GEDI L4B Gridded Aboveground Biomass Density, Version 2

Get Data

Documentation Revision Date: 2022-04-26

Dataset Version: 2

Summary

This Global Ecosystem Dynamics Investigation (GEDI) L4B product provides 1 km x 1 km (1 km, hereafter) estimates of mean aboveground biomass density (AGBD) based on observations from mission week 19 starting on 2019-04-18 to mission week 138 ending on 2021-08-04. The GEDI L4A Footprint Biomass product converts each high-quality waveform to an AGBD prediction, and the L4B product uses the sample present within the borders of each 1 km cell to statistically infer mean AGBD. The gridding procedure is described in the GEDI L4B Algorithm Theoretical Basis Document (ATBD). Patterson et al. (2019) describes the hybrid model-based mode of inference used in the L4B product. Corresponding 1 km estimates of the standard error of the mean are also provided in the L4B product. Uncertainty is due to both GEDI's sampling of the 1 km area (as opposed to making wall-to-wall observations) and the fact that L4A biomass values are modeled in a process subject to error instead of measured in a process that may be assumed to be error-free.

The GEDI instrument produces high-resolution laser ranging observations of the 3-dimensional structure of the Earth. GEDI was launched on December 5, 2018, and is attached to the International Space Station (ISS). GEDI collects data globally between 51.6° N and 51.6° S latitudes at the highest resolution and densest sampling of any light detection and ranging (lidar) instrument in orbit to date. The GEDI instrument consists of three lasers producing a total of eight beam ground transects, which consist of ~25 m footprint samples spaced approximately every 60 m along-track. The GEDI beam transects are spaced approximately 600 m apart on the Earth's surface in the cross-track direction, for an across-track width of ~4.2 km.

There are 10 data files in cloud-optimized GeoTIFF (*.tif) format included in this dataset. Each file provides 1 km estimates of mean aboveground biomass density for the period 2019-04-18 to 2021-08-04 (mission week 19 to mission week 138). Also included are two companion files in Portable Document Format (*.pdf).

