National Aeronautics and Space Administration

NASA Satellite Laser Altimetry for Coastal and Near-Shore Bathymetry

Part 1: NASA ATL24 Bathymetric Data for Coastal and Near-Shore Applications

Lori Magruder (The University of Texas at Austin), Diane Fritz (NSIDC), Joseph-Paul Swinski (NASA GSFC), & Sean McCartney (NASA GSFC/STC)

December 2, 2025

About ARSET

About ARSET

- **ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.**

- Trainings include a variety of applications of satellite data and are tailored to audiences with a variety of experience levels.

About ARSET Trainings

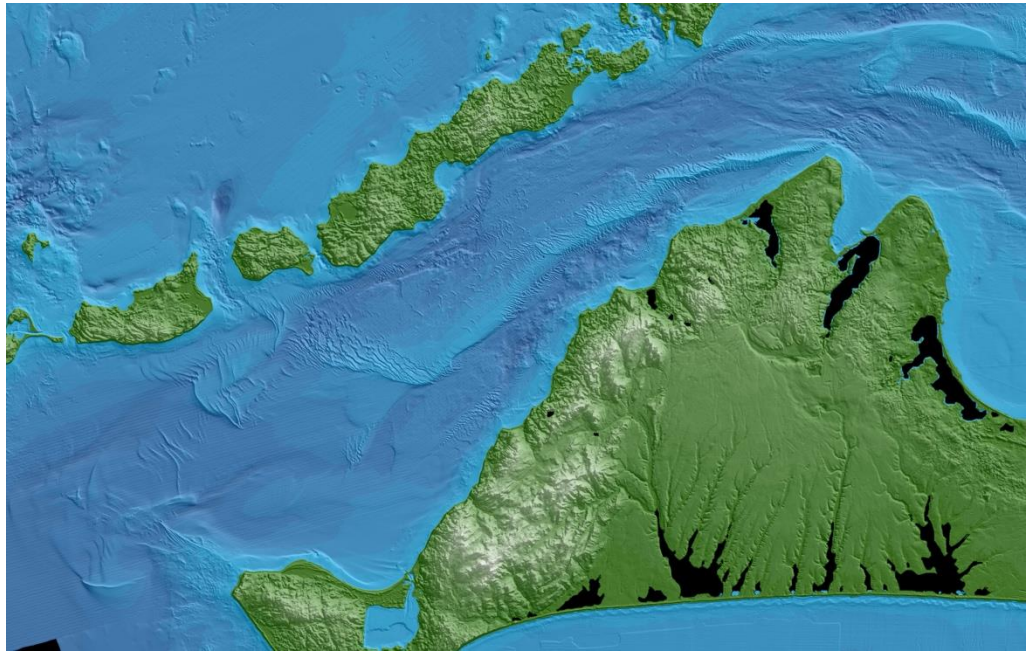
- Online or in-person
- Live and instructor-led or asynchronous and self-paced
- Cost-free
- Bilingual and multilingual options
- Only use open-source software and data
- Accommodate differing levels of expertise

- Visit the ARSET website to learn more.

NASA Satellite Laser Altimetry for Coastal and Near-Shore Bathymetry Overview

Coastal and Nearshore Bathymetry

- Nearly 80% of the world's oceans are unexplored and unmapped (NOAA, 2022).
- Successful coastal management depends on monitoring and mapping.
- Coastal bathymetry is essential for:
  - Navigational hazards for vessel operations
  - Tidal modeling and prediction
  - Tsunami risk assessment and forecasting
  - Underwater cultural heritage preservation
  - Environmental change monitoring
- Satellite derived bathymetry enhances capacity for collecting high-resolution, accurate depth data supporting varied applications.



Continuous Bathymetry and Elevation Models of the Massachusetts Coastal Zone and Continental Shelf, showing the Elizabeth Islands, Vineyard Sound, and Martha's Vineyard. Credit: USGS

Training Learning Objectives

By the end of this training, participants will be able to:

- Identify NASA bathymetry data used for global coastal and near-shore bathymetry mapping for risk reduction relating to shipping and navigation.
- Identify the applications and limitations of ICESat-2 bathymetry data (ATL24) for coastal and near-shore bathymetry mapping.
- Plot and download ICESat-2 bathymetry data (ATL24) using SlideRule Web Client.
- Analyze ICESat-2 bathymetry data (ATL24) using SlideRule Python Client.

Prerequisites

- Fundamentals of Remote Sensing
- Mapping and Monitoring Lakes and Reservoirs with Satellite Observations

Training Outline

Part 1

NASA ATL24 Bathymetric Data for Coastal and Near-Shore Applications

Dec. 2, 2025

Part 2

Techniques for Plotting and Analyzing ATL24 Coastal Bathymetry

Dec. 4, 2025

Homework

Opens December 4 – **Due December 31** – Posted on Training Webpage

A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment(s) before the given due date.

NASA Satellite Laser Altimetry for Coastal and Near-Shore Bathymetry

Part 1: NASA ATL24 Bathymetric Data for Coastal and Near-Shore Applications

Part 1 Objectives

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- Identify the applications and limitations of ICESat-2 bathymetry data (ATL24) for coastal and near-shore bathymetry mapping.
- Plot and download ICESat-2 bathymetry data (ATL24) using SlideRule Web Client.

How to Ask Questions

- Please put your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to get to all of the questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.

Part 1 – Trainers

Lori Magruder

Associate Professor

The University of Texas at Austin

Diane Fritz

Data Support Specialist

National Snow and Ice Data Center (NSIDC)

Joseph-Paul Swinski

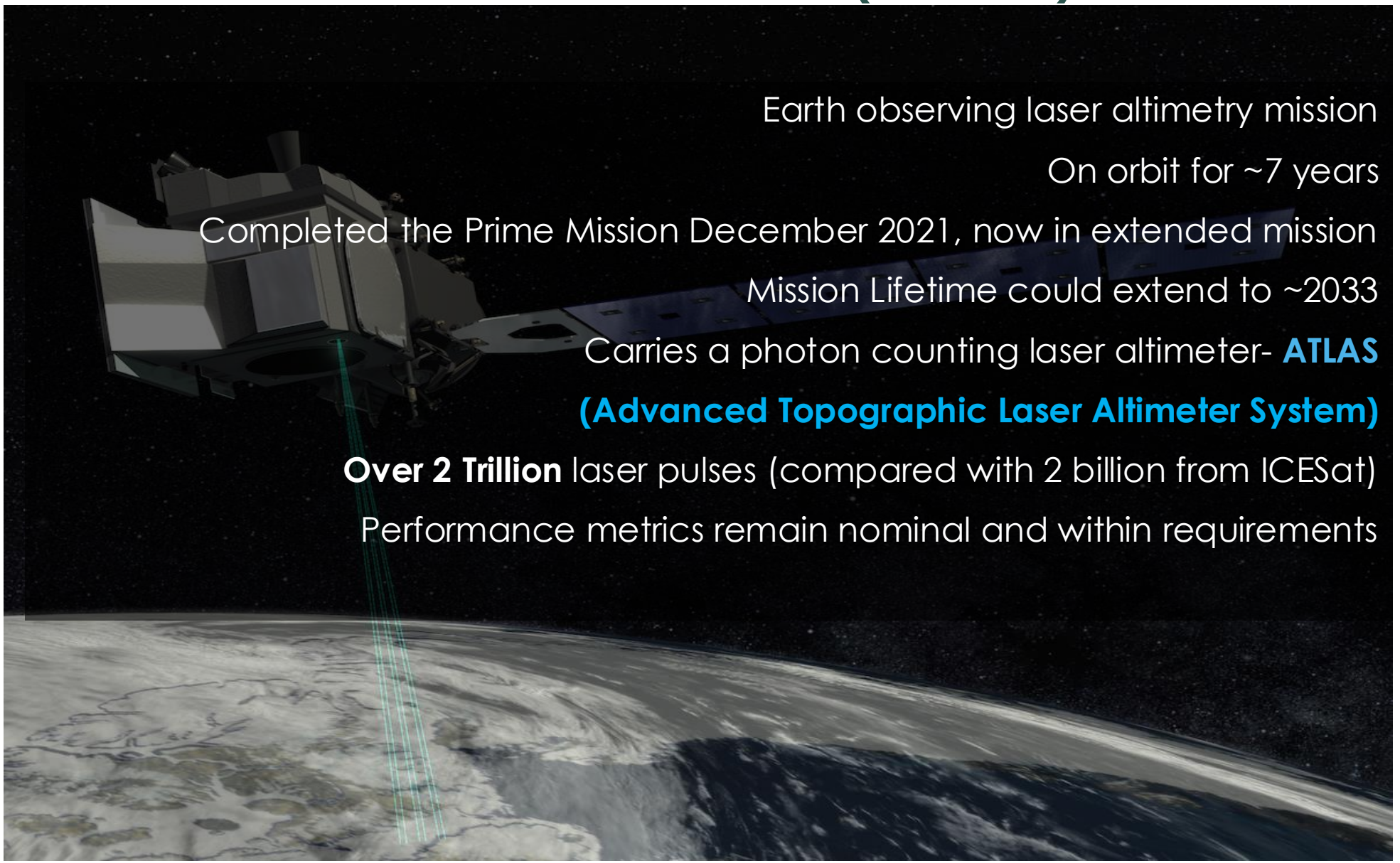
Software Developer

NASA GSFC

ICESat-2 Mission Overview

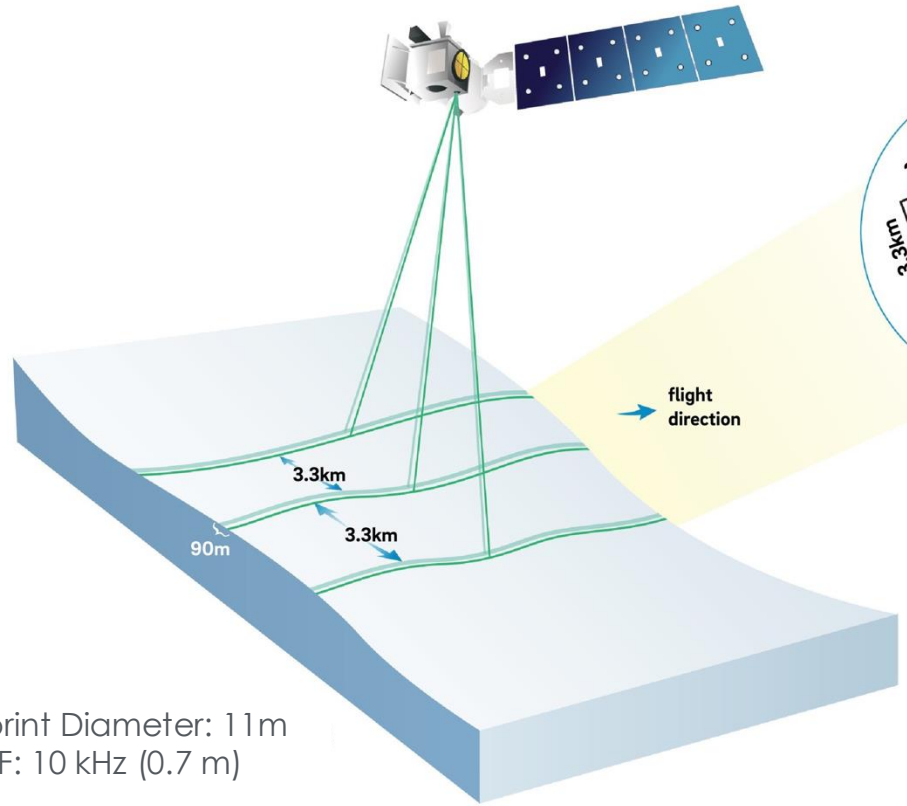
Lori Magruder, Associate Professor | Aerospace Engineering and Engineering Mechanics,
Director Center for Space Research | The University of Texas at Austin

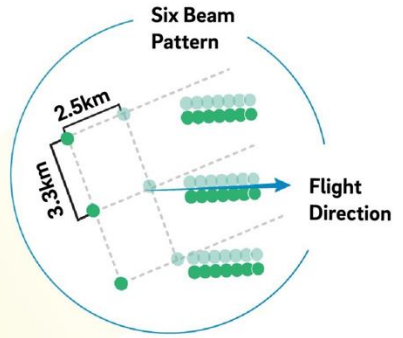
The Ice, Cloud and land Elevation Satellite-2 (ICESat-2)

