GOFC-GOLD GLOBAL OBSERVATION OF FOREST AND LAND COVER DYNAMICS

USE OF SATELLITE REMOTE SENSING IN LULUCF SECTOR

Background paper at the IPCC Expert Meeting 13-15 May 2008 to consider the current IPCC guidance on estimating emissions and removals of greenhouse gases from land uses such as agriculture and forestry

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Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) is a coordinated international effort to ensure a continuous program of space-based and in situ forest and other land cover observations to better understand global change, to support international assessments and environmental treaties and to contribute to natural resources management.

GOFC-GOLD encourages countries to increase their ability to measure and track forest and land cover dynamics by promoting and supporting participation on implementation teams and in regional networks. Through these forums, data users and providers share information to improve understanding of user requirements and product quality.

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1. Introduction

Accurate and reliable information about land areas and area changes is critically important for developing inventories that are consistent with *good practice* as defined in the IPCC Guidelines. In this context, remote sensing imagery assumes a great importance as it may represent a cost-effective tool for inventory compilers, especially with the medium resolution (c. 30 m) global coverage of satellite imagery obtained from satellites such as Landsat. Information on availability and capabilities of satellite remote sensing data could be extremely useful in filling the gaps in the availability of data regarding forests and other land cover.

This background paper is intended to present how the remote sensing imagery could be useful to the inventory compilers for the Land Use, Land Use Change and Forestry (LULUCF) sector for different level of data needs. Starting from a brief analysis of the current use of remote sensing (RS) in GHG inventories, the paper analyses the current operational capabilities of satellite remote sensing, including the discussion of the related uncertainties. In this analysis, we focused on remote sensing data from satellite and thus do not consider remote sensing data from airborne such as aerial photography. The two reasons for this restriction are: (i) there is already a long experience on the use of airborne data by national land use planning agencies and (ii) airborne data are more similar to field data in relation to their availability (limited to specific countries or regions) and to cost/accuracy issues (airborne data are usually much more expensive but can provide more spatially detailed information than satellite data).

Finally, this paper discusses specific issues on which additional guidance could be useful and presents the potential role of the 'Global Observation of Forest and Land Cover Dynamics' (GOFC-GOLD) - a technical panel of 'Global Terrestrial Observing System' (GTOS). Specifically, GOFC-GOLD could stimulate a consensus perspective among the global community of earth observation experts on methodological issues related to the use of RS for national-level land cover and land use monitoring, and the related accuracy assessment procedures. During the preparation of this background paper, the expertise from members of the GOFC-GOLD Land Cover Team was complemented by experts in UNFCCC reporting.

2. Requirements for consistent representation of land areas

2.1 Requirements under UNFCCC

Information on land areas is essential to estimate carbon stock changes and greenhouse gas emissions/removals associated with LULUCF. As the rules for reporting emissions and removals from the LULUCF sector changed over time, also the requirements for representing land areas evolved.

While the reporting of the LUCF sector in Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (1996 GL) was based on "default categories"[1], the IPCC Good Practice Guidance for LULUCF (2003 GPG-LULUCF) introduced six broad land-use categories: Forest land, Cropland, Grassland, Wetlands, Settlements, Other land. Each category is further divided into two subsections based on the status and recent history of land-use: land category remaining in the same land category and land converted to the land-use category in question[2]. For example, the following categories of change from 'Forest Land' should be considered when preparing a LULUCF inventory: Forest Land Converted to Crop Land, Forest Land Converted to Grassland, Forest Land Converted to Settlements, Forest Land Converted to Wetlands, and Forest Land Converted to Other Land. This categorization of land uses, and the necessary guidance for ensuring consistency in the reporting and avoiding overlaps or gaps, was further confirmed in the latest IPCC Guidelines for Agriculture, Forestry and Other Land Uses (2006 GL-AFOLU). Only broad and non-prescriptive definitions are provided for these land use categories: countries may use their own definitions, which may or may not refer to internationally accepted definitions (e.g. FAO), possibly stratified (e.g., by climate or ecological zones) so that the emissions/removals can be estimated at an appropriate level of detail. The definitions of land-use categories may incorporate land cover type, land use based, or a combination of the two. It is recognized that countries may use various methods to obtain data - including annual census, periodic surveys, remote sensing and international databases -, and that different types of information may be produced (e.g., maps or tabulations). In any case, definitions should be clearly described, including approaches for distinguishing between managed and unmanaged land, and applied consistently for the national land area over time.

IPCC provide guidance on the use of three generic "approaches" for representing land areas. Approach 1 identifies the total area for each individual land-use category within a country, but does not provide detailed information on the nature of conversions between land uses. Approach 2 introduces tracking of conversions between land-use categories. Approach 3 extends the information available in Approach 2 by allowing land-use conversions to be tracked on a spatially explicit basis. The approaches are not presented as hierarchical tiers, are not mutually exclusive, and countries may use a mix of Approaches for different regions over time. In any case, data should be adequate (i.e., capable of representing land-use categories and land-use changes), consistent over time, complete (all land within a country should be included) and transparently documented.

2.2 Specific requirement under the Kyoto Protocol

Instead of land-use based reporting structure used for UNFCCC, the reporting under the Kyoto Protocol is activity based, i.e. limited to specific activities defined under Articles 3.3 and 3.4, which represent a subset of the emissions and removals reported under the UNFCCC.
Art. 3.3 covers changes in C stocks between 2008 and 2012 due to human-induced Afforestation and Reforestation (AR)[3] and Deforestation (D) activities occurred since 1990. Art. 3.4 covers changes in C stocks between 2008 and 2012 due to Forest management (FM), Cropland management (CM), Grazing land management (GM) and Revegetation (RV) activites occurred since 1990.

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[1] These categories were: 5A. Changes in forest and other woody biomass stocks; 5B. Forest and grassland conversion; 5C. Abandonment of managed lands; 5D. CO2 emissions and removals from soils.

[2] For this subcategory, the IPCC default conversion period is 20 years, based on soil C pools typical time to reach equilibrium after land-use conversion.

[3] Though there is a distinction between afforestation and reforestation in the KP (i.e. if the land had not been forest for more than 50 years it is afforestation), since the methodologies for estimating emissions and removals are identical, the two activities are treated as one for reporting purposes under the Kyoto Protocol.

Chapter 4 of IPCC 2003 GPG-LULUCF provides specific guidance on categorization of lands under 3.3 and 3.4 activities. In synthesis, 3.3 activities involve a land use change and their reporting is mandatory for Annex I Parties which ratified the Kyoto Protocol. By contrast, 3.4 activities are not associated to a conversion of land, and their election is voluntary. In the initial report under the Kyoto Protocol, due by 1/1/2007, Parties have indicated which 3.4 activities were elected and also other information, such as the parameters chosen to define a "forest" under KP[4] and the methodology to distinguish deforestation from harvesting.

