DATA BRIEF

Above-Ground Biomass (AGB) Carbon

Lead scientist: **Yan Yang, Ph.D.**

CONTENTS

I. OVERVIEW

This innovative CTrees product estimates global above-ground biomass (AGB) from 2000 to present at a standard spatial resolution of 100 meters. With flexible options ranging from 30-meter to 1-kilometer resolution, the AGB maps meet diverse use cases and applications.

Our methodology uses a sophisticated multiscale spatio-temporal machine learning framework that integrates satellite imagery with extensive airborne LiDAR remote sensing measurements. CTrees also leverages a wealth of ground-level AGB data collected by our team, collaborators, national forest inventory datasets, and the broader research community.

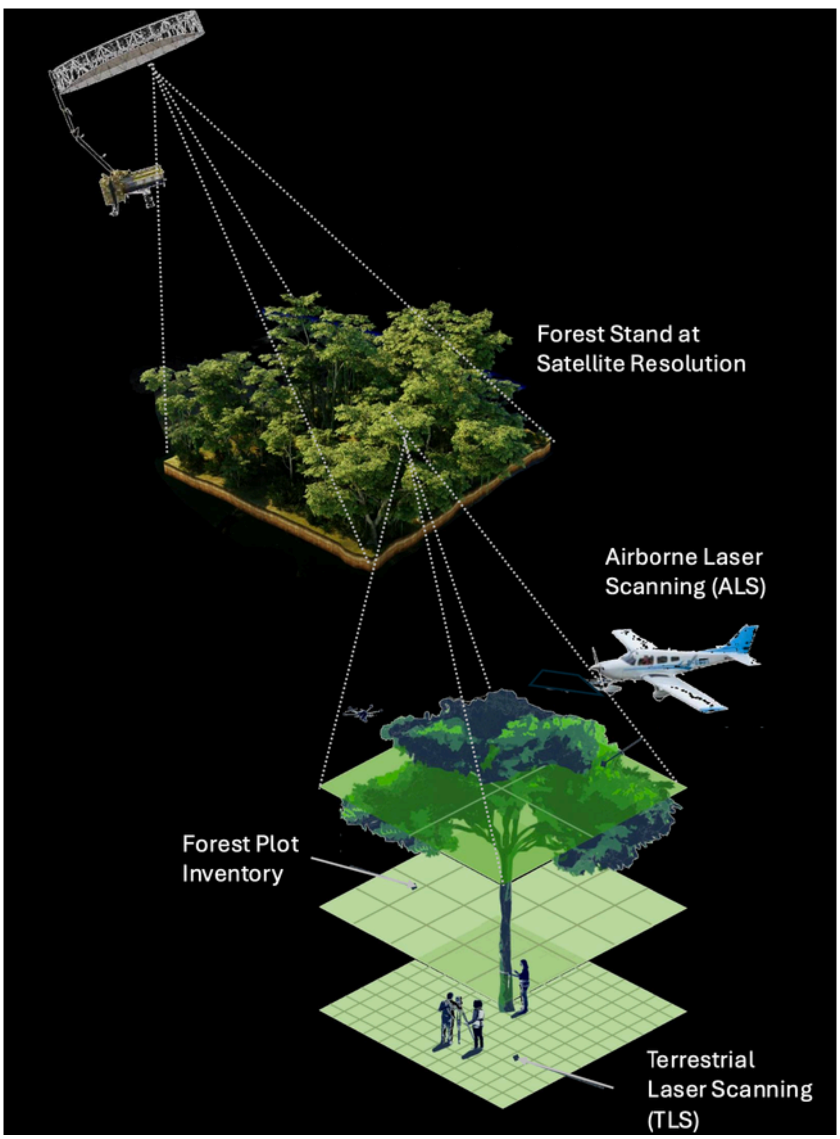
The process includes four key steps:

1. **AI-enhanced baseline metrics:** Establishing advanced vegetation height metrics and AGB maps for 2020.
2. **Annual AGB time series:** Utilizing innovative change detection modeling for continuous AGB estimates.

3. Post-processing refinements: Implementing end-of-year disturbance and recovery adjustments.
4. **Validation and uncertainty assessment:** Ensuring data accuracy and reliability at scale.

