

FRAMEWORK FOR

REMOTELY SENSED QUANTIFICATION OF FOREST CARBON

VERSION 1.0

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 ACR^{SM}

OFFICE ADDRESS

c/o Winrock International 325 W Capitol, Ste 350 Little Rock, Arkansas 72201 USA ph +1 571 402 4235

ACR@winrock.org acrearbon.org

ABOUT ACRSM

ACR is a leading global carbon crediting program operating in regulated and voluntary carbon markets. Founded in 1996 as the first private voluntary greenhouse gas (GHG) registry in the world, ACR creates confidence in the integrity of carbon markets to catalyze transformational climate results. ACR ensures carbon credit quality through the development of environmentally rigorous, science-based standards and methodologies as well as oversight of GHG project verification, registration, and credit issuance and retirement reporting through its transparent registry system. ACR is governed by Environmental Resources Trust LLC, a wholly-owned nonprofit subsidiary of Winrock International.

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Acronyms

ERR Emission reductions and/or removals

FIA Forest Inventory and Analysis

GHG Greenhouse gas

GPG Good Practice Guidance

IFM Improved Forest Management

IPCC Intergovernmental Panel on Climate Change

LiDAR Light Detection and Ranging

LULUCF Land Use, Land Use Change and Forestry

OBIA Object Based Image Analysis

QA/QC Quality assurance / quality control

RADAR Radio Detection and Ranging

RMSE Root Mean Squared Error

SOP Standard operating procedures

USDA United States Department of Agriculture

VVB Validation/Verification Body



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1 Introduction

1.1 Summary

This ACR Framework for Remotely Sensed Quantification of Forest Carbon (henceforth, the Framework) prescribes quantification standards and validation guidelines for employing Remote Sensing-based measurements of carbon pools and sources in ACR forest carbon projects.

The Framework establishes thresholds for accuracy and uncertainty of remotely sensed forest carbon stock estimates. A variety of Remote Sensing-based technologies, such as but not limited to lidar and satellite imagery, may be used to derive forest carbon estimates.

The approach is designed to decrease the required field sampling intensity necessary to derive forest carbon estimates within ACR uncertainty thresholds and to facilitate efficient long-term monitoring, reporting, and verification. The Framework leverages field sampling for Predictive Model calibration and validation of remotely sensed forest carbon estimates.

Remotely sensed carbon stock estimates are validated against traditional, plot-based inventory data (i.e., tree diameters, heights, and species) collected on randomly selected forest inventory plots. Remotely sensed forest carbon estimates must meet or exceed known and accepted statistical thresholds for accuracy and uncertainty, in comparison to plot-based inventory data.

The Framework also establishes procedures used by a Validation/Verification Body (VVB) to independently validate the accuracy of remotely sensed carbon stock estimates via field-based forest carbon sampling.

1.2 Applicability

This Framework is applicable to the following ACR forest carbon methodologies:

- Afforestation and Reforestation of Degraded Lands
- Active Conservation and Sustainable Management on U.S. Forestlands
- Improved Forest Management (IFM) on Canadian Forestlands
- Improved Forest Management (IFM) on Non-Federal U.S. Forestlands



This Framework does not supersede any of the requirements of specific ACR methodologies. Rather, this Framework addresses how the process outlined herein and the resulting outputs of this Framework can be compatible with a given Methodology's existing accounting framework.

1.3 Utilization in GHG Projects

The use of this Framework is designed to facilitate derivation of remotely sensed aboveground live biomass carbon and aboveground standing dead wood carbon pool estimates in ACR forest carbon projects. Eligible approaches leverage remotely sensed carbon estimates and field Calibration Plots to achieve required accuracy and uncertainty thresholds, inclusive of discounts for uncertainty. Estimates of aboveground live biomass carbon and aboveground standing dead wood carbon (if an "included" or "optional" carbon pool per the applicable Methodology) are used to derive corresponding belowground components via standard, approved allometric equations.

Projects utilizing methodologies that rely on tree-level inventories for the development of baselines from modeled growth and yield calculations and harvested wood products at the project Start Date (i.e., Improved Forest Management (IFM) methodologies) must utilize inventory approaches as described in the Methodology for deriving initial reporting period carbon stocks. These inventories can then be used to facilitate the use of Remote Sensing model validation in subsequent reporting periods.