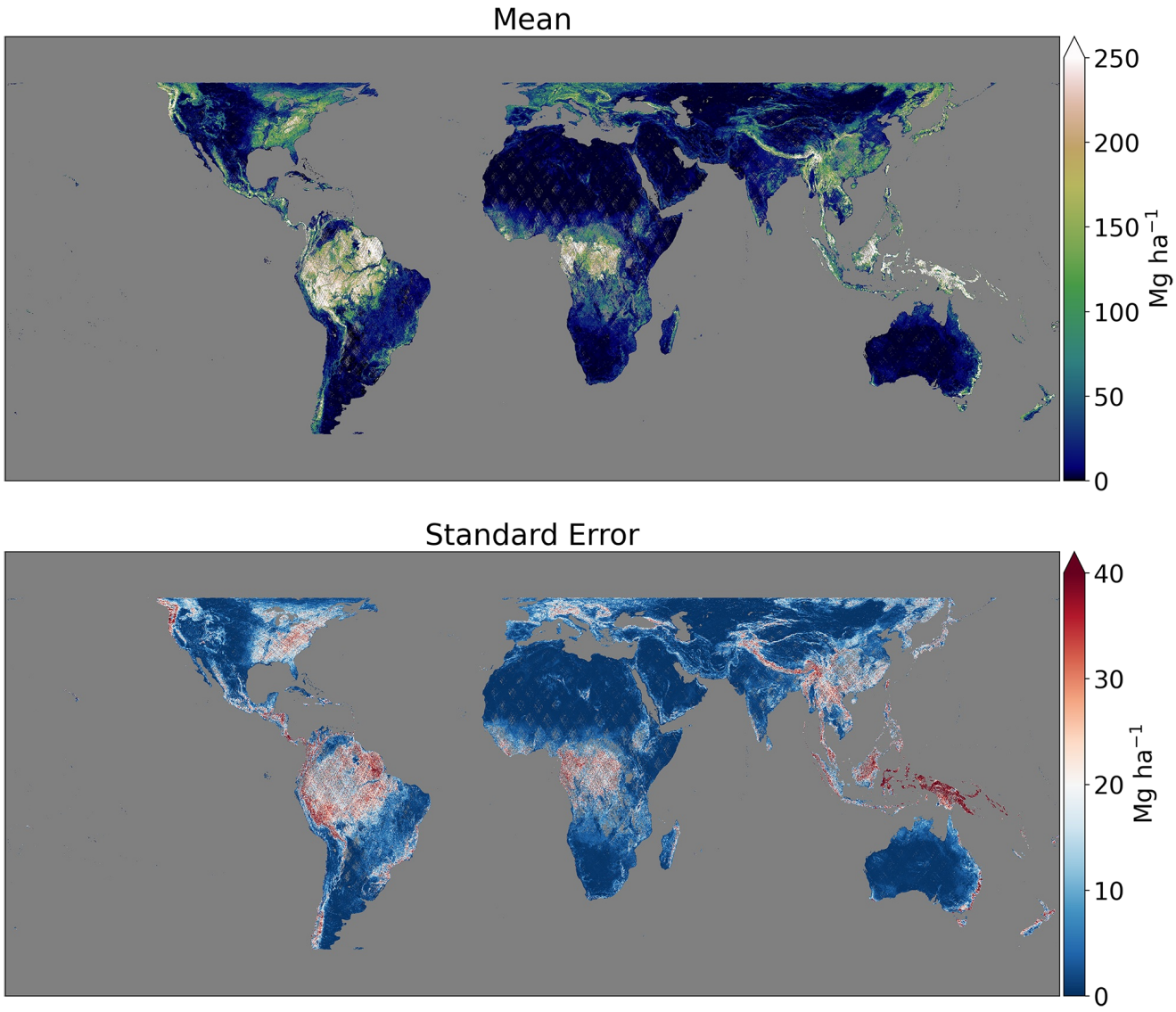

Figure 1. Gridded mean aboveground biomass density (top) and standard error of the mean (bottom).

Citation

Dubayah, R.O., J. Armston, S.P. Healey, Z. Yang, P.L. Patterson, S. Saarela, G. Stahl, L. Duncanson, and J.R. Kellner. 2022. GEDI L4B Gridded Aboveground Biomass Density, Version 2. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/2017

Table of Contents

1. Dataset Overview

This Global Ecosystem Dynamics Investigation (GEDI) L4B product provides 1 km x 1 km (1 km, hereafter) estimates of mean aboveground biomass density (AGBD) based on observations from mission week 19 starting on 2019-04-18 to mission week 138 ending on 2021-08-04. The GEDI L4A Footprint Biomass product converts each high-quality waveform to an AGBD prediction, and the L4B product uses the sample present within the borders of each 1 km cell to statistically infer mean AGBD. The gridding procedure is described in the GEDI L4B Algorithm Theoretical Basis Document (ATBD). Patterson et al. (2019) describes the hybrid model-based mode of inference used in the L4B product. Corresponding 1 km estimates of the standard error of the mean are also provided in the L4B product. Uncertainty is due to both GEDI's sampling of the 1 km area (as opposed to making wall-to-wall observations) and the fact that L4A biomass values are modeled in a process subject to error instead of measured in a process that may be assumed to be error-free.

The GEDI instrument produces high-resolution laser ranging observations of the 3-dimensional structure of the Earth. GEDI was launched on December 5, 2018, and is attached to the International Space Station (ISS). GEDI collects data globally between 51.6° N and 51.6° S latitudes at the highest resolution and densest sampling of any light detection and ranging (lidar) instrument in orbit to date. The GEDI instrument consists of three lasers producing a total of eight beam ground transects, which consist of ~25 m footprint samples spaced approximately every 60 m along-track. The GEDI beam transects are spaced approximately 600 m apart on the Earth's surface in the cross-track direction, for an across-track width of ~4.2 km.

Project: Global Ecosystem Dynamics Investigation

The Global Ecosystem Dynamics Investigation (GEDI) produces high-resolution laser ranging observations of the 3D structure of the Earth. GEDI's precise measurements of forest canopy height, canopy vertical structure, and surface elevation greatly advance our ability to characterize important carbon and water cycling processes, biodiversity, and habitat. GEDI was funded as a NASA Earth Ventures Instrument (EVI) mission. It was launched to the International Space Station in December 2018 and completed initial orbit checkout in April 2019.

