National Aeronautics and Space Administration

NASA Satellite Laser Altimetry for Coastal and Near-Shore Bathymetry

Part 2: Techniques for Plotting and Analyzing ATL24 Coastal Bathymetry

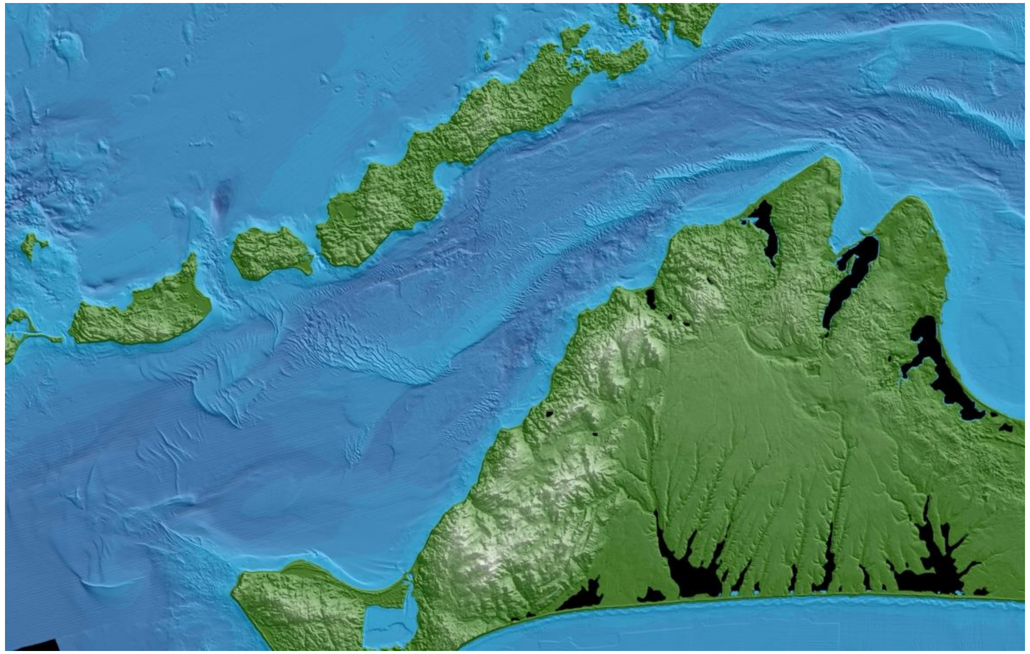
Christopher Parrish (Oregon State University), Joseph-Paul Swinski (NASA GSFC), Gretchen Imahori (NOAA), Keana Kief (Oregon State University) & Sean McCartney (NASA GSFC/STC)

December 4, 2025

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 2: Techniques for Plotting and Analyzing ATL24 Coastal Bathymetry

Part 2 Objectives

By the end of Part 2, participants will be able to:

- 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.

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 2 – Trainers

Christopher Parrish
Professor
Oregon State University

Joseph-Paul Swinski
Software Developer
NASA GSFC

Gretchen Imahori
Staff Scientist
NOAA

Keana Kief
Analyst Programmer
Oregon State University

Demo: ATL24 and Sentinel-2 SDB for Bathymetric Analysis

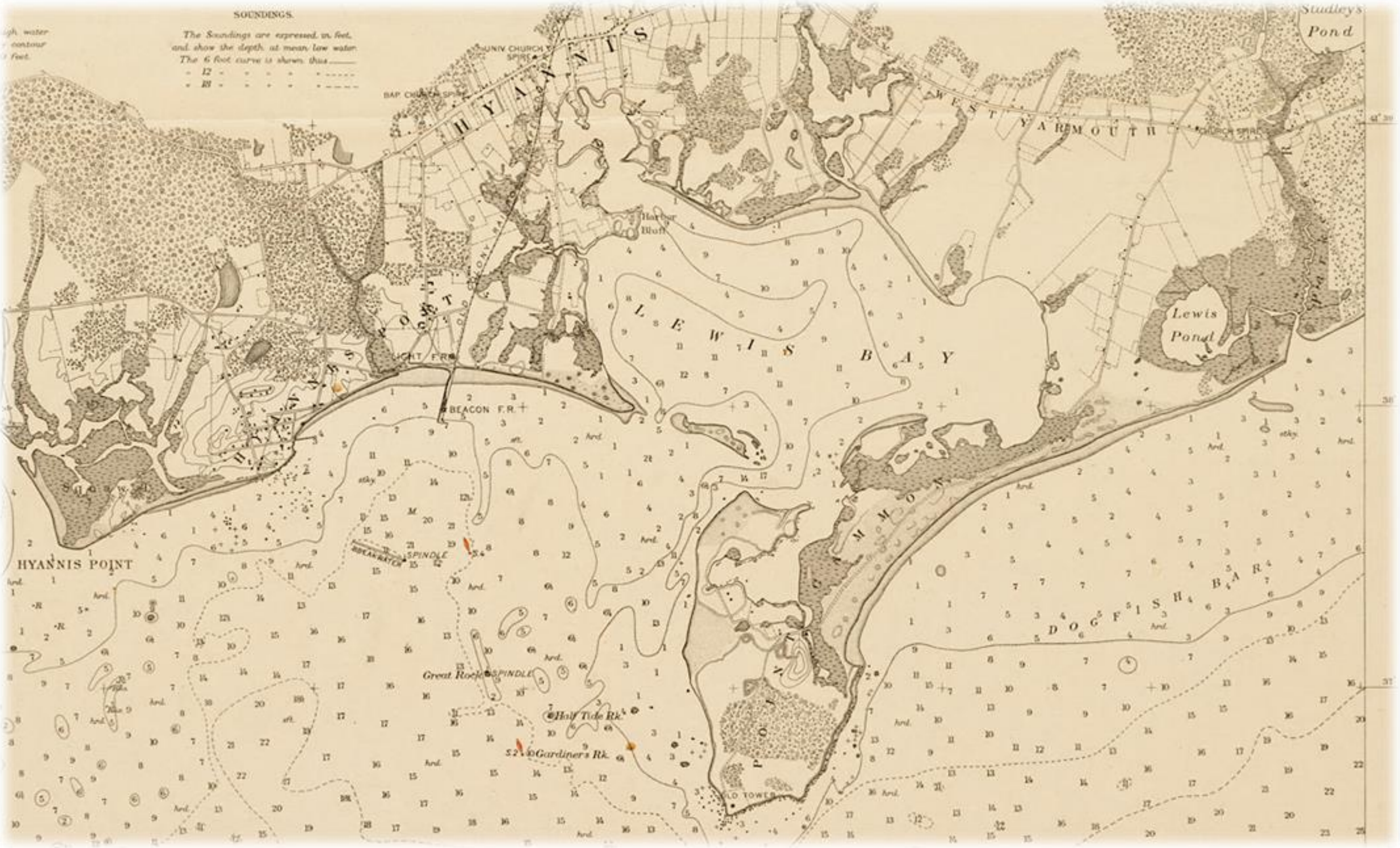
Christopher Parrish, Oregon State University

Things Needed to Follow Along With Demo

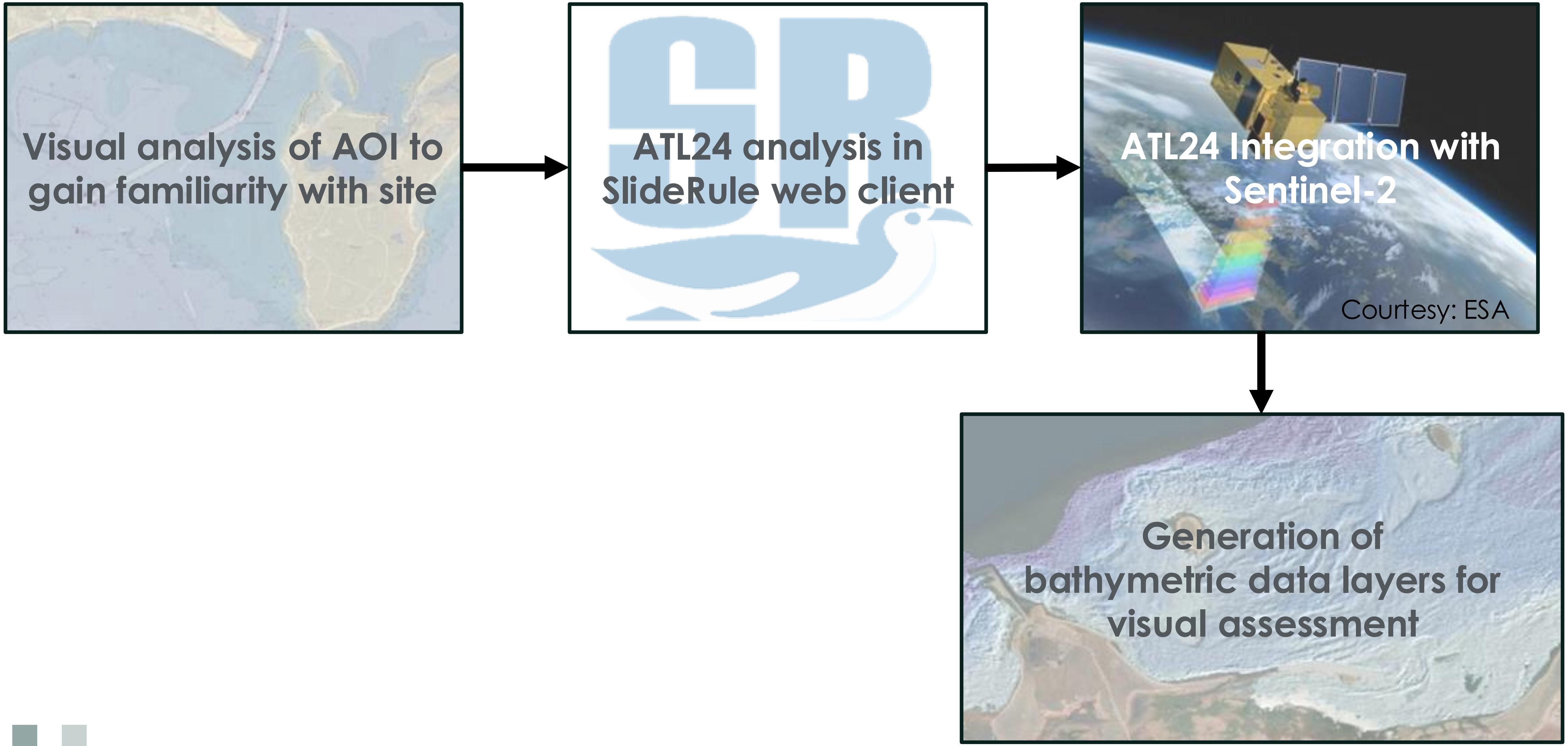
- Files (provided on ARSET training website)
  - **hyannis_aoi shapefile** (note: this is actually 8 individual files that all start with "hyannis_aoi")
  - **psdb_linear_regression.py** – Python script
- Accounts
  - EU Copernicus account (free)
    - Click 'Login' then 'Register'
- QGIS
  - Free and open-source GIS software
  - I'm using version 3.40, but any recent version should work
- Sites to bookmark
  - Copernicus browser
  - SlideRule Earth Web Client
  - NOAA WMTS ENC

