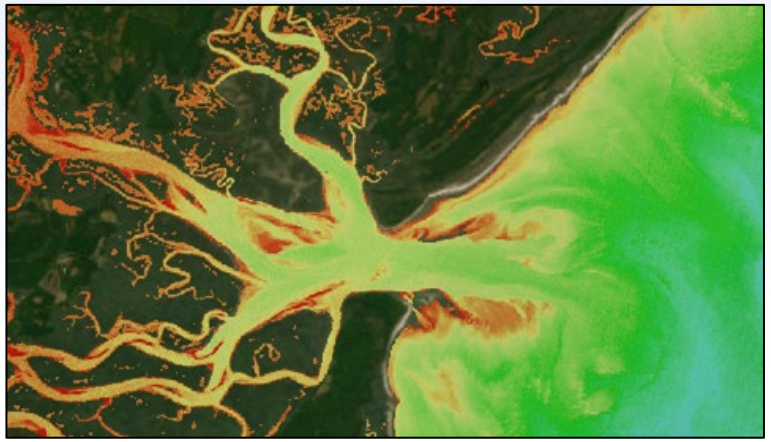
NOAA's SatBathy Tool Beta v2.1.6

Satellite Derived Bathymetry:
from research to operations



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NOAA

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National Centers for Coastal Ocean Science (NCCOS)
NOAA

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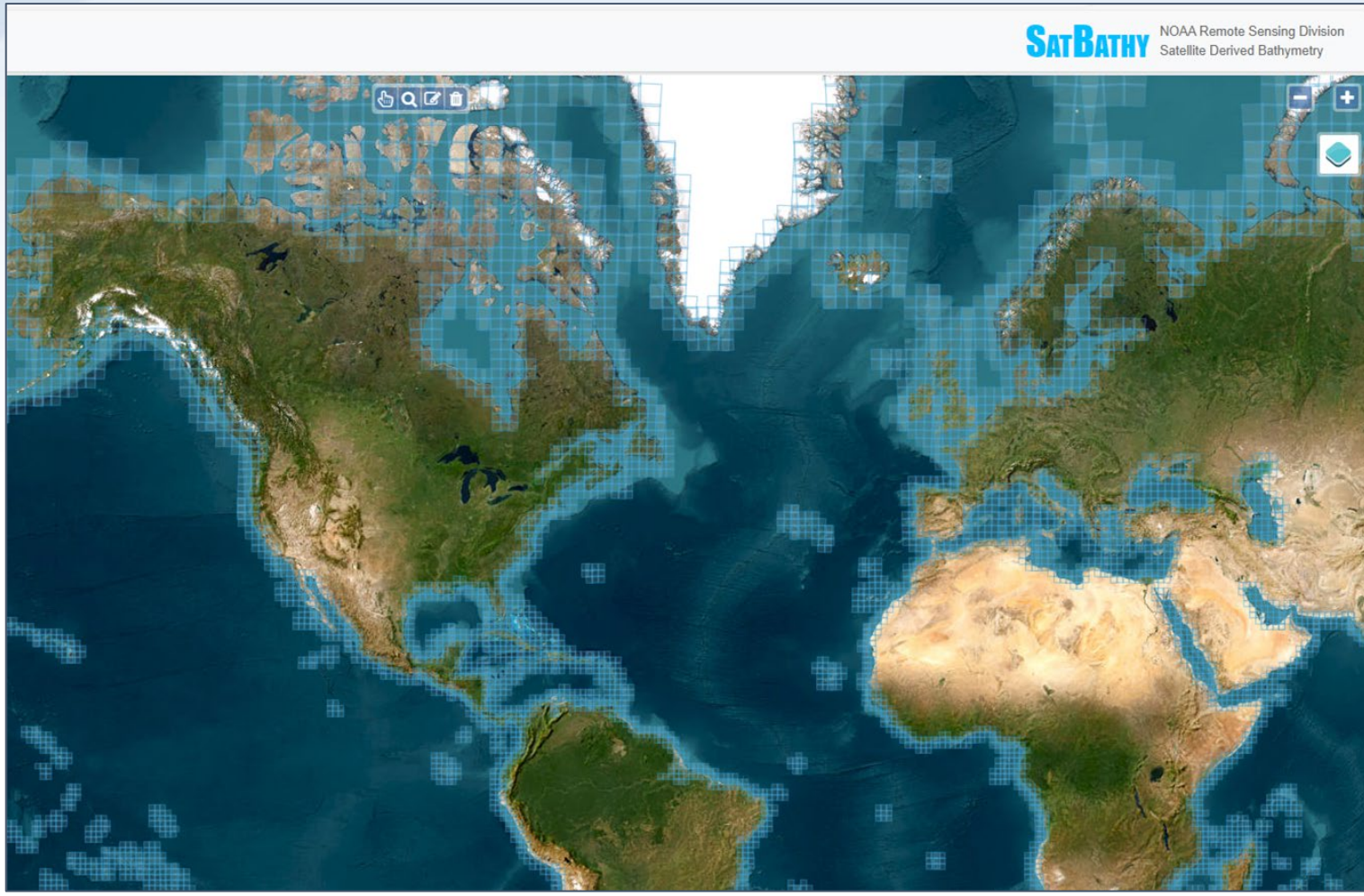
Overview

