Linking requirements with capabilities for deforestation monitoring in the context of the UNFCCC-REDD process

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Abstract
As the United Nations Framework Convention on Climate Change nears the end of a two-year period of evaluation of the issue of reducing emissions from deforestation in developing countries, participating countries have agreed on the need to address this globally important source of greenhouse gas emissions. Negotiations on policy frameworks to monitor and reduce deforestation rely on an understanding of the scientific and technical capacity to support these efforts. Current UNFCCC programs to improve observation of land and forest cover change can provide valuable input to a future policy mechanism focusing on deforestation emissions from developing countries. Countries participating in the current debate have officially referenced the value of remote sensing tools and methods for deforestation monitoring, and have identified specific needs and goals related to their implementation. Based on these identified needs, this paper outlines recommendations for a monitoring framework that can be globally applied with sufficient levels of accuracy and certainty. This framework can serve as a starting point for monitoring programs, and can be modified in response to expected progress in establishing an international policy framework for reducing emissions from deforestation.

Keywords: deforestation, remote sensing, UNFCCC, monitoring

1. Introduction
In 2005, official discussions initiated at the 11th Conference of Parties of the United Framework Convention on Climate Change (UNFCCC) established a process to analyze how reducing greenhouse gas emissions from deforestation (RED) in developing countries could contribute to the ultimate goal of the Convention. The related political negotiations in 2006 and 2007 within the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the UNFCCC involved scientific, methodological and technical issues (UNFCCC 2006, 2007a). As Parties have come to agreement on the need to address the globally important emissions source of deforestation, the reliance of policy implementation on scientific and technical capacity has become apparent. Parties and other participating organizations have sought to determine the level of technical support both needed and available for monitoring deforestation. Space-based observation has been identified as perhaps the only cost-effective means to monitor deforestation in developing countries. As the SBSTA negotiations on REDD (the second D refers to the potential inclusion of degradation, which is currently under debate) have progressed, policymakers have requested expert guidance in understanding how remote sensing methods and technology can support a future REDD framework. REDD policymakers need to understand the technical implications of policy decisions, and how technical capacity will impact important factors such as cost, feasibility and capacity needs. Equally, scientists in the fields of monitoring deforestation and resulting emissions, both ground-based and space-based, must understand the needs and goals of policymakers in order to respond with tools and methods appropriate to them.

A basic underpinning requirement to support efforts for reducing deforestation is the systematic long-term observation of forests and other land cover characteristics and changes (Santilli et al 2005). In response to this need, the \textsuperscript{`}Global
This paper will focus on the monitoring of deforestation. Please refer to other papers in this focus issue for technical work on estimation of carbon stocks and changes (Gibbs et al 2007).

2. UNFCCC implementation and land cover observations

Assessing land and forest cover changes has been a key aspect of the UNFCCC and Kyoto Protocol implementation, and both processes have initiated activities to address data and monitoring shortcomings, including the specific agreements and implementation plans, technical guidelines and examples for operation and application. This section will briefly describe relevant processes in GCOS and Kyoto, which are not related to the more recent REDD process but could benefit a future REDD mechanism, through experience with implementation and technical guidelines.

A first mechanism, ‘Reporting obligations and sustainable development’, defined by Articles 3 and 12 of the UNFCCC and the related requirements of the Kyoto Protocol, deals with national reporting obligations for Annex I (developed countries) in the sector of land use, land use change and forestry (LULUCF), including activities for Clean Development Mechanisms. The latest IPCC guidelines for agriculture, forestry and other land uses (AFOULU) define a methodology for assessing the area change in different land categories and then combining this information with associated stock changes in different carbon pools. Three different approaches are described for assessing the area change component. Approach 1 identifies the total change in land area for each land category, but does not provide information on conversions between land categories. Approach 2 involves tracking land conversions between categories. Approaches 1 and 2 provide ‘net’ area changes. Approach 3 extends Approach 2 by using spatially explicit land conversion information, thus allowing for an estimation of both ‘gross’ and ‘net’ changes within and among land categories. Such data may be obtained by various sampling methods or wall-to-wall mapping techniques (i.e. remote sensing), or a combination of the two methods. Approach 3 is the required approach for Kyoto reporting. The assessment of carbon pool changes integrates the area change data from Approach 3 with carbon stock information and may be calculated at different Tier levels of detail and accuracy (1–3). Tier 1 uses IPCC default values (i.e. biomass in forest types, carbon fraction, etc); Tier 2 requires country-specific carbon data (i.e. from field surveys, inventories, permanent plots) and Tier 3 requires national inventory-type data of carbon stocks in different pools and assessment of any change in all pools. When considering a future REDD mechanism, these existing UNFCCC approved methodologies for combining land area change data (i.e. remote sensing) and carbon stock information (i.e. from in situ or inventory data) to estimate the associated carbon emissions provide an excellent framework to build upon.