Project Site: Hyannis Harbor

1894 USC&GS Chart of Hyannis Harbor (1/20000 scale)

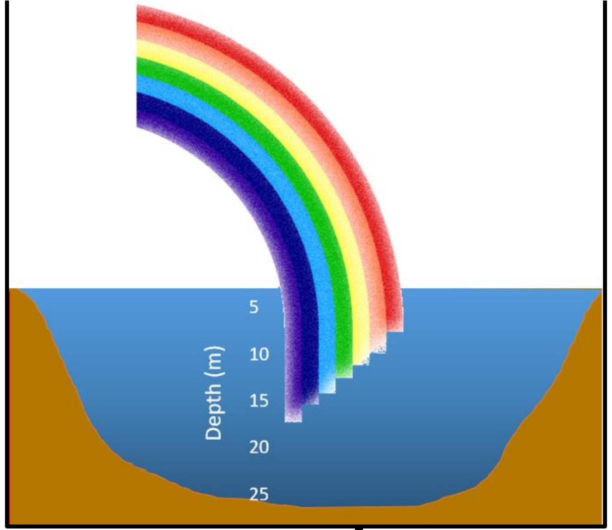


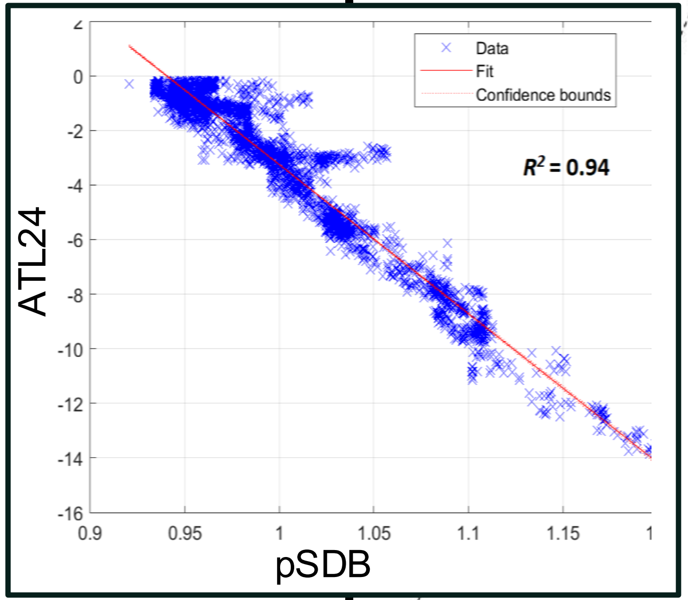
General Workflow

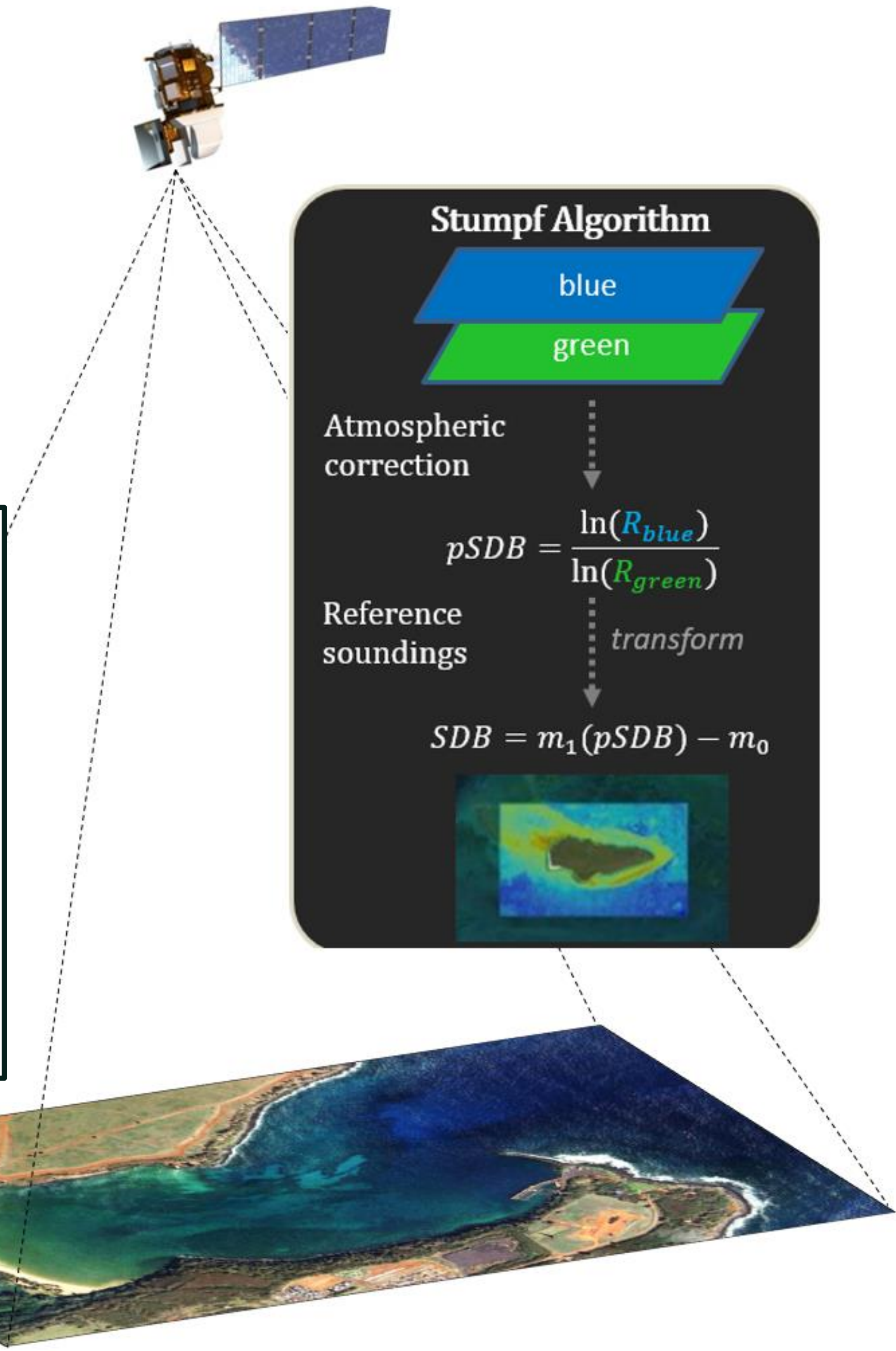


Sentinel-2 Integration Step

- Will use original (2003) Stumpf Algorithm
  - Widely-used spectral SDB approach
  - Gretchen's presentation will include latest enhancements from Caballero and Stumpf integrated into NOAA SatBathy
    - Compositing
    - Switching model
    - ACOLITE







Stumpf, R.P., Holderied, K. and Sinclair, M., 2003. Determination of water depth with high-resolution satellite imagery over variable bottom types. *Limnology and Oceanography*, *48*(1part2), pp.547-556. https://doi.org/10.4319/lo.2003.48.1_part_2.0547

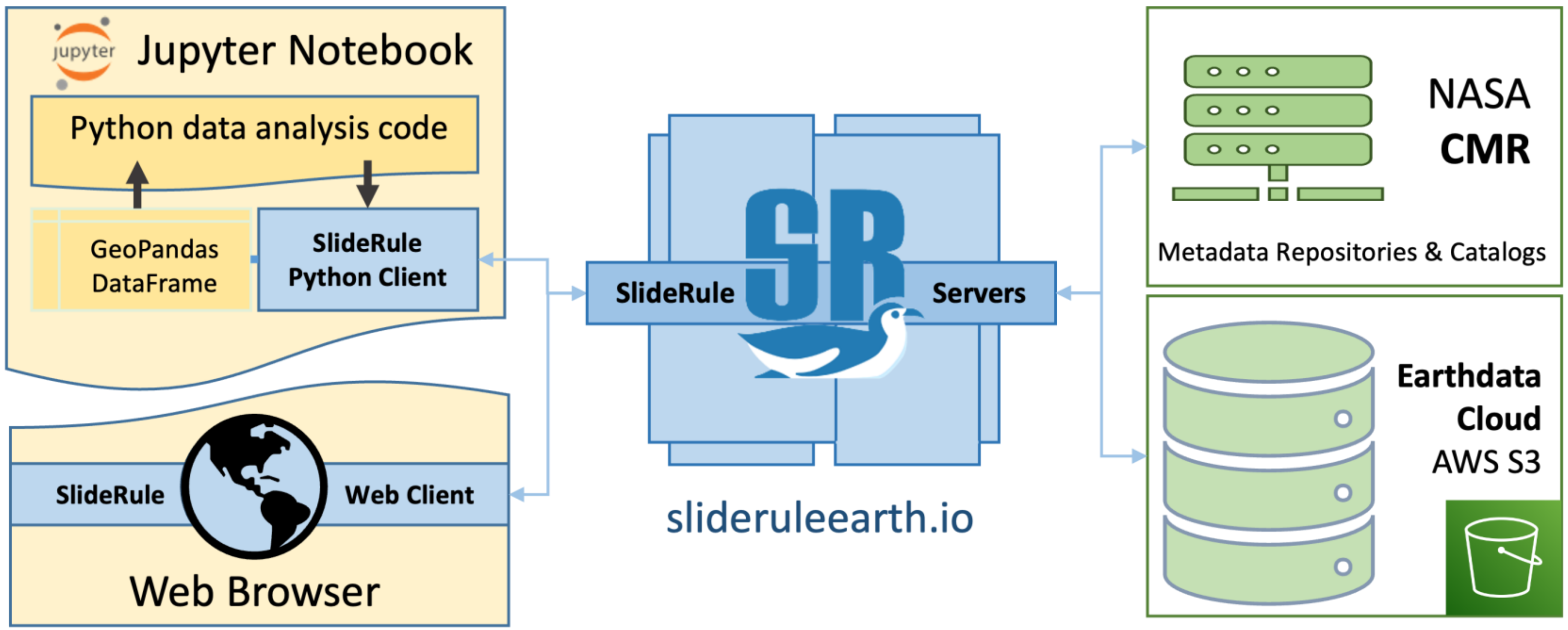
Demo: ATL24 and Sentinel-2 SDB for Bathymetric Analysis

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/sliderule
License: *BSD 3-Clause*