A complex set of specific rules apply to lands under 3.3 or 3.4 activities. Among these, the fact that a land area can only be classified under one particular activity and, once included in the Kyoto Protocol inventory, it must be accounted for the remainder of the commitment period and subsequent periods. Since the reporting under Art. 3.3 is mandatory, it has precedence over an article Art. 3.4. Precedence is also given to deforestation over AR activities. Furthermore, reporting must include information on the geographical boundaries of these areas, either encompassing units of lands or land subject to multiple activities ("reporting method 1" - Broad area identification) or units of lands or land subject to a single activity ("reporting method 2" - Complete area identification). Chapter 4.2.2.3 of IPCC 2003 GPG-LULUCF illustrates the relationships between "approaches" (see above) and "reporting methods". As a general rule, the selected approach should allow all 3.3 and 3.4 activities to be identifiable, adequately reported and tracked in the future. If this does not occur – i.e. if the approach is not spatially-explicit, or if the spatial resolution at which land-use changes are tracked is not consistent with the size parameter selected by a country to define forest – all the necessary supplementary information must be provided in a transparent way.

3. IPCC Guidance on the use of RS

The sections "Remote sensing techniques" (2.4.4.1 of 2003 GPG-LULUCF and 3A.2.4 of 2006 GL-AFOLU) provide a synthetic outline of the type of RS data acquired by sensors (optical, radar or lidar) onboard satellites, or by cameras equipped with optical or infrared sensors operated on airborne platforms. These sections also briefly discuss some of the strengths and problems of remote sensing techniques, including:

- The ability to provide spatially-explicit information and the possibility to cover large and/or remote areas that are difficult to access otherwise;
- The possibility of repeated coverage and the availability of archives of past remote sensing data that can be used to reconstruct past time-series of land cover and land use;
- The challenge of interpretation, i.e. the images need to be translated into meaningful information on land cover and land use by visual or digital (computer based) analysis.
- The risk, depending on the satellite sensor, that acquisition of data is impaired by the presence of clouds and atmospheric haze;
- The need of ground reference data and of evaluation of mapping accuracy;
- The fact that a complete remote sensing system for tracking land use conversions may require combinations of different types of remote sensing data at a variety of resolutions.

Important criteria for selecting remote sensing data and products are:

[4] The Kyoto Protocol defines a "forest" as follows: Minimum area of land of 0.05 - 1.0 ha; Tree crown cover 10 - 30%; Minimum height 2 - 5 m at maturity in situ

- Adequate land-use categorization scheme;
- Appropriate spatial resolution;
- Appropriate temporal resolution for estimating of land-use conversion;
- Availability of accuracy assessment;
- Transparent methods applied in data acquisition and processing;
- Consistency and availability over time.

Given the requirements for consistent representation of land areas outlined above, the primary use of satellite remote sensing for UNFCCC and KP reporting is for obtaining area estimates of land-use categories and of land use changes (especially when using approach 3), or for identifying geographical boundaries of lands and units of land under the Kyoto Protocol (especially when using reporting method 2).

However, satellite remote sensing may assist reporting emissions and removals of GHG gases in a number of different ways, including:

- Detection of vegetation disturbances such as forest fires and associated land degradations;
- Spatial assessment of natural hazard impacts (i.e. storm damage) to help with factoring out;
- Assisting in the stratification for the estimation of C stocks for large areas, thus complementing national forest inventories;
- Indirect estimation of above ground biomass through radar and lidar techniques;
- Verification of areas of land uses and land use changes using archived satellite observations as independent data source (see also Ch. 5.7.2 of IPCC 2003 GPG-LULUCF).

4. Current use of remote sensing techniques in GHG inventories

We analyzed the latest available National Inventory Reports (NIR) of Annex-I countries – in most cases from the 2008 submissions to UNFCCC – in order to evaluate the methods used to represent land areas and, specifically, the current use of RS techniques in the preparation of GHG inventories.

Although all the countries provided some description on the methodology used for representing land areas, in most cases it was not possible classifying it as following one of the IPCC “approaches”.

According to the available information, 23 out of 38[5] Annex-I countries (60%) explicitly indicated the use of RS techniques or of RS-products in their NIR (Table 1), even if in some case it was not specified the product and how it was used. Generally, these countries integrated the existing ground-based information (e.g., National Statistics for the agricultural, forestry, hydraulic and urban sectors, vegetation and topographic maps, climate data) with RS data (like aerial photographs, satellite imagery using visible and/or near-infrared bands, etc.), using GIS techniques. In particular, the following RS techniques were used:

1) <u>Aerial photography</u>: although analysis of aerial photographs is considered one of the most expensive method for representing land areas (unless aerial photos already exits when acquired for another purpose), 11 countries used this methodology, in combination with ground data and in some case with other RS techniques or land cover map (e.g. CORINE LC), to detect land use and land use changes. For instance, France used 15600 aerial photographs together with ground surveys (TerUti LUCAS). The reason is essentially due to the existence for some countries of historical data, although sometimes characterized by different spatial resolution and quality, which permits to monitor accurately land use and land use changes back in the past. Moreover, in some case a digital

[5] NIRs by Russian Federation and Belarus were not included in this analysis because only available in Russian.

surface model might was estimated using stereographic analysis of photographs (e.g., Italy, Switzerland and Liechtenstein).

2) Satellite imagery (using visible and/or near-infrared bands and related products): only 5 countries used detailed satellite imagery in the visible and/or near-infrared bands for representing land areas. Australia combined together coarse (NOAA/AVHRR) and detailed (LANDSAT MMS, TM, ETM+) satellite imagery to obtain long time series of data, characterized by different spatial resolution, of the desired areas (see IPCC 2003 GPG-LULUCF for an overview of the Australian methodology).
Canada reported the use of satellite imagery to generate a detailed mosaic of distinct land cover categories; according to their NIR, in 2006 they used LANDSAT, SPOT, IRS (Indian Remote Sensing System) imagery and Google maps (based on LANDSAT and QUICKBIRD) whereas in 2007 only LANDSAT imagery were used.
France used numerous satellite images for representing land areas of French Guiana. In total 16786 ground points were analysed in 1990 and 2006 using LANDSAT and SPOT imagery, respectively (see also Section 5.5).

New Zealand based their Land Cover Database (LCDB1 and 2) on SPOT (2 and 3) and LANDSAT 7 ETM+ satellite imagery; mapping of land use in 2008 will use SPOT 5 satellite imagery. Moreover, New Zealand is planning within the LUCAS[6] project to use medium spatial resolution (250 m) MODIS satellite imagery to identify the location and timing of forest harvesting. Furthermore, the actual area of harvesting and deforestation will be determined from high resolution satellite systems or aerial photography.

Sweden used remote sensing methodologies for representing land areas of high mountains, military impediments and urban land. Finland reported the use of satellite imagery together with NFI8 data only for supporting stratification of forest inventory in Northern Lapland area.

Furthermore, 10 countries used existing land cover maps, like the CORINE products (1990 and or 2000 maps, and the associated change product), that are based on interpretation of satellite imagery and their verification through ground surveys; Czech Republic and Ireland used the CORINE products for reporting all the categories indicated by IPCC (2003), whereas other countries used the CORINE Land Cover map (CLC) to report only some IPCC categories, like Estonia, Hungary, Germany, Italy, Portugal, Spain and Turkey. For example, Estonia used CLC (scale 1:100 000) together with the Estonian soil map (scale 1:10 000) to determine that more than 520 thousand of hectares of organic soils are under the forest category. Hungary reported wetlands area using CLC products. Belgium reported some inconsistencies in the agricultural sector between some area reported by the national statistics and those reported by CLC.