Related Publications

Dubayah, R., J.B. Blair, S. Goetz, L. Fatoyinbo, M. Hansen, S. Healey, M. Hofton, G. Hurtt, J. Kellner, S. Luthcke, J. Armston, H. Tang, L. Duncanson, S. Hancock, P. Jantz, S. Marselis, P.L. Patterson, W. Qi, and C. Silva. 2020. The Global Ecosystem Dynamics Investigation: High-resolution laser ranging of the Earth's forests and topography. Science of Remote Sensing 1:100002. https://doi.org/10.1016/j.srs.2020.100002

Duncanson, L., J.R. Kellner, J. Armston, R. Dubayah, D.M. Minor, S. Hancock, et al. 2022. Aboveground biomass density models for NASA's Global Ecosystem Dynamics Investigation (GEDI) lidar mission. Remote Sensing of Environment 270:112845. https://doi.org/10.1016/j.rse.2021.112845

Patterson, P.L., S.P. Healey, G. Ståhl, S. Saarela, S. Holm, H.E. Andersen, R.O. Dubayah, L. Duncanson, S. Hancock, J. Armston, J.R. Kellner, W.B. Cohen, and Z. Yang. 2019. Statistical properties of hybrid estimators proposed for GEDI - NASA's global ecosystem dynamics investigation. Environmental Research Letters 14:065007. https://doi.org/10.1088/1748-9326/ab18df

Related Datasets

Dubayah, R.O., S.B. Luthcke, T.J. Sabaka, J.B. Nicholas, S. Preaux, and M.A. Hofton. 2021. GEDI L3 Gridded Land Surface Metrics, Version 2. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1952

Dubayah, R.O., J. Armston, J.R. Kellner, L. Duncanson, S.P. Healey, P.L. Patterson, S. Hancock, H. Tang, J. Bruening, M.A. Hofton, J.B. Blair, and S.B. Luthcke. 2022. GEDI L4A Footprint Level Aboveground Biomass Density, Version 2.1. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/2056

Level 1B, Level 2A, and Level 2B data from GEDI are available from the Land Processes Distributed Active Archive Center at https://lpdaac.usgs.gov/.

Acknowledgments

This work was funded with a NASA Earth Ventures Instrument (EVI) (contract NNL15AA03C) and an inter-agency agreement (contract RPO201523) with the U.S. Forest Service Rocky Mountain Research Station. We thank the NASA Terrestrial Ecology Program for supporting the GEDI mission. The University of Maryland and the U.S. Forest Service have provided independent financial support. We thank Göran Ståhl, Svetlana Saarela, and Sören Holm of the Swedish University for Agricultural Sciences for contributions to statistical methods used in this data product.

2. Data Characteristics

Spatial Coverage: Global within a nominal latitude extent of -52 to 52 degrees

Spatial Resolution: 1 km

Temporal Coverage: 2019-04-18 to 2021-08-04

Temporal Resolution: One-time estimates

Study Area: Latitude and longitude are given in decimal degrees.

Site	Westernmost Longitude	Easternmost Longitude	Northernmost Latitude	Southernmost Latitude
Global	-180	180	52	-52

Data File Information

There are 10 data files in cloud-optimized GeoTIFF (*.tif) format included in this dataset. Each file provides 1 km estimates of mean aboveground biomass density (AGBD) for the period 2019-04-18 to 2021-08-04 (mission week 19 to mission week 138). Also included are two companion files in Portable Document Format (*.pdf). Companion files must be downloaded separately from the data files.

The naming convention for the data files is GEDI04_B_**<start_mission_wk_end_mission_wk>_<ppds>_<release_num>_<product_ver>_<spatial_resolution>_<variable>.tif**, where

- **start_mission_wk_end_mission_wk** are starting and ending weeks of the GEDI mission included in the product. Mission week 19 ("MW019") starts 2019-04-18 and mission week 138 ("MW138") ends 2021-08-04
- **ppds** is the positioning and pointing determination system (PPDS) type (02 is final)
- **release_num** is GOC SDS (software) release number,
- **product_ver** is the granule production version,
- **spatial_resolution** is "R01000M" (1 km), and
- **variable** is the gridded metric: MU=Mean; V1=Variance Component 1; V2=Variance Component 2; SE=Standard Error; PE=Percentage Standard Error; NC=Number of Clusters; NS=Number of Samples; QF=Quality Flag; PS=Prediction Stratum, MI=Mode of Inference (Table 1).

