GLAS/ICESat L1 and L2 Global Atmospheric Data, Version 33

USER GUIDE

This user guide applies to following data sets:

GLAS/ICESat L1A Global Atmosphere Data (GLA02), Version 33

GLAS/ICESat L1B Global Backscatter Data (GLA07), Version 33

GLAS/ICESat L2 Global Planetary Boundary Layer and Elevated Aerosol Layer Heights (GLA08), Version 33

GLAS/ICESat L2 Global Cloud Heights for Multi-layer Clouds (GLA09), Version 33

GLAS/ICESat L2 Global Aerosol Vertical Structure Data (GLA10), Version 33

GLAS/ICESat L2 Global Thin Cloud/Aerosol Optical Depths Data (GLA11), Version 33

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/GLA02, https://nsidc.org/data/GLA07, https://nsidc.org/data/GLA08, https://nsidc.org/data/GLA09, https://nsidc.org/data/GLA10, https://nsidc.org/data/GLA11

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, W. Hart, D. Hlavka, S. P. Palm, J. Spinhirne, and E. Welton. 2011. *GLAS/ICESat L1A Global Atmosphere Data, 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/DATA122. [Date Accessed].

Zwally, H. J., R. Schutz, W. Hart, D. Hlavka, and S. P. Palm. 2011. *GLAS/ICESat L1B Global Backscatter Data, 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/DATA127. [Date Accessed].

Zwally, H. J., R. Schutz, W. Hart, D. Hlavka, and S. P. Palm. 2011. *GLAS/ICESat L2 Global Planetary Boundary Layer and Elevated Aerosol Layer Heights, 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/DATA221. [Date Accessed].

Zwally, H. J., R. Schutz, W. Hart, D. Hlavka, S. P. Palm, J. Spinhirne, and E. Welton. 2011. *GLAS/ICESat L2 Global Cloud Heights for Multi-layer Clouds, 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/DATA222. [Date Accessed].

Zwally, H. J., R. Schutz, W. Hart, D. Hlavka, S. P. Palm, J. Spinhirne, and E. Welton. 2011. *GLAS/ICESat L2 Global Aerosol Vertical Structure Data, 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/DATA223. [Date Accessed].

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1 DETAILED DATA DESCRIPTION

1.1 Data Sets

1.1.1 GLA02

GLA02 Level-1A atmospheric data include the normalized relative backscatter for the 532 nm and 1064 nm channels, and low-level instrument corrections such as laser energy normalization for both channels, background subtraction, range square correction, dead time correction for 532 nm, photon coincidence for 532 nm, and detector gain correction for 1064 nm.

1.1.2 GLA07

GLA07 Level-1B global backscatter data are provided at full instrument resolution. The product includes full 532 nm (41.1 to -1.0 km) and 1064 nm (20 to -1 km) calibrated attenuated backscatter profiles at 5 times per second, and from 10 to -1 km, at 40 times per second for both channels. Also included are calibration coefficient values and molecular backscatter profiles at once per second. Data granules contain approximately 190 minutes (2 orbits) of data. The 532 nm data are calibrated using the molecular return from about 30 km altitude. The 1064 nm channel is not sensitive enough to measure a molecular return, and is calibrated using the instrument parameters and airborne validation measurements. The molecular backscatter cross section is computed from either standard atmospheric data (temperature and pressure as a function of height) or, when available, the NCEP gridded analysis fields of temperature and pressure interpolated to the spacecraft position and time.

1.1.3 GLA08

GLA08 contains Level-2 planetary boundary layer (PBL) and elevated aerosol layer heights data with PBL heights, ground detection heights, and top and bottom heights of elevated aerosols from -1.5 km to 20.5 km (4 second sampling rate) for up to five layers, and from 20.5 km to 41 km (20 second sampling rate) up to three layers.

1.1.4 GLA09

GLA09 contains Level-2 cloud heights for multi-layer clouds with cloud layer top and bottom height data at sampling rates of 4 seconds, 1 second, 5 Hz, and 40 Hz.

