Remote Sensing Applications at the State and Local Level

Report of a User Workshop

February 23, 2001
Lamont Doherty Earth Observatory
Palisades, NY

Sponsored by the Socioeconomic Data and Application Center (SEDAC)
Center for International Earth Science Information Network (CIESIN)

Columbia University

The User Workshop on Remote Sensing Applications at the State and Local Level was sponsored by the Socioeconomic Data and Application Center (SEDAC) of the Center for International Earth Science Information Network (CIESIN) at Columbia University.

The Workshop home page can be found at

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The Center for International Earth Science Information Network (CIESIN) was established in 1989 as an independent non-governmental organization to provide information that would help scientists, decision-makers, and the public better understand their changing world. In 1998, CIESIN relocated from its original home in Michigan to become part of Columbia University's Earth Institute.

CIESIN focuses on applying state-of-the-art information technology (e.g., computer science, data archiving, geographic information systems, and remote sensing) to interdisciplinary problems at the intersection of human and environmental systems.

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Executive Summary

The Workshop on Remote Sensing Applications at the State and Local Level was organized by CIESIN's Socioeconomic Data and Application Center (SEDAC) to address issues of availability and the needs for remotely sensed data products by local users. The workshop took place at Columbia's Lamont-Doherty Earth Observatory, in Palisades, NY and was attended by about twenty representatives from local and state governments and non-governmental organizations in New York and New Jersey.

The objective was to solicit input from potential users of geo-referenced data products derived from remotely sensed imagery, in terms of specific products needed for on-going activities and the exploration of new applications.

The increasing availability and accessibility of new technology and data for local governments and agencies are proving helpful for day-to-day decision-making processes. In particular, remotely sensed data and Geographic Information Systems have been increasingly used together for a vast range of applications, ranging from land use/land cover mapping to emergency management to characterization and monitoring of environmental and human health conditions.

SEDAC has been working with five sets of Landsat 7 ETM+ images covering parts of New York, New Jersey and Connecticut, acquired during the fall 1999 and the winter 2000. Using the above images, SEDAC's staff have explored ways to develop new and innovative products that might be useful for a wide range of applications within local and state governments. Some of these prototype products were presented at the workshop in order to get feedback from potential users about general usefulness, specific applications of remote sensing products for local governments, and specific issues users would like to see addressed by these products.

The two prototype data products presented were (i) a tailored land cover/land use classification and (ii) a greenness map. The discussion focused on usefulness of such products for a variety of applications, such as landscape assessment, environmental and health conditions monitoring, urban sprawl and urban/vegetation change studies. This led to discussions of specific applications that local governments and agency are currently involved with and interested in using, with particular emphasis on different sensors and their resolutions.

Using an evaluation form distributed the same day, participants provided helpful comments in terms of specialized classifications they would like to have, time frames for image acquisition, and data processing and integration with other data sets. Although there was an agenda item on mechanisms for data sharing and models for collaborative work between governments and organizations, those topics were not discussed in depth, given the differences in interests that emerged during the workshop and the possible difficulties in coordinating such different activities. Such discussions seemed more likely to develop in the future through individual collaborations rather than through a broader group or 'consortium'.

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1 Introduction

The Workshop on Remote Sensing Applications at the State and Local Level was organized by CIESIN's Socioeconomic Data and Application Center (SEDAC) to address issues of availability and needs for remotely sensed data products among local users. Specifically about twenty representatives from local and state governments and non-governmental organizations in New York and New Jersey attended the workshop to discuss the development of tailored applications using remotely sensed imagery. SEDAC developed prototype data products using Landsat 7 ETM+ imagery, such as a tailored land use classification and a greenness map (the latter being a simpler version of the Vegetation Fraction Index calculated for New York City by Chris Small).

The objective was to solicit input from potential users of geo-referenced data products derived from remotely sensed imagery, in terms of specific products needed for on-going activities and exploration of new applications. The possibility of forming local and regional collaborations to purchase and share imagery and other data resources was also on the agenda (see Annex 1 for the Agenda and Annex 2 for the Participants list).

The increasing availability and accessibility of new technology and data for local governments and agencies is proving helpful in day-to-day decision-making processes. In particular remotely sensed data and Geographic Information Systems have increasingly been used together for a vast range of applications, spanning from land use/land cover mapping to emergency management to characterization and monitoring of environmental and human health conditions.

The higher spatial and spectral resolutions, more frequent coverage and increased availability of new sensors will bring remote sensing to a more accessible level within local and state governments and help them deal with several issues in regional planning, resource management, public health and environmental protection.

The workshop's objectives were:

- To examine the prototype data products and discuss the possible uses for local application in terms of Land Cover/Land Use and Vegetation change detection;
- To discuss other potential applications, such as emergency management, flood mapping, air and water quality monitoring and related issues of scale and timing;
- To discuss other relevant data sets and their integration with remotely sensed data;
- To discuss other satellite data products and possible mechanisms for data sharing.

This reports provides a summary of the workshop presentations and discussions. Section 2 describes the discussion on prototype data products, including background material and comments from workshop participants. Section 3 summarizes the discussion on specific applications and integration with other data sets. Finally, Annex 3 provides background information on Landsat 7 ETM+ and other remote sensing satellite and sensors.

2 Prototype Data Products Discussion

SEDAC has been working with five sets of images covering parts of New York, New Jersey, and Connecticut, acquired during the fall of 1999 and the winter of 2000. The images were collected by Landsat 7 using the Enhanced Thematic Mapper Plus (ETM+) sensor (see Annex 3 for more information on Landsat and other satellites and sensors).

The spatial resolution (ground cell or pixel size) varies between 15 and 60 meters and allows detection and mapping of quantities such as vegetation abundance and health, presence of standing water, forest clearing, agricultural usage and other land cover changes.

Using the above images we explored several ways of making use of the high-resolution panchromatic band and the improved thermal band, and of developing new products. Some of these prototype products were presented at the workshop, in order to get feedback from potential users about general usefulness, specific applications of remote sensing products for local governments, and specific issues users would like to see addressed by these products.

The advantage of having such user-specific products is that they will be developed according to local government needs, they will be compatible with higher resolution data sets already collected and available at the local level, and they will allow a better understanding of dynamics and features that can be integrated in decision-making processes.

A classic example of such integration would be a land cover/land use change study: the resolution of the Landsat 7 data does not allow for detailed discrimination between features in the way that aerial photography or field surveys do. However, the availability of multispectral data can help better identify certain features and their condition (i.e., vegetation health monitoring). The availability of repeat coverage over a certain area will then permit the production of land cover maps for different periods and thus aid change detection studies. Changes that might be of interest can range from short-term phenomena like flooding or snow cover to long-term phenomena like urban sprawl or deforestation. Vegetation health monitoring can also be performed using images from different seasons. This could be useful in urban vegetation studies or to relate air pollution and vegetation health.

At the workshop we mainly discussed two prototype products potentially useful for local governments: (i) a tailored land cover/land use classification and (ii) a greenness map.

2.1 Tailored land cover/land use classification.

Background

Using the Landsat 7 ETM+ scene from September 1999 (Figure 1, showing Paterson, NJ and surrounding areas in visible/infrared false color), a maximum-likelihood classification was performed to produce the classified image in Figure 2.

The maximum-likelihood approach is one of the methods used in supervised classification. This type of classification is used to cluster pixels into classes corresponding to user-defined “training areas” or “region of interest” (groups of pixels that represent areas or materials that the user wants to have mapped in the final product). The first step in the supervised classification is to identify representative training areas and to develop a numerical description of the spectral attribute for each land cover type of interest. This is followed by the classification process in which each pixel is assigned to the land cover class it is most likely to belong to. The maximum likelihood method requires a large number of computations to classify each pixel, making it time and memory consuming, but it is considered one of the most accurate classification algorithms.

