A multi-stage inventory scheme for REDD inventories in tropical countries

Steffen Kuntz [a], Felicitas von Poncet [a], Thomas Baldauf [b], Daniel Plugge[c], Bernhard Kenter[c], Michael Köhl[b]

[a] Astrium GEO-Information Services, 88039 Friedrichshafen, Germany, steffen.kuntz@astrium.eads.net
[b] Institute for World Forestry, Johann Heinrich von Thuenen-Institute Leuschnerstr. 91, Hamburg, D-21031, Germany, thomas.baldauf@vti.bund.de
[c] sfm consultants, Unter den Linden 10, 21465 Wentorf , Germany, info@sfm-consultants.com

ABSTRACT

Reducing Emissions from Deforestation and Forest Degradation (REDD) is an international effort to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forest and invest in low-carbon paths to sustainable development. Of critical importance is the estimation of carbon stocks in forests and their dynamics. The paper presents a scientifically sound and technically feasible approach for carbon stock assessment over large areas by applying a multi-stage inventory concept. This concept combines in-situ data and wall-to-wall forest monitoring using medium to very high resolution remote sensing data from both, optical and SAR satellite systems. This approach assures that not only forest cover is assessed but that estimates on forest degradation and forest dynamics can be monitored with high accuracy.

Keywords: Remote sensing, REDD+, forest inventories, carbon stock, deforestation and forest degradation, multi-stage sampling

1. INTRODUCTION

Deforestation and forest degradation, through agricultural expansion, conversion to pastureland, infrastructure development, destructive logging, fires etc., account for nearly 20% of global greenhouse gas emissions, more than the entire global transportation sector and second only to the energy sector.

Reducing Emissions from Deforestation and Forest Degradation (REDD) is an effort to create a financial value for the carbon stored in forests, to offer incentives to reduce emissions from forests and to invest in low-carbon paths to sustainable development. "REDD+" goes beyond deforestation and forest degradation, and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks. Although substantial financial flows are predicted, which might reach up to US$30 billion a year (http://www.un-redd.org), many open questions are still under discussion, how to reliably assess carbon stocks and their development over time. International agreements on suitable forest monitoring strategies including sound error budgets are still lacking and remain a major challenge. This is valid for both, the countries applying for REDD and requesting financial means for necessary incentives for reducing emissions, and the international donors, who want to assure that their investments are finally contributing to forest conservation and sustainable management of forest in the tropics.

The REDD accounting scheme currently discussed uses a relative simple approach by comparing the carbon stock of an assessment at time 1 (base year; C-stock t1) with the carbon stock at time 2 (C-stock t2). The assumption is that after the successful implementations of incentives for REDD at time 2 the actual carbon stock will be higher than that of an agreed baseline. The difference between these two carbon stock values are the accountable reduced emissions, which could be traded internationally (Figure 1).

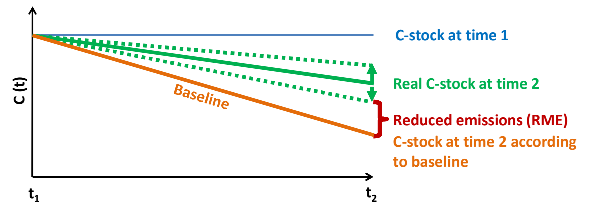

Figure 1. The REDD carbon stock accounting principle and the relationship of the baseline, total error, RME (reliable minimum estimate) and the reduction of emissions from deforestation and forest degradation.

However, any carbon stock inventory will have sources of uncertainties resulting from sampling errors, measurement errors, models applied, assumptions taken, etc. resulting in a total survey error. This is taken into account by using the reliable minimum estimate (RME) in a conservative approach.

As an example in Figure 2 Köhl et al. (2009) have estimated the impact of different accuracy levels for several countries, like e.g., Indonesia. The assumption was that the deforestation rate between 2000 and 2005 of 10.57% is used as the baseline. In a hypothetical optimal case (i.e. no errors occurring) and an emission reduction of 50% approx. 220 Mio. tons of carbon could be accounted which results in about 8 Bil. US$ (with a conversion factor for carbon into carbon dioxide of 44/12 and assuming a value of 10 US$ / tCO_2). Even when the total survey error for the carbon stock estimate is about 4% a 50% emission reduction would still be about 2.9 Bil. US$. However, if this error exceeds 6% even a country like Indonesia with a high deforestation rate could not gain financial benefits from REDD anymore or would even need to pay!