Project utilizing methodologies that do not rely on growth models for baseline development (i.e., Active Conservation and Sustainable Management on U.S. Forestlands) or projects where the baseline carbon stocks are negligible at the project Start Date (i.e., Afforestation and Reforestation of Degraded Land) may utilize Remote Sensing to derive with-project stock measurements at any point in the project following use of this Framework. Remotely sensed carbon pool estimates may only be utilized in a GHG Project if the models are deemed eligible through use of Validation Plots (Section 3), successful remeasurement of a sample of Validation Plots by an approved VVB (Section 4), and successful model approval (Section 5).

This Framework provides a Stratum-level framework for assessing model eligibility and approval. It is therefore possible to apply this Framework to provide carbon estimates for specific Strata, which may or may not constitute the whole GHG Project. The project area may consist of a single or multiple strata. Each Methodology provides details regarding stratification that shall be followed.



1.4 Project Type and Baseline Modeling

ACR forest carbon project types have varying methods for establishing estimates of baseline emissions reductions and removals.

Projects utilizing methodologies that rely on growth models to estimate forest management across a baseline period (e.g., IFM project types) must use currently approved methods as described in the applicable methodology and validation scope (e.g., field measurements, model selection and calibration for site-specific conditions and tree growth).

Projects utilizing methodologies where the initial carbon stocks are negligible in the baseline and with-project scenarios (i.e., Afforestation/Reforestation projects) may use this Framework for estimation of with-project carbon stocks.

Projects utilizing methodologies that conserve and sustainably manage forestlands at risk of conversion to non-forest uses (i.e., Active Conservation and Sustainable Management on U.S. Forestlands projects) may use this Framework to validate estimations of initial project carbon stocks to which baseline conversion rates are applied as well as ongoing measurement of the with-project scenario carbon.

Projects within these project type categories with previously validated baselines may utilize Remote Sensing data as permitted in this Framework to quantify with-project carbon stocks on a forward-moving basis (i.e., in subsequent Reporting Periods).

1.5 Reporting

If this Framework is used at the project Start Date, the Project Proponent must provide a Remote Sensing standard operating procedures (SOP) document as an appendix to the GHG Project Plan that describes the technologies and methods employed to measure and quantify forest carbon stocks. If this Framework is first used later in the project term, the Project Proponent must provide the Remote Sensing SOP document as an appendix to the Monitoring Report.

The Remote Sensing SOP document must be validated by an ACR-approved VVB and contain the following information:

- Aerial, satellite or other technologies employed and a description of the measurements taken;
- A description of the Calibration Plot measurement protocols;



- A stratum level estimate of carbon stocking derived from Calibration Plots;
- A general description of the Predictive Model and how the Calibration Plot measurements are utilized in its development;
- The stratification SOP document (if applicable), included as either a stand-alone document or as a subsection of the Remote Sensing SOP document, as further described in Section 2.2;
- The Validation Plot SOP document, included as either a stand-alone document or as a subsection of the Remote Sensing SOP document, as further described in Section 3.1;
- The participating entities involved in the implementation of this Framework and their roles and responsibilities; and
- Results of additional reporting requirements for IFM projects utilizing this Framework at the Project Start Date as detailed in Section 7.

The Remote Sensing SOP document must be amended and verified any time the aforementioned information changes.

Each time this Framework is utilized to determine carbon stocking in the GHG Project (including at first use), the Remote Sensing SOP document must be amended to include the following information specific to the most recent utilization:

- A description of the Remote Sensing measurements;
- The total number of number of Calibration Plots, and the number of Validation Plots;
- The model accuracy results, by strata, as described in Section 2 based on Calibration Plots;
- The results of the model eligibility assessments, as implemented according to Sections 3.2;
- The Stratum-level uncertainty percentage, as calculated according to Section 5; and
- The Stratum-level and total carbon estimates net of uncertainty, as calculated according to Section 6.

