Disciplina: SER-309-3 Sistemas e Sensores Avançados para Observação da Terra e de seus Ambientes

APOSTILA 01

AULA 01/12 => Sensoriamento Remoto:
contexto da Disciplina,
histórico,
estado da arte e
perspectivas

<u>Conteúdo desta Apostila:</u>

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=> History of Remote Sensing: In the Beginning

Remote sensing as a technology started with the first photographs in the early nineteenth century. Many significant events led to the launch of the Landsat satellites, which are the main focus of this tutorial. To learn about the milestones in remote sensing prior to the first Landsat, you can view a timeline of remote sensing in one of three areas - Photographic Methods, Non-Photographic Sensor Systems, Space Imaging Systems *(taken from a table that appeared in the writer's [NMS] NASA Reference Publication 1078 [now out of print] on The Landsat Tutorial Workbook).*

We present major highlights subsequent to 1979 both within this *Introduction* and throughout the *Tutorial*. Some of these highlights include short summaries of major space-based programs such as launching several other satellite/sensor systems similar to Landsat; inserting radar systems into space; proliferating of weather satellites; launching a series of specialized satellites to monitor the environment using, among other, thermal and passive microwave sensors; developing sophisticated hyperspectral sensors; and deploying a variety of sensors to gather imagery and other data on the planets and astronomical bodies.

The photographic camera has served as a prime remote sensor for more than 150 years. It captures an image of targets exterior to it by concentrating electromagnetic (EM) radiation (normally, visible light) through a lens onto a recording medium (typically silver-based film). The film displays the target objects in their relative positions by variations in their brightness of gray levels (black and white) or color tones. Although the first, rather primitive photographs were taken as "stills" on the ground, the idea photographing the Earth's surface from above, yielding the so-called aerial photo, emerged in the 1840s with pictures from balloons. By the first World War, cameras mounted on airplanes provided aerial views of fairly large surface areas that were invaluable for military reconnaissance. From then until the early 1960s, the aerial photograph remained the single standard tool for depicting the surface from a vertical or oblique perspective.

Remote sensing above the atmosphere originated early in the space age (both Russian and American programs). At first, by 1946, some V-2 rockets, acquired from Germany after World War II, were launched by the U.S. Army from White Sands, New Mexico, to high altitudes. These were referred to as the Viking program (a named used again for Mars landers). These rockets, while not attaining orbit, contained automated still or movie cameras that took pictures as the vehicle ascended. Here is an example of a typical oblique picture, looking across Arizona and the Gulf of California to the curving Earth horizon (this is shown again in Section 12). *(Note: the writer [NMS], as an Army corporal stationed at Fort Bliss in El Paso, TX was assigned as a Post newpaper reporter privileged in Spring 1947 to attend a V-2 launch at White Sands and to interview Werner von Braun, the father of the German V-2 program; little did I know then that I would be heavily involved in America's space program in my career years.)*

Early on, other types of sensors were developed that " took images using the EM spectrum beyond the visible, into the near and thermal infrared regions . The field of view (FOV) was broad, usually 100s of kilometers on a side. Such synoptic areas of regional coverage were of great value to the meteorological community, so that many of these early satellites were metsats, dedicated to gathering information on clouds, air temperatures, wind patterns, etc.

=> Some Important Dates in the Chronological History of Aerial Photography and Remote Sensing

THE UNIVERSITY OF CALIFORNIA, SANTA BARBARA
Department of Geography, Geography 115A
JOHN E. ESTES (July 21, 1939 - March 9, 2001) *last revised Spring 2002 by Jeff Hemphill*
Referência: http://pollux.geog.ucsb.edu/~jeff/115a/remotesensinghistory.html

The following represent a listing of some of the important dates in the chronological history of photography, aerial photographic interpretation, and remote sensing:

The term "photography" is derived from two Greek words meaning "light" (phos) and "writing" (graphien).

Despite the significant complexity of some modern equipment all cameras rely on the same essential features. Light enters a darkened enclosure (the camera, from the Latin word for room) through a small aperture, the size of which can often be controlled mechanically. A shutter is opened and closed to admit light for a specified period of time. Inside the camera, a ground glass lens gathers and concentrates the light, focusing it on a light sensitive field at the back of the camera - the film. Today we can have digital camera which essentially employ arrays of detectors to record incident energy levels.

No one knows when man first constructed a device that would record images by means of light

Circa 336-323 BC - Aristotle philosophizing at length about the nature of light, envisions light as a quality not as an actual substance. Aristotle noted that some objects had the potential for transparency, but this state was only rendered actual by the presence of light.

An old legend tells of a certain Arab who awoke one morning to find a miraculous vision on the wall of his tent. After studying this vision he determined that the "vision" was actually an inverted image of a group of people outside. Owing to the optimum coincidence of a number of factors, a tiny hole in the opposite wall of his tent had acted as a crude lens.

1038 AD - Al Hazen of Basra is credited with the explanation of the principle of the camera obscura

1267 - Roger Bacon uses the principle of the camera obscura to create optical illusions with sunlight

1490 - Leonardo da Vinci describes in detail the principles underlying the camera obscura (literally dark room). In essence, light would be admitted through a tiny pinhole in one wall of a darkened room, whereupon the sunlit scene outside the room would appear upside-down on the opposite wall. One had only to place a sheet of translucent paper over the image to trace its outlines.

1572 - Friedrich Risnor made topographic images using a miniaturized and mobilized camera obscura

1614 - Angelo Sala discovers that silver salts darken when exposed to sunlight

1666 - Sir Isaac Newton, while experimenting with a prism, found that he could disperse light into a spectrum of red, orange, yellow, green, blue, indigo, and violet. Utilizing a second prism, he found that he could re-combine the colors into white light.

1676 - Johann Christopher Sturm, a professor of mathematics, introduces the relax lens principle whereby a mirror is mounted at a 45 degree angle that projects na image. This is the essential development that led to the modern single lens reflex camera.

1777 - Carl Wilhelm Scheele, a Swedish chemist, discovers that silver chromate darkened by exposure to sunlight could be rinsed off with ammonia leaving the dark unexposed silver chromate crystals to form a "fixed" image, a precursor to the modern photograph.

1802 - Thomas Young puts forth basic concepts of the Young-Von Helmholtz Theory of color vision: Three separate sets of cones in the retina of the eye, one tuned to red, one to blue, and one to green.

1827 - Niepce takes first picture of nature from a window view of the French countryside using a camera obscura and an emulsion using bitumen of Judea, a resinous substance, and oil of lavender (it took 8 hours in bright sunlight to produce the image)

1829 - Joseph Nicephore Niepce and Louis M. Daguerre signed their partnership agreement (Nicephore Niepce had been working on Heliography, or sun drawing, and Daguerre on dioramas (which he constructed with the aid of a camera obscura)

1839 - Daguerre announces the invention of Daguerrotype which consistend of a polished silver plate, mercury vaoprs and sodium thiosulfate ("hypo") that was used to fix the image and make it permanent

1839 - William Henry Fox Talbot invents a new method of photography, a system of imaging on silver nitrate of silver chromate treated paper and using a fixative solution of sodium chloride. Talbot later found that the latent image could be developed in a solution of gallic acid, and he was the first person to employ a negative positive process "Calotype" laying the groundwork for modern photography.

1830's - The Germans invent stereoscopes.

1840 - Jozsef Petzval designs faster lenses and a method of making the daguerrotype plate more sensitive was developed, using a second treatment of chlorine and bromine before exposure.

1848 - Niepce de St. Victor, the cousin of Nicephore Niepce, uses eggs whites, salts and potassium iodide and bromide to make a solution that would make silver nitrate solution stick to glass. With this discovery "albumen photography" became widely popular and paper prints of photographs could be made.

1851 - Fredrick Scott Archer replaces albumen photography with collodium "wet plate" film which was used for the next 30 years because of its quick exposure time and considerably sharper negatives. This method involved coating a piece of glass with collodium as a base for the silver halide but required a mobile dark room because the coating would quickly evaporate.

1855 - James Clark Maxwell, a scottish physicist, describes color additive theory for the producing color photographs

1858 - Gasper Felix Tournachon "Nadar" takes the first aerial photograph from a captive balloon from an altitude of 1,200 feet over Paris

1860 - CC Harrison and J Schinitzler perfected the biconvex lens which reduced distortion and considerably improved clarity

1861 - A photographer named Thomas Sutton, togeyther with James Clark Maxwell, demonstrates his techniques for producing color imagery using as a bow of multicolored ribbon. (Red filter - sulfo-cyanide of iron, blue filter - ammoniac sulfate of copper, green filter - copper chloride, a fourth filter of lemon colored glass was also used.)

