TOOL FOR REMOTE SENSING BIOMASS MEASUREMENT


Funding support provided by the U.S. Agency for International Development

<table>
<thead>
<tr>
<th>Title</th>
<th>Tool for Remote Sensing Biomass Measurement</th>
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<tbody>
<tr>
<td>Version</td>
<td>v 2.0</td>
</tr>
<tr>
<td>Date of Issue</td>
<td>14-March-2014</td>
</tr>
<tr>
<td>Type</td>
<td>Tool</td>
</tr>
<tr>
<td>Sectoral Scope</td>
<td>AFOLU - REDD, IFM, ARR, WRC - LtPF, APD, RWE</td>
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</tbody>
</table>
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1 SOURCES

VCS Methodology VM0006 - Methodology for Carbon Accounting in Project Activities that Reduce Emissions from Mosaic Deforestation and Degradation, v11

VCS Module VMD0001 - REDD Methodological Module: Estimation of Carbon Stocks in the Above- and Below Ground Biomass in Live Tree and Non-Tree Pools (Version 1.1)

AR AM Tool 03 “Calculation of the number of sample plots for measurements within A/R CDM project activities.” (Version 02.1.0)

AR AM Tool 14 “Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities.” (Version 02.1.0)

CDM approved methodology AR-AM0002 “Restoration of degraded lands through afforestation/reforestation” (Version 03)

Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance for Land Use, Land-Use Change and Forestry (GPG-LULUCF), 2003. Global Observation of Forest Cover and Land Dynamics (GOFC) Sourcebook: Reducing greenhouse gas emissions from deforestation and degradation in developing

2 SUMMARY DESCRIPTION OF THE TOOL

Precise estimation of carbon in Aboveground Live Tree Biomass (ALFB) is critical for the implementation of many AFOLU projects. ALFB is the primary factor for determining baseline levels for forest carbon pools and is also used to predict and measure changes resulting from planned and actual activities. The geographic scope of AFOLU/Carbon projects is often large (>40,000 ha) and encompasses a wide range of land use/land cover (LULC) types. Statistically valid sampling strategies for such large areas using traditional ground-based forest inventory plots are often infeasible due to cost and access constraints. Current VCS methodologies have no provision for the use of remote sensing methods to determine biomass and rely solely on traditional plot-based biomass measurements.

The Remote Sensing Biomass Measurement Tool provides a method for determining ALFB through a combination of remote sensing data and field measurements to provide accurate and cost effective estimation of ALFB across varied LULC classification types and broad spatial extents. This tool is intended for use with with all approved VCS methodologies within the scope of Agriculture, Forestry, Land Use.

3 DEFINITIONS

Aboveground Live Forest Biomass (ALFB)
Live forest biomass above the soil, including the stem, stump, branches, bark, seeds and foliage for vegetation with a diameter $D_{ref}$ (<10cm old growth, >5cm for secondary and degraded)

Area of Interest (AOI)

Geographic region within which carbon in aboveground biomass is to be estimated. It could be a reference region, project area, forest stratum, leakage belt or jurisdictional program area

Remote Sensing (RS)

Imagery or other gridded data acquired from aerial or satellite platforms and ortho-rectified to a geometric coordinate system such that scale is uniform

Sample Plots (SP)

A geographic subset of the reference region or strata within which ALFB is measured in-situ using field instrumentation and used as a basis for ALFB estimation at the strata or project scale.

Validation Plot (VP)

A subset of SPs used to test predictive accuracy of the model developed using VPs.

Calibration Plot (CP)

A subset of SPs used to develop a predictive model relating RS metrics to AGB

Land Use and Land Cover (LULC)

Definition used to stratify a reference region into regions with similar characteristics

Forest Inventory and Analysis Program (FIA)

United States Department of Agriculture Forest Inventory and Analysis Program

Assisted Natural Regeneration (ANR)

Human-induced forest regeneration through silvicultural activities that induce or accelerate an increase in forest biomass, as compared to natural regeneration rates

Net Greenhouse Gas Emissions Reductions (NER)

Results of a project in terms of net emissions reductions

Agriculture, Forestry and other Land Use (AFOLU)
Following the 2006 IPCC Guidelines for national greenhouse gas inventories, the AFOLU consolidates the previous sectors LULUCF (Land Use, Land Use Change and Forestry) and agriculture.

