Forestry Department

Food and Agriculture Organization of the United Nations

MANUAL ON DEFORESTATION, DEGRADATION, AND FRAGMENTATION USING REMOTE SENSING AND GIS

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STRENGTHENING MONITORING, ASSESSMENT AND REPORTING ON SUSTAINABLE FOREST MANAGEMENT IN ASIA (GCP/INT/988/JPN)

MAR-SFM Working Paper 5 / 2007

Strengthening Monitoring, Assessment and Reporting (MAR) on Sustainable Forest Management (SFM) in Asia (GCP/INT/988/JPN)

FAO initiated the project "Strengthening Monitoring, Assessment and Reporting on Sustainable Forest Management in Asia" (GCP/INT/988/JPN) in January 2006. The five-year project is funded by the Government of Japan.

The main objective of this project is to facilitate development of harmonized forest related national monitoring, assessment and reporting (MAR) systems in the Asia-Pacific region to contribute directly to the improvement of sustainable forest management (SFM) regimes. An allied objective of the project is to enhance the use of the MAR information in national decision-making, formulation of effective forest policies, and sustainable forest management and planning.

The project accomplishes its objectives in two phases. The first two years, the Development Phase, the project would focus on: (a) international activities like the establishment of linkages with forest-related processes; (b) facilitating development of a globally harmonized framework, guidelines and database structure, including pilot testing in some countries; (c) use of MAR information in forest planning and development of forest policies at the national level; (d) establishment of a country-level network of national focal points to various forest-related processes; and (e) initiate a set of national activities that facilitate the implementation of the harmonized MAR.

The Implementation Phase spreads over the remaining three years of the project period and focuses on the implementation of the harmonized MAR, including facilitation in the establishment of database at the national level in selected project countries within the Asia-Pacific region through studies, reviews, training, workshops and expert consultations. The detailed design of this phase will be finalized on the basis of a review of the activities and the outputs of the first phase.

All countries in the Asia-Pacific region can participate in the project, although the actual level and intensity of their involvement may vary among them. Forestry departments in respective countries have been requested to nominate their national focal points for this project.

The project is organized under the Forest Resources Development Service (FOMR) in the Forest Resources Division (FOM) of FAO Forestry Department. The contact persons are:

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1. Introduction

Considerable uncertainty remains in our knowledge of deforestation, degradation, and forest fragmentation. Important research and management questions such as what is the rate of forest conversion, what is the age structure of forest re-growth, and what is the area impacted by forest degradation, selective logging, and fragmentation, are unknown in many parts of the world. Answers to these questions are critical to understand biogeochemical cycles (e.g. Carbon and Nitrogen Cycles, Nutrients), hydrological cycles (Energy/Water Balance and Climate, Sediment Transport, Erosion and Runoff), and ecological cycles (Ecosystem Health, Biodiversity (fragmentation)).

Olympic Forest (Credit: Flickr.com)

2. Basic Concepts of Deforestation, Degradation, and Fragmentation

2.1 Deforestation

Deforestation is the conversion of forested areas to non-forest land use such as arable land, urban use, logged area or wasteland. According to FAO, *deforestation is the conversion of forest to another land use or the long-term reduction of tree canopy cover below the 10% threshold*. Deforestation can result from deliberate removal of forest cover for agriculture or urban development, or it can be an unintentional consequence of uncontrolled grazing (which can prevent the natural regeneration of young trees). The combined effect of grazing and fires can be a major cause of deforestation in dry areas. Deforestation implies the long-term (>10 years) or permanent loss of forest cover.

Deforestation defined broadly can include not only conversion to non-forest, but also degradation that reduces forest quality - the density and structure of the trees, the ecological services supplied, the biomass of plants and animals, the species diversity and the genetic diversity. Narrow definition of deforestation is: the removal of forest cover to an extent that allows for alternative land use. The United Nations Research Institute for Social Development (UNRISD) uses a broad definition of deforestation, while the Food and Agriculture Organization of the UN (FAO) uses a much narrower definition.

Definitions can also be grouped into those which refer to changes in land cover and those which refer to changes in land use. *Land cover* measurements often use a percent of cover to determine deforestation. *Land use* definitions measure deforestation by a change in land use. This definition may consider areas to be forest that are not commonly considered as such. An area can be lacking trees but still considered a forest. It may be a land designated for afforestation or an area designated administratively as forest. Land cover based definitions can be measured using remotely sensed data. Detailed ground survey is needed to monitor land use type deforestation processes.

Meghalaya used to be one huge swath of green before deforestation began (Credit: Google Earth)

2.2 Forest Degradation

Forest degradation is a process leading to a ‘temporary or permanent deterioration in the density or structure of vegetation cover or its species composition’. It is a change in forest attributes that leads to a lower productive capacity caused by an increase in disturbances. The time-scale of processes of forest degradation is in the order of a few years to a few decades. For the purpose of having a harmonized set of forest and forest change definitions, that also is measurable with conventional techniques, forest degradation is assumed to be indicated by the reduction of canopy cover and/or stocking of the forest through logging, fire, windfelling or other events, provided that the canopy cover stays above 10%. In a more general sense, forest degradation is the long-term reduction of the overall potential supply of benefits from the forest, which includes wood, biodiversity and any other product or service.

Any in-depth understanding of the processes of forest degradation has to be based on an accurate monitoring of the degradation over large areas, for at least a decade. The detection of inter-annual changes in landscape spatial structure is more likely to reveal long term and long lasting land cover changes, while spectral indicators are more sensitive to fluctuations in primary productivity associated with climatic fluctuations. Different monitoring systems may be optimal for different ecosystems. A long time series of observations is always required with seasonal, annual and decadal changes. The monitoring of the spatio-temporal distribution of biomass burning may also give indications of open forest degradation.

2.3 Forest Fragmentation

Simply defined, forest fragmentation refers to any process those results in the conversion of formerly continuous forest into patches of forest separated by non-forested lands. The definitions of fragmentation are as diverse as the subject itself. For instance, a definition which uses habitat as the qualifier is "The splitting or isolating of patches of similar habitat, typically forest cover, but including other types of habitat...Habitat can be fragmented naturally or from forest management activities, such as clear-cut or logging". In another example, the definition is empirically linked to population growth, "Fragmentation is a complex phenomenon resulting from dynamic interactions between the natural landscape and society's ever-increasing demands on the land, creating a mosaic of natural and human-modified environments." However, the single tie that links these two definitions together is the idea of fragmentation referring to the process of a contiguous land base being divided into smaller pieces. In one definition the author sums this idea, "Fragmentation has been defined as the conversion of large areas of contiguous native forest to other types of vegetation and /or land use leaving remnant patches of forest that vary in size and isolation".

To better understand deforestation, degradation and fragmentation, it is important to revisit three additional terms that are often used to highlight positive changes in forest areas. These three terms are afforestation, reforestation and forest improvement

2.4 Afforestation

Afforestation is the conversion from other land uses into forest, <u>or</u> the increase of the canopy cover to above the 10% threshold. Afforestation is the reverse of deforestation and includes areas that are actively converted from other land uses into forest through silvicultural measures. Afforestation also includes natural transitions into forest, for example on abandoned agricultural land or in burnt-over areas that have not been classified as forest during the barren period. As for deforestation, the conversion should be long-term, that is areas where the transition into forest is expected to last less than ten years, for example due to recurring fires, should not be classified as afforestation areas. The concept “long-term” is central in this definition and is defined as ten years. Local climatological conditions, land use contexts or the purpose of the analysis may however justify that a longer time frame is used.

2.5 Reforestation

Reforestation is the re-establishment of forest formations after a temporary condition with less than 10% canopy cover due to human-induced or natural perturbations. The definition of forest clearly states that forests under regeneration are considered as forests even if the canopy cover is temporarily below 10 per cent. Many forest management regimes include clear-cutting followed by regeneration, and several natural processes, notably forest fires and windfalls, may lead to a temporary situation with less than 10 percent canopy cover. In these cases, the area is considered as forest, provided that the re-establishment (i.e. reforestation) to above 10 percent canopy cover takes place within the relatively near future. As for deforestation, the time frame is central. The concept "temporary" is central in this definition and is defined as less than ten years. Local climatological or land use contexts, or the purpose of the analysis, may however justify that a longer time frame is used.

2.6 Forest improvement

Forest improvement is the increase of the canopy cover or stocking within a forest. For the purpose of having a harmonized set of forest and forest change definitions, that also is measurable with conventional techniques, forest improvement is assumed to be indicated by the increase of canopy cover and/or stocking of the forest through growth. In a more general sense (cf. forest degradation) forest improvement is the long-term increase of the overall potential supply of benefits from the forest, which includes wood, biodiversity and any other product or service.

Palm Plantation (Credit: Flickr.com)

3. Agents, causes, and consequences of Deforestation, Degradation, and Fragmentation

3.1 Agents

It is important to distinguish between the agents of deforestation and its causes. The "agents" are those individuals, corporations, government agencies, or development projects that clear the forests as opposed to the forces that motivate them. Much of what has been written about deforestation fails to distinguish between "agents" and "causes". At times, this deficiency mistakenly assigns blame to groups who are only acting in an economically rational manner given the socioeconomic and political framework in which they find themselves.

Who is doing the deforestation? There is considerable debate about who is doing the deforestation and why they are doing it. Small farmers? Commercial farmers? Loggers? Cattle ranchers? The answer is all of them and more. Table 1 lists the important agents of deforestation, degradation and fragmentation.

Overhead view of clear-cutting for slash-and-burn agriculture (Credit: Flickr.com)

Table 1: Important agents leading to deforestation, degradation and fragmentation

Agents	Links to deforestation, degradation and fragmentation
slash-and-burn farmers	- clear forest to grow subsistence and cash crops
commercial farmers	- clear the forest to plant commercial cash crops, sometimes displace slash-and-burn farmers who then move to the forest
cattle ranchers	- clear the forest to plant pasture, sometimes displace slash-and-burn farmers who then move to the forest
Livestock herders	- intensification of herding activities can lead to deforestation
Loggers	- remove commercial timber, logging roads provide access to other land users
commercial tree planters	- clear mostly forest fallow or previously logged forests to establish plantations to supply fibre to the pulp and paper industry
firewood collectors	- intensification of firewood collection can lead to deforestation
mining and petroleum industrialists	- roads and seismic lines provide access to other land users, localized deforestation related to their operations
land settlement planners	- relocation of people into forested areas as well as settlement projects displacing local people who then move to the forest
infrastructure developers	- new access for other land users from road and highway construction through forested areas, flooding by hydroelectric dams

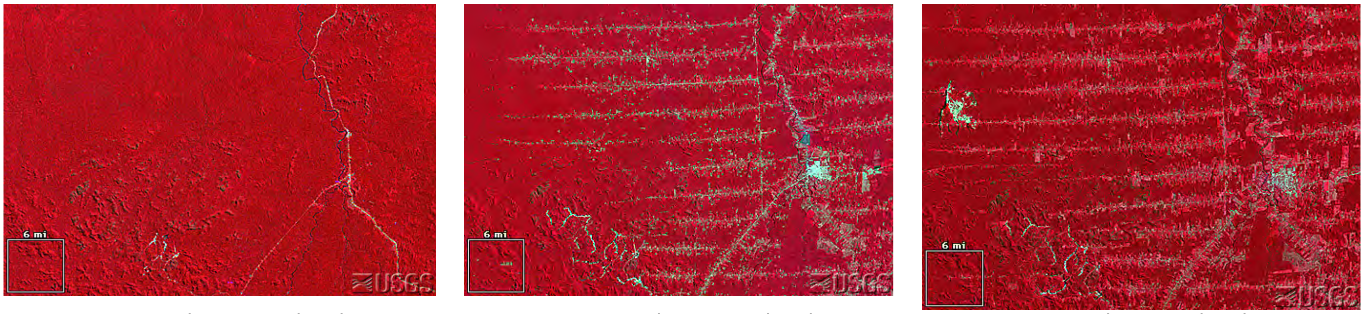
There is considerable variation region to region and country to country (see Table 2) as to which groups are the most important agents of deforestation, degradation and fragmentation.

Table 2: Important agent groups and their regions

Region	Main agents
Africa	1. slash-and-burn farmers 2. commercial farmers 3. loggers 4. livestock herders 5. refugee and civil disturbances
Asia-Oceania	1. commercial farmers 2. slash-and-burn farmers 3. loggers 4. commercial tree planters 5. infrastructure developers
Latin America and Caribbean	1. slash-and-burn farmers 2. cattle ranchers 3. commercial farmers 4. loggers 5. infrastructure developers

3.2 Causes

Deforestation has been attributed to socio-demographic factors, such as population growth and the political economy of class structure, and specific exploitation activities like commercial logging, forest farming, fuel wood gathering, and pasture clearance for cattle production. Deforestation from logging operations, particularly in stands of tropical moist forest, is often claimed to occur in a two-step sequence. First, loggers build roads into primary or old-growth forest and remove selected trees. In many places of the world, it was observed that the logging operation destroys 45-74% of the residual trees. The logging damage, however, is compounded once the loggers have left. Then, forest farmers are likely to follow the logging roads in search of new areas for cultivation. Famous fish-bone deforestation in Rondônia is a classic example (Figure 1). Thus, a substantial portion of worldwide deforestation might be explained by the logger/farmer interaction.