1.6 Validation and Verification

The applicability, implementation, and results of this Framework are subject to validation and verification by a VVB, including a ground-based remeasurement of the Validation Plots (Section 4) to confirm the implementation of the Validation Plot SOPs. VVBs generate the sequence of points to be measured by the Project Proponent as Validation Plots (Section 3.1), which mitigates the potential risk of plot selection biased toward demonstrating model eligibility. VVBs must ensure that the Remote Sensing SOP and all reporting is complete and accurate (Section 1.5) and that all calculations are properly implemented in accordance with this Framework (Sections 2 through 6) and the applicable Methodology.



This process must be described in the relevant Validation and/or Verification Report, including the following information:

- A description of the process of generating a sequence of points for Validation Plot installation and measurement, including the points generated and how they were utilized;
- A description of the Validation Plot remeasurement effort, including how it conforms to the specifications in Section 4;
- A summary of the review of calculations required by this Framework (Sections 2 through 6); and
- Relevant literature, references, interviews, and other information reviewed in understanding and corroborating the validity of the remote sensing quantification approach.

All issues regarding this Framework must be documented and resolved in an issues log pertaining to the validation and/or verification the GHG Project as a whole.

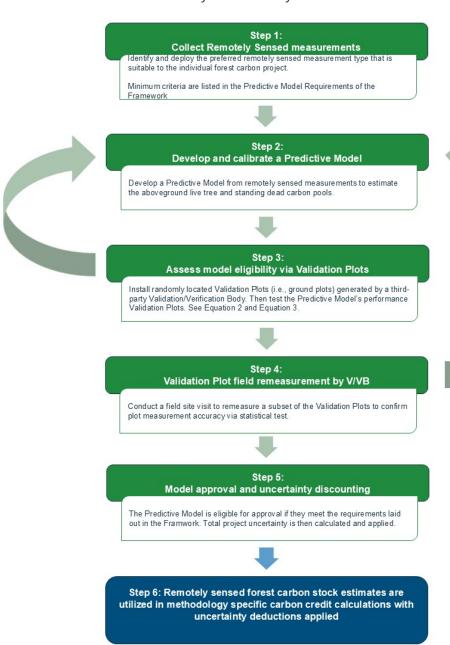
1.7 Process

The process for applying this Framework is summarized by Figure 1.



Figure 1: Steps for Developing, Assessing, and Approving the Use of Remote Sensing Data to Quantify Forest Carbon

Arrows depict necessary checks and opportunities for refinement towards validation within the prescribed thresholds for accuracy and certainty.





2 Predictive Model Development

All projects utilizing this Framework must develop a Predictive Model to estimate carbon stocks according to the specifications outlined in this section. All projects utilizing this Framework must also use the prescribed methods to estimate uncertainty and to discount carbon stock estimates for uncertainty. Predictive Models must be developed prior to engaging in the Validation Plot process with a VVB (Section 3).

2.1 Predictive Model Requirements

This Framework does not prescribe specific technologies or methods for conducting Remote Sensing but rather sets a common threshold for required precision, in relation to known carbon estimates collected via ground-based sampling. A variety of technologies and methods may be employed, however, the following minimum criteria are required for all projects:

- The entire Stratum or area of interest must be covered by Remote Sensing Pixels, and all Remote Sensing Pixels must be included in the estimation of carbon stocks. If using Object Based Image Analysis (OBIA), objects or segments must cover the entire stratum or area of interest;
- Timestamps must be provided for all Remote Sensing measurements;
- Georeferenced coordinate information must be provided for all Remote Sensing measurements;
- In addition to the precision requirements established in the ACR Standard, projects utilizing this Framework must employ the uncertainty deductions as specified in Section 6 of this Framework;
- Validation Plot estimates of forest carbon for model validation (as outlined below in Section 3.1) must be collected in accordance with the biomass estimation techniques outlined in the applicable ACR forest project methodology.

2.2 Predictive Model Design

The Predictive Model is developed to estimate aboveground live tree and standing dead tree carbon pools for a Remote Sensing Pixel, group of Remote Sensing Pixels or segment. Its output may be categorical or continuous. Predictive Models may take the form of classification models, allometric models, gradient nearest neighbor models, or other approaches meeting the relevant definition of a Predictive Model. Any type of Predictive Model is acceptable if it successfully meets the validation



criteria, is tested with Validation Plots (Section 3) and its estimates are deducted for uncertainty (Section 5) as outlined in this Framework.

