ATLAS/ICESat-2 L1B Converted Telemetry Data, Version 6

USER GUIDE

How to Cite These Data

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

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National Snow and Ice Data Center

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1 DATA DESCRIPTION

These Level-1B (L1B) data are used for system-level, quality control analysis by the Advanced Topographic Laser Altimeter System (ATLAS) ICESat-2 Science Investigator-led Processing System (SIPS). They also provide source data for the Level-2 products and the Precision Orbit Determination (POD) and Precision Pointing Determination (PPD) computations. To obtain higher level ATLAS/ICESat-2 data, including geolocated and geophysical data, visit the ICESat-2 page.

Users seeking a complete description of the ATL02 data product should consult the ICE, Cloud, and land Elevation Satellite (ICESat-2) Project Algorithm Theoretical Basis Document (ATBD) for ATL02 (Level 1B) Data Product Processing (ATBD for ATL02 V6 | https://doi.org/10.5067/7LI3JNHLHB6X).

The primary goal of the ATL02 product is to provide input to the Level-2 geolocated photon (ATL03) and normalized relative backscatter (ATL04) data sets. The data processing chain starts with the ATLAS/ICESat-2 L1A Reformatted Telemetry (ATL01) product, which reformats and unpacks the Level-0 ICESat-2 data and converts it into engineering units. ATL02 processing applies instrument corrections to the ATL01 data, removing biases from timing and pointing measurements and correcting for the effects of temperature and voltage variations on the ATLAS electronics. POD and PPD also draw from ATL02 to determine the position of the ICESat-2 observatory and pointing vector for ATLAS as functions of time.

The following figure illustrates the suite of ICESat-2 data products and their connections:
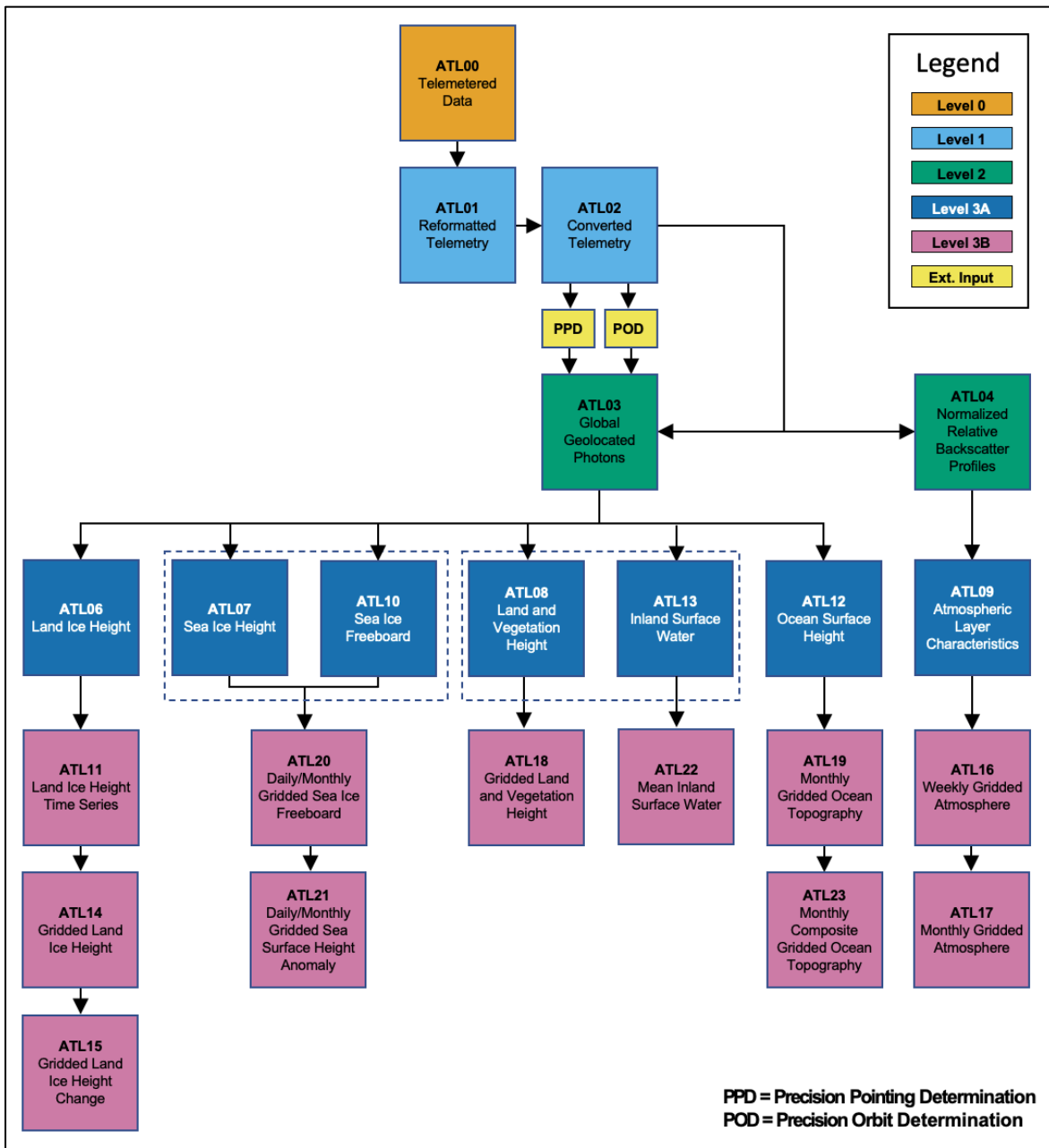
Figure 1. Schematic of the ICESat-2 data processing flow. The ATL01 algorithm reformats and unpacks the Level-0 data and converts it into engineering units. ATL02 processing converts ATL01 data to science units and applies instrument corrections. The PPD and POD solutions compute the pointing vector and position of the ICESat-2 observatory as a function of time.