1860's - Aerial observations, and possible photography, for military purposes were acquired from balloons in the Civil War. Balloons were used to map forest in 1862, but not used to acquire aerial photographs as far as scholars can tell

1873 - Herman Vogel discovered that by soaking silver halide emulsions (sensitive to blue light) in various dyes, that he could extend their sensitivity to progressively longer wavelengths, this discovert led to near infrared senstive films

1887 - Germans began experiments with aerial photographs and photogrammetric techniques for measuring features and areas in forests

1889 - Arthur Batut take the first aerial photograph from using a kite of Labruguiere France

1899 - George Eastman produced a nitro-cellulose based film type that retained the clarity of the glass plates which were in use at the time and introduced the first Kodak camera

1903 - The Bavarian Pigeon Corps uses pigeons to transmit messages and take aerial photos, and someone named Julius Neubronne patented the breast mounted pigeon camera

1906 - Albert Maul, using a rocket propelled by compressed air, took an aerial photograph from a height of 2,600 feet, the camera was ejected and parachuted back to earth

1906 - G.R. Lawrence who had been experimenting with cameras (some of which weighted more than 1,000 pounds) which were hoisted into the air with the aid of balloon kites and associated controls takes pictures of the San Francisco earthquake and fire from an altitude of 600 meters. Many people have thought these photos were taken from airplanes; but Lawrence's camera alone weighted more than the Wright Brother's plane and it's pilot combined

1907 - Auguste and Louis Lumiere, two French brothers develop a simple color photography system and establish the 35 mm standard

1908 - Pathe motion picture photographer, L.P. Bonvillain obtains first photograph from an aerial platform. The area where the pictures were taken is Camp d Auvours, near Le Mans, France

1909 - Wilbur Wright takes aerial photograph from an airplane of Centocelli, Italy, again a motion picture camera is employed. Wright is in Italy trying to sell planes to the Italy government for there campaigns in Northern Africa

1914 - WWI (World War I), produced a boost in the use of aerial photography, but after the war, enthusiasm waned

1914 - Lt. Lawes, British Flying Service, takes what is thought to be the first airphoto over enemy territory in WWI

1915 - Cameras especially designed for aerial use are being produced. Lt. Col. J.T.C. More Brabazon designed and produced the first practical aerial camera in collaboration with Thornton Pickard Ltd.

1918 - By this time in the war French aerial units were developing and printing as many as 10,000 photographs each night, during periods of intense activity. During the Meuse-Argonne offensive, 56,000 aerial prints were made and delivered to American Expeditionary Forces in four days

1919 - Canadian Forestry Mapping Program begins

1919 - Hoffman first to sense from an aircraft in thermal IR

1920's First books on aerial photo interpretation begin to be published: Lee 1922; Joerg

1924 - Mannes and Godousky patent the first of their work of multi-layer film which led to the marketing of Kodachrome in 1935

1931 - Stevens development of an IR sensitive film (B&W)

1934 - American Society of Photogrammetry founded. Photogrammetric Engineering first published. This journal of the American Society of Photogrammetry was later named Photogrammetric Engineering and Remote Sensing. The Society is also now renamed The American Society of Photogrammetry and Remote Sensing.

1936 - Captain Albert W. Stevens takes the first photograph of the actual curvature of the earth - taken from a free balloon at an altitude of 72,000 feet

1920's-30's - Interest in the peaceful uses of aerial photography increases (USDA, USAF, TVA)

1938 - The Chief of the German General Staff, General Werner von Fritsch, made a prophetic statement at this time when he said: "The nation with the best photo reconnaissance will win the next war."

1940 - W.W.II brought about more sophisticated techniques in Aerial Photographic Interpretation (API). Germany leads the world in photo reconnaissance. The beginning of W.W. II, gives a real boost to photo interpretation. Photo interpretation employed throughout the war with some notable successes e.g. V-1 rockets, radar, water depth for amphibious landings, vegetation indicators of trafficability

1942 - Kodak patents first false color I.R. sensitive film

1946 - First space photographs from V-2 rockets

1950's - Advances in sensor technology move into multi-spectral range

1954 - Westinghouse develops first side-looking airborne radar system

1954 - U-2 takes first flight

1957 - Russian launches Sputnik1, this was unexpected on our part and probed our government to make space exploration a priority.

1960 - U-2 is "shot down" over Sverdlovsk, USSR

1960 - TIROS 1 launched as first meteorological satellite

1960's - U.S. begins collection of intelligence photography from Earth orbiting satellites, CORONA

1962 - Zaitor and Tsuprun construct prototype nine lens multispectral camera permitting nine different film-filter combinations Also during this year our country came very close to nuclear war when military intelligence photography was brought into the lime light by the Cuban Missile Crisis

1963 - D. Gregg, while working at Stanford University, creates a primitive predecessor to digital photography, called the "videodisk" it could capture and store images for a few minutes

1964 - SR-71 shows up in press during Presidential Campaign, Nimbus 1 Weather Satellite Launched.

Late 1960's - Gemini and Apollo Space photography

1972 - Launch of ERTS-1, the first Earth Resources Technology Satellite. This system is later renamed Landsat-1. Carries a return beam vidicon (RBV); and, a multispectral scanner (MSS).

1972 - Photography from Sky Lab precursor of manned space station

1975 - Launch of Landsat 2

1978 - Launch of Landsat 3

1978 - Launch and failure of Seasat. First civil Synthetic Aperture Radar (SAR) satellite

1978 - Launch of Nimbus 7 (TOMS & Coastal Zone Color Scanner)

1981 - Launch of Space Imaging Radar (SIR-A) [Sometime SIR Radar systems are referred to as Shuttle Imaging Radars)

1982 - Launch of Landsat 4 (Thematic Mapper and MSS)

1984 - Launch of SIR-B

1984 - Launch of Landsat-5

1986 - Launch of SPOT-1, French Earth Resources Satellite (Systeme Probatorie de la Observation de la Terre)

1990 - Launch of SPOT-2

1991 - Launch of ERS-1 European Radar Satellite, the first satellite to be launched with an altimeter able to map the earth surface to within five centimeters

1991 - Gulf War draws public attention to aerial reconnaissance, mapping and spy satellite capabilities Village Removal (by iraqi military)

1993 - Launch of SIR-C Shuttle Imaging Radar

1993 - Launch of SPOT-3

1994 - Landsat-6 fails to achieve orbit

1995 - Early KH intelligence satellite data is declassified by an Executive Order signed by President Clinton on Feb. 23. This order authorizes the declassification of satellite photographs collected by the U.S. Intelligence community in the 1960's

1995 - Launch of ERS-2, the compliment of ERS-1 with is launched

1995 - Radarsat is launched

1995 - First indication that a new class of intelligence satellite is being developed is printed in the press. The new satellite code named 8x is said to be a major upgrade of the KH-12 spy satellite. The satellite which may weight as much as twenty tons will be able to acquire "intricately detailed images of areas as large as 1,000 square miles of the Earth's surface...with roughly the same precision as existing satellites"; according to an article in the September 28th Los Angeles Times. The Times article goes on to say that the current generation of photographic satellites photograph areas about 10 miles by 10 miles (100 sq./mi.) typically showing detail as small as about six inches

1998 - SPOT 4 with improved vegetation sensor bands achieves orbit

1999 - Landsat 7 with enhanced Thematic Mapper achieves orbit

1999 - Launch of Space Imaging IKONOS satellite (the 1st commercial 1-meter class system)

1999 - Launch of EOS AM-1 series (Terra)

2001 - Launch of Digitalglobe Quickbird satellite (commerical sub 1-meter class system)

2002 - Current best guess launch date of EOS, PM-1 (Terra II)

Last Updated 4/02

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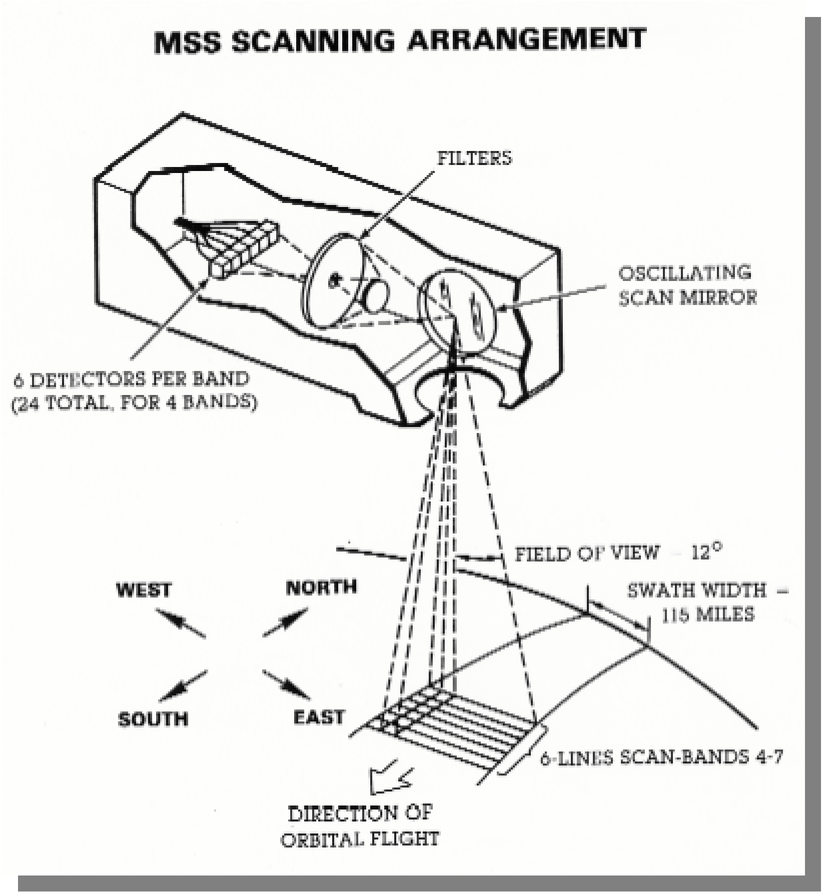
History of Remote Sensing: Landsat's Multi-Spectral Scanner (MSS)