3) Satellite or airborne radar imagery: none countries reported the use of satellite or airborne radar imagery for representing land areas. New Zealand may use satellite radar, within the LUCAS project, to identify the location and timing of forest harvesting if the evaluation of using medium spatial resolution (250 m) MODIS satellite images will be unsuccessful.

4) Airborne LIDAR: none countries reported using of LIDAR (LIght Detection And Ranging) for representing land areas of for estimating aboveground biomass.

[6] Land Use and Carbon Analysis System, not to be confounded with the European LUCAS project (see Section 5.5)

However, in New Zealand change in carbon stocks in forests planted after January 1st 1990 will be determined by measurement of trees within plots established on a 4 km grid across the country using a combination of field measurements and airborne LiDAR (Light Detecting and Ranging). The field measurement programme is underway and will be completed at the end of 2008. The LiDAR data (planned for February - April 2008) will be calibrated against the field measurements and only for forest plots that are inaccessible, LiDAR data will be processed to provide the total amount of carbon per plot; the measurement process will be repeated at the end of the first commitment period, based on the same set of plots.

Before 2008, only Norway reported (NIR 2006) the existence of national researches aimed to investigate the use of LIDAR for large scale biomass estimation; however, this methodology has not been mentioned in the latest (2008) NIR.

In conclusion, the suite of different national Annex I approaches seems very diverse. Only a minority of countries – typically characterized by large land areas not easily accessible - makes a direct use of satellite-RS for GHG inventory preparation. By contrast, most EU countries - typically characterized by a more intensive land management and by a long tradition of forest inventories – do not use satellite-RS or uses only derived products such as CORINE, at least for gathering ancillary information.

However, the situation seems in rapid development, as several Annex I countries have indicated the intention to use RS data in the near future (e.g., Italy, Netherlands, Denmark, Luxembourg, Iceland). Furthermore, the fact that the stringent reporting under Kyoto Protocol is approaching means that several countries are struggling in improving GHG inventories, which may involve more use of RS data or RS-derived products.

The situation regarding the use of RS by Non-Annex I countries is also very diverse. Given that most National Communications from those countries are not very updated or do not report much information of this issue, we restricted our analysis to the description of the national programs by Brazil and India (see Section 5.5). It is very likely that in the near future reporting requirements for non-Annex I countries will increase, e.g. in the context of the future mechanism for reducing emission from deforestation and forest degradation. This, in turn, will likely increase the need of RS data and of methodological guidance for their correct use.

Table1: Use of RS in Annex I Countries, as reported in their latest National Inventory Reports (in most cases 2008).

Annex I Countries[7]	Aerial Photography	Satellite imagery (using visible and/or near-infrared bands and related products)				Satellite or airborne radar imagery	Airborne LIDAR
		Coarse resolution	Medium resolution	Fine resolution	CORINE (CLC)		
Australia	Yes	Yes	Yes				
Austria							
Belgium					Yes[4]		
Bulgaria							
Canada	Yes		Yes	Yes[2]			
Croatia							
Czech Republic					Yes		
Denmark							
Estonia					Yes[4]		
Finland		Yes[5,6]					
France	Yes		Yes[5]				
Germany					Yes[4]		
Greece							
Hungary					Yes[4]		
Iceland			Yes		Yes[1]		
Ireland					Yes		
Italy	Yes		Yes[1]		Yes[4]		
Japan	Yes[4]						
Latvia							
Liechtenstein	Yes						
Lithuania							
Luxembourg	Yes		Yes[1]				
Monaco							
Netherlands			Yes[1]				
New Zealand	Yes	Yes[1]	Yes	Yes[1]		Yes[1]	Yes[1]
Norway	Yes						Yes[3]
Poland							
Portugal					Yes[4]		
Romania							
Slovakia							
Slovenia							
Spain					Yes[4]		
Sweden	Yes[4,5,6]						
Switzerland	Yes						
Turkey					Yes[4]		
Ukraine							
United Kingdom							
USA	Yes	Yes[6]					

Notes: 1. Use of this methodology planned in the future; 2. Methodology reported in previous NIR but not in the latest; 3. The intention to use this methodology reported in previous NIR but not in the latest; 4. Methodology used only for reporting of some IPCC categories; 5. Methodology used only for reporting of a portion of territory of the Country; 6. Methodology not specified. Note that NIRs by Russian Federation and Belarus were not included in this analysis because only available in Russian.

5. Current operational capabilities of satellite RS for LULUCF

5.1 Key features for Land Cover / Land Use monitoring from satellite RS

The key features for Land Cover / Land Use monitoring from satellite remote sensing are summarized hereafter.

- Land use versus land cover:
  - Land cover information systems usually mix land cover and land use concepts, in particular if natural vegetation is described using land cover parameters when agricultural and urban areas are described using land use criteria. However, though often not considered carefully, the distinction between land cover and land use concepts is fundamental to avoid any confusion or ambiguity.
  - Satellite remote sensing can provide accurate information on land cover.
  - Local expert information (or ground-based observations) is needed to support the land cover interpretation of remotely sensed data and to convert Land cover information into Land use information.
  - Methodological general approaches to characterize land use from land cover information are available in literature[7] but clarifications or specifications of a dedicated approach may be needed for specific needs requirements.

- Methodologies for land cover change assessments:
  - Multiple methods are appropriate and reliable for land cover monitoring at national scales.
  - For change assessment consistent methodologies need to be used between the repeated time intervals to obtain accurate results.
  - Results should be verified with reference data (ground-based or very high resolution observations), and successively, if possible, calibrated from these reference data.

- Consistent use of multi-temporal and multi-scale satellite imagery for monitoring changes:
  - Similar type of imagery (spatial resolution, spectral channels) is preferable
  - The lowest quality of available satellite imagery will determine the accuracy of results.

- Characteristics of the Satellite imagery to be selected in relation to reporting specifications / needs:
  - The Minimum Mapping unit (from the definition of LC classes) will determine the maximum spatial resolution of imagery to be used, e.g. a 1 ha MMU would require a spatial resolution of around 100 m in case of large areas of unfragmented forest or even smaller (e.g. 50 m) in case of fragmented forests.
  - Optical satellite imagery is more adapted to Land cover monitoring than radar satellite imagery.
  - As a minimum, Landsat-TM type satellite data around years 1990, 2000 and 2005 will be most suitable to assess historical rates and patterns of land cover changes with MMU of less than 1 ha in particular for developing countries.

5.2. Utility of satellite imagery for Land cover monitoring

Many data from optical sensors at a variety of resolutions and costs are available for monitoring land cover changes. Table 3.1 provides the main categories of satellite imagery and their utility for forest cover monitoring.

