GLOBAL Ecosystem Dynamics Investigation (GEDI) Level 02 User Guide

For SDPS PGEVersion 1 (P001) of GEDI L2A Data and SDPS PGEVersion 1 (P001) of GEDI L2B Data

Version 1.0

January 2020

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[1] KBR, Inc., contractor to the U.S. Geological Survey, Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota, USA. Work performed under USGS contract G15PC00012 for LP DAAC[2].

[2] LP DAAC work performed under NASA contract NNG14HH33I.

Document History

Document Version	Publication Date	Description
1.0	January 2020	Original for L2A P001 L2B P001

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1 Dataset Overview

The overall goal of the Global Ecosystem Dynamics Investigation (GEDI) mission is to advance our ability to characterize the effects of changing climate and land use on ecosystem structure and dynamics. The GEDI instrument produces high-resolution laser ranging observations of the 3-dimensional structure of the Earth. GEDI is attached to the International Space Station and collects data globally between 51.6º N and 51.6º S latitudes. GEDI measurements of forest canopy height, canopy vertical structure, and surface elevation are used to characterize important carbon and water cycling processes, biodiversity, and habitat. The GEDI data also may be used in far ranging applications such as weather forecasting, forest management, snow and glacier monitoring, and digital elevation models. 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.

This user's guide provides information about the Science Data Processing System (SDPS) PGEVersion 1 (P001) GEDI L2A Elevation and Height Metrics (GEDI02_A) and SDPS PGEVersion 1 (P001) GEDI L2B Canopy Cover and Vertical Profile Metrics (GEDI02_B) products. The GEDI02_A and GEDI02_B products are provided in HDF5 file format. The filename convention details are provided in section 2.4 of this document.

1.1 Background

The GEDI instrument consists of 3 lasers that are split and beam dithered resulting in a total of 8 beam ground transects that are spaced 600 meters apart on the Earth's surface in the cross-track direction. Each beam consists of ~25 m footprint samples approximately spaced every 60 m along track. Captured in real time by the GEDI instrument are the shapes of the transmitted and reflected laser waveforms, enabling a precise range to the reflecting surface to be calculated for every shot (after accounting for the speed of light). The laser receive waveform represents the vertical distribution of intercepted surfaces as a function of range. Over non-complex, flat terrain, the laser receive waveform shape will look similar to the shape of the outgoing (transmitted) laser pulse. Over complex or sloped terrain, photons may be reflected from multiple surfaces within the footprint resulting in a receive waveform with multiple modes. Interpretation of the laser pulse in post-processing enables precise information on surface elevation, structure, and relative canopy heights to be derived. The L1B geolocated waveform product contains precise geolocation information for the first and last sample bins of each GEDI laser return waveform. The L2 geolocated elevation and height products contain precise geolocation information for each reflecting surface within the receive waveform.

The GEDI Level 2 products contain information derived from the geolocated GEDI return waveforms. The GEDI02_A product includes ground elevation, canopy top height, and relative return energy metrics, and the GEDI02_B product provides biophysical metrics such as canopy cover and plant area index (PAI).

For a detailed description of the satellite and reference data, processing schemes, approaches, methods, and other information, refer to the following algorithm theoretical basis documents (ATBDs) and the GEDI mission website.

ATBD for GEDI Waveform Geolocation for L1 and L2 Products, Luthcke et al.

ATBD for GEDI Transmit and Receive Waveform Processing for L1 and L2 Products, Hofton et al.

GEDI ATBD for Footprint Canopy Cover and Vertical Profile Metrics, Tang et al.

1.2 Important Product Notes for P001 L2

The P001 L2A and L2B products were generated using preliminary and limited geolocation and waveform parameter calibration and validation. Data product performance, especially geolocation performance and selection of algorithm settings for waveform processing, is expected to significantly improve in future releases as data over a wider scope of instrument operating conditions and land surface conditions will be analyzed with considerably more comprehensive calibration and overall product validation.

The L2 products contain processing results for all waveforms where a valid surface return exists. Both the L2A and L2B products provide a preliminary set of quality flags and metrics that the user can use to filter shots with poor geolocation performance, waveforms of poor signal quality, and waveforms affected by cloud and other land surface conditions. See Section 6 for more details.