1.1 Parameters

Time-ordered telemetry data converted to science units and corrected for known system calibrations and environmental effects.

1.2 File Information

1.2.1 Format

Data are provided as HDF5-formatted files.

1.2.2 ATLAS/ICESat-2 Description

The ICESat-2 observatory utilizes a photon-counting lidar (the ATLAS instrument) and ancillary systems (GPS, star cameras, and ground processing) to measure the time a photon takes to travel from ATLAS to Earth and back again and determine the reflected photon's geodetic latitude and longitude. Laser pulses from ATLAS illuminate three left/right pairs of spots on the surface that trace out six approximately 14 m wide ground tracks as ICESat-2 orbits Earth. Each ground track is numbered according to the laser spot number that generates it, with ground track 1L (GT1L) on the far left and ground track 3R (GT3R) on the far right. Left/right spots within each pair are approximately 90 m apart in the across-track direction and 2.5 km in the along-track direction. Higher level ATLAS/ICESat-2 data products (ATL03 and above) are organized by ground track, with ground tracks 1L and 1R forming pair one, ground tracks 2L and 2R forming pair two, and ground tracks 3L and 3R forming pair three. Each pair also has a Pair Track—an imaginary line halfway between the actual location of the left and right beams (see Figure 2). Pair tracks are approximately 3 km apart in the across-track direction.

The beams within each pair have different transmit energies—so-called weak and strong beams— with an energy ratio between them of approximately 1:4. The mapping between the strong and weak beams of ATLAS, and their relative position on the ground, depends on the orientation (yaw) of the ICESat-2 observatory, which is changed approximately twice per year to maximize solar illumination of the solar panels. The forward orientation corresponds to ATLAS traveling along the +x coordinate in the ATLAS instrument reference frame (see Figure 2, left). In this orientation, the weak beams lead the strong beams and a weak beam is on the left edge of the beam pattern. In the backward orientation, ATLAS travels along the -x coordinate, in the instrument reference frame, with the strong beams leading the weak beams and a strong beam on the left edge of the beam pattern (see **Error! Reference source not found.**). The first yaw flip was performed on 28 December 2018, placing the spacecraft into the backward orientation. The current spacecraft orientation, as well as a history of previous yaw flips, is available in the ICESat-2 Major Activities tracking document (`.xlsx`).

