ATLAS/ICESat-2 L3A Along Track Coastal and Nearshore Bathymetry, Version 2

USER GUIDE

How to Cite These Data

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

Magruder, L. A., Parrish, C. E., Perry, J., Swinski, J. P., Holwill, M., Kief, K., & Corcoran, F. (2026). *ATLAS/ICESat-2 L3A Along Track Coastal and Nearshore Bathymetry* (ATL24, Version 2). [Data set]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ATLAS/ATL24.002 [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ATL24

National Snow and Ice Data Center

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1 DATA DESCRIPTION

This user guide refers to the Ice, Cloud and Land Elevation Satellite 2 (ICESat-2) Algorithm Theoretical Basis Document (ATBD) for Coastal and Nearshore Along-Track Bathymetry Product (ATL24) (Magruder et al., 2026).

1.1 Summary

ATL24 provides global along-track coastal and nearshore bathymetry, consisting of refraction-corrected seafloor and sea surface heights (orthometric and ellipsoidal heights and instantaneous depths), as well as associated uncertainties. The data are derived from ATLAS/ICESat-2 L2A Global Geolocated Photon Data (ATL03).

1.2 File Information

1.2.1 Format

The data are provided as HDF5-formatted files.

1.2.2 File Contents

Within data files, similar variables such as science data, instrument parameters, and ancillary data are grouped together. Figure 1 shows the top-level groups in ATL24 data files.

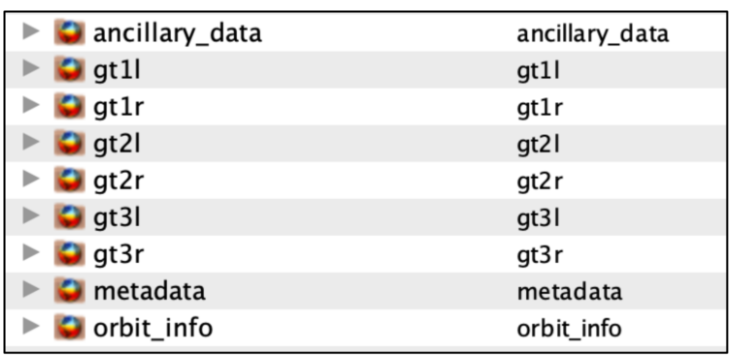

Figure 1. ATL24 top-level data groups.

The main science parameters are coastal bathymetry (e.g., `gt1l/class_ph`, `gt1l/ortho_h`) and sea surface height (e.g., `gt1l/surface_h`). The following sections describe the data groups.

1.2.2.1 ancillary_data

Information that is ancillary to the data product. This may include product and instrument characteristics and/or processing constants.

1.2.2.2 gt1l–gt3r

Six ground track groups (gt1l–gt3r) that contain the per-beam data parameters for the specified ATLAS ground track, as follows:

- `class_ph`: classification of photon (0 = unclassified, 1 = other, 40 = bathymetry, 41 = sea surface)
- `confidence`: floating point value in the range 0 to 1 indicating the confidence in the point classification from the ensemble output statistics
- `delta_time`: the transmit time of a given photon, measured in seconds from the ATLAS Standard Data Product Epoch
- `ellipse_h`: WGS84 ellipsoid height of photon (m)
- `index_ph`: unique index of photon in corresponding ATL03 file
- `index_seg`: segment index
- `invalid_kd`: binary flag that indicates the absence (value = 1) of Visible Infrared Imaging Radiometer Suite (VIIRS) data within the required timespan around the ATL03 acquisition time-tag; when VIIRS diffuse attenuation coefficient of downwelling irradiance is available, the flag is equal to 0
- `invalid_wind_speed:` binary flag that indicates the absence (value = 1) of ATL09 wind speed, which is used in the uncertainty estimation; when wind speed is available, the flag is equal to 0
- `lat_ph`: ITRF2014 latitude of each received photon (degrees north); computed from the Earth Centered Earth Fixed Cartesian coordinates of the bounce point
- `lon_ph`: ITRF2014 longitude of each received photon (degrees east); computed from the Earth Centered Earth Fixed Cartesian coordinates of the bounce point
- `low_confidence_flag:` binary flag that indicates which photons classified as sea floor have an ensemble confidence value (based on `confidence`) lower than 0.6
- `night_flag:` binary flag that indicates when the data were acquired in the absence of sunlight
- `ortho_h`: refraction-corrected orthometric height of each received photon based on the EGM08 geoid model (m)
- `sensor_depth_exceeded:` binary flag that indicates when the ATL24 photon depth is reasonable (value = 0) or outside of the sensor capability (value = 1)
- `sigma_thu`: total horizontal uncertainty (1-sigma) (m), which is the square root of the sum of the squares of the aerial and subaqueous horizontal uncertainty for each received photon
- `sigma_tvu`: total vertical uncertainty (1-sigma) (m), which is the square root of the sum of the squares of the aerial and subaqueous vertical uncertainty for each received photon
- `surface_h`: orthometric height (m) of the sea surface at the detected photon based on the EGM08 geoid model
- `x_atc`: along-track distance (m) in a segment projected to the ellipsoid of the received photon
- `y_atc`: across-track distance (m) projected to the ellipsoid of the received photon from the reference ground track (RGT)