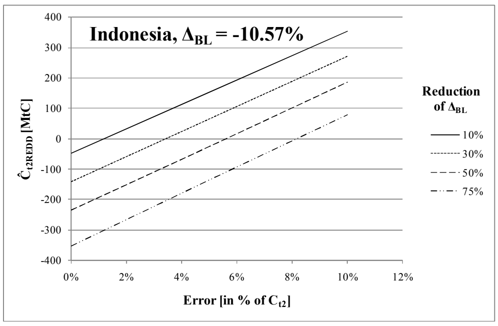

Figure 2: Impact of total survey error on accountable carbon credits (adapted from Köhl et al. 2009).

Hence, it should be of high interest for any country applying for REDD to decrease the total survey error as far as possible, in order to increase the accountable carbon from its forest. This means that a more accurate carbon stock estimate would lead to more accountable carbon in a country. For countries with a

medium forest area this could easily amount to millions of dollars more from the carbon stock exchange market.
Even more challenging is the assessment of forest degradation; i.e. forest remains forest but undergoes some change. Besides the fact that there is still an on-going debate on the definition of forest degradation, it is generally acknowledged that it means at least a reduction of the total carbon stock over a certain time. Forest degradation is one of the major sources of greenhouse gas (GHG) emissions although its significance has not been estimated on a global scale. In 2000 the total area of degraded forests and forest land in 77 tropical countries was estimated to be about 800 million hectares, of which degraded primary forest and secondary forest covered about 500 million hectares. (ITTO, 2002 cited by SIMULA, 2009).

The REDD Sourcebook (http://www.gofc-gold.uni-jena.de/redd/) recommends to use at least very high resolution (VHR) data as forest degradation can range from the removal of single trees to vast destructive logging practices, which results in a severe reduction of the canopy cover and secondary damages.

In addition, remote sensing today only may assess aboveground woody biomass (living and dead trees). Presently, further important components such as downed woody debris and litter, non-tree understory vegetation and soil organic matter can not be measured from space. As for most tropical forest types only rudimentary allometric equations are available, differing significantly according to various authors and local conditions (references), there is currently no way for large area forest monitoring to directly link remote sensing with accurate biomass estimates.

2. A MULTI-STAGE INVENTORY CONCEPT FOR REDD

Any REDD+ inventory system following the MRV (monitoring, reporting and verification) principle needs to include at least (1) deforestation monitoring, (2) forest degradation monitoring, (3) carbon stock modeling, and (4) error budget estimation. As described above remote sensing alone can only be partially fulfilling these demands. However, scientifically sound as well as technical and financial valid multi-stage forest inventory schemes are available since decades. In the following an approach is described, which combines most recent satellite technology and optimized terrestrial sampling, in order to estimate carbon stocks and translate them into tradable CO_2 equivalents.

The principle is given in Figure 3 which shows the main sampling stages of the approach. In the first stage the forest cover is assessed based on wall-to-wall forest mapping from remote sensing. Furthermore, a stratification of the main forest formations and high dynamic areas should be accomplished, if possible. For this task proven technology and a range of sensors are available, such as MERIS / MODIS, Landsat, IRS, SPOT, RapidEye etc., which can accommodate to different demands in scales (from continental to sub-regional). In case of lacking data availability of these sensors, high resolution (HR) SAR data (e.g. ALOS PALSAR, ENVISAT, RADARSAT, Sentinel-1) might be used for gap filling in tropical countries. Compatible approaches exist as Figure 4 illustrates for case studies in Borneo.

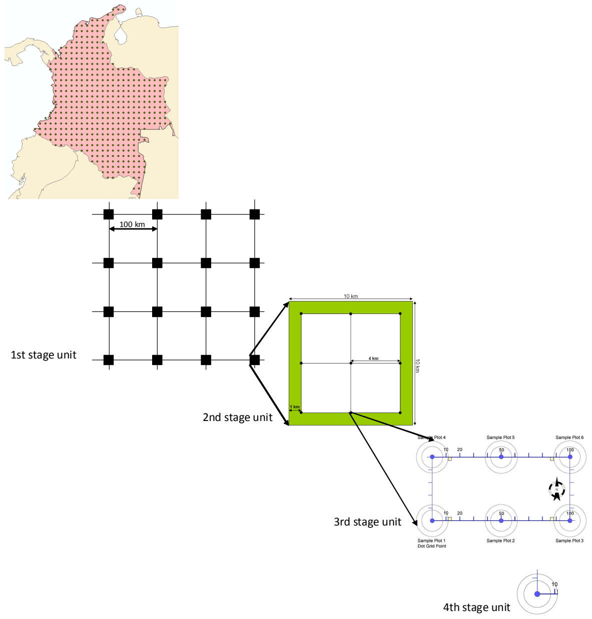

Figure 3: Schematic view of multi-stage inventory design for REDD+ inventories. Explanation in the text.