The L2A product also provides waveform processing results for multiple algorithm settings. Results for a default algorithm selection are provided in the root directory of the data product for each beam. In some cases, the selection of an alternative algorithm setting will provide a better result. See Section 6 for instructions on how to extract results for alternative algorithm settings from the L2A and L2B data files.

2 Dataset Characteristics

Global Ecosystem Dynamics Investigation elevation and height metrics data product and the canopy cover and vertical profile data product (GEDI02_A & GEDI02_B) collection, granule, and dataset characteristics are described below.

2.1 GEDI Level 2A Elevation and Height Metrics Data Global Footprint Level P001

2.1.1 Collection Level (GEDI02_A)

Table 1. Collection Level Data

Characteristic	Description
Collection	GEDI
Short name	GEDI02_A
DOI	10.5067/GEDI/GEDI02_A.001
Temporal Resolution	Varies
Temporal Extent	2019-04-18 – Present
Spatial Extent	Global (51.6 °S to 51.6 °N)
Coordinate System	Geographic (lat/lon)
Datum	WGS84
Geographic Dimensions	4.2 km across-track by one full ISS orbit along-track
File size	~5GB
File Format	HDF5

2.1.2 Granule Level (GEDI02_A)

Table 2. Granule Level Data

Number of Science Dataset (SDS) Layers	530 per beam
Columns/Row	Variable
Pixel Size	25 m (footprint diameter)

2.1.3 Data Layer Characteristics (GEDI02_A)

Please refer to the Level 2A data dictionary for a complete description of the product attributes, groups, and datasets, including datatype, dimensions, units, source, and short definition/description.

2.2 GEDI Level 2B Canopy Cover and Vertical Profile Metrics Data Global Footprint Level P001

2.2.1 Collection Level (GEDI02_B)

Table 3. Collection Level Data

Characteristic	**Description**
Collection	GEDI
Short name	GEDI02_B
DOI	10.5067/GEDI/GEDI02_B.001
Temporal Resolution	Varies
Temporal Extent	2019-04-18 – Present
Spatial Extent	Global (51.6 °S to 51.6 °N)
Coordinate System	Geographic (lat/lon)
Datum	WGS84
Geographic Dimensions	4.2 km across-track by one full ISS orbit along-track
File size	~1GB
File Format	HDF5

2.2.2 Granule Level (GEDI02_B)

Table 4. Granule Level Data

Number of Science Dataset (SDS) Layers	186 x 8 beams
Columns/Row	Variable
Pixel Size	25 m (footprint diameter)

2.2.3 Data Layer Characteristics (GEDI02_B)

Please refer to the Level 2B data dictionary for a complete description of the product attributes, groups, and datasets, including datatype, dimensions, units, source, and short definition/description.

2.3 Unique Shot Identifier

Each shot has a unique shot identifier (shot number) that is available within each data group of the product. The shot number is important to retain in any data sub-setting as it will allow the user to link any shot record back to the original orbit data, and to link any shot and its data between the L1 and L2 products. The shot number has the following format:

OOOOOBBFFFNNNNNNNN

where:

OOOOO: Orbit number

BB: Beam number

FFF: Minor frame number (0-241)

NNNNNNNN: Shot number within orbit

If a data packet is dropped (never received on the ground), NNNNNNNN will not save space for it; however, if we receive a packet with a bad Cyclic Redundancy Check (CRC) error detection, it will be “skipped” in NNNNNNNN in case it can be corrected in later processing.

2.4 File Naming Conventions

GEDI filenames (i.e., the local granule ID) follow a naming convention which gives useful information regarding the specific product/file.

In this example of a level 02A product, the filename **GEDI02_A_2019110014613_O01991_T04905_02_001_01.h5** indicates:

- **GEDI02_A** = Product Short Name
- **2019110** = Julian Date of Acquisition in YYYYDDD
- **014613** = Hours, Minutes and Seconds of Acquisition (HHMMSS)
- **O01991** = O = Orbit, 01991 = Orbit Number
- **T04905** = T = Track, 04905 = Track Number
- **02** = Positioning and Pointing Determination System (PPDS) type (00 is predict, 01 rapid, 02 and higher is final.)
- **001** = GOC SDS (software) release number
- **01** = Granule Production Version

2.5 File Format

The GEDI products are stored in Hierarchical Data Format version 5 (HDF5), a self-descriptive data file format designed by the National Center for

Supercomputing Applications to assist users in the storage and manipulation of scientific data across diverse operating systems and machines.

