WORKING PAPER

Establishing Credible Baselines for Quantifying Avoided Carbon Emissions from Reduced Deforestation and Forest Degradation

Prepared for Coalition for Rainforest Nations

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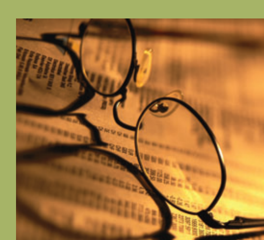

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EXECUTIVE SUMMARY

Global climate policy initiatives are now being proposed to compensate tropical forest nations for reducing the emissions of carbon from deforestation and forest degradation. This effort has the potential to include developing countries more actively in international greenhouse gas mitigation and to address a substantial share of the world's emissions which come from deforestation. A baseline is an essential precursor to a viable and robust international compensation scheme for reduced emissions from degradation and deforestation (REDD). Baselines provide a benchmark against which emissions reduction can be calculated.

To incorporate REDD in international climate policy, we propose that the baseline be developed at the national level and based on the emissions from deforestation and degradation activity during a predetermined historical reference period. Baselines can be set for various time intervals, although for REDD a minimum amount of time (perhaps 5-10 years) will be essential for taking into account variations in deforestation-related emissions..

For a REDD policy, using a national level reference historical period increases transparency, clarity, and feasibility of measurement. The historical period selected for reference periods will have profound impacts for incentives to reduce deforestation and degradation depending on each country's deforestation rate during that period relative to the potential for future deforestation. Thus, selection of a reference period will require discussion among participating nations. While some flexibility may be necessary, any reference period applied to a REDD policy should focus primarily on providing correct incentives for real emission reductions.

The technologies and tools exist to develop credible measurement of deforestation during a historical reference period. However, this paper does not discuss the crucial next step of determining carbon emissions from the deforestation to determine baseline emissions (Gibbs 2006). From a practical standpoint, the existing data and institutional capabilities for processing national deforestation measurements are not yet sufficient. There are still several critical challenges, but initiatives are underway to develop a first round of reference scenarios. There are two primary methods being used for measurement of deforestation: (1) analysis of remote sensing data from a comprehensive census of the covered area (aka,"wall-to-wall") and (2) statistical sampling of remote sensing data to develop data points for inferring rates within the area of interest. To date the wall-to-wall efforts have been more focused on national level assessments and have data that are better suited for determining national level emissions for a reference period. FAO survey data are likely not of sufficient accuracy for determining national deforestation for setting baselines.

Key technical issues that need focused effort are: (1) determining a credible policy definition and means for measuring forest degradation, and (2) determining acceptable techniques for linking measurements of deforestation and degradation to emission of greenhouse gases. Including degradation in any reference period will help expand incentives to reduce forest losses and greenhouse gas emissions, but raises several

technical challenges. Linking measurement of forest loss to measurements of carbon emissions is crucial since emissions are what is being valued and traded, not land area.

As countries work to develop their deforestation/degradation emissions baseline, several factors should be considered: 1) international or bilateral grants may be critical in helping countries increase capacity for the necessary measurements; 2) continued efforts to build forest inventory and carbon stock data are necessary to determine emissions from measurements of deforestation and degradation; and 3) the Landsat program should be accelerated and fully supported to replace the damaged satellite and increase capacity for data analysis.

At the international level, there must be continued calls for high-resolution imagery, development and expansion of radar technology and data sharing. Any REDD baseline policy should provide minimum baseline requirements to create a credible system, allow flexibility, and reward countries for reducing uncertainties in the estimates. Such an approach will allow a timely start for REDD incentives, maintain credibility, and allow capacity building and improvements over time.

1. Introduction

Deforestation, degradation and other forest clearing in the tropics currently account for about 20-25% of global greenhouse gas (GHG) emissions and constitute a significant majority of emissions from developing counties (IPCC 2000). Continued deforestation at recent rates in Brazil and Indonesia would together offset about 80 percent of the GHG emission reductions agreed to in the Kyoto Protocol (Santilli et al 2005). In addition to their critical role in the global carbon cycle and climate system, tropical forests are home to about half of the world's species and their continued loss creates large and potentially irreversible loss of biodiversity. Moreover, the livelihood of millions of people depends on the rich array of ecosystem services tropical forests provide. Recognizing the importance of tropical forests and the value of developing country participation in global climate change mitigation efforts, proposals are now being advanced to compensate tropical forest countries for reducing emissions from degradation and deforestation, or *REDD* as part of a future international climate agreement.

The notion of *reduced* deforestation and degradation raises the question of what the reduction is compared to. Therein lies the need for a baseline. The term "baseline" refers to a situation without a particular policy in place and is used as a reference case for quantifying policy performance. Because performance in the REDD setting would be matched by financial compensation, a rigorous and credible baseline is absolutely essential. Toward that end, the purpose of this paper is to provide guidance on the development of baselines for use in an REDD compensation system. The main objectives of the paper are to:

- define the basic elements of a baseline and options for its key features;
- describe the data and analytical requirements for establishing a baseline at different spatial scales;
- propose criteria for baseline credibility;
- determine whether the necessary data and analytical methods for estimating credible baselines exist and are feasible for tropical countries to develop;
- develop suggestions on how REDD baselines can incorporate advances in science and technology; and
- chart a path forward for developing baseline standards that are credible, feasible, and consistent with the underlying goals of REDD proposals.

The paper addresses the deforestation and degradation baseline in terms of area with land cover change or rates of land cover change. Ultimately, the quantities of interest are units of carbon emissions avoided by reducing deforestation. This is measured as the product of the area with land cover change and the carbon emitted as a result of that change, compared to the reference (no policy) case. Another paper in this series addresses quantification of GHG emissions from these land cover changes [See paper in this series by Gibbs]. It is important that the methods for quantifying baseline rates of land cover change discussed herein can be effectively linked to carbon measurement to develop consistent estimates of carbon emissions from deforestation and degradation.

2. Baseline Concepts and Options

The term "baseline" often generates confusion and preconceived notions that can be misleading. In an effort to minimize such confusion in this paper, we describe the different types and scales of baseline, and which is most appropriate for an international system of REDD.

