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Satellite Images for Land Cover Monitoring

Navigating Through the Maze

Introduction

Policy makers, managers, scientists and the public can view the changing environment using satellite images. More than 60 Earth observing satellites are collecting images of the Earth's surface. Remote sensing satellite systems for land cover assessment are operated by a growing number of countries including India, the United States, Japan, France, Canada and Russia.

The focus of this publication is satellite systems for land cover monitoring. On the reverse is a table that compares a selection of these systems, whose data are globally available in a form suitable for land cover analysis. We hope the information presented will help you assess the utility of remotely sensed images to meet your needs.

What is Remote Sensing?

Remote sensing is the discipline of observing the Earth's surface without being directly in contact with it. It allows us to obtain information about our planet and humans activities from a distance, which can reveal interesting features that may not be possible or affordable from ground level. This gives a global perspective on changes and the interaction of our complex biosphere components.

The tools for remote sensing are sensors installed on planes or satellites. Airborne sensors are typically photographic cameras. Although an important source of environmental information, airborne image collections often are poorly documented and for small areas. In many countries the collection of airborne photographs is restricted.

Satellite sensors acquire images of the Earth and transmit the data to ground receiving stations located throughout the world. Once these raw images are processed and analyzed, they can document changing environmental conditions like pollution, global climate change, natural resource management, urban growth, sustainable development and much more.

Even though many satellite sensors monitor the earth, which sensor to use depends on the type of environmental information needed.

What Can Remote Sensing Do For You?

Remote sensing plays an integral role in environmental assessment. Remote sensing will never replace fieldwork but it offers great support in:

- Remote and difficult to access areas like dense forests, glaciated areas, swamps, high elevations, etc.
- Areas undergoing rapid changes.
- Countries with poor infrastructure and limited transportation.
- Areas of natural hazards: flooded areas, active volcanic regions, forest fire areas, etc.
- Constructing a broad overview or a detailed map of a large area.

Remote sensing techniques can increase the speed in which one can analyze a landscape and therefore help make quick and focused decisions.

Some applications include:

Agriculture and Forestry

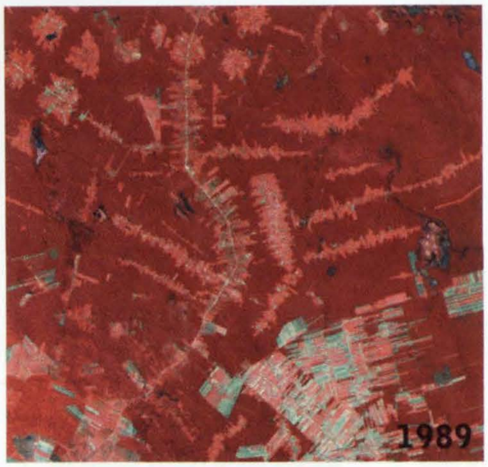
- Discriminate vegetation, crop, and timber types.
- Measure crop and timber acreage.
- Estimate crop yields.
- Measure change in forest cover.
- Assess drought impact.
- Determine soil conditions.

Land Use Mapping and Economic Planning

- Map and monitor land cover changes.
- Monitor urban growth.
- Map of land-water boundaries.
- Site power plants and other industries.
- Site for transportation and transmission routes.

Geology and Geomorphology

- Recognize different rock types.
- Map major geologic units.
- Monitor surface mining and reclamation.
- Site solid waste storage.
- Monitor volcanic activity.



Water and Coastal Resources

- Determine surface water areas.
- Monitor environmental effects of humans activities.
- Map floods and flood plains
- Determine the extent of snow and ice.
- Measure glacial features.
- Map shoreline changes.
- Trace oil spills and pollutants.

Attention should also be paid to the fact that remote sensing allows multi-temporal analysis. This means that an area of interest can be monitored over time so that changes can be detected. This allows us to analyze phenomena like vegetation growth during different seasons, the extent of annual floods, the retreat of glaciers or the spread of forest fires or oil spills.