The Reference Ground Track (RGT) refers to the imaginary track on Earth at which a specified unit vector within the observatory is pointed. During nominal operating conditions onboard software aims the laser beams so that the RGT is between ground tracks 2L and 2R (i.e., coincident with Pair Track 2). The ICESat-2 mission acquires data along 1,387 different RGTs. Each RGT is targeted in the polar regions once every 91 days to allow elevation changes to be detected. Cycle numbers track the number of 91-day periods that have elapsed since the ICESat-2 observatory

entered the science orbit. RGTs are uniquely identified, for example in ATL02 file names, by appending the two-digit cycle number (cc) to the RGT number, e.g., 0001cc to 1387cc.
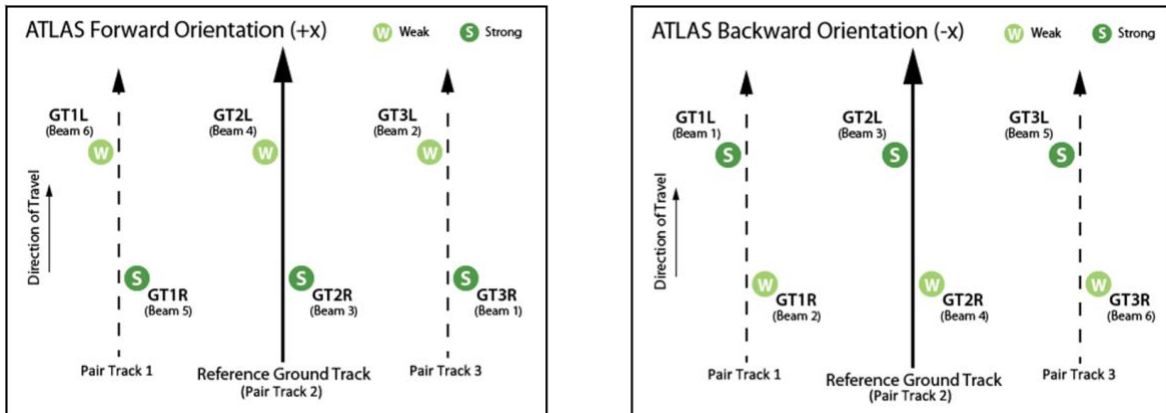

Figure 2. Spot and ground track (GT) naming convention with ATLAS oriented in the forward (instrument coordinate +x) direction and backward (instrument coordinate -x) direction.

Under normal operating conditions, data are not collected along the RGT; however, during spacecraft slews, or off-pointing, some ground tracks may intersect the RGT. Off-pointing refers to a series of plans over the mid-latitudes that have been designed to facilitate a global ground and canopy height data product with approximately 2 km track spacing. Off-pointing began on 1 August 2019 with RGT 518, after the ATLAS/ICESat-2 PPD and POD solutions had been adequately resolved and the instrument had pointed directly at the reference ground track for at least a full 91 days (1387 orbits).

Users should note that sometimes, for various reasons, the spacecraft pointing may lead to ICESat-2 data collected offset at some distance from the RGTs instead of along the nominal RGT. Although not along the nominal RGT, the geolocation information and data quality for these data are not degraded. As an example, from 14 October 2018 and 30 March 2019, the spacecraft pointing control was not yet optimized. To identify such time periods, refer to the ICESat-2 Major Activities file.