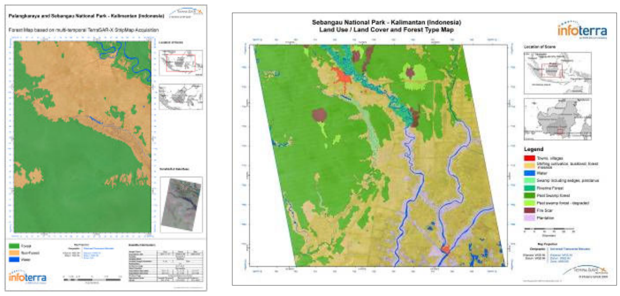

Figure 4: Examples of forest maps from SAR data. On the left a forest cover map from TerraSAR-X 3m StripMap data shows the Sebangau National Park and Palankaraya, Kalimantan. On the right a forest type map from the same extended area combining ALOS-PALSAR (allowing a higher automation of forest cover classification) and TerraSAR-X ScanSAR (improving delineation geometry and forest type / land cover mapping) is shown. © Infoterra GmbH.

Based on the wall-to-wall forest cover assessment a permanent sampling grid is applied (e.g. a regular grid of 100x100km; first stage). In Figure 3 this approach has been applied over the state of Colombia.

For each sample area (10x10 km) VHR imagery will be acquired. Here, both optical and VHR SAR satellite systems are applicable (e.g. IKONOS, QuickBird, KOMPSAT, TerraSAR-X, CosmoSkyMed, etc.). However, considering permanent samples, high revisit times in areas with high deforestation and forest degradation dynamics and frequent cloud cover, VHR SAR data will be required to assure suitable acquisitions in time. It is mandatory that the ortho-rectified VHR images will be available before the terrestrial survey starts, in order to support the laborious and difficult field work (especially in areas where no topical and accurate maps exist) and to be able to adjust the next sampling stage to the real in-situ conditions, if required. In the second stage a further sampling grid with a spacing of 4x4km and a buffer of 1km will be implemented in the above selected sampling areas resulting in 9 clusters. , as shown in Figure 4. Each cluster consists of 6 sample plots (3. stage), which are surveyed on ground and where dendrometric measurements are carried out to estimate carbon stock (Plugge et al. 2010). Of course, these measurements can be easily extended to other assessments, e.g. for information on biodiversity, rare species, soil conditions, land use. The sampling design represents a stratified four stage cluster sampling design. The design reduces the (unproductive) time required to reach sampling plots and increases cost-efficiency especially in remote areas.

This approach guarantees a sound assessment of the carbon stock in the first inventory to establish a national base year. However, due to the necessary field survey this first inventory is expensive and allocates significant resources. It can be assumed from previous experiences in tropical countries that one cluster of 6 sample plots can be assessed by one team in one day. One team should consist of 6-8 members (i.e. a team leader, 2-3 foresters and botanists, 2-3 persons for tree measurements and 1-2 assistants). However, in most cases it is expected that an adaption to the local situation is necessary and may result in different sampling intensities adjusted to regional, political and socio-economic constraints and the available resources.

The biggest advantage of this approach will be realized in the follow-up inventories. Based on the initial carbon stock assessment at time 1 the effort for follow-up inventories especially when short monitoring intervals are needed (e.g. annual monitoring of hot-spots) can be significantly reduced, as these subsequent inventories can be conducted by the remote sensing phases, only. In areas where major changes in forest cover or density are detected by remote sensing terrestrial sampling might nevertheless be required. In case of high frequency monitoring demands under tropical conditions VHR SAR data is currently an efficient tool to reliably monitor permanent sample plots (KUNTZ, 2010). Recent investigations show that TerraSAR-X data is of high geometric accuracy and its flexible tasking capabilities can be deployed even for fast progressing deforestation and forest degradation monitoring tasks (Figure 5).