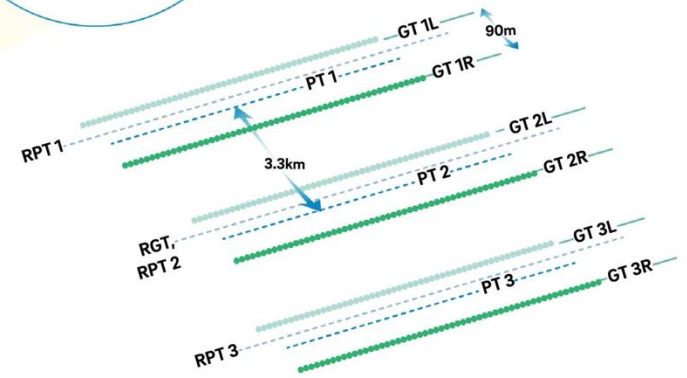


ICESat-2 Collection Strategy

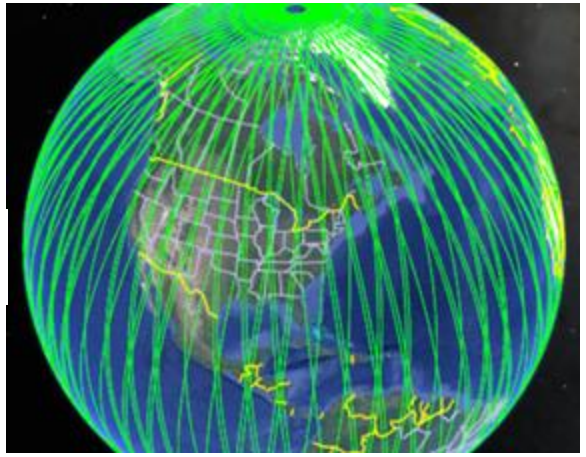
- ATLAS provides 6 individual beams from one Nd:YVO_4 laser at 532 nm wavelength and 1 nsec pulsewidth.
- Each beam provides an elevation profile.
- Beam pairs:
  - Contain a weak and strong beam separated by 90 m across track distance.
  - Are 3.3 km across track distance from other pairs.
  - Change orientation with yaw satellite yaw maneuvers.







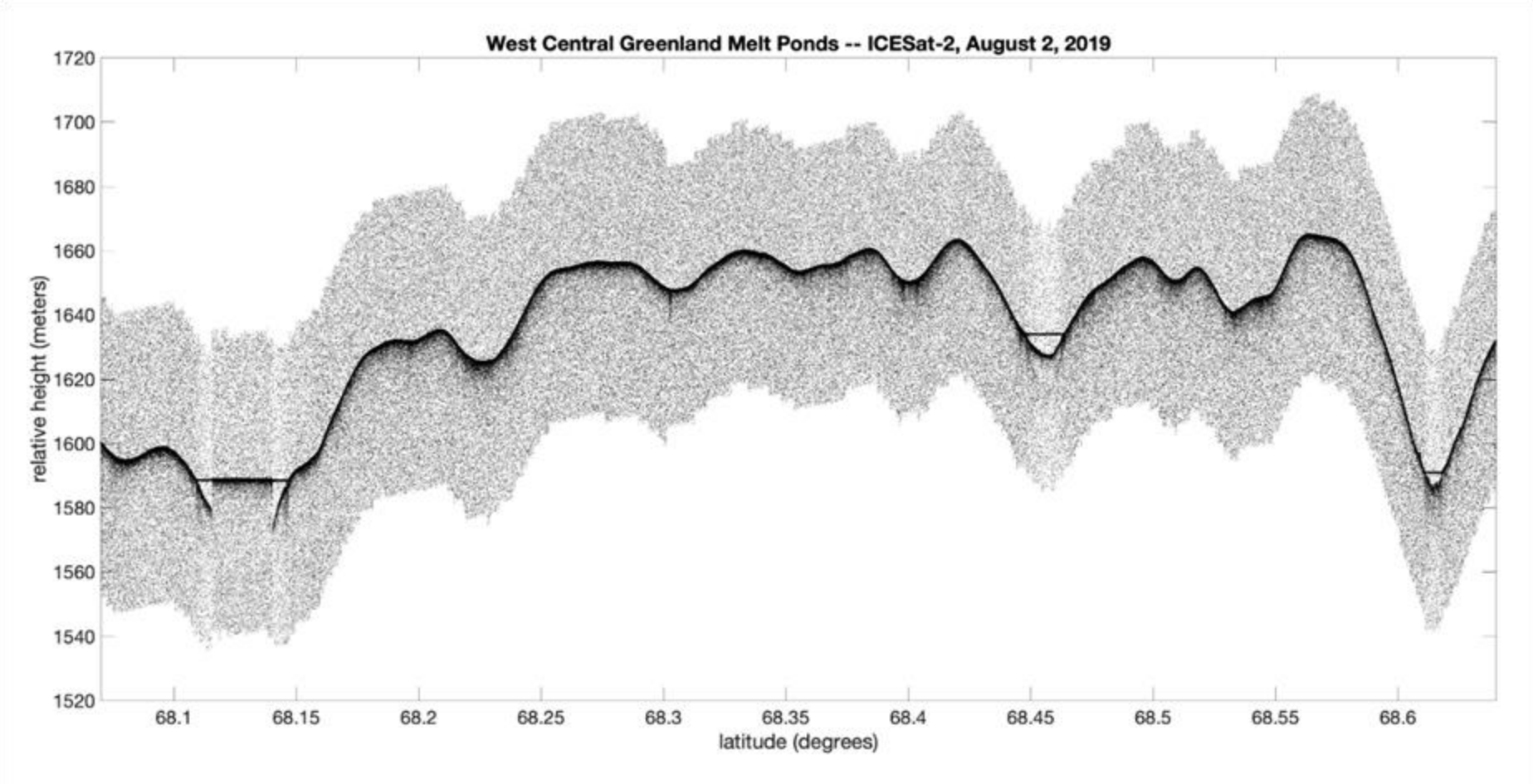
Footprint Diameter: 11m
PRF: 10 kHz (0.7 m)



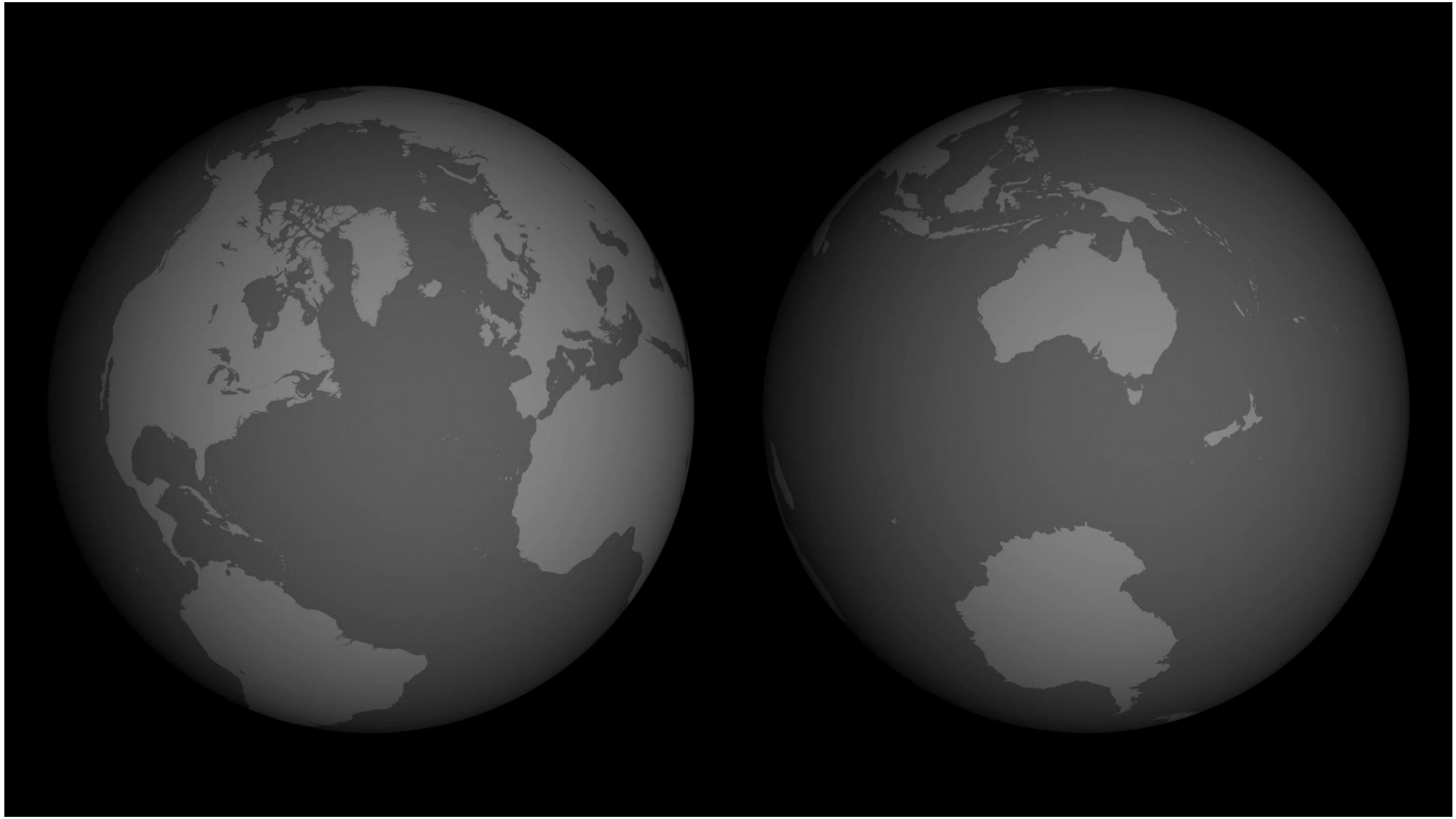
Near global coverage from 88°N to 88°S

What does the ICESat-2 Data Look Like?

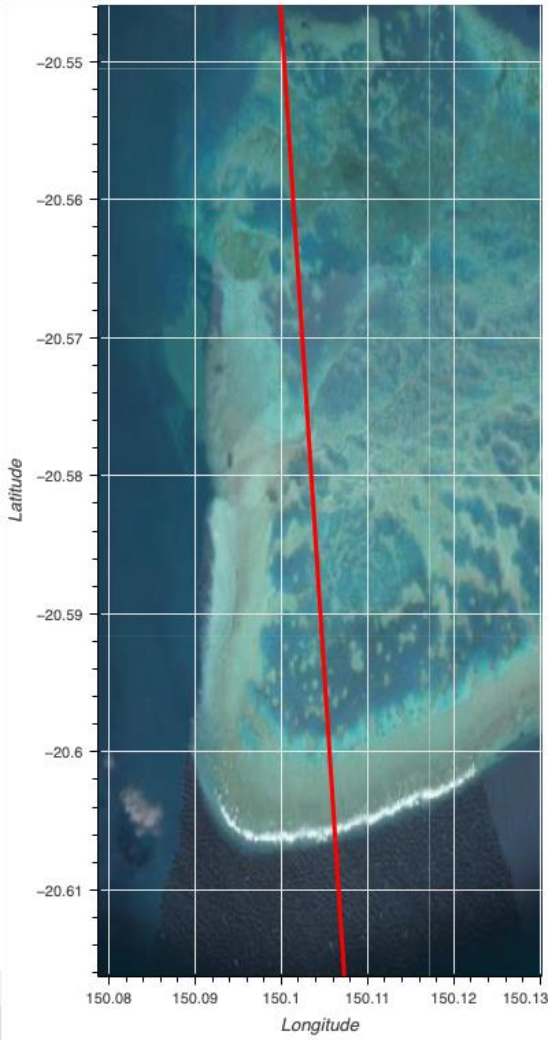
- Every photon detected by ATLAS has a latitude, longitude and elevation.
- Each surface specific ICESat-2 data product uses a unique algorithmic approach for signal finding and photon classification.

