics of IRS-P4 sensors.

Future

The slated launch of IRS-P5 (Cartosat-1) and IRS-P6 (ResourseSat) in the 2000–2002 time frame adds cadastral level capabilities for cartographic mapping and crop/vegetation analysis.

15.6.2.5 Earth Remote Sensing

Within the umbrella of the European Space Agency a group of nations has put into operation a pair of Earth Remote Sensing (ERS) satellites. The first, ERS-1, was launched in 1991 and went defunct in 2000. ERS-2, very similar to ERS-1, was launched in 1995 and is still operable. An interested reader may wish to refer to the web site http://earthnet.esrin.esa.it/eeo4.10074 for more information.

The payload in this vehicle includes several electronic instruments to carry out a number of functions:

1. A C-band (56-mm wavelength) SAR with a spatial resolution of 30 m
2. A radiometer (visible and infrared) that records sea surface temperatures and vegetative land cover
3. A wind scatterometer
4. A radar altimeter that measures wave magnitude
5. An absorption spectrometer that detects upper level ozone, trace gases, and aerosols
6. A microwave sounder that detects atmospheric humidity
7. A range device that ascertains orbit and trajectory information
8. A laser reflector that pinpoints satellite position

The web site http://www.ccrs.nrcan.gc.ca/ccrs/tekrd/satsens/sats/erse.html presents the characteristics of the ERS series.

It was intended that these sensors would provide information about the oceans, iceflows, and land resources. This active electronic system is capable of collecting reliable resource data pertinent to the technologies involving meteorology, geology, vegetation, hydrology, land use, oceanography, and glaciology regardless of time of day or the presence of cloud cover, haze, or smoke.

To get information, archived back to 1992, concerning the systems or to order data, contact Space Imaging EOSAT (Section 10-13) at:

Space Imaging EOSAT
12076 Grant Street
Thornton, CO 80241

15.6.2.6 IKONOS-2

Originally planned by Space Imaging EOSAT as a dual vehicle system, IKONOS is now composed of a single functioning satellite. Immediately subsequent to its vernal launch in 1999, telemetry from the rocket carrying IKONOS-1 ceased and was never regained. Due to technical difficulties the rocket plunged into the Pacific Ocean shortly after liftoff. IKONOS-2 was launched six months later and has continued to operate successfully since then.

Table 15.9 Width and Resolution of Spectral Bands of IKONOS-2 Digital Camera

Band	Spectral (μm)	Resolution (m)
Monochromatic	0.45–0.90	1
Multispectral		4
Blue	0.45–0.52	4
Green	0.52–0.60	4
Red	0.63–0.69	4
Near infrared	0.76–0.90	4

A visit to the Internet under the keywords "IKONOS 1 satellite," "IKONOS 2 satellite," or "Space Imaging EOSAT" would add to the reader's knowledge.

The payload's major component is, in essence, a very high resolution digital camera which is capable of gathering gray-scale and multispectral digital data from an altitude of 422 mi above the earth. The data collector is a push-broom electro-optical camera with a 10-m focal length folded by mirrors into a 2-m package. It sweeps a 700-km swath and is capable of pivoting to collect cross-track data.

Applications of this system would be similar to any those of LANDSAT or SPOT, but its very high resolution gives it a distinct advantage in analyzing information in GIS and other scientific resource projects. Table 15.9 notes the path width and resolution of spectral bands of IKONOS-2 digital camera.

Refer to http://www.erdas.com/news/Ikonos_image.html on the internet to view a striking IKONOS-2 monochromatic image.

To get information concerning the systems or to order data, contact Space Imaging EOSAT.

15.6.2.7 RADARSAT

RADARSAT's payload, a Canadian optical satellite system carried in the RADARSAT-1 vehicle, utilizes a C-band (5.6 cm) SAR, an active sensor which discharges microwave signals to the ground and captures return signals. These signals, from a single wavelength frequency, can be translated into a panchromatic image that may then be colorized by integration with data from other sources such as SPOT or LANDSAT. This system's long wavelength allows its use during the day or night under most atmospheric conditions. Figure 15.9 is a RADARSAT image scene in a Fairbanks, AK mining district.

Some of the applications that have been used or might be considered for use with RADARSAT imagery can be found in Table 15.10. Those interested in learning more about these applications may wish to log on to http://www.rsi.ca/classroom/class.htm for a more in-depth study of these applications.