1.1.5 GLA10

GLA10 contains aerosol vertical structure data with the attenuation-corrected cloud and aerosol backscatter and extinction profiles at a 4 second sampling rate for aerosols and a 1 second rate for clouds.

1.1.6 GLA11

GLA11 contains Level-2 thin cloud/aerosol optical depths data with thin cloud and aerosol optical depths. A thin cloud is one that does not completely attenuate the LIDAR signal return, which generally corresponds to clouds with optical depths less than about 2.0.

Data are in scaled integer binary format with big-endian (Unix) byte order. Each data granule has an associated browse product 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.

1.2 Format

1.2.1 Header

GLAS products are direct-access files with all records the same length. The first records at the beginning of each file contain metadata in ASCII format. The record length varies from product to product. The first two entries in the headers are the record length of all records in that file and the number of records that contain header information. This allows product readers to verify the record length and jump directly to the first data record, if necessary. Following is a sample header from a GLA12 granule:

```
RECL= 5080;
NUMHEAD= 1;
RangeBeginningTime= 0.0000000;
RangeEndingTime=189388800.0000000;
NLAT= 72.6083000;
SLAT= 30.0795000;
ELON= -32.6764000;
WLON= -99.0629000;
```

Refer to Header Descriptions for definitions of header keywords.

1.2.2 Data Records

The data records contain elements in scaled integer binary format with the following criteria:

- Record size is a multiple of eight.
- 4-byte elements are aligned on 4-byte boundaries.
- Arrays start on 4-byte boundaries.
- Byte order is big-endian (Unix).

The following figure from Jester and Lee (2002) summarizes the data structure for different byte sizes.

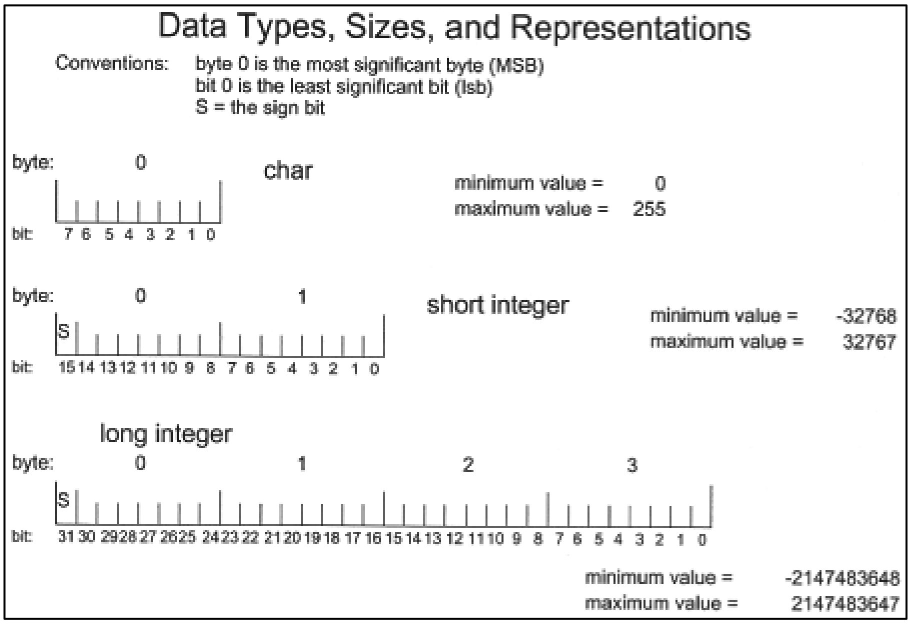

Figure 1. L1, L2 Global Atmospheric Data Structure for Different Byte Sizes

All GLAS atmospheric data are stored as 4-byte integers. Apply the appropriate scaling factor listed in the GLAS Atmosphere Data Dictionary next to each parameter name.