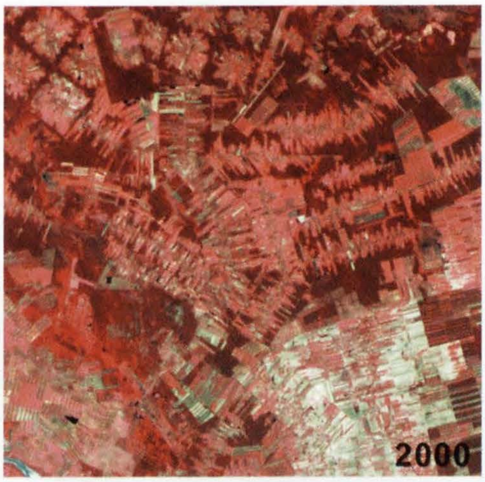
Issues that Affect Selection of Images

Satellites and their sensors can differ in many ways. Most satellite sensors image the Earth with several bands where a band is sensitive to a specific range of wavelengths within the electromagnetic spectrum. The sensors discussed here are those sensitive to visible and infrared wavelengths. Beyond these wavelengths the interpretation of the data can become very specialized. However for some applications, wavelengths such as those used in radar sensors, are very important.

The defining characteristics of a sensor are the size of an image, the region of the Earth that can seen, the smallest feature that can be distinguished, the bands used, how often images are collected, and when was the sensor in operation. Important non-technical issues include acquisition costs and data sharing limitations. Licensing agreements vary over time, by product, by sensor and by organization.

How much area does an image cover?

The area covered by a single satellite image is defined by the path width and the distance along the path. The path width is limited by how far to each side the sensor can see. The path width can vary from as little as 8 kilometers to over 2000 kilometers. The distance along the path is more arbitrary. For high-to-medium resolution sensors the tendency is to create nominally square images. The image length for low resolution images may be an entire path.



Most Earth observing satellites orbit from pole to pole and are sun-synchronous, that is they always pass overhead at the same time of the day. Overlap between paths is least near the equator and most at upper latitudes. Areas close to the pole may not be covered at all. In contrast, some weather satellites are geostationary. They monitor only one hemisphere, but at all times of the day.

What is spatial resolution?

Spatial resolution of digital satellite sensors is the distance along the ground between samples. As the satellite moves across the Earth surface it records the brightness of the surface at regular intervals. The spatial resolution of a digital sensor is distinct from that of a photographic camera. The former is based on sampling rates, while the latter is based on the grain size in the film. If you zoom into a photograph, the image will degenerate into random noise. A satellite image will decompose into tiny black and white or colored squares or picture elements called pixels.

If a satellite image has a spatial resolution of 30 meters this means that one pixel in the image represents a square of 30 x 30 meters on the Earth's surface. In an image of this resolution one cannot see small buildings, but can definitely see a football field. Some sensors image the Earth with a very low resolution, more than 1 km, suitable for general land cover mapping of large features or monitoring vegetation vigor. Others, with a resolution of 1 meter, can resolve individual trees and are suitable for validation of coarser images.

What is spectral resolution?

As spatial resolution is a sampling of space, spectral resolution is a sampling of the electromagnetic spectrum. Conceptually many narrow bands would allow different types of land cover to be more easily distinguished. In reality, much of the information contained in narrow bands may be redundant. Sensor designers attempt to optimize the selection of the bands so that they can best distinguish between different types of land cover with the fewest number of bands. Typical bands are: blue, green, red, near infrared, mid infrared and thermal infrared.

The blue band has the best penetration of water, so is useful for coral reef and sea grass monitoring. Conversely, the blue band is very sensitive to moisture in the atmosphere, so in humid climates is very noisy. The green band is relatively high and the red band is relatively low for vegetation. The near-infrared bands are high for vigorously growing vegetation. Mid or short wave infrared bands are sensitive to moisture. Thermal infrared bands are sensitive to emitted thermal radiation, such as hot spots in a city or the temperature distribution of a lake.

What are repeat cycles and dates of operation?