Demo – SlideRule Python Client

Demonstrations

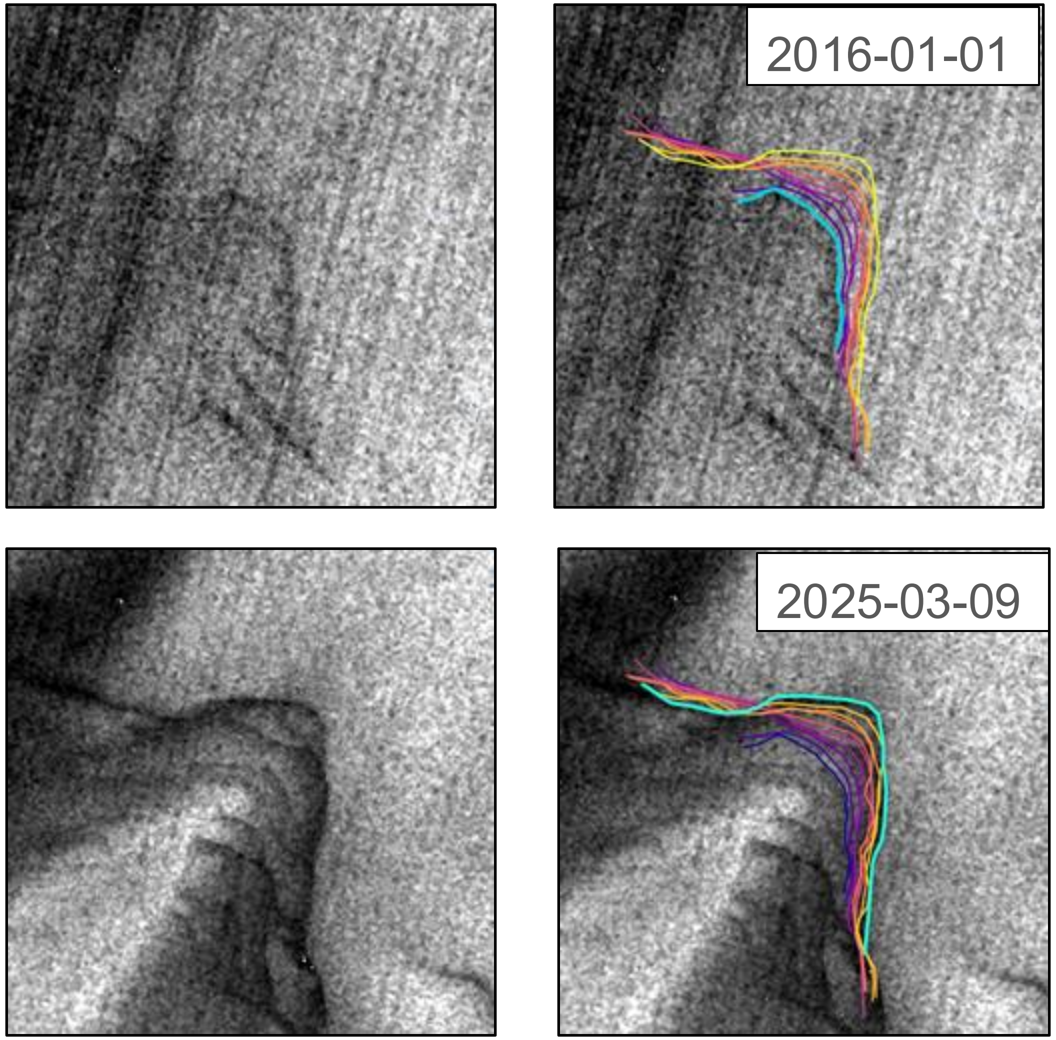
- SlideRule Web Client: https://client.slideruleearth.io
- Documentation: https://slideruleearth.io
- Python Client: https://github.com/SlideRuleEarth/sliderule/blob/main/clients/python/examples/atl24_access.ipynb

NOAA's SatBathy Tool and Integration of NASA's ATL24

Gretchen Imahori, Staff Scientist, NOAA's National Geodetic Survey
Keana Kief, Analyst Programmer, Oregon State University

Outline

- Background
- What is SDB and why is it important?
- What is SatBathy
- SatBathy desktop tool examples
- Demo
- ATL24 integration and Demo
- Future

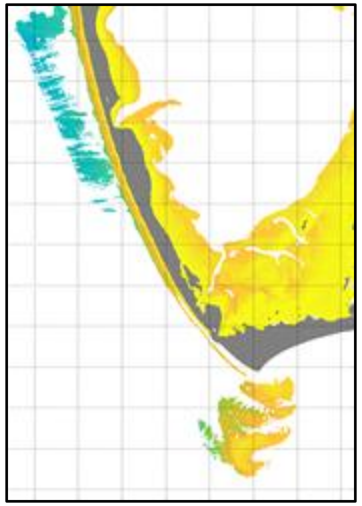


Satellite Derived Bathymetry (SDB) is an Indirect Method Of Bathymetric Measurement

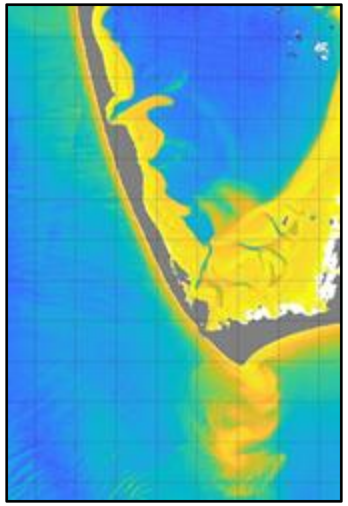
- Sounding pole
- Lead line
- Sonar
- Bathymetric lidar
- **SDB**
- Gravity-based bathymetry

Most Direct

Least Direct



bathymetric lidar



SDB

So…why do we care about SDB?

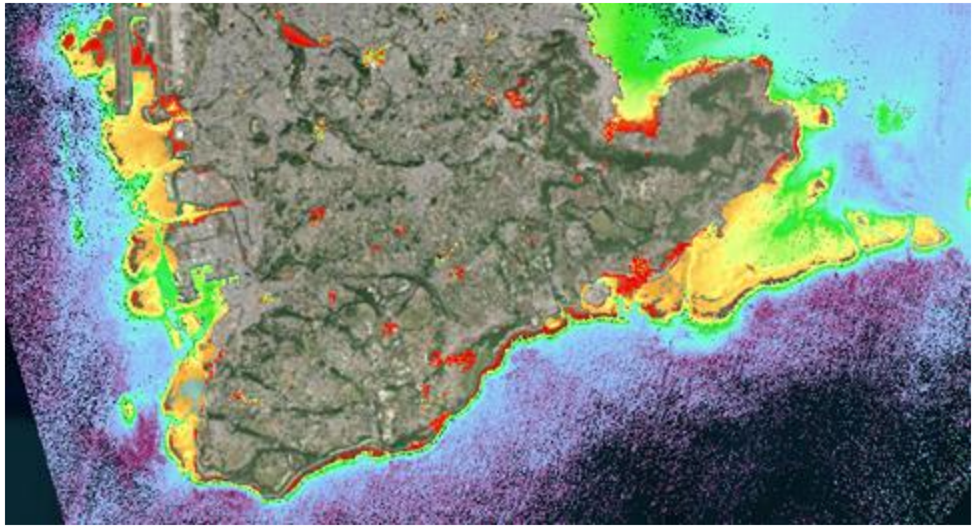
What is Satellite-Derived Bathymetry (SDB)?

Method using Sentinel-2 MSI (10m) and updated research from Dr. Rick Stumpf and Dr. Isabel Caballero (2019)

All SDB methods can be grouped into three major categories:

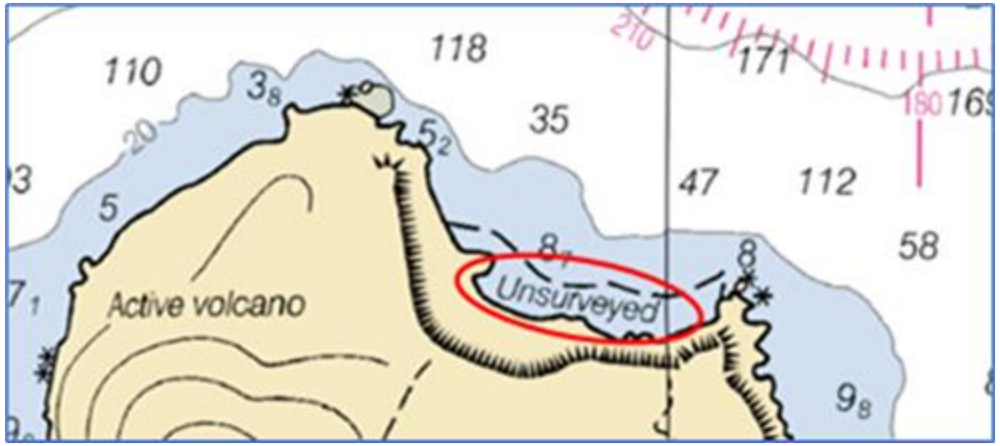
1. Spectral SDB/Spectral Radiance
   (e.g., Radiative Transfer Equation [RTE] optimization, RTE empirical, **band ratio**)
2. Photogrammetric
3. Wave Kinematics

Band-Ratio:
This approach is based on statistical relationships between reflectance and depth. It often requires known depth data to calibrate. The **compositing** approach for the band ratio solution inherently removes a lot of the faulty data.

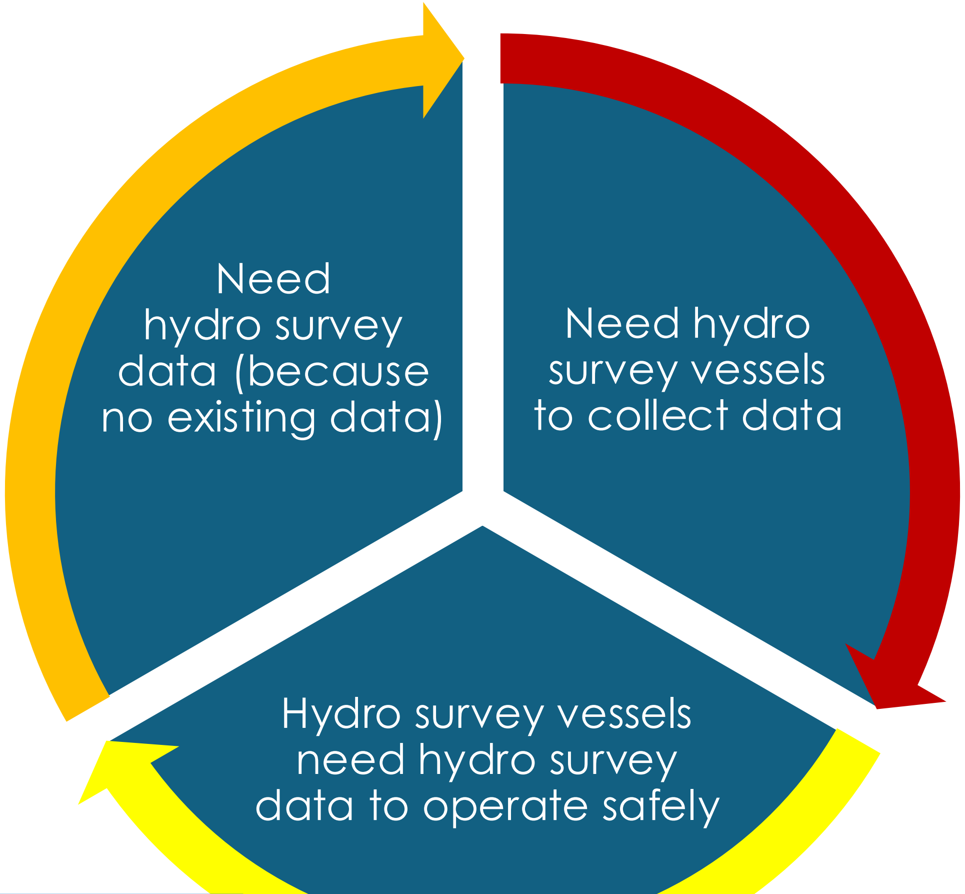


Why Do We Need SDB?