[7] e.g. Manual of Concepts on Land Cover and Land Use Information Systems, Eurostat European Communities, 2001

Table 3.1: Utility of optical sensors at multiple resolutions for deforestation monitoring (from GOFC-GOLD source book)

Sensor & resolution	Examples of current sensors	Minimum mapping unit (change)	Cost for data acquisition[8]	Utility for forest cover monitoring
Coarse (250-1000 m)	SPOT-VGT (1998-) Terra-MODIS (2000-) Envisat-MERIS (2004-)	~ 100 ha ~ 10-20 ha	Low or free	Consistent pan-tropical annual monitoring to identify large clearings and locate "hotspots" for further analysis with mid resolution
Medium (10-60 m)	Landsat TM or ETM+, SPOT HRV IRS AWiFs or LISS CBERS HRCCD	0.5 - 5 ha	<$0.001/km² for historical data $0.02/km² to $0.5/km2 for recent data	Primary tool to map deforestation and estimate area change
Fine (<5 m)	IKONOS QuickBird Aerial photos	< 0.1 ha	High to very high $2 -30 /km²	Validation of results from coarser resolution analysis, and training of algorithms

Utility of coarse resolution data

Coarse resolution (250 m – 1km) data are available from 1998 (SPOT-VGT) or 2000 (MODIS). As the temporal resolution of such coarse resolution imagery is daily, it provides the best possibility for cloud-free observations. Coarse resolution data also has cost advantages and offers complete spatial coverage. Coarse resolution data cannot be used directly to estimate area of forest change. However, these data are useful for identifying locations of rapid land cover changes for further analysis with higher resolution data. For example, MODIS data can be used as a stratification tool in combination with medium spatial resolution Landsat data to estimate forest area cleared. The targeted sampling of change reduces the overall resources typically required in assessing change over large nations. In cases where clearings are large and/or change is rapid, visual interpretation can be used to identify where change in forest cover has occurred. Validation of analyses with medium and high resolution data in selected locations can be used to assess accuracy. The use of coarse resolution data to identify deforestation hotspots is particularly useful to design a sampling strategy.

Utility of medium resolution data

Medium resolution (10-60 m) data, such as those from the optical sensors of the Landsat satellites (or similar sensors from other platforms) are considered to be the primary tool to map and estimate directly land cover area change, in particular for deforestation monitoring (see next section for more detailed description of these sensors). The USA National Aeronautics and Space Administration (NASA) launched the first satellite ('Landsat' series) with a mid-resolution sensor that was able to collect land information at a landscape scale in 1972.

[8] Costs relate to acquisition costs only. They do not include costs for data processing and for data analysis which are the main costs but more difficult to quantify in a standard manner.

A few very large countries, e.g. Brazil and India, have already demonstrated that operational wall to wall forest cover monitoring systems can be established based on medium-resolution satellite imagery. Brazil has measured deforestation rates in Brazilian Amazonia since the 1980s.

Other, newer, types of medium resolution sensors, in particular Radar (ERS1/2 SAR, JERS-1, ENVISAT-ASAR, RADARSAT and ALOS PALSAR) are potentially useful and appropriate. Radar sensors alleviate the substantial limitations of optical sensors in persistently cloudy parts of the tropics. Data from Radar have been demonstrated to be useful in project studies, but so far, they are not widely used operationally for land cover monitoring (including (tropical deforestation) over large areas or for national monitoring purposes. Over the next five years or so, the utility of radar may be enhanced depending on data acquisition, access and scientific developments.

Vegetation Canopy Lidar systems are usually operated on airborne platforms and have proven to be useful to characterize vegetation structure and biophysical variables in small-scale studies and some operational projects. Significant costs are associated for applying such methods for larger regions. Existing spaceborne LIDAR (ICESAT-GLAS) have not been designed for land monitoring. Research has shown some of their utility to characterize land cover that may evolve in the next years with new sensors and advanced algorithms.

Utility of fine resolution data

Fine resolution (< 5m) satellite data, such as those collected from commercial sensors (e.g., IKONOS, QuickBird) provide digital data of large-scale airphoto quality but can be prohibitively expensive to cover large areas. However, these data can be used to calibrate algorithms for analyzing medium and high resolution data and to verify the results — that are they can be used as a tool for “ground-truthing” the interpretation of satellite imagery or for assessing the accuracy.

5.3. Availability of current medium resolution satellite imagery

A series of seven (to date) of NASA Earth-observing ‘Landsat’ satellites have permitted continuous coverage since 1972. Landsat satellites have been launched every 2-3 years. Still in operation Landsat 5 and 7 cover the same ground track repeatedly every 16 days.

Almost complete global coverages from these Landsat satellites are available at low or no cost for early 1990s and early 2000s from NASA, the USGS, or from the University of Maryland's Global Land Cover Facility. These data serve a key role in establishing historical land cover transition rates, though in some parts of the humid tropics (e.g. Central Africa) persistent cloudiness is a major limitation to using these data. Until year 2003, Landsat, given its low cost and unrestricted license use, has been the workhorse source for mid resolution (10-50 m) data analysis.

On April 2003, the Landsat 7 ETM+ scan line corrector failed resulting in data gaps outside of the central portion of acquired images, seriously compromising data quality for land cover monitoring.
Alternative sources of data include Landsat-5, ASTER, SPOT, IRS, CBERS or DMC data (Table 3.2). NASA, in collaboration with USGS, initiated an effort to acquire and compose appropriate imagery to generate a mid-decadal (around years 2005/2006) data set from such alternative sources. The combined Archived Coverage in US Archive of the Landsat 5 TM and Landsat-7 ETM+ reprocessed-fill product for the years 2005/2006 covers more than 90% of the land area of the Earth. These data will be processed to a new orthorectifed standard and will be made available at the end of 2008.

The USGS is scheduling a no charge Web access to the full Landsat USGS archive. By September 30, 2008 the full Landsat 7 ETM+ archive (since 1999) will become available for ordering at no charge and by January 2009 all archived Landsat 5 TM data (since 1984), Landsat 4 TM (1982-1985) and Landsat 1-5 MSS (1972-1994) will be available for ordering at no charge.

Table 3.2: Present availability of optical mid-resolution (10-60 m) sensors (from GOFC-GOLD source book)

Nation	**Satellite & sensor**	**Resolution & coverage**	**Cost for data acquisition (from archive[9])**	**Feature**
USA	Landsat-5 TM (since 1984)	30 m 180×180 km²	600 US$/scene 0.02 US$/km² All US archived data will become free from 2009	Images every 16 days to any satellite receiving station. Operating beyond expected lifetime.
USA	Landsat-7 ETM+ (since 1999)	30 m 60×180 km²	600 US$/scene 0.06 US$/ km² All US archived data will become free from end 2008	On April 2003 the failure of the scan line corrector resulted in data gaps outside of the central portion of images, with serious data quality issues
USA/ Japan	Terra ASTER	15 m 60×60 km²	80 US$/scene 0.02 US$/km²	Data is acquired on request and is not routinely collected for all areas
India	IRS-P6 LISS-III & AWIFS	23.5 & 56 m		After an experimental phase, AWIFS images can be acquired on a routine basis.
China/ Brazil	CBERS-2 HRCCD	20 m	Free for developing countries	Experimental; Brazil uses on-demand images to bolster their coverage.
Algeria/ China/ Nigeria/ Turkey/ UK	DMC	32 m 160×660 km²	3000 €/scene 0.03 €/km²	Commercial; Brazil uses alongside Landsat data
France	SPOT-5 HRVIR	5-20 m 60×60 km²	2000 €/scene 0.5 €/km²	Commercial Indonesia & Thailand used alongside Landsat data

[9] Some acquisitions can be programmed (e.g., DMC, SPOT). The cost of programmed data is generally at least twice the cost of archived data. Costs relate to acquisition costs only. They do not include costs for data processing and for data analysis.

5.4. Key methodological and thematic features for land cover monitoring
Multiple methods are appropriate and reliable for land cover monitoring at national scales. Some key methodological features are indicated hereafter.