Stratification may be used to improve the accuracy of the Predictive Model's Inference and precision of carbon stock estimates. If stratification is used, a stratification SOP document detailing relevant design, inputs, parameters, rules, and techniques must be provided. The stratification SOP document must contain sufficient information such that the stratification can be examined and duplicated as necessary to provide reasonable assurance of the validity and absence of bias in associated techniques. For the estimation of carbon stocks, Strata should be defined based on properties indicative of carbon stocks. Strata must be delineated for the entire project area. For the purposes of this document, if stratification is not used, the project area is deemed a single Stratum. It is permissible to use this Framework for certain Strata and to use field inventories per the requirements of the applied Methodology for the remaining Strata.

The Project Proponent may then measure Calibration Plots and incorporate field measurements into the development of the Predictive Model. Project Proponents may utilize as many Calibration Plots as they deem necessary to adequately parameterize the Predictive Model. Calibration Plots do not need to adhere to the field inventory SOP document (Section 3.1) and may be designed, allocated, and measured using any methods at the Project Proponent's discretion. The methods for measuring and incorporating Calibration Plots are not subject to review by the VVB. However, standardization of the measurement protocols for Calibration Plots and Validation Plots is likely to better facilitate validation and verification of the remotely sensed carbon estimates.

Project Proponents must use a subset of Calibration Plots to test the predictive relationship between the Predictive Model and Calibration Plots using a cross-validation procedure to test model accuracy prior to installing Validation Plots. Calibration plot confidence intervals developed from the cross-validation procedure shall be calculated and reported (as in equation 3) in project documentation prior to engaging with the Verification Body.

If this Framework is used for Improved Forest Management (IFM) projects at the project Start Date, ground based inventories are required for estimating carbon stocking and baseline modeling. Additional process and reporting details are outlined in Section 7 below.

All Predictive Models are subject to the following requirements:

- Predictive Models must estimate the aboveground live tree and standing dead carbon pools for each Remote Sensing Pixel or object;
- The Project Proponent must develop a Predictive Model for each Stratum (i.e., one Predictive Model per Stratum);
- Predictive Models must estimate carbon for all Remote Sensing Pixels or objects within the Stratum.



• Remote Sensing Pixels located on a boundary which include area found outside the Stratum must pro-rate that Remote Sensing Pixel's carbon estimate by the percentage of area found within the Stratum.

Once all Remote Sensing Pixels or objects for a particular Predictive Model have been assigned a carbon estimate, these values are averaged to calculate a Stratum-level estimate of carbon (Equation 1) per unit area. This estimate does not yet consider any deductions for uncertainties (Section 5).

Equation 1: Stratum-Level Carbon Estimate

$$C_{PM,i} = \sum_{p=1}^{P_i} C_{PM,p,i} \Big/ N_i$$

WHERE

$C_{PM,i}$	Carbon stock (in metric tons CO_2e /unit area) for all Remote Sensing Pixels p within Stratum i , as derived from the Predictive Model (PM).
$C_{PM,p,i}$	Carbon stock (in metric tons CO_2e /unit area) for Remote Sensing Pixel p within Stratum i , as derived from the Predictive Model (PM).
N_i	Total number of Remote Sensing Pixels (n) within Stratum i.



3 Assessing Model Eligibility with Validation Plots

Once a project has developed a Predictive Model, they may assess its eligibility by installing and measuring Validation Plots (Section 3.1) and applying statistical tests (Section 3.2) to test for statistical agreement. If statistical agreement has been achieved the Predictive Model is deemed eligible for approval and the Project Proponent may submit their Validation Plots for remeasurement by the VVB (Section 4).

3.1 Validation Plot Installation and Measurement

After contracting with a VVB for a given Reporting Period (or for a stand-alone validation), the VVB must generate a randomly allocated sequence of points that are located as centroids to Remote Sensing Pixels within the Stratum (as provided by the Project Proponent). Point locations are then provided by the VVB to be measured by the Project Proponent as Validation Plots. VVBs should generate an excess of points and select from a subset, ensuring that the distribution of Validation Plots appropriately encompasses the range of the predictive model outputs. Each Stratum must have a unique sequence of points located therein. Validation Plots are distinct from Calibration Plots (i.e., their data cannot be used to calibrate the Predictive Model) for the current Reporting Period. Validation Plots may be used to calibrate the Predictive Model only in the following two instances:

- When developing a Predictive Model to be applied to a future Reporting Period, allowing Validation Plots from past Reporting Periods to be used as Calibration Plots; or
- When the eligibility assessment is restarted with a new sequence of Validation Plots, allowing the previously installed and measured Validation Plots to be used as Calibration Plots.