1.2.2.3 metadata

ATL24 metadata (algorithm versioning and build information), query metadata (geospatial and temporal extents), SlideRule metadata (sliderule server and request information), and a "DatasetIdentification" group.

1.2.2.4 orbit_info

Orbit parameters that are constant for a granule, such as the RGT number, cycle, and spacecraft orientation.

> A complete list of ATL24 parameters is available in the ATL24 Data Dictionary.

1.2.3 Naming Convention

Data files utilize the following naming convention:

`ATL24_[yyyymmdd][hhmmss]_[ttttccss]_[VVV_RR]_[vvv_rr].h5`

Example:

`ATL24_20181014001049_02350102_006_02_002_01.h5`

The following table describes the file naming convention variables:

Table 1. File Naming Convention Variables and Descriptions

Variable	Description
ATL24	ATLAS/ICESat-2 L3A Along Track Coastal and Nearshore Bathymetry
yyyymmdd	Year, month, and day of data acquisition
hhmmss	Data acquisition start time, hour, minute, and second (UTC)
tttt	Four-digit RGT number. The ICESat-2 mission has 1,387 RGTs, numbered from 0001 to 1387.
cc	Cycle number. The cycle number tracks the number of 91-day periods that have elapsed since ICESat-2 entered the science orbit.
ss	Region number. ATL03 data files are segmented into approximately 1/14th of an orbit. Region numbers range from 01 to 14. Note that some regions may not be available.
VVV_RR	Version and revision number of the input ATL03 files*.
vvv_rr	Version and revision number of the ATL24 product*.

*Occasionally, 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 region 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.

1.3 Spatial Information

1.3.1 Coverage

- Horizontal spatial coverage is nearly global, with latitudes constrained between approximately 88° N and 88° S
- Vertical spatial coverage is sea level to approximately 100 m below the EGM08 geoid. Note that this theoretical maximum may not be achievable in practice, even in the clearest waters.

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, however, that the number of photons that return to the telescope depends on surface reflectivity and cloud cover (which obscures ATLAS's view of Earth). Importantly, the number of bathymetric photon returns critically depends on the water depth, turbidity, and seafloor reflectance. As such, the spatial resolution of the retrieved parameters varies.

1.3.3 Geolocation

World Geodetic System 1984 (EPSG 4326) and ITRF2014 (EPSG 7789).

> The reference frame corresponds to that of the ATL03 input files. ITRF2014 will be replaced with ITRF2020 with the release of ATL03 v7. Orthometric heights are based on the EGM08 geoid model.

1.4 Temporal Information

1.4.1 Coverage

Temporal coverage is 14 October 2018 through the most current processing of ATL03.

> Note: Temporal updates to the product are made available to users a few times per year; these new files are not reflected in the Version History section of the user guide.

1.4.2 Resolution

Each of ICESat-2's 1,387 RGTs is targeted in the polar regions once every 91 days (i.e., the satellite has a 91-day repeat cycle). Note that satellite maneuvers, data downlink issues, and other events can introduce data gaps into the ICESat-2 suite of products. ATL03 acts as the bridge between the lower-level, instrumentation-specific data and the higher-level products. On the data set landing page under "Documentation", users can download and consult a regularly updated list of ATL03 data gaps (.xlsx).