Various reference systems and dynamic processes, or geophysical corrections, occur during an ATLAS/ICESat-2 measurement (Figure 3). Table 1 lists the corrections needed for each surface type and ICESat-2 product. For example, to determine an estimate of the mean sea surface, several well-modeled, time-varying effects must be accounted for.
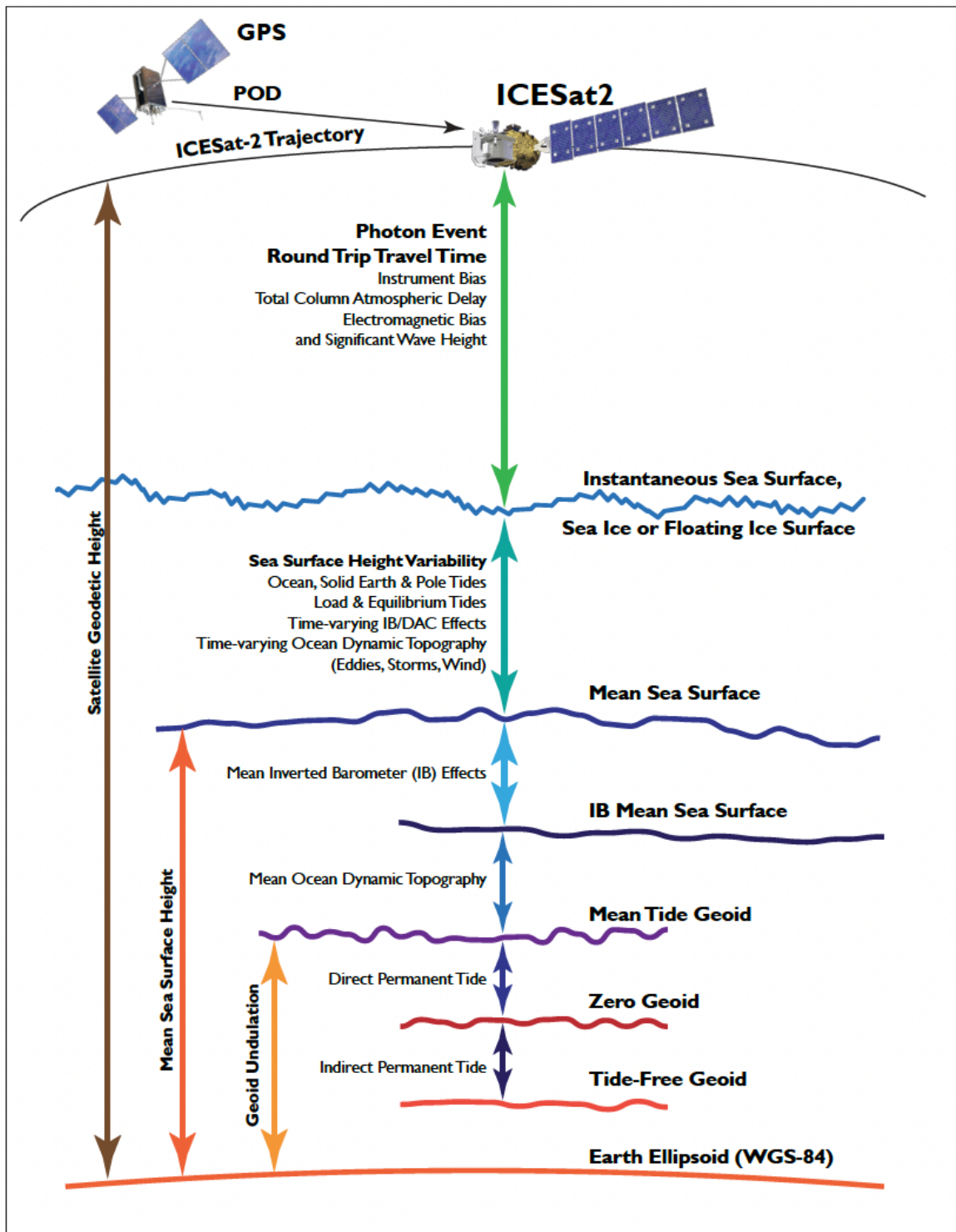
Figure 3. Geophysical corrections used in satellite altimetry. Taken from *ICESat-2 Data Comparison User's Guide for Rel006* available on the ATL03 data set landing page.

