ICE, CLOUD, and Land Elevation Satellite (ICESat) Project

GLAS_HDF Standard Data Product Specification

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1.0 INTRODUCTION

ICESat (Ice, Cloud, and land Elevation Satellite) was the benchmark Earth Observing System mission for measuring ice sheet mass balance, cloud and aerosol heights, as well as land topography and vegetation characteristics. From 2003 to 2009, the ICESat mission provided multi-year elevation data needed to determine ice sheet mass balance as well as cloud property information, especially for stratospheric clouds common over polar areas. It also provided topography and vegetation data around the globe, in addition to the polar-specific coverage over the Greenland and Antarctic ice sheets.

The GEOSCIENCE LASER ALTIMETER SYSTEM (GLAS) was the primary instrument aboard ICESat. GLAS was a laser altimeter that determined the distance from the satellite to the Earth's surface and to intervening clouds and aerosols by precisely measuring the time it takes for a short pulse of laser light to travel to the reflecting object and return to the satellite.

1.1 Identification of Document

This document is identified as the Standard Data Product Specification that describes the GLAS Level 1-2 products converted into HDF5 format (GLAS_HDF).

1.2 Scope

This document describes the GLAS_HDF Standard Data Products. Original GLAS products (GLAS_BIN) were created in an integer-binary format. The products described herein have been converted to HDF5 in order to make the products more interoperable with future ICESat-2 products and to provide a testbed for designing and creating products in standards-compliant format.

1.3 Purpose and Objectives

The purpose of this document is to provide a high-level descriptive document for the HDF data products. This document describes the purpose, content, and format of the GLAS_HDF Data Products. It describes the structure, physical storage, and organization of the GLAS_HDF Data Products. The document additionally describes file transfer methods to support product access; the data flow associated with the data products; and the data storage and generation characteristics of the data products.

1.4 Acknowledgements

The following individuals/organizations contributed to this effort:

- ICESat GLAS and ICESat-2 ATLAS Science Software Development Teams

    SGT/Jeffrey Lee, SGT/John DiMarzio, SGT/Peggy Jester, SGT/Suneel Bhardwaj, SSAI/Kristine Barbieri, SGT/LeeAnne Roberts, Sigma/David W Hancock, SGT/Thomas Feroli, Sigma/Vijay Suchdeo, SGT/Andrew Griffin

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  Standards Process Group
  Technical Infusion Working Group
- NSIDC (ICESat Data Center)
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- SMAP Product Development Team
  JPL/Barry Weiss

1.5 Document Status and Schedule

No further updates to this document are planned.

1.6 Document Change History

Revision	Date	Nature of Change
-	November 1, 2012	Original Version

2.0 RELATED DOCUMENTATION

2.1 Parent Documents

This document is subordinate to any top-level mission or instrument management plan documents, and as such, recognizes these documents as external parent documents in lineage. The recognized external EOSDIS and GLAS parent documents superior to this document are listed below.

NASA Earth Observing System Geoscience Laser Altimeter System GLAS Science Requirements Document, Version 2.01, October 1997, Center for Space Research, University of Texas at Austin.

GLAS Science Software Management Plan, NASA/TM-1999-208641/Version 3/ Volume 1, August 1998, NASA/GSFC Wallops Flight Facility.

2.2 Applicable Documents

The following documents are related to, or contain policies or references pertinent to the contents of this document.

GLAS Standard Data Products Specification - Level 1, Version 9.0, August 2012, NASA Goddard Space Flight Center.

GLAS Standard Data Products Specification - Level 2, Version 9.0, August 2012, NASA Goddard Space Flight Center.

GLAS Standard Data Products Specification - Data Dictionary, Version1.0, August 2012, NASA Goddard Space Flight Center.

GLAS_HDF Detailed Design, Revision -, November 1, 2012, NASA Goddard Space Flight Center

2.3 References

Table 2-1 contains a list of references found useful and/or authoritative.

Table 2-1 : References

Reference	Description
http://hdfgroup.org	HDF5 Documentation and examples.
http://glas.wff.nasa.gov/prod_format/v60_products	GLAS products data dictionary.
http://earthdata.nasa.gov/data/references/data-metadata-formats	NASA Data and Metadata format information.
http://science.nasa.gov/earth-science/earth-science-data/satellite-mission-data-system-requirements/	Satellite mission data requirements.
http://earthdata.nasa.gov/our-community/esdswg/standards-process-spg/rfc	List of EOSDIS-approved standards.

Reference	Description
http://earthdata.nasa.gov/our-community/esdswg/standards-process-spg/rfc/esds-rfc-007	EOSDIS HDF5 RFC
http://earthdata.nasa.gov/our-community/esdswg/standards-process-spg/rfc/esds-rfc-009-file-format-satellite-atmospheric-chemistry-data	EOSDIS Aura File Format Technical Note
http://earthdata.nasa.gov/our-community/esdswg/standards-process-spg/rfc/esds-rfc-021	EOSDIS CF Metadata Conventions RFC
http://earthdata.nasa.gov/our-community/esdswg/standards-process-spg/rfc/esds-rfc-022	EOSDIS NetCDF/HDF5 RFC
http://cf-pcmdi.llnl.gov/	CF Metadata
http://www.nodc.noaa.gov/data/formats/netcdf/	NOAA NODC NetCDF Templates

3.0 PURPOSE AND DESCRIPTION OF THE DATA PRODUCTS

3.1 Purpose of the GLAS_HDF Data Products

The primary purpose of the GLAS_HDF effort is to provide GLAS data products reformatted in a manner that promotes interoperability between GLAS data products, products from other earth science missions, and future ICESat-2 data products. These products have the purpose of enabling:

- The GLAS dataset to be available in the same standard format (HDF5) that is expected for ICESat-2. This improves cross-mission interoperability.
- The ICESat science team and user community to become familiar with HDF5 products.
- The development team to receive feedback from the community regarding the success of this effort and planned designs for ICESat-2 data formats.

3.2 GLAS_BIN Data Characteristics

In order to understand the GLAS_HDF data products, a review of the GLAS_BIN products may prove useful. GLAS data are sparse, multi-rate altimetry point data processed to ECS Levels 1A through 2. The data are stored as scaled integers within time-based, fix-record-length GLAS binary (GLAS_BIN) data files.

There are fifteen standard data products for the ICESat mission. These products contain a sum of over 2000 parameters.

GLA01, 05, 06 and 12 to 15 are the altimeter products. GLA02 and 07 to 11 are atmosphere products. GLA03 and 04 are GLAS engineering and geolocation products. GLA01 contains the altimeter return waveforms and GLA02 contains the atmosphere profiles. GLA06 contains the global elevation and GLA12 to 15 each contain specific surface elevations for ice sheet, sea ice, land and ocean data, respectively. GLA07 to 11 progressively processed atmosphere data containing calibrated backscatter, cloud layers and Optical Depth.

The majority of the parameters are 1Hz and 40 Hz. Some of the atmosphere and L1A products have other data rates. The data are time-based rather than gridded. In addition, some of the parameters are sparse. The L2A land product, for example, contains data only for the periods when the onboard DEM determines the laser is pointed over land.

To use the GLA data, a user is required to read a whole record of data at a time (usually 1-seconds worth) and then convert the desired parameters into scientific units using appropriate scale factors. Additionally, the user must unpack and/or parse any needed flag values since flags are stored in packed bytes. The GLA binary product parameters were not organized in groups of related parameters but ordered to preserve 4-byte alignment and maintained record size as changes were made over the flight years.

3.3 Description of the GLAS_HDF Data Products

The HDF conversion process is only a reformatting of the data therefore all science data values will remain the same as on the binary release 33 products. There are no value-added science parameters. The only additions are HDF5 parameters that ease the use and understanding of the data structure. The conversion is “one product to one product” and will be for all products for all time periods that the GLAS laser was firing.