A second mechanism, titled ‘Research and systematic observations’, mandates research and systematic observations to reduce uncertainties in observing the climate system in
Climate (GTOS 2007a, 2007b). It is important to note that and reporting guidelines for terrestrial observing systems for of Earth observing satellites (CEOS, see GCOS 2006), have several international institutions, among them the committee framework for the preparation of guidance materials, standards and reporting guidelines for terrestrial observing systems for climate (GTOS 2007a, 2007b). It is important to note that several international institutions, among them the committee of Earth observing satellites (CEOS, see GCOS 2006), have committed to implement the tasks specified in the GCOS implementation plan. For an update on current global land cover and forest monitoring activities please refer to Achard et al. (2007).

3. Review of relevant UNFCCC party submissions to SBSTA on REDD

The UNFCCC SBSTA process solicited three rounds of submissions from Parties on issues related to reducing emissions from deforestation in developing countries (March 2006, UNFCCC 2006; February 2007, UNFCCC 2007a; August 2007, UNFCCC 2007c). The submissions included input on positive incentives and policy issues, and technical and methodological issues. This review focuses on technical and methodological issues raised in the first two rounds of submissions, as the third round focused more specifically on the political aspects of REDD. Most of the remote sensing-related issues raised by countries in these submissions can be grouped under the following general headings:

- **Relevance**: Any monitoring system should provide an appropriate match between known REDD policy requirements and current technical capabilities.
- **Comprehensiveness**: The system should allow global applicability with initial implementation at a national level, and approaches not excluding the potential for sub-national activities.
- **Consistency**: Efforts must consider previous related UNFCCC efforts and definitions.
- **Efficiency**: Proposed methods should allow cost-effective and timely implementation, and support early action.
- **Robustness**: Monitoring should provide appropriate results based on sound scientific underpinnings and international technical consensus.

The following paragraphs bring together the main technical issues that countries raised in the first two submissions. While not exhaustive, this synthesis provides an overview of most of the points raised by countries relating to the establishment of a monitoring system for REDD.

3.1. Relevance

The role of remote sensing as an important tool for monitoring changes in forest cover was mentioned by several countries (i.e. Bolivia, EU, Costa Rica, Indonesia, Norway, UNFCCC 2006). Japan suggested that the potential limitations of remote sensing for REDD should be assessed (UNFCCC 2006). Factors such as topography and persistent cloud cover were identified as potential complications to remote sensing applications (i.e. Brazil and Vanuatu, UNFCCC 2007a).

Australia noted that the current range of available methods and approaches for monitoring forest cover change should be catalogued (UNFCCC 2006). Gabon and five African countries emphasized that tools exist to estimate forest area change (i.e. remote sensing) and carbon stocks (i.e. biome averages, forest stratification) (UNFCCC 2007a). Bolivia stated jointly with sixteen other developing countries that historical deforestation may be assessed using archived satellite data (UNFCCC 2007a).