1.2.3 Invalid Values

Not all data from GLAS are suitable for science processing, and some data may be missing. Invalid values indicate that data are either invalid or missing and should not be used for processing. Values vary by data type, and they are set to extraordinarily large numbers to indicate invalid data (Jester and Lee (2002). They are described in Table 1:

Table 1. Invalid Values by Data Type

Data Type	Invalid Value
i1b	gi_invalid_i2b (same as “127”)
i2b	gi_invalid_i2b (same as “32767”)
i4b	gi_invalid_i4b (same as “2147483647”)

Data Type	Invalid Value
r4b	3.40282E+38 x7F7FFFFF
r8b	1.797693094862316E+308 x7FEFFFFFFFFFFFF

An invalid value of “n/a”, “N/A”, or “NA” means “not applicable.” A value of “no” means there is no invalid value associated with that parameter. A value of “null” means the actual invalid value is null. This occurs in GLA01 and GLA02 parameters copied directly from Level-0 raw data, which contain unsigned integers that cannot use invalid values. Instead, flags are set if the value is invalid.

Other invalid flag names are as follows:

- i20_aer_af (GLA08)
- i4_aer_af (GLA08)
- i_FRC_af (GLA09)
- i_HRC_af (GLA09)
- i_LRC_af (GLA09)
- i_MRC_af (GLA09)

1.3 File Naming Convention

The file naming convention is as follows:

Glaxx_mmm_prkk_ccc_tttt_s_nn_ffff.dat

Refer to Table 2 for the file naming convention variables and descriptions:

Table 2. File Naming Convention

Variable	Description
xx	Product number (02, 07, 08, 09, 10, 11)
mmm	Release number for process that created the product
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.

Variable	Description
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

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 (mmm) becomes available. Users are encouraged to work with the latest 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)

1.3.1 File Naming Convention for Special-Request Data

Please see the Description of Special Request ICESat/GLAS Files for information about binary file naming for special request data from the ICESat/GLAS Data Subsetter.

1.4 File Size

Table 3 lists approximate file sizes for each product.

Table 3. Approximate Product File Size

Product	File Size
GLA02	671 MB
GLA07	827 MB

Product	File Size
GLA08	7 MB
GLA09	82 MB
GLA10	289 MB
GLA11	13 MB

1.5 Spatial 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. GLA02 and GLA07 files span two orbits. GLA08–GLA11 files span 14 orbits (1 day).

NOTE: Access to GLAS binary data was removed 01 August 2017. All GLAS data are available in HDF5 format.

1.5.1 Spatial Resolution

The atmospheric channel of GLAS measures the vertical structure of backscatter intensity (with a laser footprint of 60 m), from -1.5 km to a height of about 41 km, with 76.8 m vertical resolution. Horizontal resolution of the raw data is a function of height. Between 10.5 km and 20.5 km, eight laser shots are summed, producing a horizontal resolution of 1.4 km (5 Hz sampling rate). Between 20.5 km and 41 km, 40 shots are summed, providing a horizontal resolution of about 7.5 km (1 Hz sampling rate).

1.6 Temporal Coverage

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

Also see the visit the Date Conversion Tool to see the Pass ID for a user-specified year, day, and time.

1.6.1 Temporal Resolution

Atmospheric data are sampled 40 times per second, but not all products record data at this rate. Sampling rates include 4 seconds, 1 second, 5 Hz, or 40 Hz, depending on the product.

1.7 Parameter or Variable

See the GLAS Atmosphere Data Dictionary for formatting details of individual parameters.

1.7.1 Parameter Description

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

- GLA02 Records
- GLA07 Records
- GLA08 Records
- GLA09 Records
- GLA10 Records
- GLA11 Records

1.7.2 Flags common across all data sets

Data files contain flags that indicate the quality of input data, output data, and data corrections. If quality is reasonable, the data use and frame quality flags are set to zero. A non-zero data use or frame quality flag indicates an abnormal situation during processing; the user should review the corresponding specific flag for that product for further interpretation. The following flags are common across most ICESat/GLAS data sets.

