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# Deploying Internet-Based MRV Tools and Linking Ground-Based Measurements with Remote Sensing for Reporting Forest Carbon

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**ABSTRACT:** This research demonstrates (1) an Internet-based forest carbon measurement system to support Tier 3 level carbon stock assessments; and (2) a method that links ground-based measurements or IPCC Tier 1 biomass values with Earth Observation satellite remote sensing to map carbon across large areas at Landsat-class (15-metre) spatial resolution. We demonstrated web-based tools and carbon mapping methods in two case study areas: Sangthong District, Lao PDR and Bac Kan Province, Viet Nam. Results for carbon stock in the forest strata for these two pilot areas are reported via an online system using geographic parcels and plot information, and tree inventory data collected at the plot level. The carbon mapping method utilises a vegetation continuous fields (VCF) algorithm, which is used to downscale IPCC Tier 1 default biomass values or stratified Tier 3 biomass values to compute carbon at 15-metre Landsat pixel resolution. The Internet-based forest carbon system and mapping method is a globally-deployable, scalable MRV (measurement, reporting and verification) system that is cost-effective and uses rigorous scientifically-valid methods for calculating carbon. The system is online at http://mrv.carbon2markets.org.

**KEYWORDS:** *forest carbon, REDD+, MRV tools, satellite remote sensing*

## Introduction

Forests play a critical role in mitigating climate change through the sequestration and storage of carbon in perennial woody biomass and soils. The Intergovernmental Panel on Climate Change (IPCC) reported in 2007 that about one third of anthropogenic emissions of atmospheric $CO_2$ since 1750 are from land-use changes, primarily from deforestation and about 20% are from land-use changes for the 1990s (IPCC, 2007). Recent estimates derived from satellite remote sensing conclude that deforestation and forest degradation accounted for 7–14% of global anthropogenic $CO_2$ emissions for the period 2000 to 2005, with 32% of deforestation emissions coming from South and Southeast Asia (Harris et al., 2012).

Extremely large financial investments are now being made in forestry and agriculture carbon projects for climate mitigation in developing countries (e.g. the Climate Investment Fund — Forest Investment Program, the World Bank — Carbon Partnership Facility). While these large investments in forest and agriculture carbon initiatives are moving ahead rapidly in response to international climate policy, the basic framework for measurement and verification is almost non-existent. There is a desperate need for rapid development of proofs of concepts for what the international community calls MRV systems (monitoring, reporting and verification systems). A recent report from the World Economic Forum's *Task Force on Low Carbon Prosperity* has put it this way: "To develop the necessary level of sophistication of systems required for accurate REDD+ monitoring, reporting and verification, a major public-private initiative is required to develop comprehensive Earth Observation systems and field measurement and monitoring systems to be ready for use by 1 January 2013" (Agrawala et al., 2009).

Implementing forest carbon emission reduction and sequestration projects must show that carbon mitigation is real and permanent and do so in a cost-effective manner. Accurate measurement and monitoring of carbon stock changes in biomass must use robust scientific methods. Reporting and verification procedures must follow accepted protocols. Combined, these form the elements of an MRV system. Carbon compliance regulatory regimes, multilateral investment programmes, national reporting schemes and carbon markets will need robust, cost-effective systems for measuring, reporting and verification. This research demonstrates (1) an Internet-based forest carbon measurement system to support Tier 3 level carbon stock assessments; and (2) a method that links ground-based measurements or IPCC Tier 1 biomass values with Earth Observation satellite remote sensing analysis to map carbon across large areas at Landsat-class (15-metre) spatial resolution. We have developed a globally-deployable, scalable MRV system that is cost-effective and rigorous and have demonstrated its functionality with pilot activities in Lao PDR and Viet Nam.

### HIGHLIGHTS

- Development of online MRV tools for Tier 3 forest carbon stock measurement reporting (mrv.carbon2markets.org)
- Tier 3 carbon stock estimates for Sangthong District, Lao PDR deciduous forest and two community forests in Na Ri District, Bac Kan Province, Viet Nam
- Tier I carbon stock estimates integrating IPPC default values with Earth Observation remote sensing analysis methods for Bac Kan Province, Viet Nam
- Tier 3 carbon stock estimates integrating ground-based data with Earth Observation remote sensing analysis methods for Bac Kan Province, Viet Nam
- REDD+ forest carbon stock measurements and emissions reporting capabilities (through Internet-based tools and services) support robust scientific methods and transparency