CTrees' AGB products are founded on over 20 years of peer-reviewed expertise in open-source and publicly distributed national and global datasets supported by NASA programs in remote sensing technology, carbon cycle, and terrestrial ecology. Our data products are accompanied by robust uncertainty metrics and support a wide range of applications, including greenhouse gas (GHG) inventory and reporting at both national and global levels, local carbon accounting, nature-based climate solutions, and a variety of forest and vegetation carbon market projects.

Figure 1. Multiple observations from ground to airborne to satellite are integrated within an AI-enabled model to map vegetation above-ground biomass (AGB).



II. DATA AT A GLANCE

Units	Mg ha^{-1} (for conversion to carbon (C) multiply by 0.5 or forest-specific forest carbon factor; for conversion to CO_2e, multiple C by 3.667)
Spatial resolution	• Standard 100-meter product: Global • 1-kilometer product: Global, available on AWS S3 • 30-meter product: USA and regional on-demand customization
Temporal resolution	Annual
Temporal range	2000-2025
Unit, Scaling factor	Integer 16, Scale: 0.1
Map projection and file format	UTM (Universal Transverse Mercator) for individual tiles: Global product in geographic projection Geotiff, Cloud Optimized GeoTIFF

III. METHODOLOGY

CTrees' global land carbon maps combine ground inventory data with remote sensing from aerial and satellite sources. The primary goals are to 1) provide accurate estimates of global forest carbon stocks and changes while capturing landscape variations, and 2) extend these estimates to all woody vegetation types, including non-forested areas like woodlands, savanna, and wetlands.

CTrees follows peer-reviewed methods and leverages findings from scientific literature. Key techniques include: 1) LiDAR measurements from NASA satellites (ICESat and GEDI) to create a dataset of vegetation structure and above-ground biomass, calibrated with a large number ground plots and airborne LiDAR estimates; 2) machine learning algorithms for change detection across 100+ ecoregions using satellite radar and optical imagery; 3) estimations of below-ground biomass using ecological models; and 4) uncertainty assessment through advanced error propagation models. Please refer to a selection of peer-reviewed publications cited at the end of the document about our methodology.

The carbon maps meet accuracy standards for emission factor calculations and will be updated with new data from NASA-ISRO's Synthetic Aperture Radar (NISAR) and ESA's Biomass in 2024 and 2025.

Remote Sensing Data

A series of remote sensing datasets from airborne and spaceborne sensors are used to model and map above-ground biomass of vegetation across the landscape at different resolutions. The type of data used in the methodology varies depending on the resolution of the biomass products and applications. CTrees' approach makes use of both optical and microwave satellite observations and benefits from a large number of airborne scanning LiDAR (ALS) data acquired globally by our team, our collaborators, and publicly funded experiments. These datasets include: HLS, Landsat, ALOS PALSAR, Copernicus DEM, GEDI height metrics, ICESat-2, LiDAR CHM, forest cover change (e.g., Tropical Moist Forests, Global Forest Change), forest inventory data, and airborne liDAR biomass.

- **Landsat and Harmonized Landsat and Sentinel-2 (HLS)** images provide surface reflectance data at about 30 m sensitive to vegetation cover and density.
- **ALOS PALSAR** images with global coverage of radar backscatter measurement at different polarizations sensitive to forest structure.
- **Copernicus DEM** provides surface elevation data at 30-meter resolution measured by X-band synthetic aperture radar sensors.
- **GEDI** provides waveform LiDAR data sampling global forests between ~51.6° N and 51.6° S latitudes. GEDI L2A includes elevation and height metrics. GEDI L4A provides above-ground biomass density estimations.
- **ICESAT-2** Advanced Topographic Laser Altimeter System (ATLAS) point counting LiDAR samples across global vegetation provide vegetation structure and height in areas of low-density vegetation across boreal and woodland savanna ecoregions.
- **MODIS and VIIRS** visible and thermal band imagery at global scale and at 250- to 1,000-meter spatial resolution provide frequent observations for mapping vegetation cover and biomass at 1-kilometer resolution.

Biomass Training Data

CTrees machine learning models are trained with more than 500,000 ground plots from national forest inventory from a variety of boreal, temperate, and tropical countries along with more than one million hectares of airborne and drone-based LiDAR based estimates. A portion of plot data is set aside for validation and uncertainty assessment for different ecoregions.