Each data file covers approximately 6.5 arcminutes.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

ATLAS's 532 nm wavelength signal can penetrate water, providing shallow nearshore bathymetric data that are important for coastal and marine science, management, marine navigation, and engineering applications. Due to the micro-pulse energy level and distance between the spacecraft and the Earth’s surface, the bathymetric measurement capabilities of ICESat-2 were not well-known before the satellite's launch. ATLAS has since demonstrated the ability to reach depths of up to 40 m in some environments. ATL24 provides automated bathymetry extraction, sea surface and wave parameters, and water column statistics in all regions that provide adequate conditions for probable measurements.

On-demand and customizable, science-ready bathymetry is also available via SlideRule, a public web application programming interface for processing of science data in the cloud.

2.2 Acquisition

ATL03 provides heights above the WGS84 ellipsoid, the latitude and longitude, and time for every ATLAS photon detection. These values and data quality flags are the primary input to ATL24.

2.3 Processing

The ATL24 workflow utilizes an ensemble of classification models to handle the full extent of seafloor types, morphologies, depth ranges, water types, and cover types that exist throughout coastal and nearshore areas, as described in the following sections. See "Section 4.4 Classification Algorithms" of the ATL24 ATBD for full details (Magruder et al., 2026). Use of a bathymetric search mask (Figure 2) drastically reduces computation time by removing data that are on land or too deep/turbid for measurement. An additional density-based algorithm was run on all candidate bathymetry photons to determine a final classification.

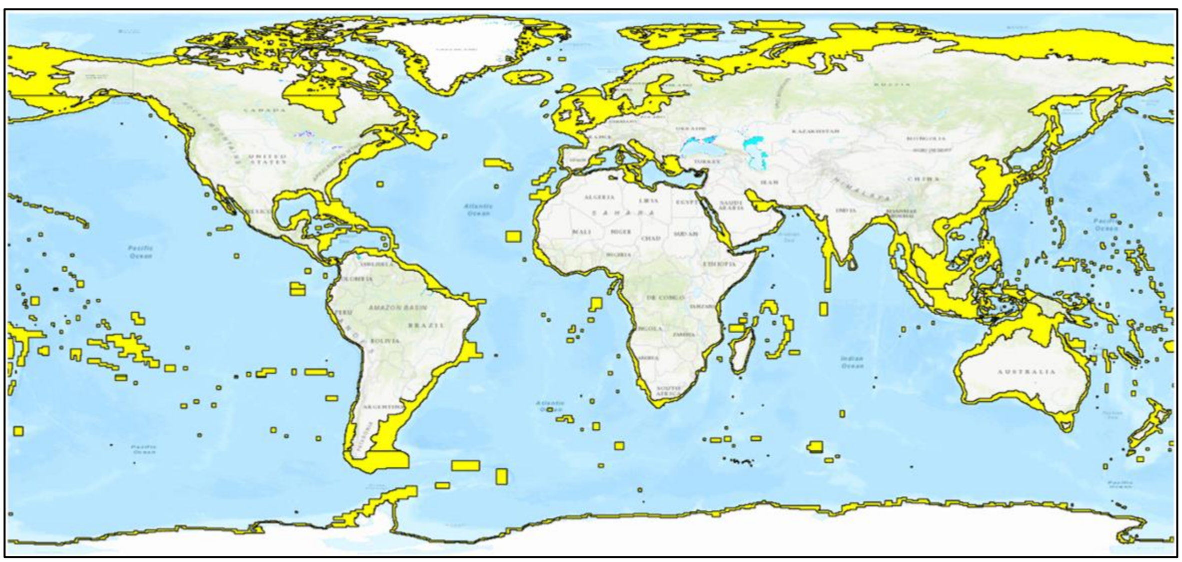

Figure 2. Global bathymetric search mask (from Magruder et al., 2025).

2.3.1 Classification Models

2.3.1.1 CoastNet Classification

CoastNet monitors ecosystems of the Portuguese Coast in near real-time. CoastNet employs a convolutional neural network designed for network architectures with significant depth and can effectively extract spatial features from input images. Fixed-size samples are selected from a 2D raster of the along-track profile, then training sample pixels are determined to contain or not contain a photon. The network then determines if each sample contains a noise photon, a bathymetry photon, or a sea surface photon at its center.

