Global Mangrove Distribution, Aboveground Biomass, and Canopy Height

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Documentation Revision Date: 2021-04-29

Dataset Version: 1.3

Summary

This dataset characterizes the global distribution, biomass, and canopy height of mangrove-forested wetlands based on remotely sensed and in situ field measurement data. Estimates of (1) mangrove aboveground biomass (AGB), (2) maximum canopy height (height of the tallest tree), and (3) basal-area weighted height (individual tree heights weighted in proportion to their basal area) for the nominal year 2000 were derived across a 30-meter resolution global mangrove ecotype extent map using remotely-sensed canopy height measurements and region-specific allometric models. Also provided are (4) in situ field measurement data for selected sites across a wide variety of forest structures (e.g., scrub, fringe, riverine and basin) in mangrove ecotypes of the global equatorial region. Within designated plots, selected trees were identified to species and diameter at breast height (DBH) and tree height was measured using a laser rangefinder or clinometer. Tree density (the number of stems) can be estimated for each plot and expressed per unit area. These data were used to derive plot-level allometry among AGB, basal area weighted height (Hba), and maximum canopy height (Hmax) and to validate the remotely sensed estimates.

Spatially explicit maps of mangrove canopy height and AGB derived from space-borne remote sensing data and in situ measurements can be used to assess local-scale geophysical and environmental conditions that may regulate forest structure and carbon cycle dynamics. Maps revealed a wide range of canopy heights, including maximum values (> 62 m) that surpass maximum heights of other forest types.

There are 348 data files in GeoTIFF format (.tif) with this dataset representing three data products for each of 116 countries. The in situ tree measurements are provided in a single .csv file.