3.2. Comprehensiveness

Countries noted at least three areas related to comprehensiveness of monitoring: that of scale, the inclusion of monitoring of degradation and whether to focus on gross or net accounting of emissions. Regarding scale, many countries proposed national-level REDD monitoring and reporting (i.e. Australia, Bolivia plus sixteen countries, Gabon plus five countries, Nepal, UNFCCC 2007a). Others identified merit in sub-national or project-level approaches (i.e. Mexico, UNFCCC 2007a). Regarding the inclusion of degradation, many countries expressed openness to considering its inclusion, including Argentina, while others such as Bolivia and the sixteen countries it represented more strongly stated that degradation should be included (UNFCCC 2007a). Colombia also favored its inclusion, as well as Gabon representing five other African countries (UNFCCC 2007a). Most submissions support the focus on assessing gross carbon emissions from deforestation (i.e. Bolivia plus sixteen countries, Gabon plus five countries, Brazil, Thailand), while India recommended net accounting through the inclusion of the impact of regrowth on carbon estimates (UNFCCC 2007a).

3.3. Consistency

The role of consistency in a REDD monitoring system was addressed most by countries in reference to the use of forest-related definitions and the application of IPCC guidelines. Australia noted that definitions of forest can be country-specific, but should be bound by common definitions already agreed upon in the context of the UNFCCC (UNFCCC 2007a). The use of existing UNFCCC definitions is further supported by others (i.e. Bolivia, Brazil, UNFCCC 2007a). However, several submissions highlighted the need to accommodate country-specific characteristics (i.e. Brazil, Thailand, Nepal, UNFCCC 2007a). The importance of considering specific national circumstances and the different scale, drivers and patterns of forest change was emphasized by a number of
Several countries made recommendations regarding the utility of the IPCC good practice guidance for LULUCF (LULUCF, AFOLU). The EU noted that remote sensing for area identification is a technique covered by the IPCC 2003 good practice guidance (Penman et al. 2003a, 2003b) and that a combination of ground-based techniques and remote sensing may be needed (UNFCCC 2006). Several countries noted that these guidelines provide a framework for linking remote sensing and ground-based techniques (i.e., Bolivia, EU, Indonesia, Thailand, Vanuatu, UNFCCC 2007a). Australia, Bolivia and Thailand recommended using Approach 3 from the IPCC good practice guidance, and also recommended the use of geographically explicit data for forest change (UNFCCC 2007a). While Australia proposed the use of Tier 3 for assessing changes in carbon pools (which requires measurement of carbon fluxes in all forest carbon pools), other submissions state that Tier selection for reporting on carbon stocks is based on national circumstances and related to data availability (i.e., Bolivia, Gabon, Thailand) (UNFCCC 2007a).

3.4. Efficiency
Timely and cost-effective implementation of REDD monitoring is vital to support REDD reporting, especially as countries consider options for early action. The need for REDD monitoring capacities in developing countries is a central issue in many submissions (e.g., EU, Thailand, Malaysia, Nepal, UNFCCC 2006). The EU noted that existing technical experiences should be shared (EU) and Australia stated that REDD monitoring systems should both incorporate and build on existing efforts to monitor and manage forest resources (UNFCCC 2007a). Early action to build capacity, implement pilot programs and other REDD enabling activities are particularly encouraged by most party submissions (UNFCCC 2006, 2007a, 2007c).

3.5. Robustness
The establishment of a credible reference against which to measure the effectiveness of emissions reduction activities is key to a transparent and robust monitoring system. The majority of submissions mentioned the use of a reference period to report on historical emissions and periodic reporting on changes in forest area and carbon stocks. Several Parties made specific proposals for defining the reference period to include at least the last five years (i.e., Bolivia, Gabon) or (at least) the last ten years (Malaysia, Brazil) (UNFCCC 2007a). Brazil proposed a minimum of four dates for the historical period and the recalibration of future emissions every three years (UNFCCC 2007a).

The submissions emphasize that methodologies and tools are available for estimating emissions from deforestation with an acceptable level of certainty (UNFCCC 2007b). The issues raised can form guiding principles for defining an appropriate monitoring framework to support REDD early action as well as readiness preparation for national REDD monitoring systems. The Earth observation community has begun the process of defining such a consensus deforestation monitoring system that is based on remote sensing (DeFries et al. 2005, 2007, Herold et al. 2006a, 2007). The following specifications can be seen as a technical response to the requirements emphasized in sections 3 and in the range of issues brought forward by Parties. Further detail and specifications can be added as the REDD political process more clearly defines its goals related to monitoring.