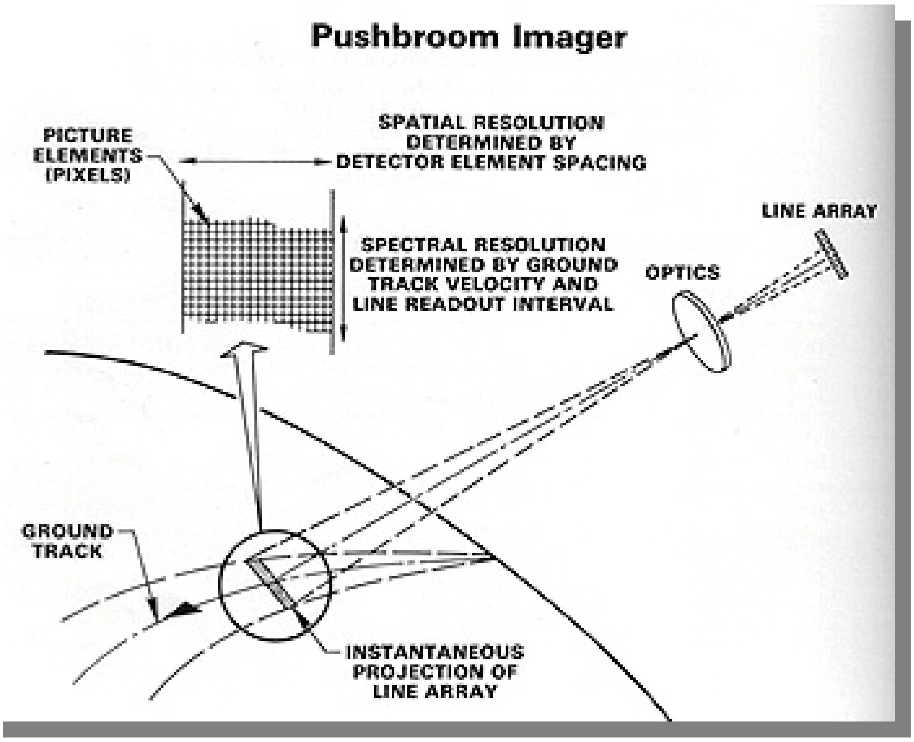
The MSS instrument has operated on the first five Landsat spacecraft. Although the basics of scanning spectroradiometric sensors were reviewed earlier in this Section, because of MSS's prime role in these missions which extended over 28 plus years some of this information is repeated and extended on this page. A simplified model of this optical-mechanical sensor appears in the next figure.



The MSS gathers light through a ground-pointing telescope (not shown). The scan mirror oscillates side-to-side over an angular displacement of ± 2.89 degrees producing a beam width of 11.56 degrees that from an orbital altitude of 917 km (about ~570 miles) covers a swath width (Angular Field of View or AFOV) across the orbital track of 185 km (115 miles). During a forward scan, which takes about 3.3 milliseconds, it sweeps a ground strip of about ~ 474 m (1555 ft) from one side of the track to the other. Reflected light gathered by this scan passes through an optical lens train, during which it is divides and passes through 4 filters that produce images in spectral bands at MSS 4 = 0.5 - 0.6 µm (green), MSS 5 = 0.6 - 0.7 µm (red), MSS 6 = 0.7 - 0.8 µm (photo-IR), and MSS 7 = 0.8 - 1.1 µm (near-IR). Light through each filter reaches its set of six electronic detectors (24 in all) that subdivide the across-track scan into 6 parallel lines, each equivalent to a ground width of 79 m (259 ft). The mirror movement rate is such that, at the orbital speed of 26,611 kph (16,525 mph), after the return oscillation, the next forward swing produces a new path of 6 lines (79 x 6 = 474 m) just overlapping the previous group of 6 lines.

Other Remote Sensing Systems - MOMS, SPOT and Charge-Coupled Devices (CCDs)

Scanners, such as those on the Landsats (MSS and TM) were the prime Earth-observing sensors during the 1970s into the 1980s. But these instruments contained moving parts, such as oscillating mirrors that were subject to wear and failure (although remarkably, the MSS on Landsat 5 continues to operate into 1999 after launch in March of 1984). Another approach to sensing EM radiation was developed in the interim, namely the Pushbroom Scanner, which uses charge-coupled devices (CCDs) as the detector. This diagram may help to better grasp the description of CCDs in the next paragraph:



A CCD is an extremely small, silicon chip, which is light-sensitive. When photons strike a CCD, electronic charges develop whose magnitudes are proportional to the intensity of the impinging radiation during a short time interval (exposure time). From 3,000 to more than 10,000 detector elements (the CCDs) can occupy a linear space less than 15 cm in length. The number of elements per unit length, along with the optics, determine the spatial resolution of the instrument. Using integrated circuits each linear array is sampled very rapidly in sequence, producing an electrical signal that varies with the radiation striking the array. This changing signal recording goes through a processor to a recorder, and finally, is used to drive an electro-optical device to make a black and white image, similar to MSS or TM signals. After the instrument samples, the array discharges electronically fast enough to allow the next incoming radiation to be detected independently. A linear (one-dimensional) array acting as the detecting sensor advances with the spacecraft's orbital motion, producing successive lines of image data (analogous to the forward sweep of a pushbroom). Using filters to select wavelength intervals, each associated with a CCD array, we get multiband sensing. The one disadvantage of current CCD systems is their limitation to visible and near IR (VNIR) intervals of the EM spectrum.

CCD detectors are now in common use on air- and space-borne sensors (including the Hubble Space Telescope which captures astronomical scenes on a two-dimensional array, i.e., many parallel rows of detectors). The first airborne pushbroom scanner to be used operationally was the Multispectral Electro-optical Imaging Scanner (MEIS) built by Canada's CCRS. It images in 8 bands from 0.39 to 1.1 µm (using optical filters to produce the narrow band intervals) and uses a mirror to collect fore and aft views (along track) suitable as stereo imagery.

The German Aerospace Research Establishment (DFVLR) developed the first pushbroom scanner to be flown in space. The Modular Optico-electronic Multispectral Scanner (MOMS) was aboard Shuttle Mission STS-7 and STS-11 in 1983 and 1984. It uses two bands, at 0.575-0.625 and 0.825-0.975 µm, to produce 20 m resolution images. The MOMS image below is an area of farmland in Zimbabwe:

MOMS-2 was flown on STS-55 in May of 1993. It has four multispectral channels (13 m resolution) and a panchromatic band (4.3 m), and is in stereo mode. Here is a panchromatic image of a city on the western shore of the Persian Gulf (locus incertae; probably in Qatar).

The first use of CCD-based pushbroom scanners on an unmanned Earth-observing spacecraft was on the French SPOT-1 launched in 1986. (Page 3-2 describes the SPOT system, which is operated as a commercial program; 4 SPOTS have now been launched) An example of a SPOT image, from its high-resolution video (HRV) camera, covering a 60 km section (at 20 m. spatial resolution) of the coastal region in southwest Oregon, is the next image we show. Note that scan lines are absent, because each CCD element is, in effect, a tiny area analogous to a pixel.

Other Remote Sensing Systems - IRS, JERS, RESURS, and OKEAN Series

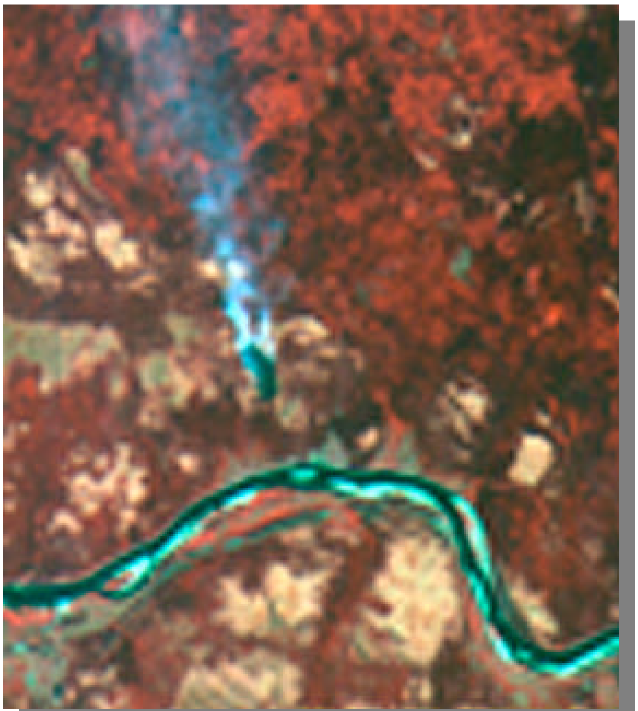
India successfully operates several Earth-resources satellites that gather data in the Visible and Near IR bands, beginning with IRS-1A in March of 1988. The latest in the series, IRS-1D, launched on September 29, 1997. Its LISS sensor captures radiation in the blue-green, green, red, and near IR bands at 23 m spatial resolution. The spacecraft also produces 5.8 m panchromatic images, as well as 188 m resolution wide-field (large area) WiFS multispectral imagery. Below are three recent images from this system, the one on the top (WiFS) showing the Grand Canyon of Arizona, in the middle a three-band color composite made by the 23 m LISS, showing mountainous terrain and pediments with alluvium fans in southern Iran, and at the bottom a 5.8 meter panchromatic view of part of the harbor at Tamil Nadu in India.

More information on the Indian remote sensing program is available from its U.S. distributor, Space Imaging, Inc. (http://www.spaceimaging.com).