19 June 1975, Landsat 2 MSS bands 4 2 1 | 1 August 1986, Landsat 5 MSS bands 4 2 1 | 22 June 1992, Landsat 4 TM bands 4 3 2

Figure 1: These images show a portion of the state of Rondônia, Brazil, in which tropical deforestation has occurred. Approximately 30% (3,562,800 sq km) of the world's tropical forests are in Brazil. The estimated average deforestation rate from 1978 to 1988 was 15,000 sq km per year. Systematic cutting of the forest vegetation starts along roads and then fans out to create the "feather" or "fishbone" pattern shown in the eastern half of the 1986 image. The deforested land and urban areas appear in light blue; healthy vegetation appears red.
Source NASA

In developing countries, high population growth coupled with rapidly expanding agriculture, and over-exploitation of forest resources is believed to be responsible for accelerated rate of deforestation. Similarly, in many parts of the world, wood production was found to be a significant contributor of deforestation. Causes of deforestation can be divided into two categories: direct causes and underlying causes.

3.2.1 Direct causes of deforestation

The most important direct causes of deforestation include logging, the conversion of forested lands for agriculture and cattle-raising, urbanization, mining and oil exploitation, acid rain and fire. In other countries, clear-cut logging practices have been the main reason for forest loss. In the early nineties, Canada and Malaysia were famous examples of countries where logging companies ruthlessly cleared mile upon mile of precious primary forests. Here too, the historical perspective should not be overlooked. Countries like Ireland and Scotland used to be almost entirely forested, but were nearly completely cleared under British rule to provide timber for English shipbuilders.

3.2.2 The underlying causes of deforestation and forest degradation

During the last few decades, the forest crisis has prompted many international, regional and national preservation initiatives, yet many have had little success. There is general agreement that this is due to the fact that these strategies were too focused on the immediate causes of deforestation, and neglected the underlying causes which are multiple and interrelated. In some cases they are related to major international economic phenomena, such as macro-economic strategies which provide a strong incentive for short-term profit-making instead of long-term sustain ability. Also important are deep-rooted social structures, which result in inequalities in land tenure, discrimination against indigenous peoples, subsistence farmers and poor people in general. In other cases they include political factors such as the lack of participatory democracy, the influence of the military and the exploitation of rural areas by urban elites. Over consumption by consumers in high-income countries constitutes another of the major underlying causes of deforestation, while in some regions uncontrolled industrialization is at the heart of forest degradation with widespread pollution resulting in acid rain. Figure 2 diagrammatically presents the causes of declining forest area.

Conversion to agriculture by burning (Credit: Flickr.com)

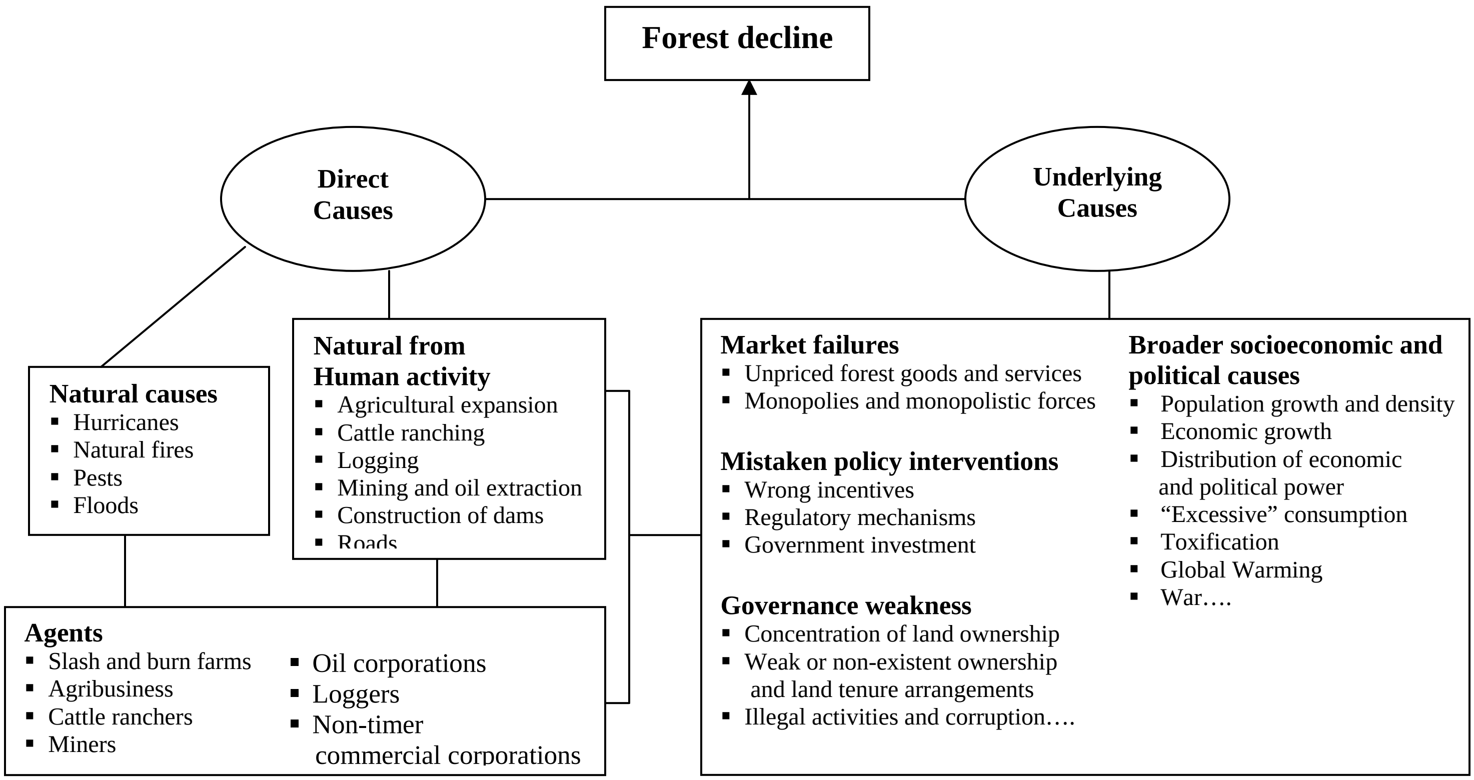


Figure 2: These diagram shows the direct and underlying causes of forest decline Adapted from: After Contreras-Hermosilla (2000), Underlying causes, CIFOR, p. 5

The causes of deforestation are many and varied. Here are few interesting findings.

- Deforestation results from complex socio-economic processes and in many situations it is impossible to isolate a single cause.
- There is no clear definition of „deforestation“, neither are there reliable estimates of its extent nor its primary causes, and – partly – as ref lection of these – there is no consensus on the underlying causes.
- Reports of tropical deforestation indicate that it occurs in diverse circumstances which obscure underlying patterns of deforestation.
- Deforestation has multiple causes with the particular mix of causes varying from place to place.
- A rich crop of explanations for deforestations have appeared, none of which, however, are definitive.
- The factors influencing deforestation are different in different continents. It may be difficult to generalize that one or several factors are the most important.
- Findings generally support the view that processes of deforestation vary by place.

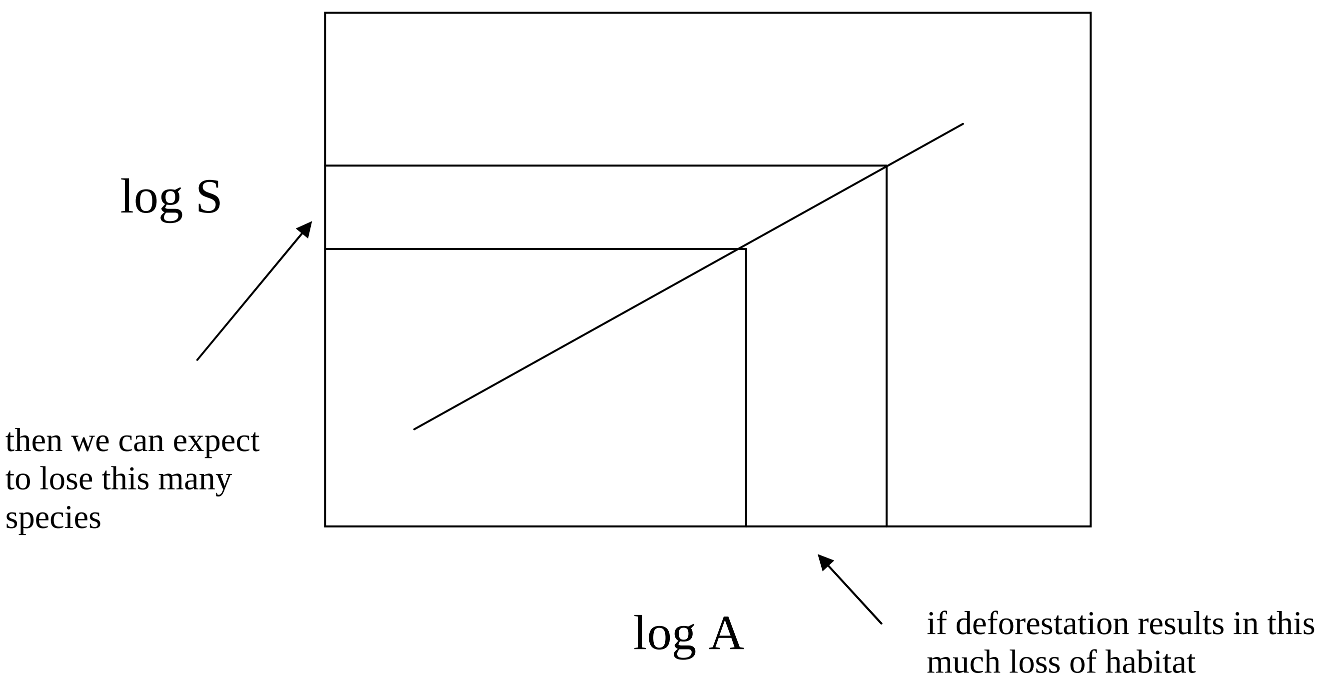
3.3 Consequences

The social consequences of deforestation are many, often with devastating long-term impacts. For indigenous communities, the arrival of "civilization" usually means the destruction of their traditional life-style and the breakdown of their social institutions. Individual and collective rights to the forest resource have been frequently ignored and indigenous peoples and local communities have typically been excluded from the decisions that directly impact upon their lives. Many of the indigenous peoples of the Brazilian states of Amazonas and Rondônia have been encroached upon by slash-and-burn farmers, ranchers, and gold miners, often resulting in violent confrontations. The intrusion of outsiders destroys traditional life styles, customs, and religious beliefs.

Watersheds that once supplied communities with their drinking water and farms with irrigation water have become subject to extreme fluctuations in water flow. The loss of safe, potable water puts communities' health at risk for a variety of communicable diseases.

In economic terms, the tropical forests destroyed each year represent a loss in forest capital valued at US$ 45billion. By destroying the forests, all potential future revenues and future employment that could be derived from their sustainable management for timber and non-timber products disappear.

Probably the most serious and most short-sighted consequence of deforestation is the loss of biodiversity. The antiseptic phrase "loss of biodiversity" masks the fact that the annual destruction of millions of hectares of tropical forests means the extinction of thousands of species and varieties of plants and animals, many of which have never been catalogued scientifically. How many species are lost each year? The exact figure is not known, a consequence of our limited knowledge of tropical forest ecosystems and our inadequate monitoring systems. Some estimates put the annual loss at 50,000 separate species but this is an educated guess at best. Fragmented stands of trees left during deforestation are usually not large enough to be self-perpetuating in terms of maintaining even an altered balance of biodiversity. Deforestation is eroding this precious resource of biodiversity.



Although there is some debate about the rate at which the atmosphere is warming, there is general agreement that it is warming. The currently accepted models predict a 0.3 degree Celsius increase per decade in global temperatures over the next century. This is due to the increase in the amount of carbon dioxide present in the atmosphere, which has risen by about

25 per cent in the last 150 years. Although it is less than 1/20 of one per cent of the earth's atmosphere, carbon dioxide has a high capacity to absorb radiant heat.

The negative consequences of global warming are catastrophic -- increasing drought and desertification, crop failures, melting of the polar ice caps, coastal flooding, and displacement of major vegetation regimes. The amount of carbon currently in the atmosphere is estimated to be about 800,000 million tons and is increasing at the rate of about 1 percent annually. Deforestation is an important contributor to global warming, however, its contribution relative to the other factors is not precisely known. The principal cause of global warming is the excessive discharges in industrialized countries of greenhouse gases, mostly from the burning of fossil fuels. Annual discharges from burning fossil fuels are estimated to be about 6,000 million tons of carbon, mostly in the form of carbon dioxide. It is thought that an additional 2,000 million tons or about 25 percent of the total carbon dioxide emissions are a consequence of deforestation and forest fire. At the regional level, deforestation disrupts normal weather patterns, creating hotter and drier weather. Unfortunately, efforts to find solutions to the deforestation crisis have not been as success in capturing investment money as have improvements to automotive exhaust emissions.

The long term impact of deforestation on the soil resource can be severe. Clearing the vegetative cover for slash and burn farming exposes the soil to the intensity of the tropical sun and torrential rains. This can negatively affect the soil by increasing its compaction, reducing its organic material, leeching out its few nutrients available, increasing its aluminum toxicity of soils, making it marginal for farming. Subsequent cropping, frequent tillage, and overgrazing by livestock accelerate the degradation of the soil.