Differences between the parameters on the original binary products (GLA_BIN) and those on the HDF5 products (GLAS_HDF) include:

- GLA_BIN parameters defined as “spares” are not present on the GLAS_HDF products.
- GLA_BIN parameters that were not implemented are not present on the GLAS_HDF products.
- Some GLA parameters that corresponded to the first and last shot have been interpolated across all shots.
- A shot counter (i_shot_count) was added to the GLAS_HDF products (if one did not already exist). When combined with the rec_ndx parameter, the shot_count enables unique identification of each pulse generated by the laser.
- GLA flags were unpacked and placed on the GLAS HDF products as individual parameters.
- The GLA04 multi-file granules were combined into a single GLAS_HDF granule.

Table 3-1 summarizes the GLAS_HDF product types.

Table 3-1 GLAH Product Types

Product ID	Product Name	Level
GLAH01	Altimetry Data File	1A
GLAH02	Atmosphere Data File	1A
GLAH03	Engineering Data File	1A
GLAH04	Combined LPA, LRS, GYRO, IST, BST, SPCA Data File	1A
GLAH05	Waveform-based Elevation Corrections File	1B
GLAH06	Elevation File	1B
GLAH07	Backscatter File	1B
GLAH08	Boundary Layer and Elevated Aerosol Layer Heights File	2
GLAH09	Cloud Height for Multiple Layers File	2
GLAH10	Aerosol Vertical Structure File	2
GLAH11	Thin Cloud/Aerosol Optical Depth File	2
GLAH12	Ice Sheet Products File	2

GLAH13	Sea Ice Products File	2
GLAH14	Land Products File	2
GLAH15	Ocean Products File	2

4.0 ENVIRONMENT

4.1 Hardware Characteristics and Limitations

The GLAS_HDF products are created within the re-used I-SIPS (ICESat Investigation-Led Processing System) environment running on Linux-based x86 hardware. Most of the code used to read the products is legacy GSAS (GLAS Science Algorithm Software) with new routines created to write the HDF5 products. Figure 4-1 illustrates the dataflow of the conversion software.

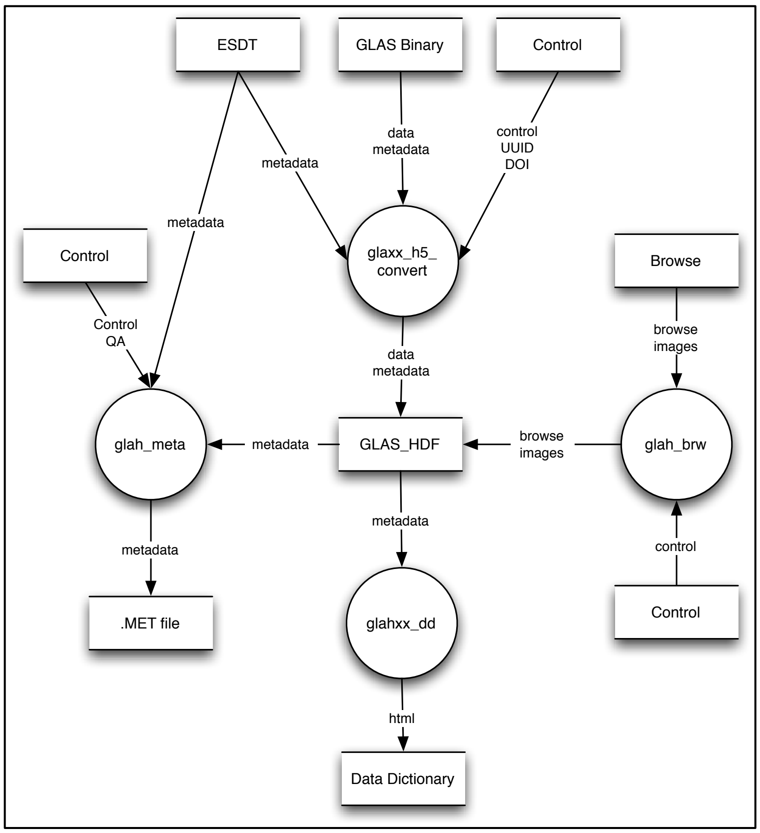


Figure 4-1 GLAS_HDF Dataflow

Version 1.8.9 of the HDF5 library was used to create the products. The HDF5 library software is available at the following URL:

http://hdfgroup.org

In addition, third-party software such as IDL and MatLab provide HDF5 interface routines.

By nature of HDF5 design, the GLAS_HDF products are platform-neutral and should be usable in both little-endian and big-endian environments. However, the products were created using Fortran and the HDF group has a note which warns about array dimensions:

"When a C application reads data stored from a Fortran program, the data will appear to be transposed due to the difference in the C and Fortran storage orders. For example,

if Fortran writes a 4x6 two-dimensional dataset to the file, a C program will read it as a 6x4 two-dimensional dataset into memory. The HDF5 C utilities h5dump and h5ls will also display transposed data, if data is written from a Fortran program."

Thus, care must be taken with multi-dimensional arrays when using the GLAS_HDF products. Multi-dimension arrays within the GLAS_HDF products are limited to two dimensions and dimension scale parameters are provided to help alleviate this potential issue. Dimension scales are described later in this document.

4.2 Data Products Medium and Characteristics

The GLAS_HDF data products will be archived within the NSIDC DAAC. The storage system will contain not only the GLAS_HDF data products, but will also contain data descriptions and data advertisements (i.e., textual descriptive and abstract information also called metadata). The products and their metadata will be part of the Earth Sciences Data Types collection.

4.3 Protocol and Conventions

GLAS_HDF data products will be delivered to the NSIDC DAAC in the same manner as the original GLAS_BIN products. This methodology is defined in the I-SIPS/NSIDC ICD.

4.4 Failure Protection, Detection, and Recovery Features

The team supporting operations at the I-SIPS will be responsible for failure protection, detection, and recovery of the generated GLAS_HDF data products stored on the I-SIPS. Initial GLAS_HDF error detection is performed during product generation as part of the product and processing quality assurance activity. The GLAS_HDF data products will be "backed up" under the routine operational functions performed at the I-SIPS. In the event of failure or error detection in the active working or archive storage, recovery would be performed from backup media or from the NSIDC DAAC archive.

NSIDC will be responsible for failure protection, detection, and recovery of the GLAS_HDF data products archived at the NSICD DAAC.

5.0 DATA FLOW CHARACTERISTICS

5.1 Volume, Size, and Frequency Estimates

Due to the use of HDF5 compression, GLAS_HDF products are expected to be substantially smaller than the original GLAS_BIN products. Test GLAS_HDF products have been up to 50% the size of the original GLAS_BIN. Table 5-1 provides an estimate of the GLAS_HDF daily volume.

Table 5-1 GLAH Data Volume Estimates

Product ID	Frequency (Granules per day)	Granule Size (MB)	Daily Volume (MB)
GLAH01	56	31	217
GLAH02	7	497	3479
GLAH03	7	TBD	TBD
GLAH04	7	15	105
GLAH05	7	15	105
GLAH06	7	6	42
GLAH07	7	512	3584
GLAH08	1	5.4	5.4
GLAH09	1	41	41
GLAH10	1	28	28
GLAH11	1	19	19
GLAH12	1	42	42
GLAH13	1	61	61
GLAH14	1	174	174
GLAH15	1	192	192

5.2 Data Transfer and Transmission

GLAS_HDF data products will be transferred to the NSIDC DAAC as described in the I-SIPS/NSIDC ICD. Procedures to access the GLAS_HDF files from the NSIDC DAAC will be provided by the NSIDC DAAC.

5.3 Timing and Sequencing Characteristics

All parameters within the GLAS_HDF products are in time order. Whereas some of the parameters have different data rates than others, the parameters with the same rates are grouped together and a reference time, record index, and shot counter are provided for each group.

5.4 Recipients and Utilization

The recipients for the products are the scientific, governmental, and educational sectors that will obtain the data products from the NSIDC DAAC. Recipients will use the products for analysis, research and to familiarize themselves with HDF5.

5.5 Access

The GLAS_HDF products are available from the NSIDC DAAC. While EOS is intended to be a globally available and utilized mission program, access to the data is still operated under a security and integrity program to protect the data and data system resources from unauthorized or destructive use. The NSIDC DAAC provides procedures for data access.