Data, which is processed in near real time, is furnished in six grades of resolution ranging from fine (8 m) to coarse (100 m) in scene sizes from 50 × 50 km to 500 × 500 km. Archived data dates back to 1996.

RADARSAT-2, which will allow capabilities of 3-m resolution, is scheduled for launch in 2002.

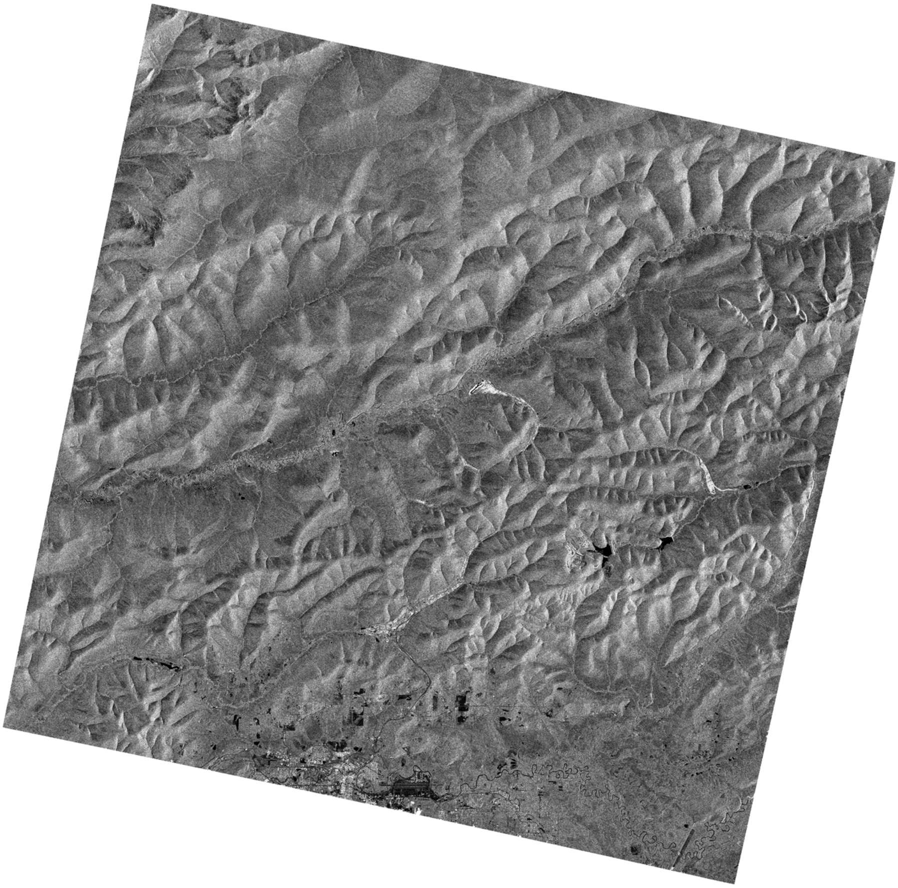

Figure 15.9 RADARSAT image scene in a Fairbanks, AK mining district provided to AeroMap U.S. by Space Imaging EOSAT. (Courtesy of AeroMap U.S., Anchorage, AK.)

Besides RADARSAT imagery, this organization also offers products from LANDSAT, SPOT, ERS, and JERS. Headquarters and client services offices can be contacted at:

RADARSAT International
13800 Commerce Parkway
MacDonald Dettwiler Building
Richmond, British Columbia
V6V 2J3, Canada

Headquarters	Client Services
Tel: (613) 231-500	(604) 244-0400
Fax: (604) 231-4900	(604) 244-0404
E-mail: info@rsi.ca	info@rsi.ca