Before proceeding, many of the baseline options attempt to deal with the issue of leakage. Leakage is the extent to which emissions controlled in one place simply shift to another place where they are not controlled. Consider Country A's efforts to control deforestation to participate in international compensation scheme for avoided emissions. For Country A, the leading driver of deforestation is land-clearing for agriculture to supply global commodity markets. Country A scales back its land-clearing efforts and receives compensation for its efforts, but Country B steps in to fill the void in commodity supply bv clearing forest for agriculture. If Country B is not a participant in the compensation schemes or does not have any other greenhouse limits in place, the benefits of Country A's actions have been eroded by Country B's actions, which will go unaccounted. This is called leakage and has been shown to have vary depending on location and nature of the compensation (Murray et al, 2004; Sohngen and Brown, 2004; Chomitz, 2002). Baselines at the national level can capture and adjust for within country leakage from local projects, but may not properly account for international leakage unless special provisions are put in place.

2.1 Scale of baseline – Local, National, Global

Baselines of deforestation and degradation can be determined at a number of spatial scales and there are costs and benefits to each.

- **Local** baselines, such as those used for individual projects at the sub-national level, focus on activities at smaller scales and can have relatively high accuracy. However, project level assessment does not take into account emissions leakage caused by the movement of deforestation to other areas (see above).
- **National** level accounting and baseline determination for deforestation are technically feasible and will avoid undetected sub-national leakage. Local reductions that shift emissions elsewhere will be captured in the national accounting. However, estimating credible national level land cover change will require improved methods to cover the greater spatial extent and must do so while maximizing accuracy.
- A **global** or pan-tropical deforestation baseline could be used as a point of reference for all countries in the system. This has been proposed as one means for differentiating between countries with high versus low deforestation relative to the global average. One suggestion is to adjust upward the national baselines for countries with lower than average historic deforestation as an incentive for maintaining these low deforestation rates (Santilli et al 2005; Mollicone et al. in press) – i.e. if the baseline is set very low, there is little room to generate credits and little incentive to maintain the low rates. This may also help to address

international leakage, providing incentive for countries with low deforestation rates to maintain them. The problem is that such an approach is politically complicated, and could create "hot air" reductions - credit for no action. Therefore, we believe further thought needs to go into such a crediting system before it is considered for baseline setting in the REDD effort. At the very least a global baseline can be used for monitoring international leakage even if it is not used for determining individual country compensation.

For an international agreement between nations, a national level baseline of deforestation and degradation is the most conceptually appropriate, feasible to implement, and most transparent. Therefore, national baselines remain the focus of this paper.

While national policies may be used to address deforestation and degradation, land use decisions tend to take place at the local level. There will likely be opportunities where a targeted local effort, such as increasing protection around a national park, could use within-country project level baselines for accounting and valuing the effectiveness of the local policy. In such cases, a local baseline and accounting would improve accuracy allowing governments some certainty in the deforestation and degradation reductions gained from the local policy. Each county could establish its own methodologies for determining local level baselines and ensuring consistency with national level accounting.

2.2 Type of Baseline -. Historical Reference Period vs. Business-as-Usual

There are two basic ways to develop a baseline, one based on observed activity over some historical period and another based on expectations of what would unfold under "business as usual".

<u>*Historical or "reference period" baseline*</u>

This baseline refers to activity and emissions in a defined period as they existed prior to a policy taking place. An example of a reference period in climate policy is the year 1990, which is the reference point for determining greenhouse gas reduction commitments under the Kyoto Protocol. For the purposes of REDD, a historical baseline would determine the extent of deforestation and degradation over a predetermined period (i.e. a 5 to 10 year period) before any policy is put into place.

<u>*Business-as-usual baseline*</u>

A business-as-usual (BAU) baseline refers to activities or emissions that might otherwise occur were a policy not put into place. For REDD, a BAU baseline would estimate the extent to which deforestation and degradation would occur over time without a policy (or project) intervention. A BAU baseline can be based on projecting forward historical trends in deforestation and can be improved by use of regional models that can incorporate biophysical, economic, and infrastructure variables to estimate likely deforestation by forest type and region (Brown et al, in press). These methods are increasing in sophistication, but have been focused primarily on setting sub-national baselines for avoided deforestation projects.

2.3 Rationale for Using a Reference Period Approach for a National Baseline

Which of these two approaches, BAU or reference period, makes the most sense for gauging national-level REDD performance? A strong case can be made for the reference period approach.

- BAU baselines, while appropriate for local projects, are less applicable to national-scale GHG accounting inherent in the REDD proposals.
- Given the national scale focus, the use of a reference period would be consistent with the approach used for national assignments in the Kyoto Protocol.
- The historic reference period approach is relatively transparent and sets a clear target for reductions, which is important for effective national policy. A BAU baseline, on the other hand, depends critically on behavioral assumptions to model BAU activity. Model specification, might miss major unanticipated shifts such as the growth in demand for agricultural commodities (e.g., soybeans) and thereby lead to misspecified national baselines. Current experiences with the EU Emissions Trading System show the difficulty of using projections of future economic activity to set national emissions baselines.

In summary, we believe that a historic reference period baseline, while not a perfect approach, has greater certainty and transparency for REDD. We will focus in the rest of this paper on the development of a historic reference period baseline.

2.4 Timeline for Reference Period Baseline

Differences in regional and temporal dynamics of deforestation complicate the selection of a uniform reference period appropriate for all countries. Some countries might benefit more from one time period than another and so the period selected may need to be politically negotiated, such as what occurred under the Kyoto Protocol. By and large though, a credible REDD reference period should encompass several years to reduce the impact of anomalous years from prevailing trends. Therefore a decadal trend or longer may be preferred, i.e. 1980s, 1990s, or 1990 to 2005. However a 5 year reference period (i.e. 1995-2000; or 2000-2005) may have advantages in terms of identifying changes in land use with more relevance to the present.