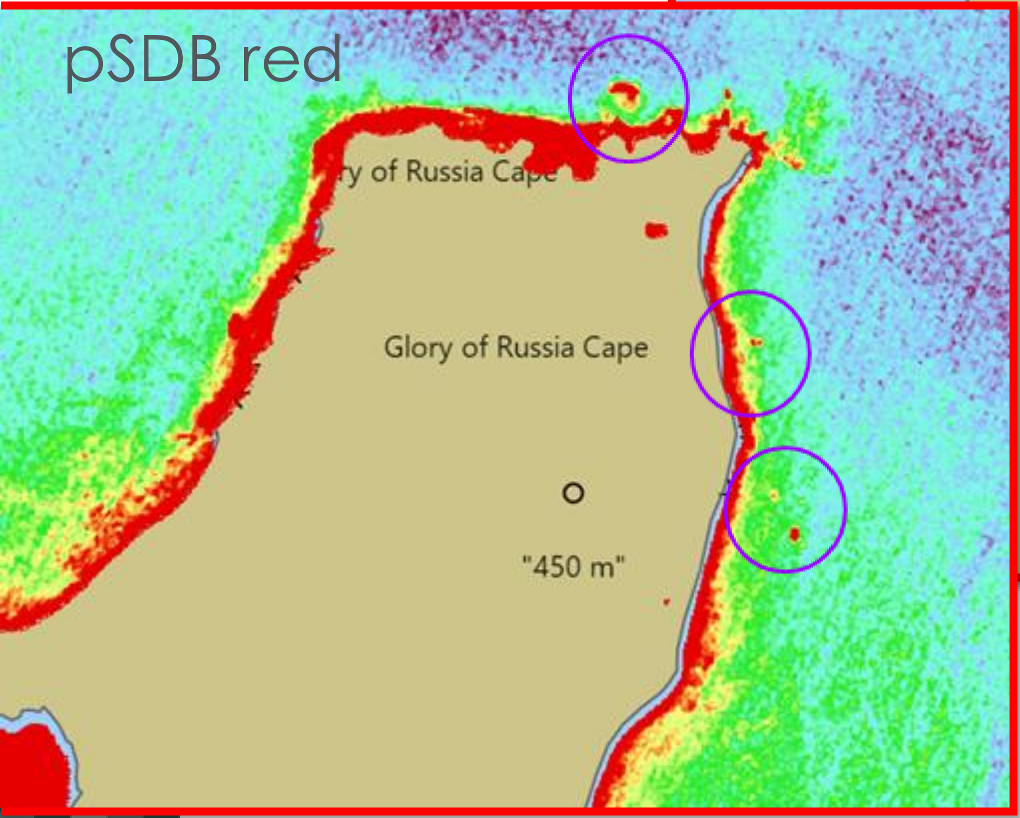
- Interim nautical chart updates
- Hydrographic survey planning/reconnaissance
- Change analysis
- To fill depth data in bathymetric lidar gaps in non-navigationally significant areas… etc.

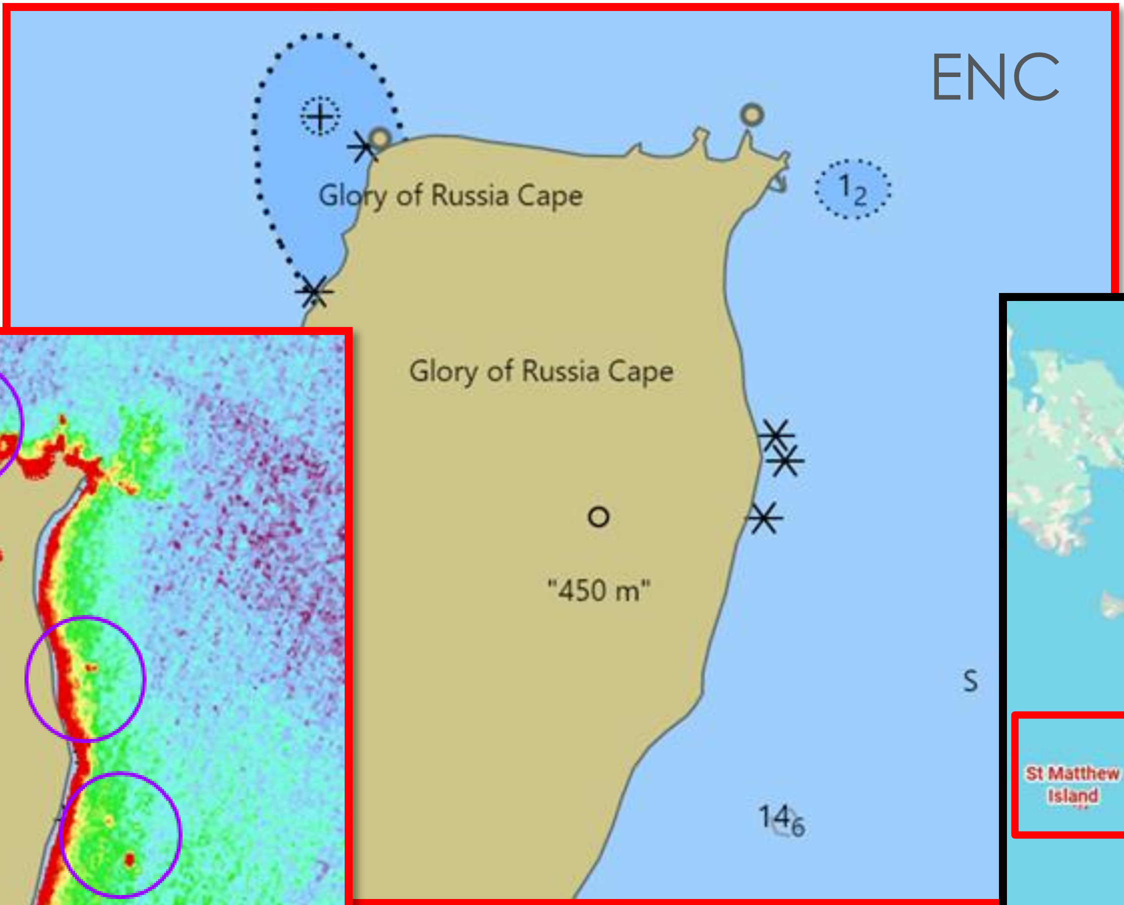


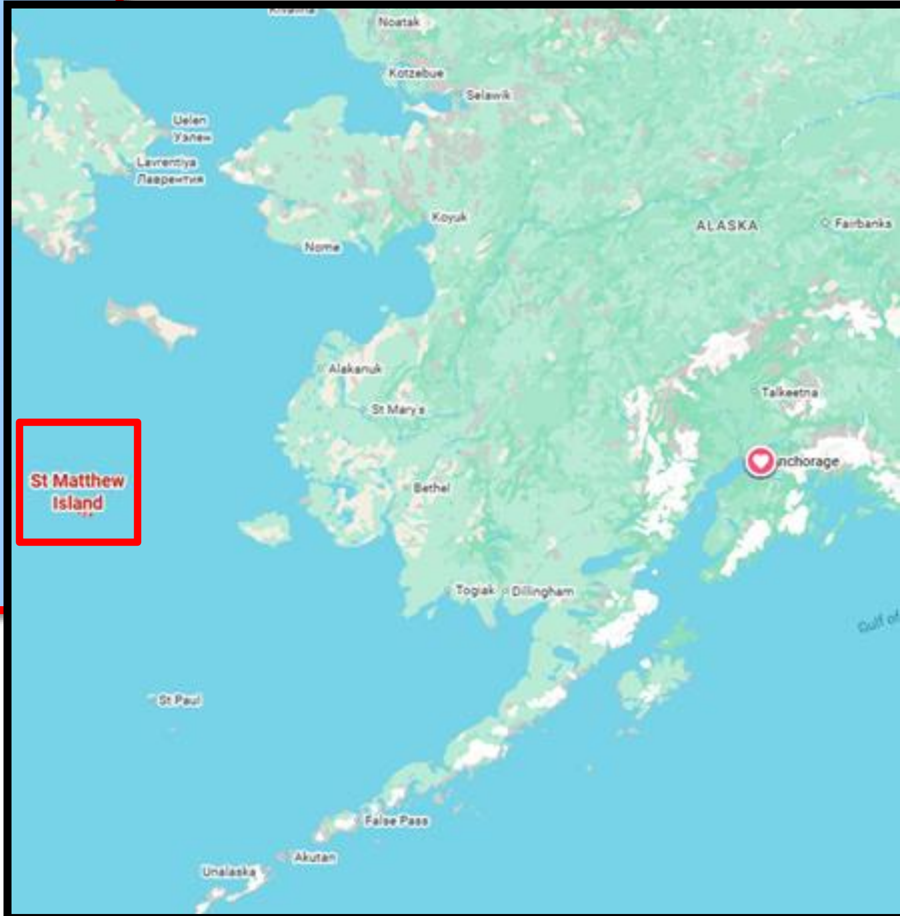
Vicious circle



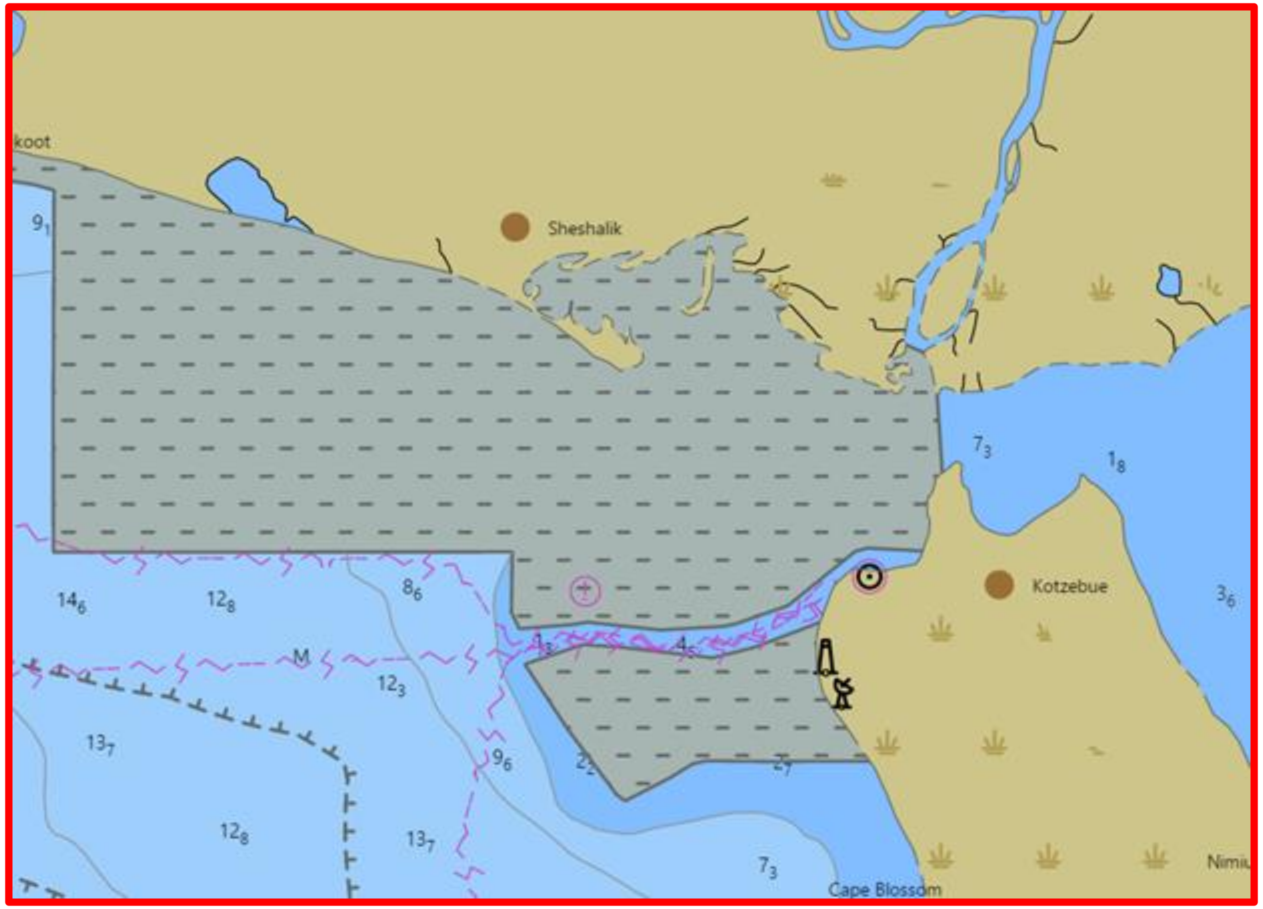
Examples of Reconnaissance: St. Matthews, AK – Potential Hazards Encircled