6.0 DATA PRODUCTS DEFINITIONS

6.1 Design Criteria

Initial requirements for GLAS_HDF design were based on shared experiences of GLAS data users and information gleaned from involvement with such earth science data communities as the Earth Science Data Systems Working Group (ESDSWG) and the Earth Science Information Partners (ESIP). The resultant design criteria include the following requirements:

- HDF5 will be incorporated as the standard data product file format (ESDS-RFC-007).
- The products will be designed with HDF5 CF-compliant parameter attributes to make the products self-documenting. This will allow data dictionaries to be created directly from the products themselves.
- The products will be designed to be NetCDF/HD5 complaint by using appropriate metadata and dimension scales.
- Since few 3rd party tools can make sense out of altimetry x,y,z data, the products will be designed to make access simple and approachable. For example, this meant minimizing the effort required for a user to plot X vs. Y in analysis environments such as IDL or MatLab.
- Each parameter will be a HDF5 dataset. This allows the user to read only the data parameters he requires.
- Parameters will be logically grouped, but at a level where desired data are not hidden.
- Data of the same rate (i.e.: 1Hz, 40Hz) will be grouped in a top-level group. Time/Location information at the same data rate will also be stored within the rate group so there is always a 1-to-1 correspondence between time/location and data parameter values.
- The products will incorporate both global and grouped metadata
- The design will support the same method of metadata exchange with NSIDC as the GLAS_BIN products. (External .MET files in ECHO format.)
- Parameters will be chunked and internally gzipped with HDF5 level-6 compression. The team intends for the HDF5 products to be significantly smaller than the parent GLA binary products.

6.2 Data Products Structure

GLAS_HDF products are created using a common model to facilitate interoperability among both the different product types and products from other earth science missions. First and foremost, all the products are created in the HDF5 format. HDF5 has some inherent advantages. One is that HDF5 internally handles endian issues. Another is that GZIP compression is enabled internally. Compression is a big advantage as it is transparent to the user but makes the HDF5 products significantly smaller that the original GLAS binary files. Furthermore, all products share the same single-parameter, rate/logical grouping, and metadata structures. Each of these constructs is detailed in the section.

6.3 Labeling and Identification

Each of the GLAS_HDF data products is uniquely identified by a GLAS_HDF standard file name. The form of this file name is:

GLAHxx_mmm_prkk_ccc_tttt_s_nn_ffff.eee

Specific elements within the file name are described in Table 6-1.

Table 6-1 GLAS_HDF File Naming Conventions

Key	Description
xx	The GLAS_HDF Product ID (01-15)
mmm	release number for process that created the produce (CCB assigned-combination of software and data)
p	repeat ground track phase
r	reference orbit number
kk	instance # incremented every time GLAS enters a different reference orbit
ccc	cycle of reference orbit for this phase
tttt	track within reference orbit
s	segment of orbit. This is 0 on files that contain multiple segments (GLA02, GLA03, GLA04,GLA07-GLA15) and 1,2,3,or 4 on GLA01, GLA05, and GLA06.
nn	granule version number (the number of times this granule is created for a specific release)
ffff	file type (numerical, CCB assigned for multiple files as needed for data of same time period for a specific ANCxx or GLAxx, i.e. multi-file granule)

6.4 Data Products Substructure Descriptions

Screenshots displayed in this section were captured from HDFView. HDFView is a Java-based HDF viewer that is freely available at the following URL:

http://www.hdfgroup.org/downloads/index.html#hdfview

This tool is highly recommended when using HDF data since it allows the user to dynamically explore the structure and content of HDF files. Command-line utilities are available in the aforementioned HDF5 library. Some of the particularly useful utilities are h5ls and h5dump.

In addition, since the GLAS_HDF products are CF and NetCDF/HDF compliant, the NetCDF utility ncdump is also able to display the content and structure of the GLAS_HDF products.

6.4.1 Parameters

The GLAS_HDF5 data are stored as individual parameters on the HDF product. A user only needs to read the desired parameters (not a whole data record). In addition, the GLAS_HDF parameters are stored in algorithm units and flag values are unpacked.

To ease the user conversion from GLAS_BIN to GLAS_HDF, most of the parameter names on GLAS_HDF are similar (if not identical) to those on the GLAS _BIN data products. The major exceptions to this are the flags that have been unpacked into new parameters.

Each parameter has CF-style attributes attached in order to make the product self-documenting. Figure 6-1 shows an HDFView window that displays, in the bottom panel, CF-style attributes associated with the selected parameter (d_elev) and, in the top right panel, the values contained within the d_elev dataset.

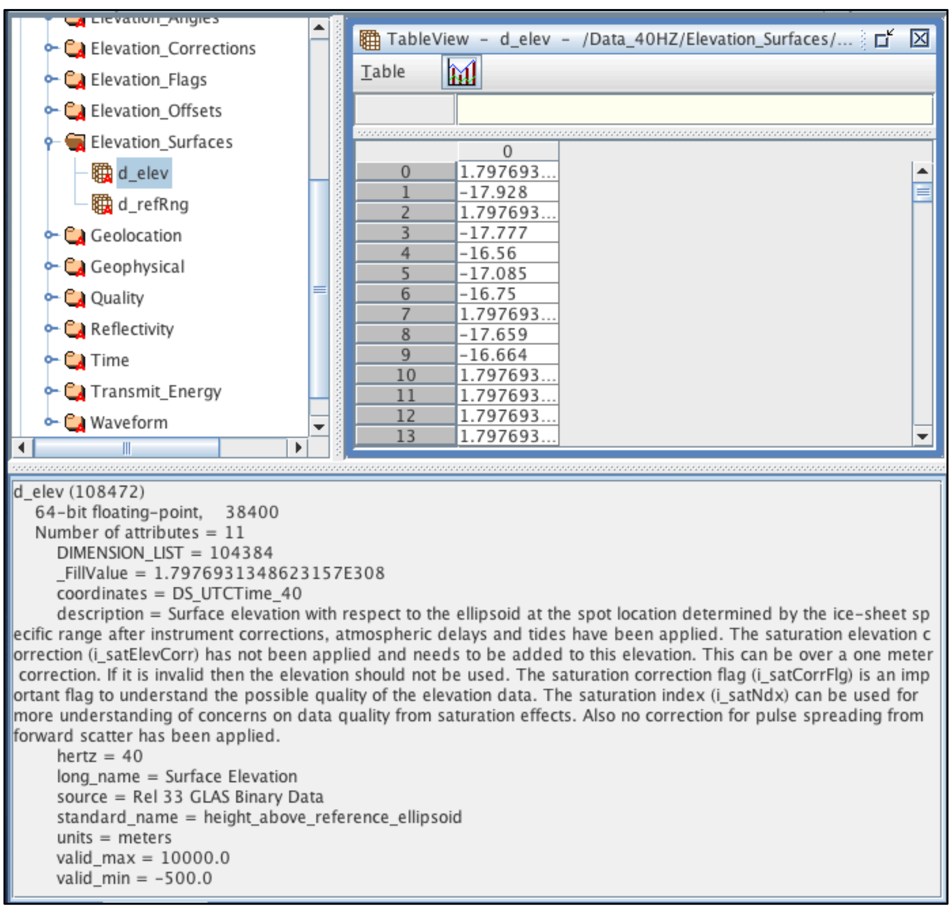


Figure 6-1: Example Parameter (Dataset)

6.4.2 Rate Groups

Since GLAS data are multi-rate (i.e.: some 40Hz, some 1Hz, etc.), the GLAS_HDF products incorporate “rate groups”. Rate groups are top-level groups labeled with a data rate containing all parameters of that particular data rate. Each rate group has a time parameter and corresponding latitude/longitude that correspond in a 1-to-1 fashion with other data parameters within that rate group. Each rate group has an attached “description” attribute that provides information about the group. Figure 6-2 shows an HDFView window that displays, in the bottom panel, the description of the Data_40HZ rate group.