3 Algorithm Description

3.1 General Geolocation Algorithm Overview

In the L2A and L2B products, the coordinates of first and last samples of the waveform are interpolated to specific ranging points in the waveform (e.g., elevation of the lowest mode). Refer to the L1B User guide for an overview of the geolocation algorithm. The user is also highly encouraged to refer to the "ATBD for GEDI Waveform Geolocation for L1 and L2 Products" for a complete description of the geolocation algorithm and definitions, and details of the geolocation and geophysical corrections parameters.

3.2 Waveform Processing Algorithm Overview

A digitally recorded return laser pulse, or waveform, represents the time history of the laser pulse as it interacts with the reflecting surfaces. The waveform can have a simple (single-mode) shape similar to that of the outgoing pulse or be complex and multimodal with each mode representing a reflection from an apparently distinct surface within the laser footprint. Simple waveforms are typical in ocean or bare-ground regions and complex waveforms in rough terrain or vegetated regions. The first and last modes (i.e., detected signal above noise) within the waveform are associated with the highest and lowest perceived reflecting surfaces within the footprint, respectively.

The waveform processing algorithms used by GEDI are described in section 1.4 of the ATBD for GEDI Transmit and Receive Waveform Processing for L1 and L2 Products and are adapted from methods developed for the analysis of waveforms acquired from NASA's Land, Vegetation and Ice Sensor (LVIS) (Blair et al., 1999). These algorithms enable the derivation of footprint level GEDI Elevation and Height Metrics (the L2A product) and the estimation of the Canopy Cover and Vertical Profile Metrics (the L2B product).

3.3 Elevation and Height Metric Algorithm Overview

Geolocation of the received waveform window is completed in the L1B algorithm. Precise timing points for various surfaces relative to the start of the received waveform are completed in the received waveform analysis. For GEDI L2A geolocation and height products, the precise timing points within each received waveform are geolocated using their computed offset to the start of the received waveform in a linear interpolation of the L1B latitudes, longitudes, and elevations.

Height products are subsequently computed relative to the elevation of the lowest detected mode.

The elevation and height metric algorithms used by GEDI are described in Section 5 of the ATBD for GEDI Transmit and Receive Waveform Processing for L1 and L2 Products.

3.4 Cover and Vertical Profile Metric Algorithm Overview

The waveforms provided in the L1B product and locations of reflecting surfaces within the footprint provided in the L2A product are used to derive the directional gap probability profile with the heights of each profile sample computed relative to the elevation of the lowest detected mode. The directional gap probability profile is then used to extract biophysical metrics from each GEDI waveform. These metrics include total and vertical profiles of canopy cover and Plant Area Index (PAI), and the vertical Plant Area Volume Density (PAVD) profile. Foliage Height Diversity (FHD) is also calculated from the PAVD profile.

The cover and vertical profile algorithms used by GEDI are described in Sections 2 and 3 of the ATBD for GEDI L2B Footprint Canopy Cover and Vertical Profile Metrics.

4 Metadata

GEDI products have two sources of metadata: the embedded HDF5 metadata and the external ECS metadata. The HDF metadata contains valuable information including global attributes and dataset specific attributes pertaining to the granule. The ECS (generated by the EOSDIS Core System) .met file is the external metadata file in XML format, which is delivered to the user along with the GEDI product. It provides a subset of the HDF metadata.

The Data Set attributes contain specific SDS information such as the data range and applicable scaling factors for the data. The LP DAAC data products page provides these details within a concise document for each of the products. An HDF5 file also contains core metadata essential for search services. It is difficult for a standard HDF call to interpret HDF5 geolocation or temporal information without further knowledge of the file structure.

5 Frequently Asked Questions

How do I cite the data?