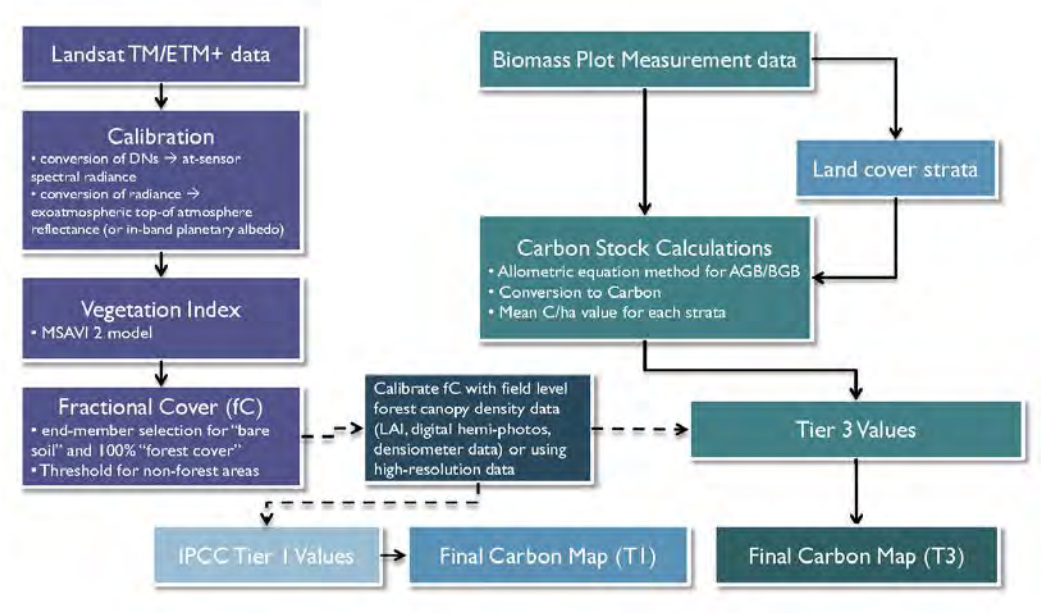
## Methods and Results

### *Pilot Project Areas*

The two pilot areas[1] selected for the research project were Sangthong District,

[1]An analysis for a third area, Savannakhet Province, Lao PDR, was also completed utilising field data collected under the SUFORD project; these findings are not presented here.

**Figure 1.** Workflow of the analysis.




Vientiane Prefecture, Lao PDR and Bac Kan Province, Viet Nam. In Bac Kan Province, data was collected supporting the MRV system at two scales — province-wide and at two community forest areas belonging to Na Muc village, Van Minh Commune and Tu Dooc village Lang San Commune, both in Na Ri District. The area is located about 200 kilometres north of Hanoi. The community forest areas are tropical moist broadleaf evergreen forests.

In Sangthong District, data was collected by the Faculty of Forestry, National University of Laos in a tropical moist deciduous forest area. This area is located approximately 80 kilometres northeast of the capital city of Vientiane and is the district where the Faculty of Forestry maintains its Training Model Forest (TMF).

Table 1 shows the number, type and dimensions of biomass plots established at each study site and the number of trees inventorised.

The plot level tree inventory data were logged in an Excel file and uploaded to the online forest carbon MRV system, which estimates the carbon stock at the plot, parcel (or strata) and project levels.

### *Remote Sensing Analysis*

Landsat data was first calibrated converting digital numbers (DNs) to at-sensor spectral radiance and then exoatmospheric top-of-atmosphere reflectance, also known as in-band planetary albedo (Chander et al., 2004). Data was then converted to a vegetation index using the Modified Soil Adjusted Vegetation Index 2 (MSAVI 2) model (Qi et al., 1994). A "vegetation continuous fields" (VCF) or "fractional cover" (FC) data set was then developed using a spectral unmixing algorithm (Matricardi et al., 2010) from two end-members (forest and bare soil). The FC data was then stratified using a land-cover

**Table 1.** Pilot area biomass plot summaries.

| Pilot Area | Number of Plots | Number of Trees | Plot Type & Dimensions |
|---|---|---|---|
| Sangthong Dist., Laos | 13<br>16 | 711<br>721 | Circular Nested 25 and 10 m radius<br>Circular Nested 50 and 20 and 10 m radius |
| Bac Kan Prov., Viet Nam | 32<br>22 | 1486<br>Var. land use systems[2] | Rectangular Nested 50 x 40; 5 x 40 m<br>Rectangular Nested 10 x 10 m |

[2] Field data collected by ICRAF-Viet Nam for a study, *Carbon stock evaluation in some types of land use in Bac Kan* by Đỗ Hoàng Chung. We used the data in forest carbon mapping with Landsat data.