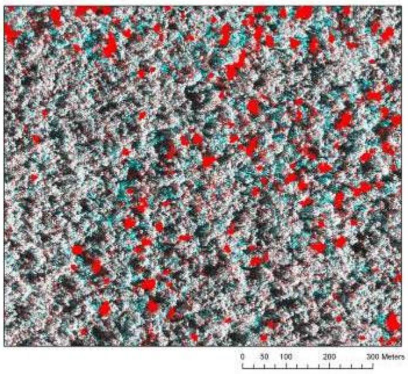

Figure 5. Multi-temporal TerraSAR-X High Resolution SpotLight image (1m resolution) from a selectively logged stand in the Amazon rainforest / Brazil. HR SpotLight Mode in RGB: R: 2008/04/20; G: 2009/08/17; B: 2009/08/17. The logging of individual trees can be detected and automatically identified (red spots). Such information is mandatory for monitoring forest degradation from space (BALDAUF 2009).

3. CASE STUDY IN COLOMBIA

Based on these encouraging results in a test site in Colombia a study is currently carried out in cooperation between IDEAM (Institute of Hydrology, Meteorology and Environmental Studies) and Astrium GEO Information Services. Aim is to demonstrate the use of TerraSAR-X imagery in a Colombian pacific tropical rainforest region, where optical image availability is very restricted due to nearly permanent cloud coverage. In addition its remoteness, the lack of appropriate infrastructure and political constraints makes is quite difficult to access the region.

In Figure 6 the location of one of the test sites (Ventana) is given. It simulates the location of a permanent sample plot of a 10 km x 10 km size. The image is orthorectified based on a digital surface model created from radargrammetry using the unique geometric accuracy features of TerraSAR-X,

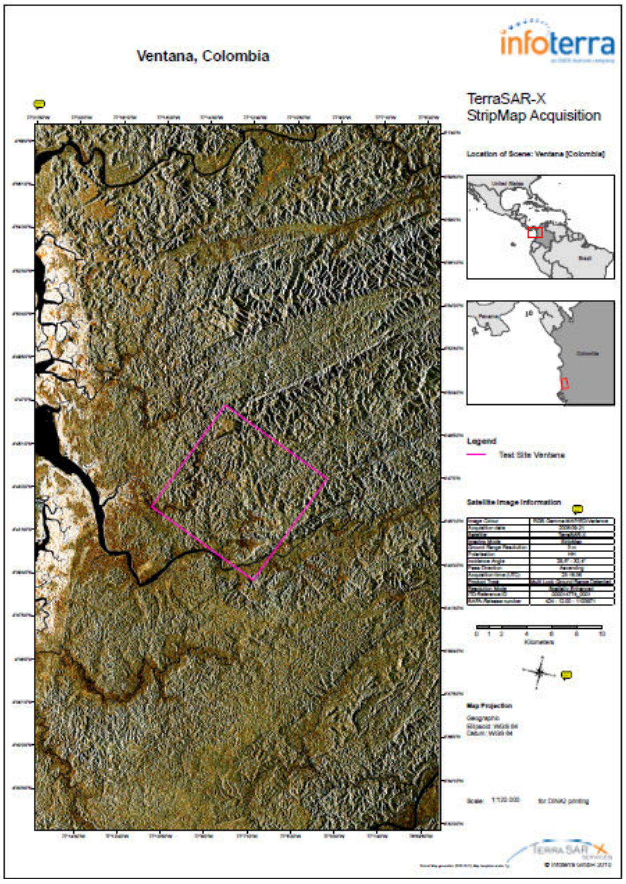

Figure 6: Location of a 10 x 10 km sample site in the Ventana test site in Colombia superimposed to orthorectified 3 m resolution TerraSAR-XStripMap data (HH polarization; acquisition Date: 2008-09-21). The image data was enhanced by texture filtering to facilitate orientation in the image.

Although deforestation does nearly not exist in this specific region by automated change detection means deploying multi-temporal TerraSAR-X data the removal of single trees or small spot logging activities can be detected (Figure 7)