If a reference period is set that covers years that have yet to pass, it can create perverse incentives for gaming the system with countries deforesting more land now to have a higher baseline and allow easier reductions later. However, based on current prices for carbon emissions, the price for avoided carbon emissions from reduced deforestation are not likely high enough to motivate a national policy of deforestation just to game the baseline.

It is expected that reference period baselines for tropical forest nations would be determined primarily using remote sensing data to detect forest change. The forest change data must then be tied to inventory and modeling data to determine the corresponding carbon emissions. Remote sensing can provide complete coverage that is based on easily visible changes in land cover and data are available for the time frames likely needed to determine a historical baseline in the 1980s and 1990s. There is some concern with data availability in the current decade for baselines and monitoring into the 2000's. Data issues are discussed in more depth below.

2.5 Implications of reference period for countries with different deforestation histories

The benefits and feasibility of REDD will differ by country depending on its historical deforestation and current forest cover (Santilli 2005).

- For those countries that have had high rates of deforestation but still have significant forest remaining, a historical reference period can provide an appropriate gauge of deforestation and degradation prevalence and set the right incentives.
- Those countries that have had low or no deforestation or that have made efforts to reduce deforestation may have fewer opportunities to further reduce deforestation. Ideally, incentives should be in place for them to maintain or increase forest cover, but they should not distort or overly complicate the design of a system for REDD. (See discussion below on credit for early action)
- Those countries that have had historically high rates of deforestation and have little forest cover remaining may have decreasing rates of deforestation. Any system that credits these countries for slowing deforestation when it would naturally occur because of declining access to the remaining forest patches would result in inflated credits. Having shorter term historical baselines, i.e. 5 yr instead of 10 yr and possibly adjusting them more frequently could limit the creation of "fake" or "hot air" credits.

The effort to develop a system for crediting countries for reduced deforestation and degradation cannot address every country's situation perfectly. A REDD system should aim to reduce carbon emission from one of the world's largest sources of carbon emissions, deforestation. For those countries with low deforestation or such high deforestation that little forest remains, alternative systems could be envisioned for increasing forest carbon, like crediting reforestation, rather than loss. Some of the proposals discussed above (in Sec 2.1) regarding the use of a global or pan-tropical baseline would address the low deforestation cases, but still need some work to resolve critical issues before they could be used.

Countries that have taken early action over the last decade, or those that might take action now, before official accounting begins, should be credited in some manner, and not be penalized by having a low baseline deforestation rate. If the reference baseline is set far enough back, it could address the early actor problem by excluding the period of their early action from the baseline and thereby, at minimum, not penalize countries for early action. If the rules of the system expanded the actual crediting period to include the period where early action occurred, then this could produce positive credits for the country. However, expanding the reference period or moving it to far back in time might miss recent social or economic drivers in countries that have shifted trends in deforestation in the recent past and thereby lead to inflated credits.

2.6 Baseline Updating

Baselines may need to be updated over time. Even if the historical reference period stays the same, baselines could be updated as our technical ability to analyze historic land cover change and carbon inventory data improves. Updating of baseline quality could be required or could be voluntary and tied to financial incentives tied to the rating and valuing of the carbon credits (see section 8 below). It might also be desirable to update reference periods at some time in the future to adjust further carbon credits to newer realities of forest cover and deforestation rates.

Updating of baseline reference periods can create serious market uncertainties and thus the manner in which updates are done and are used is crucial. It will be necessary to clarify the timeline for future updates and how they would be used up front so the market will be able to adjust. The other alternative is that the reference period is set and does not change unless there is an international renegotiation of the agreement spurred by demand for an updated baseline system.

3. Criteria for a Credible Baseline

Because the baseline is essential to determine relative reductions, and therefore the monetary value of emissions avoided from deforestation and degradation, it is vitally important for it to be a credible estimate. A credible estimate is based on sound science and the best data and quantitative methods reasonably available to the countries of interest. We consider the following as key criteria for baseline credibility.

Accuracy and Precision –All reasonable efforts must be made to ensure that estimated changes in forest cover and greenhouse gas losses closely reflect what is happening on the ground. The error or uncertainty inherent in the measurements needs to be quantified to determine how much confidence can be placed in any REDD credits. Uncertainty is unavoidable and it will vary by country. If desired, the level of uncertainty can be used to qualify the REDD values – a grading system could adjust the monetary values for REDD credits accordingly. This is discussed later in the paper.

Consistency – The measurements of forest change and the associated greenhouse gas losses made at different points in time or by different observers need to be consistent. A reference period baseline depends upon the difference between two or more measurements of forest. Better consistency between measurements means lower error and greater certainty in the calculated baseline. This can also be important if future revisions of baseline are anticipated. To maximize transparency, independent observers and market participants should be able to replicate and verify the measurements and be confident in the results.

Comprehensiveness – The baseline should cover all of the activity it is supposed to cover. For instance, if all deforestation in the country is to be included, than all locations of deforestation in a country must be included in the data used to develop the baseline estimate. If degradation is to be included, then the data need to have high enough resolution to detect and quantify the amount of area degraded. Also, carbon inventories will need to be sufficiently detailed to determine losses from all affected forest types in a country.

Environmental Integrity – For the REDD system to work in favor of climate protection, it must ensure that the corresponding greenhouse gas reductions are real. Given the various forms of uncertainty described herein, prudence suggests that baselines be set conservatively (not too high) as a safeguard against rewarding too much REDD credit and diminishing global greenhouse gas mitigation efforts.

Transparency – This is envisioned as part of an international market or some other compensation mechanism, so transparency is vitally important to ensure the integrity of the system. There must be minimum standards of transparency that all involved parties meet, much like accounting and financial reporting standards require for commercial transactions.

Flexibility – A wide range of circumstances will apply across and within countries that will affect their ability to estimate baselines. For starters, some countries have better quality data for forest cover and inventories of forest carbon than others. With remote sensing data, the ability to detect forest change particularly degradation will differ across deciduous and evergreen species, dry forests and rainforests, large continuous cover and fragmented ecosystems, etc… Given these likely differences in national level baseline estimates, the system will need to be flexible in allowing some variability in accuracy and perhaps accounting for it in valuing credit for emissions.

