GLAS/ICESat L1 and L2 Global Altimetry Data (HDF5), Version 33, 34

USER GUIDE

FOR QUESTIONS ABOUT THESE DATA, CONTACT NSIDC@NSIDC.ORG

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/GLAH01 (GLAH05, GLAH06, GLAH12, GLAH13, GLAH14, and GLAH15)

National Snow and Ice Data Center

How to Cite These Data

As a condition of using these data, you must include a citation:

Zwally, H. J., R. Schutz, C. Bentley, J. Bufton, T. Herring, J. Minster, J. Spinhirne, and R. Thomas. 2013. *GLAS/ICESat L1A Global Altimetry Data (HDF5), Version 33*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ICESAT/GLAS/DATA101. [Date Accessed].

Zwally, H. J., R. Schutz, J. Dimarzio, and D. Hancock. 2014. *GLAS/ICESat L1B Global Waveform-based Range Corrections Data (HDF5), Version 34*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ICESAT/GLAS/DATA108. [Date Accessed].

Zwally, H. J., R. Schutz, J. Dimarzio, and D. Hancock. 2014. *GLAS/ICESat L1B Global Elevation Data (HDF5), Version 34*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ICESAT/GLAS/DATA109. [Date Accessed].

Zwally, H. J., R. Schutz, D. Hancock, and J. Dimarzio. 2014. *GLAS/ICESat L2 Global Antarctic and Greenland Ice Sheet Altimetry Data (HDF5), Version 34*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ICESAT/GLAS/DATA209. [Date Accessed].

Zwally, H. J., R. Schutz, D. Hancock, and J. Dimarzio. 2014. *GLAS/ICESat L2 Sea Ice Altimetry Data (HDF5), Version 34*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ICESAT/GLAS/DATA210. [Date Accessed].

Zwally, H. J., R. Schutz, D. Hancock, and J. Dimarzio. 2014. *GLAS/ICESat L2 Global Land Surface Altimetry Data (HDF5), Version 34*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ICESAT/GLAS/DATA211. [Date Accessed].

Zwally, H. J., R. Schutz, D. Hancock, and J. Dimarzio. 2014. *GLAS/ICESat L2 Ocean Altimetry Data (HDF5), Version 34*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ICESAT/GLAS/DATA212. [Date Accessed].

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1 DATA DESCRIPTION

NOTE: References in this documentation to GLAS binary product names GLA01 to GLA15 refer to original GLAS binary data, and are retained for informational and provenance purposes. Access to GLAS binary data was removed 01 August, 2017. All GLAS data are available in HDF5 format, products GLAH01 to GLAH15.

This document covers seven data sets as listed Table 1.

Table 1. GLAS Data Sets Described in this Document

Short Name	Long Name
GLAH01	GLAS/ICESat L1A Global Altimetry Data (HDF5), V33.2
GLAH05	GLAS/ICESat L1B Global Waveform-based Range Corrections Data (HDF5)
GLAH06	GLAS/ICESat L1B Global Elevation Data (HDF5)
GLAH12	GLAS/ICESat L2 Antarctic and Greenland Ice Sheet Altimetry Data (HDF5)
GLAH13	GLAS/ICESat L2 Sea Ice Altimetry Data (HDF5)
GLAH14	GLAS/ICEsat L2 Global Land Surface Altimetry Data (HDF5)
GLAH15	GLAS/ICESat L2 Ocean Altimetry Data (HDF5)

Note: GLAH01 Release 33 did not require Surface Elevation reprocessing, so was not reprocessed into Release 34, and remains as Release 33.2. The 33.2 minor version revises the format of the d_4nsBgMean parameter from counts to volts. GLAH01 contains all altimetry information transmitted from the spacecraft, including the long and short waveforms. The number of received samples is either 200 or 544. These change at the frame boundary and are nominally set by the onboard surface-type mask. In normal operations, GLAS receives 200 samples over sea ice and ocean, and 544 samples over ice sheet and land. The transmit pulse, received echo samples, and associated digitizer addresses are transferred from Level-0 telemetry without calibration or unit changes. This is the only product that contains the altimeter transmitted and received waveforms, which may be required by altimetric scientists investigating the instrument health. This product is not intended for use by the general science community.