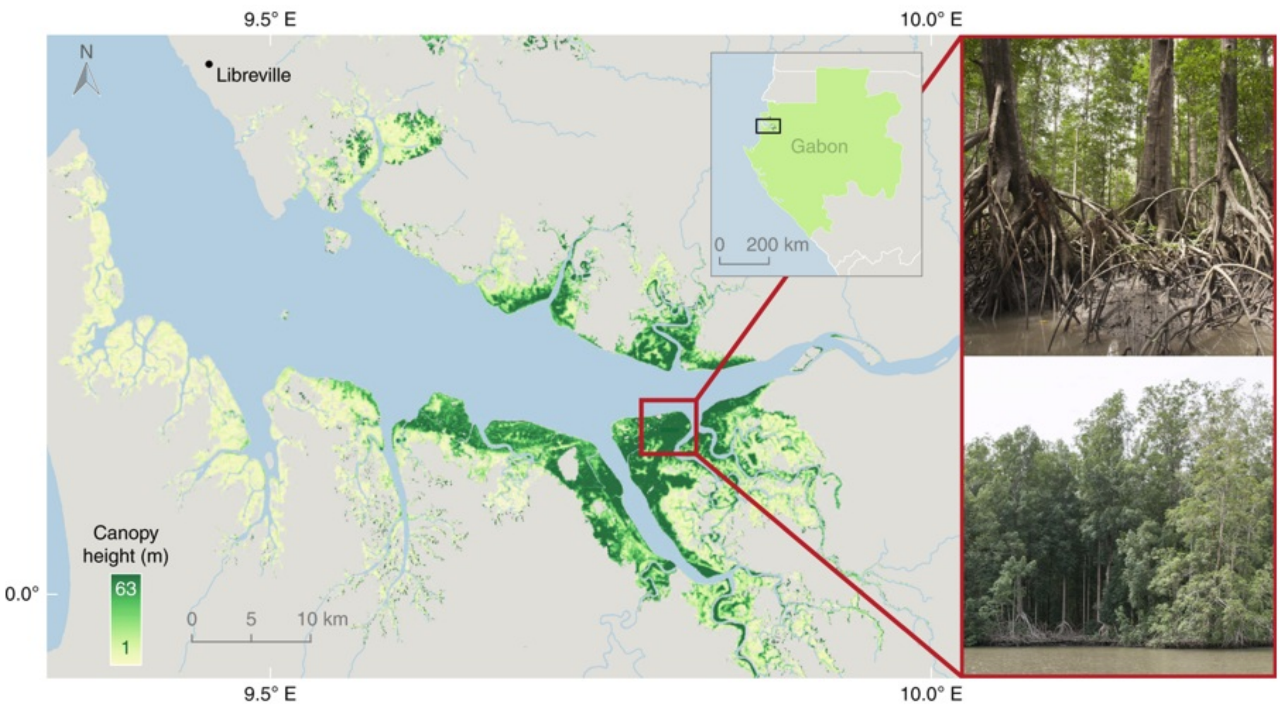

Figure 1. Mangrove forests in coastal Gabon are the tallest globally with forest stands that were estimated up to 63 m. The photo insets show locations where individual trees were measured in situ up to 65 m tall (Simard et al., 2019).

Citation

Simard, M., T. Fatoyinbo, C. Smetanka, V.H. Rivera-monroy, E. Castaneda, N. Thomas, and T. Van der stocken. 2019. Global Mangrove Distribution, Aboveground Biomass, and Canopy Height. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1665

Table of Contents

1. Dataset Overview

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These spatially explicit maps of mangrove canopy height and AGB derived from space-borne remote sensing data and in situ measurements can be used to assess local-scale geophysical and environmental conditions that may regulate forest structure and carbon cycle dynamics. Maps revealed a wide range of canopy heights, including maximum values (> 62 m) that surpass maximum heights of other forest types.

User Note: This Version 1.3 now includes the in situ tree measurement data and documentation added in March 2021. No changes to previously archived data.

Project: Carbon Monitoring System

The NASA Carbon Monitoring System (CMS) is designed to make significant contributions in characterizing, quantifying, understanding, and predicting the evolution of global carbon sources and sinks through improved monitoring of carbon stocks and fluxes. The System will use the full range of NASA satellite observations and modeling/analysis capabilities to establish the accuracy, quantitative uncertainties, and utility of products for supporting national and international policy, regulatory, and management activities. CMS will maintain a global emphasis while providing finer scale regional information, utilizing space-based and surface-based data and will rapidly initiate generation and distribution of products both for user evaluation and to inform near-term policy development and planning.

Related Publication:

Simard, M., L. Fatpyinbo, C. Smetanka, V.H. Rivera-Monroy, E. Castaneda-Moya, N. Thomas, and T. Van der Stocken. 2019. Mangrove canopy height globally related to precipitation, temperature and cyclone frequency. *Nature Geoscience,* 12: 40–45. https://doi.org/10.1038/s41561-018-0279-1

Related Datasets:

Lagomasino, D., T. Fatoyinbo, S. Lee, E. Feliciano, M. Simard, and C. Trettin. 2016. CMS: Mangrove Canopy Height Estimates from Remote Imagery, Zambezi Delta, Mozambique. ORNL DAAC, Oak Ridge, Tennessee, USA. http://dx.doi.org/10.3334/ORNLDAAC/1357

Fatoyinbo, T., E. Feliciano, D. Lagomasino, S. Lee, and C. Trettin. 2017. CMS: Aboveground Biomass for Mangrove Forest, Zambezi River Delta, Mozambique. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1522

Lagomasino, D., T. Fatoyinbo, S. Lee, E. Feliciano, C. Trettin, A. Shapiro, and M. Mwita. 2019. CMS: Mangrove Forest Cover Extent and Change across Major River Deltas, 2000-2016. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1670

Acknowledgements: Carbon Monitoring Systems grant N4-CMS14-0028.

2. Data Characteristics

Spatial Coverage: Global within a circum-equatorial band from 31 degrees north to 39 degrees south

Spatial Resolution: 30 m

Temporal Coverage: 2000-01-01 to 2009-12-31

Temporal Resolution: One-time estimates for nominal year 2000 of AGB, maximum canopy height, and basal-area weighted height across the global mangrove ecotype extent. In situ data were collected within a 15-year period after the SRTM data were obtained (2000): August 20, 2004 to May 22, 2014.

Study Area (All latitudes and longitudes are given in decimal degrees)

Site	Westernmost Longitude	Easternmost Longitude	Northernmost Latitude	Southernmost Latitude
Global equatorial	-180	180	31.000138889	-39.00013889

Data File Information

There are 348 data files in GeoTIFF format (.tif) with this dataset. The three data products: mangrove aboveground biomass (agb), maximum height (hmax), and basal area weighted height (hba) are provided in separate files for each of the 116 countries. Filenames include the country name. The in situ tree measurements are provided in a single .csv file.