The classification of the Landsat scene was performed using only 6 classes of land use/land cover to show the possibility of using a very simple classification scheme that can be used for many different applications, in particular in the urban/suburban context. Such applications might include mapping and monitoring of new developments (housing, roads, commercial development, etc.), golf courses or changes in density of vegetation and urban areas.

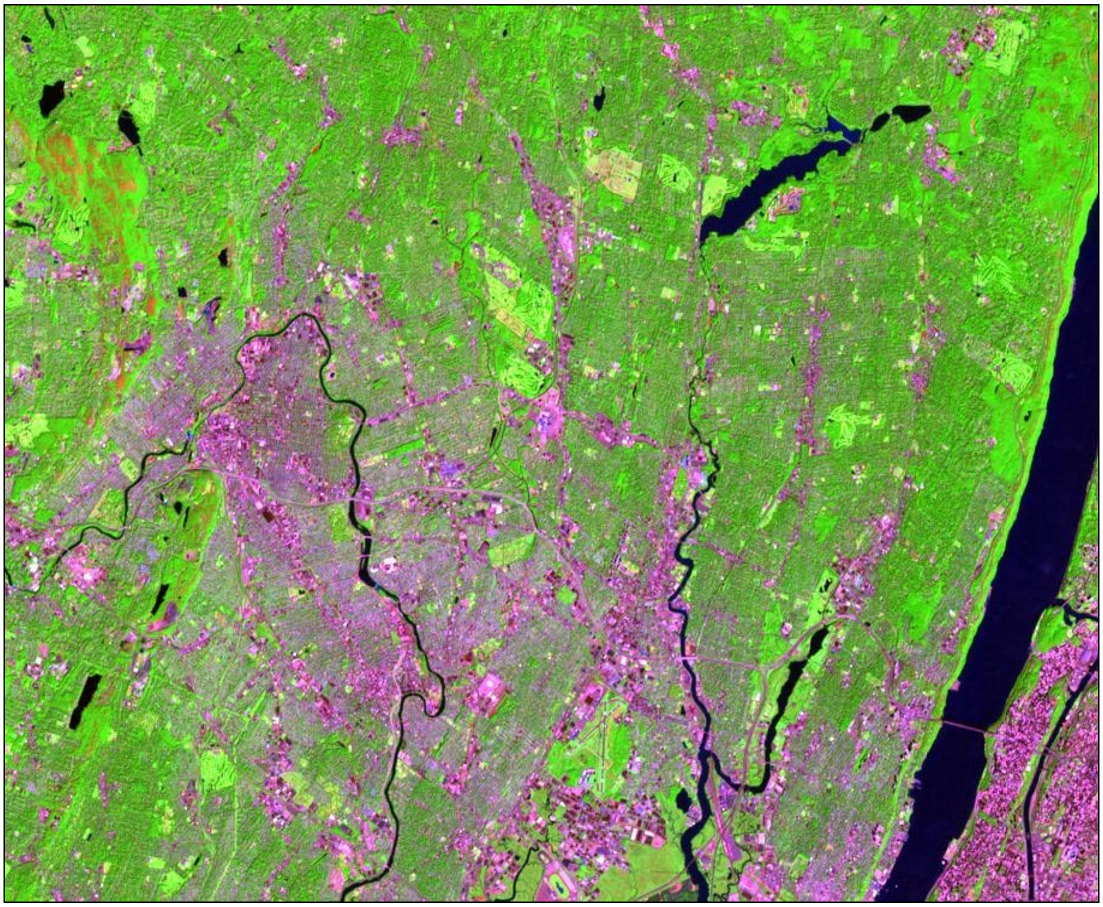

Figure 1. Landsat 7 ETM+ (9/23/99). The image is shown in visible/infrared false color (Red= Band 7, Green= Band 4, Blue= Band 2).

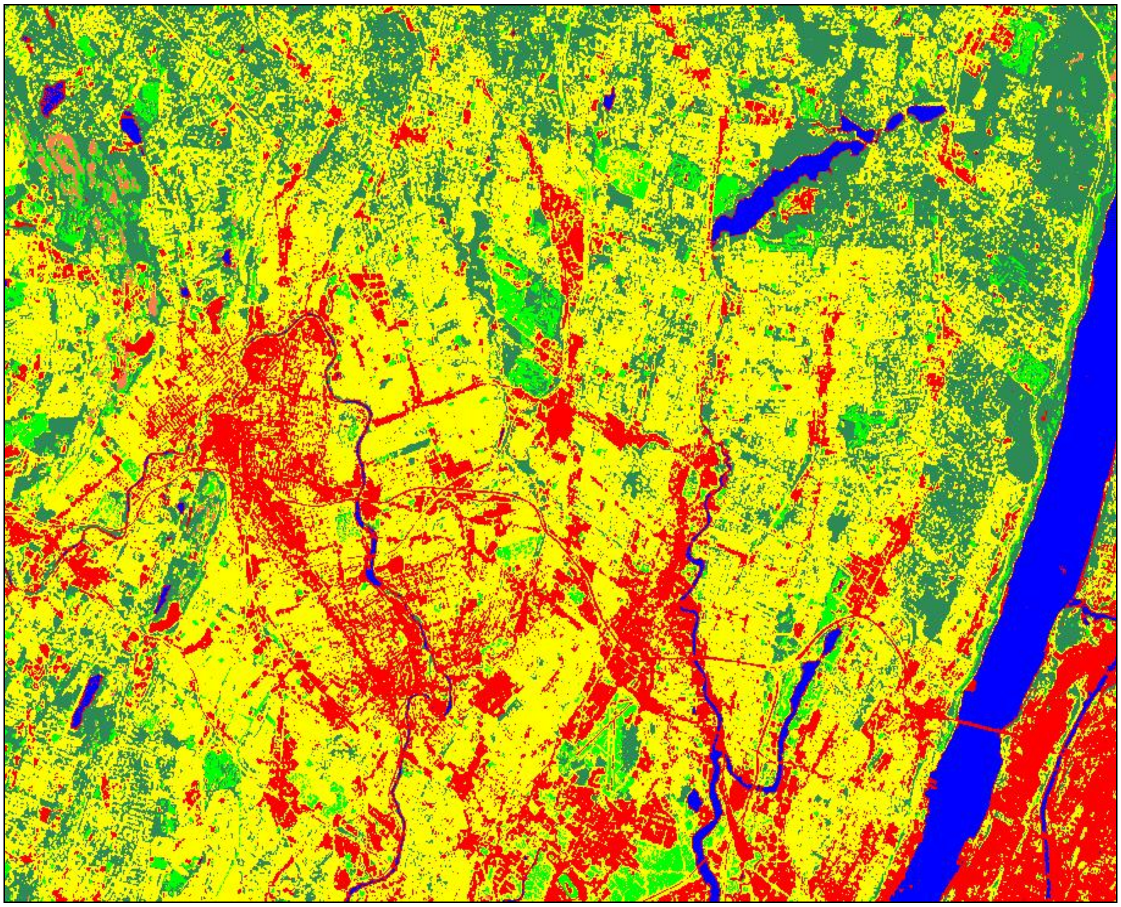

Figure 2. Maximum Likelihood Classification. Legend:

Red: Infrastructure (high intensity residential, commercial, transportation)
Yellow: Low Intensity Residential
Light Green: Urban and Recreational Grasses
Green: Forests
Blue: Water
Coral: Bare Soil, Rock

The correspondence between the unclassified image and the classified one is relatively good. Given the exploratory nature of this product, no ground truthing was performed and, consequently, no statistical accuracy tests were conducted based on control areas on the ground. This was meant to be a first attempt at establishing whether such 'tailored' products can be developed and to show an example of simplified classifications.

Looking at the "Regions of Interest" statistical distribution, it is possible to get a sense of their separability (i.e., how well the classes can be distinguished from each other). The classes that are best distinguished are Water and Grass, Water and Soil, Water and Low Intensity Residential, and Grass and Soil. The two most poorly separated are: Infrastructure and Low Intensity Residential, as expected.