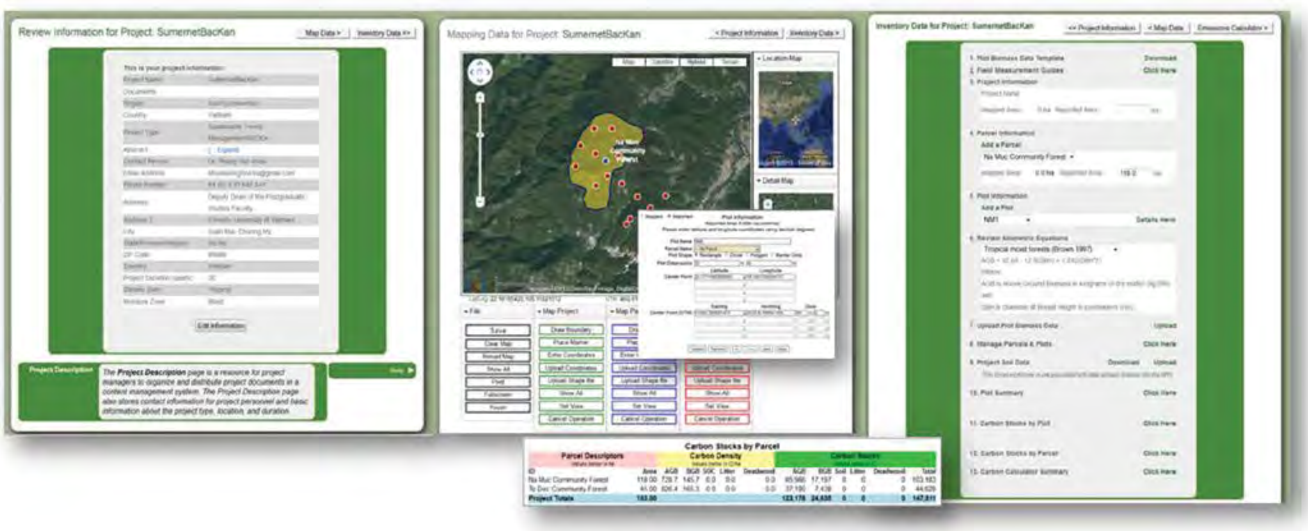


**Figure 2.** Three core components of the MRV system.

stratification map or through a forest/non-forest level slice. For each stratum where we have the mean plot level carbon estimates, we then calibrated the FC data using a linear regression equation or down-calibrated the strata-specific biomass values using the FC pixel value. This produced a final forest carbon map. In the absence of plot level Tier 3 data, the FC data can be calibrated using field-collected canopy openness data again using regression equation coefficients. IPCC Tier 1 biomass estimates (IPCC, 2006) were then applied to the calibrated FC data product for the forest strata. The output was a Tier 1 downscaled forest carbon map and a more realistic estimate than simply a "paint-by-numbers" approach of assigning the IPCC default value to polygons of the same forest type. Figure 1 shows the workflow of the method.

### *Internet-Based Forest Carbon MRV System*

The MRV system is designed as a project management system. It is Internet-enabled, with a secure login. Data is stored in a relational database which has redundant backup with bi-monthly system snapshots for restore capabilities. The core functions of the system include (1) a content management system and project registry; (2) geographic tools to support project boundaries, parcel (or strata) boundaries, and plot locations; (3) plot inventory data with tools and information to support sample plot design and data collection as well as carbon stock reporting; and (4) an emissions calculator tool designed to use either the Tier 3 biomass estimates from the plot inventory data or Tier 1 IPCC default parameters to calculate emissions *ex ante* or *ex post* in a project parcel. Figure 2 shows screenshots of the MRV system's first three core components.

### *MRV Carbon Stock Reports and Carbon Maps*

The results of the carbon stock are reported from the online MRV system for each project site. The calculations incorporate the Tropical Moist Forest allometric equation (Eq. 1) developed by Brown (1997) and a default root-to-shoot ratio of .20 for below-ground biomass.

*Tropical Moist Forest Allometric Equation* (Eq. 1)

$$AGB = 42.69 - 12.8(DBH) + 1.242(DBH^2)$$

Where:

AGB = Above Ground Biomass in kilograms of dry matter (kgDM), and

DBH = Diameter at Breast Height in centimetres (cm)

Above- and below-ground biomass is calculated at the tree level in each plot using the allometric equation and root-to-shoot ratio. The above- and below-ground

| Carbon Stocks by Parcel | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parcel Descriptors (Values below in ha) | | Carbon Density (Values below in tC/ha) | | | | | Carbon Stocks (Values below in tC) | | | | | |
| ID | Area | AGB | BGB | SOC | Litter | Deadwood | AGB | BGB | Soil | Litter | Deadwood | Total |
| Na Muc Community Forest | 118.00 | 728.7 | 145.7 | 0.0 | 0.0 | 0.0 | 85,986 | 17,197 | 0 | 0 | 0 | 103,183 |
| To Doc Community Forest | 45.00 | 826.4 | 165.3 | 0.0 | 0.0 | 0.0 | 37,190 | 7,438 | 0 | 0 | 0 | 44,628 |
| **Project Totals** | **163.00** | | | | | | **123,176** | **24,635** | **0** | **0** | **0** | **147,811** |