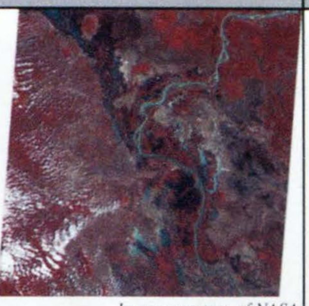
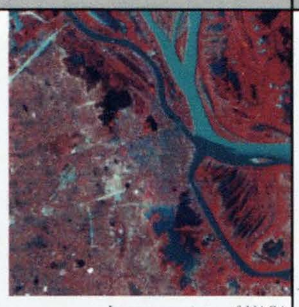
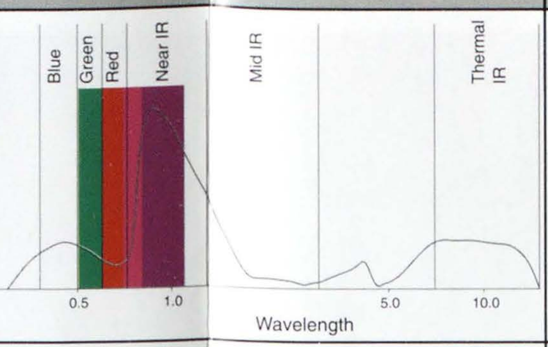
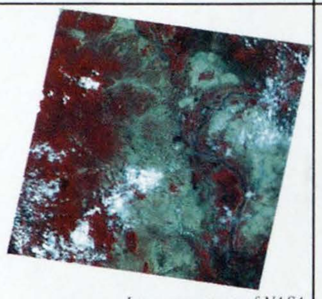
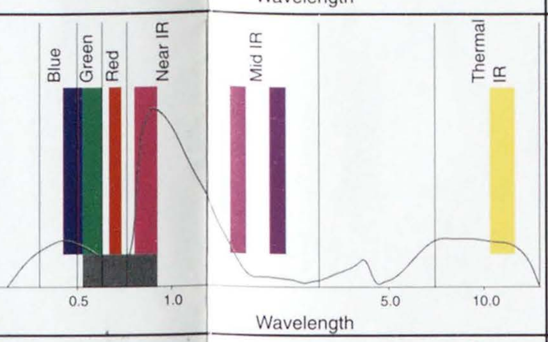
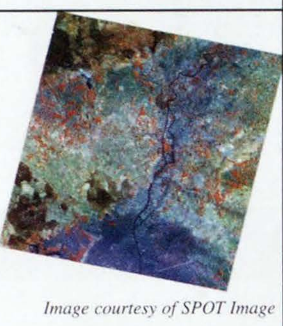
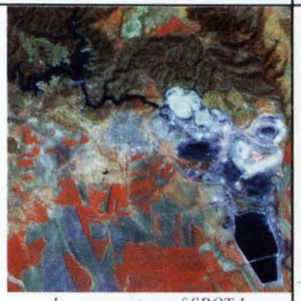
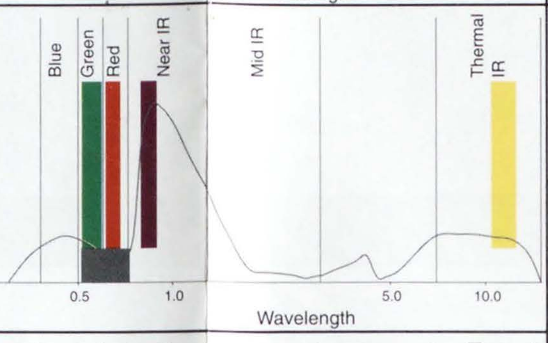
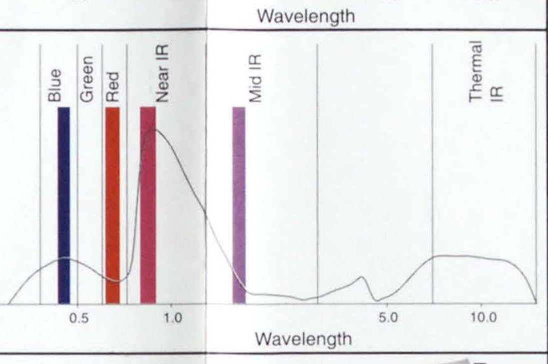
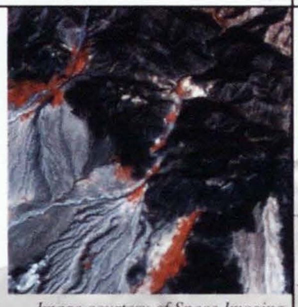
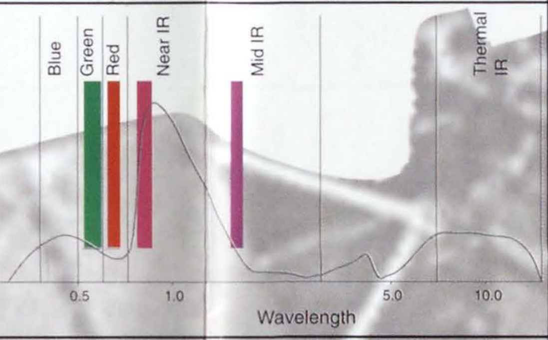
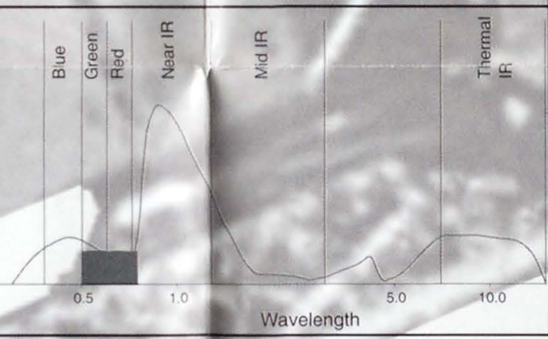
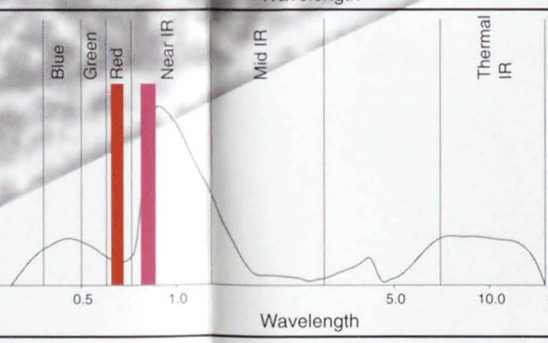