The Japanese, beginning in 1990, have flown JERS-1 and JERS-2 which include optical and radar sensors. Here is an artist's conception of JERS-1 in space:

The optical system is a seven band scanner similar in coverage to the TM. The satellites are operated by the National Space Agency, NASDA. *Here is a false color JERS-1 image of Tokyo and Tokyo Bay*

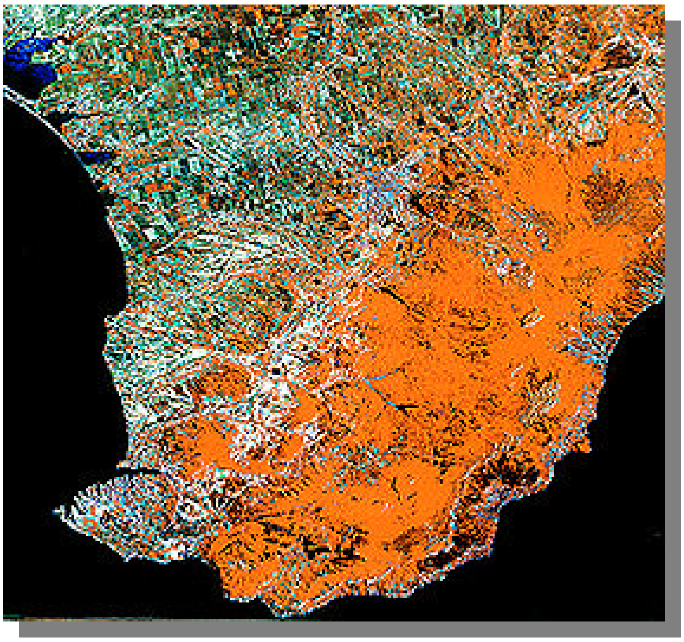
Starting in the mid 1980s, the Soviet Union (and now Russia) entered the world arena with an Earth-observing satellite program available on the open market. The RESURS-01 series (3 so far, a fourth pending) provided a multispectral system (3 Vis-NIR bands; 2 thermal) whose resolution (160 m, and 600 m for thermal) is intermediate between that of Landsat/SPOT and the AVHRR on meteorological satellites. Like Landsat RESURS are placed in near-polar, sun-synchronous orbits. Two images from this system appear below: the first is a false color composite of land near Arkhangel'sk almost due north of Moscow near the Arctic Circle and the Barents Sea.

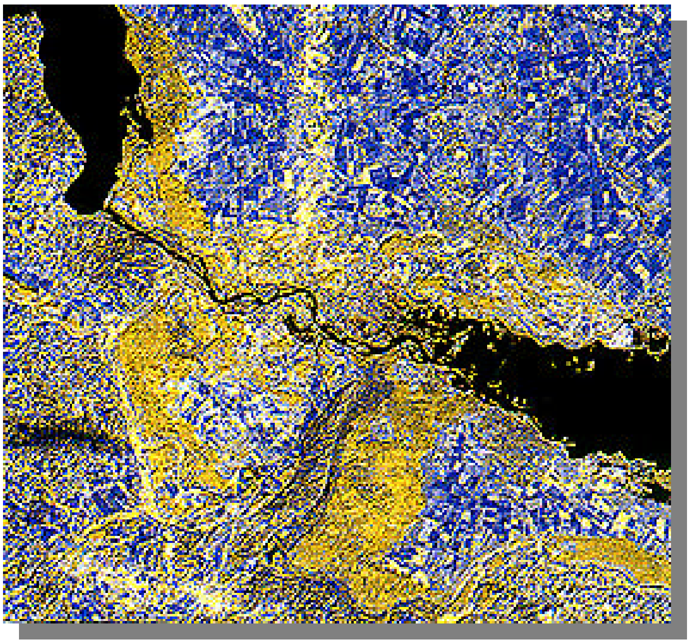


The second is part of a mosaic of Europe which here includes all of Norway, Sweden, and Denmark, and part of Finland and several Baltic nations.

This general region has recently been scanned by the SeaWiFS sensor or OrbView-2 (see page 14.3) and rendered as an oblique perspective view:

The National Space Agency of the Ukraine has its own program of space observations; it works in cooperation with the Russian Federation in using certain facilities. Its OKEAN series includes multispectral scanners, thermal sensors, and radar. Two MSU-V images (50 m resolution) show a standard false color composite (left) of the southern Crimea (Sebastapol in lower left) and a different color combination (right) of the Dnieper River in the Ukraine Lowlands, with Kiev just below the upper "lake" (caused by river damming).





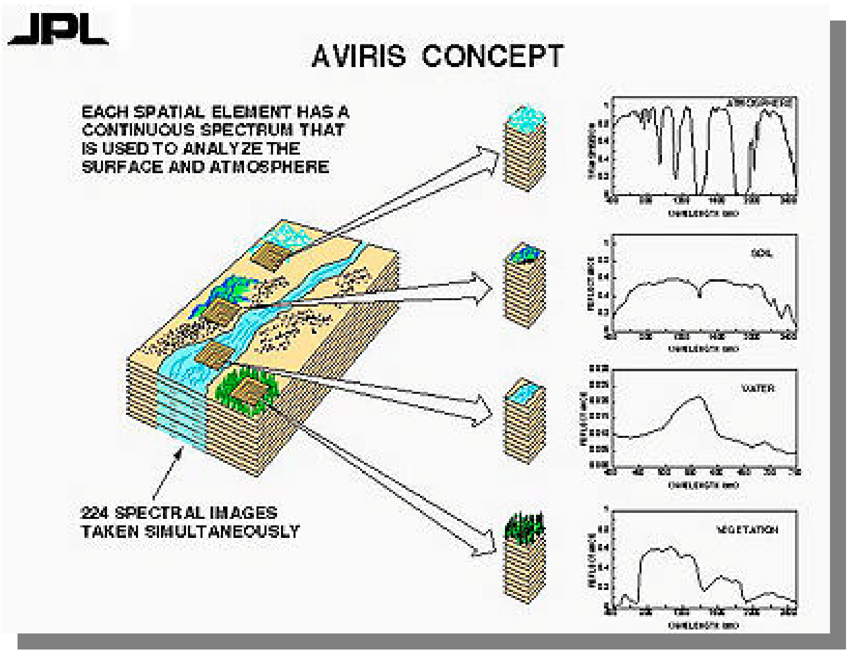
Other Remote Sensing Systems - Hyperspectral Imaging

Another major advance, now coming into its own as a powerful and versatile means for continuous sampling of broad intervals of the spectrum, is hyperspectral imaging (see second half of Section 13 for more principles and details). Heretofore, because of the high speeds of air and space vehicle motion, insufficient time was available for a spectrometer to dwell on a small area of Earth's surface or an atmospheric target.

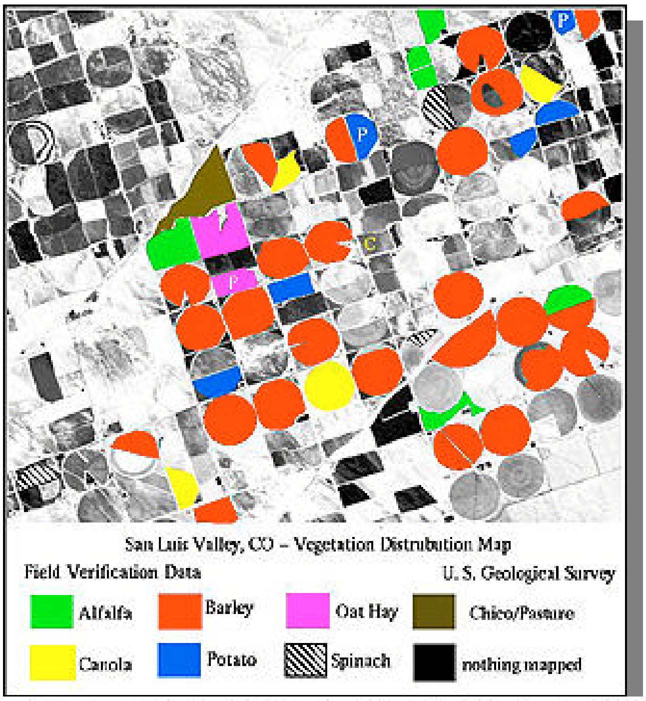
Thus, data were necessarily acquired for broad bands in which spectral radiation is integrated within the sampled areas to cover ranges, such as 0.1 µm, for instance Landsat. In hyperspectral data, that interval narrows to 10 nanometers (1 micrometer [µm] contains 1000 nanometers [1 nm = 10-9m]). Thus, we can subdivide the interval between 0.38 and 2.55 µm into 217 intervals, each approximately 10 nanometers (0.01 µm) in width. These are, in effect, narrow bands. The detectors for VNIR intervals are silicon microchips, while those for the Short Wave InfraRed (SWIR, between 1.0 and 2.5 µm) intervals consist of an Indium-Antimony (In-Sb) alloy. If a radiance value is obtained for each such interval, and then plotted as intensity versus wavelength, the result is a sufficient number of points through which we can draw a meaningful spectral curve.