The following citation information is applicable for the GEDI02_A.001 and GEDI02_B.001 products:

Dubayah, R., Hofton, M., J. B. Blair, Armston, J., Tang, H., Luthcke, S. (2020). *GEDI L2A Elevation and Height Metrics Data Global Footprint Level V001* [Data set]. NASA EOSDIS Land Processes DAAC. Accessed YYYY-MM-DD from https://doi.org/10.5067/GEDI/GEDI02_A.001.

Dubayah, R., Tang, H., Armston, J., Luthcke, S., Hofton, M., J. B. Blair (2020). *GEDI L2B Canopy Cover and Vertical Profile Metrics Data Global Footprint Level V001* [Data set]. NASA EOSDIS Land Processes DAAC. Accessed YYYY-MM-DD from https://doi.org/10.5067/GEDI/GEDI02_B.001.

What science datasets does the Global Ecosystem Dynamics Investigation Level 2A product contain?

The L2A product contains information derived from the geolocated GEDI return waveforms, including ground elevation, highest and lowest surface return elevations, energy quantile heights ("relative height" metrics), and other waveform-derived metrics describing the intercepted surface.

The detailed product contents are defined in the GEDI L2A Product Data Dictionary.

What science datasets does the Global Ecosystem Dynamics Investigation Level 2B product contain?

The L2B product contains biophysical information derived from the geolocated GEDI return waveforms including total and vertical profiles of canopy cover and Plant Area Index (PAI), the vertical Plant Area Volume Density (PAVD) profile, and Foliage Height Diversity (FHD).

The detailed product contents are defined in the GEDI L2B Product Data Dictionary.

How do I extract elevation and height metrics for alternative algorithm setting groups in L2A?

Only the suggested result for each laser footprint is stored in the root group of the L2A product for each beam. This is currently set to the output of algorithm setting group 1 (see Table 5) and will be updated as post-launch cal/val progresses.

Elevation and height metrics outputs for all algorithm setting groups can be found in the geolocation subgroup of the L2A data product. For example, elev_lowestreturn_a<n> is the elevation of lowest return detected using algorithm setting group <n>, relative to reference ellipsoid; and rh_a<n> are the relative height metrics at 1% intervals using algorithm <n> (in cm). See Section 5 of the ATBD for GEDI Waveform Geolocation for L1 and L2 Products for additional details.

How do I extract cover and vertical profile metrics for alternative algorithm setting groups in L2B?

Only the suggested result for each laser footprint is stored in the root group of the L2B product for each beam. The suggested result corresponds to the L2A algorithm setting group set in /BEAMXXX/selected_l2a_algorithm and will be updated as post-launch cal/val progresses.

In contrast to the L2A data, only a select set of L2B algorithm outputs is stored for each L2A algorithm setting group. These outputs can be found in the /BEAMXXXX/rx_processing subgroup and include the directional gap probability (pgap_theta_a<n>), canopy (rv_a<n>) and ground (rg_a<n>) waveform integrals, and the results of the extended Gaussian fit, fit the ground waveform (rg_eg_*_a<n>), where <n> is the algorithm setting group <n> (see Table 5).

These outputs enable rapid recalculation of L2B vertical profiles for different L2A algorithm setting groups. Examples of this recalculation are being prepared by the GEDI Science Team as Python Jupyter Notebooks.

6 Quality and Important Notes

L2A and L2B algorithm results are available for every shot with a valid waveform; however, we recommend the following guidelines for selecting “best” data:

1. Do not expect the GEDI coverage beams to penetrate dense forest. The GEDI coverage beams were only designed to penetrate canopies of up to 95% canopy cover under “average” conditions, so users should preference use of GEDI power beams in this case.
2. Use GEDI data acquired at night (solar_elevation < 0) where possible. The negative impact of background solar illumination on GEDI waveform quality is eliminated during this time.
3. Use the sensitivity metric available in L2A and L2B to select "best" data. The L2A and L2B quality_flag datasets (see below) use a conservative sensitivity threshold of 0.9 over land (0.5 over ocean), but under some conditions (e.g. dense forest) the user may benefit from selecting a higher threshold.

Interpretation of L2A Quality Flag

In order to provide end users with the ability to easily remove erroneous and/or lower quality returns, we provide a quality_flag. This is a summation of several individual quality assessment parameters and is intended to provide general guidance only. A quality_flag value of 1 indicates the laser shot meets criteria based on energy, sensitivity, amplitude, and real-time surface tracking quality.