2.3.1.2 BathyPathFinder Classification

This bathymetric surface extraction algorithm leverages techniques from network analysis to extract a representative sample of seafloor photon returns from an ATLAS profile containing bathymetry. All subaqueous photon returns are organized into a weighted, undirected graph. The edges are weighted proportional to the distance between the pairs of photons to which they are connected. Edges with outlier weights are removed, and the algorithm selects pairs of “target” and “source” photons that represent photons at either end of a contiguous bathymetry surface. Using the target and source pairs, the algorithm performs an optimal “least-cost” network traversal. The photons that connect the target and source photons are then extracted and classified as bathymetry.

2.3.1.3 OpenOceans Classification

OpenOceans is designed to leverage physical processes and principles for sea surface, seafloor, and water column photon classifications. The approach involves first generating a histogram of photon return heights through vertical binning of photon returns within a defined horizontal along-track window. The sea surface peak is then identified. Next, a set of Gaussian functions is fit to the histogram (a process known as Gaussian mixture model fitting), and bathymetry peaks are extracted. These bathymetry peaks are then refined and used to classify seafloor points. The final step involves calculating confidence values and implementing quality checks.

2.3.1.4 PointNet++ Classification

PointNet++ is a seafloor point classification model that is effective for segmentation of point clouds. After preprocessing, the photons are divided into groups of 8192 with easting, northing, EGM08 orthometric height, and maximum signal confidence. The values of these features are normalized, and any “remainder” photons after division are added to a photon group that has been padded out to 8192 to preserve input size; all padded photons have feature values of “1”. A group of photons are then passed into the prediction model, and the output of the prediction model assigns each photon a classification value of “0” (non-bathymetric point) and “1” (bathymetric point). At this time, the PointNet++ algorithm is not being used in the ensemble, but it may be activated at a future date.

2.3.1.5 Median Filter Classification

Median Filter is a simple empirical method for extracting bathymetry profiles from ICESat-2 data. For ATL24, all ATL03 photon ellipsoid heights are converted to orthometric heights (EGM08), and all photons more than 1.5 m below the sea surface median are retained. The method calculates median elevations for 50-photon windows and a moving standard deviation of elevations for 30-photon windows. Photons remaining after filtering are separated into 0.001º latitude segments. Segments with more than 14 photons are considered bathymetry.

2.3.1.6 Quantile Trees Classification

Quantile Trees arranges ground track profiles as 2D profile images. For each photon, the algorithm constructs an image centered on the target photon, and the distribution of photons within columns is placed into quantiles. The quantile bins in each column of the image are then used as features for a supervised learning algorithm (XGBoost). The algorithm then trains on ground tracks from hundreds of labeled data sets to produce a model that can predict noise, sea surface, and bathymetry labels for any given input ground track.

2.3.1.7 C-SHELPh Classification

The Classification of Sub-aquatic Height Extracted Photons (C-SHELPh) algorithm is an open-source tool for producing bathymetric maps. The algorithm detects the dense clustering of photons indicative of surface returns. A gridding convention provides surface heights and along-track latitudes, where 0 m is the ocean surface. The ATL24 implementation of C-SHELPh bins photons into 0.001º along-track blocks and 0.5 m vertical blocks. The number of photons in each block is counted, and a threshold is calculated based on the number of photons in all blocks. Quantile Trees provides the surface input, and the threshold is calculated for 85% and 65%.

2.3.1.8 Ensemble Classification

The supervised stacking ensemble method uses predictions from the other classifiers as inputs to predict a final classification, allowing the model to learn which combinations of predictions produce the best results. Further, more features can be added to the classifier to learn which models (mentioned above) to trust under certain conditions. Importantly, the ensemble outputs a confidence score, which provides a method of evaluating the confidence of the classification (sea surface or seafloor).

2.3.1.9 Blunder Detection

Blunder detection is a series of simple post-processing checks that ensure the classifications and elevation estimates are logical: surface elevation check, bathymetry elevation check, bathymetry relative elevation check, surface range check, and bathymetry range check. Additionally, the blunder detection re-labels stray (outlier) bathymetry photons from Class 40 to Class 0.

2.3.2 Refraction Correction

Refraction correction accounts for the change in direction and speed of laser light at the air-water interface when computing corrected spatial coordinates of seafloor points. The index of refraction of water is an important parameter in this calculation. Temperature and salinity data are used to develop a global refractive index layer with a 0.25º resolution grid.