It is important to remember that this simply gives an idea of which classes are easier to separate based only on their spectral responses in the different bands and does not ensure a good result during the classification process.

The advantage of a user-specific classification, compared with other available products, such as the recently released USGS National Land Cover Data set (see Figure 3), lies within the word "tailored": such classification will be produced based on inputs from local governments, according to their needs and potential uses of the product. The classes can be identified and selected based on specific applications and by integrating relatively coarse-resolution data, such as Landsat data, with high-resolution data, such as aerial photography—data already available in many counties. The major advantage would be the possibility of having a regular updating of the product thanks to the availability of repeat coverage, leading to appropriate land cover and land use change products.

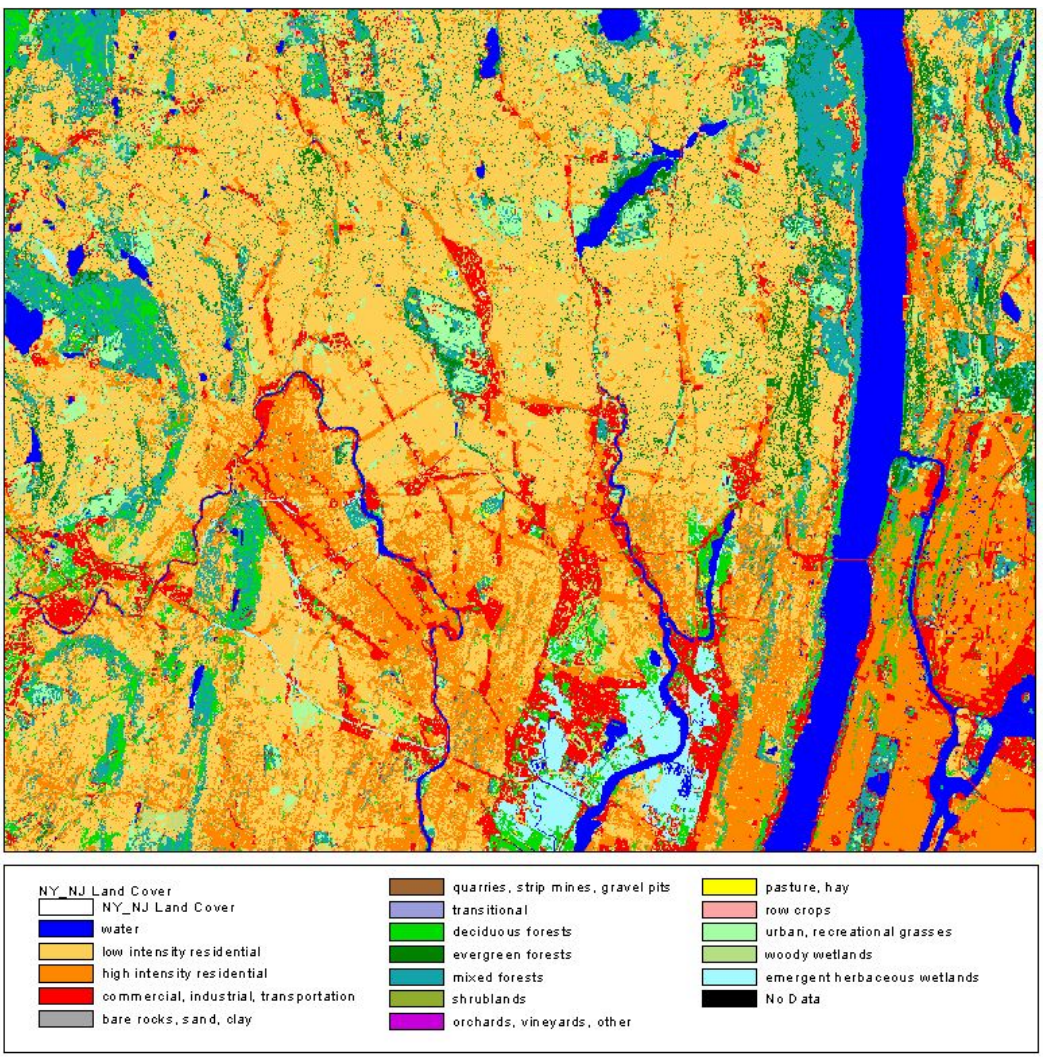

Figure 3. USGS National Land Cover Data Set. (USGS, National Land Cover Characterization Program, National Land Cover Data (NLCD) Set, 1999).

Comments

Workshop attendees expressed considerable interest in the ideas of developing tailored classification schemes and updating land use/land cover maps.

The need for user-tailored classifications was emphasized both by local governments (county level) and by regional and state groups. In the case of county governments, where detailed land use maps may already be available, we discussed the idea of integrating their high-resolution data with satellite-derived products in order to refine existing maps and to get more diverse information. Such information might be related to vegetation or the possibility of aggregating multiple classes (based on the classification results) into fewer classes according to specific uses and applications. Producing an accurate, useful classification scheme for local governments using Landsat 7 data would undoubtedly require a large amount of work, but once the methodology and the final products are in place it could represent a significant improvement for data acquisition and integration in decision-making processes.

As for the regional and state level, given the difference in scale, the development of a tailored classification scheme will require less ancillary data and could be more easily automated. In this case, participants expressed the need for having a comparable set of land use/land cover classes for assessing landscape change, in particular between forest, agriculture, and development.

These ideas led the discussion to ‘change detection’ studies and to the possibility of having regular updates of the classified images. Although limitations in the spatial resolution of the classified image were recognized, the possibility of having regular updates of such products was particularly appealing. Even county governments already provided with detailed maps liked the idea of finding a way to get their data and maps updated more regularly, such as through aggregation of data from different sources (satellite, aerial photography, ground survey, etc.). An example of a way to improve the resolution and make use of the repeat coverage is to calibrate the classification derived from satellite imagery with information from aerial photography and ground data, and then use that calibrated image to perform the classification on other images, looking both back and forward in time. This procedure minimizes the costs of collecting ancillary data to validate the classification in the future and therefore reduces both the costs and the time for the classification process itself.

Other applications that emerged during the discussion were related to integration of land use classification maps with other socioeconomic and demographic data, as further discussed in Section 3.

2.2 Vegetation Fraction Index and Urban/Vegetation Change Detection

Background

Most major metropolitan areas and neighboring suburban settlements are facing problems of urban sprawl, loss of natural vegetation and open space, and drastic change in land cover and land use. For years, land mapping at the county level has relied on aerial photography and field surveys because of the high spatial resolution required and the high level of details that can be obtained. However, satellite imagery may become increasingly important in identifying and monitoring soil conditions and various related land characteristics, such as vegetation and crops. Monitoring is one of the key uses of remote sensing, due to the availability of repeat coverage and associated high spatial and spectral resolution. Remote sensing is extensively used in monitoring changes in natural and semi-natural areas and, to a lesser extent, the effects of pollution on trees, soil, and water.

In areas such as the New York City metropolitan area, where the effects of urban sprawl are of particular concern, remote sensing can be used to monitor urban/vegetation changes and be integrated with higher resolution data available at the county level. Also, new products and methodologies, such as the ones presented at the workshop, can be developed for a vast range of applications and could potentially be updated regularly (annually or seasonally) according to user needs.

SEDAC has been exploring possible products that might help local governments display and monitor such changes and that can be used as basic tools in day-to-day decision-making processes. These products were presented in the morning session.

One such product, potentially very useful in studying urban sprawl and urban and suburban dynamics, is the ***Vegetation Fraction Index***.