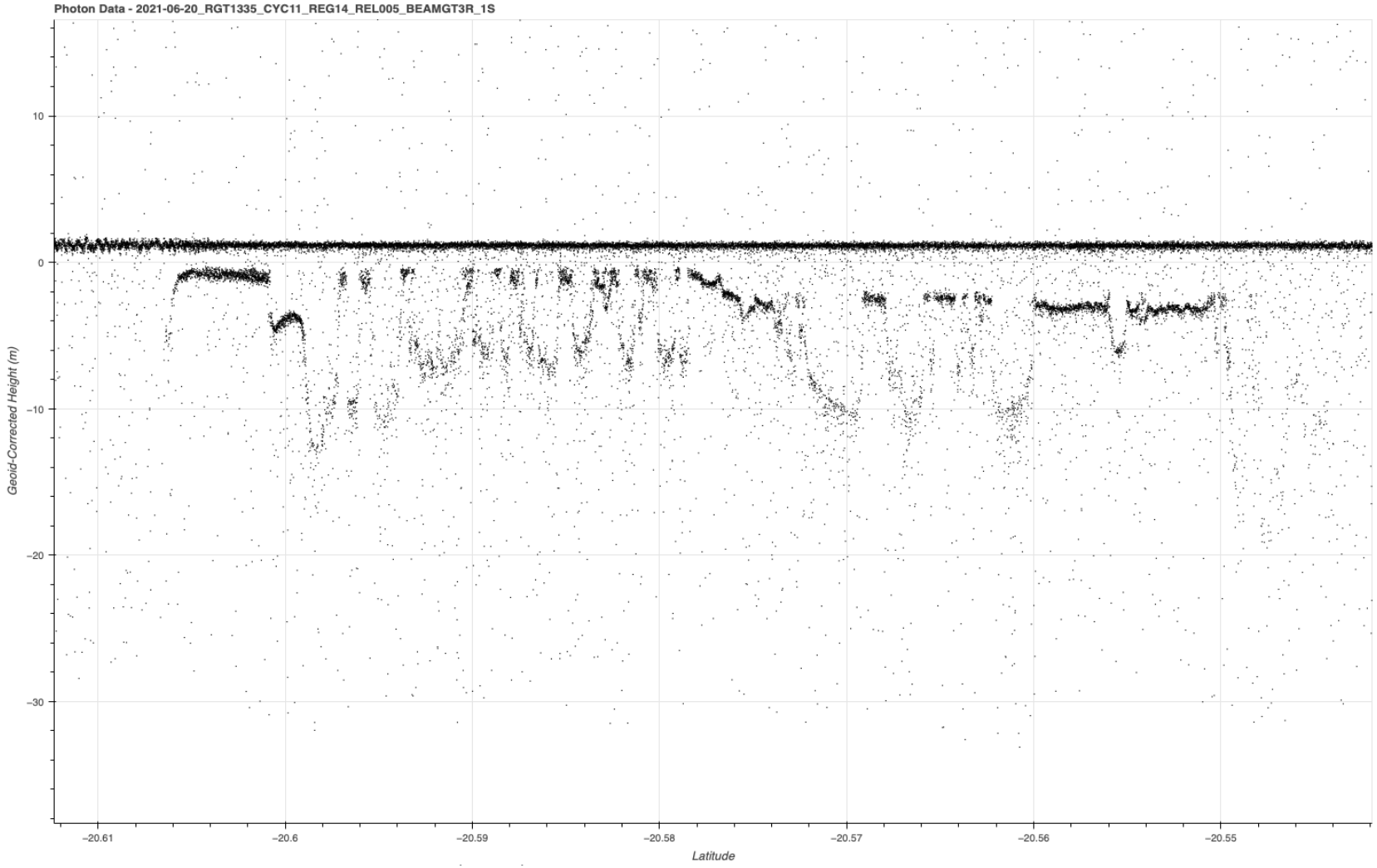


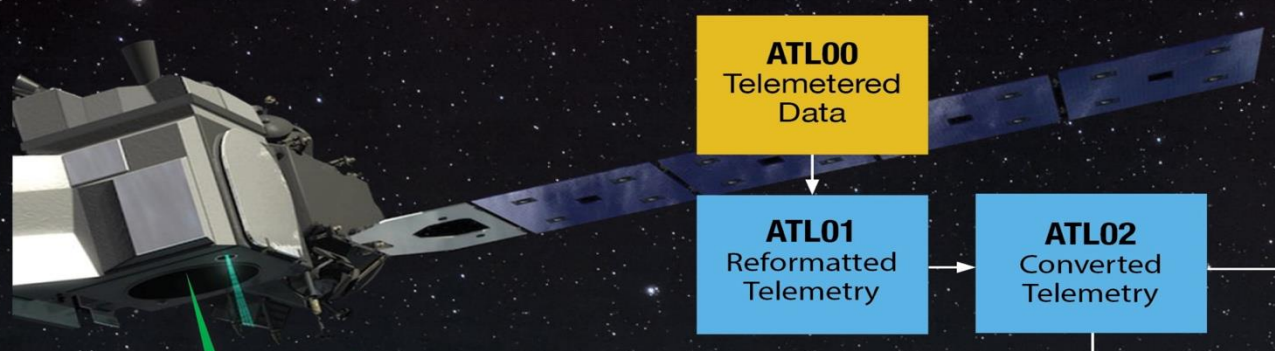
Seven years of Earth elevation data



Big Stevens Reef, Great Barrier Reef







ATL00 Telemetered Data

ATL01 Reformatted Telemetry

ATL02 Converted Telemetry

ATL03 Global Geolocated Photons

ATL04 Normalized Relative Backscatter Profiles

ATL06 Land Ice Height

ATL07 Sea Ice Height

ATL10 Sea Ice Freeboard

ATL08 Land and Vegetation Height

ATL13 Inland Surface Water

ATL12 Ocean Surface Height

ATL24 Bathymetry Product

ATL09 Atmospheric Layer Characteristics

ATL11 Land Ice Height Time Series

ATL14 Gridded Land Ice Height

ATL15 Gridded Land Ice Height Change

ATL20 Daily/Monthly Gridded Sea Ice Freeboard

ATL21 Daily/Monthly Gridded Sea Surface Height Anomaly

ATL18 Gridded Land Vegetation

ATL28 Monthly Gridded Land Vegetation

ATL22 Gridded Inland Surface Water

ATL19 Monthly Gridded Ocean Topography

ATL23 Monthly Composite Gridded Ocean Topography

ATL16 Weekly Gridded Atmosphere

ATL17 Monthly Gridded Atmosphere

LEGEND

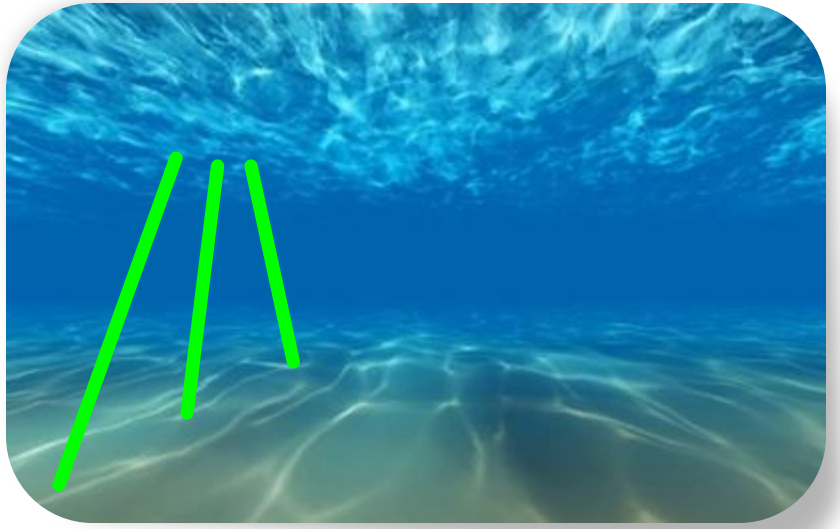
- Level 0
- Level 1
- Level 2
- Level 3A
- + Quicklook
- Level 3B

ICESat-2 Data Products

ATL24- Along-track Bathymetry Product Overview

Coastal and Nearshore Along-track Bathymetry Product (ATL24)

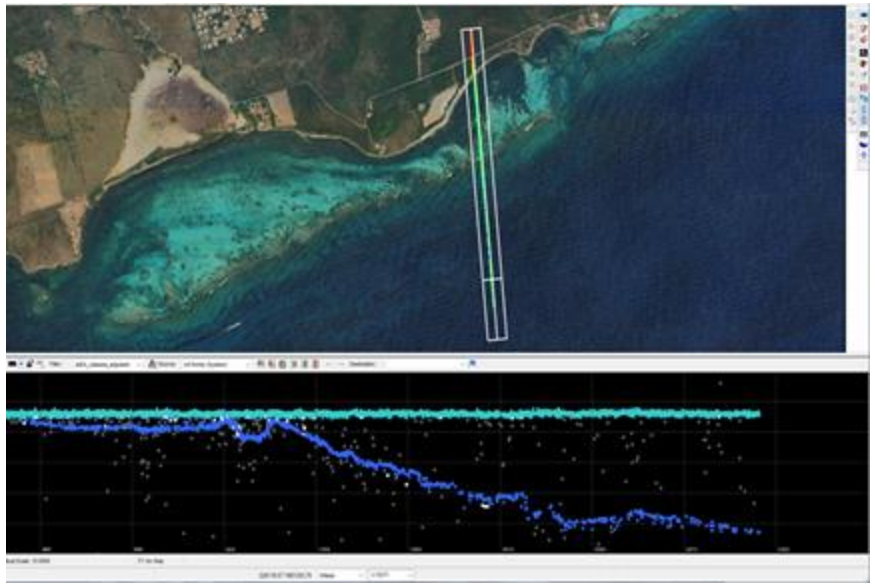
- Dedicated Coastal and Nearshore Along-Track Bathymetry Product
- Supported by ICESat-2 Project Science Office (PSO) as part of extended mission
- Provides:
  - Global photon-level classifications of seafloor and sea surface using ensemble ML model
  - Classification confidence values
  - Refraction-corrected seafloor elevations
  - Per-point uncertainty estimates

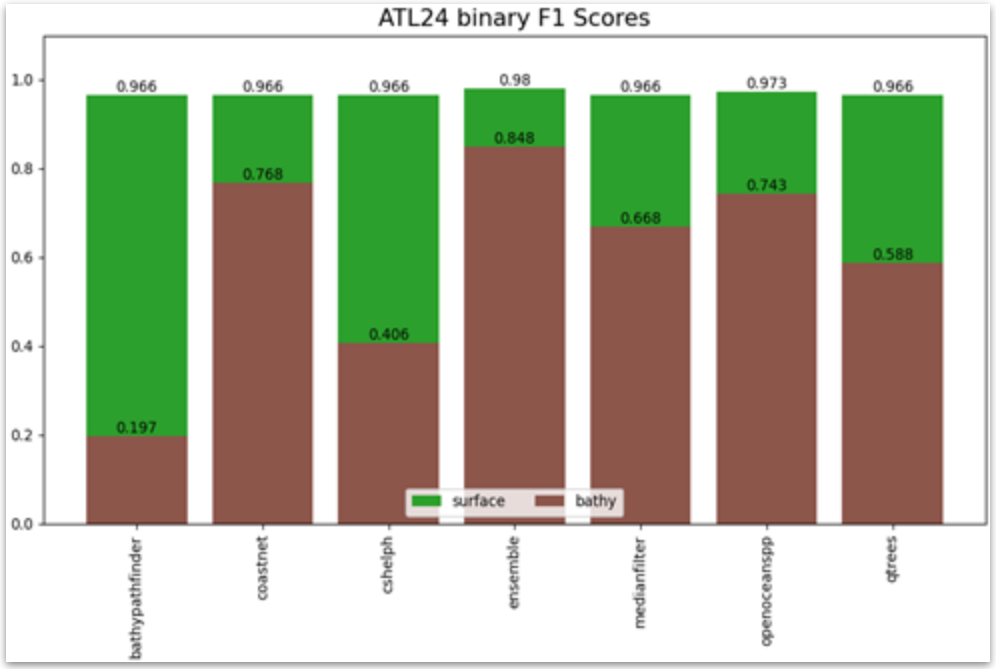


Machine Learning Ensemble Model for Seafloor and Sea Surface Classification

- Auto-classification step is colossal undertaking
  - Needs to:
    - Work globally
      - Global range of seafloor morphologies, coast and water types, wind and wave conditions, etc.
    - Be fully automated
  - No single algorithm or model can provide good results everywhere

- Solution
    - Ensemble ML
      - Leverages strengths of each base model/algorithm; outperforms any individual classifier
      - "Whole is greater than the sum of parts"
      - Another key benefit: provides a classification confidence score





Manually-labeled (reference)