Table 1. Data file descriptions

File name	Variable/Description	Units
Mangrove_agb_***country***.tif	Aboveground mangrove biomass	Mg ha-1
Mangrove_hba_***country***.tif	Mangrove basal-area weighted height (individual tree heights weighted in proportion to their basal area)	meters
Mangrove_hmax_***country.***tif	Mangrove canopy maximum height (height of the tallest tree)	meters

North_South_America_tree_measurements.csv	In situ mangrove tree measurements for locations on the coasts of North and South America.	

GeoTIFF File Properties: No data value: 0, Number of bands: one, Resolution: 30 m, EPSG: 4326

Table 2. Variables in North_South_America_tree_measurements.csv

Column name	Units/format	Type	Description
ID		Character	A unique identifier for locating a specific observation. A combination of plot_name and tree number fields.
region		Character	Continent or subcontinent of observation
subregion		Character	Country or state of observation
biome		Character	Biome type of observation - all mangrove
date	yyyy-mm-dd	Date	Date of observation
plot_name		Character	Plot name
tree_number		Character	Unique identifier for a tree in a specific plot. Trees characterized as “Severe inclined” were sometimes measured without assigning a number. These trees have been assigned M1, M2, M3, etc. within a plot.
genus		Character	Genus
species		Character	Species
dbh	cm	Numeric	Diameter at breast height (1.3 m), check tree_notes as some were estimated dbh
height	meters	Numeric	height of tree, check tree_notes as some were modeled height
live		Numeric	1 indicates tree is alive. 0 indicates tree is dead
tree_notes		Character	specific notes about a tree
use_for_allometry		Numeric	1 indicates tree was used for allometry, 0 indicates it was not.
plot_type		Character	f = fixed plot size, v = variable plot size
plot_shape		Character	shape of plot: s and square; r, circle, and circular. Missing when plot_type = v.
baf		Numeric	basal area factor: with a value of 5 for plot_type = v, otherwise missing
plot_area	m^2	Numeric	plot area
lat1		Numeric	latitude of plot location (center of circular and variable shape plots or a plot corner for square plots)
lon1		Numeric	longitude of plot location (center of circular and variable shape plots or a plot corner for square plots)
lat2		Numeric	latitude of plot location (latitude of a plot corner for square plots, otherwise missing)
lon2		Numeric	longitude of plot location (longitude of a plot corner for square plots, otherwise missing)
lat3		Numeric	latitude of plot location (latitude of a plot corner for square plots, otherwise missing)
lon3		Numeric	longitude of plot location (longitude of a plot corner for square plots, otherwise missing)
lat4		Numeric	latitude of plot location (latitude of a plot corner for square plots, otherwise missing)
lon4		Numeric	longitude of plot location (longitude of a plot corner for square plots, otherwise missing)
collected_by		Character	Collector of field observations
digitized_by		Character	Performer of GIS activities

3. Application and Derivation

Mangrove wetlands are among the most productive and carbon-dense ecosystems in the world. Their structural attributes vary considerably across spatial scales, yielding large uncertainties in regional and global estimates of carbon stocks. This study offers a baseline to monitor national and regional trends in mangrove carbon stocks (Simard et al., 2019).

4. Quality Assessment

Uncertainty was addressed by calibration with ICESat/GLAS Spaceborne Lidar mission data, refining the range of elevation data identified as mangrove cover, and subsequent validation by field data. The study only included areas with Shuttle Radar Topography Mission (SRTM) elevation values ranging from 0 to 55 m to eliminate inland areas over-classified as mangrove wetlands.

The relationship between SRTM and Basal Area Weighted Height (Hba) had a correlation coefficient R2 value of 0.78 and RMSE of 3.60 m at global scales. Additionally, SRTM values versus field measurements of max height (Hmax) had a correlation coefficient R2 of 0.70 and RMSE of 5.80 m globally. Analysis of canopy height variance obtained from SRTM, lidar, and field measurements demonstrated that SRTM height characterizes mean overstory canopy height and maintains consistency over time when measuring canopy height in established mangrove forests. Regional biomass allometric models developed for this study had a combined RMSE of 57.2 Mg ha-1 (ranging from 46.6 Mg ha-1 to 72.0 Mg ha-1) and an R2 of 0.77. The global biomass allometric model had a root mean square error (RMSE) of 87.9 and correlation coefficient R2 of 0.62. See Simard et al. (2019) for more details.