Feasibility – The proposed approaches for estimating baselines must be accomplishable with a reasonable level of effort and expense or else they will simply not be done well or done at all. Feasibility factors include data availability, analytical capabilities, cost of data collection and analysis, and institutional support for these efforts.

4. Data Required for Detecting Forest Cover Change

To start, good definitions of deforestation and degradation are needed to clarify what is being measured. For example, FAO defines deforestation as "change of land cover with depletion of tree crown cover to less than 10%." And degradation is defined as "changes within the forest class (e.g., from closed to open forest) that negatively affect the stand or site—and, in particular, lower the production capacity." While deforestation defined in this manner is likely measurable, the more subjective definition of degradation would be very difficult to align with what can be measured using remote sensing data. A key question for defining forest degradation is whether all forest management is included. Definitions should be developed with an eye toward what is likely to be measured given the goals of the policy and the data and methods reasonably available to the parties.

Data are available to measure and to some degree verify tropical deforestation for a historic baseline. Spectral remote sensing data (which uses reflected light) can cover the greatest area and is likely the best option for national scale measurement of deforestation. Numerous satellites sensors that can detect land cover change are run by India, Brazil, Australia, Nigeria, EU (and many of its member nations), US, and Japan. See Table 1 for an overview assessment of the types of satellite data and other data options.

For all areas experiencing change in forest cover, data of sufficient precision on carbon content and biomass will be needed to determine the greenhouse gas emissions associated with the forest loss (Gibbs, this series). Change in greenhouse emissions is the unit of value in the intended international carbon market.

4.1 FAO Data

One data option for estimating deforestation is the FAO national forest statistics. These data are a compilation of reports from individual nations. The FAO has been conducting global forest assessments every five to ten years since the first survey in 1947. National statistics are largely based on forest inventory data, models, and expert opinion. While valuable for their coverage over time, these data have been cited for their lack of consistency between countries and between assessments --changing definitions of forest, different methods to assess deforestation, and for unreliable and missing data in some cases (Grainger, 1996; Matthews, 2001).

The concern over a lack of standardized definition of forest cover and deforestation has been a recurring problem for the FAO effort. More than 650 definitions of forest were assembled in the course of the FRA 2000 process. Close investigation of successive assessments reveals enormous variation for individual countries (Mather 2005, Matthews 2001, Grainger 1993). Indeed, the information provided by experts for 103 developing countries, comprising 66% of global forest area, was judged to be of low to medium compatibility with previous assessments (FAO 2001). The FRA 2005 effort has made considerable improvements to the process of the country inventories (FAO, 2006), but is still likely to have significant inconsistencies among countries.

Great effort is put into developing transparent and accountable procedures. The transparency and traceability of the FAO assessments have increased through time. In the FRA 2000 and 2005, national correspondents were named along with primary documents and flags were included where data quality was deemed low in efforts to reduce the recycling of poor data and to encourage improvements.

The national statistics of 2000 were complemented by a random sample of Landsat imagery (FAO 2001). Neither the statistics nor the Landsat data are spatially refined; the national statistics provide a single value for an entire country and the Landsat analysis is only appropriate for assessment at the pan-tropical scale due to the selected sampling scheme (FAO 2001, Tucker and Townshend 2001). A much more intensive sampling scheme would likely be necessary for high accuracy in their remote sensing analysis (Tucker and Townshend 2001). Thus neither the country reporting nor the satellite sample from the FAO provide consistent and reliable estimates of deforestation rates at the national level.

Many of the concerns about the consistency and accuracy of the national statistics remain valid, even though the problems have been somewhat reduced in FRA2005. The national level aggregation of these data continues to limit their transparency and verifiability. The FRA 2010 effort will attempt a new strategy with the participation of the Global Observation for Forest and Land Cover Dynamics (GOFC-GOLD) consortium to incorporate a new remote sensing assessment of forest cover (GOFC-GOLD website). From their publicly available information it is not yet clear what methods they will use. GOFC-GOLD is an international consortium to coordinate and provide remote sensing observations of the land for management efforts.

4.2 Remote Sensing Data – For Reference Period Baselines 1980s and 1990s

If the initial deforestation and degradation baseline is set anytime in the 1980s through the 1990s Landsat and AVHRR (Advanced Very High Resolution Radiometer), both from U.S. satellites, are the only two datasets that cover this period.

The daily coverage and long-term record are all major advantages of AVHRR data. However, radiometric and geometric limitations make it useful only for initial coarse scale assessments, not for final determinations of deforestation and degradation. In particular, sensor degradation, inter-sensor calibration problems, geo-location errors, and noisy pixels have presented significant challenges to estimating rates of deforestation with AVHRR (Agbu and James 1994). Further, deforestation estimates derived from AVHRR represent a systematic bias. Hansen et al. (2004) concluded that AVHRR likely underestimates deforestation due to coarse spatial resolution and other inherent sources of error.

As a result, the best option during this period is data from the Landsat series of satellites. The Landsat data are of good quality and have an archive with imagery available starting in 1972. Landsat is moderate to high resolution data that can pick up forest clearing or a forest patch of 1 hectare or sometimes less in size (Steininger, et al. 2001; Leimggruber, et al. 2005).

NASA has made a global mosaic of Landsat data for ~1975, ~1990 and ~2000 freely available (Tucker et al. 2004). These are heavily used data for land mapping. Gaps only exist in some of the most-cloudy areas of the world, mostly in the very humid or coastal tropics, a situation that will need to be rectified if used for tropical rainforest assessment.