The spatial resolution of the satellite imagery determines the minimum detectable size of individual patches (which changing land cover between two dates) – also called Minimum Mapping unit: medium resolution (circa 30m) data allows detecting operationally over large regions (e.g. at country level) single patches of circa 1 ha. For detecting patches smaller than 0.1 ha Fine resolution (< 5 m) is needed.

Wall-to-wall (an analysis that covers the full spatial extent of the study area) and sampling approaches are both suitable methods for producing estimates of land cover area change. The main criteria for the selection of wall-to-wall or sampling approaches are:

- Wall-to-wall is a common approach if appropriate for national circumstances, in particular when a benchmark land cover map is needed.
- If resources are not sufficient to complete wall-to wall coverage, sampling is more efficient, in particular for large countries to produce accurate estimates of land cover change. Recommended sampling approaches are systematic sampling and stratified sampling which can be combined.

Both Wall to wall and sampling RS approaches can support all three approaches for Activity data, including approach 3 which is usually considered to be the most accurate.

Satellite imagery usually goes through three main pre-processing steps before interpretation: geometric corrections, cloud removal and radiometric corrections.

Many methods exist to interpret images. The selection of the method depends on available resources and whether image processing software is available. Visual scene to scene interpretation of forest cover change can be simple and robust, although it is a time-consuming method. A combination of automated methods (segmentation or classification) and visual interpretation can reduce the work load. Automated methods are generally preferable where possible because the interpretation is repeatable and efficient. Even in a fully automated process, visual inspection of the result by an analyst familiar with the region should be carried out to ensure appropriate interpretation.

For land cover change assessment consistent pre-processing and interpretation methodologies need to be used at repeated time intervals to obtain accurate results. Interdependent interpretation of multi date imagery is also preferable.

During the selection of the satellite imagery to use in any land cover assessment, seasonality of climate has to be considered: in situations where seasonal vegetation types (e.g. seasonal forest types with a distinct dry season where trees may drop their leaves) exist more than one scene should be used. Inter-annual variability has to be considered based on climatic variability.

The performance of satellite imagery to separate between different land cover types can also be dependent on the local or thematic context.

- It is in particular the case between grasslands and arable lands (crop lands) because permanent grasslands includes many different types of land cover, according to the pedo-climate, to the type of use (grazing, cutting, intensification) and to the level of artificialisation of the "natural" vegetation.

- If grasslands are a very extensive rangeland with natural vegetation, any change into a new pure-stand cultivated field will be easily detectable.
- But when grasslands are within an arable landscape, it is difficult to distinguish between permanent grasslands (> 5 years) and temporary ones (or fallows) which are indeed fully part of arable.
- Young plantation of trees may stay undetectable a few years, till the crown + shadow size allows a detection threshold;
- Zones of "agroforestry", corresponding to complex land uses (within one parcel) mixing permanent and arable crops with associated trees, would require fine resolution satellite data to be properly separated for forest cover.

Whatever is the method selected land cover change results should be ideally validated with multi-temporal ground-based or very high resolution observations. Some of the limitations mentioned above still hold for very high resolution observations; for example arable land and grassland are difficult to distinguish if grassland appears in plots with a size/shape similar to the crop fields. Also ground observation has some limitations, for example identifying if a grass is more than 5 years old (permanent) or less than 4 years old (arable land) is often difficult.

5.5. Examples of Land cover assessments using medium resolution satellite remote sensing at National level (or over larger areas)

CORINE Land cover/use maps of Europe

The European Environment Agency has developed harmonised pan-European land cover maps for years 1990 and 2000. Corine Land Cover 2000 (CLC2000) is an update for the reference year 2000 of the first Corine Land Cover database which was finalised in the early 1990s (CLC 1990) as part of the European Commission programme to COoRdinate Information on the Environment (Corine). It provides consistent information on land cover changes during the decade 1990 – 2000 across Europe.
CLC2000 is based on the photo-interpretation of Landsat satellite images (at 30m resolution with 100 m positional accuracy) by the national teams of the 27 participating countries A Minimum Mapping Unit (MMU) of 25 hectares was used for CLC 1990 (land cover patches smaller than 25 ha are not mapped) when the MMU of the change database was set to 5 ha. Forty-four land cover and use classes are used to map changes over time, including pure land cover classes (e.g. classes 1.1.1 “Continuous Urban fabric”, 2.1.3 “Rice fields”, 2.2.2 “fruit trees and berry plantations”, 3.1.1 “Broad-leaved forest”, 3.3.4 “Burnt Areas”, 4.1.2 “Peatbogs”); pure land use classes (e.g. classes 2.3.1 “Pastures”, 2.4.4 “Agro-forestry areas”) and heterogeneous land cover classes being a mixture of forest, natural and agricultural land (e.g. classes 2.4.2 “Complex cultivation” and 2.4.3 “Agriculture land with natural vegetation”). The target for Corine land cover/use attributes (thematic accuracy) is to be 85% correct.
The resulting European ‘Vector’ CLC changes database was compiled from results provided by National Teams and is based on standard methodology and nomenclature. The change product of CLC2000 is intended to show the land cover changes from year 1990 in ecosystems such as forests, lakes, pastures etc. and the impact of human activities (such as housing, food production, transport etc.) on land use.

LUCAS: European Land Use/Cover Area Frame Statistical Survey

Eurostat has carried out LUCAS to obtain harmonised information on land cover/land use and its changes with satisfactory precision at EU level. LUCAS is based on an area frame survey (sample of geo-referenced points surveyed in situ by surveyors). LUCAS data will be the main in-situ land use/cover data source for various activities at EU level and should therefore maintain the main characteristics of the data collection methods over time.

LUCAS surveys were carried out in 2001, 2003, and 2006. During the surveys of 2001 and 2003, land use and land cover information was surveyed in a two-stage regular grid. Covering 18 countries, the grid size was 18x18 km (primary sampling unit, PSU). Each PSU was a cluster of 10 secondary sampling units (SSU, altogether app. 100,000 points). The field surveyor registered land cover and land use information related to each point.

In 2006 LUCAS was based on a two-phase sampling. In the first a regular 2 km grid is laid over the EU territory. The grid nodes (nearly one million points for EU25) are photo-interpreted on aerial ortho-photos (80%) and satellite images (20%) with a land cover nomenclature of 7 classes: "Arable land", "Permanent crops", "Permanent grass", "Woodland, forest and shrub", "low or rare vegetation", "artificial" and "water and wetland".. A stratified sub-sample of these points was physically surveyed on the ground to calculate area estimates on the land cover and land use classes all over Europe.
In 2001 the LUCAS land cover nomenclature included 57 categories (including classes as C1 "Forest Area", C2 "other wooded area", C3 "Poplars, Eucalyptus", D0 "Shrubland", E0 "Permanent Grassland", G0 "Water and Wetland"), while LUCAS land use codification applied 14 land use classes (including "Agriculture", "Forestry", "Fishing" and "Mining, Quarrying" for non-urban non-industrial land uses). During 2006, the survey covered 11 countries with 170,000 ground survey points, and a nomenclature of 55 land cover and 33 land use classes. Surveyors are asked to take pictures of the landscape (N, S, W, and E.) and of the point (general view and detail of the vegetation).