- Background
- Updates & Latest capabilities
- Testing and training
- Increased deployment to NOAA's Coast Survey for project planning/ reconnaissance
- Research & Challenges
- NOAA's Vision for SatBathy/providing SDB to the public, Federal partners, etc.



Background

What is Satellite – Derived Bathymetry (SDB)?

Using satellite imagery from the Copernicus Sentinel-2 mission (10m) and updated research from Dr. Rick Stumpf and Dr. Isabel Caballero

An empirically calibrated relationship that uses ratios of logs of **blue to green and blue to red spectral bands**.

Assume uniform water clarity in the final product
(we try to reduce variations in water clarity)

Works over seafloor with varying brightness

Infers relative depth up to the extinction depth of the SDB product

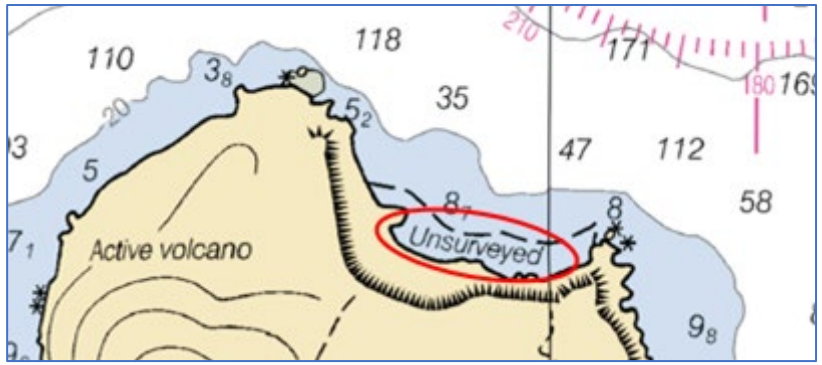
Why does NOAA need SDB?

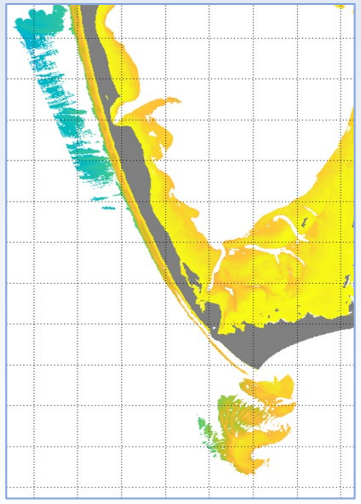
SDB is currently supporting:

- hydrographic survey planning/reconnaissance
- Interim updates to NOAA National Bathymetric Source/ Chart (eventually) until traditional surveys can be applied
- Coast Survey External Data Source validation
- Integrated Ocean and Coastal Mapping (IOCM), etc.

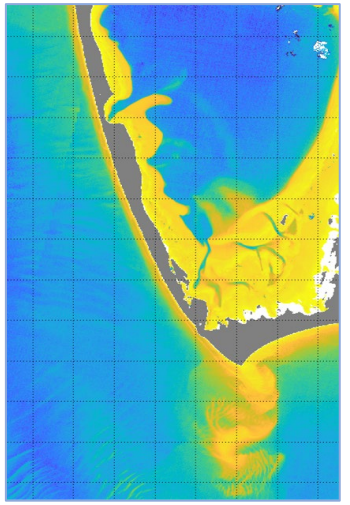
SDB will support:

- Fill in gaps for lidar and multibeam in non-navigationally significant areas
- Change analysis