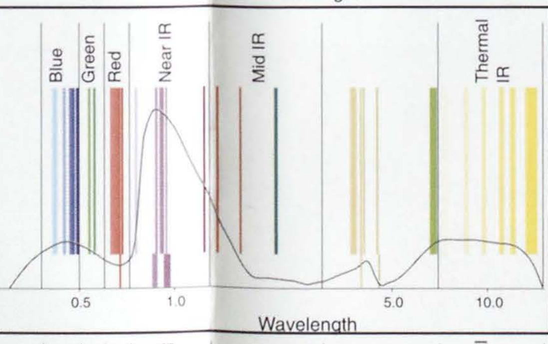
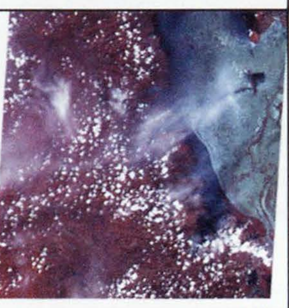
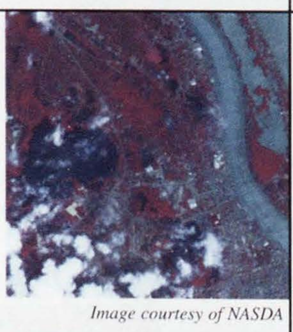
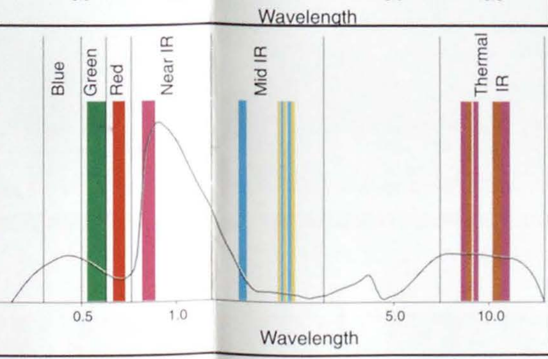
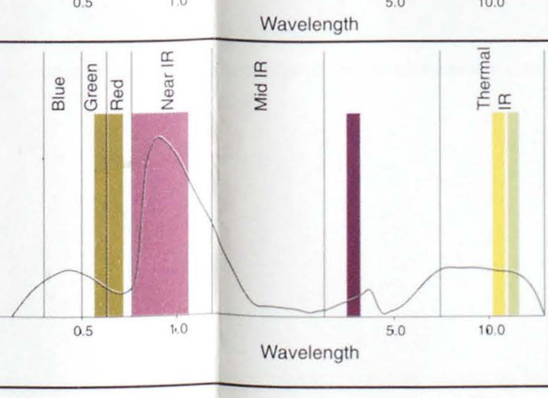
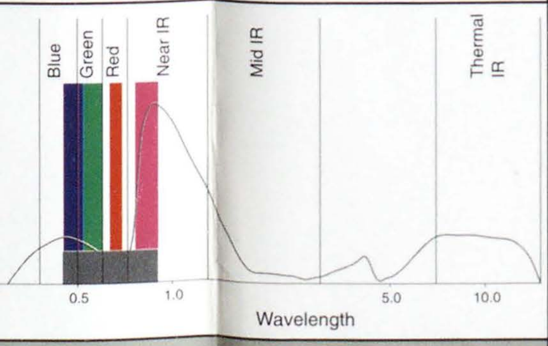
The orbital paths of most operational satellites are fixed. The repeat cycle of a sensor is the number of days before an area can be seen again. The repeat cycle varies from every day to weeks. Some sensors have overlapping paths and some sensors are pointable which effectively reduces the period between repeat coverage.