LUCAS is scheduled for 2009 with the same sampling scheme of 2006 and an area of interest enlarged to EU-27. A discussion is ongoing to take a sample of soil for 10% of the visited points in 2009.

JRC Forest cover maps of the EU territory

The JRC has developed harmonised pan-European forest cover maps at 25 m resolution for years 1990 and 2000. These maps have been using around 400 Landsat scenes (for each period) to cover the whole European Union territory and they contain 3 land cover classes: forest, non-forest and clouds/snow. The maps are generated using a fully automated processing chain using CORINE Land Cover 2000 as a training dataset. The thematic accuracy of the forest map of year 2000 has been estimated to be over 85%.

For year 2006 a dataset of around 2,000 SPOT HRV (20 m resolution) complemented by IRS-P2 LISS-III at (23.5m resolution) has been assembled and is being processed to produce an updated forest map.

French monitoring system over French Guiana

IFN (Inventaire Forestier National (IFN) has developed a new approach to report on deforestation areas for its overseas department (DOM) of French Guiana between 1990 and 2006 which is similar to a classical national forest inventory survey. Such report was needed under the Kyoto Protocol rules and no estimates of deforestation were available to fulfil these needs. IFN has developed a specific method to report on forest cover changes. A sample of circa 17,000 plots of 1 ha size each (covering 0.1% of territory) have been interpreted visually from moderate resolution (10-30 m) spatial imagery acquired between year 1990 (Landsat TM) and year 2006 (SPOT HRVIR) (Stach et al., 2007). This specific sampling method is derived from traditional forest field inventory methods and provides high accuracy estimates. For this purpose, a full coverage of SPOT satellite imagery at 10 to 20m resolution acquired from the receiving station in French Guiana has been used. The samples were located randomly using a stratified approach with 3 strata based on a priori information: change area, lake area and no change area.

Brazilian national programme for estimating annual forest cover change in Amazonia

The Brazilian National Space Agency (INPE) produces annual estimates of deforestation in the legal Amazon from a comprehensive annual national monitoring program called PRODES.
The Brazilian Amazon covers an area of approximately 5 million km^2, large enough to cover all of Western Europe, from which around 4 million km^2 is covered by forests. The Government of Brazil decided to generate periodic estimates of the extent and rate of gross deforestation in the Amazon, "a task which could never be conducted without the use of space technology".
The first complete assessment by INPE was undertaken in 1978. Annual assessments have been conducted by INPE since 1988 with a consistent methodology. For each assessment circa 210 Landsat satellite images (30 m resolution) are acquired around August and analyzed. From 2003 an approach based on digital processing is in operational phase with Landsat images rescaled at 60m resolution. Land cover classes are: forest, non-forest vegetation, historical deforestation (sum of area deforested before year of assessment), new deforestation (during year of assessment), clouds, hydrography (water). Visual interpretation (before year 2002) or visual verification of the digital processing (after year 2003) is carried out on screen at scale of 1:100.000.
Results of the analysis of the satellite imagery are published every year and are publicly available from the INPE web site (see http://www.obt.inpe.br/prodes/) including a geo-referenced, multi-temporal digital database from year 2003.

Indian national programme for estimating biannual forest cover changes

The National Remote Sensing Agency (NRSA) of India prepared the first forest map of the entire country in 1984 at 1:1 million scale by visual interpretation of Landsat data acquired at two periods: 1972-75 and 1980-82. The Forest Survey of India (FSI) has since been assessing the forest cover of the country on a two year cycle. Over the years, there have been improvements both in the remote sensing data and the interpretation techniques. The 10th biennial cycle has just been completed from digital interpretation of data from year 2005 at 23.5 m resolution with a minimum mapping unit of 1 ha. The last assessment (10th cycle) used satellite data from the Indian satellite IRS P6 (Sensor LISS III at 23.5 m resolution) mostly from the period November-December (2004) which is the most suitable period for Indian deciduous forests to be discriminated by satellite data. Satellite data are digitally processed, including radiometric and contrast corrections and geometric rectification. The interpretation involves a hybrid approach combining unsupervised classification in raster format and on screen visual interpretation of classes. The areas of less than 1 ha are filtered (removed).
India classifies its lands into the following cover classes: Very Dense Forest (tree cover > 70%); moderately Dense Forest (tree cover between 40 % and 70 %); Open Forest (tree cover between 10 – 40 %) Scrub (forest lands with tree cover <10 percent); Non-forest.
The initial interpretation is then followed by extensive ground verification which takes more than six months. An independent accuracy assessment exercise is made using field inventory data (randomly selected sample points verified on the ground) or satellite data at 5.8 m resolution. In the 10th assessment, 4,291 points were randomly distributed over the entire country. The overall accuracy of the satellite forest cover assessment has been found to be 92 %.

6. Estimating uncertainties

A thorough consideration and independent accuracy assessment using a sample of higher quality data should be an integral part of any national monitoring and accounting system. If the sample for the higher quality data is statistically balanced (e.g.: random, stratified, systematic), a calibration estimator (or similar) gives better results than the original survey. Uncertainties in GHG emissions and removals for the land sector are commonly larger than for other sectors. Chapter 5 of IPCC Good Practice Guidance 2003 provides some recommendations and emphasizes that they should be quantified and reduced as far as practicable.

For the case of using remote sensing to derive activity data, the accuracy assessment should lead to a quantitative description of the uncertainty of the area for land categories and the associated change in area observed. This may entail category specific thematic accuracy measures, confidence intervals for the area estimates, or an adjustment of the initially derived area statistics considering known and quantified uncertainties to provide the best estimate. Deriving statistically robust and quantitative assessment of uncertainties is a nontrivial task and should be an ultimate objective. Any validation should be approached as process using "best efforts" and "continuous improvement"[10], while working towards a complete and statistically robust uncertainty assessment that may only be achieved in the future.

6.1 Sources of error

Different components of the monitoring system affect the quality of the outcomes. They include:

- the quality and suitability of the satellite data (i.e. in terms of spatial, spectral, and temporal resolution),
- the interoperability of different sensors or sensor generations
- the radiometric and geometric preprocessing (i.e. correct geolocation),
- the cartographic and thematic standards (i.e. land category definitions and MMU)
- the interpretation procedure (i.e. classification algorithm or visual interpretation), and
- the post-processing of the map products (i.e. dealing with no data values, conversions, integration with different data formats, e.g. vector versus raster)
- the availability of reference data (e.g. ground truth data) for evaluation and calibration of the system

Given the experiences from a variety of large-scale land cover monitoring systems, many of these error sources can be properly addressed during the monitoring process using widely accepted data and approaches:

[10] similar to the concept applied in the National Carbon Accounting System of Australia

- Suitable data characteristics: Using Landsat-type data, for example, have been proven useful for national-scale land cover and land cover change assessments for MMU's of about 1 ha. Temporal inconsistencies from seasonal variations that may lead to false change (phenology), and different illumination and atmospheric conditions can be reduced in the image selection process by using same-season images or, where available, applying two images for each time step.
- Data quality: Suitable preprocessing quality for most regions is provided by some satellite data provides (i.e. global Landsat Geocover). Geolocation and spectral quality should be checked with available datasets, and related corrections are mandatory when satellite sensors with no or low geometric and radiometric processing levels are used.
- Consistent and transparent mapping: The same cartographic and thematic standards (i. definitions), and accepted interpretation methods should be applied in a transparent manner using expert interpreters to derive the best national estimates. Providing the initial data, intermediate data products, a documentation of all processing steps interpretation keys and training data along with the final maps and estimates supports a transparent consideration of the monitoring framework applied. Consistent mapping also includes a proper treatment of areas with no data (ie. from constraints due to cloud cover).