Ensemble

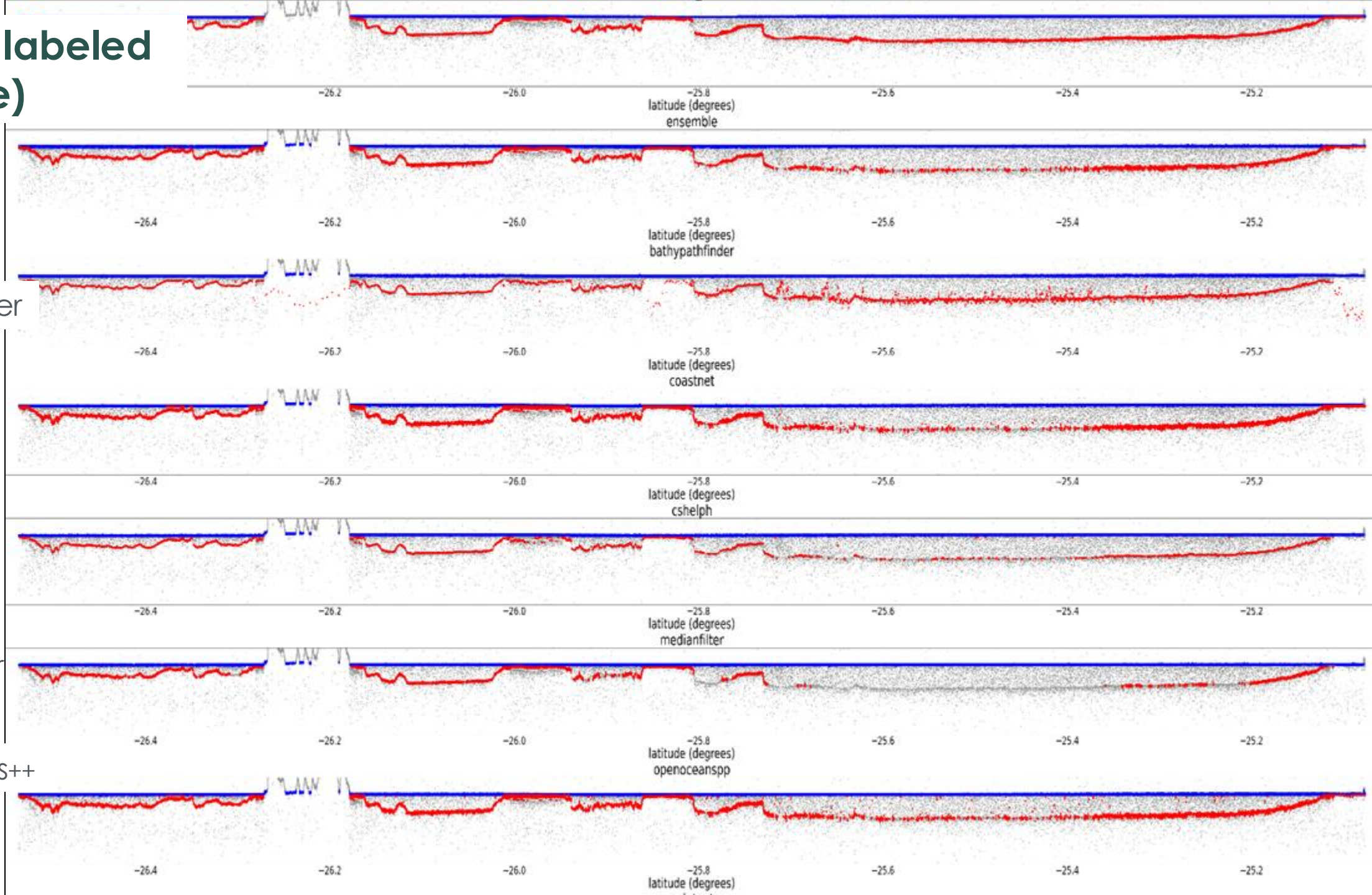
BathyPathfinder

C-SHELPh

CoastNet

Median filter

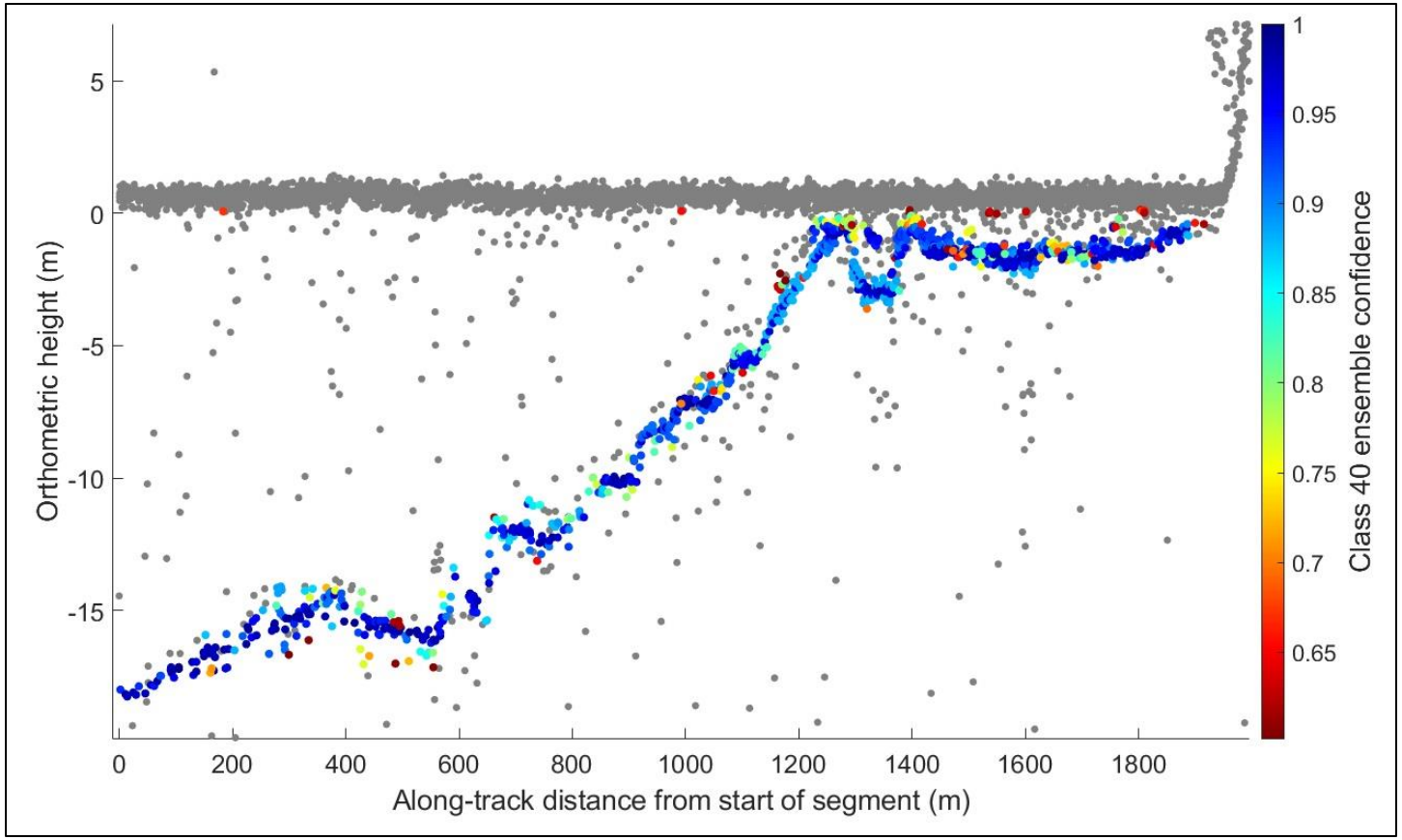
OpenOceans++



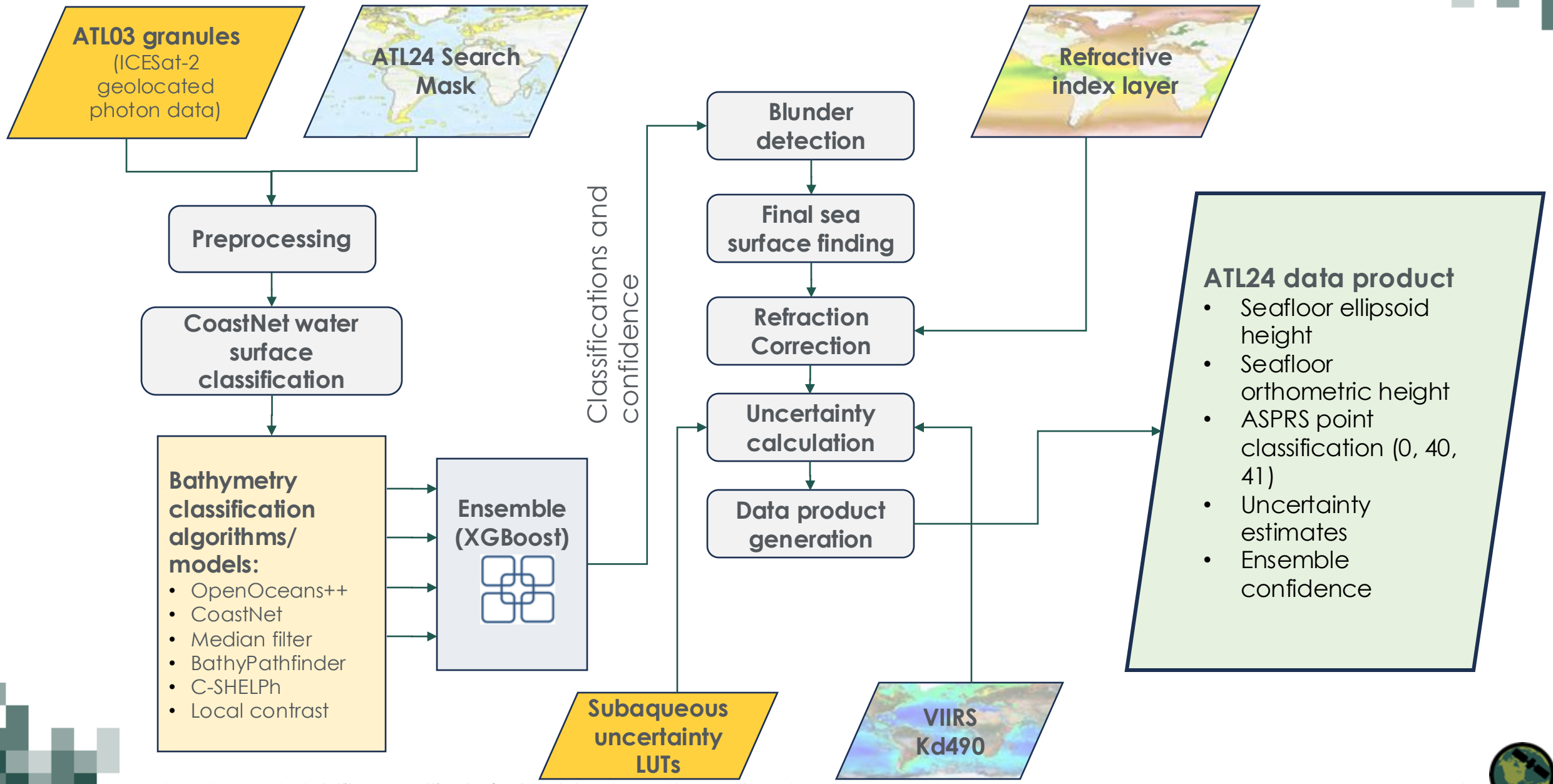
Ensemble Confidence

Opportunity for data filtering

- Each photon classified as bathymetry will have a confidence value assigned.
- This value is a derived metric relative to how many of the ensemble algorithms identified the photon as sea floor.
- ATL24 r001 v1 confidence threshold value (to avoid false positives) is 0.6
- This threshold will change with future data releases/versions.