Improved Forest Management (IFM)
AFOLU project category defined by VCS

Afforestation, Reforestation and Revegetation (ARR)
AFOLU project category defined by VCS

Reducing Emissions from Deforestation and Degradation (REDD)
AFOLU project category defined by VCS

Agricultural Land Management (ALM)
AFOLU project category defined by VCS

Wetland Restoration and Conservation (WRC)
AFOLU project category defined by VCS

Improved Cropland Management (ICM)
Specific AFOLU project type defined by VCS

Logged Forest to Protected Forest (LtPF)
Specific AFOLU project type defined by VCS

Avoided Planned Deforestation (APD)
Specific AFOLU project type defined by VCS

Restoring Wetland Ecosystems (RWE)
Specific AFOLU project type defined by VCS

Wetland Restoration and Conservation (WRC)
Specific AFOLU project type defined by VCS
4 APPLICABILITY CONDITIONS

The tool is applicable under the following conditions:

- The remotely sensed data necessary to estimate ALFB is available for the AOI and for the time period required.
- Inventory plot locations are located within the project and/or reference area.
- The project proponent shall demonstrate that biomass estimation methods available under the specific Methodology for which the use of this Tool is to be applied are not appropriate either due to accessibility constraints, security concerns, cost limitations, and/or demonstrate that the certainty of estimates produced by this Tool meet or exceed those estimated using the methods detailed within the Methodology.

5 PROCEDURES

To implement this tool, the project proponent must be able to obtain remotely acquired data covering the AOI or representative area within the AOI that can either directly measure or predict ALFB. A thorough review of relevant standards and guidelines for quantifying and reporting uncertainty is recommended as total ALFB reported at the AOI must be discounted based on uncertainty in ALFB estimation.

5.1 Stratification of the AOI (optional).

This method may employ stratification of the reference region into like biophysical land cover or forest types. If this tool is being deployed in the context of an emissions reduction project in which a historical baseline of emissions is established for LULC classes within the AOI, the LULC classification map should be used as the basis for sampling design to ensure sufficient sampling density for each LULC type. Stratification may also be used to improve the accuracy of the RS ALFB predictive relationship.

5.2 Estimation using RS predictor.

Remotely acquired data can capture an array of biophysical characteristics of the landscape at a range of scales. In many cases, data collected from RS platforms can be functionally related to ALFB such as \( f(x) = \text{ALFB} \) wherein \( x \) is one or many metrics derived directly from one or many sensors, and \( f(x) \) is a function. To employ this predictive approach, a sampling strategy is needed.

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2 Section 4.1.4 Verified Carbon Standard. 2013. VCS Standard. v3.4
to provide data used to both calibrate and validate the predictive model. A sampling design must be implemented across the reference region or within each stratum to achieve desired precision in the estimate. Sampling may use data collected from field plots only, however the use of RS (LiDAR, RADAR, hyperspectral/hyperspatial imagery) in combination with a relatively small number field plots and can be used to achieve a statistically valid sample under this methodology. Predictive relationships between RS data and field data are established using a subset of the sampled area and tested using the remainder of the sampled area using a cross validation procedure to provide both accuracy and precision, which must be clearly documented.

1. **Uncertainty sources:** Measurement, allometry, sampling, prediction
2. **Steps used:** i) Forest Stratification (optional), ii) Sampling, iii) Prediction

### 5.2.1 Step 1 Forest Stratification (optional)

While stratification can substantially increase the predictive accuracy of models extrapolating a sample area to larger areas using RS data, it is not essential to stratify the AOI if the proponent:

a) accepts increased uncertainty in the estimate, or b) employs a method that can achieve sufficient accuracy without the use of stratification.