4. A monitoring framework with minimum common characteristics
A REDD monitoring framework with a set of minimum common characteristics would provide a starting point for actors to engage in implementation activities, and to support REDD early actions and readiness mechanisms for building national REDD monitoring systems. The political negotiations are ongoing, however, based on the summary provided in section 3, an initial methodological starting point can be defined. The system may evolve over time with further specifications reflecting progress in policy development. The following specifications are suggested for the initial REDD deforestation monitoring framework as a minimum common base of technical requirements:

- **Focus**: Derive spatially explicit information on historical deforestation areas to support IPCC GPG consistent estimation of gross carbon emission in existing forest areas.
- **Scale**: Although national-level monitoring is suggested by many countries, there is not yet a decision on whether implementation will focus on national, sub-national or nested approaches. It is suggested to apply national-level monitoring to get a full picture of historical deforestation processes and, thus, maintain all options for potential future policy implementation.
- **Definitions**: The issue of definitions has been of particular importance in the negotiations and technical implementation (see Penman et al. 2003b, FAO 2006, Lund 2007). The forest definition agreed in the Marrakech accords (UNFCCC 2002) of 0.05–1 ha minimum area, 10–30% tree canopy cover and a potential of 2–5 m tree height is used by Annex I country Kyoto reporting and in current CDM projects, and is mentioned as the starting point for REDD implementation. This definition offers some flexibility for countries, i.e. remote sensing data analysis can adapt to different minimum tree crown cover thresholds (Verchot et al. 2007). However, consistency in forest classifications for all REDD activities is critical for integrating different types of information, including remote sensing analysis. Using different definitions impacts the technical Earth observation requirements and could influence cost, availability of data and the potential to integrate and compare data. There may be flexibility in the definition of the minimum area size. In general, it is technically feasible to detect deforestation with a minimum area of 0.5–1 ha using Landsat-type data (DeFries et al. 2007). There may be different spatial units for the detection of forest and of forest change. Remote
sensing data analysis becomes more difficult and more expensive with smaller minimum mapping units (MMU), i.e. more detailed MMU’s increase mapping efforts and usually decrease change mapping accuracy. Examples of current national and regional remote sensing monitoring systems include: Brazil PRODES (6.25 ha initially, now 1 ha for digital processing), India national forest monitoring (1 ha), EU-wide CORINE land cover/land use change monitoring (5 ha), GSE Forest Monitoring (0.5 ha), and conservation international national case studies (2 ha).

- **Consistency**: In addition to definitional issues, the mapping products should allow full integration with IPCC reporting guidelines on forest change. Approach 3 for area change assessment is required, assuming spatially explicit monitoring of deforestation history and the estimation of gross carbon emission.

The proposed monitoring framework of minimum common characteristics is characterized by the following technical details:

- **Satellite data**: Historical Landsat satellite (30 m × 30 m spatial resolution) data are available globally at no cost for 1990, 2000 and 2005 (available in 2008) and are suggested as a primary observation source (DeFries et al. 2005). Additional satellite observations from optical systems such as SPOT, ASTER, IRS and CBERS, (Chander 2007) and some active microwave satellite sensors (JERS, ERS-SAR, ALOS-PALSAR) are less readily available but, if existing, can be used as a complementary source. Given varying characteristics of different satellite sensors, using continuous and consistent observations simplifies data processing and analysis. Temporal inconsistencies from seasonal variations, 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. It should be noted that global Landsat availability for 1990 and 2000 reflects a rather long observation period of 10 years. If available, additional satellite data should be used to densify the multi-temporal coverage. Forest change information for 2000–2005 will be suitable to derive information on the most recent years. More complimentary information and reference data are usually available for more recent times.