In the dry forest zones, land degradation has become an increasingly serious problem, resulting in extreme cases in desertification. It affects about 3,000 to 3,500 million hectares, about one-quarter of the world's land area, and threatens the livelihoods of 900 million people in 100 countries of the developing world. Desertification is the consequence of extremes in climatic variation and unsustainable land use practices including over cutting of the forest cover. Growing populations are making ever-increasing demands on the land to produce more, leading to an intensification of use beyond the carrying capacity of the land.

By 2050, two billion people, or 20 per cent of the world's population, will suffer from water shortages. Most of these people will be living in developing countries. Once denuded, the same watersheds lose their capacity to regulate stream flows and experience rapid fluctuations in stream and river levels, often resulting in disastrous downstream flooding. Water shortage is a major health risk in terms of inadequate sewage disposal, poor personal hygiene, and insufficient potable water. Food security is threatened as irrigation water becomes scarcer. Without the protection of the tree cover, soils are exposed to the rigors of severe tropical climates and are rapidly eroded. Freshwater and coastal fisheries are devastated by the high sedimentation loads carried by the rivers, as are wildlife-rich wetlands. Sedimentation from degraded watersheds is also one of the principal causes of the decline of coastal coral reefs. The economic and environmental costs are staggering.

4. Remote Sensing of Deforestation, Degradation, and Fragmentation

Remote Sensing provides a unique opportunity to assess and monitor deforestation, degradation, and fragmentation for a number of reasons. First, with remote sensing we can work at multiple scales ranging from few meters to several kilometers. This included detailed study at local level to global forest resources assessment. Second, remotely sensed data can be acquired repeatedly (e.g. daily, monthly) that helps us monitor forest resources in a regular basis. Third, these measurements can be made in near real time basis which is quite useful for monitoring events such as forest fire. Fourth, remote sensing data has synoptic coverage and information can be acquired in places where accessibility is an issue. Fifth, we could use wavelengths that are not visible to human eye. Thus, remote sensing is the most effective means of assessing and monitoring forest resources. It is important to understand that remote sensing does not replace field survey but provides complimentary information.

4.1 Availability, Accessibility, and Affordability of Remote Sensing Data

Over the past half century, a range of airborne and space-borne sensors has acquired remote sensing data, with the number of sensors and their diversity of capability increasing over time. Today a large number of satellite sensors observe the Earth at wavelengths ranging from visible to microwave, at spatial resolutions ranging from sub-meter to kilometers and temporal frequencies ranging from 30 minutes to weeks or months. In addition, archives of remotely sensed data are increasing and these data provide a unique, but not complete, chronological data of the Earth during the specified time period. New sensors are continually being launched and existing sensors are often replaced to ensure continuity in the data record. Given this enormous resource, remote sensing has proven to be an effective tool to monitor deforestation, degradation and forest fragmentation.

Ideally, the following image characteristics are required for studying deforestation, degradation, and fragmentation.

- Cloud free and clear atmosphere during the time of data acquisition;
- Availability of imagery for the optimum date or dates;
- Spatial resolution fine enough for accurate mapping and course enough so image size is manageable;
- Band selection (band width, placement, and number of bands) optimized to identify features of interest;
- Affordable;
- Study area covered on a single image
- Multi-date imagery acquired under identical conditions
    - Water level (tide, river and lake level)
    - Consistent and “stable” phenologic state
    - Soil moisture
- Repeat interval consistent with project goals
- Same sensor and sun position when images were acquired
- Similar atmospheric conditions

Pragmatically, it is rather difficult to acquire the data with the above characteristics. Instead, the following problems are common in data acquisition process:

- unavailability of data for specific time period;
- Persistent cloud coverage throughout the year and for many years;
- Cost is too high specially for commercial satellite data;
- Availability of data in usable format (digital or hard copy);
- Licensing concerns in sharing the data;
- Classified, secure or sensitive data;
- Cost of processing, in producing value added product,
- Lack of expertise,
- Calibration/ground truth problems,
- Lack of knowledge within senior management as to how data can be used,
- Lack of equipment/software for analysis,
- Volume of data (storage/archiving),
- Resistance within the agency to change.

There are a number sources where you can get variety of data, often times, free of cost. See ***Annex II*** for selected and popular data sources. However, the data available may not necessarily be accessible to many developing countries because of slow and often times non-connectivity internet problems.

Optical sensors providing systematic observations at the regional/global level and at coarse (≥1 km) spatial resolution include the NOAA advanced very high resolution radiometer (AVHRR) and SPOT VEGETATION. At finer (10–30 m) spatial resolution, Landsat sensor (currently the Enhanced Thematic Mapper Plus or ETM+) and SPOT sensor (currently the high resolution visible infrared or HRVIR) data can be combined to provide regional and even continental level observations. The Terra-1 Moderate Resolution Imaging Spectroradiometer (MODIS) and ADEOS II Global Land Imager (GLI) represent a new generation of medium (250–500 m) spatial resolution sensors and an important bridge between those observing at fine and coarse spatial resolutions.

The acquisition of optical data is hampered by problems associated with cloud cover, haze and smoke that often limit the number of usable scenes. These limitations can be overcome using fine (10–30 m) space borne synthetic aperture radar (SAR) sensors that observe under all weather conditions and also during day and night. Key sensors include the European Resources Satellite (ERS-1/2), RADARSAT-1/2, the Japanese Earth Resources Satellite (JERS-1) SAR and the ENVISAT Advanced SAR (ASAR). These sensors have the capacity to provide more consistent coverage at continental scales and over short timeframes—if systematic acquisition strategies are implemented–and their use for regional-scale vegetation mapping has been well-proven both for the tropics and the boreal zone.

LIDAR technology has only recently been explored for vegetation characterization and mapping. The LIDAR transmits a vertical near infrared (NIR) laser pulse towards the land surface which then reflects from objects and returns to the sensor. The delay in time between the transmission and receipt of the pulse is related directly to distance and hence the height of objects (e.g. tree crowns) and the ground surface. LIDAR footprint sizes may vary from 0.25 to

5m with achievable accuracies of <25 cm in elevation. Using small footprint laser, strong relationships with variables such as tree height, stem volume, biomass and canopy closure have been obtained. Large footprint LIDAR are able to provide a complete waveform of reflected light allowing attributes such as stem diameter, basal area, stem volume and above ground biomass to be retrieved. Such sensors are currently available on airborne platforms. VCL is the first multi-beam, waveform-recording LIDAR to fly in space. The VCL is not an imaging instrument but has been designed to collect a series of point samples along the flight path. Thematic products can only be foreseen if these data are used in combination with other spatially extensive data (e.g. optical or SAR).

Table 3: Major satellite remote sensing data available

Name	Spatioal Resolution (m)	Spectral Resolution	Temporal resolution (days)	launched (year)	Web Site
Landsat	15-80	V/NIR, SWIR, TIR	16	1972	www.landsat.org
SPOT	2.5-20	V/NIR, SWIR,	26	1986	www.spotimage.fr
IRS	6-188	V/NIR, SWIR,	24	1995	www.isro.org
IKONOS	1-4	V/NIR, SWIR	3	1999	www.spaceimaging.com
QuickBird	0.61-2.44	V/NIR, SWIR,		2002	www.digitalglobe.com/
MODIS	250-1000	V/NIR, SWIR, TIR	1	1999	modis.gsfc.nasa.gov/
VEGETATION	1000	V/NIR, SWIR, TIR	1	1998	www.spot-vegetation.com/
AVHRR	1000	V/NIR, SWIR, TIR	1	1978	www.noaa.gov
MERIS	300	V/NIR, SWIR	3	2002	www.envisat.esa.int
ASTER	15-90	V/NIR, SWIR, TIR	4-16	1999	asterweb.jpl.nasa.gov/
Hyperion	30	V/NIR, SWIR,	16	2000	eo1.usgs.gov
ALI	10-30	V/NIR, SWIR,	16	2000	eo1.usgs.gov
CBRES	20-260	V/NIR, SWIR,	3-26	2003	www.dgi.inpe.br/
JERS/SAR	18	L-band	44	1992	www.eorc.jaxa.jp
Radarsat	8-100	C-band	24	1995	www.rsi.ca

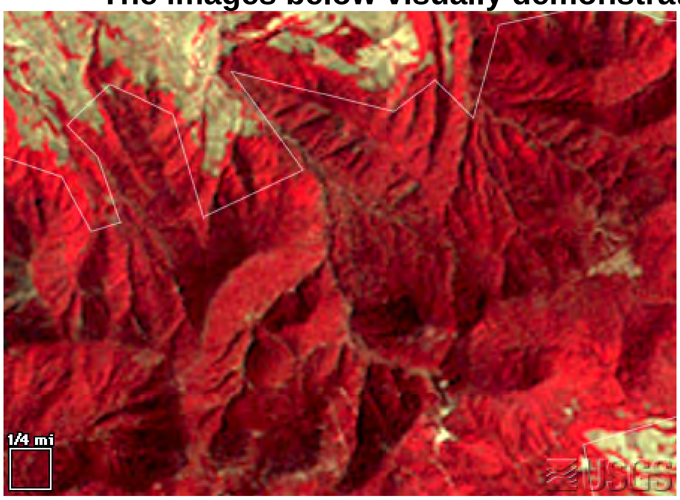
The cost of Landsat data has decreased significantly in the last 5-10 years. Similar resolution data e.g. SPOT is still expensive. The next generation of the Landsat data may be available free of charge. At the same, file sharing is likely to be one of the popular methods for data sharing.

4.2 Recent Advances in Remote Sensing Technology

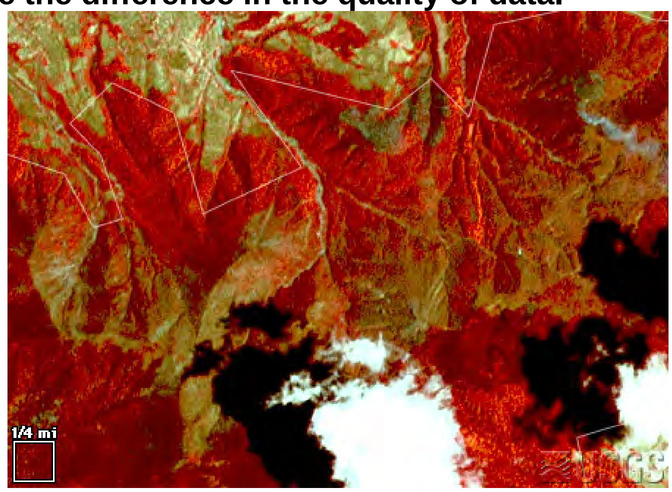
Remote Sensing technology is evolving through time. Significant improvements have been made in terms of spectral, spatial, temporal and radiometric resolutions. For example, with the improvement in spectral and radiometric characteristics quality and quantity of data acquired and archived has improved. More specifically, improvements have been observed in

1) visibility and clarity that includes more detailed image of a smaller piece of land;
2) clear definition involving more precisely the specific colors or light responses reflecting off of the field; and
3) frequent data acquisition on a regular interval of every other day or every 5-7 days.

The images below visually demonstrate the difference in the quality of data.



14 March 1986, Landsat 5 TM bands 4 3 2
Source: http://earthshots.usgs.gov/Angangueo/Angangueo



13 April 2000, Landsat 7 ETM+ bands 4 3 2

4.2.1 Methodology to Assess and Monitor Deforestation, Degradation and Fragmentation using Remote Sensing and GIS

Remote Sensing can assess and monitor two broad categories of forest cover change: categorical vs. continuous. Both types of changes can be used to assess and monitor deforestation, degradation and fragmentation. Some changes such as deforestation are inherently categorical in which areas previously classified as forests are no longer. Examples of continuous change include the change in LAI or cover of vegetation canopy over time. While the distinction between categorical and continuously measured change is simple in the abstract, it worth noting that in practice the differences are often blurred. For example, the magnitude of change in a surface property (such as burn severity) is often reduced to ordinal categories (high, medium, and low).

A. Deforestation

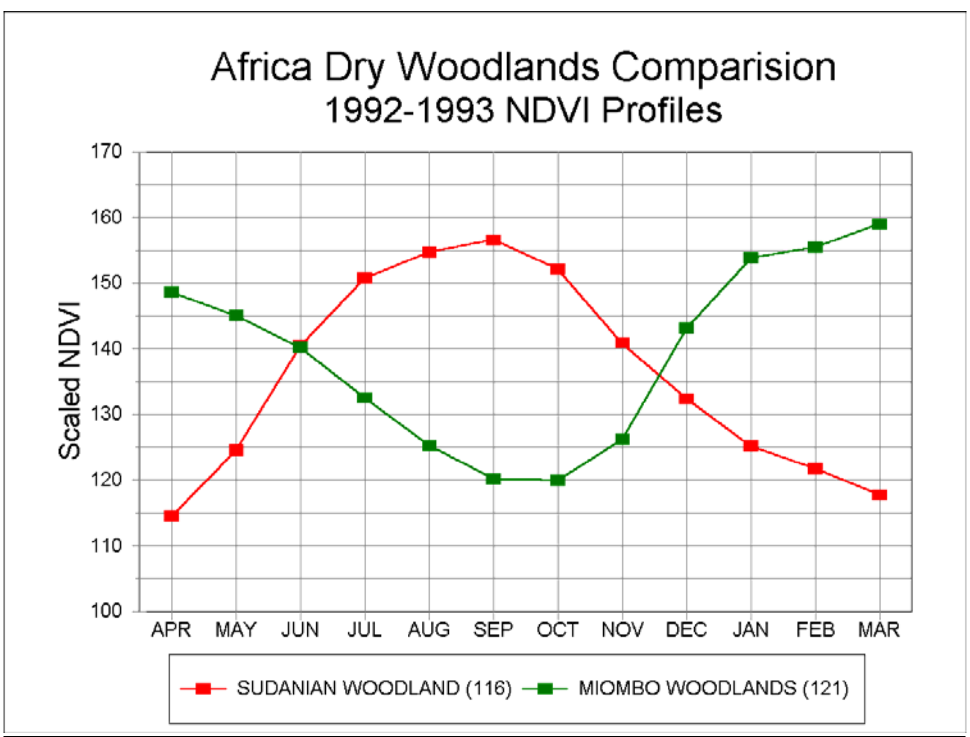
There are two main approaches for assessing and monitoring deforestation: wall-to-wall mapping and sampling strategy. Wall-to-wall mapping could be a very expensive proposition if the study is conducted in a very large area spanning different time periods. For example, wall-to-wall coverage of the entire tropical region would require thousands of Landsat scenes. Depending on the time period of interest, these scenes can cost anywhere from $400 to $600 each, adding up to a considerable investment, especially if one wishes to examine change by conducting analyses at two different dates.