Table 1. Types of data that can be used for measuring forest change

DATA TYPE	SCALE	BENEFITS	LIMITATIONS	COSTS
Remote Sensing Spectral	Low Resolution (i.e. AVHRR, MODIS) For Example: *~1km resolution* *~2700km Image coverage* *~Daily Frequency* *~10ha smallest detectable land cover*	Rapid regional/country scale assessments, very frequent imagery, overcomes issues of cloud cover, can automate	Small areas of forest change (ie. small –scale agriculture) likely missed biasing estimates of deforestation, unlikely to detect most forest degradation,	Low cost or free
	Moderate to High Resolution (i.e. Landsat, ASTER, IRS) For Example: *~30m resolution* *~180km Image coverage* *~Biweekly Frequency* *~1 ha smallest detectable land cover change*	Possible to conduct regional/country scale assessments,, possible to detect degradation, can partially automate	Smaller area covered per image, thus slower and more expensive to fully cover a region, detection of some types of degradation still need validation, in most humid regions can be difficult to find cloud free images	Low cost or free for historical data (through 1990s); Moderate to high cost for recent and new data
	High Resolution (i.e.IKONOS, Quickbird) *~4m resolution* *~ km Image coverage* *Only specified areas* *~1m smallest detectable land cover change (individual tree crowns)*	Primarily for validation, better potential for detection of degradation (been tested for selective logging)	Very small areas, slow, not automated, full country coverage not available, cloud cover can limit coverage	Expensive – must be tasked
Remote Sensing radar	Radar moderate resolution: For Example ~ 30m JERS, 15m ERS and Radarsat	RADAR signal penetrates through cloud cover	Requires high level of expertise, may not work well in mountainous regions	Moderate to expensive
Remote Sensing LIDAR	LIDAR	Can be used for biomass estimation	Small areas, aircraft or hand held sensors, requires high level of expertise	Moderate to expensive
Aerial photography		Good for validation of forest change and degradation	Usually not large areas covered, requires time and expertise	Moderate
Field Inventory	Very high resolution – direct field observation – with low-resolution statistical inference drawn for rest of population	Good for verification of forest change and, degradation, and determination of biomass; required for carbon measurements	Only small areas sampled, requires time, and substantial labor	Moderate to expensive
Regional Modeling	Low, generally	Complements other methods; necessary if BAU baseline is used	Simplified assumption, needs to be calibrated with on site data, requires substantial expertise and expert input	Low to expensive depending on model sophistication

4.3 Remote Sensing Data – For Reference Period Baselines 2000 forward

In the late 1990's a number of new satellite sensors designed for detection of land use change came on line and can supply imagery from 2000 forward (Table 2). Data options include a number of relatively high resolution sensors, fairly similar to Landsat, but many of these have less global coverage and availability of imagery. Many of them are tasked sensors that only acquire targeted locations. Landsat has the best and most available data at this resolution but unfortunately Landsat 7 (the newest of the Landsat satellites) has experienced technical difficulties since 2003. While partially corrected the useable data in the imagery has been reduced, especially for cloudy tropical regions. The older Landsat 5 satellite is aging, but remains in operation and has the best Landsat data after the 2003 malfunction of Landsat 7, but Landsat 5 has lower quality imagery than Landsat 7 data. For coarser resolution data such as AVHRR, additional sensors including MODIS (a US satellite) and SPOT_VGT (a French satellite) are generally available and all of the sensors are functional. As is the case with AVHRR data, these data are best for more-rapid warnings of areas of highest rates of change; they are not appropriate for precise estimates of rates of change over time.

The loss of good Landsat data is a problem for monitoring and for any baseline including 2003 and forward. High resolution data are necessary for high accuracy determination of forest change and other high resolution sensors have less data coverage and higher cost. Despite this, high-resolution data from Landsat will need to be combined with data from other similar sensors to determine forest change at high accuracies from 2003 forward. This will likely require international coordination of data resources (GOFC-GOLD, 2006). The renewal and continuation of the Landsat program is of primary importance for moving forward on national monitoring and determination of baselines in the future. Fortunately, global data are already available to enable us to work towards a global baseline up to the year 2003 and with cooperation it will likely be possible to fill in gaps from 2003 forward.

Table 2. High and moderate resolution satellite data for pan-tropical deforestation monitoring.

Satellite	Sensor	Spatial Resolution (ground sample distance)	Temporal Resolution (days)	Overall Status
High Resolution (< 50 m)				
Landsat 5	TM	30 m	16	Aging
Landsat 7	ETM+	30 m	16	Crippled by sensor component failure
IRS-2	ResourceSAT	6-56 m	5-24	Unknown availability
CBERS-2				Unknown availability
Terra	ASTER	20 m	26	Acquired on a task by task basis
SPOT	MSS	20 m	26	Acquired on a task by task basis
ERS	Synthetic Aperture Radar	30 m	35	Acquired on a task by task basis
RadarSAT	Synthetic Aperture Radar	8-100 m	24	Acquired on a task by task basis
Moderate Resolution (> 50 m)				
Terra/Aqua	MODIS	250 m 500 m 1000 m	Up to daily	Highly available
TIROS	AVHRR	> 1100 m	Up to daily	Highly available
SPOT	VGT	1000 m	Up to daily	Highly available
IRS	AWiFS	60 m	5	Available
EnviSAT	MERIS	300 m	3	

From: DeFries et al. 2005

5. Remote Sensing Analysis for Forest Cover Change Detection

To detect a change in forest cover (deforestation or degradation) remote sensing images from the data sources discussed above are needed for two or more time periods. By overlaying the images and determining the differences between them, the change between the two dates can be determined. This "difference" image can then be classified to show loss of forest, regrowth of forest or other changes.

5.1 Accuracy in Deforestation Measurement

For an individual Landsat scene or similar data, forest vs. non-forest determination often has accuracy around 90% to 95% (eg. Steininger, 1996). Patches of forest clearing of around 1.0 ha can be detected. At the national level with variation in topography and forest type across the landscape, perhaps some level of automation and less analyst time per image, accuracies can be a bit lower, often around 85% to 90% (eg. Steininger, et al. 2001; Leimgruber, et al. 2005). The minimum patch size usually detected at the national scale is around 2 to 5 hectares. Also, national level studies require much more ground or aerial information to cover the range of conditions across the country to assist the classification process.