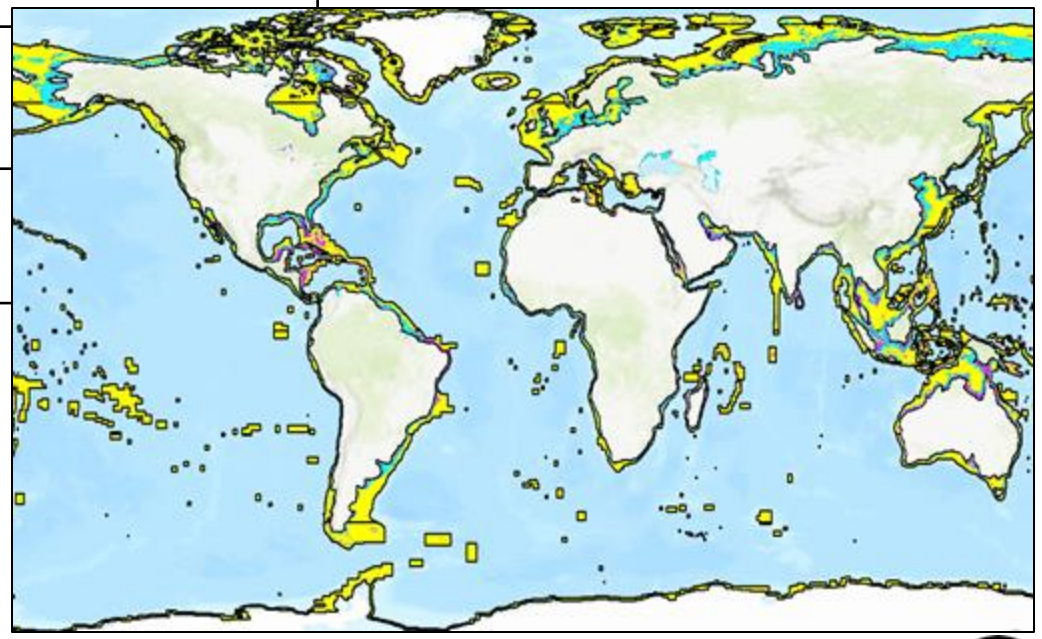


ATL24 algorithm workflow

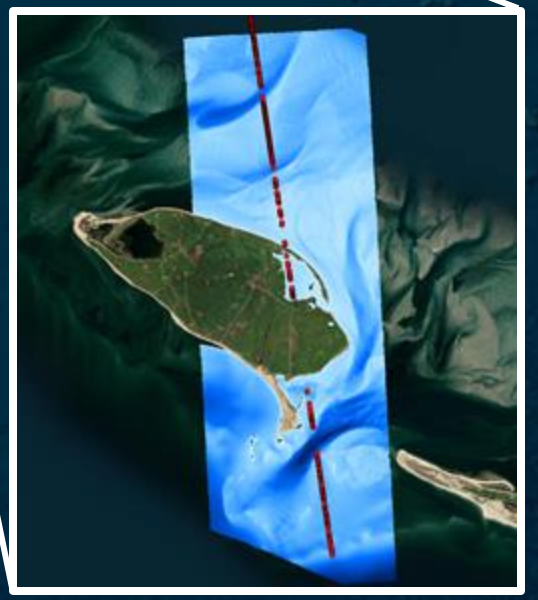


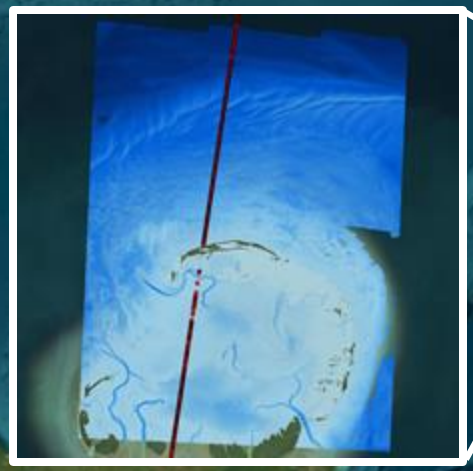
Statistics of ATL24 Version 1, Release 001

Parameter	Value
Processing completion date	February 24, 2025
Processing time	13 days (AWS)
ATL24 data volume	27.6 TB
Total linear coverage of bathymetry	13.7 million km
Number of bathymetry (Class 40) photon returns	7.3 billion
Number of high-confidence bathymetry (Class 40) photon returns (confidence > 0.6)	4.7 billion



ATL24 Accuracy Test Sites





Sandy Neck

Tuckernuck

Hatteras Inlet

Pensacola

Marquesas

Keys

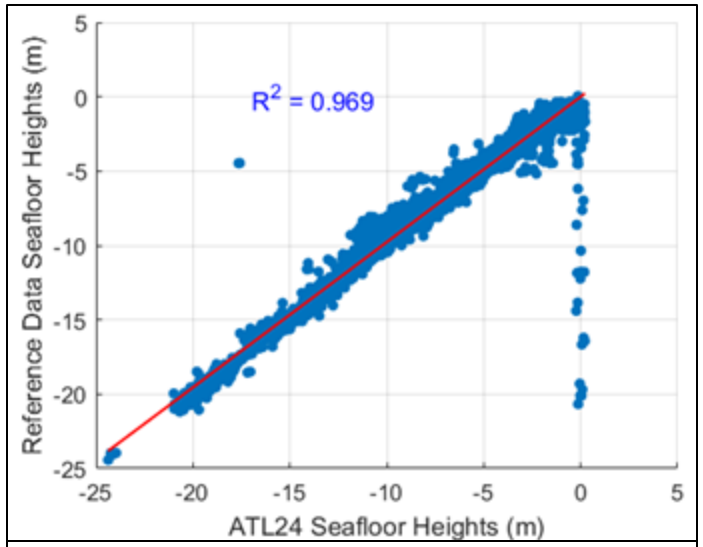
Marathon

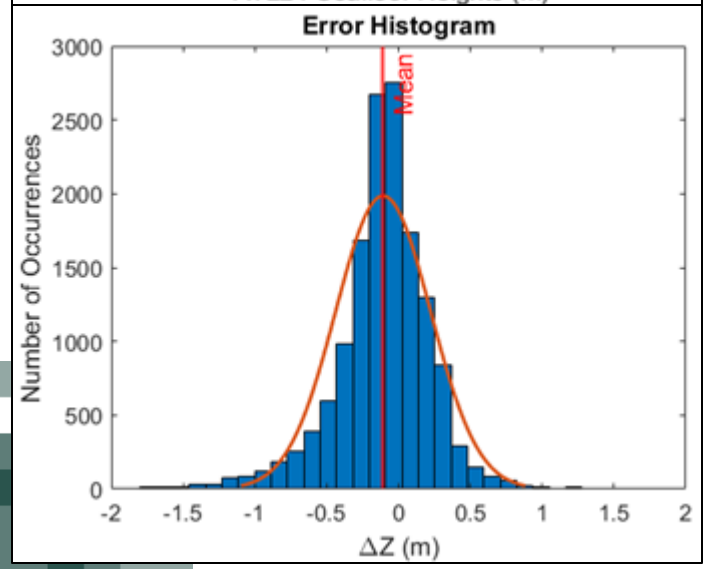
Mosquito Pier

Robin Bay

Accuracy Test Results

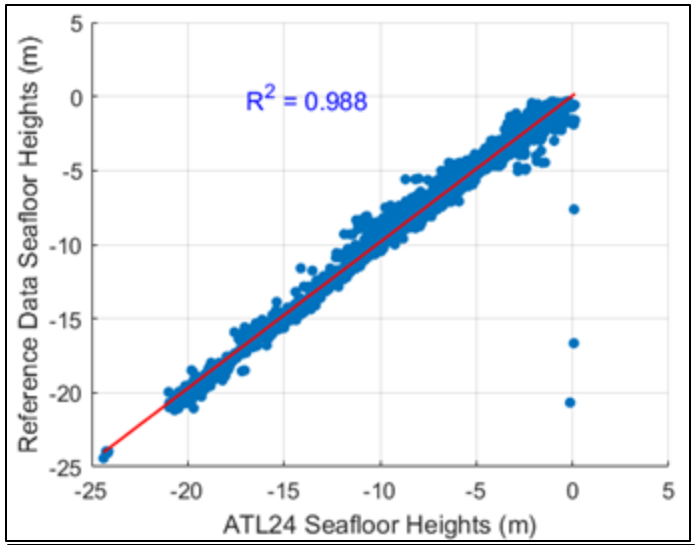
All Sites – All Bathymetric Points

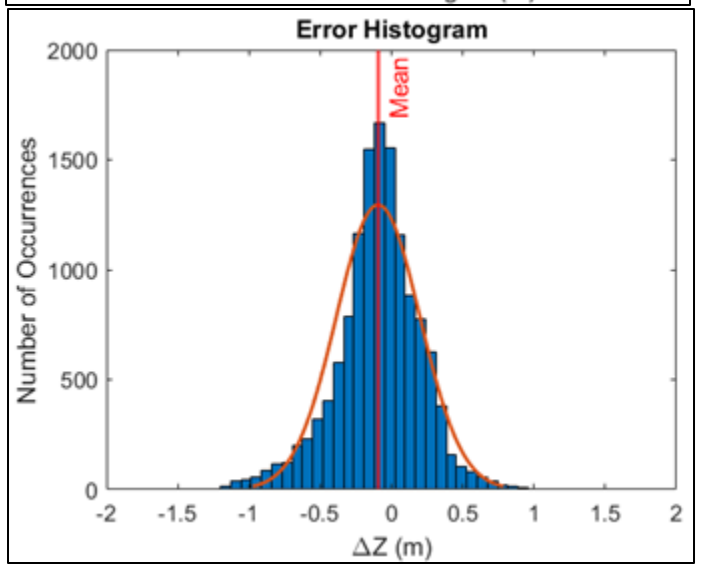




RMSE = 0.68 m
μ = -0.09 m
σ = 0.68 m
N = 14,555

All Sites – High-Confidence Bathymetric Points





RMSE = 0.43 m
μ = -0.10 m
σ = 0.42 m
N = 13,419

ATL24 Strengths and Limitations

- Strengths
  - Near global coverage of Earth's coastlines
  - Robust approach for signal finding and classification
  - Accessible via a variety of ways
  - Algorithm architecture is configured for continued ATL24 quality improvement
  - Accuracy of product has proven suitable for calibration and validation of spectral satellite derived bathymetry in most cases
- Limitations
  - Certain conditions result in variable data quality
  - Current uncertainty estimates are overly optimistic
  - Data exists only on the coastlines, coincident with the search mask
  - Photon classification conflicts between ATL24 sea surface and ATL08 terrain surface

Resources

- Parrish et al., (2025) Analysis and Accuracy of a New Global Nearshore ICESat-2 Bathymetric Dataset. *Earth and Space Science*, 12(8), e2025EA004391
- Magruder et al., (2025) ICESat-2 Coastal and Nearshore Bathymetry Product Algorithm Development. *Earth and Space Science*, 12(10), e2025EA004390
- Magruder et al., (2025) Ice, Cloud and Land Elevation Satellite-2 (ICESat-2) Project Algorithm Theoretical Basis Document (ATBD) for Coastal and Nearshore Along-track Bathymetry Product (ATL24)

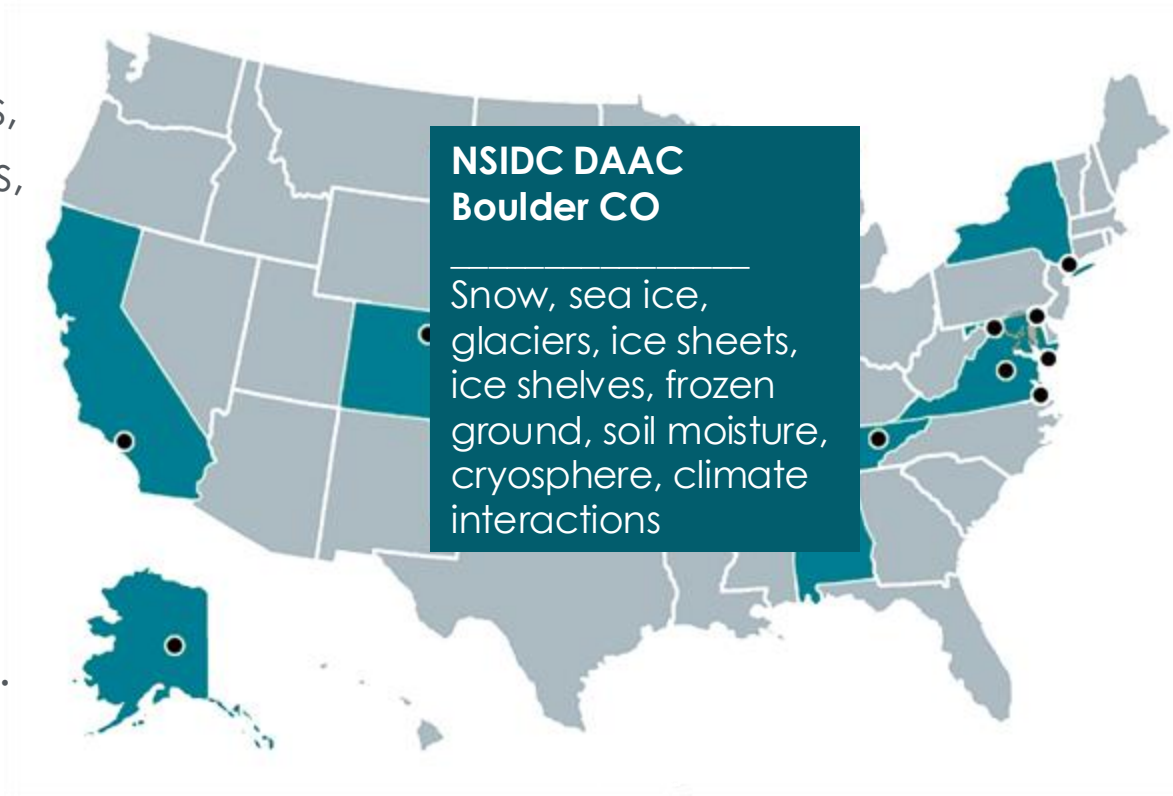
NSIDC DAAC ATL24 Data Resources and Access