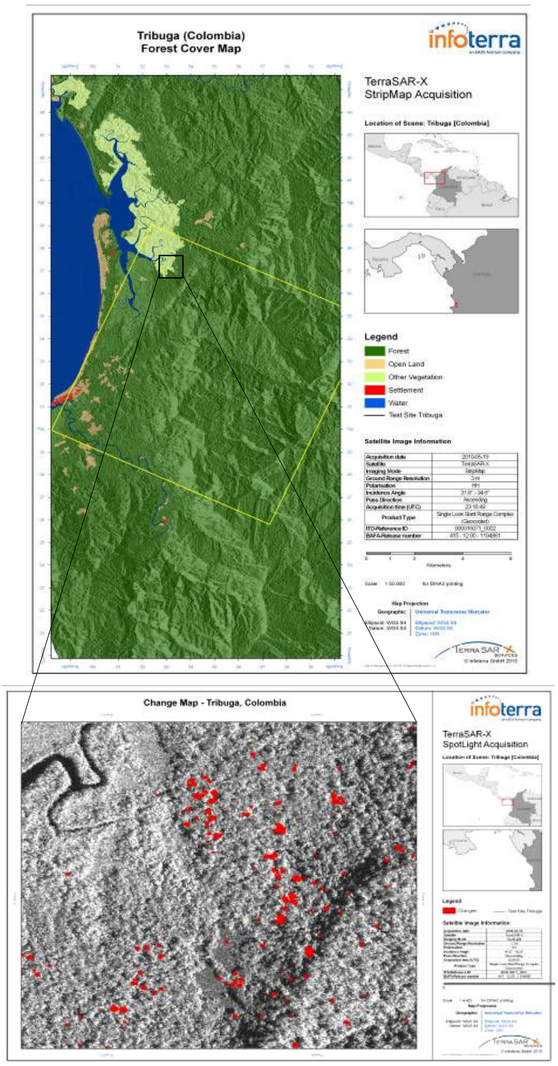

Figure 7: Forest cover map of Tribuga test site based on TerraSAR StripMap data from 2010-05-19. Below the change detection result of TerraSAR Spotlight (acquisition dates: 2010-04-01 & 2010-06-28).. The highlighted regions show that in very small spots tree crowns have been removed. The change detection process and the area delineation is highly automated.

CONCLUSIONS

As remote sensing currently does not allow the direct measurement of carbon stock in forests terrestrial measurements are mandatory. However, for efficient sampling strategies a-priori knowledge of forest cover and forest conditions is important for stratification. In addition, the combination of VHR imagery with field surveys carried out on permanent sample plots can reduce the effort for the terrestrial stage significantly.

Furthermore, the implementation of permanent sample plots is likely to reduce the error propagation in repetitive inventories. In the follow-up surveys field sampling can be reduced to a minimum in those regions where no changes are detectable or where the degree of changes (i.e. removal of single trees) can be directly observed by remote sensing. Thus the effort for repetitive sampling can be significantly reduced after the initial inventory. In areas frequently covered by clouds this task can be done by VHR SAR data, such as TerraSAR-X.

REFERENCES

Baldauf, T.; Köhl, M. Use of TerraSAR-X for Forest Degradation Mapping in the context of REDD. Presentation at the World Forestry Congress, Buenos Aires, 2009

GOFC-GOLD A sourcebook of methods and procedures of monitoring and reporting anthropogenic greenhouse gas emissions and removals caused by deforestation, gains and losses of carbon stocks in forests remaining forests, and forestation. GOFC-GOLD Report version COP15-1 (GOFC-GOLD Project Office, Natural Resources Canada, Alberta, Canada), 2009

ITTO Guidelines for the Restoration, Management and Rehabilitation of Degraded and Secondary Tropical Forests, ITTO Policy Development Series No. 13, Yokohama, 2002

Köhl, M.; Baldauf, T.; Plugge, D.; Krug, J.. Reduced emissions from deforestation and forest degradation (REDD): a climate change mitigation strategy on a critical track. Carbon Balance and Management 4, 10., 2009

Kuntz, S. Potential of spaceborne SAR for monitoring the tropical environments. Tropical Ecology 51(1): p. 3-10, 2010

Kuntz , S, von Poncet, F, Baldauf, Th., Plugge, D., Kenter, & B., Köhl, M: A multi-stage inventory scheme for REDD inventories in tropical countries. Invited paper presented at the 9th Seminar on Remote Sensing and GIS Applications in Forest Engineering, October 19 th – 21th , 2010, Curitiba – Paraná, Brazil, 2010

Plugge, D.; Baldauf, T.; Rakoto Ratsimba, H.; Rajoelison, G.; Köhl, M., Combined Biomass Inventory in the scope of REDD (Reducing Emissions from Deforestation and Forest Degradation). Madagascar , Conservation & Development, 2009 (in press)

Simula, M, Towards Defining Forest Degradation: Comparative Analysis of Existing Definitions, Forest Resources Assessment Working Paper 154, FAO, Rome, Italy, 2009

References from Websites

http://www.un-redd.org/AboutREDD/tabid/582/language/en-US/Default.aspx. Access 04. June 2010 .