- I_APID_AvFlg indicates which Level-0 packets (APIDs) for each second are available, missing, or filled. This flag is separated into Altimeter Digitizer, Photon Counter, Cloud Digitizer, GPS/DEM, and C&T sections.
- I_OrbFlg indicates quality of orbit, whether predicted or precision, loss of GPS data, maneuver-degraded, etc.
- I_AttFlg1 denotes at 1 Hz rate whether the attitude angle is large, and whether it is the result of a programmed ocean sweep, target of opportunity, or steering to a reference track.
- I_timecorflg indicates the correction status of the time-tag.

See the GLAS Atmosphere Data Dictionary for further descriptions and to view byte structures.

See the GLAS Atmospheric Products User Guide (pdf, 74 KB) for details on working with the GLAS atmospheric parameters.

2 SOFTWARE AND TOOLS

NOTE: Access to GLAS binary data and tools was removed 01 August 2017. All GLAS data are available in HDF5 format.

3 QUALITY ASSESSMENT

Browse products in PNG graphic format contain information about data quality.

Note: By accessing NASA ICESat data, the data user acknowledges their understanding that the data have certain limitations in accuracy and definition, which have primarily resulted from problems with the GLAS instrument. Continuing improvements in the calibrations and product definitions are in progress and will be reflected in future data releases. The user should review the statements on product calibrations and accuracies in ICESat/GLAS Data Releases, and consider the calibration issues in any scientific interpretation or other use of the data. Users are requested to report their findings about data quality to NSIDC User Services, to be forwarded to ICESat/GLAS Science Team, for information and comment before publication or reporting elsewhere.

See ICESat Science Investigator-led Processing System (I-SIPS) Release Information for additional details.

3.1 Normalized LIDAR Signal

The most practical way to measure data quality is to integrate the entire LIDAR signal from 20 km to the end of the profile and compute the mean signal and standard deviation. Both should fall within known limits if the data are good. A histogram of the LIDAR return is also constructed. The degree to which the histogram deviates from a Poisson distribution indicates how much of the signal is contained in the return. The "i_g_TxNrg_qf" quality flag is set for each 40 Hz shot to characterize the laser energy:

1 = full laser energy (within 90% of expected maximum value)
2 = marginal laser energy (between 70-90% of expected maximum value)
3 = deficient laser energy (less than 70% of expected maximum value)

Bore sight accuracy is assessed by integrating the 532 nm return signal from 20 km to 41 km. The expected number of integrated photons (Is) in this region is about 800. A quality flag is set, depending on the magnitude of the integrated return:

1 = excellent signal strength (Is > 800)
2 = good signal strength (600 < Is < 800)
3 = marginal signal strength (400 < Is < 600)
4 = poor signal strength (200 < Is < 400)
5 = bad data (Is < 200)

3.2 Attenuated Backscatter

Confidence flags include a measure of the variability of the calibration constant (for both channels) as a function of time, and the quality of the attenuated backscatter profile. The laser energy flag and the integrated return flag should be evaluated to eliminate bad shots. Quality of the calibration constant is assessed by evaluating its variability with time and the difference between the constants calculated at two different heights. The 532 nm attenuated backscatter cross-section profiles are checked by normalizing them by the attenuated molecular profile. This should produce a profile that ranges between 0.9 and about 10.0. This test could only be applied to data with a ground return, as the values below thick clouds will approach zero. Another test is to integrate the attenuated backscatter from 20 km to 40 km and divide by the integrated attenuated molecular backscatter to form a ratio very close to unity. A major deviation from "1" would indicate a problem (Palm et al. 2002).

3.3 Cloud Layer Height and Earth Surface Height

Quality of this product is judged by how successful it is at finding all detectable cloud layers and locating their boundaries in the atmospheric profile. The best approach is to plot the computed cloud boundaries on top of image segments constructed from LIDAR profiles. These should reveal systematic and random faults in the results of the procedure. If shortcomings exist, parameters used in the computation of thresholds will be adjusted to fix the discrepancies.