Table 1. Geophysical Corrections Applied to ICESat-2 Products

ICESat-2 Products by Surface Type	Geophysical Corrections[1]
Photon-level product (ATL03) (i.e., corrections applicable across all surface types)	Ocean loading Solid Earth tide Solid Earth pole tide Ocean pole tide Total column atmospheric range-delay
Land Ice, Land, and Inland Water (ATL06, ATL08, and ATL13)	*No corrections beyond ATL03*
Sea Ice (ATL07 and ATL10)	Referenced to mean sea surface Ocean tide Long period equilibrium ocean tide Inverted barometer (IB)
Ocean (ATL12)	Ocean tide Long period equilibrium ocean tide

[1]For details, see Section 5 of the *ICESat-2 Data Comparison User's Guide for Rel006* available on the ATL03 data set landing page.

1.2.3   File Contents

ATL02 data are segmented into granules (files) that span about 1/14th of an orbit. Granule boundaries are delineated by lines of latitude that define 14 regions numbered 01–14, as shown in Figure :
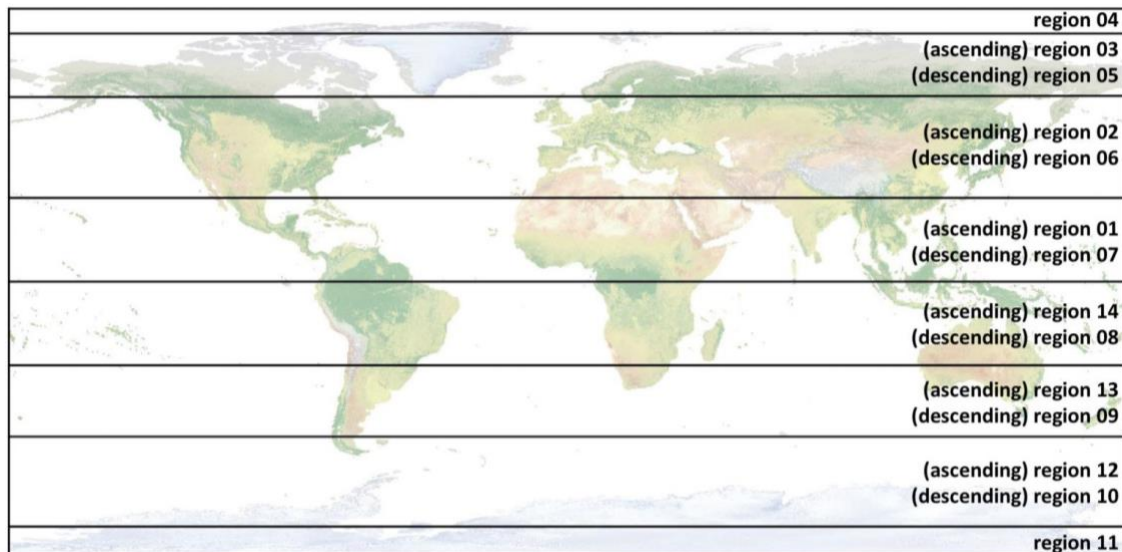

Figure 4. ATL02 region/granule boundaries.