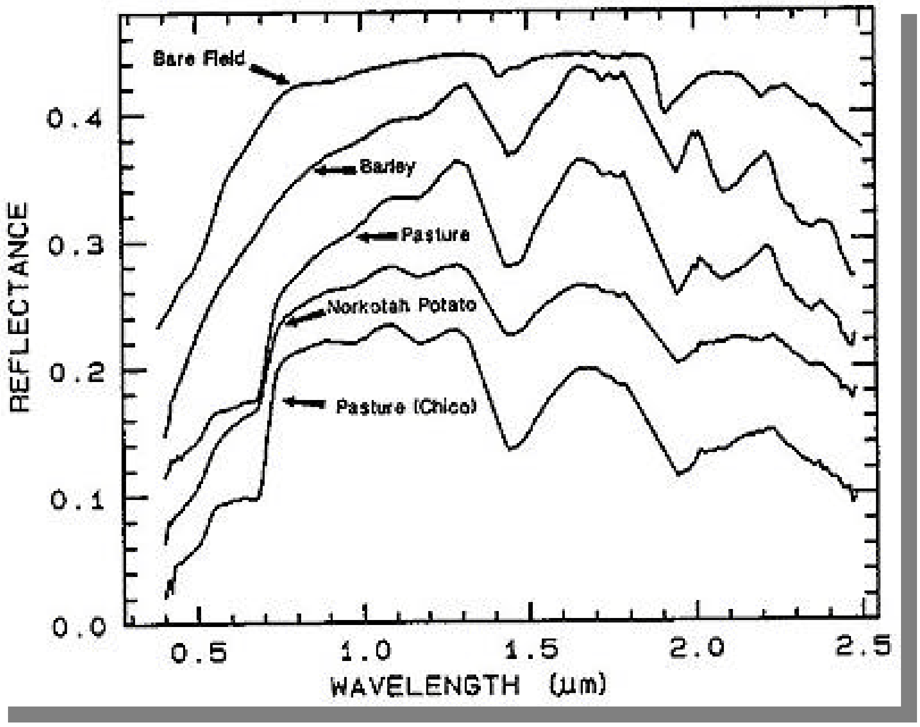
The Jet Propulsion Lab (JPL) has produced two hyperspectral sensors, one known as AIS (Airborne Imaging Spectrometer), first flown in 1982, and the other known as AVIRIS (Airborne Visible/InfraRed Imaging Spectrometer), which continues to operate since 1987. AVIRIS consists of four spectrometers with a total of 224 individual CCD detectors (channels), each with a spectral resolution of 10 nanometers and a spatial resolution of 20 meters. Dispersion of the spectrum against this detector array is accomplished with a diffraction grating. The total interval reaches from 380 to 2500 nanometers (about the same broad interval covered by the Landsat TM with just seven bands). It builds an image, pushbroom-like, by a succession of lines, each containing 664 pixels. From a high altitude aircraft platform such as NASA's ER-2 (a modified U-2), a typical swath width is 11 km.

From the data acquired, we can calculate a spectral curve for any pixel or for a group of pixels that may correspond to an extended ground feature. Depending on the size of the feature or class, the resulting plot will be either a definitive curve for a "pure" feature or a composite curve containing contributions from the several features present (the "mixed pixel" effect discussed in Section 13). In principle, the intensity variations for any 10-nm interval in the array extended along the flight line can be depicted in gray levels to construct an image. In practice, to obtain strong enough signals, data from several adjacent intervals are combined. Some of these ideas are elaborated in the block drawing shown here.

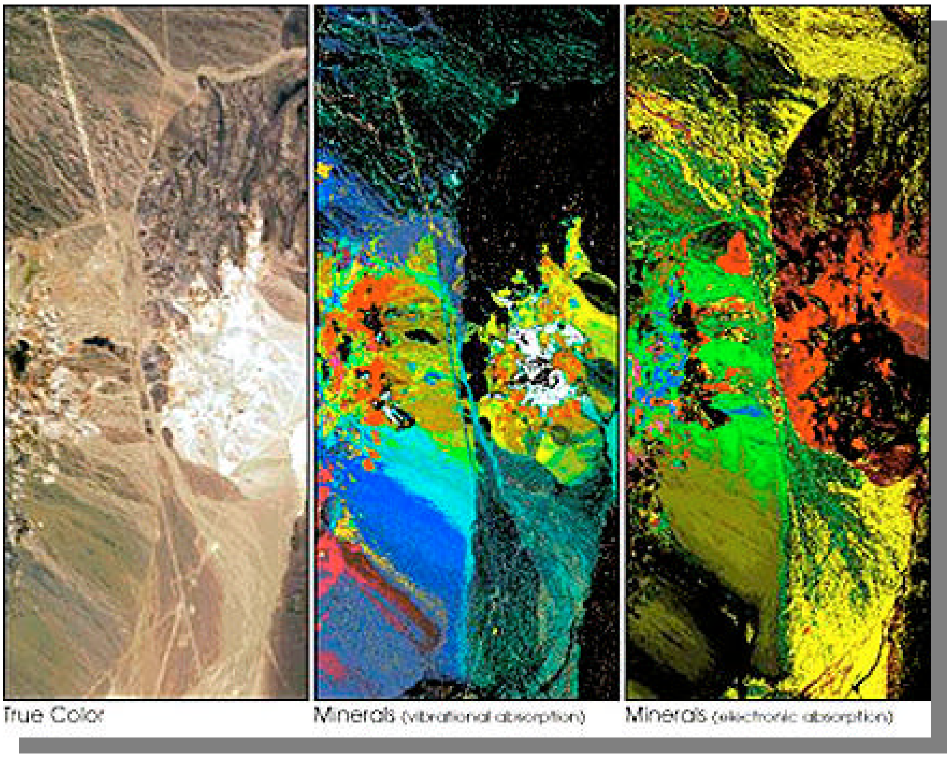


Below is a hyperspectral image of some circular fields (see Section 3) in the San Juan Valley of Colorado. The colored fields are identified as to vegetation or crop type as determined from ground data and from the spectral curves plotted beneath the image for the crops indicated (these curves were not obtained with a field spectrometer but from the AVIRIS data directly).





In Section 13 other AVIRIS images, used for mineral exploration near Cuprite, Nevada and other mining districts are displayed (see page 13-10) following an extended narrative on principles of spectroscopy and further consideration of the hyperspectral approach. A preview of the remarkable results achievable by this technology is given by this trio of images of the Cuprite district. The left image shows the area mapped as rendered in a near natural color version; the center image utilizes narrow bands that are at wavelengths in which certain minerals reflect energy related to vibrational absorption modes of excitation; in the right image, modes are electronic absorption. Shown here without the mineral identification key, the reds, yellows, purples, greens, etc. all relate to specific minerals.



We know hyperspectral data are usually superior for most analyses to broader-band multispectral data, simply because such data provide so much more detail about the spectral properties of features to be identified. In essence, hyperspectral sensing yields continuous spectral signatures rather than the band histogram plots that result from systems like the Thematic Mapper which "lump" varying wavelengths into single-value intervals. Plans are to fly hyperspectral sensors on future spacecraft (see Section 21, page 21-1). The U.S. Navy is presently developing a more sophisticated sensor called HRST and industry is also designing and building hyperspectral instruments such as ESSI's Probe 1.

The major advantage of hyperspectral sensors over broad band sensors:

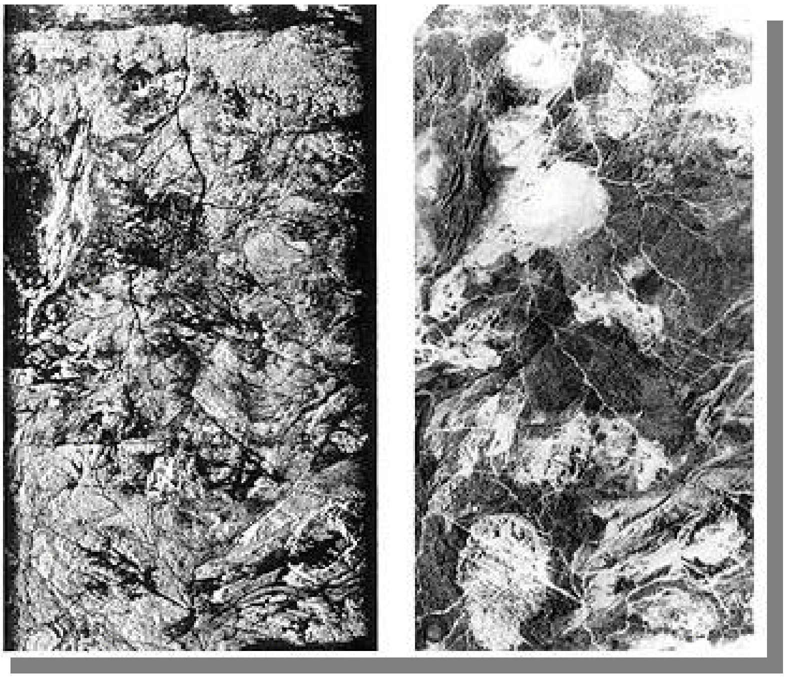
As of 2000, there are plans to put several hyperspectral sensors on to space platforms. One such instrument, called Hyperion, is part of EO-1, the first satellite in NASA's New Millenium series, launched in December, 2000. It was inserted into an orbit that places it just about 50 km (30 miles) behind Landsat 7, which allows similar images acquired at almost the same time to be compared for performance evaluation. Operated by Goddard Space Flight Center, this satellite is a test bed for new ideas in instrumentation that can be made smaller and lighter, so that launch costs can be lowered. The Hyperion consists of CCD detectors and other components that break the spectral range from 0.4 to 2.5 µm into 220 channels. Each resulting image is 7.5 by 100 km in ground coverage; resolution is 30 meters. The Atmospheric Corrector takes measurements that help to remove adverse effects from the atmosphere on image/data quality. A third sensor, the ALI (Advanced Land Imager) has 9 spectral bands and provides both multispectral images (30 m resolution) and panchromatic images (10 m).

Here is an ALI image of the central part of Washington, D.C.

Other Remote Sensing Systems - Radar and Thermal Systems

Radar (an active microwave system) has been flown on both military and civilian spacecraft because of its ability (for certain wavelengths) to penetrate clouds. Seasat, the SIR series, and Radarsat are among the instruments used so far. Thermal remote sensing, operating primarily in the 8-14 µm but also in the 3-5 µm wavelength region of the spectrum produces diagnostic data that can aid in identifying materials by their thermal properties. Some meteorological satellites have thermal sensors, as does the Landsat TM. A multispectral thermal scanner, TIMS, is described.