The following confidence tests are used for the layer boundary results of each profile:

- For each layer detected, a flag to indicate high, medium, or low confidence
- For the top and bottom of each layer, a single number indicating a number of sample bins within which the boundary exists at a specified probability
- For each profile, a single number representing the probability that an undetected layer exists
- For a positive ground signal, a flag to indicate a high, medium, or low confidence
- For a positive ground signal, the number of sample bins within which the actual ground height exists at a specified probability
- For negative ground signal detection, a probability that a detectable ground signal actually exists but the algorithm fails to calculate a ground signal

3.4 PBL and Elevated Aerosol Layer Height

Confidence of height determination is measured by the difference between the average signal levels outside and inside of the PBL. Confidence is also measured by the standard deviation of the heights for a given segment.

3.5 Optical depth

- Layers will be screened so they do not overlap or become embedded.
- Visual screening with imagery will occur to ensure layers are labeled "cloud" or "aerosol" or "polar stratospheric cloud" correctly.
- As transmission profiles are processed, transmission calculations will be tested for out-of-bounds situations such as increasing transmission with range or large negative transmission.
- Confidence flags will be produced for each particulate layer or profile to determine the number and type of suspect input parameters, and whether the transmission profiles passed their tests. This information will be passed to each of the output parameter confidence flags.

3.6 Validation by Source

A formal calibration-validation (CV) plan is pending. More information will be available in the near future.

4 DATA ACQUISITION AND PROCESSING

4.1 Theory of Measurements

A complete description of the physical and mathematical algorithms used in the generation of the data products can be found in the Algorithm Theoretical Basis Documents (ATBD).

A standard LIDAR equation represents the atmospheric return signal as a function of the backscattered cross section, range to satellite, transmission from the top of the atmosphere to a given altitude, transmitted laser pulse energy, and calibration constant:

$$p(z) = \frac{CE\beta(z)T^2(z)}{r^2} + p_b + p_d, \text{ where:}$$

β(*z*) = total atmospheric backscatter cross section at altitude *z*

T(*z*) = transmission from the top of the atmosphere to altitude *z*

r = range from the spacecraft to altitude *z*

E = transmitted laser pulse energy

C = calibration constant

p_b = range-independent background term from scattered solar radiation

p_d = range-independent background term for any detector dark signal

Elevated aerosol layers are difficult to detect because their location is not known within the atmospheric profile. They can occur anywhere above the PBL and thus require searching the entire profile. Elevated aerosol layers are important because of their effect on the radiation balance and their contamination effect on many passive microwave remote sensing measurements.

The GLAS LIDAR data can be used to measure the optical depth of clouds. Clouds are composed of particles whose shapes and sizes are not readily discernible by remote sensing; therefore, two assumptions are required to obtain cloud optical depth from LIDAR. First, the effect of multiple scattering can be reliably quantified. Multiple scattering is a deviation from the true optical depth caused by the increase in detected signal strength due to the portion of the detected signal which has experienced more than one scattering interaction. It is primarily the result of photons that are slightly deflected during scattering. This "forward scattering" decreases the perceived optical depth. The other assumption is that the value of extinction for backscatter ratio is known. This value represents the total scattered energy divided by the amount of backscattered energy (Palm, Hart, and Hlavka 2002).

4.2 Data Acquisition Methods

GLAS uses LIDAR to sense the backscatter (intensity and polarization) from clouds and aerosols in the atmosphere. The LIDAR system transmits a narrow laser beam (10-3 to 10-4 steradians, sr) at a short pulse length (10-8 seconds) toward the Earth's surface. As the laser pulse travels from the instrument, its photons interact with and are scattered by the molecular and aerosol particles in the atmosphere. A portion of the scattered light is directed back (backscattered) toward the satellite. The telescope, 1 m in diameter, collects the backscattered light, which is focused onto the detectors. The output of the detectors is sampled, or digitized, at a 1.953 MHz rate, yielding a digital measure of the backscatter intensity every 76.8 m. This sampling begins at a pre-calculated time corresponding to a height of about 41 km above mean sea level. The result is a profile of the backscatter intensity beginning at 41 km and ending at about 1 km below the geoid. Each backscatter profile contains 548 samples. The backscatter profiles are then used to derive the location and properties of clouds and aerosols.