Using the randomly allocated points from the VVB, the Project Proponent must install and measure Validation Plots following a predetermined sequence. Each Stratum must have a minimum of 30 Validation Plots. Each new sequence of Validation Plots cannot include previously measured plots.



Validation Plots may be designed as either circular or square plots, or they may match the size and shape of the Remote Sensing Pixel. While Validation Plots are not subject to any specific size requirements, they must be located completely within a single Remote Sensing Pixel and therefore may not exceed the size of the Remote Sensing Pixel. Validation Plots must be installed by the Project Proponent and monumented such that they can be efficiently relocated by the WB. Any Validation Plots that cannot be relocated by the WB shall be assigned an estimate of zero carbon for the purposes of the VVB's remeasurements or a new Validation Plot location must be randomly generated by the VVB for Project Proponent plot installation.

Validation Plots must be installed and measured according to a Validation Plot SOP document, provided by the Project Proponent for validation/verification. This document will describe the Validation Plot inventory process in detail. Prior to verification and/or validation, this document will be attached to the GHG Project Plan or, for subsequent reporting periods, the Monitoring Report. The field inventory SOP document must include the following:

- Sample size;
- Plot size and design, in-field location procedures, and monumentation;
- Data collected and measurement tools used;
- Detailed measurement procedures such that measurements are repeatable;
- Decay classification of standing dead wood, if an included pool;
- Process for recording missing volume, or tree class code as applicable, and how corresponding deductions for unsound wood were applied;
- Biomass estimation technique;
- Components of the tree selected for biomass quantification; and
- Data management systems and processes, including quality assurance / quality control (QA/QC) procedures.

Use or adaptation of inventory SOPs already applied in national forest monitoring systems such as the United States Department of Agriculture (USDA) Forest Inventory and Analysis (FIA) program,² available from published handbooks, or from the Intergovernmental Panel on Climate Change (IPCC)

¹ Packalen, P., Strunk, J., Maltamo, M., & Myllymäki, M. (2023). Circular or square plots in ALS-based forest inventories—does it matter?. Forestry, 96(1), 49-61. https://doi.org/10.1093/forestry/cpac032

² U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis National Program. (2024) Forest Inventory and Analysis national core field guide for the nationwide forest inventory, version 9.4. https://research.fs.usda.gov/sites/default/files/2024-09/wo-v9-4_sep2024_fg_nfi_natl.pdf



Good Practice Guidance (GPG) for Land Use, Land Use Change and Forestry (LULUCF)³ is highly recommended.

Validation Plot-level estimates of forest carbon must be determined using the steps and biomass estimation techniques described in the applicable ACR Methodology.

The Project Proponent may continue to install and measure Validation Plots following the predetermined sequence until all conditions for statistical agreement (Sections 3.2) are reached. If the entire sequence has been exhausted and all points have been used for Validation Plot installation, the Project Proponent may request that the VVB generate new points in the original sequence.

At any point in time or if statistical agreement cannot be reached, the Project Proponent may discontinue installation and measurement of Validation Plots in the current sequence. After discontinuation, the Project Proponent may further calibrate the Predictive Model, utilizing data from the discontinued Validation Plot sequence if desired.

To demonstrate statistical agreement of the Predictive Model with Validation Plots, the Project Proponent must request that the VVB generate a new sequence of points to be measured as Validation Plots. All measurement data collected at Validation Plots from the previous sequence is disregarded and cannot be used for reaching statistical agreement but can be used for calibration (see above).

3.2 Assessing Predictive Model Eligibility

Once the minimum number of Validation Plots have been installed and measured in a Stratum, the Project Proponent must determine whether the Predictive Model's output is statistically precise in relation to the carbon estimates derived from Validation Plot measurements using the following process.