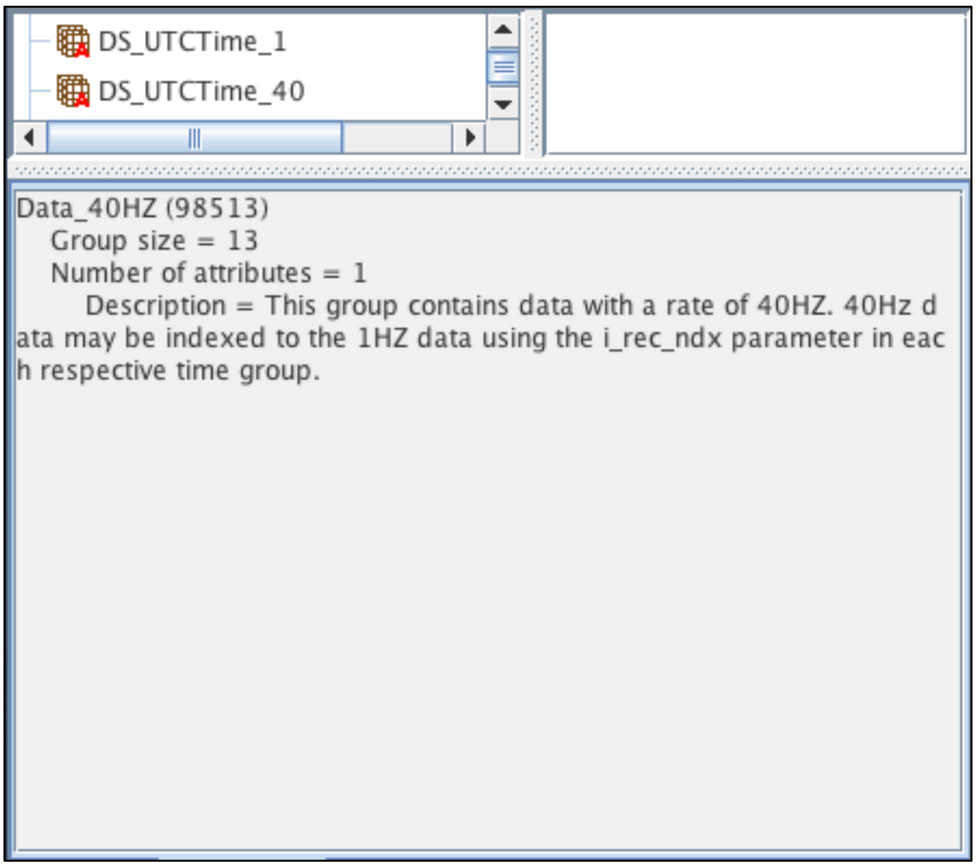


Figure 6-2 : Example Rate Group

6.4.3 Logical Groups

GLAS products have lots of parameters. There are 15 GLAS products containing a total of over 2000 parameters. To bring some order to the parameters, products feature logical groups (within each rate group) to organize the data by discipline or topic. Each logical group has a description that provides information about the group. Figure 6-3 shows an HDFView window that lists logical groups in the upper-left panel and the description of the selected group (Quality) in the lower panel.

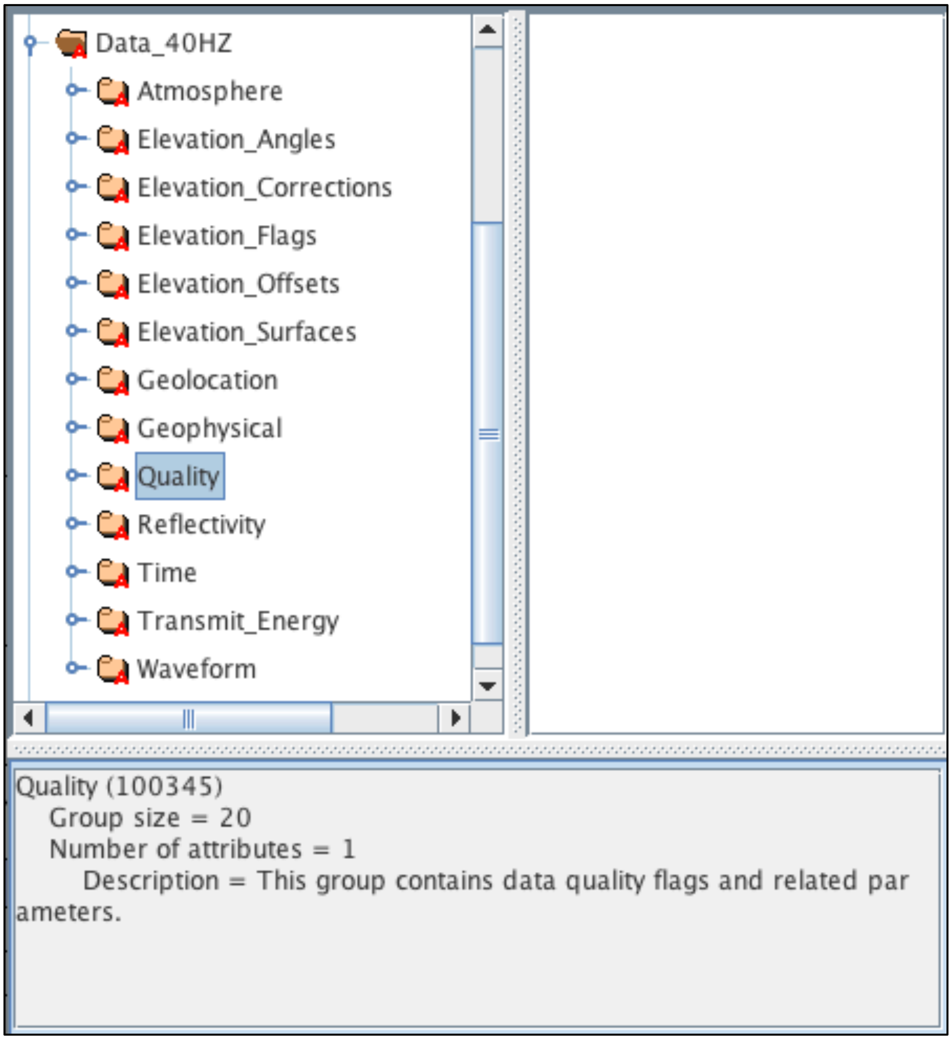


Figure 6-3 : Example Logical Groups

6.4.4 Ancillary Data

The ANCILLARY_DATA group is a special group that contains attributes that provide additional information about the science parameters. This data may include calibration measurements, table values, or even QA data. Mostly this group contains data that were present in the GLAS binary headers but not in the ESDT metadata (see Metadata section for more explanation. Figure 6-4 shows the attributes attached to the ANCILLARY_DATA group.