RSD lidar



SDB

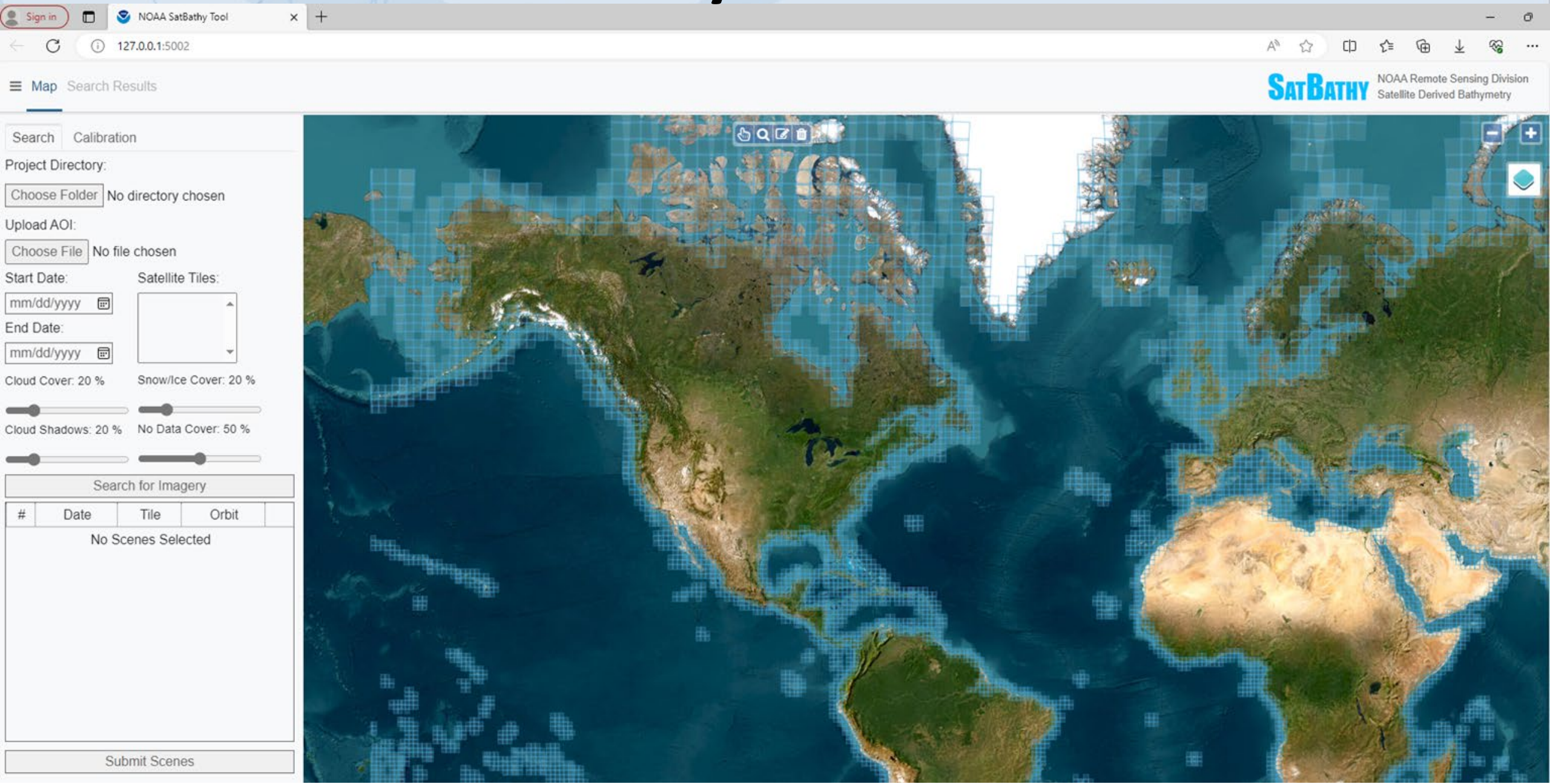
How? For localized interim chart updates

from NOAA's Nautical Chart Manual (2021):

"Satellite Derived Bathymetry (SDB) may be used to revise waterways on nautical charts that have not been recently surveyed by acoustic means, such as MBES, or by Airborne Lidar Bathymetry (ALB) **and/or are economically/strategically impractical to survey, such as extremely remote or highly dynamic areas.** The use of SDB data is especially useful where vessel traffic or the deployment of aids to navigation indicate that charted data is misleading and **there are no recent surveys to update the chart**."