GLAH05 is an intermediate product that contains important information calculated from the waveform. Level-1B waveform parameterization data include output parameters from the waveform characterization procedure and other parameters required to calculate surface slope and relief characteristics. The binary GLA05 was used for creating GLA06 and Level-2 elevation products. The higher products contain scientific parameters derived from algorithms that specifically used GLA05 as input. GLAH05 contains parameterizations of both the transmitted and received pulses and other characteristics from which elevation and footprint-scale roughness and slope are calculated. The received pulse characterization uses two implementations of the retracking algorithms: one tuned for ice sheets, called the standard parameterization, used to calculate surface elevation for ice sheets, oceans, and sea ice; and another for land (the alternative parameterization).

GLAH06 is a product that is analogous to the geodetic data records distributed for radar altimetry missions. It contains elevations previously corrected for tides, atmospheric delays, and surface characteristics within the footprint. Elevation is calculated using the ice sheet parameterization. Additional information allows the user to calculate an elevation based on land, sea ice, or ocean algorithms. Level-1B elevation data include surface elevation, surface roughness assuming no slope, surface slope assuming no roughness, and geodetic and atmospheric corrections for range measurements. Both Level-1B products are geolocated to the center of the laser footprint.

GLAH12 to GLAH15. GLAH06 is used in conjunction with GLAH05 to create the Level-2 altimetry products. Level-2 altimetry data provide surface elevations for ice sheets (GLAH12), sea ice (GLAH13), land (GLAH14), and oceans (GLAH15). Data also include the laser footprint geolocation and reflectance, as well as geodetic, instrument, and atmospheric corrections for range measurements. The Level-2 elevation products, are regional products archived at 14 orbits per granule, starting and stopping at the same demarcation (± 50° latitude) as GLAH05 and GLAH06.

1.1 Surface Type Mask

Each regional product is processed with algorithms specific to that surface type. Surface type masks define which data are written to each of the products. If any data within a given record fall within a specific mask, the entire record is written to the product. Masks can overlap: for example, non-land data in the sea ice region may be written to the sea ice and ocean products. This means that an algorithm may write the same data to more than one Level-2 product. In this case, different algorithms calculate the elevations in their respective products. The surface type masks are versioned and archived at NSIDC, so users can tell which data to expect in each product.

1.2 Parameters

Please see the following tables of data records for each product. Data records describe data product structure and parameters.

- GLAH01 Records (V33.2)
- GLAH05 Records
- GLAH06 Records
- GLAH12 Records
- GLAH13 Records
- GLAH14 Records
- GLAH15 Records

1.2.1 Parameter Description

See the GLAS HDF5 Altimetry Product Usage Guidance (PDF, 553 KB) for instructions on working with GLAS altimetry parameters. The Release 34 guidance remains the same as Release 33.

1.3 File Information

1.3.1 Format

GLAS HDF5 products are in Hierarchical Data Format 5 format, also known as netCDF-4/HDF5. The intent with the HDF5 format data is to make the Release 34 data available in the same format as several future NASA missions, including ICESat 2 and Soil Moisture Active Passive (SMAP), and to make ICESat 1 Release 34 data more accessible to a broader user community.

1.3.1.1 Header

The header description information found in the binary files is embedded in the HDF5 files.

1.3.1.2 Invalid values

Not all data from GLAS are suitable for science processing. Many parameters have invalid values or, in CF terms, "_FillValues". An invalid value means that the measurement is not valid for that element of data.

1.3.1.3 Surface-type mask

Surface-type mask data (available via HTTPS) are stored as an 10800 by 5400 byte array, where each byte represents the surface type for one 30 second grid cell on the earth. Each 10800-byte record represents a 360° latitude band. The first record starts at the North Pole, and the records follow at 30 second intervals to the South Pole.

Valid pixel values range from 1 to 15. The surface types are bit-coded, and any combination of surface type is allowed. The bit coding is:

1 = ice sheet
2 = sea ice (winter maximum extent)
4 = land
8 = ocean

Please see ICESat/GLAS Surface-Type Mask for a disclaimer and further details.