5.2 Data Challenges – Clouds and Mountains

Cloud cover can be a problem for obtaining imagery particularly in humid regions typical in tropical forest nations. For those countries or regions often covered by clouds it may not be possible to find a cloud free image every year and thus it may be necessary to find alternative satellite data, or use radar data, or perhaps even to shift the years used to bracket the baseline period plus or minus one to find cloud free images. Clouds become a greater problem in monitoring when repeated frequent imagery is needed. Radar sensor data can see through the clouds and provide measurements of forest cover. Currently satellite RADAR data are not as well archived as other data sources Also, RADAR is very difficult to use in mountainous areas and thus mostly inappropriate for land cover mapping in such regions.

Mountainous regions also increase measurement error for Landsat and other optical sensors. Steep slopes change light reflected back to the satellite sensors, and sun angle create mountain shadows that also alter reflectance. Careful selection of imagery that reduces differences in sun angle and shadows between the two images (years) being compared can help.

5.3 Methods for measuring deforestation across large regional scale

The two major approached used to date for large scale measurement of deforestation are "wall-to-wall" assessments by country and sampling methods across the tropics (i.e. FAO). For a national level baseline wall-to-wall is the method of choice.

Wall-to-wall: In wall-to-wall methods, images for an entire country or region are analyzed. The number of remote sensing scenes to cover an entire country "wall-to-wall" can be quite large, but this has not been a barrier. For example Brazil does annual wall-to-wall assessments of deforestation.

Sampling: A sampling approach can be done a couple of ways.

- Systematic sampling selects scenes a set distance apart across an entire area. For example FAO is planning to use systematic sampling in its next analysis. They will select scenes located at each 1 degree latitude by 1 degree longitude line that overlies the land (Mayaux et al 2005).
- In stratified sampling an area can be divided by many categories (strata), for example, topography, soil type, broad forest type, or degree of disturbance (hot spots), and the intensity of sampling can vary by strata with more sampling in areas of greater interest (FAO 2001, Achard 2002). Stratified sampling does not have to use random sampling. Systematic sampling at different resolutions could be used for different strata, emphasizing those of greatest interest.

A major motivation for using a sampling approach is to reduce costs and time associated with processing wall-to-wall imagery. However, estimating rates of change from sampling has been heavily debated in the literature. Tucker and Townshend (2000) investigated a random sampling approach at a national level and concluded that 90% of the area would need to be covered in order to get a 90% rate of accuracy. The full coverage of wall-to-wall processing is the best option for determining national reference period baselines.

5.4 What has been done

A number of pan tropical or country level analyses of deforestation have been done using remote sensing data. We will briefly discuss some of the main efforts and their limitations for developing national level reference period baselines.

1. The FAO conducted a remote sensing analysis using sampling of Landsat stratified by broad forest types (FAO 2001). The Landsat scenes were classified visually and included a number of different land cover types from which it may be possible to distinguish degradation in addition to deforestation. The time periods covered were 1980 to 1990 and 1990 to 2000. This was a pan-tropical analysis and the data can only provide regional estimates of deforestation. The sample size was sufficient only for continental level estimates. The newer 2005 FAO forest assessment included only national level statistics based on their surveys. No remote sensing analysis was conducted by the FAO for the FRA 2005. However, a remote sensing analysis using systematic sampling is planned for the 2010 report. This will also be a less than 1 percent sample and will most likely only provide estimates at the continental level.

2. The EU's Joint Research Committee in its most recent global assessment used coarse resolution satellite data from 1990-1997 to create a base map upon which experts selected regions of greatest deforestation, "hot spots", across the tropics (Achard 2002). The tropics were then stratified into "hot spot" and "non hot spot" regions for sampling with a greater number of Landsat scenes selected for change detection in hot spots, than in non hot spots. As with the FAO analysis, these scenes were classified visually and included a number of different land cover types from which it may be possible to distinguish degradation in addition to deforestation. A different set of land cover types were used than those for the FAO study. The stratification by hot-spots means that greater accuracy in the areas of greatest change may be achieved. However, it also means that only the percentage of deforestation in hot spots and non-hot spots can be determined. It will not be possible to determine where the deforestation occurs and thus what forest type is being lost. This will make determining carbon emissions from this data set impossible since carbon stocks vary substantially by forest type. And once again this is a pan-tropical analysis. The data can only provide regional estimates of deforestation and can not be separated to provide country level data.

3. A pan-tropical wall-to-wall global assessment of deforestation was conducted using relatively coarse resolution data (8km AVHRR) from 1982 to 2000(Hansen and DeFries 2004). As the authors acknowledge, the precision of these data is not good enough for determination of country level deforestation. It provides only an indication of areas of greatest forest change.

4. Efforts are ongoing using Landsat data to develop country level wall-to-wall measurements of deforestation. At the national level, Brazil and India have conducted comprehensive, high-resolution estimates of forest change. In other cases, international NGOs or academic institutions have conducted these with local collaborations.

   Examples of countries that have completed wall-to-wall analyses are: Brazil (http://www.obt.inpe.br/prodes/), Paraguay (http://www.guyra.org.py/deforestacion.htm), Madagascar (Harper et al. submitted), Bolivia (Killeen, et al. submitted; Steininger et al. 2001), Myanmar (Leimgruber et al. 2005), Liberia (Christie et al. submitted), Argentina (http://www2.medioambiente.gov.ar/documentos/bosques/umsef/cartografia/deforestacion_argentina.pdf), Guatemala (http://www.inab.gob.gt/). Regional efforts include work in the tropical Andes and non-Brazilian Amazon including Bolivia, Colombia, Ecuador, Peru and Venezuela (http://science.conservation.org/portal/server.pt?open=512&objID=628&mode=2&in_hi_userid=124186&cached=true) and most of the Congo basin (Central Africa Republic and Democratic Republic of Congo,http://carpe.umd.edu/decadal-forest-change-mapping-products). A number of different NGOs and academic institutions are involved in these efforts. At this time these wall-to-wall efforts only measure forest and non-forest; they do not provide multiple land classifications. As a result it is not possible to determine forest degradation from the existing data. With additional analysis (and thus additional time and cost) wall-to-wall data could be classified to detect degradation or forest management. A few large area, satellite based studies of selective logging in the Brazilian Amazon have shown that wall-to-wall detection of forest management is possible in some regions (Souza et al. 2005; Asner et al. 2005).