During his overview, Chris Small briefly described the results of his study on New York City vegetation (shown in Figure 4). Estimates of vegetation fractions have been obtained through a linear spectral mixing model. The model is based on the assumption that the reflectance of each pixel of the image is a linear combination of the reflectance of each ‘material’ present within the pixel. This allow one to determine the relative abundance of the ‘materials’ based on their spectral characteristics. In the case of New York City, three main components have been recognized to describe the spectral variance in the scene: low albedo (water, shadow, and roofing), high albedo (cloud and roofing), and vegetation. The model has proven to be very accurate: a quantitative validation of Landsat-derived vegetation estimates with vegetation measurements from aerial photography showed an agreement to within 10% for vegetation fractions greater than 20%, across the full range of vegetation abundance (Small, 2001).

Such a product allows one to identify the green areas and quantify the proportions of vegetation versus urban land in an immediate and easily interpretable way.

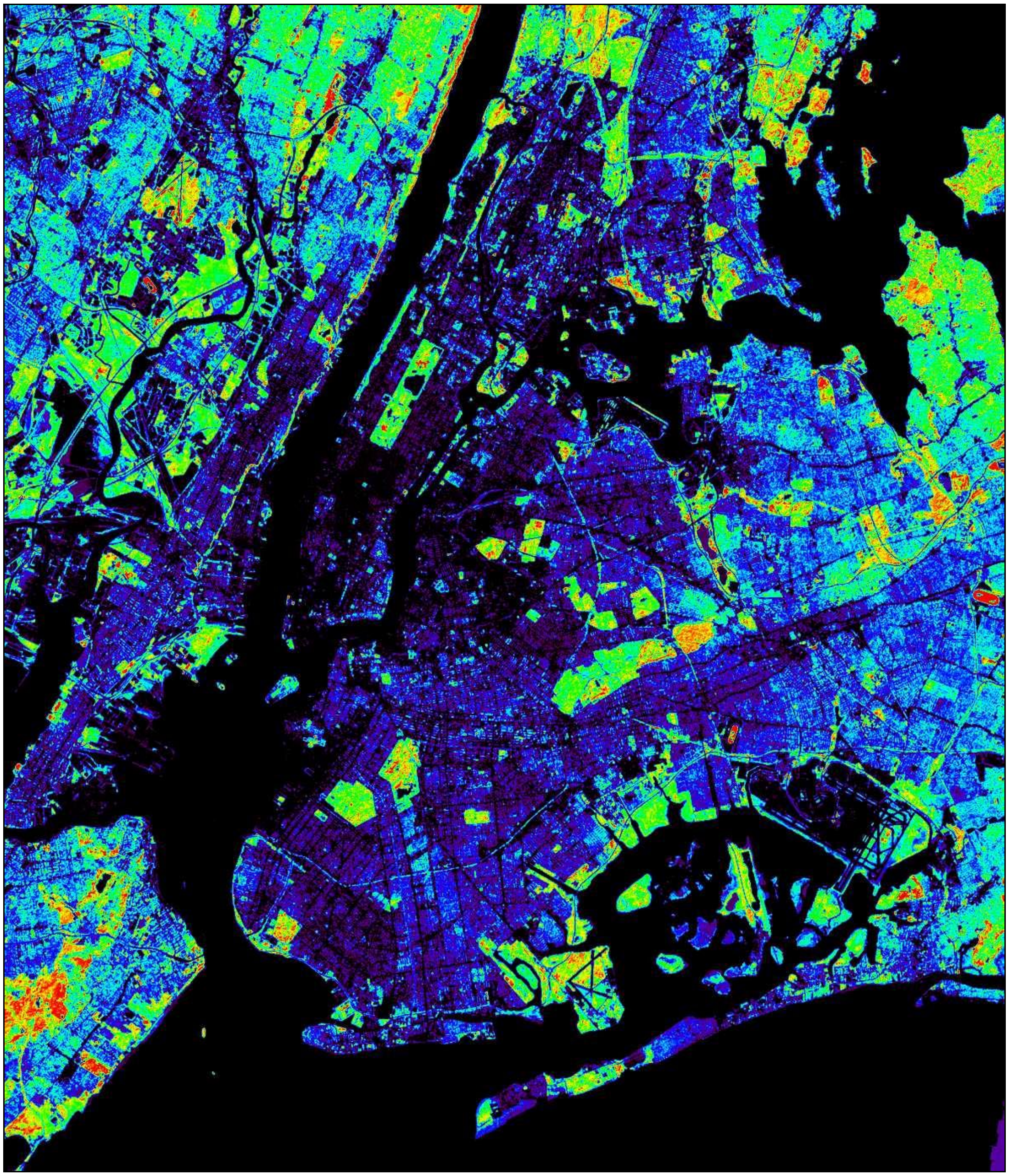

Figure 4. New York Urban Vegetation, estimated from Landsat 7 imagery, 9/23/99. Vegetation fraction showed above range from sparse (blue <10%) to dense (red > 90%). Black areas contain negligible vegetation or are in shadow (Small, 2001).

An even simpler model is a ***Greenness map***, obtained by performing a Tasseled Cap Transformation on the original Landsat data.

The Tasseled Cap Transformation on Landsat TM data performs an orthogonal transformation of the original data into a new three-dimensional space, consisting of a "Brightness" index, a "Greenness" index, and a third component related to soil features. In the case of Landsat MSS data, the Tasseled Cap Transformation generates four indices: a Soil Brightness Index, a Green Vegetation Index, a Yellow Stuff Index, and a Non-such Index, related to atmospheric effects (ENVI, 2000).

In order to visualize the differences between vegetation and non-vegetated areas, such as urban and water, only the Greenness Index has been displayed using a logarithmic green and white scale, where the deeper green corresponds to more vegetation. Figure 5 and Figure 6 show the Greenness Index for a portion of southern New York, obtained using Landsat MSS data from 1987 and 1991, respectively.

Performing the transformation on data obtained in two different periods permits showing changes in the proportion of urban and forested areas. Some of the most visible differences are indicated by the red arrows in the 1991 image. Note that the spatial resolution for these images (Landsat MSS) is 80 x 80 meters; therefore, many minor changes cannot be detected.

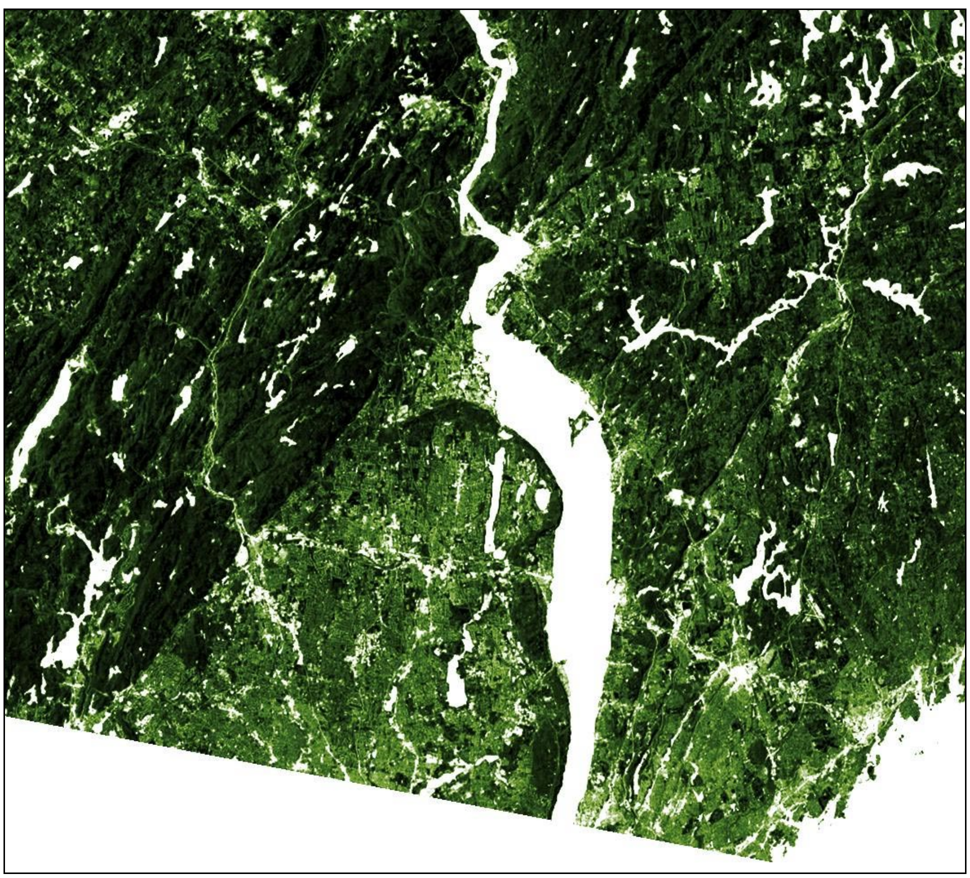

Figure 5. Greenness map obtained from Landsat MSS imagery, 06/10/87.