The alternative to wall-to-wall coverage is the use of a sampling strategy. The sampling strategy specifies the portion of the entire area of interest that must be analyzed, and results are then extrapolated from the sample to the entire region. The sampling strategy also specifies how the location of the samples is determined. For example, in the commonly used stratified random sampling schemes, the sampling is equally partitioned out by some independent stratification of the region, such as ecological biome, rainfall, elevation, or some landcover classification. Thus, if the 'lowland evergreen forest' strata of a given classification covers 35% of the total area, then 35% of the samples will be constrained to this strata, and changes for that strata can be independently computed.

Unfortunately, for the issue of deforestation, these types of random sampling schemes often do not work well. Deforestation is rarely a randomly located occurrence in a region. Rather, most deforestation occurs next to or near previous deforestation, or near the roads which provide access. Industrial logging, on the one hand, may be centered on company's concessions. Deforestation due to clearance for pasture or farming will likely be centered on previous farms or pasturelands. In either case, it is not randomly distributed around the landscape. Thus, schemes using random sampling of a non-random process will not provide very accurate results. Some authors describe stratification and sampling schemes might be a better option to evaluate tropical deforestation than simple random sampling. Their methodology relies upon expert knowledge of deforestation hot spots. Tucker and Townshend (2000) used Monte Carlo simulations to investigate this issue with Landsat data for Bolivia, Colombia, and Peru, and found that, on average, approximately 88% of the area needed to be sampled in order to estimate deforestation to within 20% of the actual amount 90% of the time. Thus, results from anything much less than wall-to-wall coverage must be closely scrutinized to ensure the adequacy of the sampling strategy.

A variety of methodologies exist for deriving deforestation estimates from satellite data. The simplest methods use manual interpretation of printed images, similar to methods long used for interpretation of aerial photographs. The interpreter simply draws lines around areas of different forest types, which are then manually summed. This requires that the interpreter know the region, or at least how to differentiate its forest types from one another and from various forms of agriculture and plantations. Change can be assessed by either comparing the results from two separately interpreted images, or by performing a multi-date analysis; in this case, image transparencies are overlaid and areas of change between the images are delimited. However, several problems arise from this method. First, there is the uncertainty of the human element; although human knowledge of the region may make differentiating forest areas straightforward, it will also make the results dependent on the specific interpreter involved and their experience in this type of analysis. Second, the quality and scale of the printed images will also affect the results. The scale will determine the minimum mappable unit, which may affect results in areas with highly fragmented landcover or deforestation. Despite these uncertainties, on-screen digitizing using remote sensing and GIS software is quite popular in many countries.

More sophisticated methodologies use computers to distinguish the various forest types, based on all the spectral information available in the images. Conceptually, this is a much more appealing process, since the computer can analyze changes in all of the bands of the image, while humans are generally limited to viewing a falsecolor combination of three bands. Nevertheless, computer classification is also dependent on human interaction; in one form, supervised classification, the human analyst delineates sample regions (training classes) of the different landcover types. The computer then compares the spectral information from the remainder of the image to that from the sample regions, and thereby indicates which pixels are most similar to which of the sample regions. Thus, this method depends on the specific sample regions chosen by the analyst, which, again, is dependent on the professional knowledge and experience of the analyst. This method is particularly attractive if sufficient field data is available. The alternate method, unsupervised classification, lets the computer determine the best classes based on the entire image. However, this method then requires the human analyst to aggregate the resulting computer defined classes into standard landcover and forestry classes. Again, this requires knowledge of the area or at least of the types of land cover in the area, and experience with the methods. As with the manual methods, the computer can also perform multi-image analyses, in which areas of change between two images are classified. Several other change detection methods are described in section 4.3.1. These computer methods also greatly facilitate the registration of one image to another; due to slight changes in orbit or sensor pointing, images of the same region, by the same satellite, generally will not perfectly align with one another. For coarser resolution imagery, this is generally less of a problem, but for the high resolution images needed for forest cover monitoring, such misregistration can cause major problems for multi-image change detection procedures.



B. Forest Degradation

Forest degradation is a process leading to a ‘temporary or permanent deterioration in the density or structure of vegetation cover or its species composition’. It is a change in forest attributes that leads to a lower productive capacity. It is caused by an increase in disturbances. The time-scale of processes of forest degradation is in the order of a few years to a new few decades. Thus, it is more difficult to identify and monitor using remotely sensed data. For example, rapid regeneration tends to obscure the spectral/spatial signature of the recently clear-felled or degraded forest.

Any in-depth understanding of the processes of forest degradation has to be based on an accurate monitoring of the degradation over large areas, for at least a decade. The detection of inter-annual changes in landscape spatial structure is more likely to reveal long term and long lasting land cover changes, while spectral indicators are more sensitive to fluctuations in primary productivity associated with climatic fluctuations. Different monitoring systems may be optimal for different ecosystems. A long time series of observations is always required with seasonal, annual and decadal changes. The monitoring of the spatio-temporal distribution of biomass burning may also give indications of open forest degradation.

Degradation is generally grouped into classes based on the degrading activity (selective logging, burning) and intensity. Quantification of the impacts is measured in terms of forest structure and composition. For example, forest degradation classes can be grouped into intact forest, moderately logged, heavily logged, lightly burned, and heavily burned. They can be further described in terms of physical characteristics, biomass and canopy cover.

C. Forest Fragmentation

Forest fragmentation is generally defined as the process of subdividing continuous forests into smaller patches, which results in the loss of original habitat, reduction in patch size, and increasing isolation of patches. Forest fragmentation can be measured and monitored in a powerful new way by combining Remote Sensing, GIS, and analytical software (e.g. FRAGSTAT). For example, the length of forest clearance edges and patches of fragmented forest can be directly measured in satellite images.

Forest fragmentation can be enumerated using high-altitude aerial photography and satellite data. In the past both high resolution and coarse resolution data have been used for this purpose depending on the objective of the study. AVHRR and MODIS data remain useful at continental and global scales, however, finer resolution satellite data (e.g. Landsat, SPOT, IRS) is recommended for studying smaller geographic areas. Existing land cover data can also be used to build forest fragmentation database. Other GIS data layers particularly roads data play a prominent role in the fragmentation assessment.

4.3 Data Basis and Methodologies

4.3.1 Deforestation

Digital image processing in conjunction with spatial analysis in a Geographic Information System are effective means for quantifying deforestation. When implementing a deforestation monitoring project, three major steps are involved:

(1) selection of appropriate satellite data
(2) image preprocessing including geometrical rectification and image registration, radiometric and atmospheric correction, and topographic correction if the study area is in mountainous regions;
(3) selection of suitable techniques to implement change detection analyses; and
(4) accuracy assessment.

Results may depend on several factors including the following.

(1) precise geometric registration between multi-temporal images,
(2) calibration or normalization between multi-temporal images,
(3) availability of quality ground truth data,
(4) the complexity of landscape and environments of the study area,
(5) change detection methods or algorithms used,
(6) classification and change detection schemes,
(7) analyst's skills and experience,
(8) knowledge and familiarity of the study area, and
(9) time and cost restrictions.

Several change detection methods and algorithms are available. Because of the impacts of complex factors, different authors often arrived at different and sometimes controversial conclusions about which change detection techniques are most effective. In practice, it is not easy to recommend a suitable algorithm for a specific change detection project. Hence, a review of change detection techniques used in previous research and applications is useful to understand how these techniques can be best used to help address specific problems. Identification of a suitable change detection technique play an important role in producing good quality change detection results.

Change detection methods are grouped into seven categories: (1) algebra, (2) transformation, (3) classification, (4) advanced models, (5) Geographical Information System (GIS) approaches, (6) visual analysis, and (7) other approaches.

The algebra category includes image differencing, image regression, image ratioing, vegetation index differencing, change vector analysis (CVA) and background subtraction. These algorithms have a common characteristic, i.e. selecting thresholds to determine the changed areas. These methods (excluding CVA) are relatively simple, straightforward, easy to implement and interpret, but these cannot provide complete matrices of change information. CVA is a conceptual extension of image differencing. This approach can detect all changes greater than the identified thresholds and can provide detailed change information. One disadvantage of the algebra category is the difficulty in selecting suitable thresholds to identify the changed areas. In this category, two aspects are critical for the change detection results: selecting suitable image bands or vegetation indices and selecting suitable thresholds to identify the changed areas.

The transformation category includes Principal Component Analysis (PCA), Gramm–Schmidt (GS), and Chi-square transformations. One advantage of these methods is in reducing data redundancy between bands and emphasizing different information in derived components. However, they cannot provide detailed change matrices and require selection of thresholds to identify changed areas. Another disadvantage is the difficulty in interpreting and labeling the change information on the transformed images.

The classification category includes post-classification comparison, spectral–temporal combined analysis, expectation–maximization algorithm (EM), unsupervised change detection, hybrid change detection, and Artificial Neural Network (ANN). These methods are based on the classified images, in which the quality and quantity of training sample data are crucial to produce good quality classification results. The major advantage of these methods is the capability of providing a matrix of change information and reducing external impact from atmospheric and environmental differences between the multi-temporal images. However, selecting high-quality and sufficiently numerous training sample sets for image classification is often difficult, in particular for historical image data classification. The time consuming and difficult task of producing highly accurate classifications often leads to unsatisfactory change detection results, especially when high-quality training sample data are not available.

The advanced model-based change detection category includes the Li–Strahler reflectance model, spectral mixture models, and biophysical parameter estimation models. In these methods, the image reflectance values are often converted to physically based parameters or fractions through linear or nonlinear models. The transformed parameters are more intuitive to interpret and better to extract vegetation information than are spectral signatures. The disadvantage of these methods is the time-consuming and difficult process of developing suitable models for conversion of image reflectance values to biophysical parameters. The GIS-based change detection category includes the integrated GIS and remote sensing method and the pure GIS method. The advantage of using GIS is the ability to incorporate different source data into change detection applications. However, different source data associated with different data accuracies and formats often affect the change detection results.

The visual analysis category includes visual interpretation of multi-temporal image composite and on-screen digitizing of changed areas. This method can make full use of an analyst's experience and knowledge. Texture, shape, size and patterns of the images are key elements useful for identification of LULC change through visual interpretation. These elements are not often used in the digital change detection analysis because of the difficulty in extraction of these elements. However, in visual interpretation, a skilled analyst can incorporate all these elements in helping make decisions about LULC change. The disadvantage of this method is the time consumed for a large-area change detection application and it is difficult to timely update the change detection results. It is also difficult to provide detailed change trajectories.

In addition to the six categories of change detection techniques discussed above, there are also some methods that cannot be attributed to one of the categories indicated above and that have not yet frequently been used in practice. They include a knowledge-based vision system, area production model, and use of indices etc.

In general, change detection techniques can be grouped into two types: (1) those detecting binary change/non-change information, for example, using image differencing, image ratioing, vegetation index differencing and PCA; and (2) those detecting detailed 'from–to' change, for example, using post-classification comparison, CVA and hybrid change detection methods. One critical step in using the methods for change/non-change detection is to select appropriate threshold values in the tails of the histogram representing change information. In conclusion, some generalizations are possible:

To summarize,

- There is not a single method of change detection in remote sensing that is best for all kinds of imagery, deforestation, and locations; and
- There are clearly sets of methods more appropriate for some applications than others**.**

4.3.2 Forest Degradation

Forest degradation is more difficult to measure using remotely sensed data compared to deforestation. Moderate spatial resolution images often do not provide detailed information about degraded forests. For example, forest structure and composition (e.g. crown size, liana density, tree species, etc) cannot be retrieved at these moderate spatial resolutions (i.e. 20–30mpixel size). In addition, old degraded forests (i.e. .2 years) are difficult to distinguish from intact forests with both Landsat and SPOT images. However, there are a number of techniques available and used to assess forest degradation. In addition, high resolution satellite data such as IKONOS and QuickBird seems promising (Figure 3).