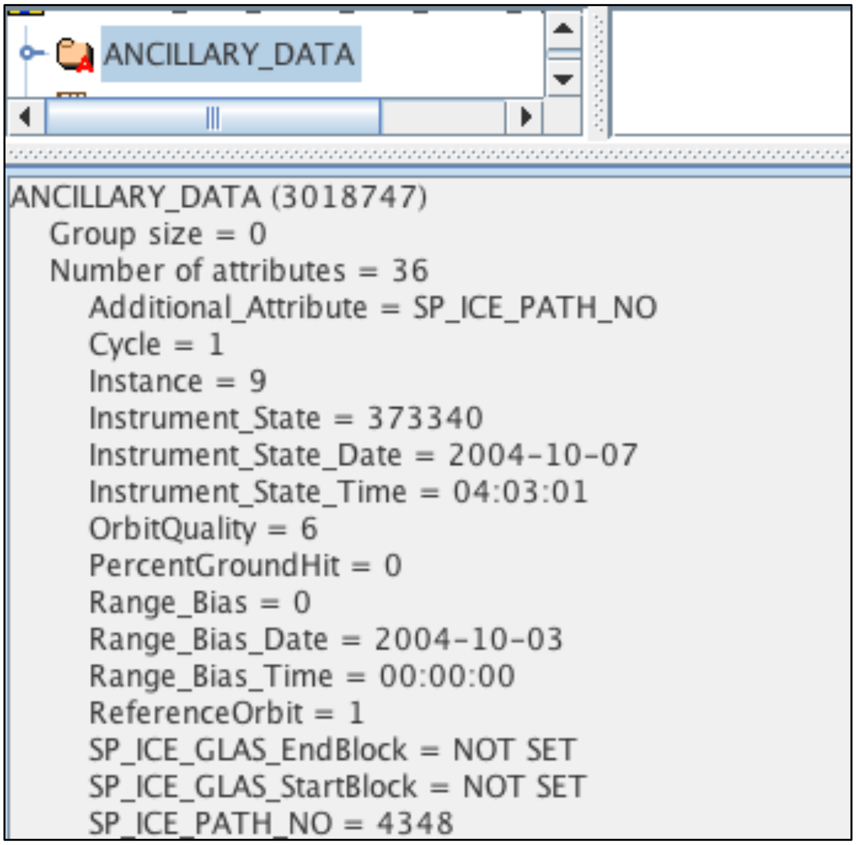


Figure 6-4: Example Ancillary Data

6.5 Dimension Scales

Dimension scales are the mechanism by which NetCDF associates array dimensions with a physical representation. For example, most of the GLAS_HDF datasets are dimensioned by time, so a corresponding "time" dimension scale is used to associate each array element of the dataset with a corresponding array element of the "time" dimension scale.

For complete NetCDF compliance, a dimension scale is needed for every single or multiple dimensioned parameter in the product. Multiple parameters may share the same dimension scale as long as their array lengths are the same.

Generically, this means that for every parameter "z(x)", there must be a dimension scale "y" that has dimensions equivalent to "z" and has a value corresponding to each element of the z array. Extending this to two dimensions, for every parameter z(x,y), there must be two dimensions scales "x" and "y" with number of elements equal to the respective dimensions of z and containing corresponding values. Additional requirements are that :

- Any parameter identified as a dimension scale must be stored within the same group or within a higher-level group than any other parameter that references it.

- No dimension scale may contain invalid values (or have a _FillValue attribute attached).

The GLAS_HDF products incorporate the following conventions regarding dimension scales:

- Each dimension scale variable is named with a "DS_" prefix. (e.g.: DS_utctime). This makes dimension scales easily distinguishable from other parameters.
- For time-based dimension scales, the time parameter is "hard linked" from the dimension scale back to the group where the dimension scale parameter would logically be stored (e.g.: DS_utctime --> /Data/Time/utctime). A "hard link" is a HDF5 convention where the link is a pointer associated with the HDF5 object ID of the object being referenced. This allows both the link and the referenced object to share the same HDF object ID. Note that the link name is the dimension scale name without the "DS_" prefix.

Example 1:

Define elev(100) as a rank(1), 100-element array of elevation measurements. Also define time as a rank(1), 100-element array of time measurements and that there is a 1-to-1 correspondence between the respective "time" and "elev" measurements. "time" is identified as a dimension scale associated with "elev". Note that since time is now a "dimension scale" (as well as a parameter) it needs to be stored within the same group or at a higher level within the HDF file.

Example 2:

Define cloud_lay(100,10) as a rank(2) array of cloud layer measurements. For each measurement there is an associate time and height. These are defined as time(100) and height(10). Identify time, height as dimension scales associated with "cloud_lay". Time corresponds with the first dimension (100) and height corresponds to the second dimension (10). Again, both time and height need to be stored within the same group as or at a higher group level than parameters that refer to that dimension scale.

Figure 6-5 shows an HDFView window that displays the DS_UTCTime_1 dimension scale in the top-left panel, the DS_UTCTime_1 values in the top-right panel, and DS_UTCTime_1 attributes in the lower panel. Note that the "REFERENCE_LIST" identified the HDF5 object IDs of the datasets using DS_UTCTime_1 as their dimension scale. Also notice that "CLASS" identifies the parameter as a dimension scale.

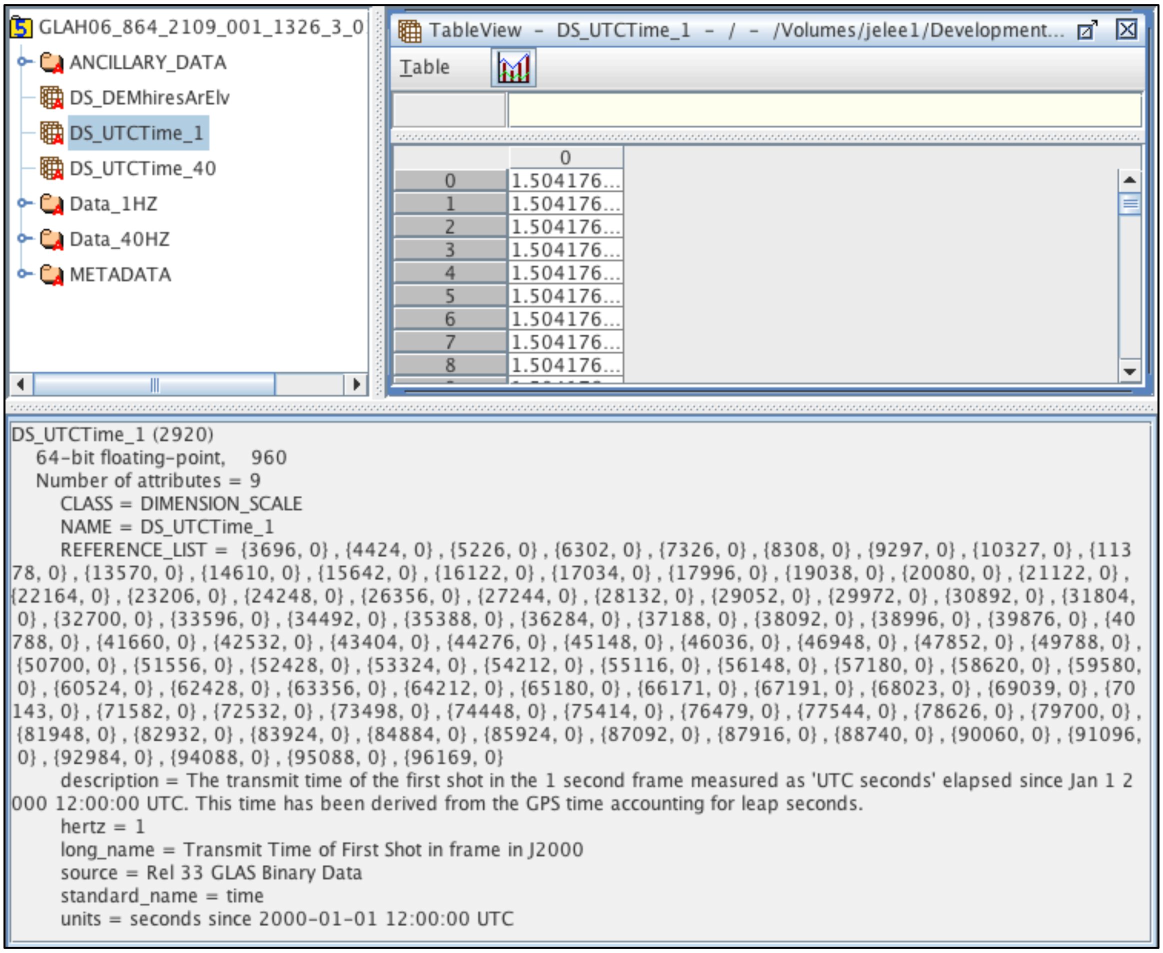


Figure 6-5: Sample Dimension Scale

6.6 Metadata Descriptions

GLAS_HDF metadata is derived from a combination of Earth Observing System (EOS) Clearinghouse (ECHO)-style inventory-level metadata present within GLA product headers, collection and inventory-level metadata provided by ECS-generated ESDT descriptor files, information from the GLAS Data Dictionary, and some additional local metadata specific to the GLAS_HDF effort. There are three distinct flavors of this metadata: parameter-level, grouped, and global.

Appendix B contains portions of a sample GLAS_HDF ESDT descriptor file.