5. Data Acquisition, Materials, and Methods

Following is a brief synopsis of the data collection, data processing, and modeling methods implemented to produce the three mangrove products and in situ field data. See Simard et al. (2019) for more details.

Mangrove ecotype extent map

To identify mangrove ecotype areas and mask non-mangrove regions in the SRTM elevation dataset, we used the global mangrove extent map from Giri et al. (2011). This map is coincidental with the SRTM data set (that is, they are both from 2000) and, so far, it is the only one that specifically maps mangroves from Landsat data at 30-m resolution. Only areas with SRTM elevation values ranging from 0 to 55 m above mean sea level were included so as to remove some areas falsely identified as mangroves. This threshold value preserves the tallest mangrove forest stands.

Mangrove canopy height estimation with SRTM and ICESat/GLAS

The canopy height maps were generated using SRTM DEM data collected in February 2000 and lidar heights from the ICESat/GLAS Spaceborne Lidar mission. GLAS lidar altimetry data were collected globally from 2003 to 2009, providing the only global lidar canopy and height measurement, with sparse samples distributed across the globe. The GLAS lidar-derived maximum canopy height is defined as the height of the lidar pulse containing all its energy between the ground and the top of the tallest tree (referred to as the relative height of the 100th percentile, RH100). A regression model was applied relating GLAS RH100 to SRTM elevation measurements obtain a global map of maximum canopy height:

$$\mathrm{SRTMH}_{max} = 1.697 \times H_{SRTM}$$

where H_{SRTM} represents the original SRTM DEM, and SRTMH_{max} is the new maximum canopy height data set. The mean and maximum SRTMH_{max} values were computed for each country.

The SRTM estimates of H_{max} (that is, SRTMH_{max}) were validated with in situ collected data in Pongara National Park to confirm the validity of the tallest canopy height values in Gabon. The heights of five of the tallest observed trees were measured using a laser rangefinder, confirming the location of the areas with the tallest mangrove canopy in the world (with all five trees measuring between 62 m and 65 m). In addition to H_{max}, a map of H_{ba}, the basal area weighted height was generated and used as input for the AGB map. SRTMH_{ba} was calculated by relating field values of H_{ba} to SRTM DEM elevations:

$$\mathrm{SRTMH}_{ba} = 1.0754 \times H_{SRTM}$$

where H_{SRTM} represents the original SRTM DEM and SRTMH_{ba} the new basal area weighted canopy height dataset.

In situ forest measurement locations

The selected field sites (331 plots in total) included a wide variety of forest structure and mangrove ecotypes (for example, scrub, fringe, riverine and basin) with measured in situ tree heights ranging from 1 to 65 m. The mangrove field sites (Figure 2a) were distributed along a latitudinal range from 26º S (Maputo Reserve, Mozambique) to 25º N (Everglades, USA), encompassing the equatorial region. In situ data were collected within a 15-year period after the SRTM data were obtained (2000).