Each data granule has associated browse products that users can quickly view to determine the general quality of the data in the granule. Browse products consist of image plots of key parameters and statistics.

1.3.2 Naming Convention

The file naming convention is as follows:

```
GLAH05_634_2131_002_0084_4_01_0001.H5
```

```
GLAHxx_mmm_prkk_ccc_tttt_s_nn_ffff.h5
```

Where:

Table 2. File Naming Convention

Variable	**Description**
GLAH	Indicates GLAS HDF5 data product
xx	Product number (01, 05, 06, 12, 13, 14, or 15)
mmm	Release number for process that created the product = 634
p	Repeat ground-track phase (1 = 8-day, 2 = 91-day, 3 = transfer orbit)
r	Reference orbit number; this number starts at 1 and increments each time a new reference orbit ground track file is obtained.
kk	Instance number, incremented every time the satellite enters a different reference orbit.
ccc	Cycle of reference orbit for this phase; the cycle number restarts at 1 every time the instance number changes. The cycle number then increments within the instance (kk) every time Track 1 for that orbit is reached. Most instances begin in an arbitrary track (not 1) because of how the tracks are numbered.
tttt	Track within reference orbit; tracks are defined from a reference orbit. Each track begins and ends at the ascending equator crossing. Tracks are numbered such that Track 1 is the closest track to Greenwich Meridian from the east and then contiguous in time after that. For transfer orbits, for which we have no predefined reference orbit, Track 1 is the first track for which we have data for that instance (kk).
s	Segment of orbit
nn	Granule version number; the number of times this granule is created for a specific release
ffff	File type; numerical, assigned for multiple files as needed for data of same time period for a specific data product; a multifile granule
h5	HDF5 file

Algorithms that generate altimetry products are continually being improved, as limitations become apparent in early versions of data. As a new algorithm becomes available, a new release number (mmm) becomes available. Users are encouraged to work with the latest release. Release-34 is the newest and final release.

Note: Beginning with Release-28, a new convention is used for the release number (mmm) in file names.

Please see the following for more information:

- ICESat/GLAS YXX Release Numbers
- ICESAT/GLAS CSR SCF Release Notes for Orbit and Attitude Determination (PDF file)

Table 3 lists approximate file sizes for each product.

Table 3. Approximate File Size of Products

Product	File size
GLAH05	1 MB to 11 MB
GLAH06	0.7 MB to 6 MB
GLAH12	2 MB to 29 MB
GLAH13	1.5 MB to 39 MB
GLAH14	1.7 MB to 117 MB
GLAH15	1.5 MB to 118 MB

Total volume of the HDF5 Altimetry data products is approximately 517 GB.

1.4 Spatial Information

1.4.1 Coverage

GLAS/ICESat coverage is global between 86° N and 86° S with occasional off-nadir pointing to the poles or other targets of opportunity. GLAH01 (V33.2), GLAH05, and GLAH06 files span 1/4 orbit, split at ± 50° latitude. GLAH12-15 files span 14 orbits.

Spatial searching is disabled for GLAH01 (V33.2). The orbit for GLAH01 is a predicted orbit and does not show any target-of-opportunity pointing. Spatial searching for GLAH01 is not enabled in because of a potentially large number of false negatives. If you order GLAH05 to GLAH15 data granules (which support spatial searching) and you require matching GLAH01 granules, please note the data times and/or file names from the GLAH05 to GLAH15 granules; use these times to perform your search for GLAH01 granules.

1.4.2 Resolution

GLAS is a profiling instrument that collects data only where the altimeter points, nominally along the ground track. At 40 pulses per second, the centers of 60 m spots illuminated by the laser on the earth's surface are separated in the along-track direction by 172 m from a 600 km altitude orbit.

1.5 Temporal Information

1.5.1 Coverage

Please refer to the Data Release Schedule for the temporal coverage of specific products and descriptions of past releases.

See the Date Conversion and Track Conversion tools to see Pass ID information for a user-specified year, day, and time.

1.5.2 Resolution

Data are sampled at 40 times per second.

2 DATA ACQUISITION AND PROCESSING

2.1 Acquisition

The ICESat GLAS Release 34 HDF5 data are converted directly from the Release 34 binary data. Data files were not re-processed during conversion. However, parameters in the HDF5 files are re-ordered, re-named, and logically grouped to take advantage of the HDF5 file structure.