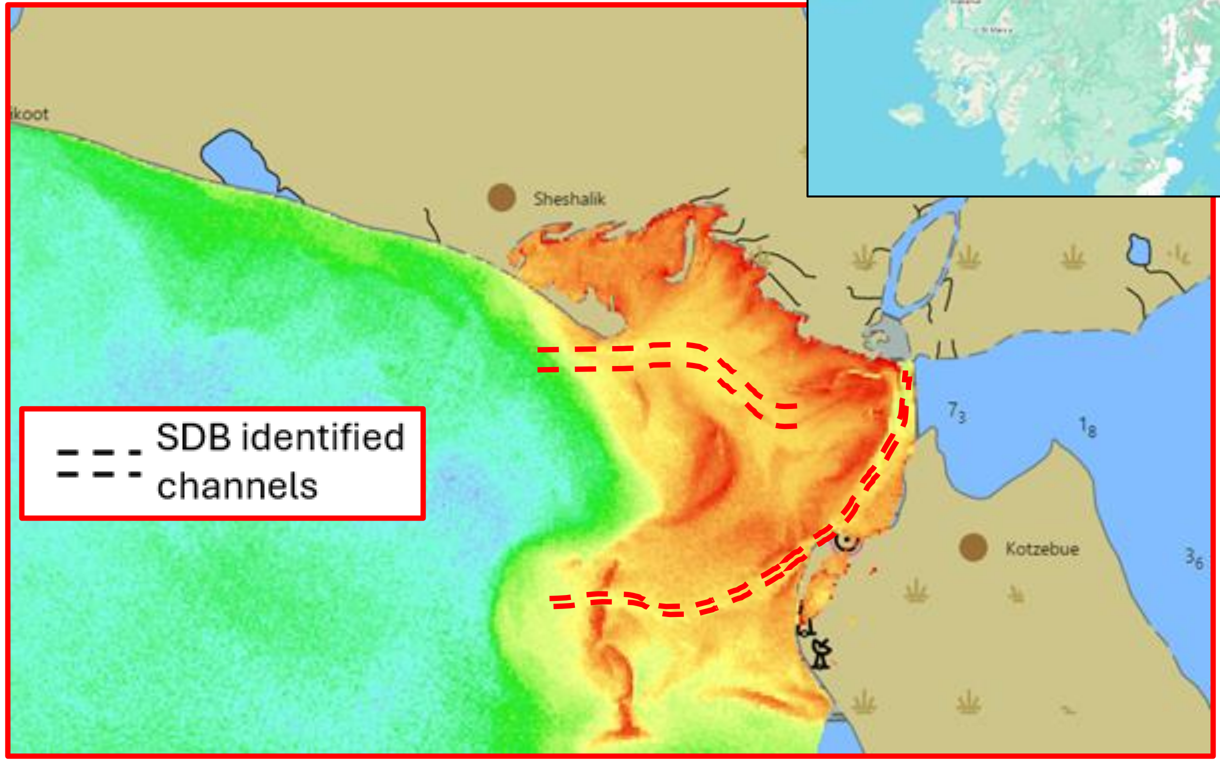




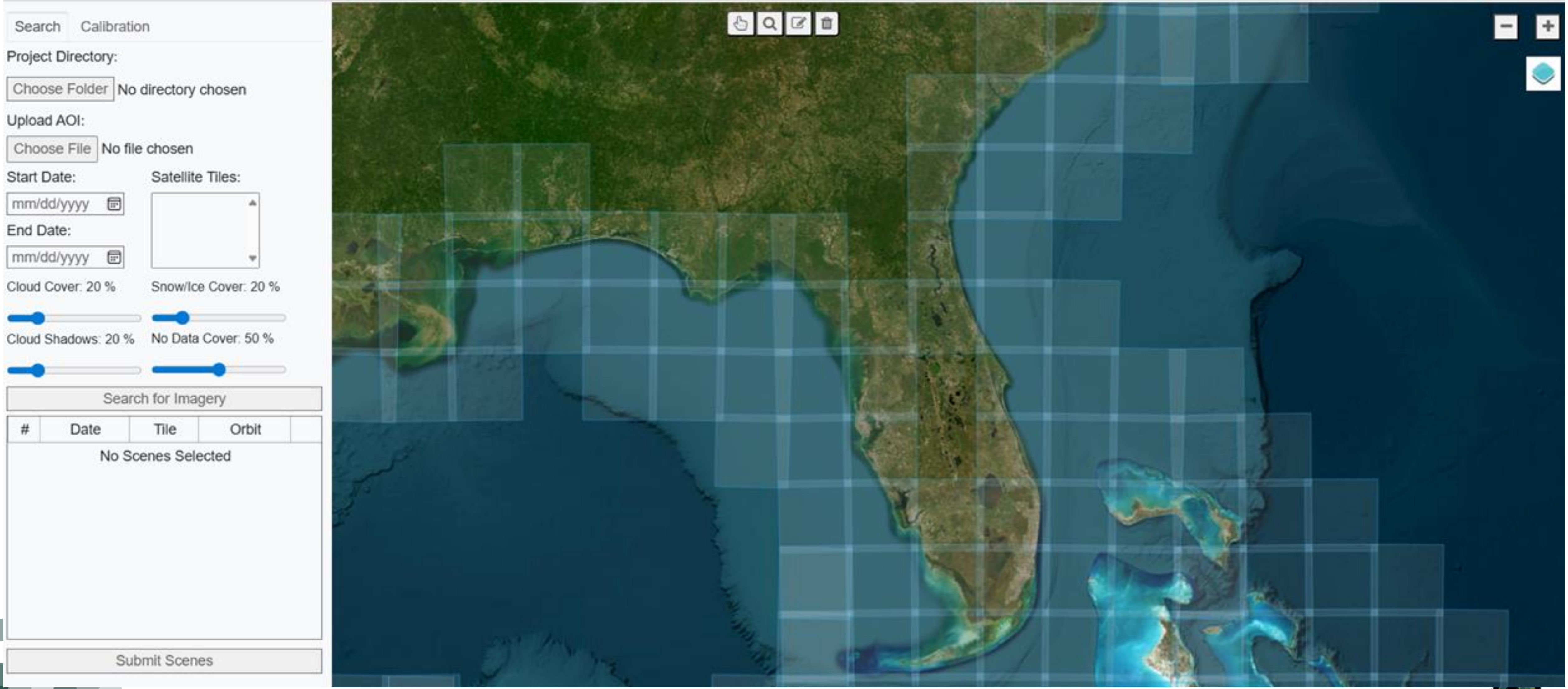


Identifying Hazards and Natural Channels in Kotzebue, AK

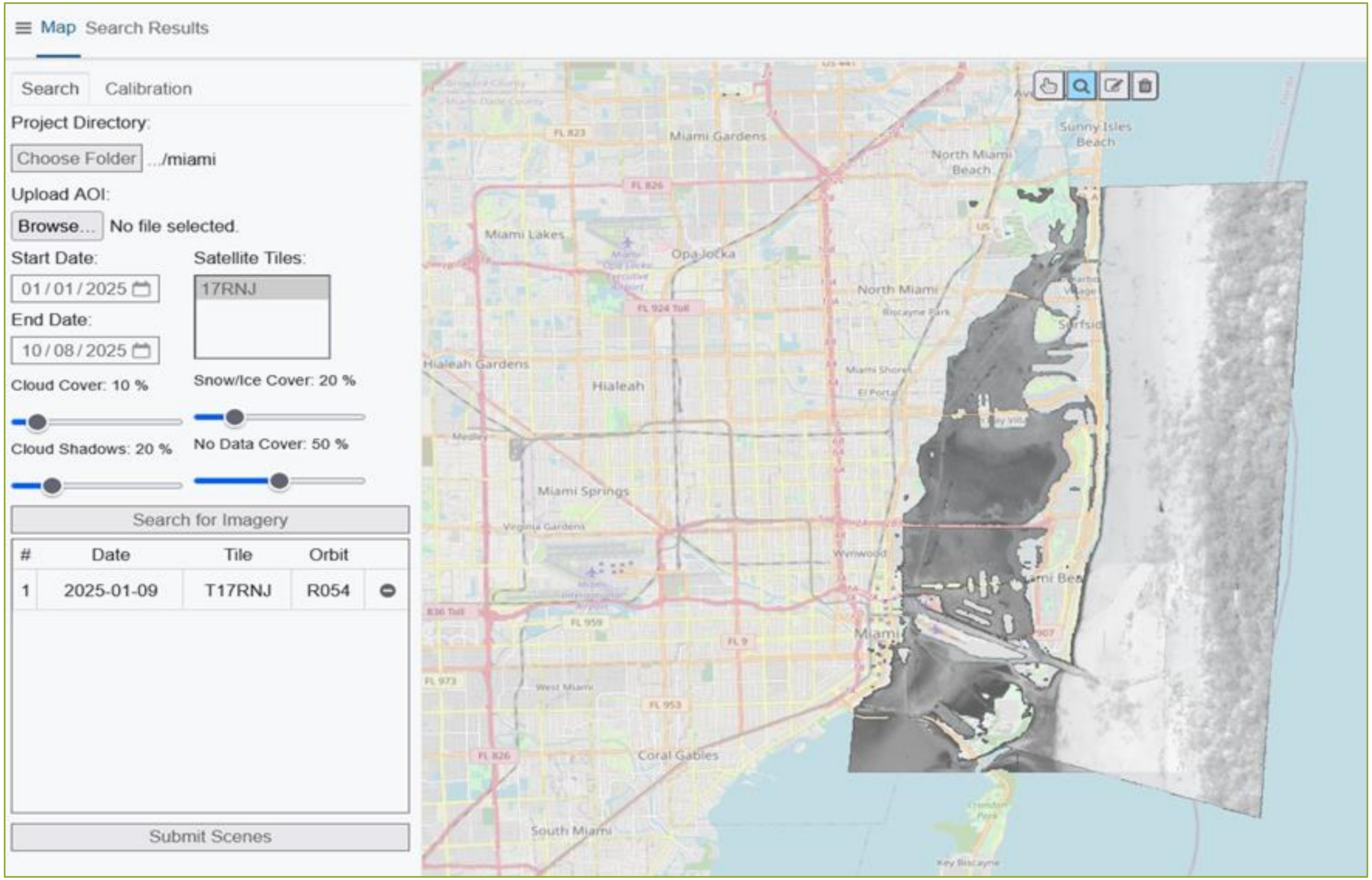




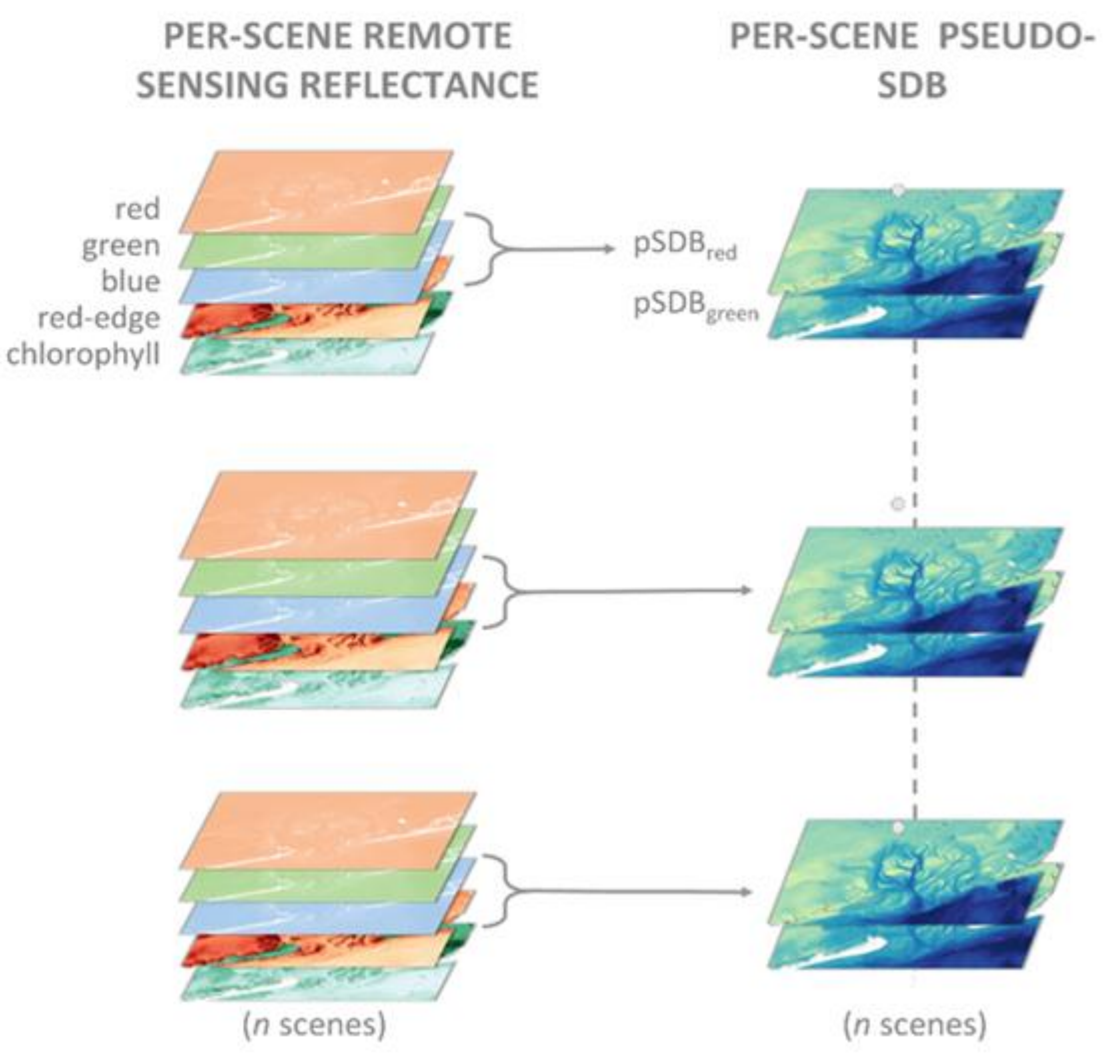