If stratification is used as a basis for sampling design, the result must be a wall-to-wall (tessellation) map of like forest types within the AOI. A range of RS (or other) data sources can be used in this step. However, the functional relationship between the RS and ALFB should be described in detail and reference empirical relationships demonstrated in relevant scientific literature. To ensure independence metrics used in ALFB estimation using RS data, data used in the stratification step may be used as long as the errors are propagated correctly to predict ALFB from sampled data. In the case of a multi-sensor (multi-spectral, etc.) RS platform it is justifiable to use data collected synchronously as long as data from the same sensor are not employed in both stratification and biomass estimation methods.

If this tool is being used the context of emissions reductions projects (REDD+, CDM, etc.), the project proponent should consider use of the LULC classification scheme developed for establishing the historical emissions baseline and MRV as the basis for stratification.

Project proponents should consider two stratification options: 1) LULC classes may be used as strata if ALFB densities within each LULC class are relatively constant; or 2) LULC classes may be further subdivided into multiple strata if sufficient biophysical variance exist within the LULC class. Reduction in uncertainty of ALFB estimation can, in some cases, be achieved through establishing strata with homogeneous biophysical (i.e biomass density) characteristics.

LULC classification and forest stratification procedures must follow the guidelines similar to the one set forth in Section 8.1.2 of VCS Methodology VM0006 or the appropriate guidelines listed in any other approved VCS methodologies for which this methodological tool (Remote Sensing Biomass Measurement) is being applied.
5.2.2 Step 2: Sampling

The area to be sampled by RS and/or in-situ measurement plots is determined by the desired precision of the estimate of ALFB for the AOI. In this document, we refer to sampling as a means of collecting representative data from a geographic subset of the AOI used in predicting and validating ALFB density for the entire project area. Thus sampling can be conducted via in situ ground-based plots or by a remote sensing platform. Sampling should be conducted to an extent to sufficiently reduce the variance around the mean area-normalized biomass estimate within the desired confidence interval (α).

5.2.2.1 Step 2a: Sampling design

5.2.2.1.1 Sampling with RS data

Sampling to achieve an unbiased estimate of ALFB can be conducted using ground based plots or a combination of a reduced number of ground based plots and an intermediate RS dataset. Estimation of ALFB based upon in-situ measurement plots may have large errors due to the size of plots, sampling density, and the potential bias due to location of plots creating an statistically unsystematic sampling. In addition, sampling sufficient area to achieve desired precision in the estimate over large areas based solely upon in-situ measurement plots may be infeasible due to cost and logistics. Intermediate aerial RS data such as Light Detection and Ranging (LiDAR), RADAR, or multispectral imagery can substantially reduce the overall cost of field data collection as large areas can be covered in much less time and with less expense than field crews. However, the use of intermediate RS data introduces an additional source of error. Thus selection of an RS platform such as LiDAR that can directly obtain metrics strongly related to ALFB is critical. In the case where such data can be obtained, additional error can be readily reduced when averaged over larger area\(^4\). The accuracy of the predictive relationship between intermediate RS and ALFB must be clearly presented and the uncertainty in the estimate must be used in discounting project level ALFB.

5.2.2.1.2 In-situ measurement plots

In-situ measurement plots, or Sample Plots (SPs) are used to develop and validate statistical relationships between RS metrics and ALFB. SPs must be established at random across the area they are considered to be representative of (stratum, RS flightline). Adherence to random selection without replacement\(^5\) of SP locations is critical. Plot design should follow established guidelines for the forest type being sampled (RAINFOR\(^6\), FAO, others). A/R Methodological Tool

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\(^4\) See Asner et al 2013.

\(^5\) In the event that subsequent randomly selected plot locations overlap, the later plot should be discarded and another random selection made.

03\(^7\) may be used for guidance to estimate the number and size of necessary PSPs. Plots must not overlap.

5.2.2.2 Step 2b: Estimation of ALFB in Plots

Field data collection at SPs should include diameter (\(D_{ref}\)) and height (\(H\)) for measured trees and specific identification for wood density estimation. If wood density (\(D\)) for each species is not collected in field sampling, values should be taken from Table GPG-LULUCF 3A.1.9\(^8\).