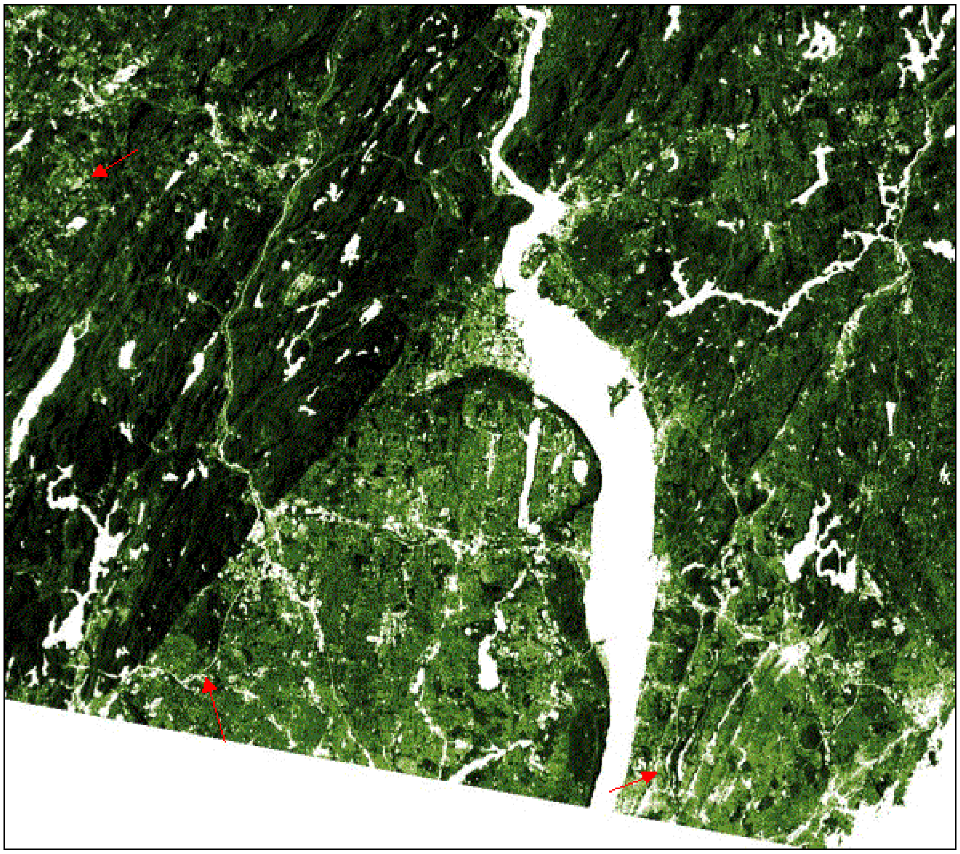

Figure 6. Greenness map obtained from Landsat MSS imagery, 06/21/91.

The most striking change is the road in the lower left corner, not visible in the 1987 scene, but clearly identifiable in the 1991 scene. That road is the last section of Interstate I-287 to have been built, between I-80 and I-87. The whole Interstate was completed in 1993. The area in the top left corner (Sugar Loaf, NY) shows a slight reduction in the amount of vegetation, which cannot be uniquely attributed to anything without further study. Another area showing change is the one in the bottom right corner (in Westchester County), where a minor urban enlargement is clearly recognizable.

It must be said that the previous two greenness maps show vegetation and urban areas mainly in a qualitative way. Looking at the greenness histograms reported in Figure 7 can give an idea of the distribution of pixels according to the greenness values, although properly quantifying such changes requires a quantitative method, like the Vegetation Fraction model above described.

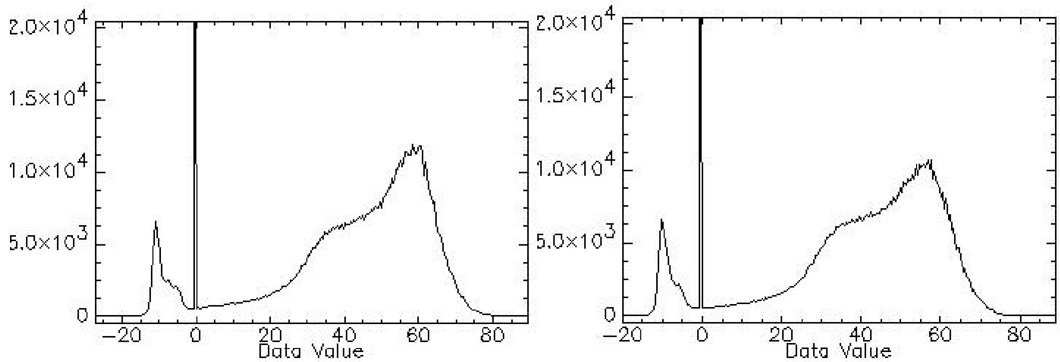

Figure 7. Greenness histograms for the 1987 and 1991 scenes, respectively.

The peak in the negative values corresponds to water, while the peak in the positive values (around 60) corresponds to vegetation. The broad range of numbers in between corresponds to a variety of combinations of vegetation and urban land cover. The shape of the curve is not dramatically different for the two scenes; only the vegetation peak appears to be lower (fewer pixels for 'pure' vegetation) in 1991, and there seems to be a larger 'mixed' area for values between 30 and 50. However, as already mentioned, this should not be interpreted as a quantitative representation of vegetation change.

Comments

Greenness maps and the consequent vegetation/urban change detection studies are straightforward to understand and interpret. For this reason, these products did not generate the same level of comment and feedback as the land use/land cover maps, although they might find applications in a variety of fields, such as the study of urban sprawl.

The resolution of the Landsat data limits their use to tracking vegetation changes at a broader scale (regional, rather than county level) and therefore did not elicit too much interest among the local government representatives. Participants from county governments seemed more interested in changes between different land cover classes than just vegetation vs. urban land cover.

Nevertheless, the potential importance of such tools and products in monitoring vegetation health should be noted, given the availability of repeat coverage and of data collected at different wavelengths. This type of information could be integrated with higher resolution data, such as from IKONOS (increased spatial resolution: 4 m in the multispectral, 1 m in the panchromatic band) or AVIRIS (images collected in 224 contiguous bands, with ground resolution of 20 meters (high altitude)or 4 meters (low altitude)) in order to be more useful for local and county level applications (see the Satellites/Sensors section in Annex 3).

3 Other Applications and Integration with Relevant Data Sets

During the workshop, only the above prototype data products were presented. However, a number of other possible applications that might benefit from the use of remotely sensed data were discussed.

Specifically, we reviewed the feasibility of using remote sensing for a variety of applications (like air and water quality issues, floodplains mapping, etc.) and the possibility of integrating satellite data with other relevant data sets, in particular socioeconomic and population data.

3.1 Applications

Workshop attendees were interested in re-examining projects in which they have been involved to see whether the use of remote sensing data could have helped to improve data acquisition and facilitate the process of building a powerful information system for their organizations.

As mentioned in the Introduction, the purpose of getting more and better data is to allow a better understanding of environmental and human conditions that will, in turn, lead to better management of natural resources and improve not only quality of life for local communities, but also ease the entire decision-making process at the government level. By looking at specific applications and interests, the needs and use of remotely sensed data can be more easily outlined.