The following table lists the latitude bounds and region numbers for all 14 granule regions:

Table 2. ATLAS/ICESat-2 Granule Boundaries and Region Numbers

Region #	Latitude Bounds	Region #	Latitude Bounds
01	Equator → 27° N (ascending)	08	Equator → 27° S (descending)
02	27° N → 59.5° N (ascending)	09	27° S → 50° S (descending)
03	59.5° N → 80° N (ascending)	10	50° S → 79° S (descending)
04	80° N (ascending) → 80° N (descending)	11	79° S (descending) → 79° S (ascending)
05	80° N → 59.5° N (descending)	12	79° S → 50° S (ascending)
06	59.5° N → 27° N (descending)	13	50° S → 27° S (ascending)
07	27° N (descending) → Equator	14	27° S → Equator (ascending)

1.2.4   Data Groups

The following sections summarize the data structures within ATL02 data files. This product comprises about 1,400 output parameters that are used for system-level quality control, POD and PPD computations, or as pass-through data for higher level products. A comprehensive discussion of ATL02 processing and output variables is beyond the scope of this user guide. However, detailed information is available in Appendix A of the ATL02 ATBD.

Within data files, similar variables and metadata are grouped together according to the HDF model, as shown in Figure 5.
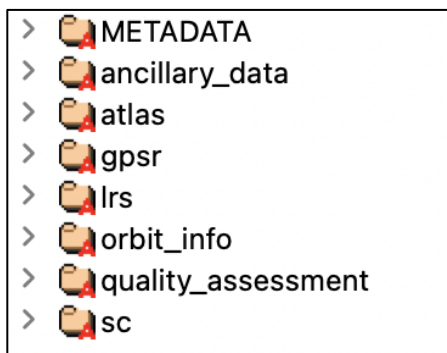
Figure 5. Top-level data groups for an ATL02
granule as displayed in HDFView.

Descriptions of the top-level groups are as follows:

- `METADATA`: ISO19115 structured metadata represented within HDF5.
- `ancillary_data`: information ancillary to the data product. This may include product characteristics, instrument characteristics and/or processing constants.
- `atlas`: parameters relating to the photon counting electronics (PCE) atmospheric data histograms (normally 25 hz).

- `gpsr`: parameters related to the GPS receiver.
- `lrs`: parameters relating to the laser reference system (LRS) packet decommutated data.
- `orbit_info`: orbit information.
- `quality_assessment`: quality assessment data, such as QA counters, QA along-track data, and/or QA summary data.
- `sc`: spacecraft (SC) ancillary science packet #1 decommutated data.

A complete list of all ATL02 parameters is available in the ATL02 Data Dictionary. For more details about the data and metadata structures within ATL02 data files, consult the ATL02 ATBD.

1.2.5   Naming Convention

Data files utilize the following naming convention:

`ATL02_[yyyymmdd][hhmmss]_[ttttccss]_[vvv_rr].h5`

Example:

`ATL02_20210713014743_02971201_006_02.h5`

Table 3 describes the file naming convention variables.

Table 3. File Naming Convention Variables and Descriptions

Variable	Description
`ATL02`	ATLAS/ICESat-2 L1B Converted Telemetry Data
`yyyymmdd`	Year, month, and day of data acquisition
`hhmmss`	Hour, minute, and second of data acquisition (UTC)
`tttt`	Reference Ground Track. The ICESat-2 mission has 1,387 RGTs numbered from 0001 to 1387.
`cc`	Cycle Number. Each of the 1,387 RGTs is targeted in the polar regions once every 91 days. The cycle number tracks the number of 91-day periods that have elapsed since ICESat-2 entered the science orbit.
`ss`	Segment number. ATL02 data files are segmented into approximately 1/14th of an orbit. Segment numbers range 01–14. Note that some segments may not be available.
`vvvv_rr`	Version and revision number[*]

NOTE: [*]From time to time, NSIDC receives reprocessed granules from our data provider. These granules have the same file name as the original (i.e., date, time, ground track, cycle, and segment number) but the revision number has been incremented. Although NSIDC deletes the superseded granule, the process can take several days. If you encounter multiple granules with the same file name, please use the granule with the highest revision number.

Each data file has a corresponding XML file that contains additional science metadata.
XML metadata files have the same name as their corresponding `.h5` file, but with `.xml` appended.

1.3 Spatial Information

1.3.1 Coverage

Spatial coverage is global.