To estimate the ALFB of a specific tree species within a sample plot based on field measurements, relevant allometric equation should be applied. If species-specific biomass data has been measured via destructive sampling methods for forests similar to those found in the AOI, the project proponent may derive equation coefficients using the collected data and replace the default values. Allometric equations specified in GPG-LULUCF Annex 4A.2 Table 4.A.1 may be used. See additional guidance on selection and use of allometric equations for ALFB in Picard et al. (2012) and Chave (2005).

Sampling techniques such as field-based direct volume measurement that can be demonstrated to meet or improve accuracy of the above allometric equation may be accepted if evidence is provided.

The following steps are used to estimate ALFB per hectare for each forest unit.

1. ALFB in sample plot \(p\) of stratum \(i\) is calculated as follows:

\[
ALFB_{PLOT,p,i} = \sum_j ALFB_{TREE,j,p,i}
\]

2. ALFB per hectare in plot \(p\) of stratum \(i\) is estimated as follows:

\[
ALFB_{UNIT,p,i} = \frac{ALFB_{PLOT,p,i}}{A_{p,i}}
\]

where:

<table>
<thead>
<tr>
<th>ATB(_{TREE,j,p,i})</th>
<th>Tree biomass of specific tree of species (j) in sample plot (p) of stratum (i); units = tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATB(_{PLOT,p,i})</td>
<td>Tree biomass in sample plot (p) of stratum (i); units = tons</td>
</tr>
</tbody>
</table>

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\(^7\) CDM Executive Board. Calculation of the number of sample plots for measurements within A/R CDM project activities. EB 46 Report Annex 19.

\(^8\) From http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/Chp3/Anx_3A_1_Data_Tables.pdf
### 5.2.2.3 Step 2c: Error Estimates

Mean ALFB and variance of ALFB per hectare in the stratum are estimated as follows:

\[
ALFB_{AVG,i} = \frac{\sum_{p=1}^{n_i} ATB_{UNIT,p,i}}{n_i}
\]

\[
s^2_{ALFB,i} = \frac{n_i \cdot \sum_{p=1}^{n_i} (ALFB_{UNIT,p,i}^2 - (\sum_{p=1}^{n_i} ALFB_{UNIT,p,i})^2 / n_i)}{n_i \cdot (n_i - 1)}
\]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>ALFB_{AVG,i}</td>
<td>Mean ALFB per hectare in stratum i; units = tons/ha</td>
</tr>
<tr>
<td>ATFL</td>
<td>ALFB per hectare in sample plot p of stratum i; units = tons/ha</td>
</tr>
<tr>
<td>(n_i)</td>
<td>Number of sample plots in stratum i; dimensionless</td>
</tr>
<tr>
<td>(s^2_{ALFB,i})</td>
<td>Variance of ALFB per hectare in stratum i; units = (t ha(^{-1}))^2</td>
</tr>
</tbody>
</table>

Mean ALFB per hectare within the project area and its variance are estimated as follows:

\[
AFLB_{AVG,TOT} = \sum_{i=1}^{M} w_i \cdot AFLB_{AVG,i}
\]

\[
s^2_{AFLB} = \sum_{i=1}^{M} w_i^2 \cdot \frac{s^2_{ALFB,i}}{n_i}
\]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFLB_{AVG,TOT}</td>
<td>Mean ALFB per hectare within the project boundary; units = t ha(^{-1})</td>
</tr>
<tr>
<td>(w_i)</td>
<td>Ratio of the area of stratum i to the sum of the area of all biomass estimation strata within the project boundary</td>
</tr>
<tr>
<td>(s^2_{AFLB})</td>
<td>Variance of mean ALFB per hectare within the project boundary</td>
</tr>
</tbody>
</table>

Margin of error of the ALFB per hectare within the project area is estimated as follows:

\[
e_{AFLB} = t_{VAL} \cdot s_{AFLB}
\]

where:

- \(t_{VAL}\) is the value from the Student’s t-distribution table
- \(s_{AFLB}\) is the standard error of the mean ALFB per hectare within the project boundary
### 5.2.2.4 Step 2d (optional): Intermediate RS sampling

In cases where it is difficult to accurately predict project-wide ALFB based on the extrapolation of field plots to forest strata or project area (i.e. very large and remote project areas), an intermediate RS step may be used to increase the sampling accuracy. See Asner et. al. (2013) for an example of this approach. RS data collection should be designed such that flightlines will result in sufficient coverage of all strata to achieve desired precision of the resulting estimate. In cases where an intermediate RS dataset is used to upscale plot data, error must be combined from upscaling plot data to intermediate RS data and from intermediate RS estimate to the AOI.

### 5.2.3 Step 3: Prediction

To estimate carbon in ALFB, field or RS data must be extrapolated to the extent of the strata or project area.

For all ALFB estimation (strata or project) the following metrics must be generated:

- ALFB density ($t \text{ ha}^{-1}$)
- RS metric(s) used in predicting ALFB
- RMSE of the RS-based biomass estimate compared with field data.

ALFB density prediction using RS data is done using a random selection of Calibration Plots (CP) derived from the PSPs within a stratum to develop predictive model relating RS data to field measures. In this step, metrics contained in the RS data are mined for their predictive power vis a vis ALFB as measured in field data. Once a predictor is selected, it is used to estimate ALFB for the remainder of CPs constituting the Validation Plots (VP) within the strata. Cross validation should be employed and results reported to assess the accuracy of the predictive model.

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9 CDM Executive Board. Calculation of the number of sample plots for measurements within A/R CDM project activities. EB 46 Report Annex 19.
Accuracy of the predictive model should be assessed comparing the actual ($\gamma$) versus predicted ($\gamma'$) ALFB density values for the VPs:

$$
\varepsilon = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\gamma'_i - \gamma_i)^2}
$$

Estimates of carbon in ALFB must be discounted based upon the accuracy of the estimate. Review the appropriate discounting mechanism from the methodology or the VCS guidance documents.

### 5.2.3.1 Step 3b (optional): Intermediate RS Sampling

If an intermediate RS dataset is employed to upscale plot level data, a similar approach is used for error estimation as in the use of PSPs. For a given reporting stratum (LULC class in the case of emissions reduction projects) a fraction of the area defined by the spatial intersection of the footprint of the intermediate RS dataset and the stratum can be used to develop a predictive model relating the intermediate RS data to the RS data with wall-to-wall AOI coverage. The predictive accuracy of the model relating intermediate RS and wall-to-wall AOI is then reported using the remainder of the intersecting area. Error estimation for the target stratum or project ($\varepsilon$) is calculated as the sum of errors from extrapolation of plots to RS data (above) and errors upscaling from intermediate RS:

$$
\varepsilon = \varepsilon_{int} + \varepsilon_{aoi}
$$

Where

$$
\varepsilon_{int} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\gamma'_i - \gamma_i)^2}
$$

and

$$
\varepsilon_{aoi} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\delta'_i - \delta_i)^2}
$$

where:

$\delta$ and $\delta'$ are ALFB density values from validation regions (eg pixels) used in upscaling intermediate RS data to the stratum or project area.

If the project developer has elected to stratify the project area, this procedure is then replicated for all strata in the project area. ALFB density values and associated uncertainty can then be reported for each strata and/or for the project area.
### DATA AND PARAMETERS

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<thead>
<tr>
<th>Data / Parameter</th>
<th>( A_{p,i} )</th>
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<tbody>
<tr>
<td>Data unit</td>
<td>ha</td>
</tr>
<tr>
<td>Description</td>
<td>Area of plot ( p ) in sample ( i )</td>
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<tr>
<td>Equations</td>
<td></td>
</tr>
<tr>
<td>Source of data</td>
<td>Field or geospatial measurement</td>
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<td>Description of measurement methods and procedures to be applied</td>
<td>For rectangular plots, geographic location should be reported as the coordinate pair (latitude, longitude) of the northwest and the bearing and length of each</td>
</tr>
<tr>
<td>Frequency of monitoring/record ing</td>
<td>Once every verification period.</td>
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<tr>
<td>QA/QC procedures to be applied</td>
<td>Utilize industry standard techniques for measurement</td>
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| Purpose of data | *Calculation of baseline emissions*
|                 | *Calculation of project emissions*
|                 | *Calculation of leakage*