Each Validation Plot is paired with the Remote Sensing Pixel inside of which it is located. The carbon estimate derived from the Validation Plot measurements is treated as the observed point and compared with the Predictive Model output for that Remote Sensing Pixel. The differences between these two values (i.e., the errors) are used to calculate the Predictive Model's Root Mean Squared Error (RMSE) (Equation 2) as well as the Standard Error (Equation 3). These results are then used to

³ Penman, J., Gytarsky, M., Hiraishi, T., Krug, T., Kruger, D., Pipatti, R., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., Wagner, F. (2003) Good practice guidelines for land use, land-use change and forestry. ISBN 4-88788-003-0. https://www.ipcc.ch/site/assets/uploads/2018/03/GPG_LULUCF_FULLEN.pdf



determine the Predictive Model's precision using Validation Plots to be deemed eligible for carbon estimation and to test the Project Proponent's reported calibration metrics.

Equation 2: Predictive Model Root Mean Squared Error

$$RMSE_i = \sqrt{\frac{\sum_{p=1}^{V_i} \left(y_{p,i} - \widehat{y}_{p,i}\right)^2}{N_i}}$$

WHERE

RMSE _i	Root mean squared error (in metric tons CO₂e/unit area) for Stratum i.
${\mathcal Y}_{p,i}$	Predicted value for Remote Sensing Pixel p in Stratum i.
$\widehat{\mathcal{Y}}_{p,i}$	Validation Plot value for Remote Sensing Pixel p in Stratum i .
$N_i \ \ \text{Total number of Remote Sensing Pixels (n) paired with Validation Plots within Stratum i.}$	

Equation 3: Predictive Model 90% Confidence Interval

$$CI_i = \left(\frac{RMSE_i}{\sqrt{N_i}}\right) \times 1.645$$

WHERE

CI_i	Confidence Interval (%) at 90% confidence for Stratum i.
RMSE _i	Root mean squared error (in metric tons CO₂e/unit area) for Stratum i.
N_i	Total number of Remote Sensing Pixels paired with Validation Plots within Stratum i.

A Predictive Model is deemed to be accurate and eligible if the following conditions are met:

• The Predictive Model root mean squared error (RMSE_i; Equation 3) is below 20% of the stratum level Predictive Model's average carbon estimate, and



• The Predictive Model Confidence Interval (CI_i; Equation 4) is equal to or less than 10% of the Stratum level Predictive Model's average carbon estimate.

Predictive Models which meet these conditions are eligible for providing carbon estimates for the project, subject to further limitations (Section 4). If the project contains multiple Strata and hence Predictive Models, each Predictive Model must individually be assessed for statistical agreement with Validation Plots.



4 Validation Plot Field Remeasurement

After the Project Proponent has determined that the model is eligible for approval (Section 3), the VVB will conduct a field site visit to confirm the implementation of their Validation Plot measurement SOPs. The VVB must conduct a remeasurement of a sample of the Validation Plots, to be carried out according to the following specifications:

- The VVB's Validation Plot remeasurements must statistically agree with the Project Proponent's Validation Plots measurements using a two-tailed Student's t-test at the 90% confidence interval. This test shall be paired.
- Any Validation Plots that cannot be efficiently relocated by the VVB shall be assigned an estimate of zero carbon for the purposes of remeasurements and the t-test or must be replaced by another randomly located Validation Plot.
- The minimum number of remeasured Validation Plots in the batch shall be determined by calculating the square root of the number of Validation Plots installed by the Project Proponent from the sequence as below in Equation 4:

Equation 4: Minimum Remeasured Validation Plot Count

WHERE	$n_{RemeasuredVPs} = \sqrt{n_{VPs}}$
n _{Remeasured} VPs	Minimum number of Validation Plots (VP) to be remeasured.
$n_{ m VPs}$	Total number of Validation Plots (VP) installed and measured by the Project Proponent from the sequence.

• If the project contains multiple Strata (and hence Predictive Models), remeasured Validation Plots may be located within the lesser of either 1) five (5) strata selected by the verifier based on a strategic assessment of risk, or 2) fewer than five (5) strata comprising ≥90% of the proportional project carbon stocks. The Student's t-test(s) may be performed either independently by Strata, or at a consolidated project level, so long as absence of bias and statistical agreement of the t-test(s) can be demonstrated.