Interpretation of L2B Quality Flag

In order to provide end users with the ability to easily remove erroneous and/or lower quality returns, and returns not corresponding to the land surface, we provide a quality_flag based on the outputs of the selected L2A algorithm settings group. Results are available for every shot with a valid waveform, but sometimes these results are not directly meaningful, such as vertical profile metrics over the ocean.

As done for L2A, quality_flag is a summation of several individual quality assessment parameters and other flags and is intended to provide general guidance only. A quality_flag value of 1 indicates the cover and vertical profile metrics represent the land surface and meet criteria based on waveform shot energy, sensitivity, amplitude, and real-time surface tracking quality, and the quality of extended Gaussian fitting to the lowest mode.

Interpretation of RH Metrics

The L2A data product provides relative height (RH) metrics, which are “lidar perceived” metrics that have the following characteristics:

1. RH100 = elev_highestreturn - elev_lowestmode
2. The RH metrics are intended for vegetated surfaces. Results over bare/water surfaces are still valid but may present some confusing results.
3. The lower RH metrics (e.g., RH10) will often have negative values, particularly in low canopy cover conditions. This is because a relatively high fraction of the waveform energy is from the ground and below elev_lowestmode. For example, if the ground return contains 30% of the energy, then RH1 through 15 are likely to be below 0 since half of the ground energy from the ground return is below the center of the ground return, which is used to determine the mean ground elevation in the footprint (elev_lowestmode).

L2 Algorithm Setting Groups

Table 5 outlines the L2A algorithm group settings used to interpret each waveform. Setting group 1 is the default setting, which is designed to work in the majority of cases. Additional setting groups are designed to provide information in cases where less than optimal observing conditions were experienced, for example low energy ground reflections or higher background noise. Condition cases that may be experienced include:

- The lowest selected mode has triggered on noise, thus elev_lowestmode will be below the actual ground surface. An algorithm with a higher signal end threshold setting may be more appropriate.
- The lowest selected mode falls above the actual ground surface: energy from the ground surface may be weak. An algorithm with a lower signal end threshold setting may be more appropriate.
- Highest detected return is below the canopy top. An algorithm with a lower signal start threshold setting may be more appropriate.
- Highest detected return is above the canopy top (cloud and fog are examples for this condition). An algorithm with a higher signal start threshold setting may be more appropriate.

The geolocation (latitude, longitude, elevation) of all detected modes are provided for each waveform for each algorithm group setting (lat/lon/elevs_allmodes_a<n>) allowing the end user the flexibility to reselect an appropriate mode for their study. Custom selection of algorithm setting groups by users of the L2A and L2B data products may lead to improved results in local areas.

Table 5. L2A algorithm setting groups. σ represents the standard deviation of the background noise level.

Setting group	Smoothing width (noise)	Smoothing width (signal)	Waveform signal start threshold	Waveform signal end threshold
1	6.5σ	6.5σ	3σ	6σ
2	6.5σ	3.5σ	3σ	3σ
3	6.5σ	3.5σ	3σ	6σ
4	6.5σ	6.5σ	6σ	6σ
5	6.5σ	3.5σ	3σ	2σ
6	6.5σ	3.5σ	3σ	4σ

For complete and updated information regarding product quality, see the [GEDI Mission Website.]

7 Known Issues

There are numerous time periods where the geolocation performance suffers due to non-optimal operating conditions. The “degrade” flag should be understood as a general indicator of a potential issue. These orbit degradation periods are discussed in more detail in the L1B User guide.

In some conditions (e.g. high canopy cover), the default algorithm setting selection may be suboptimal. All pending updates to L2A algorithm setting group selection are globally optimized to improve global product performance. For specific sites, the user is encouraged to check the alternative output parameters in the geolocation subgroup.

The surface classification is currently made at the shot level using the TanDEM-X DEM. Valid surface waveforms in some high elevation regions (e.g. Himalayas) may have the surface_flag parameter incorrectly set to 0. Additionally, the TanDEM-X DEM is also used to separate ocean and land surface waveforms at the footprint level for the L2B quality_flag, which may cause misclassification in some coastal areas.