NOAA's SatBathy Desktop Tool v3.1



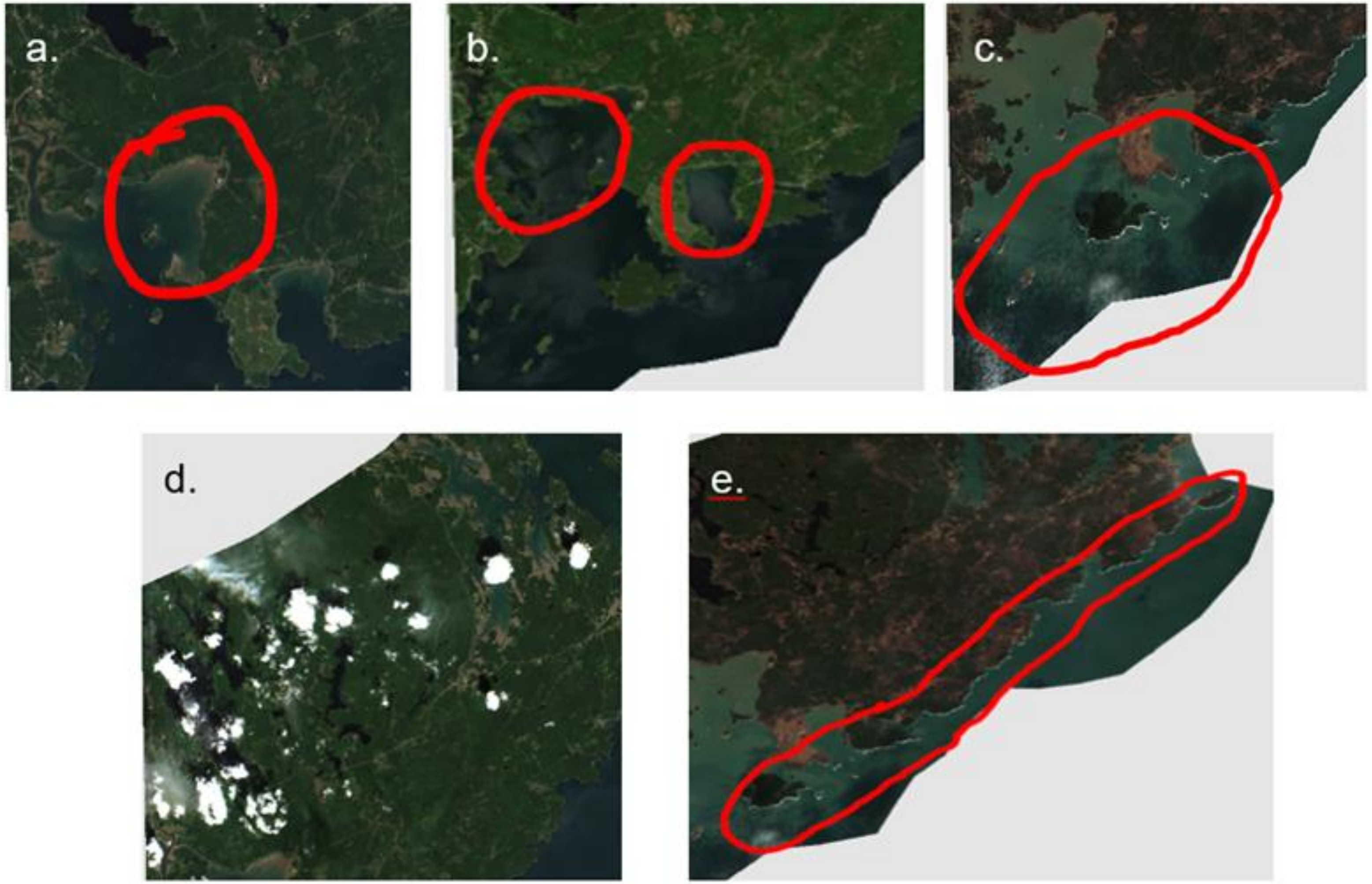
SatBathy Desktop Demo



SatBathy Workflow and Composite Product



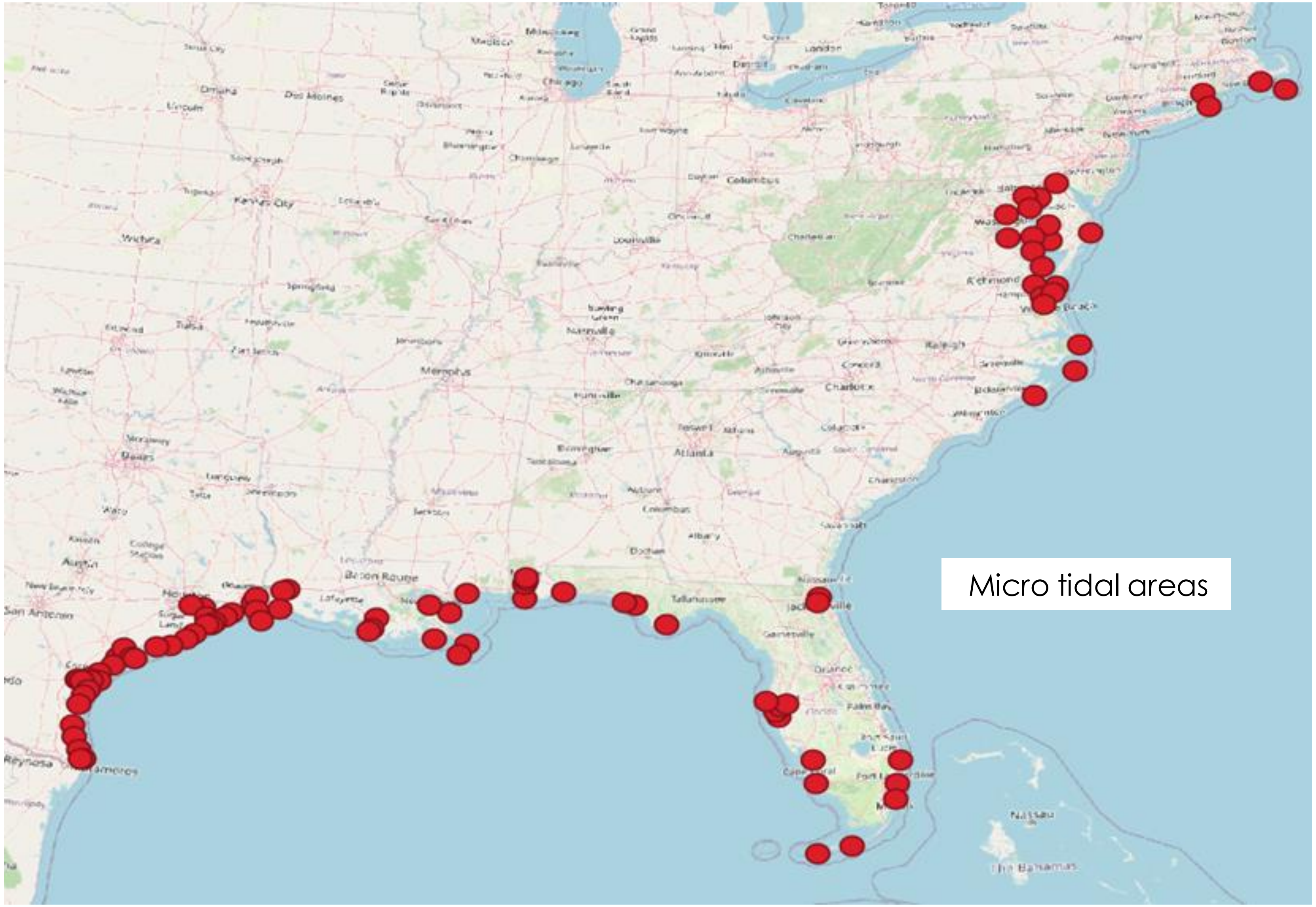
Items to Consider When Selecting Imagery