4.2.1 Data Source

Please refer to the Ancillary Data Products list in Section 6 of the ICESat/GLAS Long Term Archive for details of ancillary files used to create GLAS standard products.

4.3 Derivation Techniques and Algorithms

4.3.1 Normalized LIDAR Signal (GLA02)

The algorithm applies range and laser energy normalizations, computes and subtracts the ambient background signal, and performs dead time correction to the photon-counting channel (532 nm) and gain correction to the 1064 nm channel. Dead time correction is calculated using a look-up table that contains a dead time corrected value for each possible output from the 532 nm channel (with a sum of eight individual photon counting detectors). The raw, non-corrected signal from the 532 nm channel ranges from 0 to 100 photons per bin. In the case of the 1064 nm channel, the digital counts that are output from the analog-to-digital converter must first be converted back to a voltage using an equation that relates digital counts to the voltage. This is converted to watts by multiplying by the detector responsivity (W/V), determined from laboratory testing.

The ground search begins at the end of the 1 Hz profile and works upward for a maximum of 25 bins. The algorithm searches the signal until one bin exceeds a preset threshold value of 25 photons per bin, which is much larger than the threshold for cloud detection. Once the algorithm detects ground, the maximum of that bin and the following three bins are stored as the "ground-return peak signal."

The algorithm flags the 532 nm data that are saturated by strong signals from dense clouds. This is done by creating a saturation profile that has a one-to-one correspondence with the 532 nm channel return signal bins. Each bin of the 532 nm channel is checked against a maximum value above which the signal is considered saturated. This value is approximately 80 counts per bin (assuming all 8 photon counting detectors are operational). The test is performed on the raw data, not on the normalized signal. The saturation profiles are written to the GLA02 product (Palm, Hart, and Hlavka 2002).

4.3.2 Calibrated Attenuated Backscatter (GLA07)

Prior to running the GLA07 algorithm, the calibration utility computes the LIDAR calibration constant for both channels. The utility reads in GLA02 and computes averages of the data in two calibration "zones," or regions of the atmosphere devoid of cloud or aerosol. The calibration zones are roughly at 30 km and 10 km altitude, and are between 2 km and 4 km thick. The upper calibration zone is used for the 532 nm channel, and the lower zone is used for the 1064 nm channel. The GLA02 data are averaged along the ground track for about 1000 km in a continuous fashion throughout the 1/4-orbit granule. The algorithm also calculates and averages the molecular backscatter within the calibration zones. The ratio of the average molecular backscatter to the average normalized relative backscatter (GLA02) gives the calibration constant. The calibration utility produces about 10 to 12 calibration constants per orbit, which are written to a file.

The GLA07 algorithm reads the calibration file and uses a polynomial or piecewise linear fit to obtain a calibration constant for each second. The calibration constant is then used to compute the calibrated attenuated backscatter. See (Palm, Hart, and Hlavka 2002) for details.

GLA07 outputs a profile (41 km to -1 km, below the geoid) of calibrated attenuated backscatter for the 532 nm channel at 5 Hz and a profile (10 km to -1 km, below the geoid) at 40 Hz. The calibrated attenuated backscatter profiles for the 1064 nm channel are output at 5 Hz (20 km to -1 km, below the geoid) and 40 Hz (10 km to -1 km, below the geoid). GLA07 also performs vertical alignment of the data so that each bin is referenced to height above mean sea level (Palm, Hart, and Hlavka 2002).

4.3.3 Planetary Boundary Layer (PBL) and Aerosol Layer Heights (GLA08)

The GLA08 product provides the top and bottom height of elevated atmospheric aerosol layers throughout the depth of the troposphere and extending into the middle stratosphere to 41 km. It simultaneously provides the height of the PBL. A maximum of three aerosol layers above 20 km are resolved with a horizontal resolution of 150 km (20 seconds) and a vertical resolution of 100 m. Below 20 km altitude, a maximum of five aerosol layers are reported with horizontal and vertical resolutions of 30 km (4 seconds) and 100 m, respectively. The PBL height is resolved at two horizontal resolutions of 30 km and 1.5 km (5 Hz) with a vertical resolution of 100 m. These products are generated only at nadir along the spacecraft ground track. GLA08 also contains a polar stratospheric cloud flag that attempts to identify whether a given aerosol layer has a high probability of being such a cloud, based on layer altitude, temperature, and geographic location (Palm, Hart, and Hlavka 2002).