- **Methods**: Full spatial coverage can be provided by available satellite data; a wall-to-wall approach is common and provides consistent observations of historical deforestation. A statistical sampling approach needs fewer resources and may be suitable as well (Achard et al. 2002). Various methods are available and appropriate to analyze satellite data on changes in forest cover. These methods range from traditional visual photo interpretation to sophisticated digital analysis. A variety of methods can be applied, depending on technical capabilities, deforestation patterns and characteristics of the forest. Visual scene-to-scene interpretation of forest cover change in multi-date images is perhaps the most basic approach, and the easiest to implement. This technique is suggested as a minimum methodological requirement for image analysis. Sophisticated (digital) approaches with more efficient processing may lead to more accurate results (Skole and Tucker 1993, Steininger 1996, Souza et al. 2005). Factors complicating the image interpretation such as clouds and topography should be taken into account, either during the visual interpretations or with appropriate digital processing methods. Persistent cloud cover will limit the availability of suitable optical remote sensing data and complicate the image analysis and statistical forest change assessment (i.e. dealing with areas of no data). Data from several years may be required to fully cover the area of interest; an issue to be reflected in the derivation of forest change rates.

- **Accuracy assessment**: An independent accuracy assessment using a sample of higher quality data/estimates should be an integral part of any monitoring system that is linked to a carbon accounting and crediting system. Approaches and quasi-standard methods exist for validating remote sensing-derived land cover maps (Strahler et al. 2006, Wulder et al. 2006). Accuracy assessments of land and forest cover change have been demonstrated (Lowell 2001, Stehman et al. 2003). However, no uniform methods currently exist, though they can be developed by the technical community. In many developing countries there are obvious limitations in the availability of appropriate reference data for 1990–2000. More reference data are usually available for 2000–2005. Given the constraints for providing a statistically robust land change accuracy assessment in all places, the Earth observation community proposes the approach of using ‘best efforts’ and ‘continuous improvement’, similar to that applied in the national carbon accounting system of Australia (Lowell et al. 2003). This perspective assumes that an internationally agreed and suitable mapping approach is applied in a transparent and consistent manner to derive the best national estimates. Time series consistency in terms of geolocation, spectral characteristics, climate variability and phenology, as well as clouds and topography should be properly addressed. The monitoring should ideally work backwards from a most recent reference point to use the highest quality data first and allow for progressive improvement in methods. Growing experience (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 deforestation estimates. If no robust reference data are available, at a minimum, a consistency assessment should allow some estimation of the forest change quality, i.e. reinterpretation of small samples in an independent manner by regional experts. Any uncertainty bounds should be treated conservatively. A full accuracy assessment should be included for future deforestation monitoring. Such an effort would need to employ higher resolution or in situ data and agreed international technical guidelines that will evolve over time.
deforestation on a national level. Historical reference scenarios
the status of current political negotiations, and previous
for REDD implementation (UNFCCC 2007b). Considering
that associated technical capabilities are available and robust
Analysis of remotely sensed data from satellites is the
5. Conclusions
Analysis of remotely sensed data from satellites is the
only practical approach to measure changes in forest area
in the majority of developing countries; this assumption
has been advocated by the Earth observation community
(DeFries et al 2005). The political process has recognized
that associated technical capabilities are available and robust
for REDD implementation (UNFCCC 2007b). Considering
the status of current political negotiations, and previous
and related UNFCCC activities, this paper has presented a
REDD monitoring framework to estimate gross historical
deforestation on a national level. Historical reference scenarios
can be developed consistently from the 1990s onwards with
confidence using historical Landsat (1990/2000/05) data as a
primary source (DeFries et al 2005, 2007). As a minimum
common base, national deforestation monitoring should use
Landsat data for visual scene-to-scene interpretations of gross
deforestation in a consistent and transparent manner for IPCC
GPG-based estimation of carbon stock changes.

This methodology provides a starting point for all actors to begin
prompt REDD implementation and for nations to build
historical databases and develop and improve their monitoring
capacities. The methodological specifications reflect the recent
UNFCCC negotiations and current technical capabilities. Both
will evolve over time and result in more detailed monitoring
specifications and continuous improvement of forest area
change estimates.

This paper has a sole technical focus on monitoring
deforestation. It is recognized that the issue of forest
degradation has been discussed in the UNFCCC-REDD
process. However, the UNFCCC discussions so far have
provided little information and guidance on how to include
this issue in any REDD implementation. Some information on
technical capabilities in monitoring degradation is provided in
this issue (Souza et al 2008). Along with evolving UNFCCC
negotiations, the Earth observation community is ready to help
with linking the policy requirements and technical degradation
monitoring capabilities, in a similar manner to the framework
provided here for deforestation.

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