<table>
<thead>
<tr>
<th>Data / Parameter</th>
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<tr>
<td>Data unit</td>
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</tr>
<tr>
<td>Description</td>
<td>Wood density of species $j$</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>Equations</td>
<td></td>
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<tr>
<td>Source of data</td>
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| Purpose of data                          | • Calculation of baseline emissions  
                                             • Calculation of project emissions  
                                             • Calculation of leakage |
| Calculation method                       |                            |
| Comments                                 |                            |

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<tr>
<th>Data / Parameter</th>
<th>$D_{ref}$</th>
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<tr>
<td>Data unit</td>
<td>cm</td>
</tr>
<tr>
<td>Description</td>
<td>Reference diameter of a tree used in allometric calculation of volume</td>
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<tr>
<td>Equations</td>
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### Reference Diameter

<table>
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<th>Field measurement</th>
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<tbody>
<tr>
<td>Description of measurement methods and procedures to be applied</td>
<td>Reference diameter is usually 1.3M above the ground surface on the tree but can vary depending upon species. Consult appropriate sampling guidelines.</td>
</tr>
<tr>
<td>Frequency of monitoring/recording</td>
<td>Once every verification period.</td>
</tr>
<tr>
<td>QA/QC procedures to be applied</td>
<td>Utilize industry standard techniques for measurement</td>
</tr>
</tbody>
</table>
| Purpose of data                               |无忧我写 | Calculation of baseline emissions
| Calculation method                           |                                      |
| Calculation method                           |                                      |
| Comments                                     | This parameter could be any other diameter or dimensional measurement applicable for the model or data source used |

### Tree Height

<table>
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<tr>
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<td>m</td>
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<tr>
<td>Description</td>
<td>Height of tree</td>
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<tr>
<td>Equations</td>
<td></td>
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<tr>
<td>Source of data</td>
<td>Field measurement</td>
</tr>
<tr>
<td>Description of measurement</td>
<td>Tree heights should be measured using standard survey equipment.</td>
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## Methods and Procedures to Be Applied

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<th>Frequency of Monitoring/Recording</th>
<th>Once every verification period.</th>
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<td>QA/QC procedures to be applied</td>
<td>Utilize industry standard techniques for measurement</td>
</tr>
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</table>

### Purpose of Data
- Calculation of baseline emissions
- Calculation of project emissions
- Calculation of leakage

### Calculation Method
- This parameter could be any other diameter or dimensional measurement applicable for the model or data source used

### Data / Parameter
- **RMSE**

### Data Unit
- Unitless

### Description
- Assessment of accuracy of predicted model

### Equations

### Source of Data
- Field measurement and RS data

### Description of Measurement Methods and Procedures to Be Applied
- Varies depending on type of field measurement and/or RS data being compared

### Frequency of
- Once every verification period.
<table>
<thead>
<tr>
<th><strong>monitoring/record ing</strong></th>
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<tbody>
<tr>
<td><strong>QA/QC procedures to be applied</strong></td>
<td>Utilize industry standard techniques for measurement</td>
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<tr>
<td><strong>Purpose of data</strong></td>
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</tr>
<tr>
<td>• Calculation of baseline emissions</td>
<td></td>
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<tr>
<td>• Calculation of project emissions</td>
<td></td>
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<tr>
<td>• Calculation of leakage</td>
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<td><strong>Calculation method</strong></td>
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<tr>
<td><strong>Comments</strong></td>
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### 7 REFERENCES


IPCC. 2003b. Definitions and Methodological Options to Inventory Emissions from Direct Human-Induced Degradation of Forests and Devegetation of Other Vegetation Types. Intergovernmental Panel on Climate Change, Geneva, Switzerland.