The repeat cycle is critical for two reasons. One, some types of change or monitoring require frequent observations. Two, cloud cover may obscure the ground. Sensors with long repeat cycles, which tend to be high spatial resolution sensors, may only acquire a cloud free image once every several years in some climates.

How do these characteristics interact ?

Wide paths tend to be associated with low spatial resolution. High spatial resolution means large data volumes. Wide paths are linked to short repeat cycles.

Tradeoffs exist between spatial and spectral resolution. To achieve high spatial resolutions some sensors have a panchromatic band, which is essentially a very wide band.

Satellite: Sensor		Spatial Extent: The total area covered by an image. The width of the image is the path width. The length of an image is not always constant, although a tendency exists for approximately square images. The nominal number of scenes needed to map Africa (30,264,000 km^2) and Costa Rica (50,000 km^2) are provided for each sensor. The actual number of scenes may be considerably higher depending on overlap and the shape of the country.	Spatial Resolution or Pixel Size: The spatial resolution of a sensor is a function of how frequently the sensor samples the ground. The pixel size is usually close to the sampling rate of the sensor. Objects on the ground need to be considerably larger than the spatial resolution to be detected. Example images are 375-by-375 pixels. The estimated number of land pixels for Africa and Costa Rica are provided for each sensor. Estimates are in millions of pixels.	Spectral Resolution: The sensors collect light in different parts of the spectrum. Grey line shows typical vegetation curve. Blue: penetrates shallow waters Green: high for green vegetation Red: low for green vegetation Near IR: high for vigorously growing vegetation Mid IR: sensitive to moisture variation Thermal IR: emitted thermal radiation	Repeat Cycle and Dates in Operation: Frequent coverage increases the chances of cloud-free images. Multiple images within a growing season allows knowledge of plant phenology to be used in land cover mapping. Images collected through many years allows the detection of land-use and land-cover change. In some cases more than one satellite is operational, decreasing the period between coverages.
Landsat	Multi-Spectral Scanner	185 km wide 170 km long Africa: 960 Costa Rica: 2 Phnom Penh, Cambodia  *Image courtesy of NASA*	80 m Africa: 5,000 Costa Rica:8 (with 30 m pixels) Phnom Penh, Cambodia  *Image courtesy of NASA*		18 day repeat cycle for Landsats 1-3 16 day repeat cycle for Landsats 4 & 5 Operational since 1972 on Landsats 1-5.