6.6.1 Parameter-level Metadata

Parameter-level metadata is implemented as CF attributes attached to each parameter dataset. Whenever a CF “standard_name” was available for the parameter is was stored in the CF “standard_name” attribute. The source for most of the information was the GLAS Product Database. The GLAS Product Database contained descriptive information about each parameter in the GLA binary files. This information was edited appropriately and applied as attributes to the GLAS_HDF files. Additional attributes were added for CF compliance. Appendix C contains the list of parameter-level CF attributes supported.

Error! Reference source not found. Figure 6-6 shows example parameter metadata for the d_elev parameter.**Error! Reference source not found.**

```
d_elev (108472)
   64-bit floating-point,    38400
   Number of attributes = 11
      units = meters
      hertz = 40
      long_name = Surface Elevation
      standard_name = height_above_reference_ellipsoid
      description = Surface elevation with respect to the ellipsoid at the spot
location determined by the ice-sheet specific range after instrument correcti
ons, atmospheric delays and tides have been applied. The saturation elevati
on correction (i_satElevCorr) has not been applied and needs to be added to
 this elevation. This can be over a one meter correction. If it is invalid then th
e elevation should not be used. The saturation correction flag (i_satCorrFlg) i
s an important flag to understand the possible quality of the elevation data.
The saturation index (i_satNdx) can be used for more understanding of conc
erns on data quality from saturation effects. Also no correction for pulse spr
eading from forward scatter has been applied.
      source = Rel 33 GLAS Binary Data
      coordinates = d_UTCTime_40
      valid_min = -500.0
      valid_max = 10000.0
      _FillValue = 1.7976931348623157E308
      DIMENSION_LIST = 104384
```

Figure 6-6 : Example Parameter Metadata

In addition, CF contains special attributes that help describe flag. The flags on GLA binary files were (mostly) packed flags. GLAS_HDF flags have been (mostly) unpacked into individual flags. The CF "flag_meanings" and "flag_values" attributes help describe the meanings of the flags.

Figure 6-7 shows the "flag_values" and "flag_meanings" attributes for the icesheet flag (surf_is_flg). In this example, a value of "0" indicates "no_ice_sheet" and a value of "1" indicates "ice_sheet". Yes, the convention defines "flag_values" as comma-separated and "flag_meanings" as space-delimited.

The long_name attribute shows the name of the GLA binary flag from which the GLAS_HDF flag was derived (i.e.: unpacked).

```
surf_is_flg (74448)
   8-bit character,    960
   Number of attributes = 10
      hertz = 1
      long_name = Region Type
      description = Ice Sheet flag, indicates presence of ice sheet in the regi
on.
      source = Rel 33 GLAS Binary Data
      coordinates = d_UTCTime_1
      flag_values = 0,1
      flag_meanings = no_ice_sheet ice_sheet
      valid_min = 0
      valid_max = 1
      DIMENSION_LIST = 2920
```

Figure 6-7 : CF Flag Metadata

6.6.2 Grouped Metadata

Grouped Metadata contains the filled collection and inventory-level content of the EOSDIS "Metadata Configuration File" (MCF). An MCF file is a template that describes the metadata values that will be ingested into ECS databases. This content is the same information present in GLA binary detached metadata file (GLA.MET). In order to store the metadata information as HDF5 grouped attributes, some reorganization and re-labeling was necessary. However, all of the information identified within the MCF file is present within the grouped metadata. The benefit of the grouped metadata is that it is able to represent more complex structures than simple metadata and this is the mechanism by which GLAH_HDF detached metadata ingest files (GLAS_HDF.MET) are created for NSIDC.

This concept embodies the notion of storing the requisite data within the product and generating the presentation via external software. Appendix D contains a sample of grouped metadata.

6.6.3 Global Metadata

The GLAS_HDF grouped metadata is certainly complete and human-readable, but not exactly human-friendly. Metadata attributes are buried within various levels of grouping and that grouping does not always sort the more useful metadata to the top. In order to help this, GLAS_HDF products have global metadata implemented as attributes attached to the root level of the GLAS_HDF file. This results in metadata information that is both human-friendly and follows CF metadata recommendations. It also results in data duplication, but the benefits outweigh the additional storage required for the duplicated data. There is an additional risk that the set of metadata deemed "useful" is not fully inclusive. However, any metadata not stored as global metadata can be accessed via the grouped metadata (just not as easily).

Appendix E contains a sample of global metadata.

6.6.4 Provenance Metadata

The process that converts GLAS_HDF data from an integer-binary format into HDF5 is transformative. However, it was desired to keep provenance information regarding the process that created the original GLA binary file since that contains important traceability information.

Without a conclusive existing standard to define provenance, the GLAS_HDF provenance implementation is focused on instrumenting the product with the information necessary to generate a provenance map. The goal was to provide enough information, in an identifiable fashion, that external software can generate a provenance map in the format of its choosing.

Appendix F contains an example of provenance metadata.

In the example provenance information is defined by a series of “steps”. Each “step” is implemented as a HDF5 group that contains attributes identifying the processing time, processing agent, inputs and outputs corresponding to that particular “step” of processing.

As implemented, “STEP_1” contains the provenance information associated with the production of the original GLA binary file. “STEP_2” contains the provenance information associated with the conversion of the original GLA binary file to HDF5.

In addition, GLAS_HDF was part of an EOSDIS pilot project to instrument earth science granules with DOIs (digital object identifiers). Each GLAS_HDF product type has a unique DOI registered with the International DOI Foundation (http://www.doi.org). A DOI can be used, for example, to uniquely identify each datatype cited in a research paper.

Expanding upon the EOSDIS DOIs, each GLAS_HDF granule has also been assigned a Universally Unique Identifier (UUID) that can be used to uniquely identify each individual GLAS_HDF granule.

The relevant DOI and UUID global attributes stored both as global metadata and in the grouped metadata. The attributes names and example values follow:

identifier_file_uuid	D65E7C2A-7BC1-444F-AE6F-991DAD0B45FF
identifier_product_doi	10.5067/ICESAT/GLAS/DATA105
identifier_product_doi_authority	http://dx.doi.org

6.7 Data Dictionaries

The GLAS_HDF data products are designed to be self-documenting, thus a user can easily generate a data dictionary using a tool such as h5ls, h5dump, or ncdump. For convenience, a formatted data dictionary for each product is online at the ICESat HDF website:

http://icesat.gsfc.nasa.gov/icesat/hdf5_products/data_dicts/

Both HTML and PDF versions are available. PDF versions are more useful for generating hardcopy.

7.0 DATA USAGE NOTES

Rate groups are the most important concept to understand when attempting to use GLAS_HDF data. Parameters within a rate group always have the same time-based dimension and always linked to a time-based dimension scale. That means that for every parameter in the rate group, there is a 1-to-1 correspondence with every other parameter in the rate group at a given time. And since the time dimension scale is shared by each parameter in the group that also means that the array index of each parameter within a rate group corresponds to other parameters with the same index.

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. Users can programmatically query the invalid value for each value by reading the parameter-attached attribute "_FillValue". The IDL example in Appendix A illustrates how this is done.

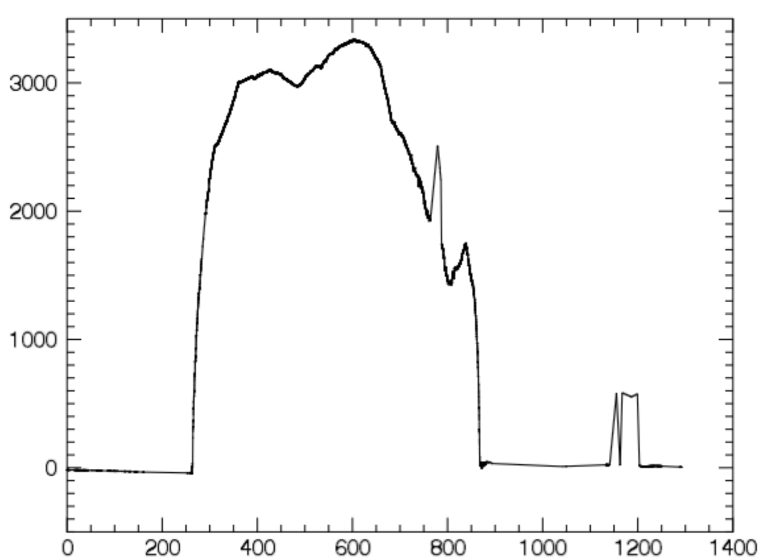
Ancillary data are stored as attributes attached to the root-level ANCILLARY_DATA group. The important thing to remember is that most of these values are stored as strings and must be converted to numeric equivalents in order to be used.