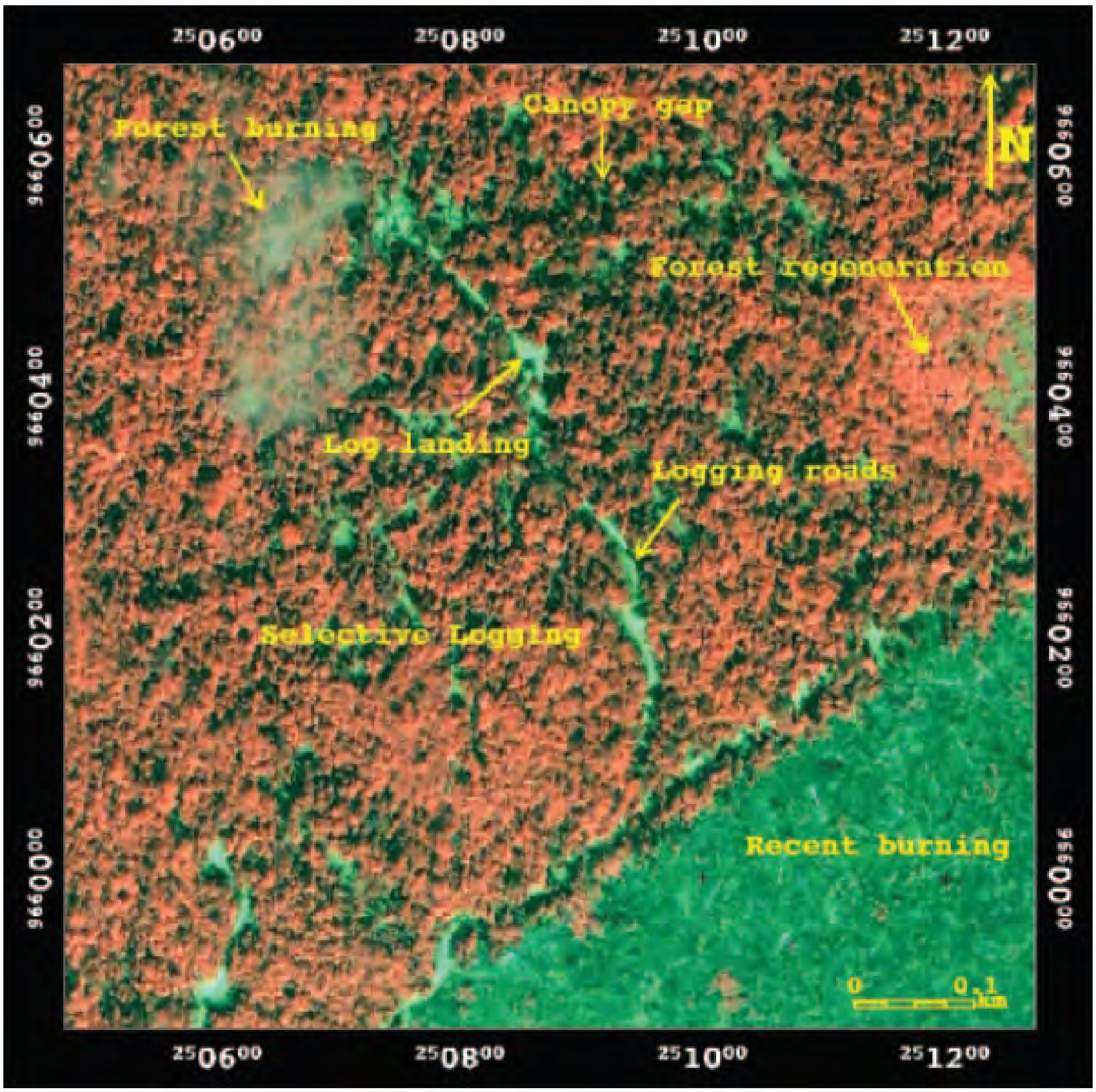


Figure 3: Ikonos image of a degraded forest showing log landings, logging roads, canopy damaged areas, burned forest, regeneration and forest (cover).

The estimation by remote sensing of biophysical attributes that are indicative of forest degradation has been conducted using either an empirical approach or a physically-based approach. In the empirical approach, many authors have characterized the surface using vegetation indices that are arithmetic combinations of spectral bands. Most of these indices are variants of the normalized difference vegetation index (NDVI), computed as the ratio between the difference and the sum of the radiances measured in the near infra-red and red parts of the electromagnetic spectrum. These variants display different levels of sensitivity to perturbing factors such as soil colour changes or atmospheric effects.

Empirical studies and simulations with radiative transfer models support the interpretation of vegetation indices in terms of the fraction of photosynthetically active radiation absorbed by the vegetation canopy, canopy attributes (e.g. green biomass or green leaf area index), state of the vegetation (i.e. vegetation vigour or stress) and instantaneous rates associated with the activity of the vegetation (Myneni et at., 1995). Inter-annual variations in primary production in the Sahel have been monitored using annual integration of vegetation index data at a coarse spatial resolution. Similar data have also been used to detect large-scale tropical deforestation. The methods used in these studies are not necessarily suitable for the detection of changes associated with slow rates of forest degradation due to spatial and temporal sampling issues. First, the level of spatial aggregation of the data used in these studies (i.e. 8 by 8 km in the case of pre-processed time series of Global Area Coverage data from the Advanced Very-High Resolution Radiometer on the NOAA series of orbiting platforms) is too coarse to allow for the detection of subtle changes in the density or structure of vegetation cover. Second, integrating vegetation index data on an annual basis hides variations in the phenological cycle of the vegetation cover. Third, the time consistency of the data over several years is not always ensured due to, in the case of AVHRR, a lack of on-board calibration of radiances, instrument change-over, and a drift in equator crossing-time of the satellite's orbit over the years. Time series of high spatial resolution data can overcome several of these limitations.

Land surface temperature (Ts), derived from the thermal channels of satellite sensors has also been used as a biophysical indicator of the surface in empirical studies. Ts is related, through the surface energy balance equation, to surface moisture availability and evapo- transpiration, as a function of latent heat flux. A few empirical studies have demonstrated the potential of these data for forest-cover change analysis, e.g. to detect forest disturbances, to locate the boundary between shrub and woodland savannas in West Africa, or to map the boundary between tropical rain forest and savanna vegetation. A few authors have combined a vegetation index such as NDVI with Ts data to describe change studies. The slope of the Ts-NDVI relationship is interpreted in terms of surface resistance to evapotranspiration.

Physically-based approaches, relying on model inversion, have also been developed. In these methods, a scene model is constructed to describe the form and nature of the energy and matter within the scene and their spatial and temporal order. This scene model is coupled with anatmospheric and a sensor model. This coupled remote sensing model is then inverted to infer, from the remotely sensed measurements, some of the properties or parameters of the scene that were unknown. Concerning tropical forest ecosystems, these methods are not yet sufficiently robust to be applied routinely for a large-scale monitoring of forest-cover changes, due to the difficulty for representing adequately in a model the natural variability in landscape structure and composition.

For example, Franklin & Strahler (1988) applied a model inversion approach to generate regional estimates of tree size and density in West Africa, using Landsat TM data. They used the Li-Strahler canopy reflectance model. A woodland stand is modeled geometrically as a group of objects casting shadow on the background. The reflectance of a pixel is modeled as a linear combination of the signatures of the major scene components (i.e. illuminated tree crown, illuminated background, shadowed tree and shadowed background), weighted by their relative areas. Inversion results over a sample of observations were satisfactory for the estimation of tree density and cover but poor for tree size. The application of this type of approach for monitoring woodland degradation would probably require further developments for a more robust approach.

Remote sensing offers the possibility to analyze changes in spatial structure at the scale of landscapes. Indicators of the degradation of the vegetation cover can be derived from such measures. For example, Pickup & Foran (1987) developed a method to monitor and landscapes used for pastoralism based on the spatial variability of the vegetation. The spatial autocorrelation function and mean-variance plots of a spectral indicator were found to be successful in discriminating between the cover responses typical of good and poor rainfall years. For drought conditions, the decrease in spatial autocorrelation with increasing spatial lag was rapid since the ground surface is bare and most of the vegetation signal comes from scattered areas of trees and shrubs. A low decay rate of the autocorrelation function indicated a greater spatial uniformity of the landscape, e.g. during wet periods, when more ground cover is present so reducing the contrast between the bare soil signal and that produced by trees and shrubs. Similar observations were made by Lambin (1996) over the seasonal and inter-annual cycle of three West African landscapes. Vogt (1992) also analyzed the seasonal changes in spatial structure of a West African landscape, showing that there is a marked seasonal cycle in the spatial structure of a vegetation index (NDVI), surface temperature and albedo, and that zones of ecological transition have an identifiable seasonal dynamic in spatial structure. However, the monitoring of these spatial variability measures only provides for a qualitative description of the cover state. Lambin & Strahler (1994) showed that the detection by remote sensing of land-cover change processes is Index and suface temp) and spatial indicators of surface condition. Their study suggested that the detection of inter-annual changes in landscape spatial structure is more likely to reveal long term and long lasting land-cover changes while spectral indicators are more sensitive to fluctuations in primary productivity associated with the inter-annual variability in climatic conditions. The long term monitoring of landscape spatial pattern in addition to other biophysical variables can thus lead to the detection of a greater range of processes of landscape modification.

The spatial pattern of a changing landscape also contains some information on the processes of land-cover change. Certain categories of changes in human land use tend to fragment the landscape (e.g. expansion of extensive agricultural exploitation, forest degradation driven by small-scale logging, overgrazing or desertification around deep wells). Other land use changes increase landscape homogeneity (e.g. large-scale intensive cultivation or ranching). Spatial processes of gap expansion in a forest cover have been modeled to predict the total gap area and gap size distribution. One can hypothesize that landscapes with a very low or very high level of disturbance are characterized by a low spatial heterogeneity, while landscapes with a medium level of disturbance are very heterogeneous.

Land-cover changes take place at a variety of temporal scales, i.e. short events with detectable effects only for a few months, modifications in seasonal trajectories of ecosystem attributes, processes that affect the land cover through several seasonal cycles, and long term, permanent changes. Open forest degradation may affect, and therefore be indicated by, the phenology of the vegetation cover. The analysis of the temporal trajectories of vegetation indices based on high temporal frequency remote sensing data allows us to monitor vegetation phenology and biome seasonality (Justice et al., 1985).Processes such as a shortening of the growing season, a dephasing of the phenology of different vegetation layers, or modifications of the cover due to disturbances such as fires, can only be detected if inter-annual changes in the seasonal trajectories of vegetation covers are analyzed. For any landscape with a strong seasonal signal, the detection of inter-annual changes needs to take into account explicitly the fine-scale temporal variations. If data from only one or a few dates a year are used to measure inter-annual changes, the undersampling of the temporal series hinders the change detection accuracy and might lead to the detection of spurious changes.

A quantitative evaluation of differences in seasonal development curves of remotely sensed data was applied for land-cover change analysis by Lambin & Ehrlich (1997). In this study, a measure of the deviation in seasonal trajectories was computed for 10 years of continental-scale remote sensing data. Subtle processes of land-cover change could be detected this way. Results suggested that land-cover changes in Africa mostly involve erratic variations in land-cover conditions due to droughts, temporary modifications in seasonality, Ikonos images, which can be acquired with resolution as fine as one meter, offer a new capability to map forest degradation in the Amazon region.

In summary, some important lessons may be learned from this review.

- Degradation of forest-cover is often a complex process, with some degree of reversibility as the productivity of forests is partially controlled y climatic fluctuations;
- Regular monitoring of several biophysical variables can lead to an accurate detection of forest degradation;
- Repetitive measurements of spectral, spatial and temporal indicators of the land surface have to be performed;
- long time series of observations is required to be able to detect trends in forest degradation that depart is a significant way from short-term, climate-driven fluctuations in forest conditions; and
- monitoring system can combine indicators of the degradation itself, its proximate causes, and other surface processes linked with the vegetation cover.

4.3.3 Forest Fragmentation

Fragmentation is generally defined as the process of subdividing a continuous habitat type into smaller patches, which results in the loss of original habitat, reduction in patch size, and increasing isolation of patches. Forest fragmentation can be measured and monitored in a powerful new way.

Land cover or Forest/Non-forest classification can be used together with other GIS data layers to compute fragmentation indices. GIS layers such as road maps, urban/peri-urban maps, ecoregions etc. can be used together with fragmentation model to infer important information on fragmentation. One of the commonly used software is Fragstats, which provides a powerful and comprehensive set of descriptors of spatial pattern at the landscape, class and patch levels. Several of these metrics are partially or wholly redundant, so, one can select a set of -indicators at the patch and class level as being of the most interest to them in assessing fragmentation.

At the patch level, the three indicators namely patch size (area in hectares), patch shape (using the shape index, which computes the complexity of patch shape by comparing it with the equivalent most compact patch of identical area, starting from 1 when most compact and increasing without limit as the patch becomes more irregular) and nearest neighbor index (the nearest edge–edge distance in meters between a patch and its nearest neighbor of the same category) is considered to quantify distinct aspects of patch structure. The one-tailed Mann–Whitney *U*-tests can be used assess whether patch size, shape and nearest neighbor distance differed significantly (p=0.05) from year to year and across different landscape zones.

At the class level, the interest may be to compare descriptive metrics of land-cover pattern between forest and non-forest classes, and across categories of land-cover change. These indices can be grouped into categories of area, shape, core, diversity, and contagion/interspersion. To simplify interpretation, the following indices can be considered, assuming that they quantify different aspects of structure

(a) *Number of patches*: the total number of patches in this category.