4.3.4 Cloud Layer Height (GLA09)

The backscattered LIDAR signal increases above background levels when clouds or aerosols are encountered. GLA09 employs an algorithm to find all such occurrences within the profile. The 1064 nm and 532 nm channel data are used to search for layers. The 532 nm channel is more sensitive at searching for layers. Using the 1064 nm channel does not increase the number of layers found; however, it provides a degree of redundancy in case the 532 nm channel fails.

A general method initially locates layer boundaries using a return threshold; then each layer is tested to see if it is cloud or aerosol. The algorithm tests 4 seconds, 1 Hz, 5 Hz, and 40 Hz data. The 4 second data are first searched for the presence of layers, and if detected, the layers are characterized as either cloud or aerosol. If the layer is an aerosol, no further searches are performed at higher resolutions, and the layers are passed to the GLA08 algorithm. If the layer is a cloud, then the higher-resolution searches are performed. Discrimination criteria for aerosol and cloud layers are summarized in Table 5 (Palm, Hart, and Hlavka 2002).

Table 4. Discrimination Criteria for Aerosol and Cloud Layers

Criteria	Aerosol	Cloud
Signal Magnitude (top)	2.1×10^{-6} m^{-1} sr^{-1}	3.0×10^{-6} m^{-1} sr^{-1}
Signal Gradient (top)	-7.5×10^{-7} m^{-1} sr^{-1} km^{-1}	-1.5×10^{-6} m^{-1} sr^{-1} km^{-1}
Altitude (top)	~ 5 km	~ 11 km
Horizontal Extent	N/A	N/A
Horizontal Homogeneity	0.25 - 0.35	0.2 - 1.0
Vertical Extent	~4 km	~6 km
Vertical Homogeneity	0.12 - 0.30	0.4 - 0.8
Relative Humidity	~35%	>75%
Attenuation	0.3	0.6

4.3.5 Attenuated Corrected Backscatter and Aerosol Vertical Structure (GLA10)

The GLA10 products include aerosol and cloud backscatter profiles corrected for attenuation, and aerosol and cloud extinction profiles. These products take into account a multiple scattering factor that corrects for forward-scattering effects of particulates. The cloud and aerosol backscatter and extinction profiles have a horizontal resolution of 7.5 km (1 second) and 30 km (4 seconds), respectively. The vertical resolution is 76.8 m. These products are complete profiles, but they are computed only within the cloud and aerosol layers identified by the GLA08 and GLA09 algorithms. The aerosol profiles encompass the vertical range of 0 km to 41 km altitude, and the cloud profiles extend from 0 km to 21 km. The algorithm also computes extinction-to-backscatter ratios used in the computations and a flag indicating whether the ratios were retrieved from a lookup table or were computed from the data.

The algorithm calculates particulate extinction cross-section profiles and particulate layer optical depths of clouds, aerosols, and polar stratospheric clouds. These are apparent, or effective, values without multiple scattering effects factored out. First, the algorithm defines the boundary condition at the top of any cloud or aerosol layer (determined from GLA08 or GLA09) and calculates the two-way particulate transmission within that layer.

Processing continues throughout each layer until the transmission reaches a predefined threshold or the algorithm detects the signal from the earth's surface. In order to obtain the relative density for aerosol and cloud scattering, the LIDAR return signal must be solved for the actual particulate backscatter cross section without attenuation. Once these have been determined, the algorithm calculates the aerosol extinction cross-section profiles. An aerosol extinction-to-backscatter ratio obtains the extinction profile for visible wavelengths. Given a 180 degree phase function value, the algorithm calculates the vertical profile of the visible extinction cross-section of a cirrus cloud from the top to the upper limit of effectiveness of an attenuation correction (Palm, Hart, and Hlavka 2002).