2.3.3 Computing Uncertainties

ATL24 is tested using the NOAA BlueTopo data set, the best publicly available bathymetric data set, through a series of steps outlined in "Section 5 Performance Assessment and Validation" of the ATL24 ATBD (Magruder et al., 2026).

2.4 Quality, Errors, and Limitations

ATL24 generally has very high amounts of class imbalance: (1) the sea surface often produces a very high number of surface photons relative to the background noise photons; (2) bathymetry is typically very rare, even when selecting ground tracks that lie near coastal regions. Shallow water bathymetry can produce as many photons as the sea surface, whereas photons eventually decrease to zero as depth increases in deep water bathymetry. See "Section 5 Performance Assessment and Validation" of the ATL24 ATBD (Magruder et al., 2026).

3 VERSION HISTORY

Table 2. Version History Summary

Version	Date	Description of Changes
2.0	19 May 2026	• An additional density-based algorithm was run on all candidate bathymetry photons to determine a final classification • The “profile” and “stats” variables under the “/metadata” group were removed because they are not relevant to version 2 • An “atl24” variable under the “/metadata” group was added to capture the specific versioning information related to the new algorithm. This new variable will be used going forward to precisely capture the versioning information of the algorithms that are run. • A “DatasetIdentification” subgroup was added to the “/metadata” group
1.0	1 Apr 2025	Initial release

4 RELATED DATA SETS

ATLAS/ICESat-2 L2A Global Geolocated Photon Data (ATL03)

ATLAS/ICESat-2 L3A Along Track Inland Surface Water Data (ATL13)

5 RELATED WEBSITES

SlideRule Earth Web Service

6 ACKNOWLEDGMENTS

James Dietrich and Jeff Lee

7 REFERENCES

Magruder, L. A., Brunt, K., Neumann, T., Klotz, B., & Alonzo, M. (2020). Passive ground-based optical techniques for monitoring the on-orbit ICESat-2 altimeter geolocation and footprint diameter. *ESS Open Archive*. https://doi.org/10.1002/essoar.10504571.1

Magruder, L. A., Parrish, C., Perry, J., Holwill, M., Swinski, J. P, & Kief, K. (2025). ICESat-2 Coastal and Nearshore Bathymetry Product Algorithm Development. *Earth and Space Science*, *12*(10). https://doi.org/10.1029/2025EA004390

Magruder, L. A., Parrish, C., Perry, J., Swinski, J. P, Holwill, M., Kief, K., & Corcoran, F. (2026). Ice, Cloud and Land Elevation Satellite (ICESat-2) Project Algorithm Theoretical Basis Document (ATBD) for Coastal and Nearshore Along-track Bathymetry Product (ATL24). NASA. https://doi.org/10.5067/UIN5PPVS10WW

8 DOCUMENT INFORMATION

8.1 Publication Date

May 2026

8.2 Date Last Updated

May 2026

APPENDIX A – ICESAT-2/ATLAS DESCRIPTION

The ICESat-2 observatory utilizes a photon-counting lidar (the ATLAS instrument) and ancillary systems (GPS, star tracker cameras, and ground processing) to measure the round-trip time a photon takes to travel from ATLAS to Earth and back again. The time-of-flight, absolute time, spacecraft location and pointing are used to determine the reflected photon's geodetic height, latitude, and longitude.

The ATLAS instrument uses a single laser and a beam splitter to illuminate six different “spots” that each trace out a ~11 m wide track (Magruder et al., 2020) as ICESat-2 orbits Earth (Figure A - 1). Three of the spots are considered “strong” (spots 1, 3, and 5) and the other three “weak” (spots 2, 4, and 6). Three independent Photon Counting Electronics (PCEs) record the photons returned to the telescope, each for a single pair of strong/weak spots. PCE1 records spots 1 and 2; PCE2 records spots 3 and 4; and PCE3 records spots 5 and 6.

Higher-level ATLAS/ICESat-2 data products are organized by ground track (GT), with GT1L and GT1R forming pair one, GT2L and GT2R forming pair two, and GT3L and GT3R forming pair three. Each GT is numbered according to the relative location of the laser spot that generates it, with GT1L on the far left and GT3R on the far right. Left/right beams within each pair are approximately 90 m apart in the across-track direction and 2.5 km in the along-track direction.