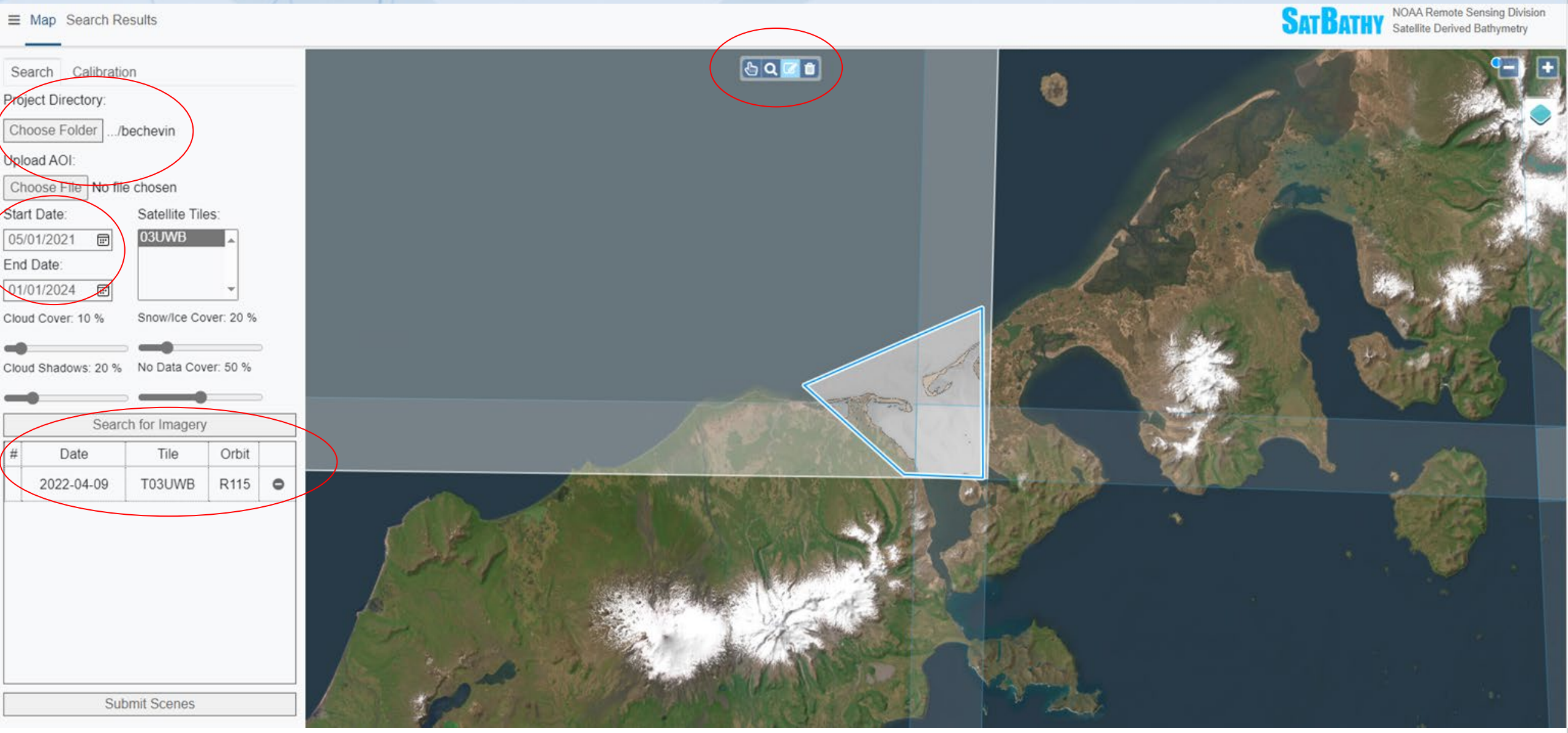
What is SatBathy?