It is recommended to pick images with:

a. low turbidity
b. little or no sunglint
c. little or no shadows due to clouds
d. little or no clouds in the AOI
e. little or no ice or snow

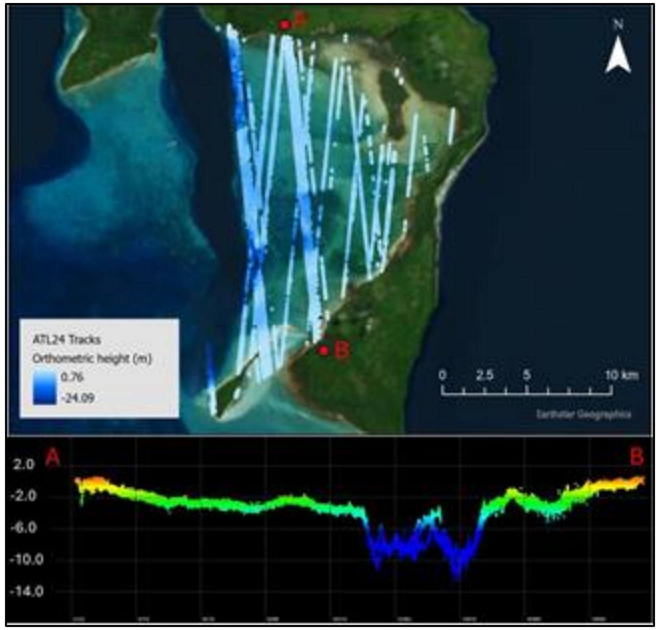
The Importance of Tides: Micro and Macro Tidal Areas



Motivation for Integrating ATL24 into SatBathy

- Entirely independent reference data source
- Near global coastal coverage
- Complementary nature of passive (SDB) and active (ICESat-2/ATL24) remote sensing
- Max depth ranges are generally quite comparable (~1 Secchi depth, occasionally slightly deeper)
- ATL24 accuracy tests confirm its suitability for SDB calibration and validation

ICE, CLOUD, AND LAND ELEVATION SATELLITE-2



ALT24 Demo portion

Requesting ATL24 Data Using Slide Rule

- SlideRule's Python API for ATL24 allows users to request granule data.
- SatBathy does an AOI (area of interest) request for ATL24 data from Oct 2018 to Nov 2024.
- Uses a confidence threshold of 0.7 to remove some false bathymetry

```
# Set confidence threshold to 0.7, default is 0.6.
# Setting the confidence threshold this high will only return class 40 points.
parms = {
    "atl24": {
        "confidence_threshold": 0.7,
        "anc_fields": [
            "sigma_thu",
            "sigma_tvu"
        ]
        # "class_ph": [0, 40, 41]
    },
}

# print(satbathy_aoi_path)

# Pass in the area of interest provided by the user.
# Use prod/temp/support/aoi_geojson_4326.geojson.
# ATL24 Spatial Reference System(s): WGS 84 (EPSG:4326)
atl24_data = sliderule.run("atl24x", parms, aoi=str(satbathy_aoi_path))
length = len(atl24_data['geometry'])
```

ICESat-2 ATL24 Implementation

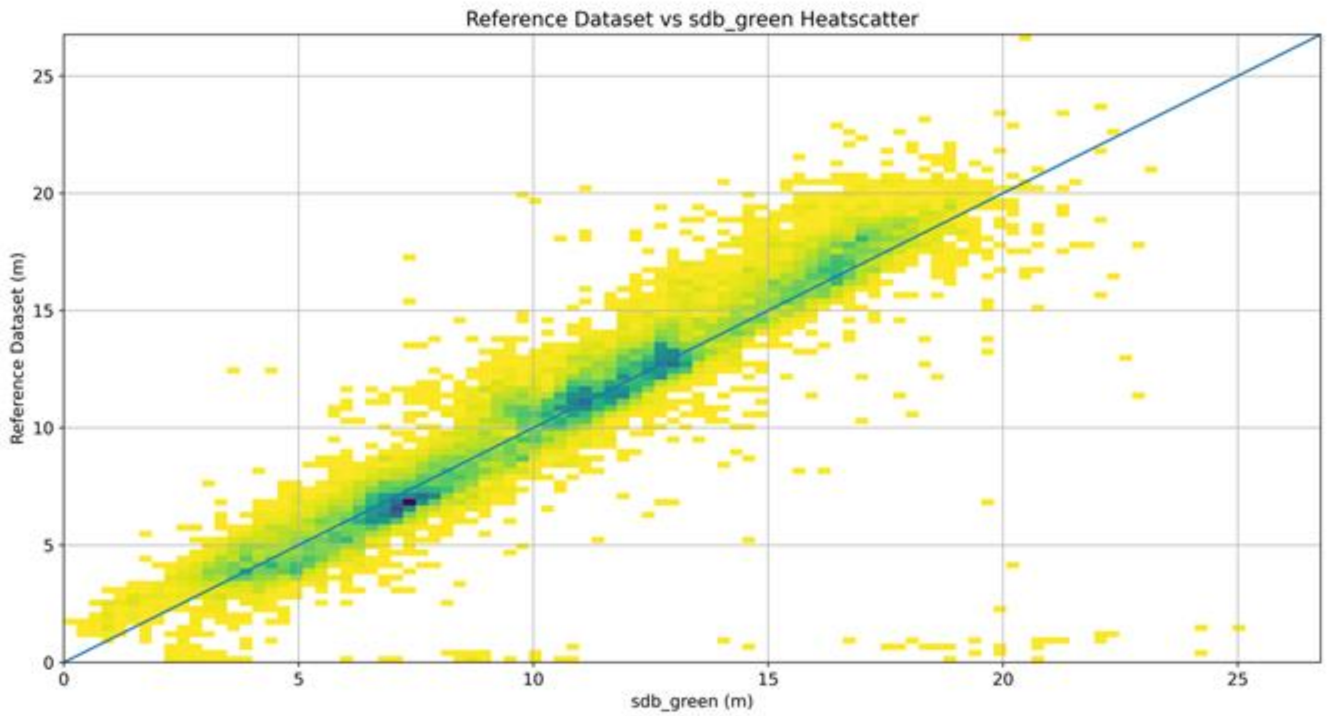
SDB created using 'zero shoreline' values

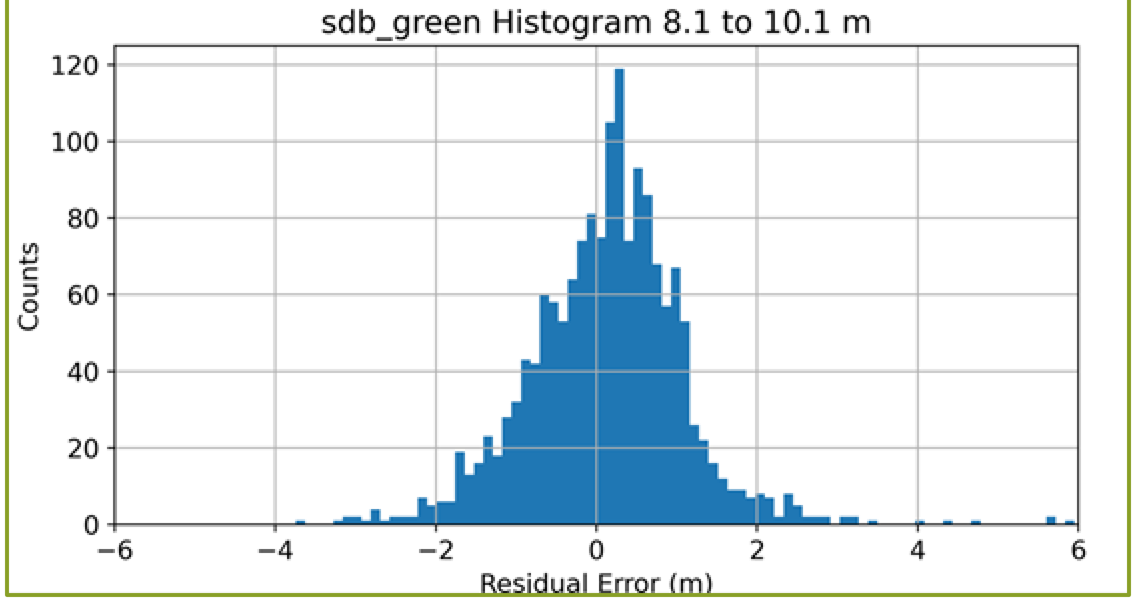
ATL24 photon data gathered

re-grid photons

Comparison of SDB with ATL24 bathy

Used to validate results, can re-calibrate 'zero shoreline' values and re-run SDB and validation