Table 1. File names and descriptions. All data are for the period 2019-04-18 to 2021-08-04.

File Names	Description	Units	No Data Value	Data Type
Data Files				
GEDI04_B_MW019MW138_02_002_05_R01000M_MU.tif	Mean aboveground biomass density (MU): Estimated mean AGBD for the 1 km grid cell, including forest and non-forest	Mg ha^{-1}	-9999	Float32

File Names	Description	Units	No Data Value	Data Type
GEDI04_B_MW019MW138_02_002_05_R01000M_V1.tif	Variance component 1 (V1): Uncertainty in the estimate of mean biomass due to the field-to-GEDI model used in L4A		-9999	Float32
GEDI04_B_MW019MW138_02_002_05_R01000M_V2.tif	Variance component 2 (V2): If Mode of Inference = 1, this is the uncertainty due to GEDI's sampling of the 1 km cell. If Mode of Inference = 2, this is uncertainty owing to the model predicting biomass using wall-to-wall data, calibrated with the L4A footprint product		-9999	Float32
GEDI04_B_MW019MW138_02_002_05_R01000M_SE.tif	Mean aboveground biomass density standard error (SE): Standard Error of the mean estimate, combining sampling and modeling uncertainty	Mg ha^{-1}	-9999	Float32
GEDI04_B_MW019MW138_02_002_05_R01000M_PE.tif	Standard error as a fraction of the estimated mean AGBD (PE). If >100%, the cell values are truncated to 100.	percent	255	UInt8
GEDI04_B_MW019MW138_02_002_05_R01000M_NC.tif	Number of clusters (NC): Number of unique GEDI ground tracks with at least one high-quality waveform intersecting the grid cell			UInt16
GEDI04_B_MW019MW138_02_002_05_R01000M_NS.tif	Number of samples (NS): Total number of high-quality waveforms across all ground tracks within the grid cell			UInt16
GEDI04_B_MW019MW138_02_002_05_R01000M_QF.tif	Quality flag (QF): 0=Outside the GEDI domain 1=Land surface 2=Land surface and meets GEDI mission L1 requirement (Percent standard error <20% or Standard Error < 20 Mg ha^{-1})			UInt8
GEDI04_B_MW019MW138_02_002_05_R01000M_PS.tif	Prediction stratum (PS) determined by plant functional type and continent. PS is associated with an L4A model parameter covariance matrix that contributes to the Model Error Variance (Table 2).		0,241	UInt8
GEDI04_B_MW019MW138_02_002_05_R01000M_MI.tif	Mode of interference (MI): Method used for a particular cell. Until mission completion, only those cells where hybrid inference is possible will be populated with a mean biomass value 0=None applied 1=Hybrid Model-Based 2=Generalized Hierarchical Model-Based			UInt8
Companion Files				
GEDI_ATBD_L4B_v1.0.pdf	The Algorithm Theoretical Basis Document (ATBD) provides additional details regarding the product model and gridding procedure.			
GEDI_L4B_Gridded_Biomass.pdf	A PDF copy of this user guide.			

Data File Details

Properties of the Cloud-Optimized GeoTIFF Data Files

- Bands: 1
- Scale factor: 1
- Number of columns: 34,704
- Number of rows: 14,616
- Map Projection: Equal-Area Scalable Earth (EASE)-Grid 2.0 Global (https://nsidc.org/data/ease)
- Datum: World Geodetic System 1984
- EPSG: 6933
- Map units: meters
- X-axis map coordinate of the outer edge of the upper-left pixel: -17367530.45
- Y-axis map coordinate of the outer edge of the upper-left pixel: 7314540.83

Table 2. Prediction stratum (PS) codes in GEDI04_B_MW019MW138_02_002_05_R01000M_PS.tif. The first part of the code is a plant functional type and the second part is a world region.