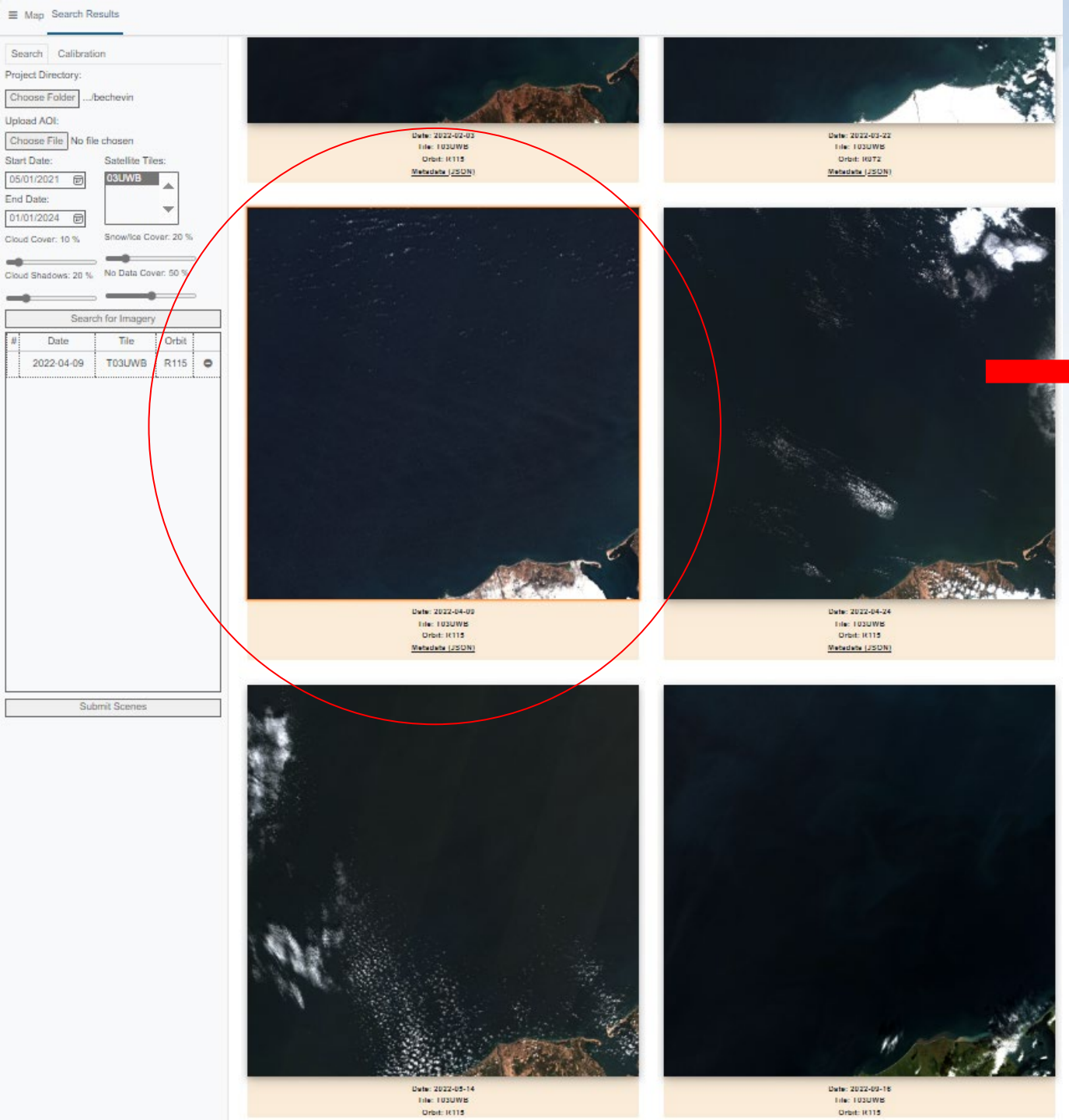
SatBathy beta v2.1.6



Basic steps to create SDB using SatBathy

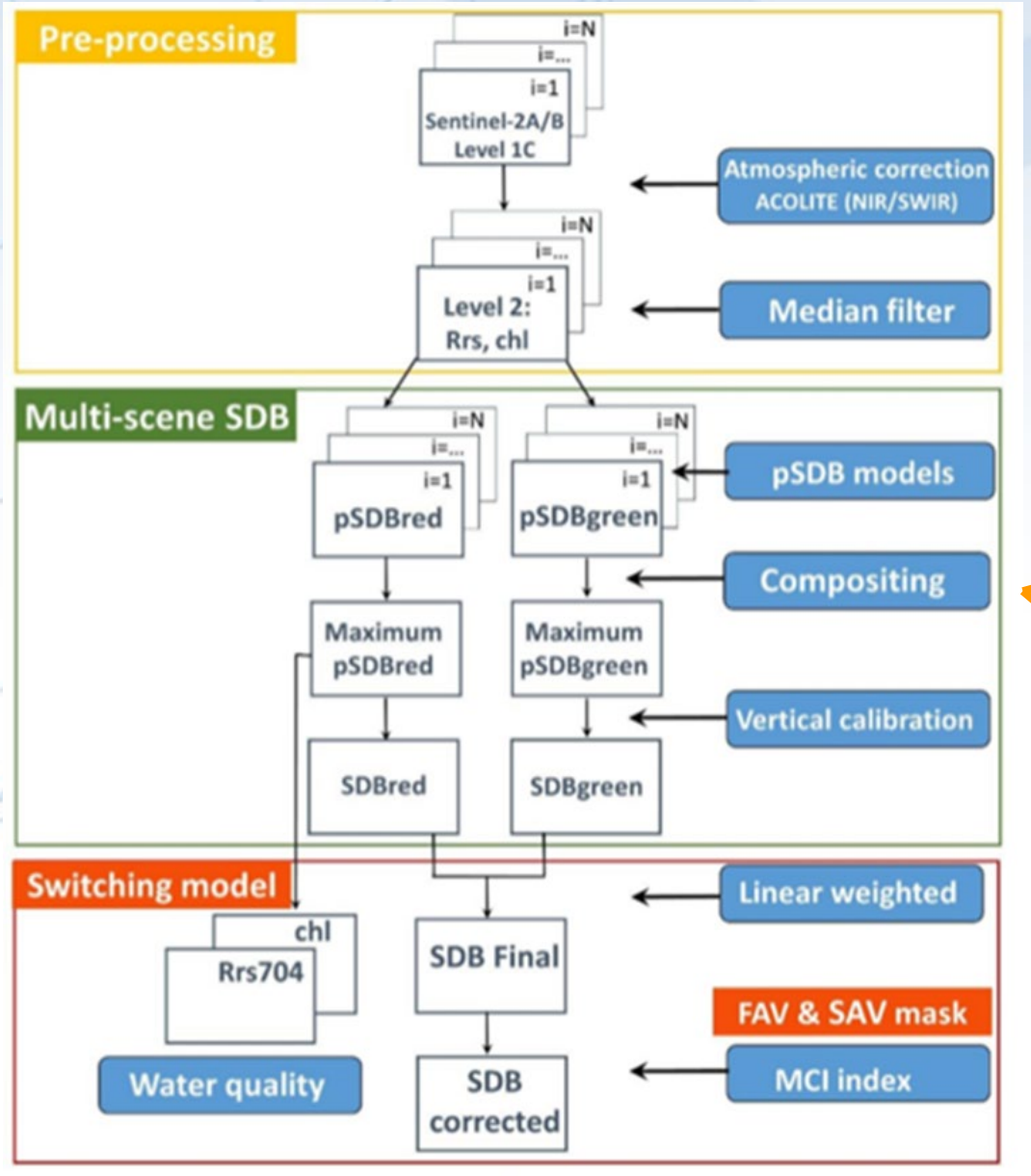