The mapping between the strong and weak spots of ATLAS, and their relative positions 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 (Figure A - 1, left), with the weak spots leading the strong spots. In the backward orientation, ATLAS travels along the -x coordinate in the instrument reference frame, with the strong spots leading the weak spots (Figure A - 1, right). Atmospheric profiles are generated from strong spots only, and the instrument orientation determines which GT label ("gtx") corresponds to which profile. The spacecraft orientation is tracked in the ICESat-2 Major Activities document (.xlsx).

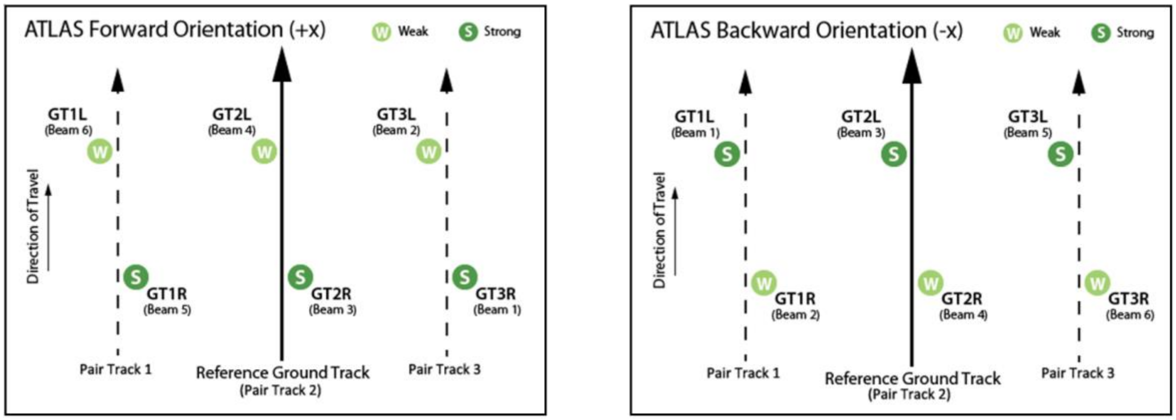

Figure A - 1. Spot and Ground Track (GT) naming convention.

The Reference Ground Track (RGT) is an imaginary track on Earth through the six-spot pattern that is used to point the observatory. 1,387 RGTs are sampled over the course of 91 days, allowing seasonal height changes to be detected. Onboard software aims the laser beams so that the RGT is between GT2L and GT2R (i.e., coincident with Pair Track 2). Nominal RGT pointing occurs over the oceans and polar regions and is periodically adjusted over vegetated land areas to broaden global coverage. 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 by appending the two-digit cycle number (cc) to the RGT number.

Over lower latitudes, the satellite points slightly off the RGT during most cycles to measure canopy and ground heights. Off-pointing began on 1 August 2019 with RGT 518 after the ATLAS/ICESat-2 Precision Pointing Determination (PPD) and Precision Orbit Determination (POD) solutions were adequately resolved, and the instrument had pointed directly at the RGT for at least a full 91 days (1,387 orbits).

NOTE: ICESat-2 RGTs with dates and times can be downloaded as KML files from NASA's ICESat-2 | Technical Specs page, below the Orbit and Coverage table. Pointing plans summarized by cycle and off-pointing angle are posted in the ICESat-2 Major Activities document.

The ATLAS data and data collected from ancillary systems are telemetered to the ground and processed into several data products (Figure A - 2). The ATL01 algorithm reformats and unpacks the Level 0 data and converts it into engineering units. ATL02 processing converts ATL01 data to science units, applies instrument corrections, and produces photon time-of-flight data. The PPD and POD solutions compute the pointing vector and position of the ICESat-2 observatory as a function of time. ATL02, PPD, and POD are used to produce the global geolocated photon data of ATL03 and the normalized relative backscatter profiles of ATL04, which are the base products for all higher-level data sets.