Cell value	Code	Description
1	DBT_Af	deciduous broadleaf trees (DBT) of Africa (Af)

Cell value	Code	Description
2	DBT_Au	deciduous broadleaf trees of Australia and Oceania (Au)
3	DBT_Eu	deciduous broadleaf trees of Europe (Eu)
4	DBT_NAs	deciduous broadleaf trees of North Asia (NAs)
5	DBT_SA	deciduous broadleaf trees of South America (SA)
6	DBT_SAs	deciduous broadleaf trees of South Asia (SAs)
7	DBT_NAm	deciduous broadleaf trees of North America (NA)
8	EBT_Af	evergreen broadleaf trees (EBT) of Africa
9	EBT_Au	evergreen broadleaf trees of Australia and Oceania
10	EBT_Eu	evergreen broadleaf trees of Europe
11	EBT_NAs	evergreen broadleaf trees of North Asia
12	EBT_SA	evergreen broadleaf trees of South America
13	EBT_SAs	evergreen broadleaf trees of South Asia
14	EBT_NAm	evergreen broadleaf trees of North America
15	ENT_Af	evergreen needleleaf trees (ENT) of Africa
16	ENT_Au	evergreen needleleaf trees of Australia and Oceania
17	ENT_Eu	evergreen needleleaf trees of Europe
18	ENT_NAs	evergreen needleleaf trees of North Asia
19	ENT_SA	evergreen needleleaf trees of South America
20	ENT_SAs	evergreen needleleaf trees of South Asia
21	ENT_NAm	evergreen needleleaf trees of North America
22	DNT_Af	deciduous needleleaf trees (DNT) of Africa
23	DNT_Au	deciduous needleleaf trees of Australia and Oceania
24	DNT_Eu	deciduous needleleaf trees of Europe
25	DNT_NAs	deciduous needleleaf trees of North Asia
26	DNT_SA	deciduous needleleaf trees of South America
27	DNT_SAs	deciduous needleleaf trees of South Asia
28	DNT_NAm	deciduous needleleaf trees of North America
29	GSW_Af	grasses, shrubs, and woodlands (GSW) of Africa
30	GSW_Au	grasses, shrubs, and woodlands of Australia and Oceania
31	GSW_Eu	grasses, shrubs, and woodlands of Europe
32	GSW_NAs	grasses, shrubs, and woodlands of North Asia
33	GSW_SA	grasses, shrubs, and woodlands of South America
34	GSW_SAs	grasses, shrubs, and woodlands of South Asia
35	GSW_Nam	grasses, shrubs, and woodlands of North America

User Notes

GEDI measurements are made over the Earth's surface nominally between 51.6° and -51.6° latitude. Because the instrument can be rotated on its ISS mount up to 6 degrees, the lasers can be pointed up to 40 km on either side of the ISS ground track. Thus, the exact spatial coverage of L2 products will vary slightly by orbit. In addition, L4B gridded coverage might differ slightly from L4A or L2 data owing to footprint quality checks and grid cell filtering. Currently, the data files have a range of 85° to -85° latitude that corresponds to the full extent of the EASE-Grid 2.0, but data cells with valid data values nominally fall within the range of 52° to -52° latitude.

3. Application and Derivation

GEDI is the first mission purpose-built for creating the kind of mapped estimates of aboveground biomass density (AGBD) provided in this L4B product. A closed-form estimation process (described below) allows estimation of mean AGBD at the scale of the 1 km grid cell, with millions of such cells creating a surface that represents our best understanding of the spatial distribution of tropical and temperate forest biomass. Such maps support a broad range of scientific, policy, and management applications (Herold et al., 2019).

Application of L4B estimates must begin with the understanding that the estimate covers the entire area of the 1 km cell, whether that area is completely forested or not. No high-resolution forest mask was used to filter out non-forest waveforms because (1) this approach preserves the option of including non-forest biomass in estimates at the 1 km scale; and (2) constraining estimates with one version of a forest cover mask may make those estimates less

relevant in a context that uses a different mask. If users need a biomass estimate specific to the forest area within a 1 km cell, they can divide the mean 1 km AGBD by the fraction of the cell that is forested according to their preferred forest map.