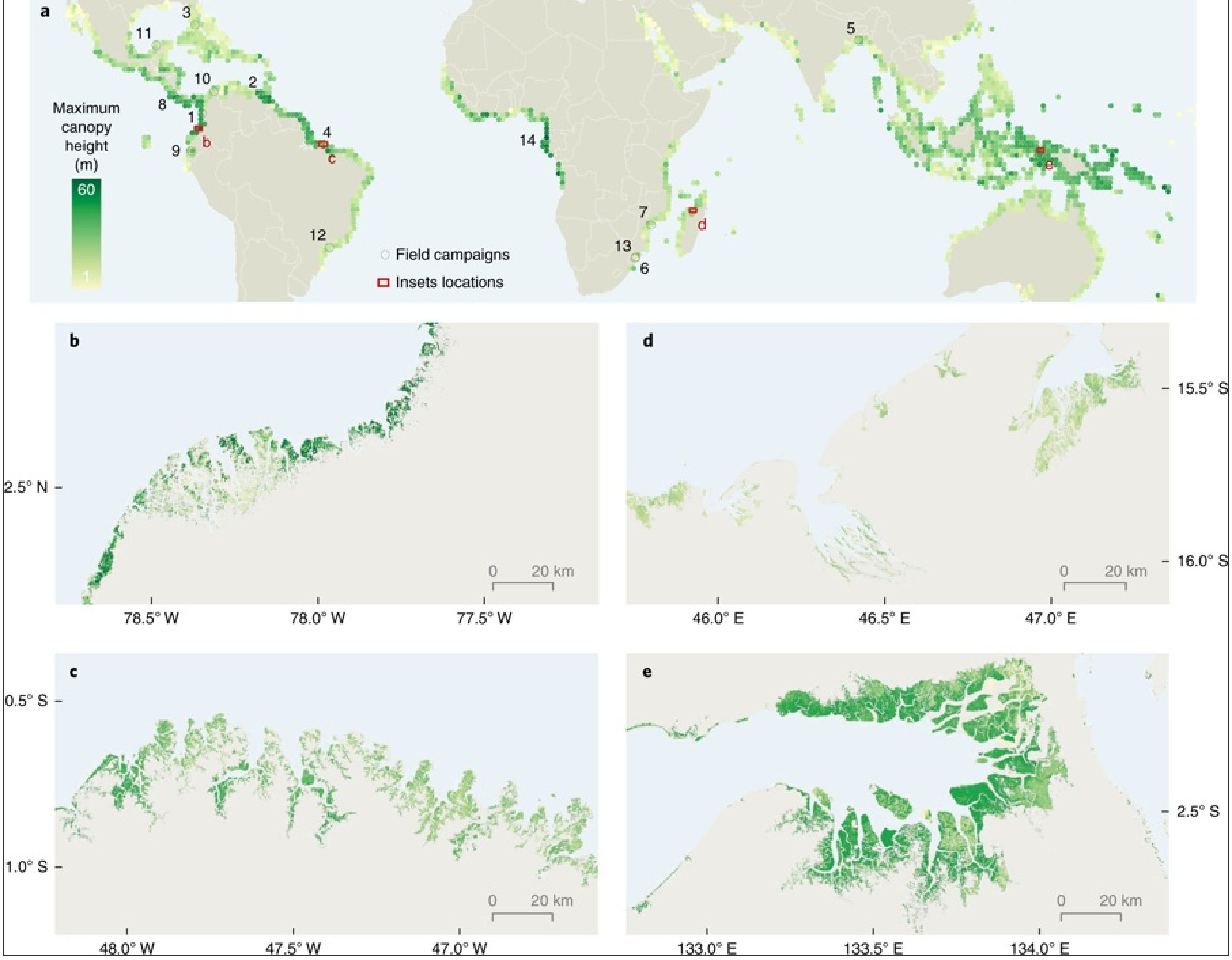

Figure 2. Global map of mangrove maximum canopy height and location of sampling sites (numbers) where in situ data were collected. High-resolution insets in b–e: (b) Coastal Nariño and Cauca (Colombia),(c) Coastal Pará (Brazil), (d) Bombetoka Bay (Madagascar), and (e) Bintuni Bay (West Papua, Indonesia). From Simard et al. (2019).

Data Source User Notes:

- Only data for North and South American locations are provided in this dataset.
- Data for the Zambezi delta are publicly available at: https://www.fs.usda.gov/rds/archive/catalog/RDS-2017-0053.
- The data collected at the Sundarbans, Khulna, Bangladesh location are not public. See the publication: Rahman, M. M., Khan, M. N. I., Hoque, A. K. F. & Ahmed, I. Carbon stock in the Sundarbans mangrove forest: spatial variations in vegetation types and salinity zones. Wetl. Ecol. Manag. 23, 269–283 (2015). https://doi.org/10.1007/s11273-014-9379-x

Estimating forest structure attributes

Field data were used to estimate forest structure attributes (that is, H_{ba}, H_{max} and AGB). Most of the data were collected in field plots throughout the Americas and Africa, using fixed or variable plot sizes. Within variable plots, trees were selected using a fixed-angle gauge. For each selected tree, the species was identified and the diameter at breast height (DBH) and height were measured using a laser rangefinder or clinometer.