Another class of satellite remote sensors now in space are radar systems. Radar commonly provides a very different view of the same landscape compared with a visible image. This is obvious in this pair showing an ancient terrain in Egypt with fractures in a crystalline terrain evident in the left image (SIR-A radar) and plutons in the same scene in the Landsat image on the right.



The first civilian radar system to operate from space was mounted in a Space Shuttle. Seasat was an experimental L-Band radar whose primary mission was to measure ocean surfaces. However, it produce very informative images of the land surface, including this scene that includes Death Valley, one of the prime test sites for determining the capabilities of various sensors.

Among systems now operational are the Canadian Radarsat, ERS-1 and ERS-2 managed by the European Space Agency, and JERS-1 and JERS-2 under the aegis of the National Space Development Agency of Japan, NASDA. As an example, here is the first image acquired by Radarsat, showing part of Cape Breton in Nova Scotia, and the surrounding waters.

The European Space Agency, ESA, also has flown radar on its ERS-1 and ERS-2 satellites. Here is an image in black and white showing the San Francisco, California, metropolitan area and the peninsula to its south, as well as Oakland, California, the East Bay, and beyond.

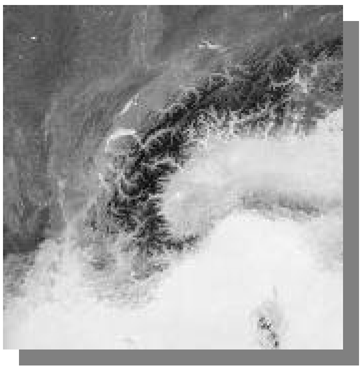
Looking radar images => two characteristics of the radar images that seem to differ from those of Landsat:

NASA, through its Jet Propulsion Laboratory (JPL) in Pasadena, California, has flown three radar missions on the Space Shuttle. The SIR (Shuttle Imaging Radar) series has used different wavebands and look conditions, with many excellent images over much of the globe having been acquired. Appearing below is a SIR-C image obtained on October 3, 1994 during a flight of the Space Shuttle. This is a false color composite made by assigning the L-Band HV, L-Band HH, and C-Band images to red, green, and blue respectively. The area shown is that part of Israel containing disputed West Bank territory that includes Jerusalem (yellowish patterns on left) and the top of the Dead Sea.

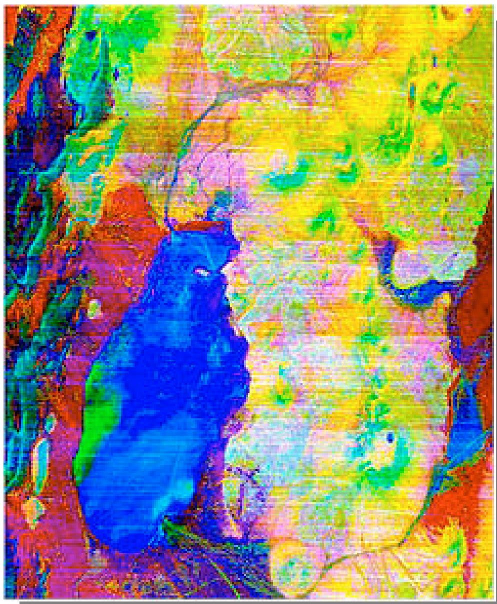
Remote sensors that cover two **thermal intervals** - the 3-5 µm and 8-14 µm broad bands (corresponding to two atmospheric windows) allowing sensing of thermal emissions from the land, water, ice and the atmosphere - have been flown on airplanes for several decades. Many of the meteorological satellites include at least one thermal channel. A thermal band is included on the Landsat Thematic Mapper.

The principles behind thermal remote sensing are treated. For now, let us look at two representative samples of the types of thermal images that indicate the kinds of information resulting from operation of thermal sensors on moving platforms above the Earth's surface.

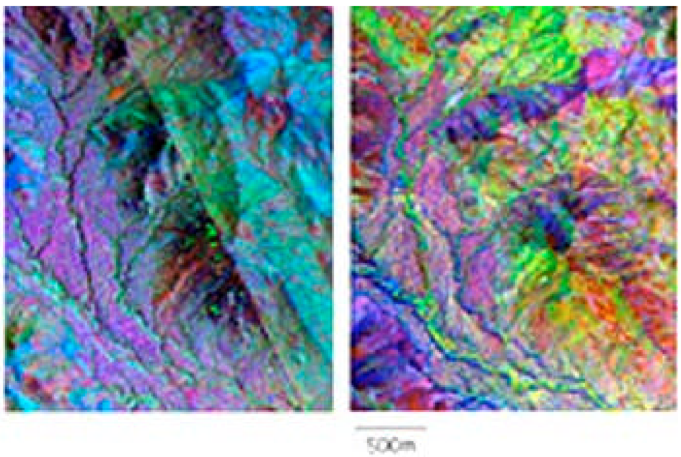
This next image was made from a satellite dedicated to sensing one thermal property - thermal inertia (defined on page 9-3). The Heat Capacity Mapping Mission (HCMM) was launched in 1978 and is described on page 9-8. This image covers about 700 km (435 miles) on a side and was taken at night (daytime thermal images were also generated) on July 16, 1978 over southern Europe using a sensor that integrates thermal emissions within the wavelengths from 10.5 to 12.5 µm. The darker area in the upper left portrays lowlands in eastern France and southwestern Germany. The Alps form a broad arc crossing the image. The blackish pattern within the Alps corresponds to the cold higher elevations (with some snow). The lighter-toned land below the Alps is the Piedmont and western plains of Italy's Po Valley. The light tones near the image bottom are the waters of the Mediterranean Sea, which at night are warmer (heat sink) than most land surfaces.



Thermal data, especially from the 8-14 µm region become more valuable in singling out (classifying) different materials when this spectral interval is subdivided into bands, giving multispectral capability. NASA's JPL has developed an airborne multiband instrument called TIMS (Thermal IR Multispectral Scanner) that is a prototype for a system eventually to be placed in space. The images it produces are notably striking in their color richness, as evident in this scene that includes a desert landscape around Lunar Lake in eastern California.



The image pair below covers a part of the White Tank Mountains of Arizona. The left image is made from 3 TIMS bands; the right is a false color composite formed from visible band data on another multispectral scanner onboard the aircraft that gathered TIMS emitted radiation.



While these color patterns make some sense when interpreted through geologic maps, aerial photos, field visits (ground truth), etc., it is hard to envision what they mean just from this image pair. Perhaps a better insight and context will result from the view below, which is an oblique or perspective "photo" showing the full extent of the White Tank Mountains (a fault block range) and surrounding desert and agricultural farms, about 40 km (25 miles) west of Phoenix.

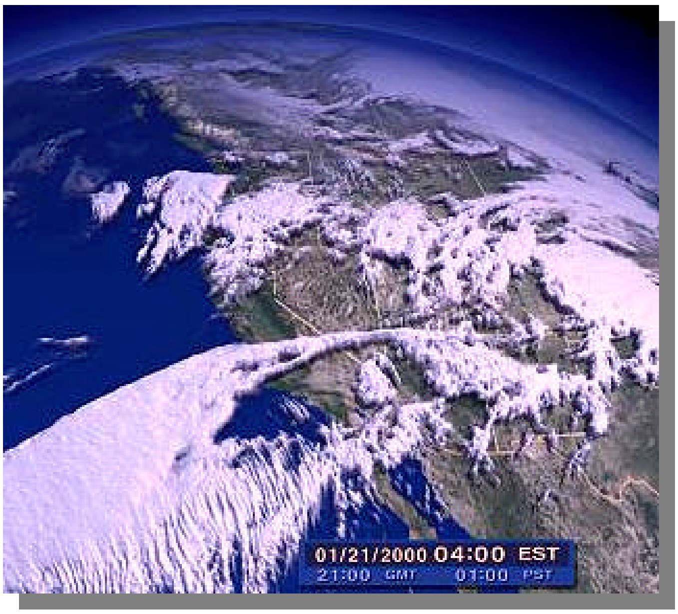
But, this is really a "trick picture", in that it is made from Landsat TM bands (1,2,3) that have been registered to Digital Elevation Model (DEM) data that contain heights above sea level, from which a 3-dimensional representation is constructed.

Other Remote Sensing Systems: Meteorological, Oceanographic and Earth System Satellites

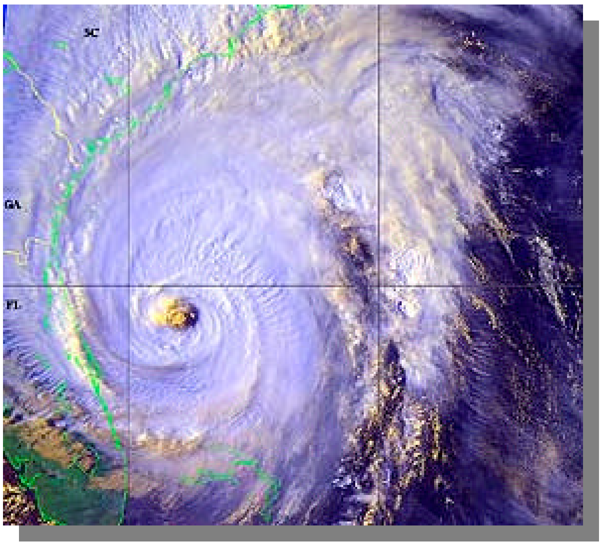
Satellite-and Shuttle-based remote sensors are especially adept at providing image and physical property data regarding atmospheric and ocean surface conditions, usually scanned from meteorological/oceanographic platforms. Example from two of these (GOES and NOAA) are described on this page but the main treatment is reserved in other section. Metsats look mainly at cloud cover, water vapor, wind patterns, advancing fronts, and certain atmospheric properties. SeaWiFS is a dedicated oceanographic satellite whose sensor measures in multibands (visible and near IR) that specify ocean color and chlorophyll content (in algae and plankton). To these specialized satellites should now be added a third group - a large array of satellites just launched or to be launched in the next 5 years that gather integrated information on the Earth System - land, marine, atmosphere, and biological aspects of the terrestrial environments. Although not the first directed towards this endeavor, Terra is now operating and returning data that prove the value of this approach.