GEDI's primary L4B algorithm is hybrid inference (Ståhl et al., 2010; Patterson et al., 2019) in which mean biomass is estimated from an incomplete sample of modeled biomass values (available via the L4A product, Dubayah et al., 2022). Conventionally, the kind of linear observations collected by GEDI, or other air- or space-borne platforms, is treated as a cluster sample. Since at least two clusters are required to calculate a variance under hybrid estimation, GEDI's primary algorithm may only be applied to 1 km cells containing samples from at least two intersecting ground tracks. At the end of the mission, mean biomass in cells without sufficient clusters will be estimated instead with Generalized Hierarchical Model-Based inference (GHMB). This approach uses a second-level model that extends biomass to a surface predicted from wall-to-wall imagery. The "Mode of Inference" L4B variable describes which method was used for a particular cell. Until mission completion, only those cells where hybrid inference is possible will be populated with a mean biomass value; other cells will have a value of zero.

4. Quality Assessment

GEDI's L1 science requirement states that 80% of 1 km cells must be estimated to be within a standard error of either 20 Mg ha $^{-1}$ or 20% of the estimate, whichever is greater. The Quality Flag variable (2=meets L1 requirement) facilitates tracking of mission progress with respect to this goal.

Uncertainty (i.e., the standard error of the estimate) was assessed using sample theory in conjunction with observed sample numbers and variances. This approach to uncertainty is consistent with designed samples used by the world's national forest inventories, including the Forest Inventory and Analysis (FIA) program of the U.S. Forest Service (Menlove and Healey, 2020). As described in the L4B Algorithm Theoretical Basis Document, the uncertainty of the estimated mean biomass is determined either through the estimator described by Patterson et al. (2019; for hybrid estimation) or by Saarela et al. (2018; for Generalized Hierarchical Model-Based inference (GHMB)).

Both variance estimators have two components. The first component is model covariance due to the L4A field-to-GEDI aboveground biomass density (AGBD) model. For hybrid estimation, the second variance component relates to GEDI's sample design. For GHMB, the second component relates to the fit of an additional model that links L4A predictions to wall-to-wall imagery. The Variance Component 1 and 2 variables allow the user to decompose uncertainty expressed in the Standard Error variable into its primary components, whether the Mode of Inference is hybrid or GHMB estimation.

5. Data Acquisition, Materials, and Methods

The GEDI instrument is aboard the International Space Station (ISS) and its mission aims to characterize ecosystem structure and dynamics to enable improved quantification and understanding of the Earth's carbon cycle and biodiversity. GEDI is led by the University of Maryland in collaboration with NASA Goddard Space Flight Center. GEDI science data algorithms and products are created by the GEDI Science Team.

The GEDI instrument produces high-resolution laser ranging observations of the 3-dimensional structure of the Earth. GEDI was launched on December 5, 2018, and is attached to the ISS. GEDI collects data globally at the highest resolution and densest sampling of any light detection and ranging (lidar) instrument in orbit to date. The GEDI instrument consists of 3 lasers producing a total of 8 beam ground transects, which consist of ~25 m footprint samples spaced approximately every 60 m along-track. The GEDI beam transects are spaced approximately 600 m apart on the Earth's surface in the cross-track direction, for an across-track width of ~4.2 km.

The GEDI L4B gridded aboveground biomass density (AGBD) uses a hybrid estimation to create an exhaustive coverage of non-overlapping 1 km x 1 km mean biomass estimates, together with a grid of standard errors for each 1 km estimate (a process also called "gridding"). As described above, hybrid inference accounts for both model uncertainty and uncertainty related to the GEDI sample within a single grid cell. The 1 km^2 resolution global EASE-Grid 2.0 is used to partition the GEDI L4A dataset (by footprint center point) into grid cells. This grid features equal-area cells and compatibility with many existing biosphere datasets. More information on this grid can be found in Brodzik et al. (2012) and from NSIDC (https://nsidc.org/data/ease). The gridding procedure is described in the GEDI L4B Algorithm Theoretical Basis Document (ATBD), while the L4A footprint biomass predictions are described in that product's User Guide (Dubayah et al., 2022). The elevation and height metric algorithms used by GEDI are described in the ATBD for GEDI Transmit and Receive Waveform Processing for L1 and L2 Products (Hofton and Blair, 2019).