(b) *Edge density*: total edge per unit area for the class, in meters per hectare.

(c) *Mean area*: average patch area for the class, in hectares.

(d) *Mean shape index*: measures the average complexity for a category, of patch shape, compared to a square patch of identical area. For a single patch, the shape index is 1 when square, and increases without limit as the patch becomes more irregular.

(e) *Mean nearest neighbor distance*: average nearest neighbor distance in meters for all patches belonging to the class.

(f) *Clumpy*: Measures the extent to which the habitat is aggregated, by comparing the values observed with those expected under a spatially random distribution, and takes values from -1 to 1.

(g) *Interspersion-juxtaposition index*: measures the degree of interspersion of patches of this class, with all other categories. This index takes values from 0 to 100, decreasing as the distribution of patch adjacencies among types becomes increasingly uneven.

The indices of number of patches, mean area and edge density correspond to area/density/edge metrics, and provide indications of the degree of fragmentation for different forest/land-cover types and forest/land-cover change trajectories. The mean shape index is a metric of shape, the mean nearest neighbor distance an indicator of proximity or isolation, and the clumpiness and interspersion-juxtaposition index measure the contagion and interspersion of pixels in the landscape.

Techniques for Forest Fragmentation Analysis

There are a number of commercial as well as well free software and programs available to perform fragmentation analysis. Fragstats, ArcView/ArcInfo, and APACK are few examples. Fragstats is a shareware, new version of which is based available in Graphical User Interface (GUI) interface. The software can be downloaded from this website: http://www.umass.edu/landeco/research/fragstats/fragstats.html. Path Analyst (http://flash.lakeheadu.ca/~rrempel/patch/) is also a shareware graphical interface for Fragstats that runs as an extension to ArcView GIS. One of the benefits of Patch Analyst is its ability to use ARC grid format raster files directly rather than the images that are required by the native Fragstats implementation, Processing time may be longer compared to Fragstats.

The ARC software packages do not provide for analysis of landscape fragmentation analysis directly, but with a limited amount of knowledge of the command syntax, users can create many custom analyses that perform some of the same analyses as other bundled fragmentation analysis software. For this purpose GRID program within ArcInfo is necessary. Some of the functions that can be used for the analysis include: gridclip, imagegrid, region group, statistics, frequency, reclass, zonalgeometry, and core areas.

APACK (landscape.forest.wisc.edu/Projects/**APACK**/**apack**.html) is a shareware tool for processing large raster data sets consisting of landscape information (e.g. classified satellite imagery). It calculates most of the statistics available from Fragstats. APACK has a command line parameter entry.

4.4 Data Modeling

Generally speaking, deforestation models may be grouped into (1) Malthusian, (2) economic/technologic, (3) dependency, and (4) political economic (or ecologic) categories. In the Malthusian models, population growth is held accountable for deforestation. In the economic/technologic framework, property relations, externalities, and inappropriate technology are considered responsible. Political economic explanations point to social structures such as class relations, and dependency theory suggests that the adoption of crops ill-suited to their environments (by domestic capitalists or foreign interests) for sale and world markets is at the basis of ecological degradation. We could also relate this with respect to the time scale.

1. Short time scales: individual & social responses to new opportunities & constraints created by **markets** & **policies**.
2. Long time scales: **demographic** factors: population increase & decrease, breakdown of extended families, migration.

Extreme **biophysical** events trigger further change.

5. Using ERDAS Imagine

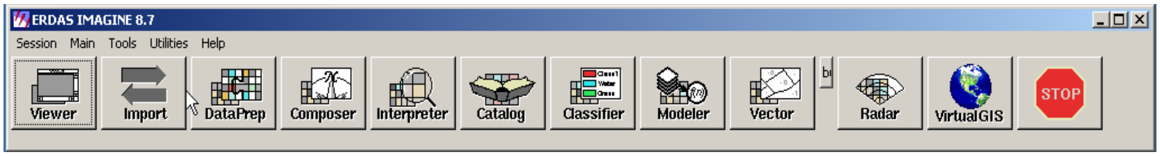
Objective

- √ To introduce basic ERDAS IMAGINE display and screen cursor control procedures.

5.1 Cursor Operations and Image Display

We will be analyzing two images in this exercise. Both files are copied in your computer under/training directory.

After you have successfully logged onto the system, launch IMAGINE by going to the Start Menu - Remote Sensing - ERDAS IMAGINE 8.7. (or later version) Wait a few seconds for all menus to appear. Examine the icon panel along the top of the screen. These icons represent the various components and add-on modules available with the current license. You have the option of displaying the icon panel horizontally across the top of the screen or vertically down the left side of the screen using the [Session | Flip Icons] menu item.



Cursor Operations: Familiarize yourself with the five menu items located along the top of the icon panel in the left corner: [Session], [Main], [Tools], [Utilities], & [**Help**]. The Session menu controls many of the session settings such as user preferences and configuration options. The [Main] menu allows access to all the modules located along the icon panel. The [Tools] menu allows you to display and edit annotation, image, and vector information, access surface draping capabilities, manage post script and true type fonts, convert coordinates, and view *Erdas Macro Language* (EML) script files. The [Utilities] menu allows access to a variety of compression and conversion algorithms including JPEG, ASCII, image to annotation, and annotation to raster. The [Help] menu brings up the *IMAGINE On-Line Documentation* as well as icon panel and version information. An index of keywords helps you to quickly locate a help topic by title. A text search function also helps you find topics in which a word or phrase appears. The menu you will probably use the most under the [Session] menu is the *Preference Editor*. The *Preference Editor* is accessed under [Session | Preferences]. It allows you to customize and control many individual or global IMAGINE parameters and default settings. Use the left mouse button (lmb) on the scroll arrows on the side of this menu to examine the available categories. With the *User Interface & Session* category open, change the *Default Data* and *Output Directories* to whatever you like (for example):

c:\Temp\Ex02

Save these changes using the [User Save] or [Global Save] buttons and close the editor. Proper use of these preferences can reduce the time it takes you to perform image processing tasks.

Image Display: Now, you are ready to display the first image. Move the cursor back to the IMAGINE *Viewer* and select the File dropdown menu with the lmb. Select [File | Open | Raster Layer] to get to the *Select Layer to Add:* dialog. You can also type [Ctrl R] or click on the *Viewer* icon that looks like a manila folder that is half open to accomplish the same task. Additional *Viewers* may be opened by clicking the [Viewer] icon on the IMAGINE icon panel.

On the left side of the menu you should see a list of files in the current folder. Navigate to the desired folder if necessary. Position the cursor over the file you want to display (e.g. *mangrove00.img*) and click the lmb once (do not double-click). The file name should appear in the file name window in the *Viewer*. If you do not see the correct files then you are either not looking in the correct folder or you do not have the [Files of type] specified as *IMAGINE Image (*.img)*.

Before clicking [OK], you need to assign the spectral bands of the image to the color planes red, green, blue (RGB). Click on the [Raster Options] folder tab and assign band 3 (NIR) to red, band 2 (Red) to green, and band 1 (Green) to blue. Make sure that the [Display] option is set to [True Color] . You also have the option of making the image fit the *Viewer* frame by depressing the small box next to *Fit to Frame*. Now you are ready to click [OK]. If the SPOT image is requiring less space in the IMAGINE *Viewer* (there are large black borders on the sides) then you can resize the IMAGINE *Viewer* to use your screen desktop area more efficiently. This will become important in future exercises when many IMAGINE *Viewers* will need to be open at once. To remove an image displayed in the IMAGINE *Viewer* move to the [File] dropdown menu in that *Viewer* and select it with the lmb, then find the [Clear] option and select it. You can also click on the *Close Top Layer* or *Eraser* tool icons in the *Viewer*.

To find out additional information about this image, go to the [Utility] drop down menu in the open *Viewer*. Choose [Layer Info] and wait for the *ImageInfo* dialog box to appear. You can also access *ImageInfo* by clicking on the "info" icon in the *Viewer* icon menu (third one from the left). Now answer the following questions:

1a) What is the pixel size in the X and Y direction?

1b) What are the units of measurement?

1c) What map projection is the image georeferenced to?

5.2 Magnification and Overlay Operations

The next image we will browse is a Landsat Thematic Mapper (TM) scene of Burma, *mangrove90.img*.

Magnification: To magnify (or reduce) an image, the easiest option is to use the *Interactive Zoom In* (or *Interactive Zoom Out*) tools that are located immediately above the image in the gray *Viewer* area. The area over which you place the cursor will be the general center for the area that is magnified. However, you may at some times wish to magnify the image by a certain factor, such as 2X or 4X. To do so you can select [Zoom] under the [View] menu or [Quick View] menu and then select the appropriate choice. When you choose Zoom in by X or Zoom out by X you can also choose the interpolation method. These methods will be evaluated in class at a future time, but you might wish to try each method for the sake of understanding them. When you have completed your selection click [OK] and the magnified image will appear. Another method of explicitly specifying the zoom factor is under the [Raster Options] feature when you open a file. When [Fit to Frame] is not highlighted, you can enter in the [Zoom by] factor in the lower left hand corner. Finally, you also have the ability to change the frame scale of the image. The process can be implemented using the [View | Scale] option. The icon with the hand also gives you panning capabilities within the Viewer.

You can also create a magnifying window by either choosing [View | Create Magnifier] or accessing the [Quick View] menu and selecting [Zoom | Create Magnifier]. This brings up an additional window that corresponds to the *AOI Box* in your *Viewer*. The *AOI Box* can be resized by dragging on the corners. To close the magnifier, place your cursor inside it and select the [Close Window] option in the [QuickView] menu.

Sometimes it is necessary to determine the coordinates and brightness values of specific pixels in the displayed image. The inquire cursor allows you to do this. Go into the [Quick View] menu of the IMAGINE *Viewer* and select [Inquire Cursor]. This will open a pixel information menu that allows you to move a crosshair cursor on the *Viewer*. You can use the black arrows to move the crosshair cursor in any pixel increment you set. For now leave the increment at **1.00** and note that the increment is variable between the file and map coordinate system. You can move the crosshair cursor using the black arrows or by pressing and holding the lmb while the mouse cursor touches the crosshair cursor. For "fine tuning" use the keyboard arrows to move the cursor. The black circle will move the crosshair cursor back to the center of the Viewer.

Reference system values for the image can be obtained in either *Map*, *Paper*, *File*, or *Lat/Lon*, or *MGRS* coordinates. Notice that the coordinate system is defined for you. The image projection is also shown but if you have not selected the *Map* option then you may not necessarily be viewing the *x, y* coordinates of that projection system. The table shows the R,G,B pixel brightness values for both the image file (*File Pixel*) and the color lookup table (*LUT Value*). Move the Viewer Cursor and notice how the values change. To move the *Inquire Cursor* using the mouse you must initially place the arrow cursor at the center of the crosshairs and click on the lmb. Keep the lmb depressed to move the *Inquire Cursor*.

Overlay: Now close the **Inquire Cursor** dialog and open another image in **Viewer #1** without closing the TM scene. You can use IMAGINE to overlay imagery that is georeferenced to the same coordinate system. To do this, be sure to uncheck the [Clear Display] option under Raster in the [Select Layer to Add] dialog box. Now overlay the file **mangrove00.img** on top of the TM scene.


Ottawa, Canada (Credit: Digital Globe)

6. Hands-On Exercise

6.1 Opening a Raster File

- Choosing a file: Click on icon go to File/Open/Raster Layer in menu
  - Type in file name
  - Browse
  - Click on recent files
- Raster options
  - Assigning bands
    - True color (bands 3,2,1)
    - False color composite (other combinations)
  - Color, black & white, relief

Utility Menu (on View Window):

- Cursor Inquiry (via Utility or + icon)
  - Geographic coordinate information
  - Pixel value information
  - Changing color/shape of cursor (use Utility menu)
- Measurement Tool (via Utility menu or Ruler icon)
  - Coordinate data
  - Polyline data

    - Polygon
    - Changing units (Edit tab on Measurement Tool window)
- Layer Information (via Utility Menu)
- Mage merges
    - First open second image
    - Swipe
    - Blend
    - Flicker

6.2 View Menu on View Window

- Arrange Layers
    - Make sure second image is open
    - Open arrange layers dialog
- Zooming (via right click on window, icons, or view menu)
    - In/out icons
    - Magnifying glass icons
    - Right click in view window
    - Magnifying box (Create Magnifier in Viewer menu)
- Display two images that are linked geographically
    - Have both images open, one on top of the other
    - Go to View/Split/Split Horizontal on the View Menu
    - Open the file name in the Select Layer to Add on the new viewer
    - Go to View/Link-Unlink Viewers/Geographical
- Rotate/flip etc. –on the View Menu

Raster Menu on View Window:

- Band Combinations on Raster Menu
    - Play with variations
    - Think on what meaning of image is when all IR bands are shown

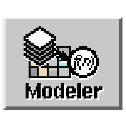
6.3 Working with Spatial Modelers

Objectives:

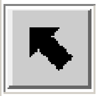
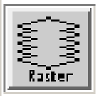
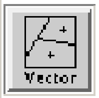
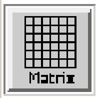
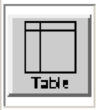
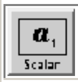
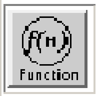
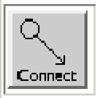
√ Introduce the ERDAS Imagine Spatial Modeler.
√ Compute various image statistics using Spatial Modeler.