Presented here are some of the key areas discussed, in addition to the obvious benefit that state and local governments may gain from having regular updates on urbanized areas, infrastructure, and new developments. Urban and suburban applications will be further discussed in the "Integration with Relevant Data" discussion.

Landscape Assessment

One of the key applications that can greatly benefit from satellite data, including medium resolution sensors such as Landsat ETM+, is regional landscape assessment and landscape change. Such studies can be pursued using the tailored land cover map or the vegetation maps presented during the workshop (see Section 2).

The basic concept is that vegetation features can be distinguished from other features because of their different spectral responses in the visible and infrared regions. In the near infrared bands, vegetation has a peak of reflectance that water and urban do not have because of reduced absorption by chlorophyll and other pigments. Also, as previously described, the scale at which landscape assessment is done is usually regional. This allows the use of Landsat data even for the 1970s and 1980s, when the TM sensor was not yet available. The coarser resolution of MSS data can still be useful for regional-scale applications.

The priority for landscape studies will then be to determine which land cover classes are most important to identify based on specific needs. These needs vary from watershed management to forest cover or agricultural mapping to linking forest extent and closeness to residential areas for disease mapping and monitoring (e.g., Lyme disease).

Air Quality

Air quality applications basically deal with use of remote sensing to determine the effects of air pollution on vegetation and would be particularly useful in urban and suburban areas.

The change in spectral signature of a damaged plant gives an indication of the nature and the level of air pollution damage. Such changes can be detected by looking at the corresponding change in foliage colors and differences in structure and texture of the canopy. For small areas or within cities, this will require high-resolution sensors such as IKONOS. Assessing the effects of air pollution and separating them from those of drought or diseases are not easy tasks. Diseases can equally affect trees and make them change color and give a different spectral signature, which can be misinterpreted as an effect caused by pollution. Remote sensing data in this case must be integrated with field observations and measures of air pollution. The increasing number of studies of trees affected by specific diseases will allow mapping of their spectral signature and comparison with trees suspected of being affected by air pollution.

Water quality

Pure water reflects some of the incident radiation in the visible bands of the electromagnetic spectrum and absorbs almost all of it in the near- and middle-infrared bands. Therefore, in the infrared, water appears dark and is easily distinguishable from other land features. The spectral response of water may vary with the presence of suspended sediments, which increase the amount of radiation reflected. Some of these sediments, such as suspended solids from soil erosion, can significantly impact the spectral reflectance and be identified easily in the visible bands. Phytoplankton cannot be easily distinguished from inorganic materials by common satellites (Landsat). Even other more specific sensors (e.g., SeaWiFS, MODIS) require complex and sophisticated calibrations.

Nevertheless, for the kind of applications discussed at the workshop, such as water quality modeling and watershed management, traditional remotely sensed data (e.g., slope, soil, and land cover characteristics) can be used as input to hydrological models. Such models can then be used to estimate non-point source water pollution (e.g., derived from urban runoff, construction, agriculture, irrigation, and soil erosion). Non-point source water pollution is very common but also difficult to detect given the limitation of traditional *in situ* measurements techniques in identifying and modeling such diffuse sources of pollution. The integration of *in situ* measurements with remotely sensed data in GIS modeling can provide useful information on water quality applicable to many planning and management issues.

Floodplain Mapping and Emergency Management

Monitoring sensitive areas such as wetlands, parks, or land in urbanized watershed for emergency management usually requires high spatial resolution data in a timely fashion.

Relatively stable areas can be monitored every one or two years, whereas more critical areas need to be monitored more often (at least seasonally (Lillesand, 2000)). In the case of disasters such as floods, storms, tornadoes, earthquakes, or fires, it would be ideal to have images both pre- and post-disaster. Even though the pre-disaster data would need to be updated less frequently (every one to five years), it is important that they are at a comparable high resolution (1-5 m) with the post-disaster data (less than 2 m). In disaster management, satellites with medium ground resolution, such as Landsat or SPOT, are not very useful, even though the temporal resolution is relatively high (16 and 26 days, respectively). Normally, panchromatic and near-infrared aerial photography or IKONOS panchromatic data acquired immediately after a disaster are the best ways to map the extent of the disaster and to estimate its effects. If clouds are present, imaging radar can provide the most useful information.

Health Applications

The contribution of environmental factors to human health and diseases has been recognized and discussed since the time of Hippocrates. Well before the formulation of scientific explanations for illnesses, there have been references to areas with “bad air” and “bad water.” Responsibility for controlling such environmental hazards in order to safeguard public health has increasingly fallen on the shoulders of local and regional governments. In turn, officials attempt to educate and solicit input and assistance from local residents.

Key environmental health issues include human exposure to contaminated air, water, and soil and the spread of infectious diseases. Some of these health concerns are related directly to human activities, such as toxic spills and emissions, pesticide runoff, and radiation releases. Others can be naturally occurring, though are often indirectly affected by human-induced changes, such as arsenic in groundwater or vector-borne diseases. In the case of West Nile Virus and Lyme Disease, human infections depend upon the proximity of arthropod vectors, animal hosts, and human populations.

Land cover, land use, and environmental conditions are useful predictors of potential risk. In order to monitor and control the spread of West Nile Virus, local governments have attempted to map the locations of dead birds and mosquito breeding sites (areas of standing water). To track high-risk areas for Lyme Disease, they focus on the suburban extensions of new developments into heavily vegetated areas. Identifying areas of high risk using traditional field surveys can be costly and time-consuming. Local governments could utilize remotely sensed imagery to more effectively select areas for surveillance and intervention.

Unfortunately, the resolution of satellites such as Landsat is not sufficient to identify many of the parameters needed to monitor vector-borne diseases. However, it would be possible to use the medium-resolution satellite data as a baseline for major features (vegetated areas and large wetlands). Those images could then be integrated with either high-resolution satellite (IKONOS) or aerial photography data and supplemented with data collected on the ground. Together, remote sensing and GIS could provide local and regional governments with useful tools and information to help address these types of environmental health issues. Although not discussed during the workshop, a similar approach might be used to determine routes of exposure from hazardous waste sites and spills. In addition, integrated remote sensing/GIS could be used to evaluate alternative sites for hazardous facilities such as incinerators, in order to minimize the impact on local populations and ecosystems.

3.2 Integration with Relevant Data Sets

Products derived from satellite imagery can be easily integrated into a GIS with other data layers relevant to specific applications.

One of the most useful applications that emerged during the workshop was the integration of land cover and land use change maps with population data derived from the U.S. Census. The main interest is to determine the land cover and land use classes in which population changes are occurring, in terms of both total population density and population composition (by age, sex, and race). Another interesting application is to determine whether and to what extent population changes are occurring in the same areas where land use changes are occurring or have occurred. With the release of data from the 2000 Census, such analyses will be possible for 1990 and 2000.

The main issue in this case would be to find the proper scale to combine satellite-derived data (particularly if Landsat data are used) and population data, collected at the tract or block level.

The integration of remotely sensed data with population data relates also to the broader topic of urban and suburban remote sensing and the resolution needed for many urban applications. The spatial resolution at which urban and suburban features and changes can be detected is usually more important than the spectral resolution. Therefore, if data are needed more frequently than every five or ten years (usually the case), IKONOS is probably the best source, although such data are currently quite expensive. Again, calibration of coarser resolution data (panchromatic Landsat, for instance) with higher resolution (panchromatic IKONOS) data could solve some of the resolution-related issues, reducing costs and potentially providing more frequent coverage.