Diane Fritz | Data Support Specialist
National Snow and Ice Data Center (NSIDC)

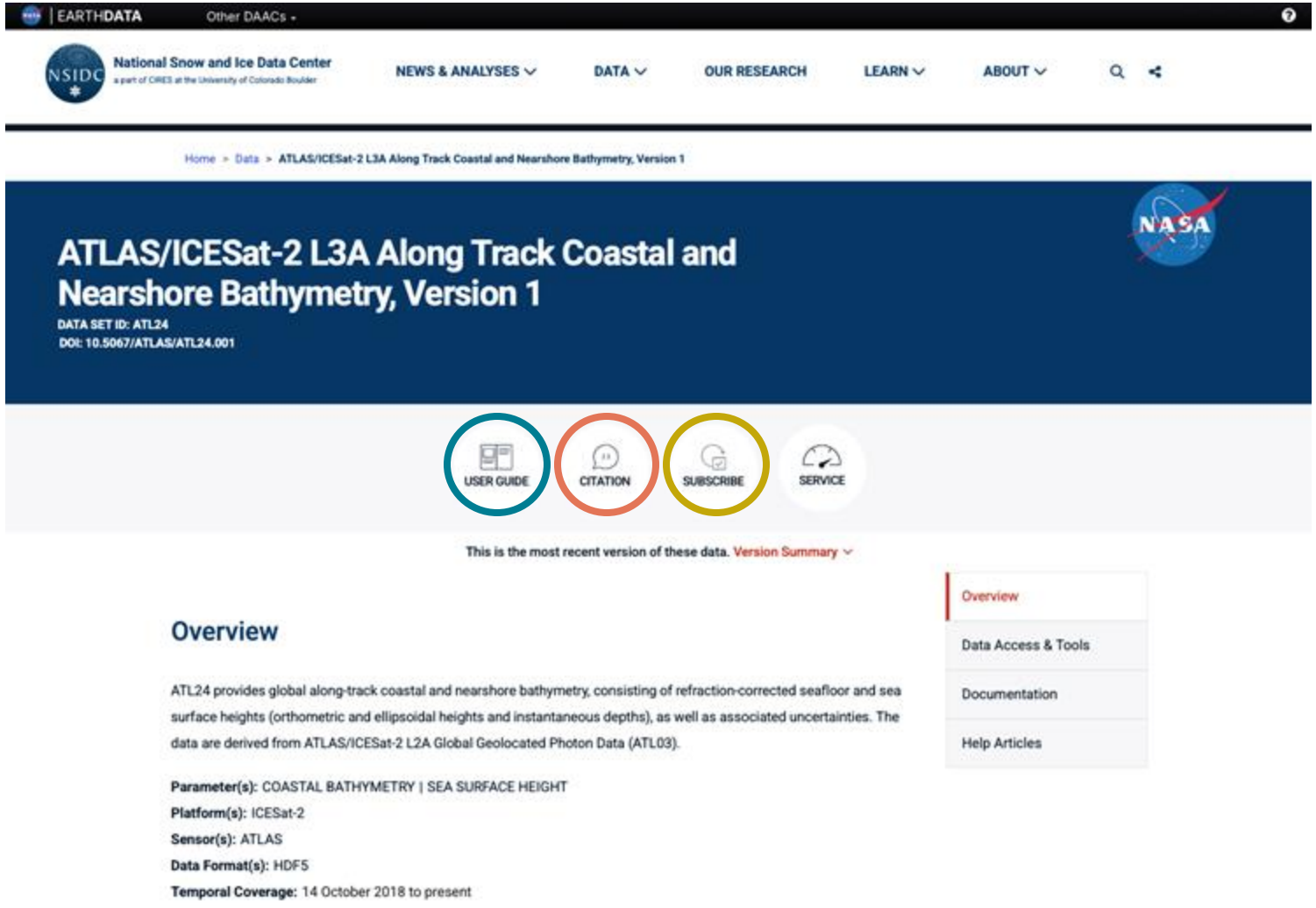
The Role of the NSIDC DAAC

Preserving, documenting and providing access to over 1400 data sets including from ICESat-2.

- NASA National Snow and Ice Data Center (NSIDC)
- Includes data from satellite missions, airborne surveys, field observations, weather stations, historical records, and data rescue projects.
- One of 11 NASA Distributed Active Archive Centers (DAACs).
- Data is available for free to anyone!
  - Helpful to have some prior experience working with commonly used scientific data formats (e.g. GeoTIFF, NetCDF, or HDF)
  - Most data sets have user guides to help



Data Set Specific Landing Pages



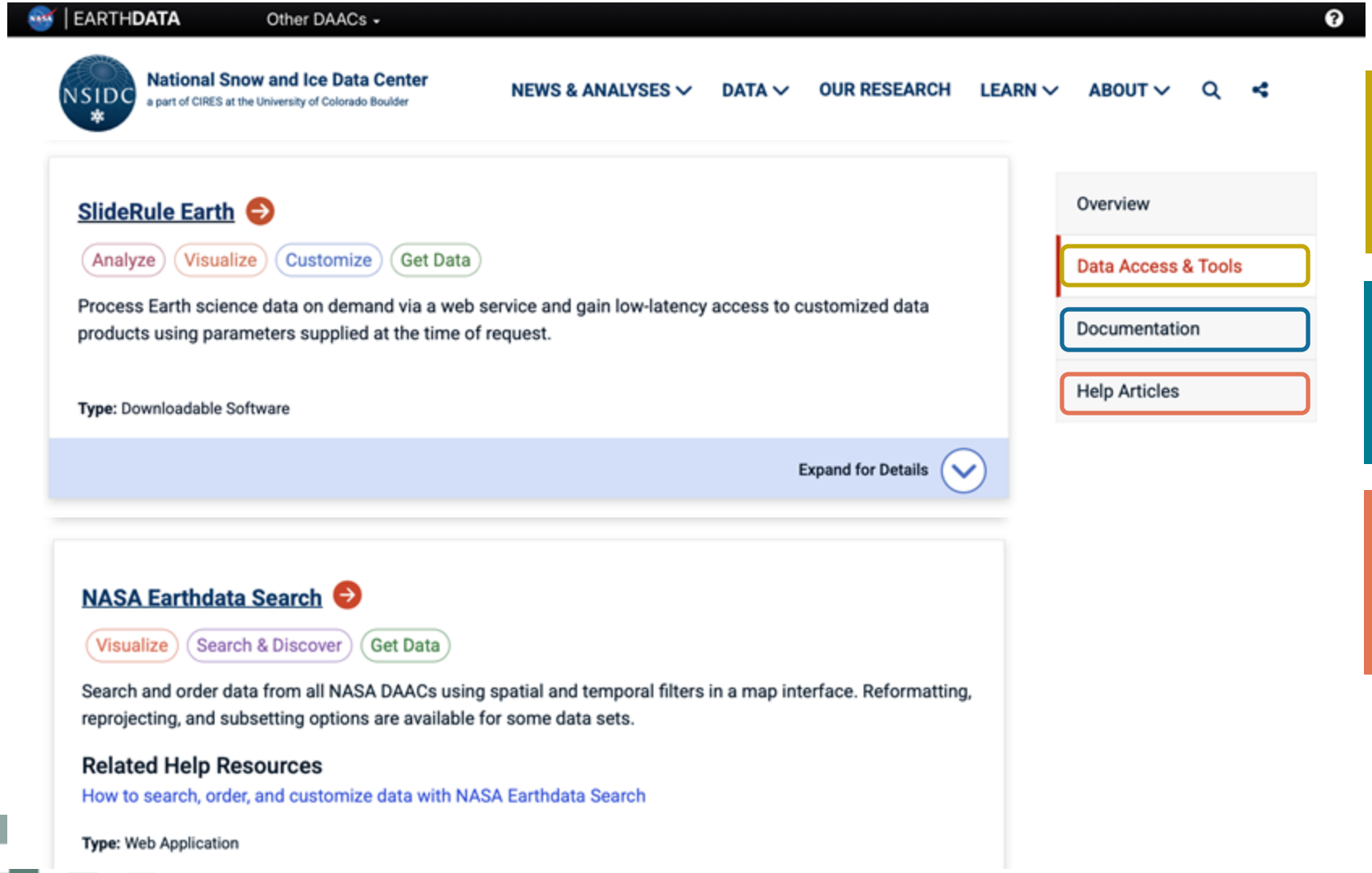
[NSIDC Landing Page for ATL24]

User Guide:
Comprehensive product documentation on file structure, variable info, data acquisition, etc.

Citation

Subscribe:
Sign up to receive email updates of the data set.

Data Landing pages: Access, Documentation and Help Articles



Access:
Tools and services for accessing the data.

Documentation:
Known issues, ATBDs, Data dictionaries, User guides

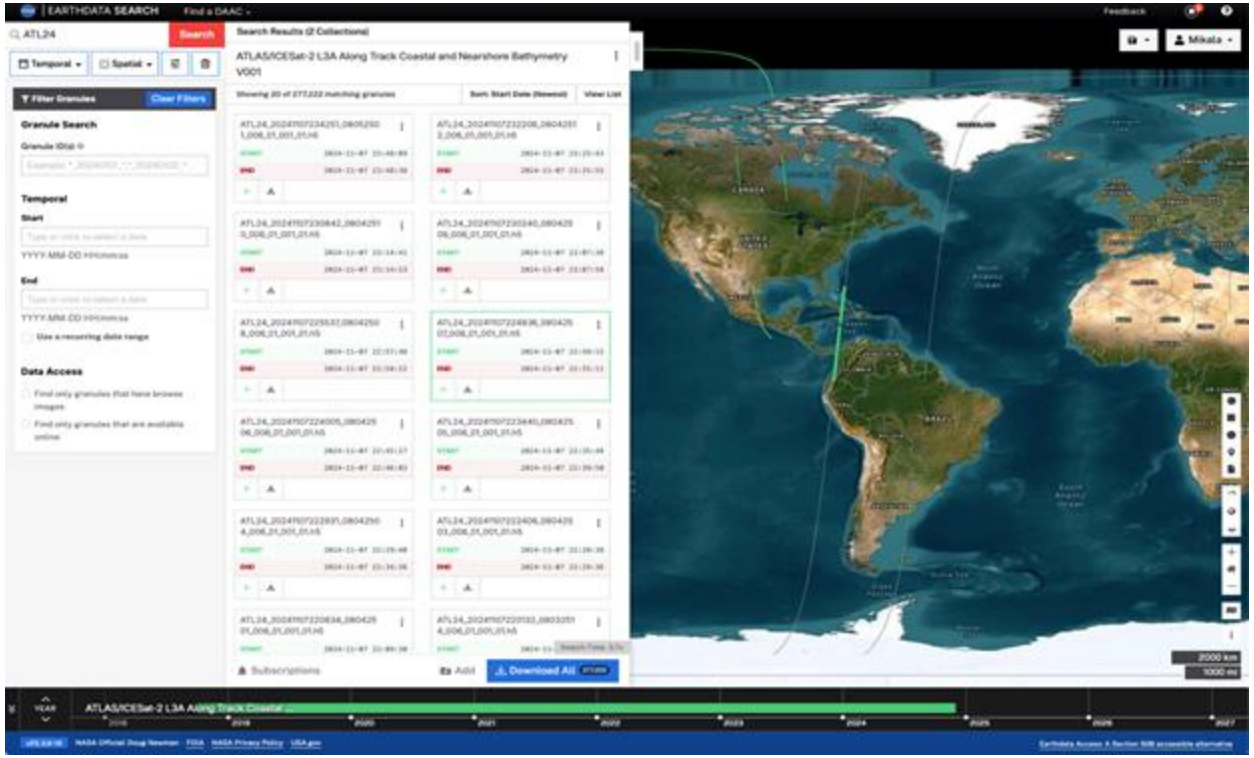
Help articles:
Useful information for the data product.