Introduction to Spatial Modeler:

Begin by opening the Spatial Modeler menu by selecting the Modeler icon in the Imagine icon panel. Review the function of each of the Model Maker's tools before going on.



Create a NDVI image using Spatial Modeler:

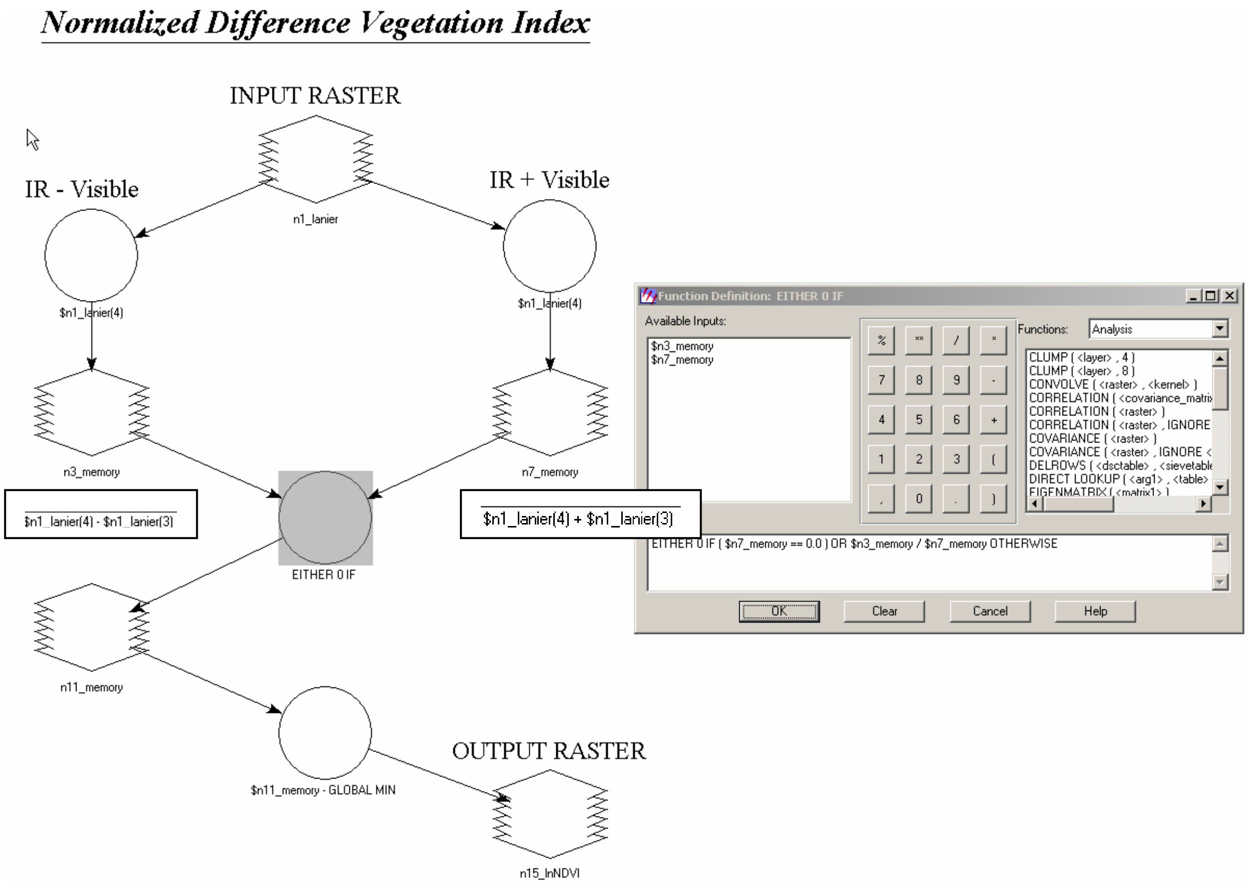
Description of the Model Maker Tools	
	Use this tool to **select items** on the Model Maker page. Once selected, these graphics (or text) can be moved or deleted. Click and drag a selection box to select multiple elements. Multiple selected elements can be dragged to a new location as a unit. You can also use the arrow to double click on any of the graphics below to further define their contents.
	Creates a **raster object**, which is a single or layer-set of raster data typically used to contain or manipulate data from image files.
	Places a **vector object**, which is usually an Arc/Info coverage or an Annotation layer.
	Creates a **matrix object**, which is a set of numbers arranged in a fixed number of rows and columns in a two-dimensional array. Matrices may be used to store numbers such as convolution kernels or neighborhood definitions.
	Creates a **table object**, which is a series of numeric values or character strings. A table has one column and a fixed number of rows. Tables are typically used to store columns from an attribute table, or a list of values which pertain to individual layers of a raster layer-set.
	Creates a **scalar object**, which is simply a single numeric value.
	Creates a **function definition**, which are written and used in the Model Maker to operate on the objects. The function definition is an expression (like "a + b + c") that defines your input. You can use a variety of mathematical, statistical, Boolean, neighborhood, and other functions, plus the input objects that you set up, to write function definitions.
	Use this tool to **connect objects and functions together**. Click and drag from one graphic to another to connect them in the order they are to be processed in the model. To delete a connection, simply click and drag in the opposite direction (from the output to the input).
	Creates **descriptive text** to make your models readable. The Text String dialog is opened when you click on this tool.

Select the **Model Maker** button in the **Spatial Modeler** menu. Now, create your own NDVI spatial model with your knowledge of NDVI (**NDVI = (NIR -Red)/(NIR+Red)**). Run your model and open your output image. If you didn't get the proper image, please make it sure that you declare the raster as float, not integer, in the input/output raster object windows.

Save and open the model. Explore other menu and tool options.

2a. Check your output image. Does it show the similar pattern with your knowledge of NDVI?

There are built-in models of NDVI for several sensors (e.g., TM, MSS, and AVHRR) in ERDAS IMAGINE. Select the **Indices** button in the **Spectral Enhancement** in the **Image Interpreter** menu. Set **Select Function** as **NDVI** in the Indices window and click **View** button in the bottom, and you get the spatial model like this.



6.4 Image Classification

Objectives:

- √ Define and evaluate a signature.
- √ Perform supervised classification.
- √ Generate clusters using an unsupervised classification approach (ISODATA).
- √ Evaluate the clusters in image feature space.

Part I Training Site Selection

***Signature Extraction*:**

To begin, open mangrove90.img in a viewer and fit to frame. The ERDAS Imagine **Signature Editor** allows you to create, manage, evaluate, edit, and classify signatures (.sig extension). Both parametric (statistical) and non-parametric (feature space) signatures can be defined. In this exercise, we will be defining signatures by collecting them from the image to be classified using the Signature Editor and Area of Interest (AOI) tools. The **Signature Editor** can be accessed through the **Classifier** icon in the Imagine icon panel. This device will enable you to select and save training sites and make them available for future use in a supervised classification. You may launch the Signature Editor without having obtained any previous signatures or you can retrieve a .sig file using **Load** under the **File** menu within the Signature Editor. The Signature Editor has many interesting and useful tools. The tools you should concern yourself with are the buttons directly beneath the menu bar, especially the three that have pluses and minuses on them. These will be used in conjunction with the AOI editor to enter training sites into a .sig file. The first button, it looks like an **L** with a plus next to it, is used to add a currently selected AOI site to the file. The next one to the right will replace the highlighted field with the current AOI site. The third button is used to merge training sites (signatures) once you feel they have similar spectral characteristics.

	Create New Signature(s) from AOI
	Replace Current Signature(s) with AOI
	Merge Selected Signatures

To gather the spectral signature of the sites you would like to place in the signature editor as training sites, you will need to use the **AOI** (Area Of Interest) tools. The **AOI** menu can be accessed through the current viewer's menu bar. In the **AOI** pull down menu you will be presented with many choices (AOI Styles changes the way the cursor styles look). The **Tools** and **Commands** options are important because they allow you to select the type of polygon, modify the polygon, etc. with which you want to encompass your AOI. The **Seed Properties** option is also important because it allows you to modify the limits of seed area growth by area and/or distance in addition to letting you select the **Neighborhood** selection criteria. We will be using the Neighborhood default setting which specifies that four pixels are to be searched, then only those pixels above, below, to the left, and to the right of the seed or any accepted pixels are considered contiguous. Under **Geographic Constraints,** the **Area** check box should be turned on to constrain the region area in pixels. Enter **500** into the **Area** number field and press Return. This will be the maximum number of pixels that will be in the AOI. Enter **10.00** in the **Spectral Euclidean Distance** number field. The pixels that are accepted in the AOI will be within this spectral distance from the mean of the seed pixel. Before closing the Seed Properties window, click on **Options** and make sure that the **Include Island Polygons** box is turned on in order to include nonadjacent polygons within the logical growth region.

To begin the process, you must select an area on the image using one of the **AOI** tools, such as the polygon or rectangle tool, or you can place a seed and grow a region using the **Region Grow** tool (looks like a magnifying glass in the AOI menu). Use whatever you need in that particular instance; just make sure you think you know what the area represents in terms of ground cover. In the viewer, zoom into an area where you want to select an AOI using the viewer's magnifier tool and then select the AOI polygon tool and draw a polygon around your chosen area (or you may plant a seed to grow). After the AOI is created, a bounding box surrounds the polygon or region, indicating that it is currently selected. While the area is selected, use the **Create New Signature** button to add the selected area into the Signature

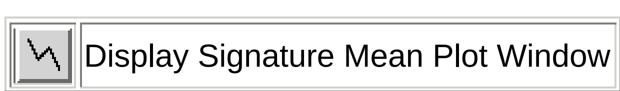
Editor. Now click inside the **Signature Name** column for the signature you just added and give it a name (use names like urban1, urban2, etc. to define your individual AOIs). You may also want to change the color in the **Color** column. You can use the **Image Alarm** tool under **View** in the **Signature Editor** to get a preview of the extent that the classes you have chosen represent the rest of the image. If you select the **Image Alarm** option a pop-up box titled **Signature Alarm** will open. In this box you can choose to indicate classes that overlap and the color that represents overlap. This can be useful if you are considering merging classes. The signature alarm will also, as mentioned, let you see the extent of each of the classes (you will need to do this anyway before you can see the overlap). Do this by selecting (highlighting) a class or a set of classes in the signature editor using the cursor. You can select the color you would like to represent the class as by clicking on the colored square with the right mouse button. Once you have made your selections click on the OK button in the signature alarm and let Imagine do its work. Using this tool, you can see what areas are covered and which are not using the classes you have selected (according to the rules of parallelepiped classification logic). For this exercise, take at least three relatively distinct training sites for each of the following classes found in the scene:

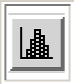
1. **Mangrove**
2. **Agriculture**
3. **Water bodies**
4. **Barren lands**

When you are done generating the training sites for these 4 classes and you feel they are representative of the whole scene based on your use of the signature alarm, save the signature editor file using the **Save As** menu item under file in the signature editor menu.

Feature Selection:

The **Signature Mean Plot** button to the left of the histogram in the signature editor, allows you to view the mean plots of your training data on the screen and thus estimate which of the TM bands best discriminates between the different training sites that you have selected. Select this option as well as the histogram (if you feel this is more helpful, use the all selected signatures and all bands option and make sure you have all of the classes highlighted when you do this). The most precise way to accomplish the task of determining which bands to use is to through the use of the separability option under the **Evaluate** menu in the **Signature Editor.** Select 3 for the **Layers Per Combination** choice. Use the **Best Average** listing method and click **OK.** The results of this operation will appear in a pop-up box titled **Separability CellArray.** Note which 3 bands seem to do the best job of spectrally separating your classes. Also note which classes overlap and which are spectrally separable. You will need this information for the next part of the exercise.



	Display Signature Histogram Window

Supervised Classification:

Now that you have specified your training sites, you are ready to proceed with the supervised classification. Under the **Classify** menu in the **Signature Editor,** choose the **Supervised Classification** option. Because you have already selected a signature file it will not ask for one. If you were to close the signature editor and access the supervised classification through the Imagine **Classifier** menu, you would be able to open a .sig file. In the **Supervised Classification** pop-up box that appears give a name for your output file. The **Parametric Rule** setting should be set to **Minimum Distance** (note: the textbook gives a good description of the differences, advantages and disadvantages of the various classification logic schemes) and everything else should be left as you find them. Select **OK** when everything is in place. Open a new viewer and display the results, then answer the following questions concerning signature extraction and supervised classification:

1) What function does the Image Alarm present?
2) Explain why you think the mean plot and the separability cellarray seem to differ on the three most important bands in certain instances.
3) Which Distance Measure method did you choose and why? Which three bands appear to best separate the classes? (Use the results from the Signature Separability measures on this one)
4) Which land cover classes seem to be confused the most and why do think this is the case?
5) If you could combine or throw out certain signatures (training sites) to create sufficient separability between classes, which would you manipulate and how?

Unsupervised Classification (Clustering):

Unsupervised classification differs from a supervised classification in that the computer develops the signatures that will be used to classify the scene rather than the user. The classification process results in a number of spectral classes which the analyst must then assign (***a posteriori***) to information classes of interest. This requires knowledge of the terrain present in the scene as well as its spectral characteristics.