Annex 1. Workshop Agenda

February 23rd, 2001

Lamont Hall, at Columbia University's Lamont-Doherty Earth Observatory

9:15 **Coffee and Refreshments**

9:30 – 9:45 **Introduction, *Robert Chen***, Deputy Director, CIESIN, and Manager, SEDAC

9:45 – 10:00 **Workshop Goals**, ***Francesca Pozzi***, Research Associate, CIESIN

10:00 – 10:30 **Remote Sensing Overview**, ***Christopher Small***, Lamont-Doherty Earth Observatory, co-Project Scientist, SEDAC

10:30 – 12:30 **Demonstration and discussion of prototype derived products**:

1. (10:30-11:30) ***Land cover classification***: how can this be tailored to users' needs, which classes are useful to identify, potential applications
2. (11:30-12:30) ***Vegetation Fraction Index*** and ***Vegetation Change Detection***: uses and applications

12:30 – 1:15 **Lunch** (catered)

1:15 – 2:00 Discussions **on users' needs**:

- Other possible applications (emergency management, flood mapping etc)
- Scale
- Timing: what is required to make imagery and associated data valuable to users?
- Other relevant datasets and their integration with remotely sensed data
- Issues of privacy and sensitive information

2:00 – 2:30 **Discussion: Mechanisms for data sharing**.

2:30 – 2:45 **Break and change location** (to Geoscience)

2:45 – 4:30 **Hands On**: Visit to Remote Sensing and Visual Lab and discussion of the images and the prototype derived products in more details.

- Discussion of other satellite products (IKONOS).
- Break up into smaller working groups

Annex 2. List of Participants

Name	Organization	Address	City/State	Email
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Annex 3. Background Information

Landsat 7

Landsat 7 was launched on April 15, 1999 from the Western Test Range at Vandenburg Air Force Base on a Delta-II launch vehicle. It consists of a spacecraft bus, built by Lockheed Martin Missiles and Space in Valley Forge, Pennsylvania and the Enhanced Thematic Mapper Plus (ETM+) instrument, developed by Raytheon Santa Barbara Remote Sensing in Santa Barbara, California. The satellite orbits the Earth at an altitude of approximately 438 miles (705 kilometers) with a sun-synchronous 98-degree inclination and a descending equatorial crossing time of 10 a.m. It crosses over any given area every 16 days.

The ETM+ instrument is an eight-band multispectral scanning radiometer capable of providing high-resolution image information of the Earth's surface. It detects spectrally-filtered radiation at visible, near-infrared, short-wave, and thermal infrared frequency bands from the sun-lit Earth.

Nominal ground sample distances or "pixel" sizes are 49 feet (15 meters) in the panchromatic band; 98 feet (30 meters) in the 6 visible, near-, and short-wave infrared bands; and 197 feet (60 meters) in the thermal infrared band.

The ETM+ will produce approximately 3.8 gigabits of data for each scene. The spectral and spatial resolutions for the ETM+ are reported in Table 1.

Band Number	**Spectral range (microns)**	**Ground Resolution (meters)**
1	.45 to .515 (blue)	30
2	.525 to .605 (green)	30
3	.63 to .690 (red)	30
4	.75 to .90 (near-infrared)	30
5	1.55 to 1.75 (mid-infrared)	30
6 (Thermal)	10.40 to 12.5 (thermal infrared)	60
7	2.09 to 2.35 (mid-infrared)	30
8 (Panchromatic)	.52 to .90 (red and near-infrared)	15

Table 1. Landsat 7 ETM+ Spectral and spatial resolutions.

Satellites/Sensors

The following table lists the most known and used satellites and their sensors, with specifications about spectral, spatial, and temporal resolutions, what they can detect, and applications they can be used for.

Satellite	Sensor	Spectral Resolution (Wavelength in µm)	Spatial Resolution	Temporal Resolution	What Can Be Detected?	
					Spatial	**Temporal**
LANDSAT 4, 5 URL: *http://geo.arc.nasa.gov/sge/landsat/landsat.html*	**MMS** (Multispectral scanner system)	**1**: 0.5-0.6 (G) **2**: 0.6-0.7 (R) **3**: 0.7-0.8 (VNIR) **4**: 0.8-1.1 (NIR)	80 m; 185 Km swath width	16 days	Mapping coastal features in sediment-laden water Mapping roads and urban areas Vegetation studies and mapping land/water boundaries	Deforestation Urban and suburban development
	TM Thematic Mapper	**1**: 0.45-0.515 (B) **2**: 0.52-0.60 (G) **3**: 0.63-0.69 (R) **4**: 0.75-0.90 (NIR) **5**: 1.55-1.75 (Mid-IR) **6** (thermal): 10.40-12.5 **7**: 2.09-2.35 (Mid-IR)	30 m (visible, near and mid-IR); 120 m (thermal IR); 185 Km swath width	16 days	Soil/vegetation differentiation & coastal water mapping Vegetation mapping Plant species differentiation Biomass survey Snow/cloud differentiation Thermal mapping Geological mapping	Changes in heat islands Vegetation/land use patterns
LANDSAT 7 (1, 2, 3, 6 are inactive) URL: *http://landsat7.usgs.gov/*	**ETM +** (Enhanced Thematic Mapper)	**1**: 0.45-0.515 (B) **2**: 0.52-0.60 (G) **3**: 0.63-0.69 (R) **4**: 0.75-0.90 (NIR) **5**: 1.55-1.75 (Mid-IR) **6** (thermal): 10.40-12.5 **7**: 2.09-2.35 (Mid-IR) **8** (pan): 0.52-0.90	30 m (visible, near and mid-IR), 15 m (panchromatic), 60 m (Thermal Infrared); 185 Km swath width	16 days	Major Thoroughfares Large Buildings Forest Stands Agricultural Plots Coastline Advance/Retreat Rugged Topography Sea Ice Coverage	Changes in human infrastructure Development patterns Migration patterns Agricultural variations Urban/Rural interchange

Satellite	Sensor	Spectral Resolution (Wavelength in µm)	Spatial Resolution	Temporal Resolution	What Can Be Detected? Spatial	Temporal
IKONOS 1, 2 Launched in 1999 by the United States (IKONOS 2 failed) URL: *http://www.tbs-satellite.com/tse/online/sat_ikonos_2.html*	**MMS** (Multispectral) and **PAN** (Panchromatic)	**1**: 0.45-0.53 (B) **2**: 0.52-0.61 (G) **3**: 0.64-0.72 (R) **4**: 0.76-0.88 (VNIR) **Pan**: 0.45 – 0.90	4 m (visible), 1 m (panchromatic); 11 Km swath width	26 days (680 km sun-synchronous orbit)	Roads, vehicles, buildings, infrastructure (panchromatic) Land use, agricultural uses, vegetation (color imager)	Changes in human infrastructure Development patterns Migration patterns Agricultural variations Urban/Rural interchange
SPOT 1, 2, and 4 (3 is inactive) Launched by France from 1986-1998 Engineering work has begun on SPOT 5 with a proposed launch date in late 2001 URL: *www.spot.com/*	Two **HRVIR** (High Resolution Visible, Infrared) push-broom sensors. Provides coverage between 87 degrees north and 87 degrees south	**1**: 0.50-0.59 (G) **2**: 0.61-0.68 (R) **3**: 0.79-0.89 (NIR) **4**: 1.58-1.73 (SWIR) – added on SPOT 4 **Pan**: 0.51-0.73	20 m (Visible, Near Infrared), 10 m (panchromatic); 60 Km swath width	26 days	Agriculture (Resource mapping, production management, crop classification) Land Use (Urban and suburban land use, land mapping, energy, human infrastructure) Oceanography (water quality management) Water resources (Surface water, soil moisture and evapotranspiration, lakes and rivers studies, wetlands and habitat mapping, resource assessment) Geological applications (mapping, economic geology, engineering geology, hazards and land morphology. oil and gas exploration) Engineering applications (terrain analysis, site investigation, water resources engineering, transport studies. Forest monitoring (inventory, forest management) and vegetation cover study (especially the VEGETATION sensor)	Deforestation Suburban/Urban land use changes Residential Development Coastal Pollution Water resource pollution monitoring Snow and Ice mapping Harvest forecasting Conservation monitoring Hazard prediction Landslide hazards Forest damage assessment
	VEGETATION instrument (on SPOT 4).	**1**: 0.43-0.47 (B) **2**: 0.61-0.68 (R) **3**: 0.78-0.89 (NIR) **4**: 1.58-1.75 (SWIR)	1 Km; 2200 Km swath width	Daily		