NSIDC Landing Page

Data Discovery and Access

NASA Earthdata Search:

- Discover, visualize, and access petabytes of Earth observing data from all NASA DAACs.
- Filter data by mission, keyword, spatial and temporal range, filename, etc.
- Provides customization services (e.g., subsetting) for select data sets.



NASA Earthdata Search →

Visualize | Search & Discover | Get Data

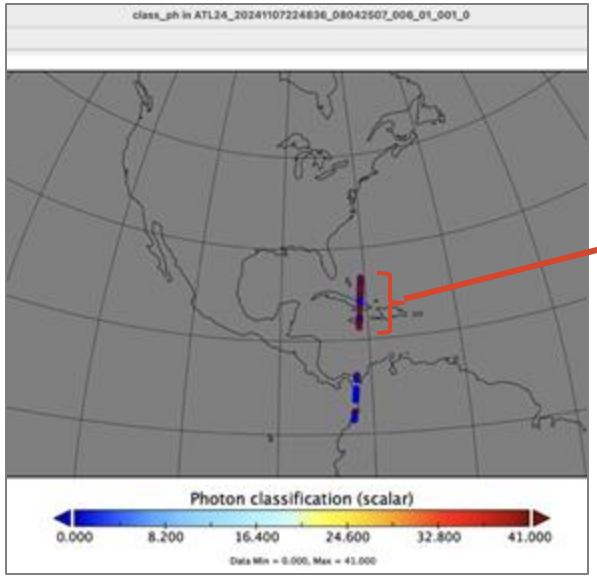
Search and order data from all NASA DAACs using spatial and temporal filters in a map interface. Reformatting, reprojecting, and subsetting options are available for some data sets.

How to search, order, and customize data with NASA Earthdata Search

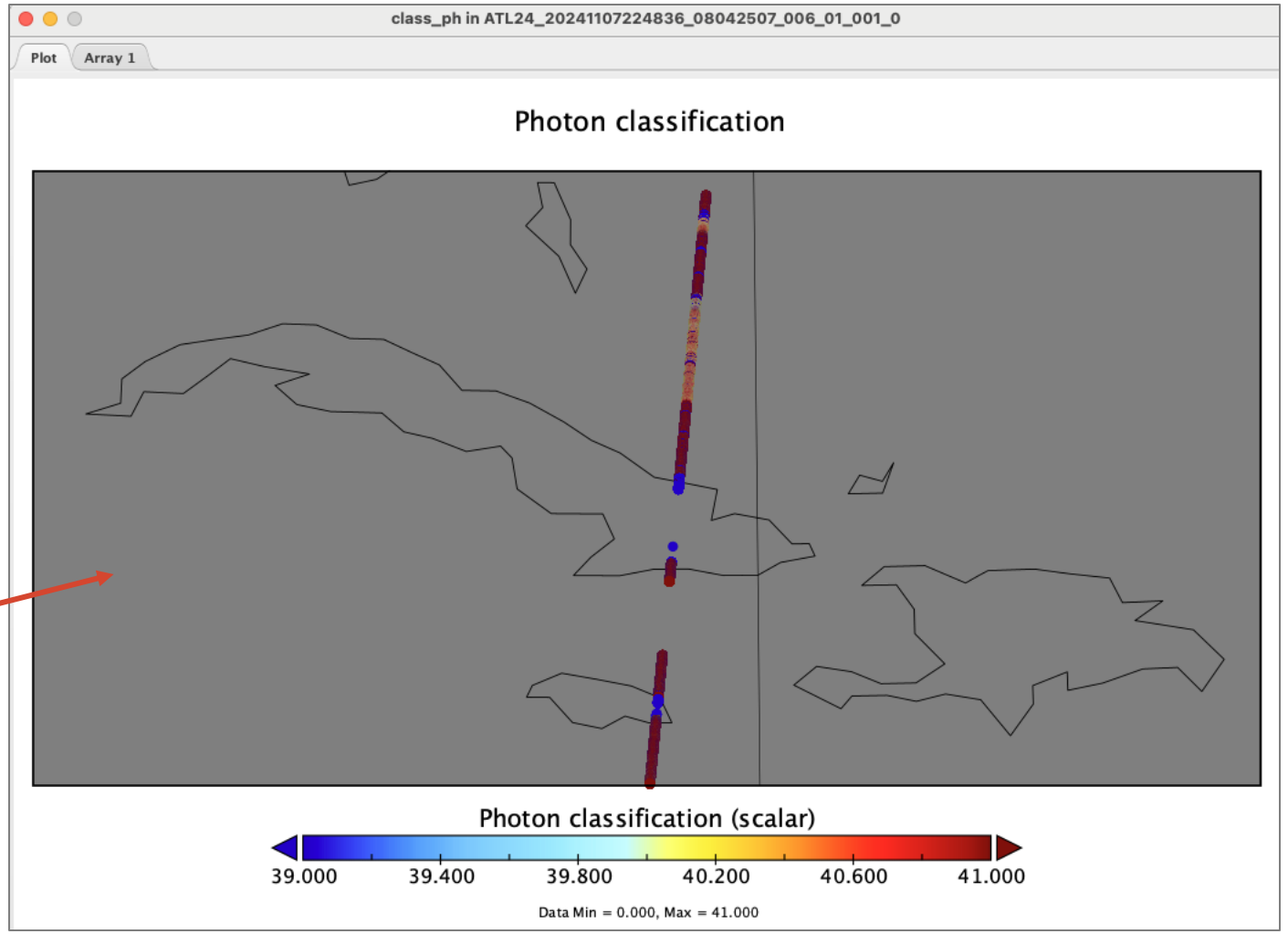
Type: Web Application

ATL24 Bathymetry Visualized in Panoply

- Variable example: class_ph
  - 40 = bathymetry photon
  - 41 = sea surface photon
  - 1 = other
  - 0 = unclassified



Full Granule



Zoomed-in view with scale changed to highlight bathymetry photons

Demo: Finding and Spatially Subsetting ATL24 with EDSC

- Use NASA's EarthData Search (EDSC) GUI
- Find and spatially subset ATL24 bathymetry data
- Area near Bahamas on November 7, 2024
- Open and display downloaded data in Panoply

Resources

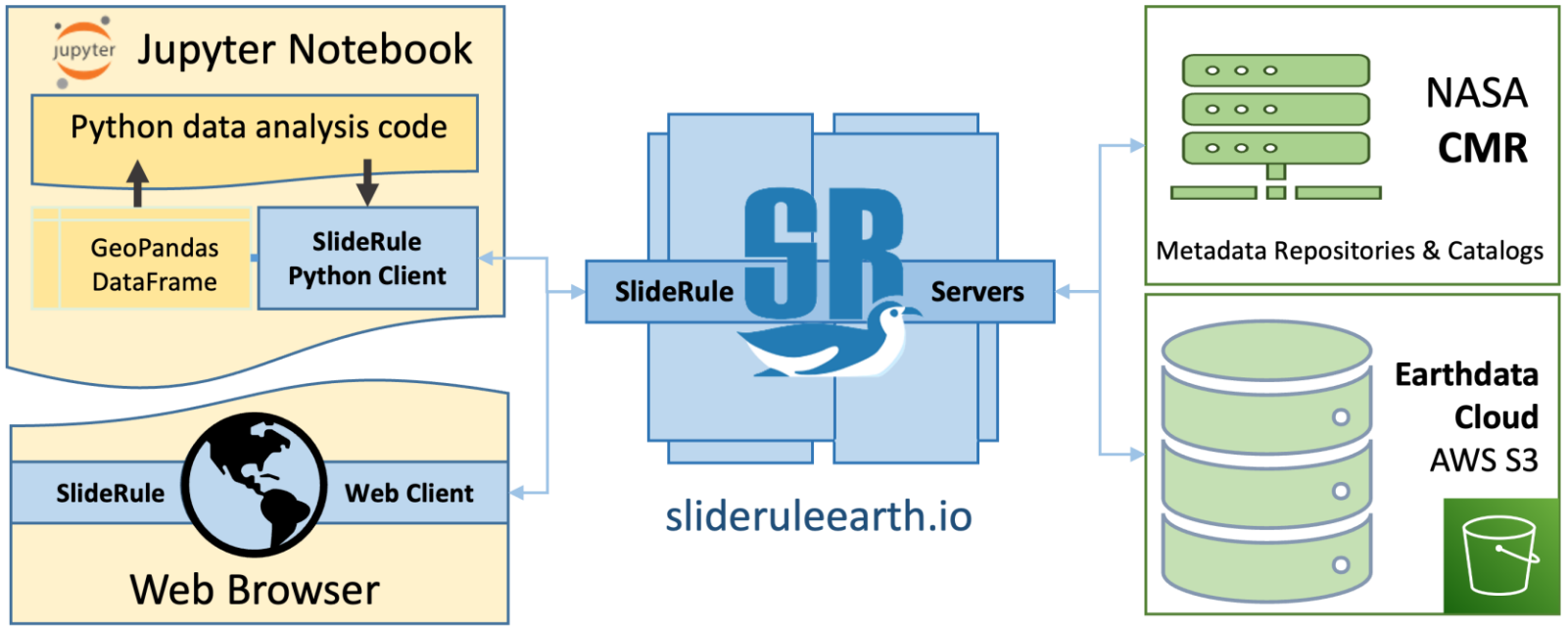
- ATL24 data set landing page
- Earthdata Login
- NASA's EarthData Search
- Panoply – A data viewer developed by NASA (good for HDF files)
- EarthData Search guide – Harmony subsetting with a GUI
- Harmony API guide – Programmatic subsetting
- SlideRule Earth – Refer to other sessions of the training!

Slide Rule Earth
Enabling Rapid, Scalable, Open Science

Tom Neumann, David Shean, Ben Smith, Tyler Sutterley, JP Swinski
Scott Henderson, Carlos Ugarte, Eric Lidwa, Jeff Lee

What is SlideRule?