• Remeasured Validation Plot allocation may be based on a strategic assessment of risk, proportional carbon stocking, proportional acreage, or another reasonable and demonstrably non-biased method. Validation Plot selection and resampling order must be systematic and non-biased. This might be accomplished by assigning a remeasurement order to all Validation Plots in the batch prior to the field visit and progressing through the order until both the minimum number of remeasured Validation Plots and the required statistical agreement are reached.

In addition to the reporting requirements set forth in the ACR Validation and Verification Standard, validation/verification reports pertaining to field visits with a remeasurement of Validation Plots must include details about the remeasurement effort, including how it conformed to the aforementioned specifications.

If the VVB's Validation Plot remeasurements do not statistically agree with the Project Proponent's Validation Plot measurements, the models are no longer considered eligible. The Project Proponent may systematically collect new Validation Plot data before requesting a new field remeasurement. The new Validation Plots data must meet the above specified accuracy thresholds for the Predictive Model (Sections 3.2), and the Project Proponent may further calibrate the Predictive Model if desired. New field remeasurements must utilize a new batch of Validation Plots. If new Validation Plots are required, previously measured Validation Plot data may be used to further recalibrate the Project Proponents updated Predictive Model.



5 Model Limitations and Approval

This section describes the conditions under which a Predictive Model may or may not be approved to provide carbon estimates and uncertainty deductions for its Stratum.

Projects may use eligible models (i.e., those in statistical agreement with Validation Plots; Section 3) for up to five (5) years following the start date of the latest Reporting Period upon which a full verification with a successful eligibility assessment was performed, including Validation Plot remeasurement by a VVB (Section 4). At each Reporting Period, eligible models are also subject to the following test for Stratum-level uncertainty.

Stratum-level uncertainty is expressed as a percentage in the equation below for evaluating the Stratum's total uncertainty in the carbon stock estimates.

Equation 5: Stratum-Level Uncertainty Percentage

$$UNC_{i} = \frac{RMSE_{i}}{C_{PM,i}} \times 100\%$$

WHERE

UNC _i	Uncertainty percentage (%) for Stratum i.
RMSE _i	Uncertainty (in metric tons CO₂e/unit area) for Stratum i, expressed as the root mean squared error for the Predictive Model of Stratum i.
$C_{PM,i}$	Average carbon stock (in metric tons CO_2e /unit area) for Stratum i, as derived from the Predictive Model (PM).

To be eligible to provide carbon estimates and uncertainty deductions for the Stratum, a Predictive Model's uncertainty percentage (UNC_i) must be equal to or less than 20%. Predictive Models which meet this condition are considered approved. If the project contains multiple Strata, the models of each Stratum must individually be assessed for uncertainty percentage.



6 Calculation of Total Carbon Net of Uncertainty

This section describes the process for using approved models (Section 5) to calculate the final estimates of aboveground live tree and standing dead carbon pools, net of any uncertainty deductions. First, Stratum-level carbon estimates subtract the corresponding uncertainty. Second, the Stratum-level, uncertainty-adjusted carbon estimates are summed to calculate total carbon net of uncertainty for the entire project area.

Equation 6: Stratum-Level Carbon Estimate Net of Uncertainty

$$C_i = C_{PM,i} - UNC_i$$

WHERE

 $C_{PM,i}$

Carbon stock (in metric tons CO_2e) for Stratum i, as derived from the Predictive Model (PM).

 ${\sf UNC}_i$ Uncertainty percentage (%) for Stratum i.

Equation 7: Total Carbon Estimate Net of Uncertainty

$$C_{Total} = \sum_{i=1}^{I} C_i$$

WHERE

C_{Total}	Total carbon stock net of uncertainty deduction (in metric tons CO₂e).
$C_{\mathbf{i}}$	Carbon stock net of uncertainty deduction (in metric tons CO_2e) for Stratum i.
I	Total number of Strata (i).



7 Process for Projects Validating Remote Sensing Models Under IFM Methodologies

Project Proponents may Validate Remote Sensing based Predictive Models for use in IFM projects at any point in time. IFM projects that have been previously Validated (i.e. post Reporting Period 1) shall use the process detailed above to incorporate Remote Sensing-based estimation of carbon pools into with project measurements following Predictive Model Approval.