A known ranging issue affect the absolute elevations of two of the eight beams (Beam0000 and Beam0001). Please see the L1B User guide for more information.

The unit for /BEAMXXXX/rh dataset in the L2A file is meters, but the attributes / data dictionary internal to the file specify it as centimeters. This will be corrected in a future release.

8 Dataset Access

The GEDI02_A and GEDI02_B products are available through the LP DAAC Data Pool and NASA Earthdata Search.

9 Contact Information

LP DAAC User Services
U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center

47914 252nd Street Sioux Falls, SD 57198-0001
Phone Number: 605-594-6116
Toll Free: 866-573-3222 (866-LPE-DAAC)
Email: lpdaac@usgs.gov
Web: https://lpdaac.usgs.gov

GEDI Science Team Contact: Ralph Dubayah (PI), Professor of Geographical Sciences at the University of Maryland: dubayah@umd.edu

10 Citations

Dubayah, R., Hofton, M., J. B. Blair, Armston, J., Tang, H., Luthcke, S. (2020). *GEDI L2A Elevation and Height Metrics Data Global Footprint Level V001* [Data set]. NASA EOSDIS Land Processes DAAC. Accessed YYYY-MM-DD from https://doi.org/10.5067/GEDI/GEDI02_A.001.

Dubayah, R., Tang, H., Armston, J., Luthcke, S., Hofton, M., J. B. Blair (2020). *GEDI L2B Canopy Cover and Vertical Profile Metrics Data Global Footprint Level V001* [Data set]. NASA EOSDIS Land Processes DAAC. Accessed YYYY-MM-DD from https://doi.org/10.5067/GEDI/GEDI02_B.001.

11 Publications, References and Resources

The following publications are the best starting point for users to obtain more detail on the GEDI mission and development of the Elevation and Height Metrics Data and Canopy Cover and Vertical Profile Metrics Data products:

Blair, J.B., Rabine, D. L., Hofton, M. A. (1999). The Laser Vegetation Imaging Sensor: a medium-altitude, digitisation-only, airborne laser altimeter for mapping vegetation and topography. *ISPRS J. Photogramm. Remote Sens.* **54**, 115–122.

Dubayah, R. O., Blair, J. B., Goetz, S. J., Fatoyinbo, L., Hansen, M. C., Healey, S. P., Hofton, M., Hurtt, G., Kellner, J. R., Luthcke, S., Armston, J., Tang, H., Duncanson, L., Hancock, S., Jantz, P., Marselis, S., Patterson, P., Qi, W., Silva, C. (2020). The Global Ecosystem Dynamics Investigation: High-resolution laser ranging of the Earth's forests and topography. Science of Remote Sensing (in press).

Hofton et al. (2020). ATBD for GEDI Transmit and Receive Waveform Processing for L1 and L2 Products.

Luthcke et al. (2020). ATBD for GEDI Waveform Geolocation for L1 and L2 Products

Tang and Armston (2020). GEDI ATBD for Footprint Canopy Cover and Vertical Profile Metrics.

11.1 Websites and Data Portals

The GEDI Mission maintains a website at: https://gedi.umd.edu/.

The GEDI_02A and 02B products are available through the LP DAAC Data Pool and NASA Earthdata Search.

11.2 Additional Resources

The GEDI L1B data dictionary can be found at: https://lpdaac.usgs.gov/documents/585/gedi_l1b_dictionary_P003_v1.html

The GEDI L2A data dictionary can be found at: https://lpdaac.usgs.gov/documents/585/gedi_l2a_dictionary_P001_v1.html

The GEDI L2B data dictionary can be found at: https://lpdaac.usgs.gov/documents/585/gedi_l2b_dictionary_P001_v1.html

NASA Goddard Space Flight Center video on “NASA’s Laser Mission to Measure Trees” at: https://www.youtube.com/watch?v=qpzFn5bqhl4

Webinar Recording Available: The Potential of GEDI Lidar for Biodiversity Conservation Applications by Scott Goetz and GEODE lab members Patrick Burns and Patrick Jantz: https://consbio.org/products/webinars/scgis-webinar-potential-gedi-lidar-biodiversity-conservation-applications