In summary, all of the sampling remote sensing efforts to date are pan-tropical assessments that provide estimates of deforestation on a regional basis, not by country. The wall-to-wall efforts have completed a number of countries but more effort will be required to cover the entire tropical rainforest region. Also some verification of accuracy of these different wall to wall assessments may be needed. The only other country level data available comes from FAO national statistics data which lack consistency.

5.5 Measurement of Forest Degradation

Another type of forest change that many are considering including in an international system is forest degradation. A key question that needs to be answered is how forest degradation will be defined. Will it includes all types of forest management or are only particular land uses to be included and can these be distinguished from the others in measurement. In our discussion below forest management and degradation are not distinguished. We describe the measurement of partial forest clearance, mostly via selective logging, but one may need to further distinguish whether this logging is part of a rotational forestry cycle, where forest (and carbon) stock will re-accumulate or whether, for example, this is part of permanent conversion to non-forest use or shifting cultivation. The role of fire in permanently and temporarily altering the landscape can also be a factor. Should policymakers choose to include degradation along with deforestation in the REDD compensation program, it raises a number of data and measurement issues discussed below.

Detection of forest degradation and forest management is much more difficult than detecting deforestation. Recent detection efforts by Achard (2002) and FAO (2001) visually classify selected individual high resolution (Landsat) images into a number of land cover classes with significant confidence. This may allow detection of forest degradation within those selected areas. Wall-to-wall efforts for measuring forest degradation effort to date focused on the detection of selective logging and fire damage in the Brazilian Amazon (Souza et al. 2005; Asner et al. 2005). These methods are still in the research and development phase, but Brazil has been developing country-level detection of selective logging and fire and may provide the first indication of its practical inclusion for national level baselines and monitoring.

While these are promising examples of what could potentially be done at a national level given time and funding, there is still uncertainty about what how much and what types of degradation can be determined and at what accuracy on a national scale. It is even more difficult to determine the carbon emissions to assign to different types and degrees of forest degradation and the accuracies of such an effort (Gibbs, this series). Current sampling (stratified) efforts by hot spots do not allow determination of forest loss or degradation by forest type making calculations of carbon emissions impossible. Knowing the difference in carbon loss from different intensities of logging or shifting cultivation or other types of forest degradation is difficult at this time.

Further work is needed to find ways to link forest degradation more directly to carbon emissions. Spectral methodology similar to those used by Asner et al. (2004), which can determine changes in forest gap fraction, might provide a measure of a forest's degradation that could be correlated to loss of forest carbon. Also, LIDAR sampling that can determine canopy shape or a simpler version, canopy top and bottom, can potentially be used for calculating biomass. This would allow greater accuracy in linking degradation and deforestation to carbon emissions. Substantial efforts would be needed to expand development and use of such methods.

Achard et al. (2002) estimated that forest degradation covers half again as much forest land as is deforested every year. It is important to consider whether forest degradation and management should be included, how it should be defined, and whether it can be measured with great enough accuracy to be included when the system is put into place. With current knowledge it seems premature to include degradation, but focused effort in this area maybe able to rapidly improve the situation.

6. Costs and Institutional Requirements

Many of the main remote sensing data that would be used for national level baselines can be found for free or used freely by others after the initial imagery is purchased (Landsat, MODIS, AVHRR, SPOT, VEGETATION). There are no legal restrictions on the use of the imagery. This is important because once someone purchases an image; they are free to provide copies to anyone or to upload the data to a site providing public access. This means that the data used to create a map are free to use by the public, and the public can look at the source data used for a map and decide if they agree with the data interpretation. This allows transparency at a very high level; i.e., not only can the public see a map, they can see the original images that it is based on and challenge the map if they find the interpretation suspect. Most efforts to produce national-scale maps of forest cover take advantage of the free data and purchase additional data only where the free data have gaps.

If free imagery is available, costs are primarily associated with the processing of the data. For resource-constrained countries, costs can be addressed through financing arrangements coordinated by existing multilateral lending institutions such as the World Bank.

Among tropical rainforest nations, Brazil and India have established programs for monitoring deforestation, and wall-to-wall deforestation assessments are being developed for many countries. The US and EU have methods capable of measuring deforestation across the tropics, but other rainforest nations may want to build the capabilities internally. The existing satellite systems are sufficient for establishing baselines for deforestation across the tropics. Whether there is sufficient data on the greenhouse gas emissions from this deforestation across the tropics is a question of accuracy that is discussed in greater detail in the Gibbs paper in this series. It is also clear that more work is needed on how to measure the change in forest biomass from forest management and degradation.

Further effort needs to focus on building national forest carbon inventories to enable better emissions estimates. Also, other countries may want to build remote sensing monitoring capabilities. Overtime financial, logistical, and technical support can be put in place to help countries build their own measurement programs.

7. Scientific and Technical Needs for Improving Baseline

Several scientific and technical solutions will enable the production of credible and affordable baselines for deforestation in developing countries. These include:

- There is an on-going need for frequent high resolution imagery. Landsat satellites have been a central technology that lately has experienced funding shortages and mechanical problems. The Landsat program should be fully supported and updated.
- More pervasive field inventories and surveys to measure greenhouse gas emissions associated with deforestation and to validate remote sensing results will

provide key “reality checks” to the overall system of land cover classification and change detection.

- Many developing countries have limited capacity to operate and manage the technical components needed to develop credible REDD baselines. Grant programs to help countries set up national remote sensing assessments and training technicians should be a priority for international and bi-lateral funding agencies.
- Research for more efficient and reliable ways to detect degradation and determine carbon emissions should be prioritized including the development and expansion of RADAR and LIDAR sensors.
- Methods for assessing accuracy/error must be transparent and widely accepted.
- More efficient analytical methods to speed the rate at which land use change detection is conducted would be helpful for the monitoring of REDD emission reductions and credits.