1.3.2 Resolution

The ATLAS instrument transmits laser pulses at 10 kHz. At the nominal ICESat-2 orbit altitude of 500 km, this yields approximately one transmitted laser pulse every 0.7 meters along ground tracks. Note that the number of photons that return to the telescope depends on surface reflectivity and cloud cover (which obscures ATLAS's view of Earth). Therefore, the spatial resolution varies.

1.3.3 Geolocation

Geographic locations are presented in geodetic latitude, longitude, and ellipsoidal height (above the WGS 84 ellipsoid, ITRF2014). The following table contains details about WGS 84:

Table 4. Geolocation Details

Geographic coordinate system	WGS 84
Projected coordinate system	N/A
Longitude of true origin	Prime Meridian, Greenwich
Latitude of true origin	N/A
Scale factor at longitude of true origin	N/A
Datum	WGS 84
Ellipsoid/spheroid	WGS 84
Units	degree
False easting	N/A
False northing	N/A
EPSG code	4326
PROJ4 string	+proj=longlat +datum=WGS84 +no_defs
Reference	https://epsg.io/4326

1.4 Temporal Information

1.4.1 Coverage

13 October 2018 to present

1.4.2   Resolution

Each of ICESat-2's 1,387 RGTs is targeted once every 91 days (i.e., the satellite has a 91-day repeat cycle).

2   DATA ACQUISITION AND PROCESSING

2.1 Background

Figure illustrates the on-board data processing from photon input capture to intermediate data output to downlink telemetry. The processing includes a function to time tag key events such as laser transmit, return events, and the time of day (TOD) these measurements are made. To reduce the volume of data downlinked to Earth, ICESat-2 uses on-board flight software and a statistical approach to identify and downlink the most likely signal photons as well as data on atmospheric conditions.
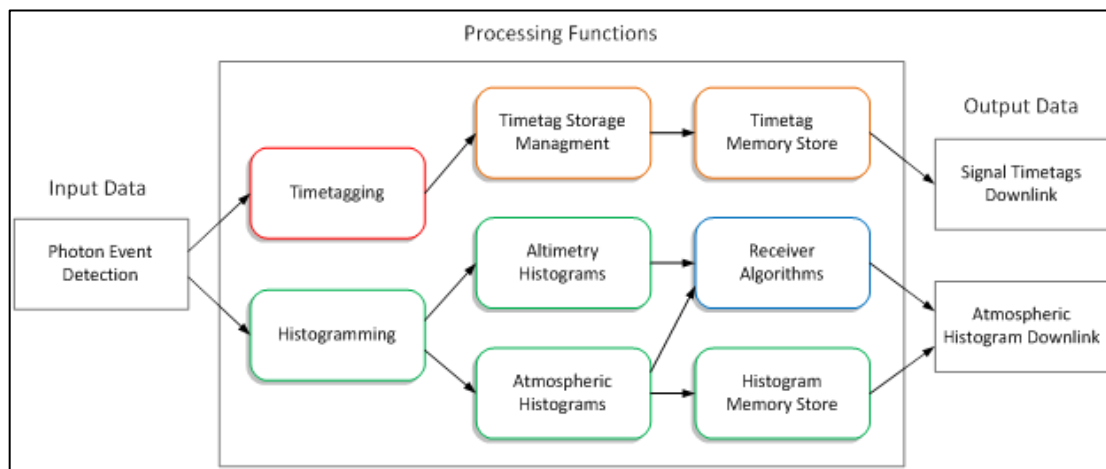

Figure 6. Block diagram illustrating ATLAS on-board data processing.

Three PCE cards perform this function on-board via histogramming and so-called receiver algorithms. Three receiver algorithms run concurrently on three identical processors, one on each of the three PCE cards. Each PCE card contains the electronics for both the strong and weak beams of one reference ground track. The sole purpose of these algorithms is to reduce the volume of telemetry data while maximizing the probability of downlinking surface returns.