Until the end-of-mission application of Generalized Hierarchical Model-Based inference (GHMB), all grid cells without a valid hybrid mean biomass estimate will have a value of zero. The distribution of zero cells is not uniform, with higher non-response found (1) earlier in the mission life; (2) closer to the equator where the ISS overpass pattern is more sparse; (3) in cloudy areas; and (4) in areas where reference ground tracks were not sampled because of the Mission's Year 2 orbital resonance problem. The latter problem involved repeated coverage of some ground tracks at the expense of others because of an unscheduled change in ISS altitude. For cells with valid estimates, the estimated standard error of the mean depends upon factors such as the fit of L4A footprint biomass models (reflected in Variance Component 1) and the density of observations and ground tracks (reflected in the Variance Component 2). For 1 km cells with a valid estimate, the Prediction Stratum grid provides a link to the L4A model data (e.g., parameters, variance-covariance matrix, etc.) used for prediction, where the value represents the row number in the */ANCILLARY/model_data* compound dataset that is available within every L4A product file (see Dubayah et al., 2022).

6. Data Access

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

GEDI L4B Gridded Aboveground Biomass Density, Version 2

Contact for Data Center Access Information:

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

7. References

Brodzik, M.J., B. Billingsley, T. Haran, B. Raup, and M.H. Savoie. 2012. EASE-Grid 2.0: Incremental but Significant Improvements for Earth-Gridded Data Sets. ISPRS International Journal of Geo-Information 1:32-45. https://doi.org/10.3390/ijgi1010032

Dubayah, R.O., J. Armston, J.R. Kellner, L. Duncanson, S.P. Healey, P.L. Patterson, S. Hancock, H. Tang, J. Bruening, M.A. Hofton, J.B. Blair, and S.B. Luthcke. 2022. GEDI L4A Footprint Level Aboveground Biomass Density, Version 2.1. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/2056

Herold, M., S. Carter, V. Avitabile, A.B. Espejo, I. Jonckheere, R. Lucas, R.E. McRoberts, E. Næsset, J. Nightingale, R. Petersen, J. Reiche, E. Romijn, A. Rosenqvist, D.M.A. Rozendaal, F.M. Seifert, M.J. Sanz, and V. De Sy. 2019. The role and need for space-based forest biomass-related measurements in

environmental management and policy. Surveys in Geophysics 40:757–778. https://doi.org/10.1007/s10712-019-09510-6

Hofton, M. and J.B. Blair. 2019. Algorithm Theoretical Basis Document (ATBD) for GEDI transmit and receive waveform processing for L1 and L2 Products. Version 1. NASA Goddard Space Flight Center; Greenbelt, Maryland. https://doi.org/10.5067/DOC/GEDI/GEDI_WF_ATBD.001

Menlove, J., and S.P. Healey. 2020. A comprehensive forest biomass dataset for the USA allows customized validation of remotely sensed biomass estimates. Remote Sensing 12:4141. https://doi.org/10.3390/rs12244141

Patterson, P.L., S.P. Healey, G. Ståhl, S. Saarela, S. Holm, H.E. Andersen, R.O. Dubayah, L. Duncanson, S. Hancock, J. Armston, J.R. Kellner, W.B. Cohen, and Z. Yang. 2019. Statistical properties of hybrid estimators proposed for GEDI - NASA's global ecosystem dynamics investigation. Environmental Research Letters 14:065007. https://doi.org/10.1088/1748-9326/ab18df

Saarela, S., S. Holm, S. Healey, H.-E. Andersen, H. Petersson, W. Prentius, P. Patterson, E. Næsset, T. Gregoire, and G. Ståhl. 2018. Generalized hierarchical model-based estimation for aboveground biomass assessment Using GEDI and Landsat Data. Remote Sensing 10:1832. https://doi.org/10.3390/rs10111832

Ståhl, G., S. Holm, T.G. Gregoire, T. Gobakken, E. Næsset, and R. Nelson. 2010. Model-based inference for biomass estimation in a LiDAR sample survey in Hedmark County, Norway. Canadian Journal of Forest Research 41:96-107. https://doi.org/10.1139/X10-161