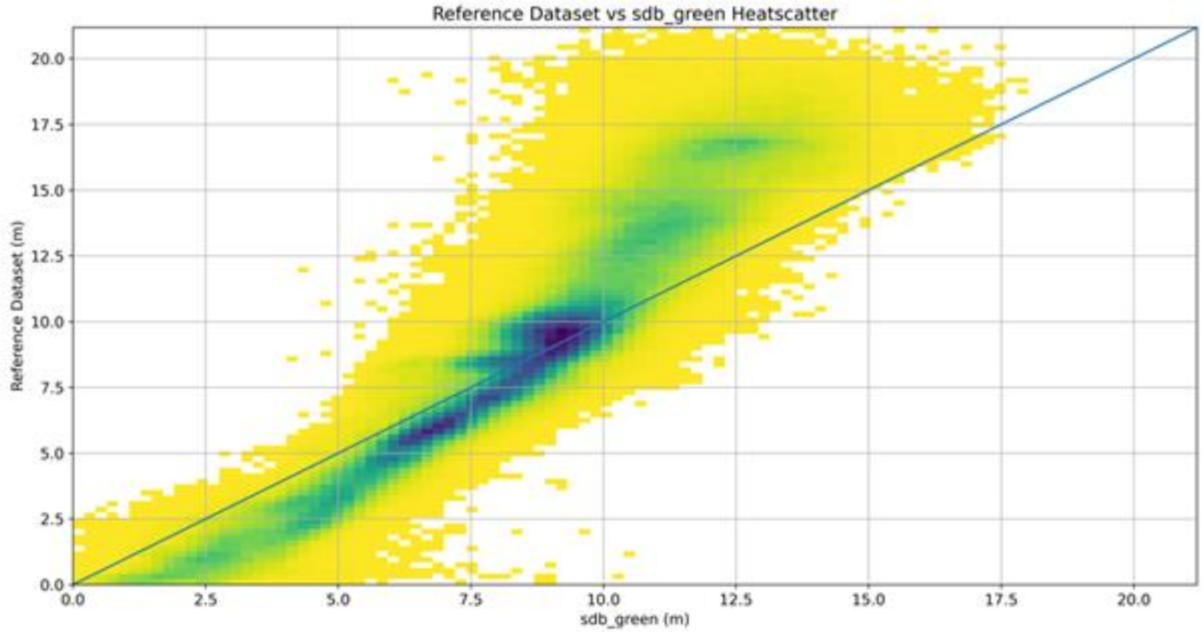


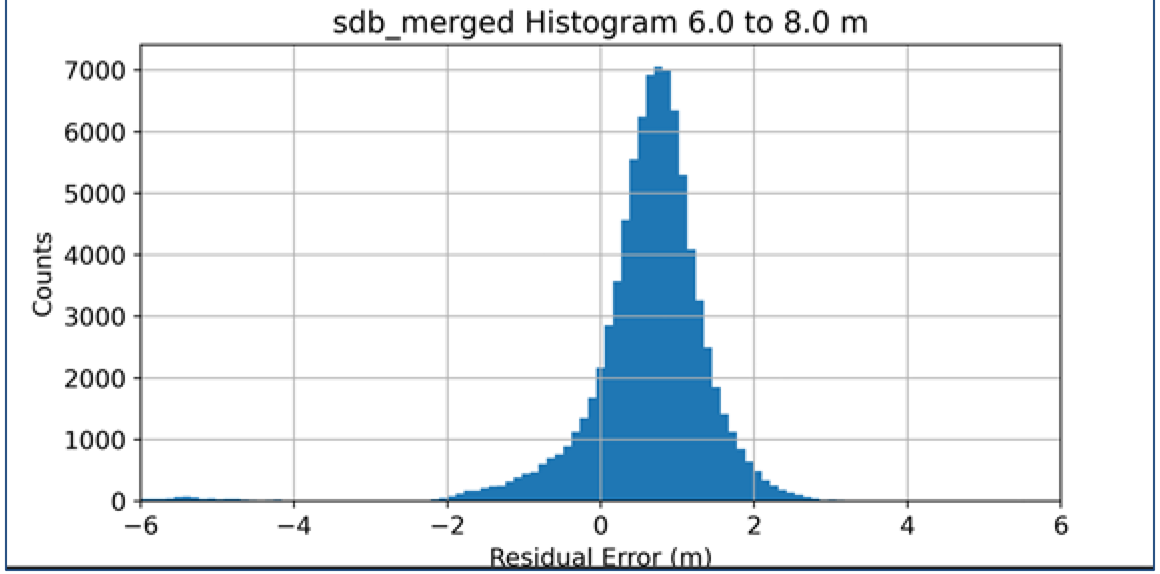


Updates for SatBathy Desktop v3.1

Validation Code Implemented

The validation code generates error statistics, heatscatter plots, and residual error histograms for sdb_red, sdb_green, and sdb_merged.





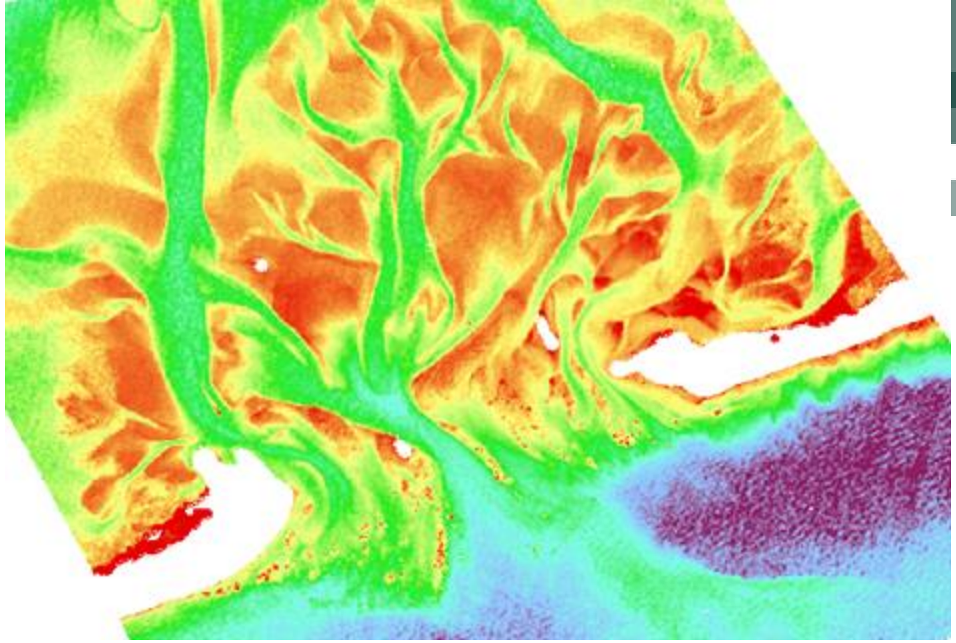
sdb_merged Error Statistics

	0.0 to 2.0 m	2.0 to 4.0 m	4.0 to 6.0 m	6.0 to 8.0 m	8.0 to 10.0 m	10.0 to 15.0 m	15.0 to 20.0 m	20.0 to 25.0 m
Median Abs. Error	0.314	1.501	1.053	0.761	0.517	1.725	4.266	8.505
Mean Abs. Error	0.507	1.473	1.096	0.843	0.644	1.878	4.338	9.389
Bias (MBE)	0.308	1.146	0.999	0.606	-0.206	-1.839	-4.338	-9.389
Count	42636	51100	66249	84950	133066	148939	68199	464

Tide Module

Create an ‘on datum’ SDB composite product using the Aviso FES 2014b tide model

1. Extract S2 scene granule sensing time
2. Query the tide model at each x, y, t point
3. Create gridded water level rasters (LMSL)
4. Composite the water level rasters according to maximum pSDB red or green
5. Adjust calibrated SDB red or SDB green products using the water level grid composite



Local mean sea level applied to SDB for Hatteras, NC

Water level for Hatteras, NC

Citation: "The FES2022 Tide product was funded by CNES, produced by LEGOS, NOVELTIS and CLS and made freely available by AVISO". CNES, 2024."

Resources

- Caballero, I. and Stumpf, R.P, 2023. Confronting turbidity, the major challenge for satellite-derived coastal bathymetry, Science of The Total Environment, Volume 870, 161898,ISSN 0048-9697. https://doi.org/10.1016/j.scitotenv.2023.161898

- Caballero, I. and Stumpf, R.P., 2021. On the use of Sentinel-2 satellites and lidar surveys for the change detection of shallow bathymetry: The case study of North Carolina inlets. Coastal Engineering. https://doi.org/10.1016/j.coastaleng.2021.103936

- Caballero, I. and Stumpf, R.P., 2020. Atmospheric correction for satellite-derived bathymetry in the Caribbean waters: from a single image to multi-temporal approaches using Sentinel-2A/B. Optics Express, 28(8), pp.11742-11766. https://doi.org/10.1364/OE.390316

- Caballero, I. and Stumpf, R.P., 2020. Towards routine mapping of shallow bathymetry in environments with variable turbidity: contribution of Sentinel-2A/B satellites mission. Remote Sensing, 12(3), p.451. https://doi.org/10.3390/rs12030451

Resources (Continued)

- Caballero, I. and Stumpf, R.P., 2019. Retrieval of nearshore bathymetry from Sentinel-2A and 2B satellites in South Florida coastal waters. Estuarine, Coastal and Shelf Science, 226, p.106277. https://doi.org/10.1016/j.ecss.2019.106277
- Caballero, I., Stumpf, R.P. and Meredith, A., 2019. Preliminary Assessment of Turbidity and Chlorophyll Impact on Bathymetry Derived from Sentinel-2A and Sentinel-3A Satellites in South Florida. Remote Sensing, 11(6), p.645. https://doi.org/10.3390/rs11060645
- Stumpf, R.P. K. Holderied, M. Sinclair, 2003. Determination of water depth with high-resolution satellite imagery over variable bottom types. Limnology and Oceanography, v. 48(1, part 2), pp. 547-556. https://aslopubs.onlinelibrary.wiley.com/doi/10.4319/lo.2003.48.1_part_2.0547

Special Thanks to the SatBathy Team

- Bryan Eder, NOAA
- Rick Stumpf, NOAA
- Chris Parrish, Oregon State University
- Brian Madore, NOAA
- Ruth McCullough, Oregon State University
- Jon Sellars, NOAA
- Starla Robinson, NOAA
- Starla Robinson, NOAA
- Anthony Klemm, NOAA
- Kyle Ward, NOAA
- Rudy Troche, NOAA
- Isabel Caballero, Spanish National Research Council
- Matt Sharr, NOAA (former NOAA Corps)
- Mike Aslaksen, NOAA

Part 2:
Summary

Summary

- ATL24 can be integrated with optical bands (blue and green wavelengths) for deriving satellite-derived bathymetry (SDB).
- 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.
- SlideRule Python Client can be used to access ATL24.
- SlideRule provides documentation for Python Client including example scripts, user guide, and developers guide.
- SatBathy is a hybrid web/desktop tool created by NOAA for automating SDB.
- SatBathy utilizes 10-meter resolution satellite imagery from the Copernicus Sentinel-2 mission, Amazon Web Service (AWS), and ACOLITE atmospheric correction processor.
- SatBathy integrated ATL24 product as an independent reference data source.

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

Training 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.
- National Snow and Ice Data Center (NSIDC) provides access to ATL24 data, metadata, and tools.
- SlideRule is a public web service with low-latency access to on-demand data products stored in S3.
- SlideRule Python API can be used to access ATL24.
- SatBathy is a hybrid web/desktop tool created by NOAA for automating SDB.
- SatBathy utilizes 10-meter resolution satellite imagery from the Copernicus Sentinel-2 mission, Amazon Web Service (AWS), and ACOLITE atmospheric correction processor.
- SatBathy integrated ATL24 product as an independent reference data source.

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.

Acknowledgements

Christopher Parrish
Professor
Oregon State University

Joseph-Paul Swinski
Software Developer
NASA GSFC

Gretchen Imahori
Staff Scientist
NOAA

Keana Kief
Analyst Programmer
Oregon State University

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2. Follow the instructions sent in response.

Thank You!