IFM projects utilizing this Framework to Validate Remote Sensing based Predictive Models for IFM projects at the project Start Date may establish an approved Predictive Model. However, RP1 carbon stocks must be estimated from field plot-based inventories which also coincides with the methodology approved baseline modeling processes. Initial Reporting Period carbon stocks, baseline modeling and uncertainty calculations will be estimated from full field plot-based inventories. Subsequent Reporting Period project stocks can rely on approved Remote Sensing based measurements, approved Growth Model (e.g. FVS) or field-based measurements for up to 5 years. Use of this Framework and Remote Sensing based Predictive Model approval must occur at least every 5 years.

In instances where this Framework is utilized in IFM projects from the Project Start date, additional reporting is required. In conjunction with the steps outlined in this Framework from section 1-6, initial ground-based inventories shall be used as Calibration Plots as well as for baseline modeling. Stratum-level Predictive Models must calculate and report model accuracy in the form of a Root Mean Square Error (RMSE) (Equation 8). These calculations should be reported with average stratum level carbon stocking values.

Equation 8: Initial Inventory Stratum-Level Predictive Model Precision Assessment

$$RMSE_{PM,i} = \sqrt{\sum_{p=1}^{P_i} \frac{(y_{p,i} - \widehat{y}_{p,i})^2}{N}}$$



WHERE

$RMSE_{PM}$	RMSE (in metric tons CO₂e/unit area) for Stratum i
y_p	Predicted value for Remote Sensing Pixel p in Stratum i .
$\hat{\mathcal{Y}}_p$	Observed value for the initial forest inventory plot in Stratum i
1	Total number of initial forest inventory plots (p) within Stratum i.



Definitions

Calibration Plot A type of Ground Plot measured by the Project Proponent to calibrate the

Predictive Model.

Ground Plot Sample of the project area using measurements collected in the field. Ground

Plots may be further defined as either Calibration Plots or Validation Plots.

Inference Process by which a Predictive Model assigns an estimate of the aboveground

live tree and standing dead carbon pools for a Remote Sensing Plot based on

its measurements.

Remote Sensing

Pixel

A discrete geographic area measured via Remote Sensing and used as a unit for carbon estimation by the Predictive Model and uncertainty estimation by the

UM. Remote Sensing Pixels must be uniformly sized and may not

geographically overlap.

Predictive Model Algorithm that utilizes Remote Sensing data to estimate aboveground live tree

and standing dead carbon pools for a Remote Sensing Pixel or a group of

Remote Sensing Pixels.

Remote Sensing Acquiring data from a distance, typically from satellite or aircraft, including (but

not limited to) aerial imagery, Light Detection And Ranging (LiDAR), Radio

Detection And Ranging (RADAR), or multispectral imagery.

Stratum Entire or part of a project area which has similar properties, for example

topography, forest types, density classes, volume, age classes, management

regime, site index, or other properties indicative of carbon stocks.

Validation Plot A type of Ground Plot measured by the Project Proponent to assess the

eligibility of the Predictive Model. Plot locations are randomly generated and selected by the VVB. A subset (batch) of Validation Plots is remeasured by the

VVB.



Appendix A: References

- Packalen, P., Strunk, J., Maltamo, M., & Myllymäki, M. (2023). Circular or square plots in ALS-based forest inventories—does it matter?. Forestry, 96(1), 49-61. https://doi.org/10.1093/forestry/cpac032
- Penman, J., Gytarsky, M., Hiraishi, T., Krug, T., Kruger, D., Pipatti, R., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., Wagner, F. (2003) Good practice guidelines for land use, land-use change and forestry. ISBN 4-88788-003-0.
 - https://www.ipcc.ch/site/assets/uploads/2018/03/GPG_LULUCF_FULLEN.pdf
- Picard, R. R., & Cook, R. D. (1984). Cross-validation of regression models. Journal of the American Statistical Association, 79(387), 575-583. https://doi.org/10.1080/01621459.1984.10478083
- U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis National Program. (2022) Forest Inventory and Analysis national core field guide, volume I: Field data collection procedures for phase 2 plots, version 9.2. https://www.fia.fs.usda.gov/library/field-guides-methods-proc/docs/2022/core_ver9-2_9_2022_SW_HW%20table_rev_12_13_2022.pdf