Considering the application of suitable satellite data and internationally agreed, consistent and transparent monitoring approaches, the accuracy assessment should focus on providing measures of thematic accuracy.

6.2 Accuracy of land cover category and area, versus land cover area change

There are methodological differences in estimating the thematic mapping accuracy of land categories, their areas, and the changes in area. Approaches and quasi-standard methods exist for validating remote sensing-derived (singe-date) land cover maps. The techniques include assessing the accuracy of a given map based on independent reference data, and measures such as overall accuracy, errors of omission (error of excluding an area from a category to which it does truly belong, i.e. area underestimation) and commission (error of including an area in a category to which it does not truly belong, i.e. area overestimation) by land cover class, or errors analyzed by region, and fuzzy accuracy (probability of class membership), all of which may be estimated by statistical sampling. Using these approaches estimates on the area estimate can be derived as well, i.e. to what extent a category's area is over- or underestimated.

Accuracy assessment of land cover change and area change resulting from multi-date satellite image analysis presents its own unique set of issues. It is usually more complicated to obtain suitable, multi-temporal reference data of higher quality; in particular for historical times frames. It is easier to validate land cover change errors of commission by examining areas that are identified as having changed. Because frequency and distribution of change classes are rare and not regular, it is hard to validate errors of omission among large area identified as unchanged. Errors in geo-location of multi-temporal datasets, inconsistent processing and analysis, and any inconsistencies in cartographic and thematic standards are exaggerated in change assessments. The lowest quality of available satellite imagery will determine the accuracy of change results. Perhaps, land cover change can then be related to the accuracy of forest/non-forest condition at both the beginning and end of satellite data analysis. However, in case of using two single date maps to derive land cover change, their individual thematic error is multiplicative when used in combination. These problems are known and have been address in studies successfully demonstrating accuracy assessments for land cover change.

6.3. Implementation elements for a robust accuracy assessment

Independent of whether to assess land cover area or area change there are three principal steps for a statistically rigorous validation: sampling design, response design, and analysis design.

Sample design

The sampling design is a protocol for selecting the locations at which the reference data are obtained. A probability sampling design is the preferred approach and typically combines random or systematic stratified sampling with cluster sampling (depending on the spatial correlation and the cost of the observations). Estimators should be constructed following the principle of consistent estimation, and the sampling strategy should produce accuracy estimators with adequate precision. The design-based sample will define the sample size, sample locations and the reference assessment units (i.e. pixels or image blocks). Stratification should be applied in case of rare classes (i.e. for change categories) and to reflect and account for relevant gradients (i.e. ecoregions) or known factors influencing the accuracy of the mapping process.

Systematic sampling with a random starting point is more efficient than random sampling and is also more traceable. Sampling errors can be quantified with standard statistical formulas, although the estimation is more difficult for systematic sampling. Non-sampling errors (systematic bias) are more difficult to assess and require cross-checking actions (supervision on a sub-sample etc..). The order of magnitude of commission or omission errors gives an idea of the margin for subjectivity when straight estimators are used (pixel counting or similar, without calibration or regression estimators).

Response design

The response design consists of the protocols used to determine the reference or ground condition label (or labels) and the definition of agreement for comparing the map label(s) to the reference label(s). Reference information should come from data of higher quality, i.e. ground observations or higher-resolution satellite data. Consistency and compatibility in thematic definitions and interpretation is required to compare reference and map data.

Analysis design

The analysis design includes estimation formulas and analysis procedures for accuracy reporting. A suite of statistical estimates are provided from comparing reference and map data. Common are the use of error matrices, class specific accuracies (of commission and omission error), (adjusted) area estimates, and associated variances and confidence intervals.

6.4 Considerations for implementation and reporting

The rigorous techniques described in the previous section heavily rely on probability sampling designs and the availability of suitable reference data. Although a national monitoring system has to aim for robust uncertainty estimation, it is to be recognized that a statistical approach may not be achievable or practicable, in particular for monitoring historical land changes (i.e. deforestation between 1990-2000) or in many developing countries.

In the early stages of developing a national monitoring, the verification efforts should help to build confidence in the approach. Growing experiences (i.e. improving knowledge of source and significance of potential errors), ongoing technical developments, and evolving national capacities will provide continuous improvements and, thus, successively reduce the uncertainty in the land and land change estimates. The monitoring should work backwards from a most recent reference point to use the highest quality data first and allow for progressive improvement in methods. More reference data are usually available for more recent time periods. If no thorough accuracy assessment is possible or practicable, it is recommended to apply the best suitable mapping method in a transparent manner. At a minimum, a consistency assessment should allow some estimation of the quality of the observed land change, i.e. trough the reinterpretation of small samples in an independent manner by regional experts. In this case of lacking reference data for land cover change, validating single date maps usually helps to provide confidence in the change estimates.

Information obtained without a proper statistical sample design can be useful in understanding the basic error structure of the map and help to build confidence in the estimates generated. Such information includes:

- Spatially-distributed confidence values provided by the interpretation or classification algorithms itself. This may include a simple method by withholding a sample of training observations from the classification process and then use those observations as reference data. While the outcome is not free of bias, the outcomes can indicate the relative magnitude of the different kinds of errors likely to be found in the map.
- Systematic qualitative examinations of the map and comparisons (both qualitative and quantitative) with other maps and data sources,
- Systematic review and judgements by local and regional experts,
- Comparisons with non-spatial and statistical data.

Any uncertainty bound should be treated conservatively, in order to avoid a benefit for the country (e.g. an overestimation of sinks or underestimation of emissions) based on highly uncertain data.
For future periods, a statistically robust accuracy assessment should be planned from the start and included in the cost and time budgets. Such an effort would need to address be based on a design-based sample, using suitable data of higher quality, and transparent reporting of uncertainties. More detailed and agreed technical guidelines for this purpose can be provided by the technical community.

7. Is additional clarification/guidance needed?

Based on the analysis presented in previous chapters and the feedback received from specific countries, we identified the following areas where further IPCC guidance could be helpful for the inventory compilers:

<u>1) Land use vs land cover</u>
Land use is characterized by the arrangements, activities and inputs people undertake in a certain land cover type. Multiple uses can overlap on the same piece of land, either at the same time, e.g. in agroforestry, or in different periods of the year, e.g. with seasonal rotation between agriculture and pasture. The land use classification scheme largely affects the land representation process.
Land cover is the observed biophysical cover on the earth's surface. Land cover classes do have measurable physiognomic characters, such as vegetation height, tree crown percentage or biomass density within a spatial unit. As a result, land cover monitoring represents an indirect but objective method to measure the effects of land use changes over time.