4.3.6 Cloud and Aerosol Optical Depths (GLA11)

The GLA11 product provides the optical depth at 532 nm for all aerosol layers detected by GLA08 including the PBL and polar stratospheric clouds. It also calculates the optical depth of cloud layers that do not completely attenuate the LIDAR signal return, which generally corresponds to clouds with optical depths less than about 2.0. The optical depths are corrected for multiple scattering, and the output includes a multiple scattering warning flag used by the altimetry processing to identify returns with significant pulse stretching.

The particulate effective optical depth is directly related to the particulate effective transmission calculated in GLA10. The particulate layer optical depth is based on the same transmission solution calculated in GLA10, but it uses the relationship of the extinction cross-section profile in the layer to optical depth. The final products from these calculations are the optical depths for each of the particulate layers that meet predefined criteria. The particulate transmission vertical profile is calculated only inside cloud and aerosol layers. Optical parameters used in transmittance calculations are obtained either empirically or from prior studies of aerosol layers (Palm, Hart, and Hlavka 2002).

4.3.7 Processing Steps

Please refer to the following for more information about changes and known errors with each data release:

- ICESat/GLAS Data Releases
- NASA Wallops Flight Facility's Release Notes

4.4 Error Sources

GLAS atmospheric data are prone to the following errors described below.

4.4.1 Normalized LIDAR Signal

- Limited knowledge of the laser energy and performance
- Inaccurate dead time (photon coincidence) correction factors for the 532 nm channel, and digital-to-analog conversion factors for the 1064 nm channel

- Bore site inaccuracy
- How well the etalon filter is tuned to the laser frequency (532 nm channel)

4.4.2 Attenuated Backscatter

- Presence of aerosol or clouds in the portion of the atmosphere used to calculate the calibration constant
- Error involved with computing the molecular backscatter cross section at the calibration height (errors in knowledge of atmospheric temperature and pressure)

4.4.3 Cloud Layer Height and Earth Surface Height

- Multiple scattering may cause the cloud bottom to appear somewhat lower than it actually is.
- Low signal-to-noise ratio may cause false positives.

4.4.4 PBL and Elevated Aerosol Layer Height

- Low signal-to-noise ratio may cause false positives
- Accuracy of satellite altitude and time of laser fire in the absence of a detectable ground return
- Sampling frequency (bandwidth, which determines the vertical resolution of the data)
- Number of LIDAR shots averaged together (horizontal resolution)
- Optical depth of the PBL

4.4.5 Optical depth

- Error in optical depth increases with layers of decreasing geometrical depth

Note that Level-0 data from 19 November to 14 December 2003 have a time stamp error, where dates are reset to 01 January 2000. This passes through to all higher-level products.

4.5 Sensor or Instrument 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.

5 REFERENCES AND RELATED PUBLICATIONS

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5.1 Related Data Collections

- GLAS/ICESat L1A Global Engineering Data
- GLAS/ICESat L1A Global Laser Pointing Data
- GLAS/ICESat at NSIDC
- ICESat-2 at NSIDC

6 CONTACTS AND ACKNOWLEDGMENTS

H. Jay Zwally

ICESat/GLAS Project Scientist

NASA/Goddard Space Flight Center

Greenbelt, MD, USA

Bob E. Schutz

ICESat/GLAS Science Team Lead

University of Texas at Austin

Center for Space Research

Austin, TX, USA

Steve Palm
Science Systems and Applications, Inc.
Lanham, MD, USA

William Hart
Science Systems and Applications, Inc.
Lanham, MD, USA

Dennis Hlavka
Science Systems and Applications, Inc.
Lanham, MD, USA

James D. Spinhirne
NASA/Goddard Space Flight Center
Greenbelt, MD, USA

Ellsworth Welton
NASA/Goddard Space Flight Center
Greenbelt, MD, USA

7 DOCUMENT INFORMATION

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