To that end, these algorithms count the received photon events and generate histograms to aid the statistical signal processing. The receiver algorithms also select the signal location around the ground and instruct the hardware to telemeter a vertical band of received time-tags about this location in real-time. To achieve this, the algorithms set a vertical range window between -500

meters (i.e., below ground) and 6 kilometers, bin the histograms at 3 meters, and time-tag photon events within the bins over 200 consecutive laser shots.

The width of the horizontal range window depends on the surface type (for example, ocean, land ice, or land) as well as the topography. Concurrently, the algorithms generate atmospheric histograms (strong beams only) that aggregate photon events within 30-meter bins over 400 consecutive laser shots. Thus, atmospheric histograms are generated every 0.04 seconds and span 280 meters of along-track distance.

2.2 Acquisition

The ATL01 algorithm unpacks and reformats the Level-0 data and converts it into engineering units. These data, along with ancillary products comprising instrument configuration parameters, calibrations, and ruler clock (Ultra-Stable Oscillator) behavior, are input to ATL02 for processing.

2.3 Processing

Users who are interested in the theory and computations used to generate the ATL02 product should consult the ATL02 ATBD. In general, ATL02 processing converts Level-1A parsed, partially reformatted, and time-ordered telemetry data (ATL01) into science-unit-converted, time-ordered telemetry. ATL02 processing also generates some preliminary products needed by the Level-2, Level-3A, and Level-3B data products. The list of ATL02 products includes but is not limited to:

- All data, including house-keeping and ancillary data, converted to scientific units;
- Reconstructed absolute time-bias corrected TOD for all laser fire times and time tagged data;
- Time of flight (TOF) for each photon event, corrected for known system time biases and time base errors;
- Raw histogram atmospheric profiles, range-corrected to height and aggregated to 25 Hz frames;
- Approximate location for each beam footprint on the WGS 84 reference surface using the Spacecraft GPS position and Spacecraft pointing control data.

2.4 Quality, Errors, and Limitations

A multi-faceted data quality assurance process is applied to the ATL02 data product using the following utilities:

- Custom Python scripts are used for pre-launch validation of the algorithm implementations, telemetry conversions, etc., in the ATLAS Science Algorithm Software (ASAS) code.
- On-board ASAS QA scripts are integrated directly into the utilities which create the ATL02 HDF5 data products. These scripts screen for catastrophic errors in the product and, if

found, halt further processing of the granule. These scripts are executed each time an ATL02 data product is created.

- ICESat-2 Science Computing Facility (SCF) Limit Checking Scripts are used to perform rote limit checks on parameters contained in the HDF5 data products. These scripts check the values contained in the ATL02 product and alert the responsible party when something is out of bounds. Limit checking flags issues that warrant additional investigation but are not severe enough to halt the processing of the granule. These scripts are executed each time an ATL02 data product is created.
- ICESat-2 Instrument Support Facility (ISF) Trending enables tracking of overall trends in the results output by the ATL02 HDF5 data product. Trending is used to evaluate the long-term stability of the ATLAS instrument as well as key parameters that are used to produce the ATL02 HDF5 data products. ISF trends are monitored within the context of operations and engineering judgement. These trends are used to help identify areas where additional investigation may be needed without halting ATL02 product creation.

3   VERSION HISTORY

A summary of the version history is provided in Table 5, followed by a detailed list of changes for the current version.

Table 5. Version History Summary

Version	Release Date
V1	May 2019
V2	October 2019
V3	May 2020
V4	April 2021
V5	November 2021
V6	May 2023

Changes for Version 6 are as follows:

- Corrected the implementation of the computation of receiver sensitivity as a function of transmit/receive misalignment.
- Updated calibration data products that affect computation of TOF, i.e., delay line cell widths, receiver channel skews, and start skews.

4   DOCUMENT INFORMATION

4.1 Publication Date

May 2023

4.2 Date Last Updated

February 2024