Satellite	Sensor	Spectral Resolution (Wavelength in µm)	Spatial Resolution	Temporal Resolution	What Can Be Detected?	
					Spatial	Temporal
NOAA - 7 Launched in 1981 and deactivated 1986 due to an power failure URL: *http://podaac.jpl.nasa.gov/sst/*	**AVHRR** (Advanced Very High Resolution Radiometer)	**1**: 0.58-0.68 (G and R) **2**: 0.72-1.10 (NIR) **3**: 3.53-3.93 (Mid-IR) **4**: 10.3-11.3 (Thermal IR) **5**: 11.5-12.5 (Thermal IR)	4.4 Km (Global Area Coverage), 1.1 Km (Local Area Coverage); 2800 Km swath width	2 times per day; 8-day and monthly averaged data available	Day and night cloud top and sea surface temperatures Ice and snow conditions	Changes in climate and global land and sea temperatures Changes in snow and ice coverages
AVIRIS Airborne Visible Infrared Spectrometer (instrument on board of planes) URL: *http://makalu.jpl.nasa.gov/aviris.html*	**Hyperspectral airborne** sensor Uses a scanning mirror in a "wisk broom" manner	Contains 224 different detectors each with a wavelength sensitive range of 10 nm, allowing it to cover the entire range between 0.4 and 25 µm.	20 m (high altitude), 4 m (low altitude); 11 Km swath width	Only scheduled flights	Ecology (chlorophyll, leaf water, lignin, cellulose, pigments, structure, non-photosynthetic constituents) Geology (mineralogy, soil type) Cloud and Atmospheric studies (water vapor, clouds properties, aerosols, absorbing gases) Oceanography/Coastal and Inland Waters (chlorophyll, dissolved organics, sediments, bottom composition, bathymetry) Snow and Ice Hydrology (grainsize, impurities) Biomass burning (smoke, combustion products) Environmental Hazards Commercial	Snow and Ice Hydrology (melting, snow cover fraction) Commercial (agricultural correction) Ecology (changes in vegetation and community maps) Oceanography (changes in plankton coverage and chlorophyll) Forest Fires
ERS2 (Active)	**AMI** (Active Microwave Instrumenta-tion) with SAR-Image Mode, SAR-Wave Mode, Scatter-ometer Mode and Radar Altimeter	5.3 GHz (C-Band) 13.5 GHz for the Radar Altimeter	30 m (SAR) 50 Km (Scatter-ometer); 80-100 Km swath width (SAR-Image mode); 5 Km swath width (SAR-Wave mode), 500 Km swath width (Scatterometer mode)	3 day, 35 day or 168 day cycles	All-weather instrument Ocean wave height/lengths, wind speed/direction, ice parameters, sea surface & cloud top temperatures, cloud cover and atmospheric water vapor.	Alterations and observations in ocean, land, ice, atmosphere, and climate Flood activity Changes in ocean activity, coastal regions and ice caps

Satellite	Sensor	Spectral Resolution (Wavelength in µm)	Spatial Resolution	Temporal Resolution	What Can Be Detected? Spatial	What Can Be Detected? Temporal
ERS2 (Cont'd)	**ATSR-M** (Along Track Scanning Radiometer with Microwave Sounder)	1.6, 3.7, 11, 12 (IR), 23.5 and 36.5 GHZ (Microwave)	1 Km (IR), 22 Km (Microwave); 500 Km swath width	3 day, 35 day or 168 day cycles	All-weather instrument Ocean wave height/lengths, wind speed/direction, ice parameters, sea surface & cloud top temperatures, cloud cover and atmospheric water vapor.	Alterations and observations in ocean, land, ice, atmosphere, and climate Flood activity Changes in ocean activity, coastal regions and ice caps
	GOME (Global Ozone Monitoring Experiment). Sensor is a double spectrometer	**1**: 0.24-0.295 **2**: 0.29-0.405 **3**: 0.40-0.605 **4**: 0.59-0.79	40 x 2Km 40 x 320 Km; 960 Km swath width			
	AATSR (Advanced Along Track Scanning Radiometer)	0.65, 0.85, 1.27, 1.6	0.5 Km; 500 KM swath width			
SEASTAR URL: *http://seawifs.gsfc.nasa.gov/SEAWIFS.html*	**SeaWiFS** (Sea-viewing Wide Field Sensor)	**1**: 0.402-0.422 **2**: 0.433-0.453 **3**: 0.480-0.5 **4**: 0.5-0.520 **5**: 0.545-0.565 **6**: 0.66-0.68 **7**: 0.745-0.785 **8**: 0.845-0.885	1.1 Km (local area coverage) 4.5 Km (global area coverage); 285 Km swath width	1 day	Ocean color and chlorophyll Subsurface scattering Atmospheric correction Atmospheric correction Sea-surface temperature	Changes in phytoplankton Designed to provide global coverage of the oceans on a regular basis
TERRA URL: *http://terra.nasa.gov/About/*	**ASTER** (Advanced Spaceborne Thermal Emission and Reflection Radiometer)	14 bands, with wavelengths ranging from 0.52 to 11.65	15 m (VNIR), 30 m (SWIR), 90 m (TIR); 60 Km swath width	4-16 days By request	Major Thoroughfares Large Buildings Forest Stands Agricultural Plots Coastline Advance/Retreat Rugged Topography Sea Ice Coverage	Infrastructure Changes Residential Developments Deforestation/ Reforestation Harvest Flood Area Landslides & Mass Movements

Satellite	Sensor	Spectral Resolution (Wavelength in µm)	Spatial Resolution	Temporal Resolution	What Can Be Detected?	
					Spatial	**Temporal**
TERRA (cont'd)	**MODIS** (Moderate Resolution Imaging Spectro-Radiometer)	36 bands, with wavelengths ranging from 0.405 to 14.38	250 m (bands 1-2), 500 m (bands 3-7), 1000 m (bands 8-36); 2330 x 10 Km swath width	1-2 days	Ideal for large scale changes in the biosphere, measures photosynthetic activity of land and marine plants Surface temperature measurements, Deforestation Forests, Open Canopy Vegetation, Large Scale Agriculture Water Clarity, Atmospheric Aerosols, Smoke Plumes, Snow Cover, Ocean Temperature	Forest Fires Regional Harvest/ Cycles Plankton Blooms Sediment Plumes Maps extent of snow and ice brought by winter storms and frigid conditions
	MISR (Multi-angle Imaging Spectro-Radiometer)	4 bands, with wavelengths ranging from 0.44 to 0.86	275 m; 360 Km swath width	9 days	The amount of sunlight scattered in the atmosphere under natural conditions, Atmospheric aerosol particles (formed by both natural and human activities) Cloud Cover/Type, Vegetation Type	Smoke Plumes Regional Air Quality Climate Regional Forest Canopy Structure
	CERES (Clouds and Earth's Radiant Energy System)	**Shortwave**: 0.3-5 **Longwave**: 8-12 **Total**: 0.3->200	20 km	Daily	Cloud/radiation flux measurements for models of oceanic and atmospheric energetics The cross track mode continues measurements of Earth Radiation Budget Experiment and Tropical Rainfall Measuring Mission	Contributes to wider range weather forecasting
	MOPITT (Measure-ment of Pollution in the Troposphere)	2.3 (CH_4) 2.4 and 4.7 (CO)	22 Km horizontally and 3 Km vertically; 640 Km swath width	3 – 4 days	Measurements of pollution in the troposphere Used to determine the amount of Carbon dioxide and methane in the atmosphere	

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