All metadata parameters stored on the GLAS binary product headers are contained within the GLAS_HDF products. If the parameter is part of the ECHO metadata, the parameter is stored within the root-level METADATA structured metadata. If the parameter is not contained within the ECHO metadata, the parameter is attached to the ANCILLARY_DATA group.

Appendix A

This appendix contains a sample IDL routine and its resulting image. The IDL routine plots GLAH06 elevation vs. time for all valid elevations. It is intended as a proof of concept to validate the simplicity of the GLAS_HDF design.

```
pro plot_elev
;
; Open the file
;
  f_id=H5F_OPEN("GLAH06_864_2109_001_1326_3_01_0002.h5")
;
; Read Time
;
  time_id=H5D_OPEN(f_id, "/Data_40HZ/Time/d_UTCTime")
  time=H5D_READ(time_id)
  H5D_CLOSE, time_id
;
; Read Elevation values and the fill value attribute
;
  elev_id=H5D_OPEN(f_id, "/Data_40HZ/Elevation_Surfaces/d_elev")
  elev=H5D_READ(elev_id)
  at_id=H5A_OPEN_NAME(elev_id, "_FillValue")
  bad_val=H5A_READ(at_id)
  H5A_CLOSE, at_id
  H5D_CLOSE, elev_id
;
; Plot the good data
;
  good=where(elev ne bad_val[0], count)
  if (count gt 0) a=plot(time[good]-time[0], elev[good])
  H5F_CLOSE, f_id
end
```



IDL Elevation Plot

Appendix B

This section contains a small portion of a sample ESDT descriptor file. The entire file is over a hundred pages long. This file is parsed by the GLAS_HDF metadata software to form the basis of the GLAS_HDF metadata.

```
/*****************************************************************/
/* JLP                 2012/02/29        8050264          */
/* Created HDF5 version 33 ESDT based on current binary version 33  */
/*   ESDT                                    */
/*****************************************************************/
GROUP = METADATA
  GROUP = COLLECTIONMETADATA
    GROUPTYPE = MASTERGROUP

    OBJECT = DLLName
      Data_Location = "MCF"
      Mandatory = "TRUE"
      NUM_VAL = 1
      Value = "libDsESDTGlGLASPoly.001Sh.so"
    END_OBJECT = DLLName

    OBJECT = GranuleTimeDuration
      Data_Location = "MCF"
      Mandatory = "FALSE"
      NUM_VAL = 1
      Value = 1620
    END_OBJECT = GranuleTimeDuration

    OBJECT = SpatialSearchType
      Data_Location = "MCF"
      Mandatory = "TRUE"
      NUM_VAL = 1
      Value = "Orbit"
    END_OBJECT = SpatialSearchType

    GROUP = MimeTypes
      OBJECT = ScienceMimeType
        Data_Location = "MCF"
        Mandatory = "FALSE"
        NUM_VAL = 1
        Value = "application/x-hdfeos"
      END_OBJECT = ScienceMimeType

      OBJECT = BrowseMimeType
        Data_Location = "MCF"
        Mandatory = "FALSE"
        NUM_VAL = 1
        Value = "application/x-hdfeos"
      END_OBJECT = BrowseMimeType

      OBJECT = BrowseOnlineMimeType
        Data_Location = "MCF"
        Mandatory = "FALSE"
```

```
            NUM_VAL = 1
            Value = "image/jpeg"
        END_OBJECT = BrowseOnlineMimeType
    END_GROUP = MimeTypes

    GROUP = CollectionDescriptionClass
        OBJECT = ShortName
            Data_Location = "MCF"
            Mandatory = "TRUE"
            NUM_VAL = 1
            Value = "GLAH06"
        END_OBJECT = ShortName

        OBJECT = LongName
            Data_Location = "MCF"
            Mandatory = "TRUE"
            NUM_VAL = 1
            Value = "GLAS/ICESat L1B Global Elevation Data (HDF5)"
        END_OBJECT = LongName

        OBJECT = CollectionDescription
            Data_Location = "MCF"
            Mandatory = "TRUE"
            NUM_VAL = 1
            Value = "Data granules contain approximately 23 minutes (1/4 orbit) and include the surface
elevation, surface roughness assuming no slope, surface slope assuming no roughness and geodetic and
atmospheric corrections for the range at the full 40/sec resolution."
        END_OBJECT = CollectionDescription

        OBJECT = VersionID
            Data_Location = "MCF"
            Mandatory = "TRUE"
            NUM_VAL = 1
            Value = 33
        END_OBJECT = VersionID
    END_GROUP = CollectionDescriptionClass

    GROUP = ECSCollection
        OBJECT = RevisionDate
            Data_Location = "MCF"
            Mandatory = "TRUE"
            NUM_VAL = 1
            Value = "2012-02-29"
        END_OBJECT = RevisionDate

        OBJECT = SuggestedUsage
            Data_Location = "MCF"
            Mandatory = "TRUE"
            NUM_VAL = 1
            Value = "This is a global file that can be used by scientists investigating surface elevation, slope,
reflection, and other surface characteristics. This product will be used with GLAH05 to create the level 2
surface-specific altimeter products (GLAH12-15)."
        END_OBJECT = SuggestedUsage
```

Appendix C

This appendix contains a listing of parameter CF attributes supported by GLAS_HDF.

Parameter-Level CF Attributes

Attribute	Description
_FillValue	A value used to represent missing or undefined data. Not allowed for coordinate data except in the case of auxiliary coordinate varibles in discrete sampling geometries.
coordinates	Identifies auxiliary coordinate variables, label variables, and alternate coordinate variables.
flag_meanings	Use in conjunction with flag_values to provide descriptive words or phrases for each flag value. If multi-word phrases are used to describe the flag values, then the words within a phrase should be connected with underscores.
flag_values	Provides a list of the flag values. Use in conjunction with flag_meanings.
long_name	A descriptive name that indicates a variable"s content. This name is not standardized.
source	Method of production of the original data.
standard_name	A standard name that references a description of a variable"s content in the standard name table.
units	Units of a variable"s content.
valid_max	Largest valid value of a variable.
valid_min	Smallest valid value of a variable.

Parameter CF attribute descriptions were copied from :

http://cf-pcmdi.llnl.gov/documents/cf-conventions/1.6/cf-conventions.html.

Appendix D

This appendix contains examples of structured metadata. This table was generated entirely from a sample product by the data dictionary creation software.

/METADATA

Attribute	Example Value
description	This group contains structured, computer-parseable ECHO-style collection and inventory-level metadata.
HDFVersion	HDF5 1 8 8
identifier_file_UUID	15955791-7A98-4B39-B34C-9C31D4816E2F
identifier_product_DOI	10.5067/ICESat/GLAS/GLAH06
ControlFile	cf_name=test.ctl

/METADATA/COLLECTIONMETADATA

Attribute	Example Value
DLLName	libDsESDTGlGLASPoly.001Sh.so
GranuleTimeDuration	1620
SpatialSearchType	Orbit

/METADATA/COLLECTIONMETADATA/AdditionalAttributes_1

Attribute	Example Value
AdditionalAttributeDatatype	float
AdditionalAttributeDescription	Percent of data for this granule that had a detected ground return of the transmitted laser pulse.
AdditionalAttributeName	PercentGroundHit

/METADATA/COLLECTIONMETADATA/AdditionalAttributes_1/PhysicalParameterDetails

Attribute	Example Value
ParameterUnitsofMeasurement	Percent
ParameterRangeBegin	0.0
ParameterRangeEnd	100.0
ParameterValueAccuracy	1
ParameterMeasurementResolution	1