| Carbon Stocks by Parcel | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parcel Descriptors (Values below in ha) | | Carbon Density (Values below in tC/ha) | | | | | Carbon Stocks (Values below in tC) | | | | | |
| ID | Area | AGB | BGB | SOC | Litter | Deadwood | AGB | BGB | Soil | Litter | Deadwood | Total |
| Deciduous_Forest | 3,628.00 | 93.3 | 18.7 | 0.0 | 0.0 | 0.0 | 338,574 | 67,715 | 0 | 0 | 0 | 406,288 |
| **Project Totals** | **3,628.00** | | | | | | **338,574** | **67,715** | **0** | **0** | **0** | **406,288** |

**Figure 3.** Carbon stock reports for both pilot project areas.

biomass density, reported in tons of carbon per hectare, is then computed for each plot. For all plots associated with a specific parcel, the mean above- and below-ground biomass is calculated. Total carbon stock is computed using the area of the parcel and the mean above- and below-ground biomass density derived from all plots associated with the parcel. Figure 3 shows the carbon stock reports for both pilot project areas indicating the project and parcel areas, the above- and below-ground carbon density values, and above- and below-ground carbon stocks.

The carbon mapping analysis of Bac Kan Province used subsets of two adjacent Landsat images for complete coverage of the provincial area. Data was processed to FC as per the method describe. A threshold value of FC=30 was used to determine forest and non-forest. A Tier 1 forest carbon map was then developed by multiplying the FC value of all forest class pixels with the IPCC Tier 1 default biomass value of 130 tDM per ha of above-ground biomass from table 4.7 of IPCC (2006). The result is a carbon stock estimate for the province of 44,901,883 tC or an average of 92 tC per ha. A Tier 3 forest carbon map was developed integrating a land-use and land-cover data set and biomass data from field plots with the FC data product. The output map estimates carbon stock in Bac Kan at 28,928,355 tC or an average of 60 tC per ha (see Figure 4).

## Conclusion

A fully deployed, Internet-based forest carbon system that supports project geographic strata and plot data as well as tree inventory data from field-level biomass plots can serve as a major linchpin for a REDD+ MRV scheme. Tier 3 reporting from this online tool integrated with robust methods for mapping forest carbon using satellite remote sensing data can help scale up this REDD+ MRV system, lowering MRV costs associated with a field-level-only approach. We successfully demonstrated the Internet-based forest carbon MRV system and the remote sensing forest carbon mapping method at two project sites in Lao PDR and Viet Nam. The system is currently online as a version 1.4.1 deployment at http://mrv.carbon2markets.org.

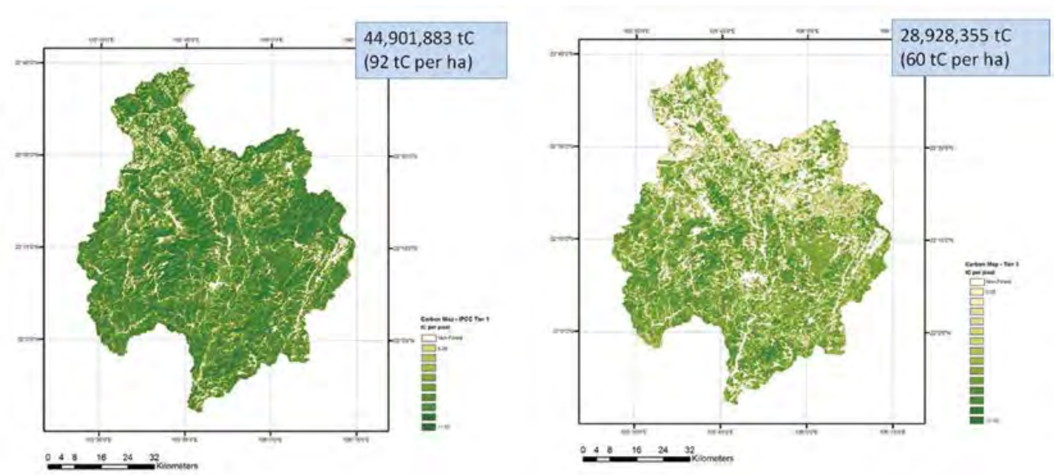



**Figure 4.** Forest carbon maps resulting from the carbon mapping analysis.

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## EBLU2011-02CMY(C)-SKOLE

### PROJECT TITLE

**Developing an MRV System for REDD+: Scaling Up from Project Level to a National Level REDD+ MRV Systems for Laos and Viet Nam**

### COUNTRIES INVOLVED

Lao PDR, USA, Viet Nam

### PROJECT DURATION

2 years

### APN FUNDING

US$ 65,000

### PROJECT LEADER


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