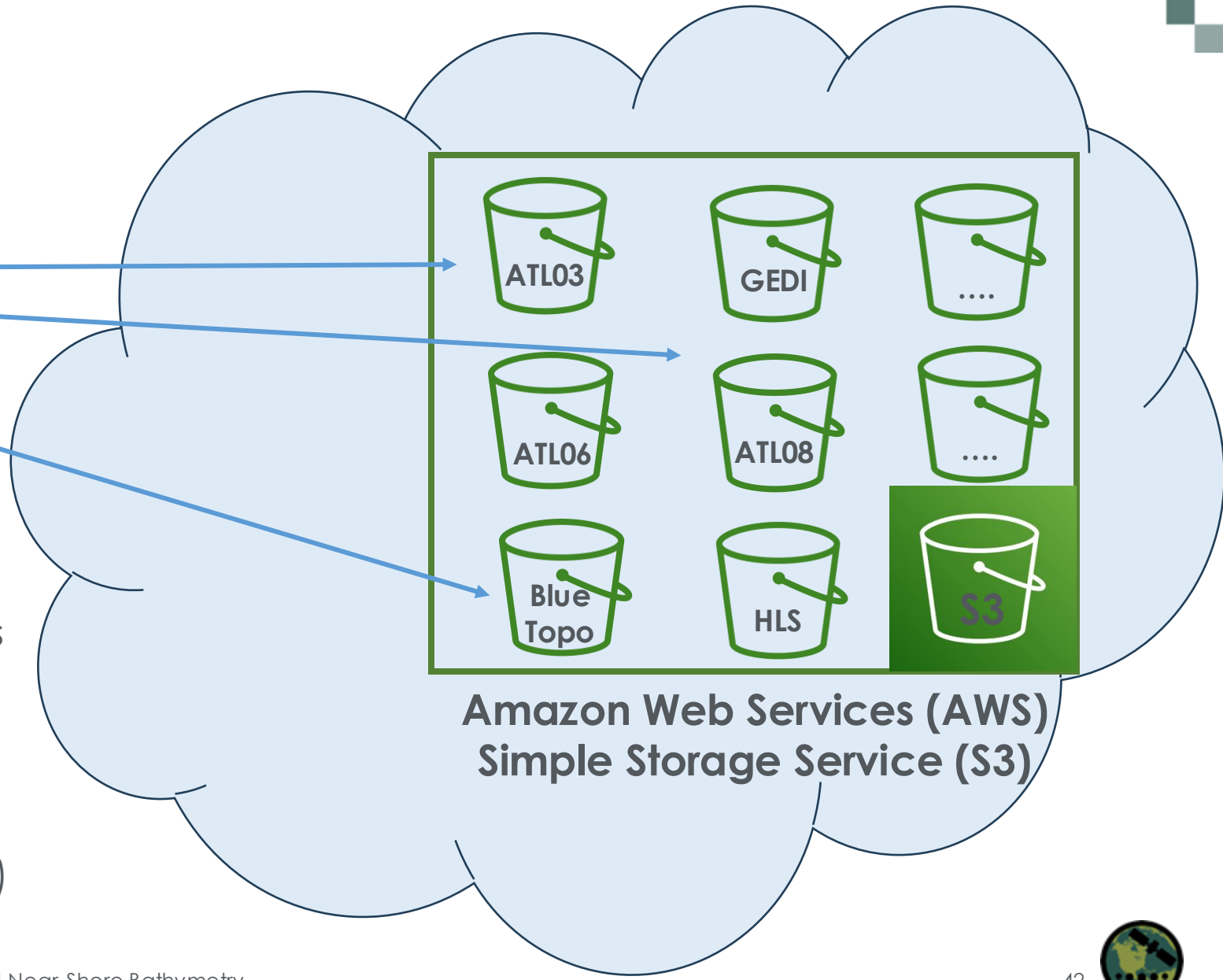
- SlideRule is a **public web service** with REST-like APIs for processing science data.
- It provides researchers and other data systems with low-latency access to **on-demand data products** using processing parameters supplied at the time of the request.
- Runs in **AWS us-west-2** and has access to ICESat-2, GEDI, Landsat, and a growing list of other datasets stored in S3.
- Multiple clients are supported by the SlideRule team: **Python**, **Web**, **Node.js**, **cURL.**



Website: slideruleearth.io
Point of Contact: jp.swinski@nasa.gov
Code: github.com/slideruleearth/siderule
License: *BSD 3-Clause*

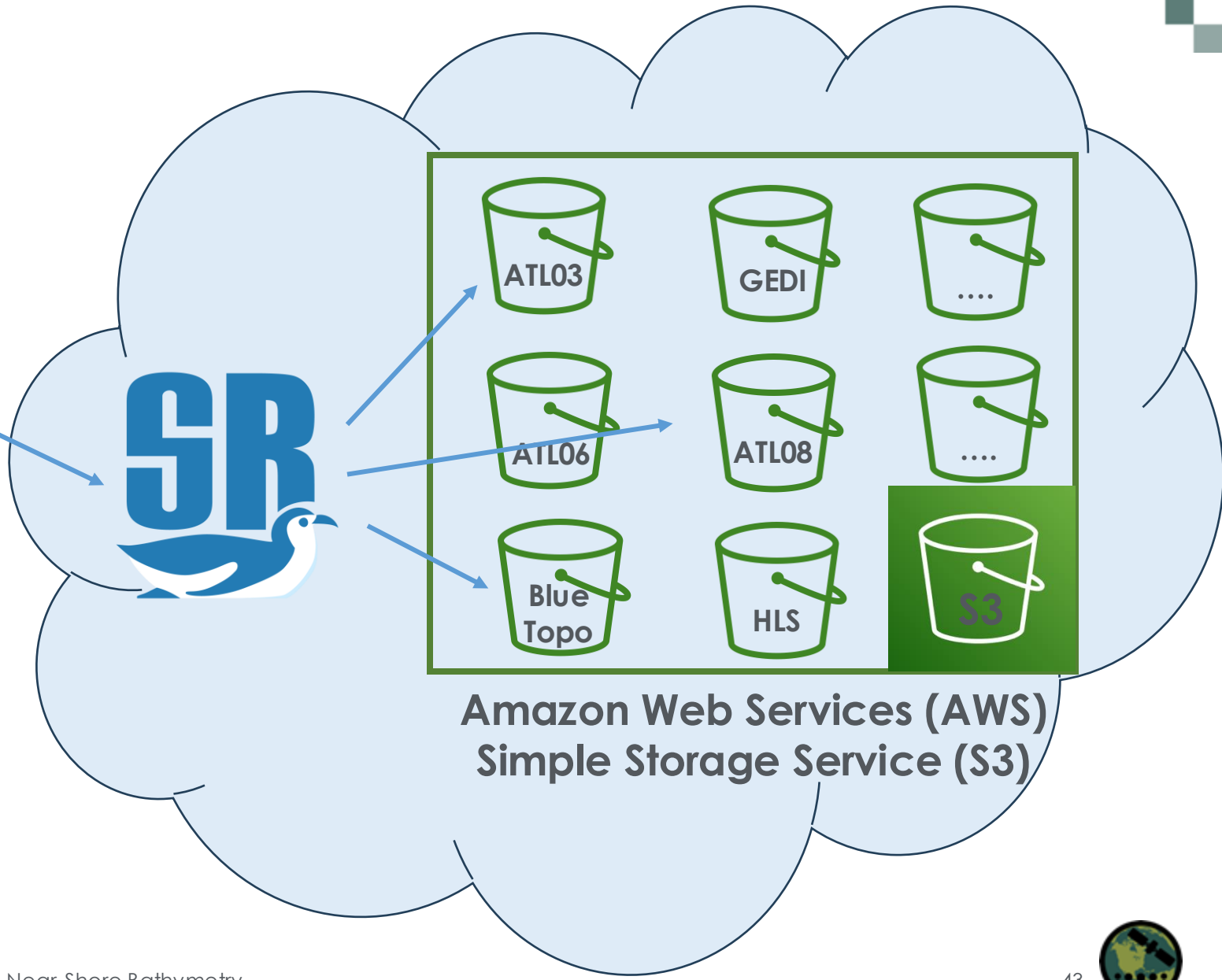
Accessing cloud data directly

- Challenging to work with global scale data from a laptop or single JupyterHub instance
- Must know format of different datasets (how do I get acquisition date from ArcticDEM rasters?)
- Common compute intensive operations needed to make data ready to use (point-cloud to elevation)



Accessing cloud data with SlideRule

- Optimized **direct access** to the raw data
- Efficient **subsetting** services for combining data from multiple sources into a single response
- **On-demand processing** next to the data for generating customized data products using parameters supplied in the user's request.



Demonstrations

- SlideRule Web Client: https://client.slideruleearth.io
- Documentation: https://slideruleearth.io
- Python Client: https://github.com/SlideRuleEarth/sliderule/blob/main/clients/python/examples/atl24_access.ipynb

Demo – SlideRule

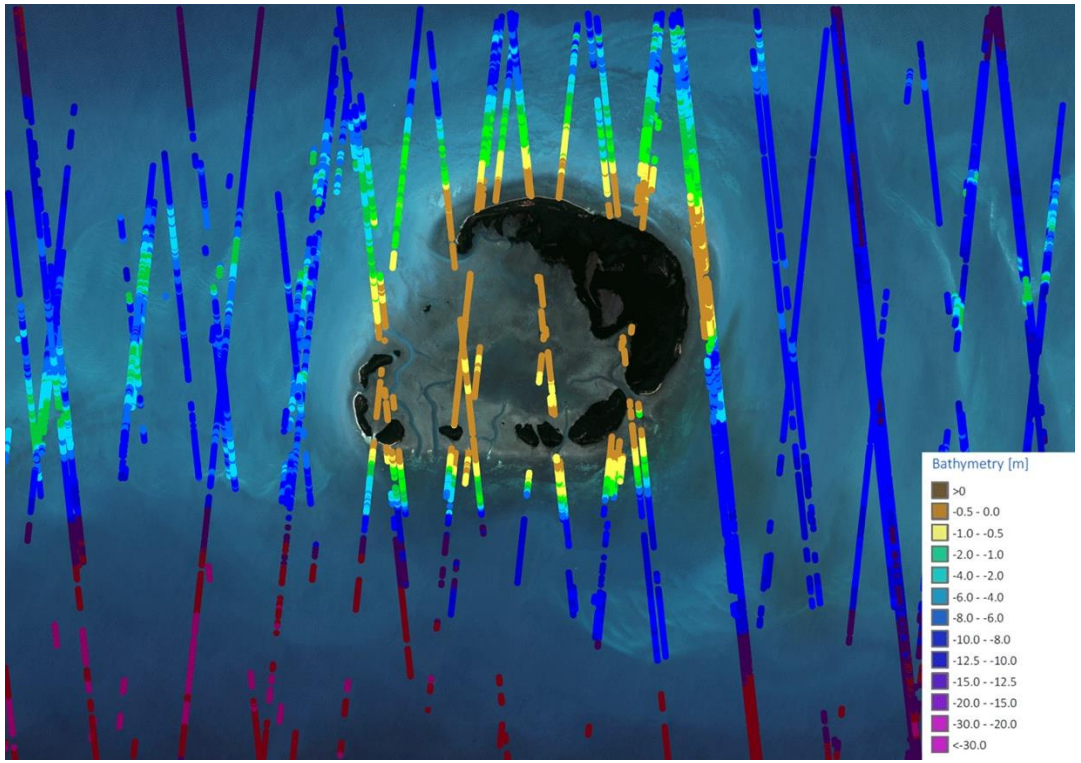
Part 1:
Summary

Summary

- NASA's ICESat-2 carries a photon counting **laser altimeter** (ATLAS).
- ATLAS provides near contiguous along-track sampling using **6 individual beams** of **green light** (532 nm wavelength) providing high vertical resolution.
- Every photon detected by ATLAS has a **latitude, longitude and elevation**.
- ATLAS provides surface-specific data products developed by experts, and include products for land ice, sea ice, the atmosphere, vegetation and land, oceans and inland water.
- **ATL24** product provides ATLAS-derived **coastal bathymetry** via Ensemble ML models where each photon classified as bathymetry will have a confidence value assigned.
- National Snow and Ice Data Center (**NSIDC**) provides access to ATL24 data, metadata, and tools.
- NASA's **EarthData Search** is used to find and spatially subset ATL24 bathymetry data.
- SlideRule is a **public web service** with low-latency access to **on-demand data products** stored in S3.
- SlideRule provides **on-demand processing** next to the data for generating customized data products using parameters supplied in the user's request.

Looking Ahead to Part 2

- Generate satellite-derived bathymetry (SDB) using methodologies combining ATL24 bathymetry with optical satellite data from Sentinel-2.
- Python workflows for filtering, visualizing, and analyzing bathymetric point clouds.
- Integration of ATL24 into existing NOAA workflows for nautical charting and coastal zone management.
- Overview of NOAA's SatBathy tool and its capabilities for automated SDB generation with ATL24.



Credit: Edward Albada

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on Dec. 4, 2025
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by December 31, 2025**

- **Certificate of Completion:**
  - Attend both live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

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1. Send an email with no subject line to arset-join@lists.nasa.gov.
2. Follow the instructions sent in response.

Resources

- ATL24 data set landing page
- Earthdata Login
- NASA's EarthData Search
- Panoply – A data viewer developed by NASA (good for HDF files)
- EarthData Search guide – Harmony subsetting with a GUI
- Harmony API guide – Programmatic subsetting
- SlideRule Earth – Refer to other sessions of the training!
- Magruder et al., (2025) ICESat-2 Coastal and Nearshore Bathymetry Product Algorithm Development. *Earth and Space Science*, 12(10), e2025EA004390
- Magruder et al., (2025) Ice, Cloud and Land Elevation Satellite-2 (ICESat-2) Project Algorithm Theoretical Basis Document (ATBD) for Coastal and Nearshore Along-track Bathymetry Product (ATL24)
- Parrish et al., (2025) Analysis and Accuracy of a New Global Nearshore ICESat-2 Bathymetric Dataset. *Earth and Space Science*, 12(8), e2025EA004391


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Thank You!