Spatial Modeling

Spatial modeling of AGB will be performed using ecoregion-specific LightGBM models, which have been proven to outperform other models in terms of performance metrics relying on accuracy, spatial integrity, and computation time. The steps for applying the model to develop maps include:

- **Global structure-based ecoregions:** Development of 120 ecoregion areas based vegetation height clusters for mapping height metrics, and 60 ecoregion clusters with reasonable training data for AGB mapping. The clustering strategy ensures that regional variability is accurately represented while minimizing boundary artifacts.
- **Height metrics:** Global spatial maps of four vegetation relative height (RH50, RH75, RH90, and RH98) metrics resolution using GEDI and ICESAT-2 height data aggregated at 100-meter spatial resolution before training the model.
- **Base AGB map:** Baseline biomass map for the year 2020 using RH metric maps and RS data trained by ground and LiDAR based plots across ecoregion clusters at 100-meter resolution.
- **AGB time series maps:** Application of change detection machine learning model using annual RS data to develop annual AGB maps from 2000-2024. In the change detection phase, we incorporate each pixel's disturbance history since 2000 and ecoregion characteristics. Detected changes capture key forest dynamics, including deforestation, fire, degradation, regrowth, and stable forests.
- **Post-processing:** Several filtering steps are designed and applied on time series AGB maps to ensure the annual biomass maps represent the end-of-the-year disturbance and recovery status of vegetation, and filter any outliers in the estimation process that does not meet spatial and temporal characteristics of biomass dynamics and productivity.
- **Uncertainty estimates:** Spatial uncertainty estimation at the pixel level by developing bootstrapping approach for biomass estimation and error propagation from different sources of uncertainty.

IV. VALIDATION OF AGB MAPS

By developing uncertainty maps at the pixel level, we employ various validation approaches to assess how our biomass maps align with plot-level data across the entire biomass spectrum. We analyze mean above-ground biomass (AGB) estimates at sub-national levels (state and county), using adequately sized plot data to identify bias and make corrections at a larger scale. Additionally, we compare mean and total carbon estimates at the national level with countries that routinely monitor and report GHG inventories in the forest sector.

When repeat inventory measurements are available, our annual biomass maps serve as a crucial tool to confirm changes in national carbon stocks. The results presented below encapsulate the overall validation and performance of our maps, showcasing their accuracy and reliability.

Plot-level validation (Figure 2) of the global 1-hectare map reveals consistent estimates across the entire global biomass range with gradual systematic error increasing in high-biomass forests where existing satellite data and forest heights are less sensitive to biomass variations due to larger diameter trees and denser canopy forests.

Figure 2. Pixel-level validation across the biomass range over independent data sets from a combination of ground plots and high-quality LiDAR AGB estimates at 1-hectare level.