As suggested earlier, among the first satellites in the U.S.'s entry into space were those designed to demonstrate that weather systems and climate variations could be monitored at regional or even continental scales, thus greatly improving the realtime surveillance of clouds, temperature variations, water vapor, and moving fronts (especially tornadic vortices and hurricanes). The Nimbus series has already been mentioned, but the images there emphasize land features rather than meteorological conditions. In Section 14, we will review the entire history of the "Meteorology from Space" programs that include satellites operated by several other countries. Suffice here to show two typical examples.

The first is a January 21, 2000 scene covering part of the western U.S. and adjoining Pacific Ocean as imaged many times each day by the GOES 10 (geostationary) satellite. The land tones are darkened so that the cloud patterns, in white to gray tones, stand out.

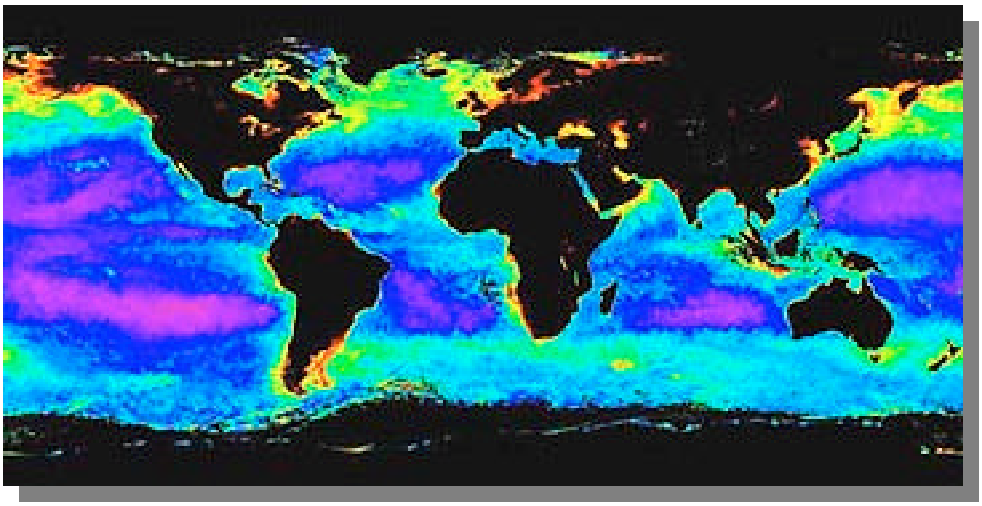


The second scene was made by the NOAA 15 satellite that was the principal monitoring system that followed the westward progress of the powerful Hurricane Floyd which struck the U.S. mainland in mid-September of 1999. This color composite shows Floyd in the early morning of September 15 after it had passed over the northern Bahamas and was bearing down on the north Florida coast. The size of this hurricane can be grasped by noting that the bottom left of the image covers the Everglades (in green) whereas the top left includes all of the Georgia coast into South Carolina.



Many meteorological satellites are adept at picking out chracteristics of the oceans such as silt/sediment patterns, temperatures, wave trains, and current circulation. But several satellites have been flown primarily to sense these and other properties of the ocean surface (again, see Section 14). Among these are Seasat, Radarsat, the Coastal Zone Color Scanner (CZCS) on Nimbus 7, and SeaWiFS (now operating).

On SeaWiFS, several bands cover the blue, green, and red parts of the visible spectrum, and into the near infrared, yielding data that can be used to display variations in ocean color or, for particular bands, indications of the distribution and intensity of chlorophyll that resides mainly in surficial plankton. This SeaWiFS image maps the generalized ocean colors as well as chlorphyll concentrations (in red, yellow, and orange colors) on a near global scale during September, 1997.

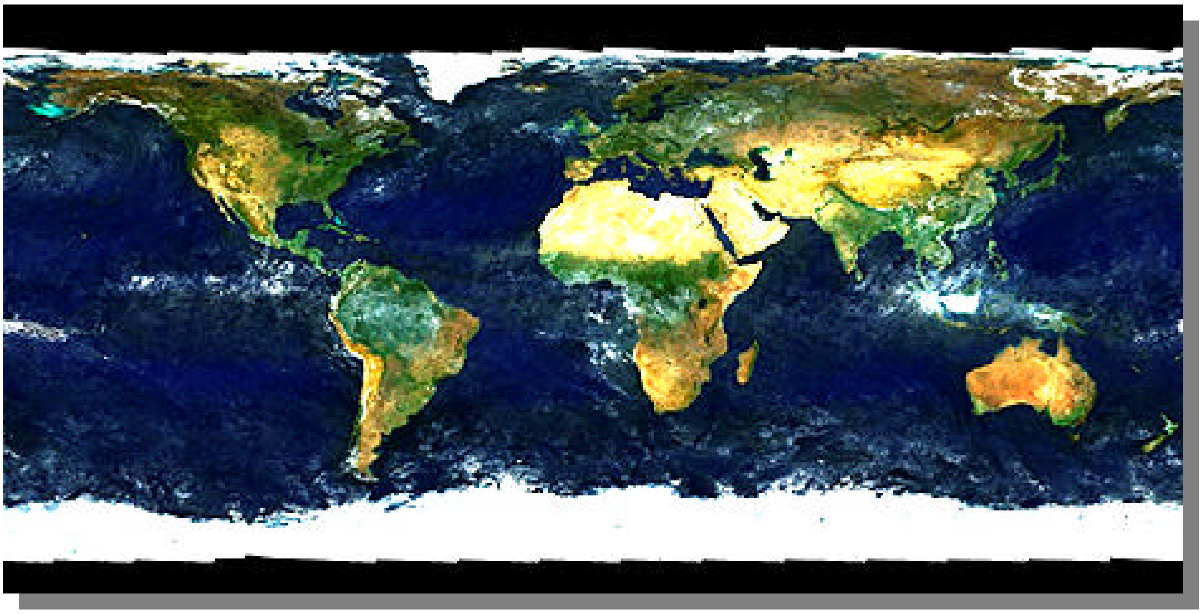


Terra is the "flagship" satellite in the **Earth Science Enterprise (ESE)** that is the United States contribution to a continuing scientific effort often referred to as the International Geosphere-Biosphere Program. Mentioned at the end of the Overview, the IGBP and its spin-offs are of sufficient scope and merit to deserve its own Section. The five sensors on **Terra** are: MODIS, MOPITT, MISR, ASTER, AND CERES.

For the moment, we show here just a single image made by the ASTER instrument on Terra.

This scene is of volcanoes in the Andes mountain chain of South America. Volcanoes are important components of the Earth System being studied by the ESE in that they affect the environment on regional to worldwide scales by expelling into the atmosphere gases and dust that can affect weather patterns.

The last image in this Introduction is also constructed from a multispectral satellite sensor which produces color imagery. It is a natural color "portrait" of the entire globe, in which vegetation-rich areas are in green, vegetation-poor (including deserts) areas are in various shades of yellow and brown, and ice is in white. One thing brought out in this world view, is that a large part of the total land surface does not have extensive vegetation cover - this helps to visualize the possibly precarious state of those biomes that contain most of the living species, recycle oxygen to the atmosphere, and provide organic raw materials and foodstuffs for the health and survival of the human race and many members of the animal kingdom.



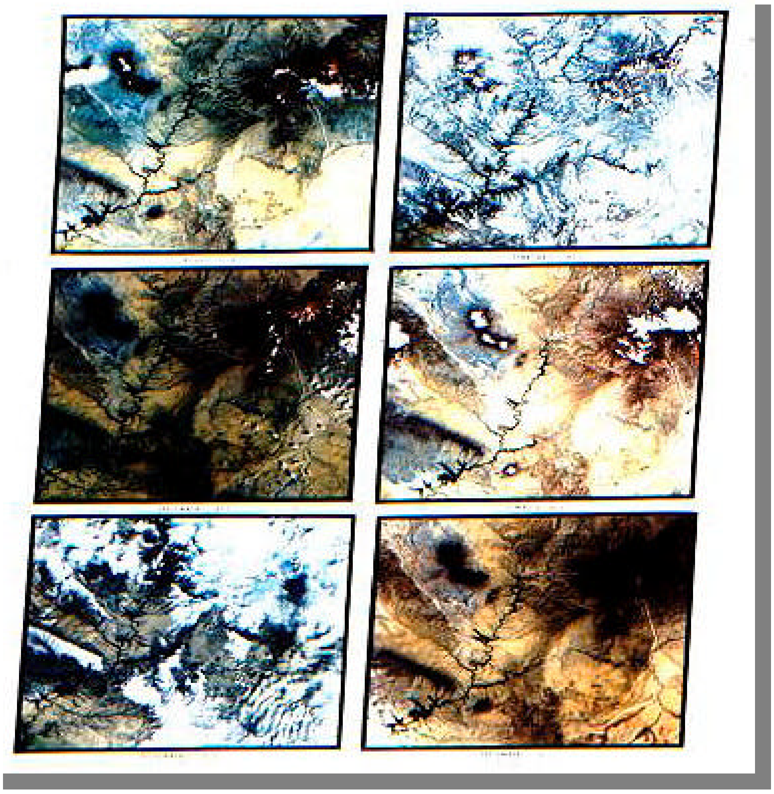
The Systems (Multisource) Approach to Remote Sensing

As may already be evident from earlier pages in this section, remote sensing data is of such nature and volume as to require it to be compatible with processing and outputing by computers. They are the easiest, fastest, and most efficient way to produce images, extract data sets, and assist in decision making. One special function is to assist in manipulating other kinds of data about the spatial or locational aspects of areas in the world that are the subjects of interpretation and decision making. Today, the approach to analyzing a problem or determining a plan dealing with some aspect(s) of monitoring or managing these areas for specific uses or development is embodied in the concept of a Geographic Information System (GIS). This page previews this tool but Section 15 will be devoted to understanding its capabilities and applications.