The **Unsupervised Classification** option is selected in the **Classification** menu under the **Imagine Classifier** icon. You will notice that the **Unsupervised Classification** dialog box states that it is an ISODATA unsupervised classification. The **Iterative Self-Organizing Data Analysis Technique (ISODATA)** is a widely used clustering algorithm and is different from the formerly used chain method because it makes a large number of passes through the remote sensing dataset, not just two passes. It uses the minimum spectral distance formula to form clusters. It begins with either arbitrary cluster means or means of an existing signature set, and each time the clustering repeats, the means of these clusters are shifted. The new cluster means are used for the next iteration.

The ISODATA utility repeats the clustering of the image until either a maximum number of iterations has been performed, or a maximum percentage of unchanged pixels has been reached between two iterations. Performing an unsupervised classification is simpler than a supervised classification, because the signatures are automatically generated by the ISODATA algorithm. However, as stated before, the analyst must have ground reference information and knowledge of the terrain, or useful ancillary data if this approach is to be successful.

To begin the unsupervised classification, click on the **Classification** icon and then select **Unsupervised Classification...** Fill in the input and output information in the Unsupervised Classification dialog box. Give both the Output Cluster Layer and Output Signature Set a similar name. Make sure that under **Clustering Options** the **Initialize from Statistics** box is **on** and set **Number of Classes** to **30.** Set **Maximum Iterations** to **20** and leave the **Convergence Threshold** set to **0.950.** Maximum Iterations is the number of times that the ISODATA utility will recluster the data. It prevents the utility from running too long, or from getting stuck in a cycle without reaching the convergence threshold. The convergence threshold is the maximum percentage of pixels whose cluster assignments can go unchanged between iterations. This prevents the ISODATA utility from running indefinitely. Leave everything else in its default state. When you have entered all the relevant information click **OK** to begin the process.

Cluster Identification:

To aid in evaluation we will need to view the results of the clustering so that we may see how the clusters are arranged in feature space and thereby make informed decisions about the nature of the cluster. The first step that will allow us to do so is the creation of feature space images. The Feature Space Image button can be found on the Classification menu. When it has been selected a dialog box will appear saying Create Feature Space Images at the top. Select the original image (not the clustered one) as the Input Raster Layer and make sure the Output Root Name is similar to the raster layer and the directory path is correct. Leave the rest of the selections at their default settings and click OK. When the processing is complete open a new viewer and view the output images. Note that the 2_5 (and other options) represents the layers that are being shown in the image. In this case layer 2 (band 2) will be displayed on the x-axis and layer 5 (band 5) on the y-axis. ***Pay close attention when you look in the book for help in determining what clusters represent which ground elements.***

The next step is to open the Signature Editor (under the Classification menu) with the *.sig file you created in the unsupervised classification. Select all the clusters (they should all be highlighted in yellow). In the Signature Editor main menu select Feature and then in that pull-down menu select Objects. This will display a Signature Objects dialog box that allows you to tell Imagine which viewer you want to receive the signature editor information about the clusters. In this case we want the viewer in which you have displayed your chosen feature space graphic. Select that viewer # in the Signature Objects space provided that represents this viewer. Select Plot Ellipses and Plot Means (or you can try the others if you like). Leave everything else in it's default state and click OK. Only selected clusters in the Signature Editor window will be drawn. More than likely your ellipses and means are multi-tonal in nature. If you would like them all to be white, red, green, etc... select all the classes in the Signature Editor dialog box using the mouse and change the color to the one you desire. Save the information as an Annotation Layer.

To analyze the content of the clusters, you should use a combination of techniques. The first should be to use the mean scatter plot to make some educated guess about the information in each cluster. You might want to label each of the 30 clusters on the scatter plot using the **Label** option in the **Signature Objects** dialog box so you know what cluster is containing which class. You will more than likely have to zoom in to get a better look at some of the clusters given the close proximity of clusters to each other. You should also have a viewer open with the original scene displayed. This will further help you identify the land cover class. If you are feeling adventurous, you can overlay your classified image on the original image and set all the clustered image's colors to transparent using the **Raster Attribute Editor** found under the Viewer menu (Raster - Attributes). Once you have set all classes to transparent then you can individually color (by making them opaque) particular classes and see where they are on the image. Another method may be to use the **Utility - Swipe** or the **Utility - Fade** tools in the Viewer by opening the classified image on top of the raw data (do not **Clear Display** after opening the first raw image). Regardless of how you choose to proceed you should not rely on any one particular method but a combination of methods and some common sense to arrive at a sound classification.

When you have decided upon the class breakdowns, use the **Raster Attribute** editor to assign class names and colors to the classification image. Create the same five classes you used in the supervised classification and place each of the 30 clusters into one of the classes by giving it the same color and class name as every other cluster in that class. When you satisfied with your unsupervised classification, finish the lab.

6.5 Change Detection of Coastal Vegetation

Objectives:

- √ Compare and contrast two different change detection methods to analyze changes in land use/land cover between two dates.

Introduction:

Change detection is the process of identifying differences in the state of a feature or phenomenon by observing it at different times. In remote sensing it is useful in land use/land cover change analysis such as monitoring deforestation or vegetation phenology. However, there are many remote sensor system and environmental parameters that must be considered whenever performing change detection. Failure to understand the impact of the various parameters on the change detection process can lead to inaccurate results. Ideally, the remotely sensed data used should be acquired by a remote sensor system that holds temporal, spatial, spectral, and radiometric resolutions constant. For example, changes in radiance values between images may be caused by a number of different factors such as a field which may have different soil moisture content and therefore appear different in two individual images.

Bring up two viewers and display the 1990 and 2000 images and compare them side-by-side. These images depict mangrove forests in Burma. Visually examine the differences as an initial familiarization technique. It is important to have an idea of where you might expect to see changes.

Change Detection Methods:

Of the many change detection methods available, we will be examining three. Ideally, it is important that the analyst has knowledge of the cultural and biophysical characteristics of the area and preferably some ancillary data. The analyst should also be aware of the different techniques available, including the limitations and advantages of their respective algorithms.

Method 1: Image Differencing in Spatial Modeler

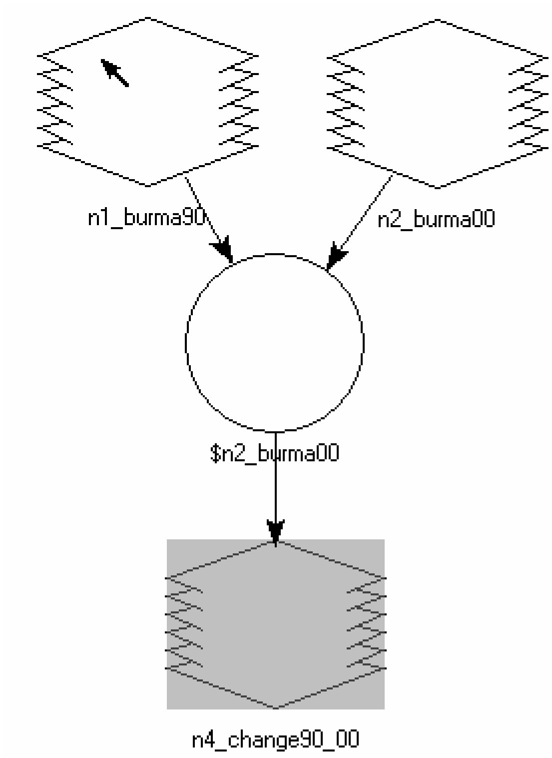
This involves the subtraction of two images and the addition of a constant value to the result. These results can be demonstrated in a differenced distribution for each band.

The Spatial Modeler function in ERDAS Imagine allows the user to graphically create a spatial model and execute it. In this simple example, we will create a change detection model which uses both *mangrove90.img* and *mangrove00.img* as inputs, develops an image differencing algorithm as the function, and creates a change detection image as an output.

Begin by opening the **Spatial Modeler** menu by selecting the Modeler icon in the Imagine icon panel. Review the function of each of the Model Maker's tools before going on.

Now select the **Model Maker** button in the **Spatial Modeler** menu. Wait for the Model Maker dialog box and the model tools to appear. Select the **raster object tool** and place a raster object in the model window (towards the top left of the window). It will have a question mark as a title for now, but you will assign the input raster file later. Repeat the process and place a second and third raster icon in the window (one on the top right and one near the bottom center. If you make a mistake, use the **Edit** menu to cut the selected mistake out of the model.

Now select the **function tool** and place a function symbol near the center of the model window. Use the **connect tool** to connect the raster objects on top to the function symbol by selecting a point inside the top left raster icon and dragging a line to the center of the function symbol. Release the mouse and a connection arrow should appear. Now connect the upper right raster icon to the function symbol, and then the function symbol to the lower raster object. The resulting function should look somewhat like the model depicted below:



Now double click on the top left raster object. The Raster Object dialog box will open. Select *mangrove90.img* as the input and leave all other options in their default state. When this is completed, select **OK**. The name of the image should now be present below the raster object. Complete the same process for the upper right raster object with *mangrove00.img* as the input.

Next, double click on the **function symbol.** In the Function Definition window that appears, you will create the image differencing algorithm to be used in this model. In the list showing the available inputs, the number in parentheses corresponds to the individual raster layer. We will be using the full scene image for the calculations and NOT the individual layers. Use the dialog box calculator to create the following algorithm in the blank space in the bottom of the dialog box.

$n1_mangrove90 - $n2_mangrove00 + 128

Finally, double click on the bottom raster object, which is your raster model output, and give it an output file name. Again, leave the rest of the selections in their default state. When all objects are labeled and the function definition complete, look at the top of the model window and find the **Process** option. Run the model by selecting **Run**. When the model is processed, select **OK** and exit the Model Maker without saving any changes. In a new viewer, display the model output image using the same RGB layers you used in the first part of the exercise.

1) Why add a constant of 128 to the image difference equation?

2) After running an improved image difference equation of your choice, compare the output model image with the two original images. What areas appear to have the most land cover change? What do the different colors represent?

Method 2: Multi-Date Visual Change Detection Using Write-Function Memory Insertion

This method involves the use of one band from each date of imagery. Each band is put in an image plane to create a layer stack and the composite is displayed. The corresponding colors represent change in either direction or no change.

Select the **Interpreter** icon in the Image icon panel and then select the **Utilities** option. In the menu that appears, select the **Layer Stack.** We will be creating a layer stack using only the NIR bands in each of the 1994 and 1996 images. When the Layer Stack dialog box appears, only select layer 3 of *mangrove90.img* as the first input file and click **Add**. This should add the first input image name and path into the blank space above the Add button. Now add the 1996 NIR band to the image by selecting layer 3 of the *mangrove00.img* in the input file space. After you have specified an output file name, leave the rest of the information in its default state and click **OK.** Wait until the processing is complete and then display the output image in true color mode. Assign layer 1 to red, layer 2 to green, and blue to either layer 1 or 2 (Note: 1:2:2 seems to be provide the most clearly defined change areas). After the image is displayed, go to **Raster - Band Combinations** and turn off the blue gun by clicking on the button next to the word **Blue.** This combination leaves you with just the red (1994) and green (1996) layers in the viewer window. The resulting image should have only red, green and yellow shades.

Method 3: Change Detection using Specific Threshold

Select this option to compute the differences between two images and to highlight changes that exceed a user-specified threshold. You will be creating two new output image files, which you can save to a directory. Open a viewer to see the files. To open this dialog, select **Image Interpreter | Utilities... | Change Detection...**. **Before Image:** The Before Image (*mangrove90.img*) is the earlier of the two images. If you are comparing bands of one image, you do not have to click to select from the Before Image popup list. **Layer:** If you are working with a multiband image, you may choose any band for analysis in conjunction with the Before Image. The Before Image should match the After Image when you compare the two images. **After Image:** The After Image (*mangrove00.img*) is subtracted from the Before Image to provide the image difference and Highlight Change image. The After Image is the more recent of your two themes and reflects change over time. **Layer:** If you are working with a multiband image, you may choose any band for analysis in conjunction with the After Image. The After Image should match the Before Image when you compare the two images. **Image Difference File:** A grayscale image composed of single band continuous data. This image is the direct result of subtraction of the Before Image from the After Image. Since Change Detection calculates change in brightness values over time, the Image Difference File reflects that change using the grayscale image. Type in a name for this file here and save it to a directory. **Highlight Change File:** The Highlight Change Image is a five-class thematic image, typically divided into the five categories of Background, Decreased, Some Decreased, Unchanged, Some Increase, and Increased. Type in a name for this file here and save it to a directory.

Good Luck!

Surabaya Coast from Space (Credit: Digital Globe)

BIBLIOGRAPHY

1. FAO, (2004). FAO Global forest resources assessment update 2005 Terms and definitions (Final version), Food and Agriculture Organization of the United Nations, Rome. Available at: http://www.fao.org/docrep/007/ae156e/AE156E00.htm#TopOfPage.

2. Lambin E. (1996). Monitoring Forest Degradation in Tropical Regions by Remote Sensing: Some Methodological Issues. *Global Ecology and Biogeography*, Vol. 8, No. 3/4, Tropical Open Woodlands Special Issue (May - Jul., 1999), pp. 191-198

3. Riitters, K., J. Wickham, R. O'Neill, B. Jones, and E. Smith. 2000. Global-scale patterns of forest fragmentation. Conservation Ecology 4(2): 3. [online] URL: http://www.consecol.org/vol4/iss2/art3/

4. Remote Sensing Tutorial by NASA, available at: http://rst.gsfc.nasa.gov/

5. SOUZA C. M. ROBERTS D. (2005). Mapping forest degradation in the Amazon region with Ikonos images. International journal of remote sensing, vol. 26, n°3, pp. 425-429.