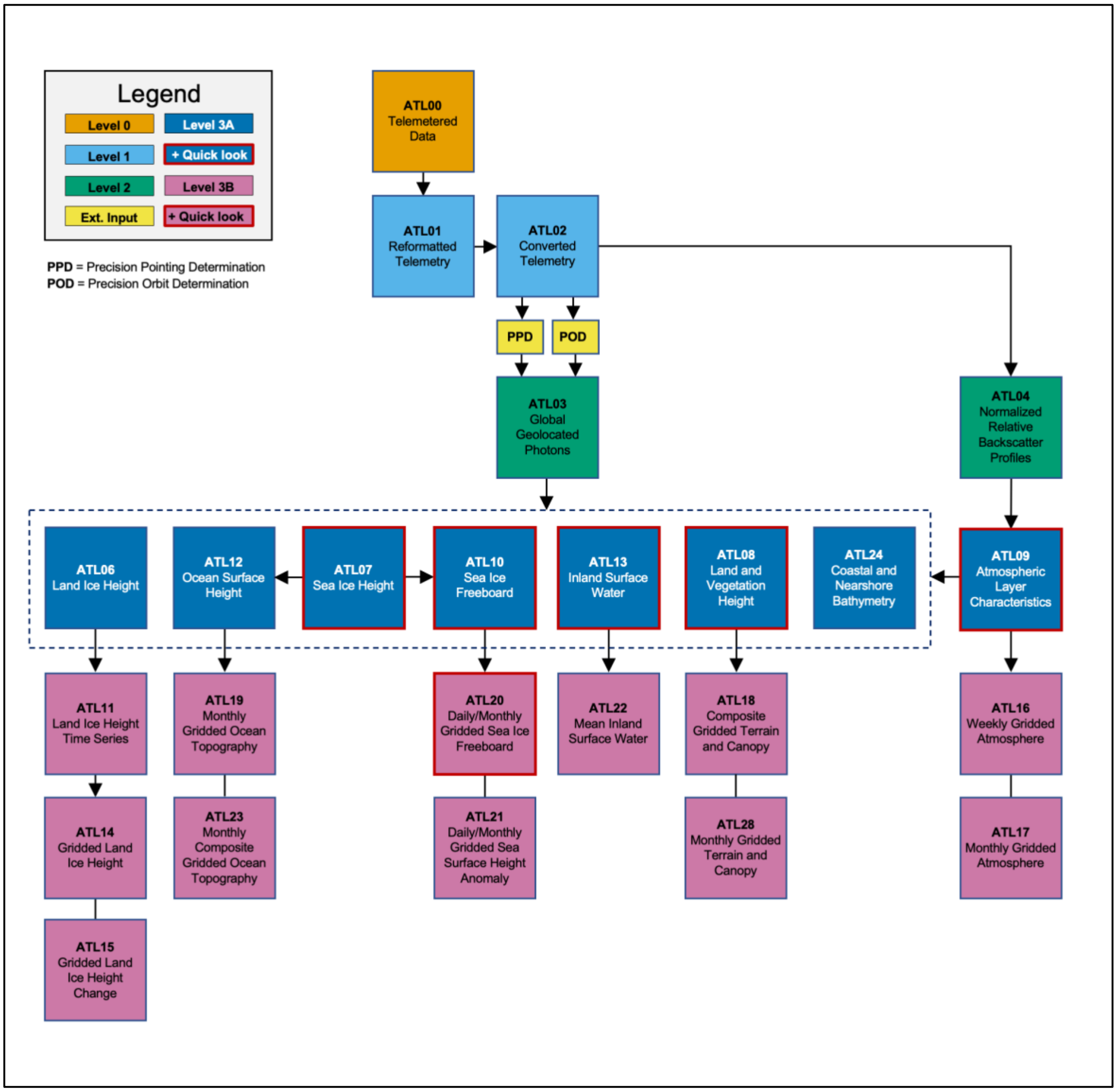

Figure A - 2. Schematic of ICESat-2 data processing and data products.

In satellite altimetry, the reflection point of an emitted signal occurs on an instantaneous and often dynamic planetary surface (Figure A - 3). For ICESat-2, reflective surfaces include oceans, inland water bodies, solid ground, ice, vegetation, and manmade structures. Depending on the product and surface type, geophysical corrections are applied to measurements to account for various time-varying processes (Table A - 1). Upper-level products may undergo additional height corrections, including corrections for pulse shape and instrument characteristics. For more information, refer to the data product's ATBD.