Landsat	Thematic Mapper	185 km wide 170 km long Africa: 960 Costa Rica:2 Phnom Penh, Cambodia  *Image courtesy of NASA*	30 m bands 1-5,7 60 m thermal 15 m panchromatic Africa: 34,000 Costa Rica: 56 (with 20 m pixels) Phnom Penh, Cambodia  *Image courtesy of NASA*		16 day repeat cycle TM available since 1982 on Landsats 4 and 5. ETM+ available since 1999 on Landsat 7. The panchromatic band is only available on Landsat 7 ETM+
SPOT	Multi-spectral and Panchromatic	60 km wide 60 km long Africa: 8500 Costa Rica: 14 Sevilla, Spain  *Image courtesy of SPOT Image*	20 m multispectral 10 m panchromatic Africa: 76,000 Costa Rica: 125 Near Sevilla, Spain  *Image courtesy of SPOT Image*		26 day repeat cycle 5 day repeat viewing with pointable sensor Satellite operational since 1986.
SPOT	Vegetation	2200 km wide variable length Africa: 6 Costa Rica: 1 Nile River and Red Sea  *Image courtesy of SPOT Image*	1 km Africa: 31 Costa Rica: 0.05 Nile River and Delta  *Image courtesy of SPOT Image*		4 out of 5 day repeat cycle Satellite operational since 1986.
IRS	LISSIII	142 km wide 142 km long Africa: 1500 Costa Rica: 3 Iran  *Image courtesy of Space Imaging*	23.5 m 70 m mid IR Africa: 55,000 Costa Rica: 91 (with 23.5 m pixels) Iran  *Image courtesy of Space Imaging*		24 day repeat cycle Satellite operational since 1996.
IRS	Panchromatic	70 km wide 70 km long Africa: 6200 Costa Rica: 11 St. Petersburg, Russia  *Image courtesy of Space Imaging*	5.8 m Africa: 900,000 Costa Rica: 1500 St. Petersburg, Russia  *Image courtesy of Space Imaging*		24 day repeat cycle 5 day repeat viewing with pointable sensor Satellite operational since 1996.
IRS	WIFS	810 km wide 810 km long Africa: 50 Costa Rica: 1 Tunisia and Italy  *Image courtesy of Euromap*	188 m Africa: 860 Costa Rica: 1.5 Sicily  *Image courtesy of Euromap*		5 day repeat cycle Satellite operational since 1996.
Terra	MODIS	2330 km wide variable length Africa: 6 Costa Rica: 1 Nile River and Red Sea  *Image courtesy of NASDA*	250-1000 m Band dependent Africa: 500 Costa Rica: 0.8 (with 250 m pixels) Nile River and Delta  *Image courtesy of NASDA*		1 day repeat cycle Satellite operational since 2000.
Terra	ASTER	60 km wide 60 km long Africa: 8500 Costa Rica: 14 Phnom Penh, Cambodia  *Image courtesy of NASDA*	15 m vis and near IR. 30 m mid IR 90 m thermal IR Africa: 135,000 Costa Rica: 225 (with 15 m pixels). Phnom Penh, Cambodia  *Image courtesy of NASDA*		16 day repeat cycle 4 day repeat cycle with pointable sensor Satellite operational since 2000.
AVHRR		3000 km wide variable length Africa: 6 Costa Rica: 1 Nile River and Red Sea  *Image courtesy of NOAA*	1.1 km Africa: 26 Costa Rica: 0.042 Nile River and Red Sea  *Image courtesy of NOAA*		1 day repeat cycle Satellite operational since 1978.
Ikonos		11 km wide 11 km long Africa: 253,000 Costa Rica: 420 Sanaa, Yemen  *Image courtesy of Space Imaging*	4m multispectral 1m panchromatic Africa: 31,000,000 Costa Rica: 50,000 (with 1 m pixels) Sanaa, Yemen  *Image courtesy of Space Imaging*		5 day repeat cycle 1.5 day repeat viewing with pointable sensor Satellite operational since 1999.