The current criteria to define land use categories or activities in the context of GHG reporting are designed to provide flexibility, but also leave some space to ambiguity (e.g. in the forest definition under the Kyoto Protocol only tree cover is mentioned, apparently suggesting that we are in front of a pure land cover definition), and it does not provide indications on the predominance of their socio/economic functions. By contrast, the FAO forest definition, adopted since the FRA2000 survey, clearly explains that a land should not contain other predominant land use like urban or agriculture to

be considered as forest, and provides some guidance on the possible hierarchical structure of a land use classification scheme.
A clarification of the Land Use definitions and their concepts highlighting the relationships between land cover and land use is desirable (e.g. as used for the LUCAS survey of Eurostat). In future communication Parties should report and explain the methodological approach that has been implemented to derive land use from land cover information.

2) Detail of the technical guidance on RS
The approaches selected by countries for their GHG inventories seem very diverse, probably due to the fact that most of the national monitoring systems have not been developed for GHG accounting but were translated to serve such purpose. This highlights that some basic level of consistency would be needed between the different methodologies.

However, the current IPCC Guidance on RS methods is rather general and concise. Some countries have noticed that such guidance provides little new information for Parties which already developed their own RS system and, on the other hand, is of limited use for Parties which do not have yet experience on this matter. Although the IPCC chapter on RS should not be transformed in a technical RS manual, more detailed guidance would be useful in several specific issues, including:

- Better description of characteristics of satellite imagery (e.g. spatial and temporal resolution, cost and availability) to be used in relation to the definition selected by the country (minimum land area). This has also implication on the accuracy (see also point 3).
- Existing standard image classification methodologies, with a special focus on land use identification based on IPCC land use categories;
- Integration of different data, i.e. more info on potentialities and problems of methods for combining in situ observations with RS satellite data;
- Indication of cost of data processing and analysis;
- Better description of specific issues and problems related to the detection of burned areas with satellite RS techniques;

Furthermore, more references to published scientific literature would be useful.

3) Assessment of accuracy of land cover / land use change
Despite a number of successful case studies, there are no uniform methods for the accuracy assessment of land cover / land use change. The GOFC-GOLD community (who has developed consensus guidelines to validate single date land cover maps), has already started the process to develop such internationally agreed approaches for the case of land cover and use change. When a consensus will be reached on such approaches, further IPCC guidance would certainly be helpful for inventory compilers and increase the comparability of estimates among parties.

4) Availability of existing land cover/ land use datasets
The IPCC 2003 GPG-LULUCF and 2006 AFOLU provided a table with examples of existing global land cover datasets. However, these global dataset are not well suited for supporting national GHG inventories given the spatial resolution currently used for producing these datasets. Therefore, more examples on regional and national-level databases would be useful. Furthermore, as these databases are rapidly evolving, a web-based type of information would give the possibility of being continuously updated.

5) Examples of use of RS in support of GHG inventories.

IPCC 2003 GPG-LULUCF included some example of countries using RS for GHG inventory purposes (New Zealand and Australia). We suggest additional explanations of successful experiences for using satellite RS for national deforestation monitoring in developing countries. Using detailed methodological examples (i.e. from Brazil or India) would provide some useful guidance and confidence for developing countries to start building national carbon accounting system (i.e. as anticipated for the post-2012 period).

Box: the GOFC-GOLD expert group

"Global Observation of Forest and Land Cover Dynamics" (GOFC-GOLD, www.fao.org/gtos/gofc-gold/), a technical panel of the Global Terrestrial Observing System (GTOS, www.fao.org/gtos/), sponsored by FAO, UNESCO, WMO, ICSU and UNEP, is a coordinated international effort to ensure a continuous program of space-based and in situ forest and land cover observations to better understand global change, to support international assessments and environmental treaties and to contribute to natural resources management. GOFC-GOLD encourages countries to increase their ability to measure and track forest and land cover dynamics by promoting and supporting participation on implementation teams and in regional networks. Through these forums, data users and providers share information to improve understanding of user requirements and product quality.

GOFC-GOLD aims at providing a suitable expert forum to develop consensus perspective among the global community of earth observation experts on methodological issues relating to the use of remote sensing for national-level land cover and land use monitoring, and related accuracy assessment procedures. In this context, a dedicated GOFC-GOLD working group is active since the initiation of the UNFCCC process on Reducing Emissions from Deforestation and Forest Degradation (REDD) in 2005. The group has organized REDD expert workshops, and has contributed to related UNFCCC/SBSTA side events and GTOS submissions. The activities resulted in a draft of a user friendly sourcebook on "*Reducing Greenhouse Gas Emissions from Deforestation and Degradation in Developing Countries: A Sourcebook of Methods and Procedures for Monitoring, Measuring and Reporting.*" Based on the current status of negotiations and UNFCCC approved methodologies, this sourcebook aims to provide additional explanation, clarification, and methodologies to support REDD early actions and readiness mechanisms for building national REDD monitoring systems. It emphasizes the role of satellite remote sensing as an important tool for monitoring changes in forest cover, and provides clarification on applying the IPCC Guidelines for reporting changes in forest carbon stocks at the national level. A number of international experts in remote sensing and carbon measurement and accounting have contributed to the development of this sourcebook and GOFC-GOLD has provided an independent expert platform for international cooperation and communication to formulate scientific consensus and provide technical input to the discussions and for implementation activities.

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A few key references

Achard F., DeFries R., Eva H.D., Hansen M., Mayaux P. and H-J Stibig (2007) Pan-tropical monitoring of deforestation, *Environ. Res. Lett.* 2 045022 (11pp)

Brown S., Achard F. Braatz B., Csiszar I., DeFries R., Frederici S., Grassi G., Harris N., Herold M., Mollicone D., Pandey D., Pearson T., Shoch D., Souza C. (2007) *Reducing Greenhouse Gas Emissions from Deforestation and Degradation in Developing Countries: A Sourcebook of Methods and Procedures for Monitoring, Measuring and Reporting*. GOFC-GOLD, First version, 91 p. (available at: http://www.gofc-gold.uni-jena.de/redd/)

DeFries R., F. Achard, S. Brown, M. Herold, D. Murdiyarso, B. Schlamadinger and C. de Souza (2007) Earth Observations for Estimating Greenhouse Gas Emissions from Deforestation in Developing Countries. *Environmental Science and Policy* 10:385 – 394.

EEA (2004) *Corine Land Cover 2000: Mapping a decade of land cover changes*. European Environment Agency Copenhagen, 15 p.

Eurostat (2003): *The Lucas survey European statisticians monitor territory*. Working papers and Studies, Publications of the European Communities, Luxembourg, 23 pp.

FSI (2004) State of Forest Report 2003. Forest Survey of India (Dehra Dun)

INPE (2007) Monitoring of the Brazilian Amazonian: Projeto PRODES. National Space
1325 Agency of Brazil (Available at http://www.obt.inpe.br/prodes/index.html)

Stach, N., Salvado, A. , Petit, M., Ingrassia, F., Joubert, P. Deshayes, M. (2007) Monitoring land use and land use changes in French Guiana by optical remote sensing. Forestsat 2007 Conference (Forests and Remote Sensing: Methods and Operational Tools). Montpellier, France, Nov. 2007.

Strahler, A., Boschetti, L., Foody, G. M., Fiedl, M. A., Hansen, M. C., Herold, M., Mayaux, P., Morisette, J. T., Stehman, S. V., Woodcock, C. (2006). *Global Land Cover Validation: Recommendations for Evaluation and Accuracy Assessment Of Global Land Cover Maps*. Report of Committee of Earth Observation Satellites (CEOS) - Working Group on Calibration and Validation (WGCV), JRC report series.