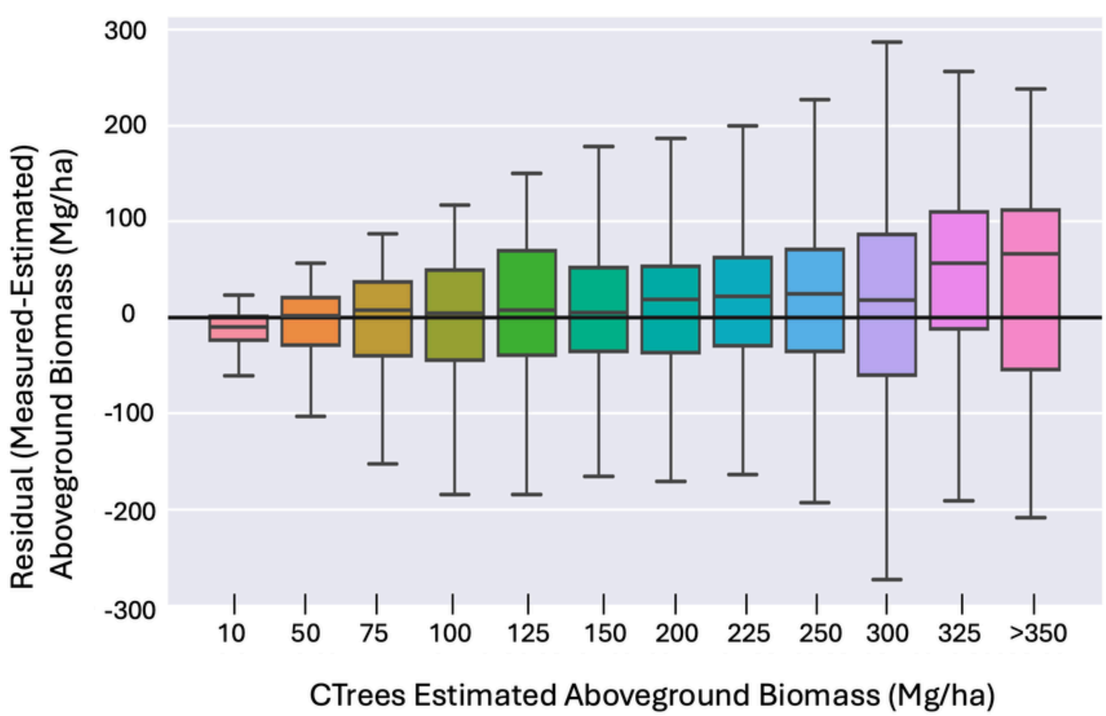
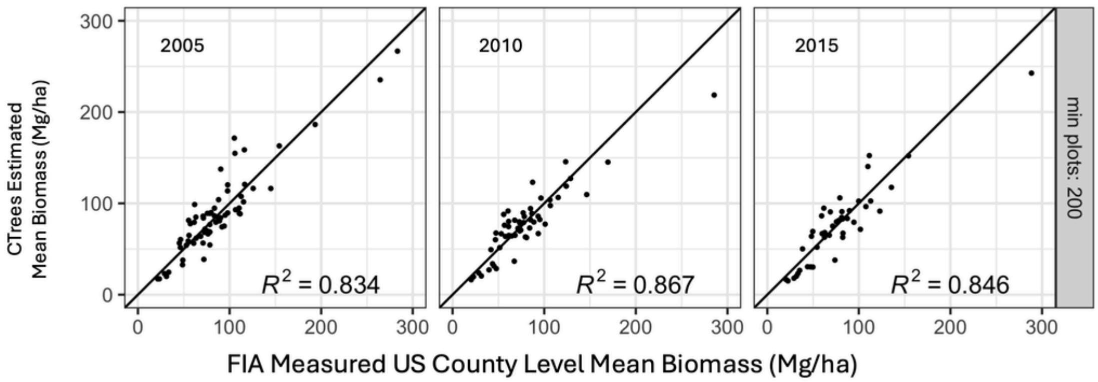
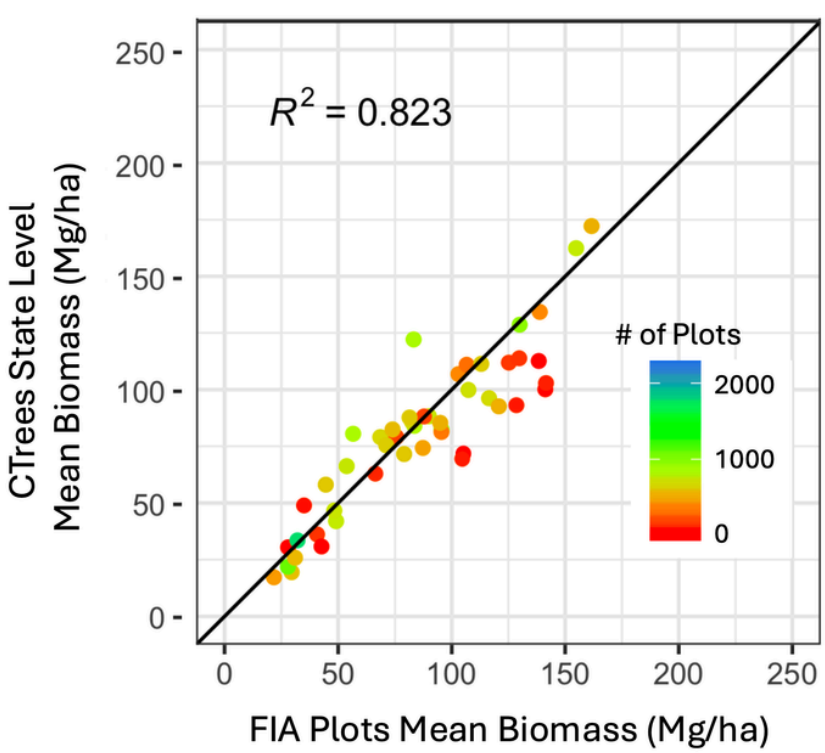


Figure 3. Validation of the AGB map over the U.S. county levels with at least 200 forest inventory plots.