Current test area Bechevin Bay, AK

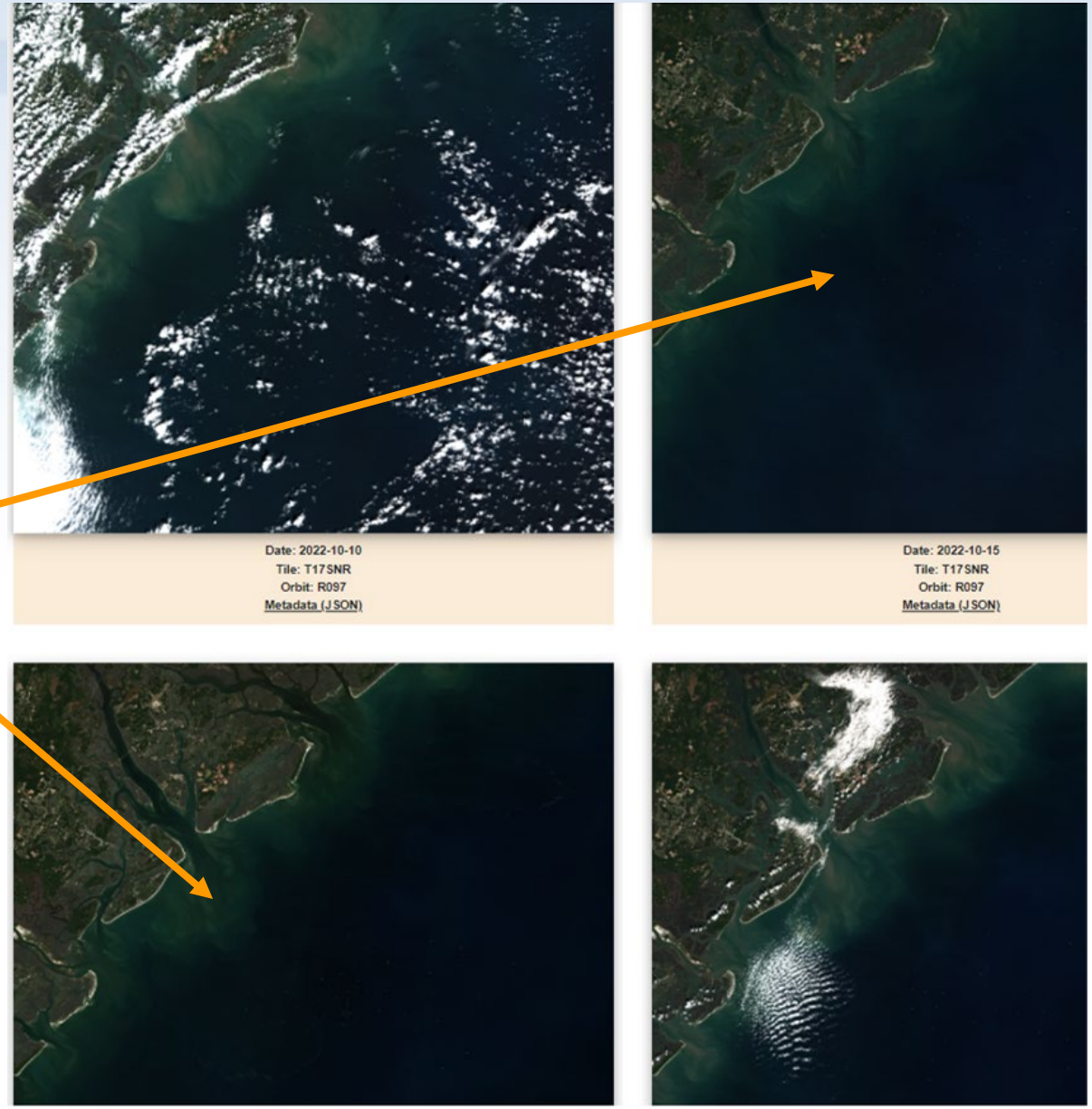


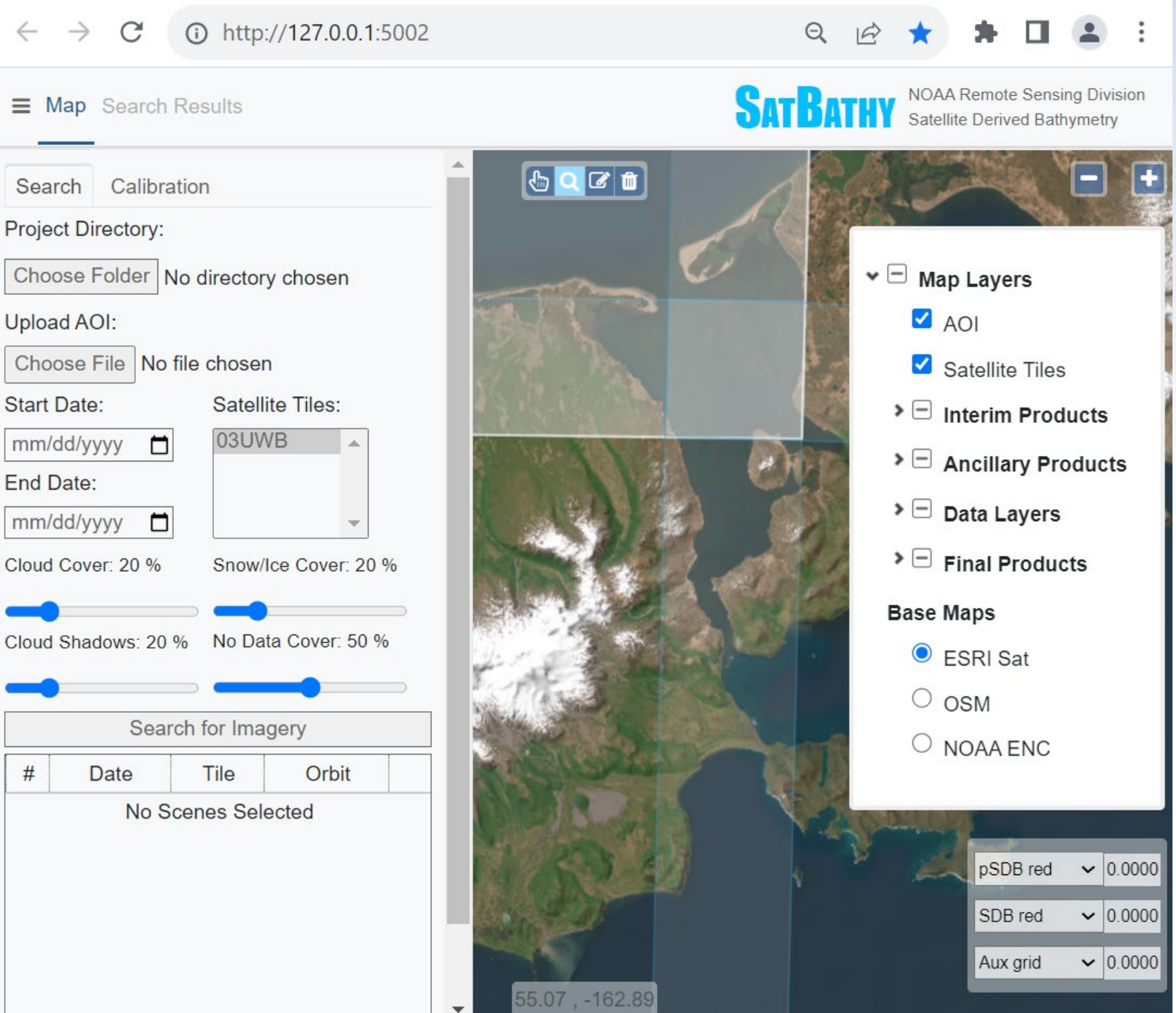


- low turbidity
- little or no clouds or cloud shadows
- little or no sun glint or haze
- little or no snow/ice