Table A - 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 delay
Land Ice, Land, and Inland Water (ATL06, ATL08, and ATL13)	*No geophysical corrections beyond ATL03*
Sea Ice (ATL07 and ATL10)	ATL03 corrections Referenced to mean sea surface Ocean tide Long period equilibrium ocean tide Dynamic atmosphere correction
Ocean (ATL12)	ATL03 corrections 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.

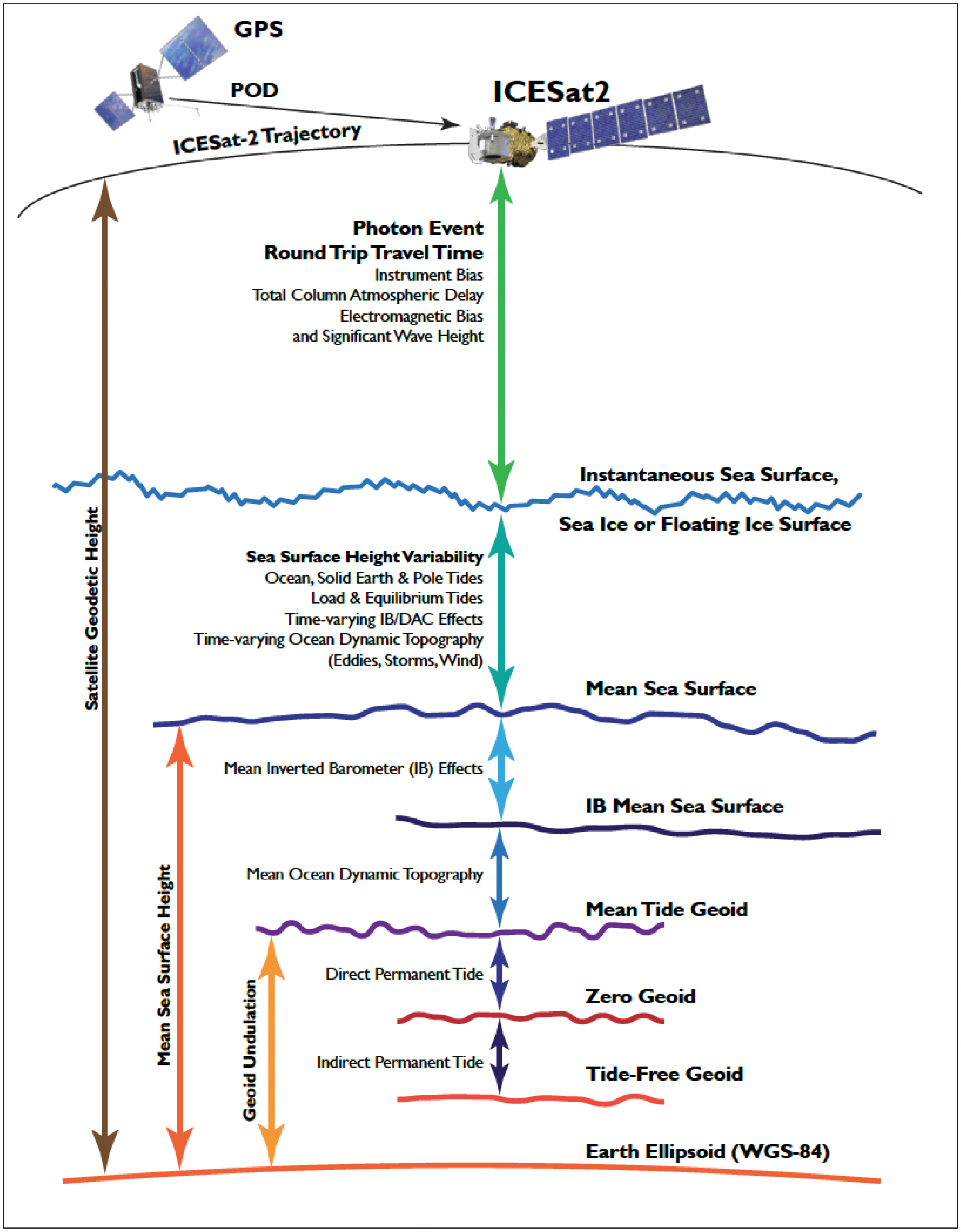

Figure A - 3. Geophysical corrections used in satellite altimetry (Source: *ICESat-2 Data Comparison User's Guide for Rel006,* available on the ATL03 data set landing page).