/METADATA/COLLECTIONMETADATA/CollectionDescriptionClass

Attribute	Example Value
ShortName	GLAH06
LongName	GLAS/ICESat L1B Global Elevation Data (HDF5)

CollectionDescription	Data granules contain approximately 23 minutes (1/4 orbit) and include the surface elevation, surface roughness assuming no slope, surface slope assuming no roughness and geodetic and atmospheric corrections for the range at the full 40/sec resolution.
VersionID	33

/METADATA/COLLECTIONMETADATA/Contact

/METADATA/COLLECTIONMETADATA/Contact/ContactOrganization_1

Attribute	Example Value
Role	Data Originator
HoursofService	M-F, 8:00am to 4:30pm Eastern Time
ContactInstructions	Contact by e-mail first
ContactOrganizationName	ICESat Science Investigator-led Processing System (I-SIPS)

/METADATA/COLLECTIONMETADATA/Contact/ContactOrganization_1/ContactOrganizationAddress_1

Attribute	Example Value
StreetAddress	Building 22, NASA Goddard Space Flight Center
City	Greenbelt
StateProvince	Maryland
PostalCode	20771
Country	USA

/METADATA/COLLECTIONMETADATA/Contact/ContactOrganization_1/OrganizationEmail

Attribute	Example Value
ElectronicMailAddress	David.W.Hancock@nasa.gov

/METADATA/COLLECTIONMETADATA/Contact/ContactOrganization_1/OrganizationTelephone_1

Attribute	Example Value
TelephoneNumber	757-864-1238
TelephoneNumberType	Voice

Appendix E

This appendix contains example global metadata. This table was generated entirely from a sample product by the data dictionary creation software.

Attribute	Example Value
featureType	timeSeries
ShortName	GLAH06
title	GLAS/ICESat L1B Global Elevation Data (HDF5)
comment	Data granules contain approximately 23 minutes (1/4 orbit) and include the surface elevation, surface roughness assuming no slope, surface slope assuming no roughness and geodetic and atmospheric corrections for the range at the full 40/sec resolution.
summary	This is a global file that can be used by scientists investigating surface elevation, slope, reflection, and other surface characteristics. This product will be used with GLAH05 to create the level 2 surface-specific altimeter products (GLAH12-15).
license	http://nsidc.org/data/icesat/disclaimer.html
references	http://nsidc.org/data/docs/daac/glas_icesat_l1_l2_global_altimetry.gd.html (Guide Document for this product at NSIDC), http://nsidc.org/daac/icesat/index.html (GLAS Product page at NSIDC)
AccessConstraints	Data may not be reproduced or distributed without including the CitationForExternalPublication for this product included in this Metadata. Data may not be distributed in an altered form without the written permission of the GLAS Science Team.
CitationforExternalPublication	The data used in this study were produced by the GLAS Science Team at the ICESat Science Investigator-led Processing System (I-SIPS) at NASA/GSFC. The data archive site is the NSIDC DAAC.
contributor_role	Science Software Development Manager., GLAS Science Team Leader, ICESat Project Scientist, Deputy Science Software Development Manager
contributor_name	David W. Hancock (David.W.Hancock@nasa.gov), Bob E Schutz (schutz@utcsr.ae.utexas.edu), Jay Zwally (Jay.Zwally@nasa.gov), John P DiMarzio (John.P.Dimarzio.1@gsfc.nasa.gov)
creator_name	ICESat Science Investigator-led Processing System (I-SIPS)
creator_email	David.W.Hancock@nasa.gov
publisher_name	NSIDC User Services
publisher_email	nsidc@nsidc.org
publisher_url	http://nsidc.org/daac/icesat/index.html
platform	Ice, Cloud, and Land Elevation Satellite (ICESat)

instrument	Geoscience Laser Altimeter System (GLAS)
campaign	3A
processing_level	1B
date_created	2012-04-27T16:09:34.000000Z
spatial_coverage_type	Horizontal
history	2011-05-16T13:39:34 glas_alt ACC GLA06_864_2109_001_1326_3_01_0001.DAT, 2012-04-27T16:09:34.000000Z GLA06_h5_convert Version 1.0 (May 2012) ./GLAH06_864_2109_001_1326_3_01_0002.h5
geospatial_lat_min	-90.0
geospatial_lat_max	90.0
geospatial_lon_min	-180.0
geospatial_lon_max	180.0
geospatial_lat_units	degrees_north
geospatial_lon_units	degrees_east
keywords	Earth Science > Land Surface > Topography > Terrain Elevation, Earth Science > Land Surface > Topography > Surface Roughness, Earth Science > Cryosphere > Glaciers/Ice Sheets > Glacier Elevation/Ice Sheet Elevation, Earth Science > Hydrosphere > Glaciers/Ice Sheets > Glacier Elevation/Ice Sheet Elevation, Earth Science > Oceans > Sea Surface Topography > Sea Surface Slope, Earth Science > Cryosphere > Sea Ice > Reflectance, Earth Science > Land Surface > Surface Radiative Properties > Reflectance, Earth Science > Oceans > Sea Ice > Reflectance, Earth Science > Cryosphere > Sea Ice > Ice Roughness, Earth Science > Oceans > Sea Ice > Ice Roughness, Earth Science > Oceans > Sea Surface Topography > Sea Surface Height
Attribute	Example Value
featureType	timeSeries
ShortName	GLAH06
title	GLAS/ICESat L1B Global Elevation Data (HDF5)

Appendix F

This appendix contains example provenance metadata. This table was generated entirely from a sample product by the data dictionary creation software.

/METADATA/PROVENANCE

/METADATA/PROVENANCE/STEP_1

Attribute	Example Value
ProcessDateTime	2011-05-16T13:39:34

/METADATA/PROVENANCE/STEP_1/ProcessAgent

Attribute	Example Value
Name	glas_alt
Type	1B
Version	ACC
Description	This process is an instantiation of the GLAS Science Algorithm Software (GSAS) 1B ATBDs.

/METADATA/PROVENANCE/STEP_1/ProcessInput

Attribute	Example Value
Name	GLA05_863_2109_001_1326_2_01_0001.DAT, GLA05_863_2109_001_1326_3_01_0001.DAT, GLA09_863_2109_001_1317_0_01_0001.DAT, GLA11_863_2109_001_1317_0_01_0001.DAT, , [truncated]
Type	GLA05, GLA05, GLA09, GLA11, ANC01, ANC01, ANC01, [truncated]
Version	863, 863, 863, 863, 006, 006, 006, 006, 006, 006, 006, 006, 006, [truncated]

/METADATA/PROVENANCE/STEP_1/ProcessOutput

Attribute	Example Value
Name	GLA06_864_2109_001_1326_3_01_0001.DAT
Type	GLA06
Version	864
UUID	not_set
DOI	not_set

/METADATA/PROVENANCE/STEP_2

Attribute	Example Value

ProcessDateTime	2012-04-27T16:09:34.000000Z

/METADATA/PROVENANCE/STEP_2/ProcessAgent

Attribute	Example Value
Name	GLA06_h5_convert
Type	Data_Reformat
Version	Version 1.0 (May 2012)
Description	GLA06 Conversion PGE

/METADATA/PROVENANCE/STEP_2/ProcessInput

Attribute	Example Value
Name	./test.ctl, ../../data/tai-utc.dat, ./GLA06_864_2109_001_1326_3_01_0001.DAT, ./DsESDTGlGLAH06.033.desc
Type	IN_CNTL, IN_ANC_TAIUTC, IN_GLA06, IN_ESDT
Version	0, 0, 1, 1

/METADATA/PROVENANCE/STEP_2/ProcessOutput

Attribute	Example Value
Name	./GLAH06_864_2109_001_1326_3_01_0002.h5
Type	OUT_GLAH06
Version	1
UUID	15955791-7A98-4B39-B34C-9C31D4816E2F
DOI	10.5067/ICESat/GLAS/GLAH06

Appendix G

Data dictionaries for all release GLAS_HDF products are available in both HTML and PDF format on the GSFC ICESat website at the following location:

http://icesat.gsfc.nasa.gov/icesat/hdf5_products/data_dicts/