Table 15.10 RADARSAT Applications

Hydrology	Agriculture	Geology
Watershed modeling	Crop assessment	Geological mapping
Soil moisture	Crop type	Structure mapping
Wetland conditions	Crop damage	Surfacial bedrock maps
Snow pack conditions	Land use monitoring	Lineament identification
Fresh water ice	Temporal change	Hydrocarbon exploration
Lake ice	Compliance monitoring	Sedimentology maps
River ice	Farming activity	Mineral exploration
	Land use elevation	Quaternary mapping
Forestry	Soil condition monitoring	Landform delineation
Recon mapping	Tillage practice	Surfacial material
Terrain analysis	Soil moisture	Geological hazard
Forest cover types		Seismic zones
Commercial forestry	Disaster Management	Landslide hazard
Clearing mapping	Flood mapping	Coastal erosion
	Extent	
Marine	Damage	Land Use/Land Cover
Coastal zone monitoring	Oil spill monitoring	Land use monitoring
Vegetation mapping	Detection	Use/cover patterns
Mapping	Mapping	Temporal change
Ship target detection	Emergency response	Land cover delineation
Vessel location	Forest fires	Vegetation
Wake detection	Burn delineation	Cover types
Aquaculture detection	Damage assessment	Base mapping
Location		Land use
Mapping		Land cover
Ocean circulation		Cultural features
Feature ID		

An interested reader may wish to contact the Internet page "How to order RADARSAT-1 Data" at http://www.space.gc.ca/sectors/earth_environment/radarsat/order_d_ata/default.asp.

15.6.2.8 RDL Space Corporation

Much of the time photogrammetry deals with large-scale mapping, while the resolution of satellite data is compatible with medium- to small-scale mapping. During the recent past the sciences of GIS, GPS, and photogrammetry necessarily became comingled to satisfy the solution needs of specific projects. With regard to large-scale mapping, one of the issues arising from the utilization of satellite data has long been the matter of pixel resolution.

The RDL Space Corporation has developed a satellite system that will soon be gathering commercially obtainable information at a finer resolution. This radar imaging system, known as RADAR1, is capable of delivering SAR data to a pixel size of a single meter. As is true with all radar procedures, RADAR1 is undeterred by the time of day, weather, or clouds. By logging on to the web site http://www.rdl.com/space_corp/space_corp.html the reader may find a contact that will furnish more specific information about this satellite.

Table 15.11 Characteristics Comparison of Several Sensors

	Swath (km)	Revisit	Archive	Area
RADARSAT-1	50–500	24 days	1996	Global
ERS	100	35 days	1992	Global
LANDSAT 4,5	185	16 days	1972	Global
LANDSAT 7	185	16 days	1999	Global
SPOT	60	26 days	1986	Global

15.6.2.9 Data Comparison

Table 15.11 notes some comparable characteristics of several satellite systems.

15.7 AIRBORNE SENSORS

Some sensor systems are transported by aircraft rather than satellites.

15.7.1 Airborne Visible Infrared Image Spectrometer

One such sensor is the Airborne Visible Infrared Image Spectrometer (AVIRIS)* payload, operating as a cooperative effort by NASA (National Aeronautics and Space Agency) and JPL (Jet Propulsion Laboratory), which employs a NASA ER-2 aircraft as a platform flying at an altitude of 20 km above sea level, or an Otter aircraft at lower altitude.

Each sweep of its "whisk broom" action samples a swath 11 km wide with a pixel resolution measuring 17 m. Its various detectors sense 224 electromagnetic channels, each 0.01 µm wide, simultaneously in the 0.4- to 2.5-µm range of the electromagnetic spectrum, which covers visible, near infrared, and portions of the far infrared. Figure 15.10 represents the concept of a stack of band measurements captured in a single sweep of the scanning mirror. Simplistically, the channels in a hyperspectral capture may resemble multiple layers of information in a GIS database.

Some applications that have been used or might be considered for use with the AVIRIS system may be found in Table 15.12.

15.7.2 Thermal Infrared Multispectral Scanner

Another airborne system is the Thermal Infrared Multispectral Scanner (TIMS), developed in a cooperative effort by NASA, JPL, and Daedelus Enterprises. This optical scanner is carried by a NASA aircraft, mostly within the confines of the United States. Table 15.13 lists the spectral channels sensed by TIMS.

This variable scan-rate sensor has a resolution of 25 ft when flown an altitude of 10,000 ft. Refer to the web site http://edcimswww.cr.usgs.gov:5725/sensor_documents/tims_sensor.html for further information.

* The web site http://makalu.jpl.nasa.gov/ presents a discussion of the AVIRIS system.