8. Determining Responsibility for Setting National Baselines

Moving forward, parties must decide where the responsibility lies for measuring the baselines. Data availability, analytical resources, cost, sovereignty and capacity-building are all factors that affect who should develop the baseline that would apply to each participating country. Two different approaches are described here. Ultimately, this is a decision that the parties must make via intergovernmental negotiation.

Option 1: Centralized Intergovernmental Effort

Variation in data quality and analytical capabilities across countries may call for a centralized, inter-governmental effort to develop baselines for each country. This approach can produce consistent baseline estimates across countries using the most advanced methods possible. Such a system could be funded and maintained by a central body; perhaps one created by the UNFCCC (e.g., IPCC or one of its technical subsidiaries) and could be based on a single data foundation with a time series of global coverage, such as Landsat imagery. The actual data source and the analytical options for utilizing these data (e.g., wall-to-wall v sampling) are discussed above and can be decided upon by future deliberation of parties. Once those decisions are made, the data and methods can be applied by the central body to develop the national baseline estimates. This centralized approach ensures consistency across countries, is transparent, and is likely a more economical way to develop national estimates than each country embarking on a separate process. However, it is important that the countries participate in the process in some way, either as participants in the data collection and analysis exercise or as reviewers of methods and results before a national baseline is deemed final.

Option 2: Each Country Develops Own Baseline Subject to International Standards

While recognizing the consistency and cost advantages of the centralized approach, it may infringe on the sovereignty of individual nations and might not sufficiently utilize and develop local expertise. Therefore, another option is to allow individual countries to develop their own baseline estimates, subject to standards and guidelines established by the type of intergovernmental body referenced above. This is similar to the system now in place under the UNFCCC under which individual countries report their changes in carbon stocks from land use, land use change and forestry (LULUCF) following *Good Practice Guidelines* developed by the IPCC (IPCC 2003).

While general guidance can be given by a central body, it may not be practical or feasible for all countries to use the same data sources or employ the same methods due to technical and resource constraints. So some flexibility will be in order. This diversity of baseline approaches and quality across countries, while understandable, should be considered in assigning credits in an REDD compensation system. One option for addressing this is a standards-based approach for assigning national REDD credits.

Under a standards-based approach, the intergovernmental body establishes minimum requirements that all countries must meet in terms of the quality of data and the analytical methods they employ to develop the baseline. Any country not meeting these requirements will not be eligible to receive REDD credits. The requirements will be high enough to ensure an adequate level of credibility, but not so high that they will be unattainable by resource-constrained countries. Estimates developed under the minimum requirements, however, could have relatively high measurement error. This may call for REDD credits computed using a baseline estimated with the minimum standards being given less value than (discounted) if they were computed against a more robust and precise baseline estimate. Such a system could work as follows:

1. A country submits data on its national baseline estimate and the corresponding error bounds at an agreed confidence level (e.g., 2.0% +/- 0.8% at 90% confidence level for the specified reference period).
2. The intergovernmental body verifies the estimate and error bounds.
3. The country's official baseline could be set at the lower end of the confidence interval, which provides a conservative estimate of the baseline rate (e.g., 1.2% in the example here, or 40% below the mean estimate).

The more precise the estimate, the tighter the confidence interval will be and the more credit can be granted, all else equal. The process by which crediting is linked to uncertainty can be determined by market participants, subject to established rules of the REDD market.

The advantage of the decentralized approach is that it allows each country the flexibility to employ the data and methods that work best for them. Each can weigh the benefits of additional precision (more credits) against the costs of data and analysis necessary to get that precision. Generally, the best methods are more expensive to implement and may not be feasible in all countries at the moment. But this approach would provide incentive for continued improvement in baseline accuracy and ultimately more confidence that the measured reductions in deforestation and degradation are real.

9. Summary recommendations

As the discussion above demonstrates, there are a number of important technical issues and decisions to resolve before a REDD baseline system can be put in place at the national level. However, we believe all of these issues are resolvable and forward movement on REDD systems are warranted. Toward that end, the paper's recommendations can be summarized as follows:

- For an international policy on REDD a national historic reference period baseline would maximize transparency and best engage national policies.
- Countries with low or no deforestation and degradation would be unlikely to benefit from this system. This means these countries would have little disincentive for deforestation, which could result in cross country leakage of carbon emissions. Further thought should be given to strategies for reducing this problem.
- If it makes sense to use a global or pan-tropical baseline to control for international leakage, initiating REDD at a national level cannot move forward without completion of a global/pan-tropical baseline.
- Parties will need to consider whether future updating of the baseline and reference period will be required when building the current system. If so, it will be necessary to incorporate updating without adding so much uncertainty about future carbon value that the market for REDD credits is undermined.
- Field inventory data on deforestation are sparse and inconsistent and the time required to acquire more data makes this approach infeasible for measuring deforestation anytime soon.
- Remote sensing data are therefore the best option for determining forest change. While needed country-level analyses are not fully available yet, the data necessary for a reference period ending before 2003 are available and with international cooperation sufficient data may be available for later years as well. The methods for determining deforestation are fairly well established. Ideally some field or other high resolution validation will be used to determine accuracy.
- Data on baseline land cover change is ideally delineated by forest type and age to better link with carbon models to estimate the emissions associated with deforestation and degradation.
- Sufficient inventory data and modeling resolution on carbon emissions from forest loss are crucial to use deforestation rates to determine the emissions baselines critical for the REDD system (Gibbs paper).
- Forest degradation needs to be clearly defined before inclusion in the policy.
- Given current remote sensing methods and difficulties determining the carbon loss for different intensities and ages of forest management and degradation, it will be difficult to include these activities in the baseline with much accuracy.

However, new methods using spectral data or new LIDAR data may help and with focused effort rapid progress could be made.

- Implementation options for baseline determination can be
  - A centralized effort by an intergovernmental body, which ensures consistency, reduces overall costs and increases transparency, or
  - A decentralized effort with each country developing its own estimates that are subject to minimum standards, and valued with improved crediting terms for exceeding the minimum requirements.
    - If the latter approach is chosen, this allows for flexibility, ensures minimum quality standards are met, and rewards countries for continued improvements. Its also strengthens capacity-building at the country level.

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