Please refer to the corresponding binary product documentation (e.g. GLA01) for details on Data Acquisition Methods, Theory Of Measurements, Derivation Techniques and Algorithms, and Processing Steps.

A complete description of the physical and mathematical algorithms used in the generation of the data products can be found among the ICESat/GLAS Technical References.

2.2 Quality, Errors, and Limitations

2.2.1 Quality Assessment

Browse products contain quality information. These browse products are available along with corresponding data granules.

Browse images that accompany each data file contain the statistics listed below. Quality control for land and ice sheet products begins with calculating the percent of measurements for which no signal was found. For those measurements in which a signal was found, the following are tabulated (Brenner et al. 2000):

- Percentage of measurements for which the fitting procedure is successful
- Percentage of measurements that may be degraded from detector saturation

Each data granule has a set of histograms displaying statistical information about waveform characteristics. These are only provided for signals with successful fits:

- Differences between the centroid of the received waveform and the centroid of the Gaussian fit to the last peak
- Number of peaks in each of the smoothed waveforms
- Standard deviation of the fit to the received waveform
- Skewness of each peak return (for single Gaussian fits only)
- Kurtosis of each peak return (for single Gaussian fits only)
- Percent of saturated signal compared to a real signal within the signal region. (See Saturation Correction Guidance)

For measurements in which a signal is found and successfully processed, the mean and standard deviation of the following quantities are calculated for each 100 km strip along the ground track.

- Number of peaks in the smoothed waveform
- Number of peaks in the Gaussian fit
- Standard deviation of the fit to the received waveform for each measurement
- Skewness of each pulse return
- Differences between the centroid of the received waveform and the centroid of the Gaussian fit to the last peak
- Maximum smoothed amplitude
- Reflectance
- Ice sheet roughness (assuming a flat surface)
- Surface slope (assuming a smooth surface)
- Surface elevation

2.2.1.1 Validation by Source

The GLAS Science Team has developed a set of procedures for verifying and calibrating Level-1 science products to ensure that appropriate geophysical interpretations can be drawn from the data products and to reduce the level of geophysical uncertainty in the data. A formal calibration-validation (CV) plan is pending. More information will be available in the near future.

2.2.2 Error Sources

2.2.2.1 GLAS Release 34 Correction of Release 33 Data Issues

1. Correction to the ICESat Data Product Surface Elevation due to an Error in the Range Determination from Transmit-Pulse Reference-Point Selection (Centroid vs Gaussian)
    - It was determined that an important correction to the surface elevations on the ICESat products was not applied. The range from which the surface elevation should have

been calculated is from the midpoint of the Gaussian peak on the transmit pulse to the midpoint of the Gaussian peak on the received pulse. However, the location of the centroid of the transmit pulse was inadvertently used and the difference (defined as G–C) between the transmitted pulse centroid and Gaussian peak was never applied. The effect of this error of omission varies on a shot-to-shot basis and for the calibration passes over the Salar de Uyuni in Bolivia varied from ± 6 cm over the mission. Similar results were found when tabulating the track-averaged corrections (G–C) over Antarctica. Note that the (G–C) values are fairly constant within a campaign, so any elevation data adjustments made to data release 633 or older for "campaign-level" biases that were determined to an independent reference surface would eliminate the G–C error from the elevation data on an average basis.

- The surface elevations on GLA06 (global elevation product), GLA12 (ice sheet), GLA13 (sea ice), and GLA15 (ocean) are affected. The GLA14 (land) elevations are computed using the centroid of the received pulse, as well as the centroid of the transmit pulse, and therefore the elevation calculation on GLA14 is correct as intended. However, GLA14 data users who use the range Increment for the up to six Gaussian fitted peaks may want to use the G–C correction also.