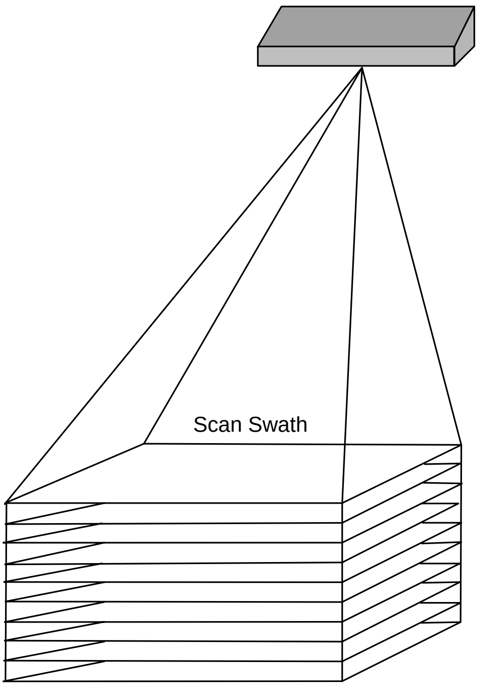

Figure 15.10 Representation of the concept of a stack of band measurements captured in a single sweep of the scanning mirror.

Table 15.12 AVIRIS Applications

Atmosphere	Snow and Ice Hydrology
Water vapor	Snow cover fraction
Clouds	Grain size
Gases	Impurities
	Melting
Ecology	
Vegetation species	Biomass Burning
Community maps	Smoke
Vegetation chemistry	Combustion products
	Fire temperature
Geology	
Mineralogy	Environmental Hazards
Soil types	Geological substrate
	Contaminants
Coastal and Inland Waters	
Chlorophyll	Commercial
Plankton	Mineral exploration
Dissolved organics	Agriculture
Bottom composition	Forest status

Table 15.13 Spectral Channel of TIMS Sensor

Channel	Spectral (μm)
1	8.2–8.6
2	8.6–9.0
3	9.0–9.4
4	9.4–10.2
5	10.2–11.2
6	11.2–12.2

Developed for use in geological studies, this system also has uses in vegetative biomass studies.

15.7.3 Digital Multispectral Videography

DMSV is the collection of multispectral data of the earth's surface from a fixed-winged aircraft with the use of a multispectral video camera system. These systems can be economical and timely data collection tools for small projects requiring analysis of land use and change similar to systems utilized in satellite-based platforms. Color Figures 1 and 2* demonstrate the collection of natural color and color infrared DMSV data over a site in Alaska. Color Figure 3* further demonstrates a thematic map generated from DMSV data. The thematic map represents supervised classification techniques used to analyze vegetation types. The use of DMSV allowed for the data to be collected at the optimum time period from a fixed-winged aircraft. This allowed the project manager to minimize typical scheduling and cost issues. The aircraft and sensor are generally under the control of the mapping firm. The necessary flights are therefore scheduled at the optimum time periods on relatively short notice. Flight cost may be minimized due to the economics of using a small aircraft and support staff along with the fact that the aircraft mobilization time to the project site may be kept to a minimum.

15.8 SOURCES OF SATELLITE IMAGERY

Scanned data and image reproductions are available for purchase.

15.8.1 SPOT

Information concerning SPOT satellite products can be obtained from:

SPOT Image Corporation
1897 Preston White Drive
Reston, VA 20191-4368
Tel: (703) 715-3100 or (800) ASK-SPOT
Fax: (703) 648-1813

* Color figures follow page 42.

The web site http://www.spot.com/home/distri/na/List_2000.htm lists the North American distributors of this product.

15.8.2 LANDSAT

Information concerning LANDSAT satellite products can be obtained from:

Space Imaging EOSAT
12076 Grant Street
Thornton, CA 80241
Tel: (800) 232-9037

15.8.3 National Oceanic and Atmospheric Agency

Information concerning NOAA satellite products can be obtained from:

Satellite Data Service Division
National Climatic Data Center
World Weather Building, Room 1
Washington, D.C. 20233

The Emporia State University in Kansas provides a web page that may be of interest to the potential user of geospatial data. Log on to http://www.emporia.edu/earth-sci/geosourc.htm for a listing of 38 on-line sources for global GIS and geospatial data, primarily at governmental agencies and universities.

15.8.4 Space Imaging EOSAT

IRS, ERS, IKONOS-1, and LANDSAT imagery may all be ordered from:

Space Imaging EOSAT
12076 Grant Street
Thornton, CO 80241
Tel: (800) 232-9037