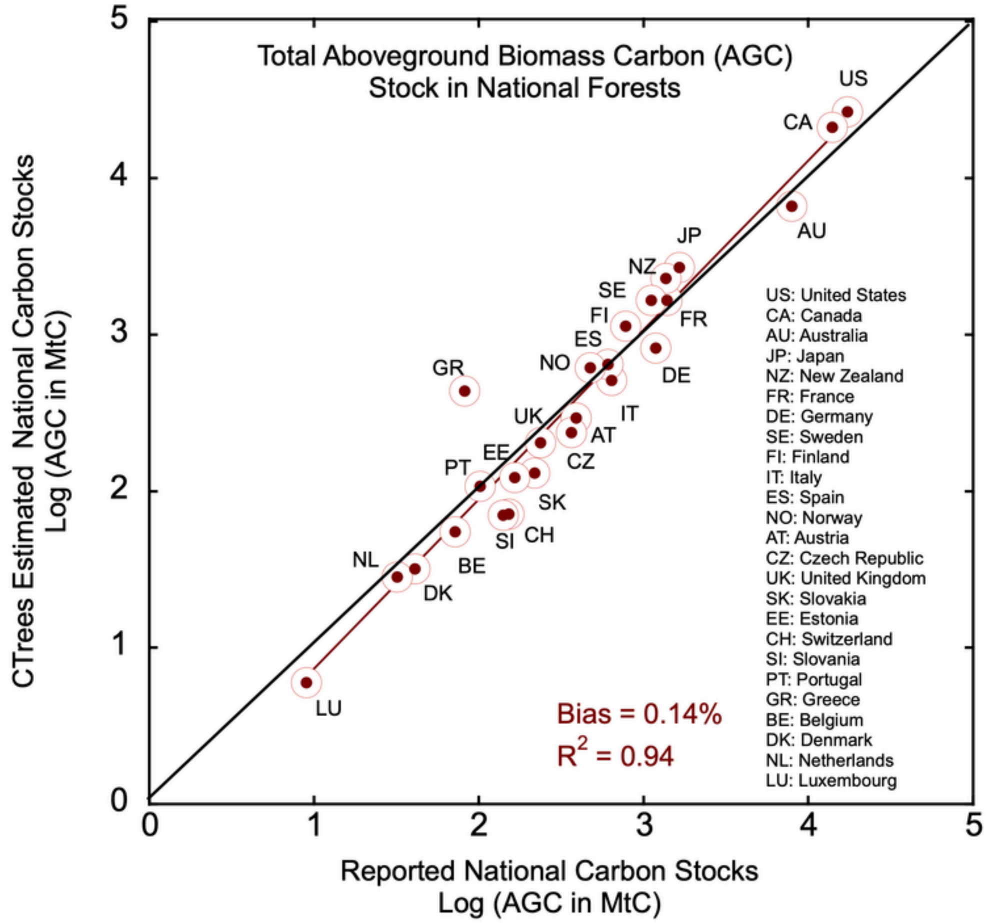
Validation of the biomass map at the smallest jurisdictional unit that can simulate a project-level mean carbon stock shows consistent accuracy of the maps across multiple years (Figure 3) (Yu et al., 2022). More recent year validation with the U.S. Forest Service Forest Inventory and Analysis (FIA) data will be performed after renewal of access to FIA plot locations. The uncertainty shown in the county-level comparison may be related to size of FIA plots (0.44 ha) compared to map pixel (1-ha), definition of forest area, and the mismatch between the plot data collection and remote sensing imagery within the year of inventory.

Figure 4. Comparison of CTrees biomass map with U.S. state-level mean biomass with plots covering all forest types and disturbance regimes within the continental U.S. (CONUS).



Comparison with the U.S. state-level FIA estimates captures the consistency of biomass map accuracy across a continental scale covering a variety of temperate and boreal ecosystems with a combination of needle-leaf and broad-leaf and deciduous forests (Figure 4) (Yu et al. 2022).

Figure 5. Comparison of CTrees global carbon stock (aboveground + belowground) map with nationally reported estimates over forest areas for the year circa 2020.



At the global scale, CTrees carbon stocks can be compared to countries that have regular forest inventory measurements and report carbon stocks to the UN Framework Convention on Climate Change (UNFCCC), as part of GHG inventory reporting, and to the UN Food and Agricultural Organization (FAO). The results demonstrate that the overall variations of carbon stocks from CTrees maps agree with national data accumulated from inventory data collected over 5-10 years for GHG reporting (Saatchi et al., 2025).

V. REFERENCES

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VI. ACCESS THE DATA

To learn more and inquire about data partnerships, please email **info@ctrees.org**.