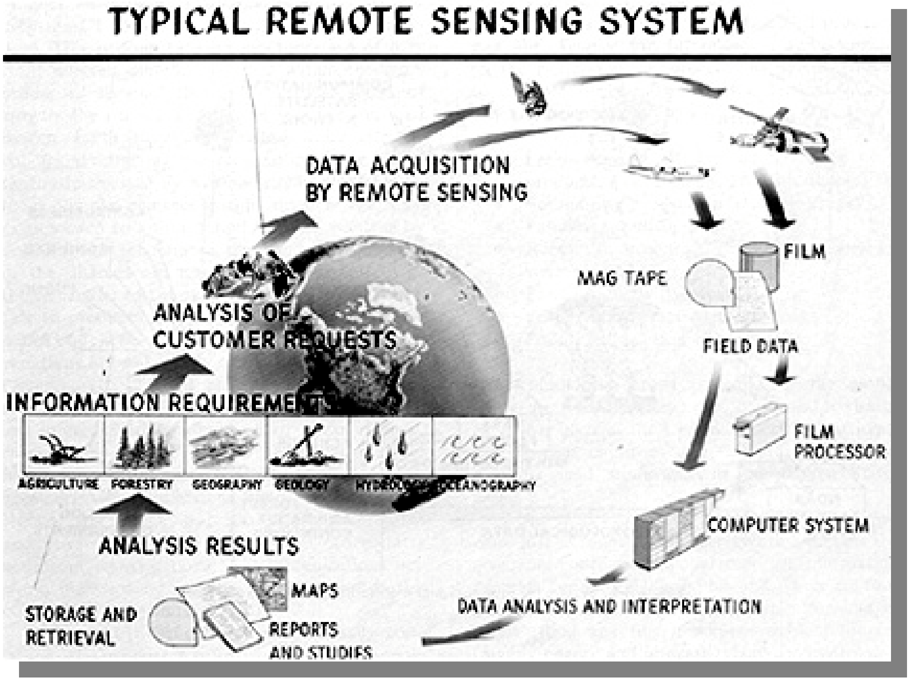
Since the early days of monitoring the Earth by orbiting spacecraft, the development of computer-aided techniques for reliably identifying many categories of surface features within a remotely sensed scene, either by photointerpretation of enhanced images or by classification ranks in itself as an outstanding achievement. Numerous practical uses of such self-contained information are being made without strong dependence on other sources of complementary or supporting data. Thus, automated data processing assists in recognizing and mapping, as an example, major crop types, estimating their yields, and spotting early warning indicators of potential disease or loss of vigor. However, many applications, particularly those involving control of dynamic growth or change systems, or decision making in management of natural resources, or exploration for nonrenewable energy or mineral deposits, require a wide variety of input data of various kinds (from multisources) not intrinsic to acquisition by spaceborne sensors such as those on Landsat, SPOT, and others of similar purpose.

Some data are essentially fixed or time-independent - slope aspect, rock types, drainage patterns, archaeological sites, etc. - in the normal span of human events. Other data come from measurements or inventories conducted by people on the ground or in the air - weather information, population censuses, traffic flow patterns, soil erodability, etc. However, many vital data are transient or ephemeral - crop growth, flood water extent, insect infestation, limits of snow cover, etc. - and must be collected in a timely sense. Pertinent remote sensing data play a key role in this last instance, and in fact satellite monitoring is often the only practical and cost-effective way to acquire data frequently over large regions.

A given scene imaged at different times of the year can show great variety. Changing Sun angles, atmospheric variations, seasonal differences in vegetation cover, presence of snow, and other variables will produce often pronounced contrasts in the spectral responses that determine "how an image looks". This is evident in this montage of 6 Landsat MSS images of an area in the desert of Utah.



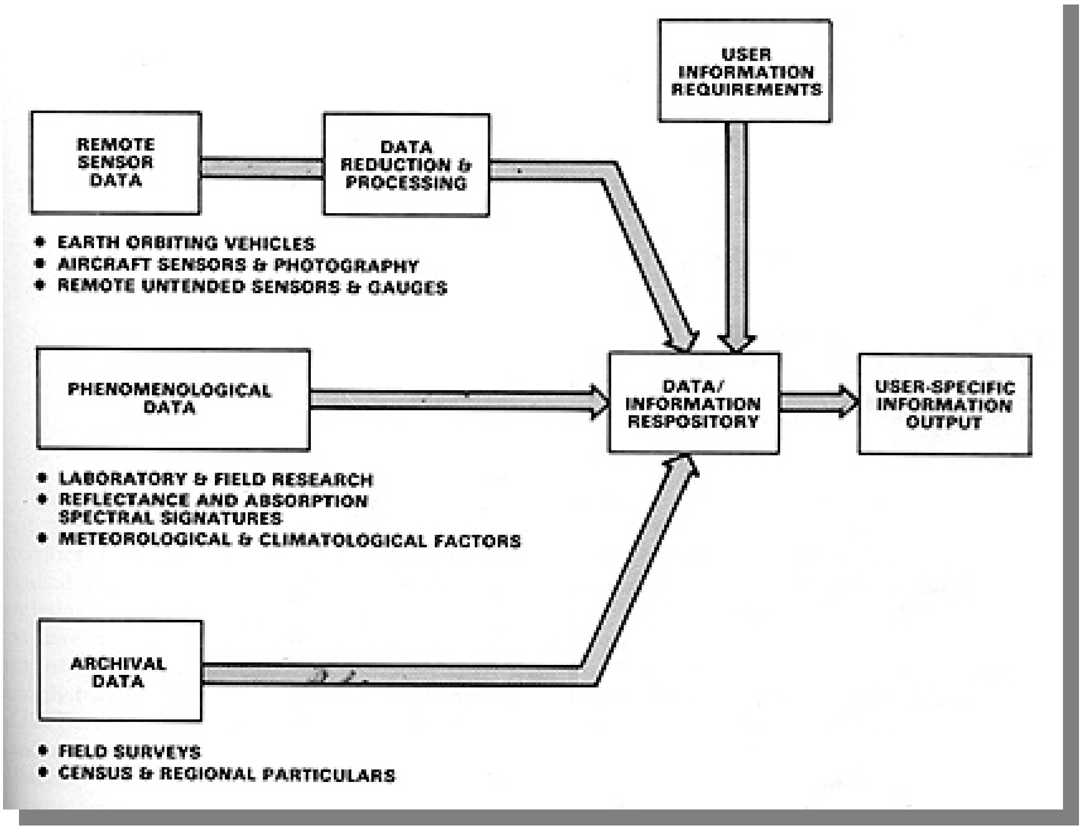
One should always keep in mind that remote sensing is an integral part of a larger Information Management System. In fact, in many applications, the user community employs remote sensing inputs as a key component of a continuing cycle of decision making. Consider this diagram:



This chart shows a simple closed-loop cyclic process, unencumbered by the various feedback loops that no doubt exist. The starting point, and end point as well, is the set of panels labeled Information

Requirements. This focuses on the ultimate driver of any information management system: the user and his/her recurring needs. Various disciplines concerned with Earth observations and resources are represented (one not shown is Meteorology). The terrestrial globe in the background reminds us that the system should be worldwide in scope. Information requirements logically lead to user/customer demands. The best remote sensing system approach is the one most responsive to these demands.

There has by now been full realization that the best current and future uses of most Earth-observing data from satellites (or astronauts) stem from correlating and interleaving this type of data with various other types that together are essential inputs to decision making and applications models. This is embodied in the "Multi" concept, described in another Section, but summarized here by these terms: Multistage; Multilevel; Multisensor; Multispectral; Multitemporal; Multisource. Remote sensing data constitute an integral element of a more general Earth Survey Information System, as exemplified here:



The bulk of the data in such systems have in common a geographical significance, that is, they are tied to definite locations on the Earth. In this sense, they are similar to or actually make up what has become a powerful tool in decision making and management: the Geographic Information System (GIS; also known as geobased or geocoded systems). Because vast amounts of spatial or geographically referenced data must be gathered, stored, analyzed in terms of their interrelations, and rapidly retrieved when required for day to day decisions, a GIS that accepts these data must itself be automated (computerized) to be efficiently utilized.

The importance of GIS as a unifying means of handling geospatial data, including often mandatory inputs from remote sensing, warrants na extended explanation of how its works and what is does. This is the subject of Section 15. In Section 1 you will learn how computers with appropriate software are an essential part in processing, manipulating, and integrating data such as is the output of Landsat and other systems. It is safe to say that today, without computers, remote sensing from space would be next to impossible.

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