Questions That Need to be Asked Before Using Satellite Images

Often simple answers do not exist for selecting and using satellite images in projects.

- Compromises may be required even in the most ideal scenario. In the simplest terms a satellite image must be available.
- No simple method exists for calculating cost of data acquisition. Many issues need be considered.
- Satellite images are pictures of the Earth. Cost and expertise is needed to extract information for the satellite images.
- Data providers fall into three broad and overlapping types: government agencies, quasi-public organizations and private companies. Services available and copyright issues need to be considered.

Criteria for sensor selection:

- Coverage: Are images available for your area?
- Spatial resolution: What size are the features you need to map?
- Spectral resolution: What types of features need to be distinguished?
- Dates of operation: During what years are images available?
- Repeat cycle: What types of variation through time are important: within or between years?

Criteria for image selection:

- How much cloud cover is acceptable?
- How critical is the time of year?
- How important is the year?
- If multiple images are needed, do they need to be in specific seasons of one year, the same season in multiple years, and so on?

Cost of data acquisition:

- Who you work for and where you live may affect cost of data.
- Redistribution policies may affect with whom you can share your data.
- Data may be available at little or no cost.
- If no-cost data are available, do they fit your needs: resolution, data of acquisition, and so on?

Cost of data analysis:

- Do you have staff to do the analysis or will the analysis be contracted?
- Satellite images can be either manually interpreted or they can be classified with a computer. Different types of expertise are needed and different types of costs are incurred.
- Is training needed? If so, what type of training?
- The cost of validating the quality of the analysis is often a forgotten and hidden cost. Without validation the value of the analysis is limited.

Other More Specialized Sensors Important for Land Cover Monitoring

- Radar sensors have all-weather capability for quantifying variation in surface roughness that is crucial for monitoring floods, fires, oil spills, wind speed and wind direction. Examples of radar sensors include Radarsat, ERS, JERS, SIR-C, Seawifs, and Seawinds
- Cameras were carried on many older satellites and continue to be used on many manned space missions. The older photographic images extend the environmental record back to 1962 and many are of high spatial resolution. Examples of space photography include Corona, Argon, Shuttle, Gemini and Apollo handheld, and TK-350, KVR-1000, MK-4, and KFA-1000.
- Sensors on geostationary satellites have the unique ability to provide continuous coverage of a region. These satellites are at much higher altitudes than are most Earth observing satellites and are designed for weather monitoring. A critical ability of sensors on these satellites is to monitor cloud cover and to provide rainfall estimates. Examples of these satellites include GMS, GOES-E, GOES-W, GOMS, Meteosat and Insat.
- Further information on new sensors as they are launched and on other specialized sensors such as DMSP, ATRS, TRMM, MISR, and QuikScat can be found at http://www.na.unep.net.

Satellite Remote Sensing for Environmental Assessment and Monitoring
Satellite sensors are available with resolutions from 1 m to 1 km. These resolutions are suitable for both large area and local applications.
In remote areas, satellite images may provide the only practical source of information.
For some applications, such as land cover analysis over large areas, no cost effective alternative exists.
Satellite images can be effectively analyzed either by image interpretation or by computer analysis.
Many satellite sensors collect images for the entire world.
Satellite image archives exist that document the Earth's surface back to the early 1960s.
Many of the satellite images can be acquired at no cost or at the cost of reproduction with no restrictions on image sharing.
In all cases, expert and local knowledge should be used to validate or guide the analysis of satellite images.

Disclaimers

The views expressed in this text do not necessarily reflect those of the agencies cooperating in this project. Satellite sensor specifications may be approximated or summarized. The designations used and material presented above do not imply the expression of any opinion whatsoever on the part of the cooperating agencies concerning the legal status of any country, territory, city, or area or of its authorities, or of the delineation of its frontiers or boundaries.

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Satellite Systems for Land Cover Monitoring

Navigating Through the Maze

For further information on remote sensing view:

http://www.na.unep.net/

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