2. Dry Troposphere Correction Jitter
   - It was reported that at times the dry troposphere range correction contained several centimeters of jitter. The issue was traced to the threshold range being used to determine the dry troposphere correction in regions of rapidly changing shape of the return signal waveforms. This was normally in poor signal areas or very rough terrain. At times the threshold range relative to the standard fit would jump tens of meters and induce several centimeter changes in the dry troposphere correction. Changes were made to use the centroid range to determine the troposphere correction. The centroid closely follows the standard fit range.
   - During the investigation it was determined that the GSAS code was using only one of the 6–hour met files for the pressure inputs. Code was modified to properly interpolate between the two 6–hour met files.
3. The GLAS product high resolution DEM was determined to have issues in the Southern Latitude when the source was SRTM data. It was reported to have wrong values that showed as banding.
   - There was an interpolation error in the southern latitudes during the creation of the SRTM track files (ANC51). The code error caused the DEM values to be correct at the mid-point latitude between the interpolation points, with increasing errors on either side. This resulted in the banding error seen when comparing GLAS SRTM DEM values with the source SRTM DEM. The higher the DEM gradient the larger the error so they were significant over Australia. The code was fixed and track files were re–created.
4. The order of preference for which values are used when the SRTM and CDED overlap was changed. Starting with this release the SRTM is always used in the overlap region.
5. Some parameters on GLA14 were invalid when i_elev was valid.
   - It was determined that if any standard fit for a one second was invalid, checks were not made to determine if GLA14 had valid elevations during that second. Changes were made to provide the parameters based on a valid alternate fit if the standard fit was invalid for a shot.
6. GLA12, 13, 14 and 15 atmosphere character confidence flag was always zero.

- It was determined that the atmosphere confidence flag from GLA09 was not being placed on GLA12, 13, 14, and 15. Changes were made to correctly put the confidence flags on the products.

7. Occasional mismatch of GLA09 atmosphere characteristic flag value and the value reported on GLA06 and 14.
   - On occasion the atmosphere characteristic flag was zero on GLA06 and 14 when a non-zero value was on GLA09. It was determined that the time tolerance check for the one second GLA06 time to the GLA09 time tag did not allow for sufficient jitter between the time tags. This caused a GLA09 record not to be selected as the source for the values. Several other parameters were also found to be invalid.
8. Saturation Correction. See Saturation Correction Guidance.

For further detail, see the GSAS V6.1 Release Notes May 2014 document.

2.3 Instrumentation

2.3.1 Description

The Geoscience Laser Altimeter System (GLAS) instrument on the Ice, Cloud, and land Elevation Satellite (ICESat) provides global measurements of polar ice sheet elevation to discern changes in ice volume (mass balance) over time. Secondary objectives of GLAS are to measure sea ice roughness and thickness, cloud and atmospheric properties, land topography, vegetation canopy heights, ocean surface topography, and surface reflectivity.

GLAS has a 1064 nm laser channel for surface altimetry and dense cloud heights, and a 532 nm LIDAR channel for the vertical distribution of clouds and aerosols.

Please refer to the official ICESat/GLAS web site at NASA GSFC for details of the ICESat platform and GLAS instrument.

Also see ICESat Reference Orbit Ground Tracks for a summary of the orbits for each laser operational period.

3 SOFTWARE AND TOOLS

The following external links provide access to software for reading and viewing HDF5 data files. Please be sure to review instructions on installing and running the programs.

HDFView: Visual tool for browsing and editing HDF4 and HDF5 files.

HDF Explorer: Data visualization program that reads Hierarchical Data Format files (HDF, HDF-EOS and HDF5) and also netCDF data files.

Panoply netCDF, HDF and GRIB Data Viewer: Cross-platform application. Plots geo-gridded arrays from netCDF, HDF and GRIB datasets.

For additional tools, see the HDF-EOS Tools and Information Center.

For tools related to the original binary GLAS data, see the ICESat GLAS web page.

4 REFERENCES AND RELATED PUBLICATIONS

Please refer to the Published Research page.

4.1 Related Data Collections

Ice sheet altimetry data sources include:

Radar altimetry polar ice sheet data (Goddard Space Flight Center Ice Altimetry)

Shuttle Laser Altimetry data

4.2 Related Websites

NASA ICESat & ICESat-2

NASA Operation IceBridge

NSIDC DAAC IceBridge Data

NSIDC DAAC ICESat-2

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6 DOCUMENT INFORMATION

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