For all sites, field basal area weighted height H_{ba} was calculated as

$$H_{ba} = \sum_i(\pi r^2_i \times H_i) \;/\; \sum_i(\pi r^2_i)$$

where H_i and r_i are the height and radius (that is, DBH/2) of tree *i*, respectively, in meters.

H_{max} was defined as the height of the tallest tree within a plot.

Tree density

Users can estimate the tree density, as the total number of trees within the plot normalized by plot area. However, for the plots sampled with the “variable plot method (v)”, a fixed plot area is not available. For tree density estimates in plots using a variable plot method, each tree has its own plot size given the tree dbh and the ‘baf’ (Basal Area Factor) (Simard et al., 2009). For all variable plots: baf = 5. At baf=5, the cruising angle is 0.02249719.

Thus, plot area can be derived from the following equation:

Plot area (m^2) = Pi *(DBH/(100*CA))^2, where DBH is diameter at breast height and CA is the cruising angle.

After applying this equation to all trees within the variable plot, normalize tree density by hectares. To do this, divide the number of m^2 in a hectare by the average plot area: 10000/ average plot area = tree density per hectare.

Global mangrove biomass allometry development

The in situ field data were used to derive stand-level allometry between AGB, basal area weighted height H_{ba} and maximum canopy height H_{max}. AGB was estimated for each individual tree tagged inside the plot, using regional or site-specific allometric equations as described by previous studies. The Chave et al. (2014) generalized pantropical tree allometric model was used with species-specific wood density from the global wood density database (Chave et al., 2009) to calculate the above- and belowground (root) biomass of individual trees. The sum of individual trees within the plot was then computed and normalized, using plot sizes, to represent total forest stand AGB density in Mg ha^{-1}. Regional and global models were generated between plot-level canopy height and plot-level AGB density, where height and AGB relationships were fitted to the regression model:

$$AGB = a \times H_x^b$$

where H_x can represent either H_{ba} or H_{max}. The global model was generated using all of the plot data ($n = 331$) and H_{ba} of the field data, while the regional models were generated for the Americas (using data from Colombia, USA, Venezuela, Brazil, Costa Rica, Ecuador, Mexico, $n = 81$), East Africa (using data from Mozambique, $n = 101$) and South Asia (using data from Bangladesh, $n = 149$).

Large-scale AGB estimation with SRTM

The global mangrove forest AGB map was generated by linking the field-measured biomass–height allometry (described above) with SRTM estimates of H_{ba} (that is, SRTMH_{ba}). This procedure is a two-step process where SRTM is converted to SRTMH_{ba} and then to AGB using appropriate field-derived H_{ba} to AGB allometry. Total (above- and belowground) biomass and carbon stock estimates by country were generated by summing all corresponding pixels, while accounting for belowground biomass and soil carbon. The total aboveground carbon stocks per country were calculated assuming a stoichiometric factor of 0.451 as the AGB conversion factor. Total root biomass was estimated as 49% of the AGB.

6. Data Access

These data are available through the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

Global Mangrove Distribution, Aboveground Biomass, and Canopy Height

Contact for Data Center Access Information:

- E-mail: uso@daac.ornl.gov
- Telephone: +1 (865) 241-3952

7. References

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8. Dataset Revisions

Version 1.3: The in situ tree measurement data file and documentation were added in April 2021. No changes to previously archived data.

Version 1.2: Data files were updated in May 2019 because the height to biomass (AGB) conversion equations in the associated Nature Geoscience publication were correct but were implemented incorrectly when generating the publicly available data files. These have now been corrected. The Hba and Hmax data were updated so that they are now capped at the 95th percentile of the maximum value (55 m), as outlined in the publication. Countries without Hba and Hmax data have been omitted.

Version 1.1: Science-quality data were released in March 2019. All preliminary data files were replaced with new files that incorporated some changes to the aboveground biomass estimation algorithm. In addition, several files with missing data were replaced.

Version 1.0: Preliminary data were released in November 2018 to accompany the publication of the Simard et al, 2019 paper in Nature Geosciences.