Using Compositing to Reduce Turbidity

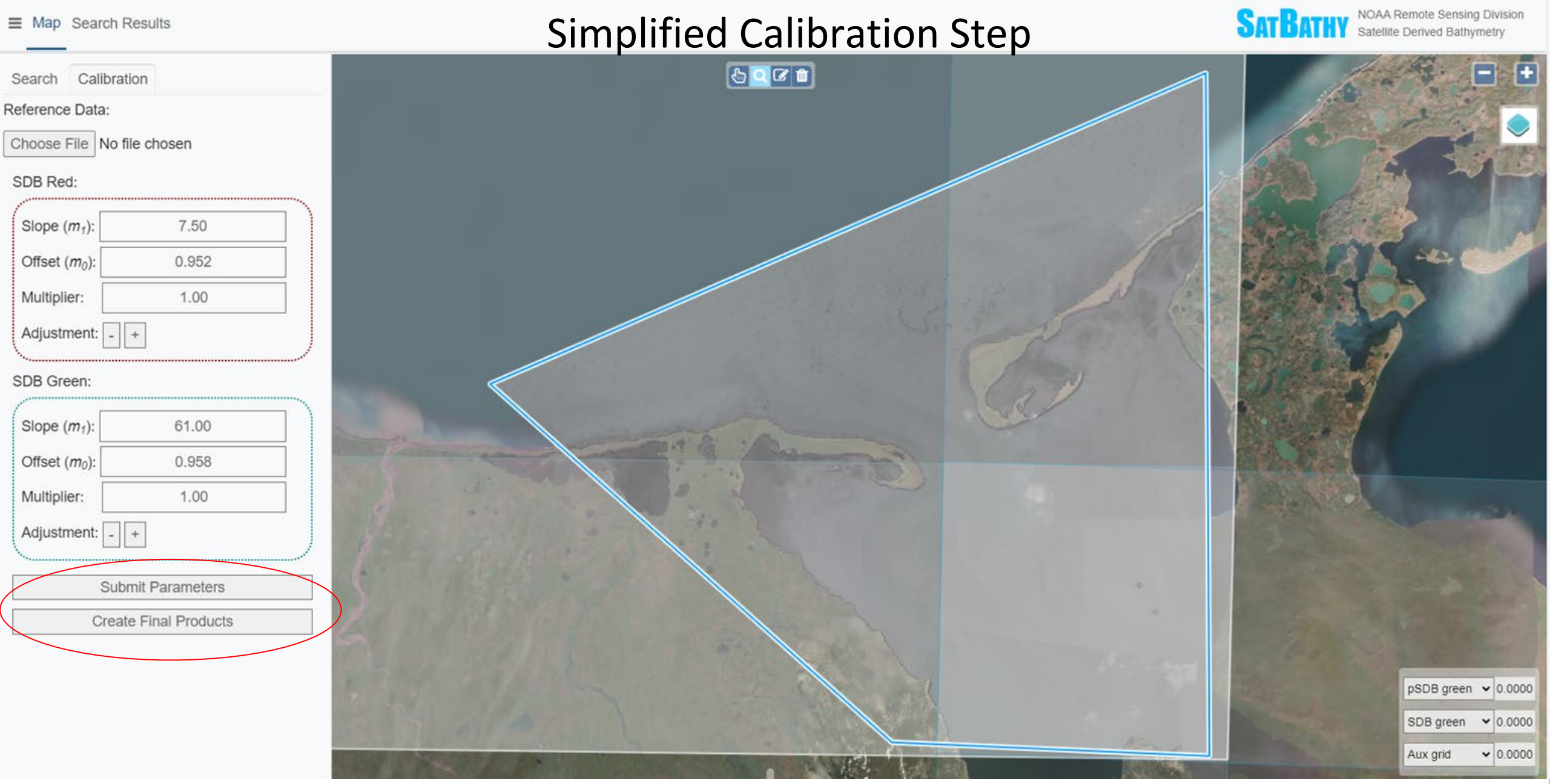






- pSDB = pseudo SDB (relative SDB - not referenced to a datum and does not have meaningful units)
- Need to create SDB products relative to a datum (in this case Local MSL)

Simplified Calibration Step

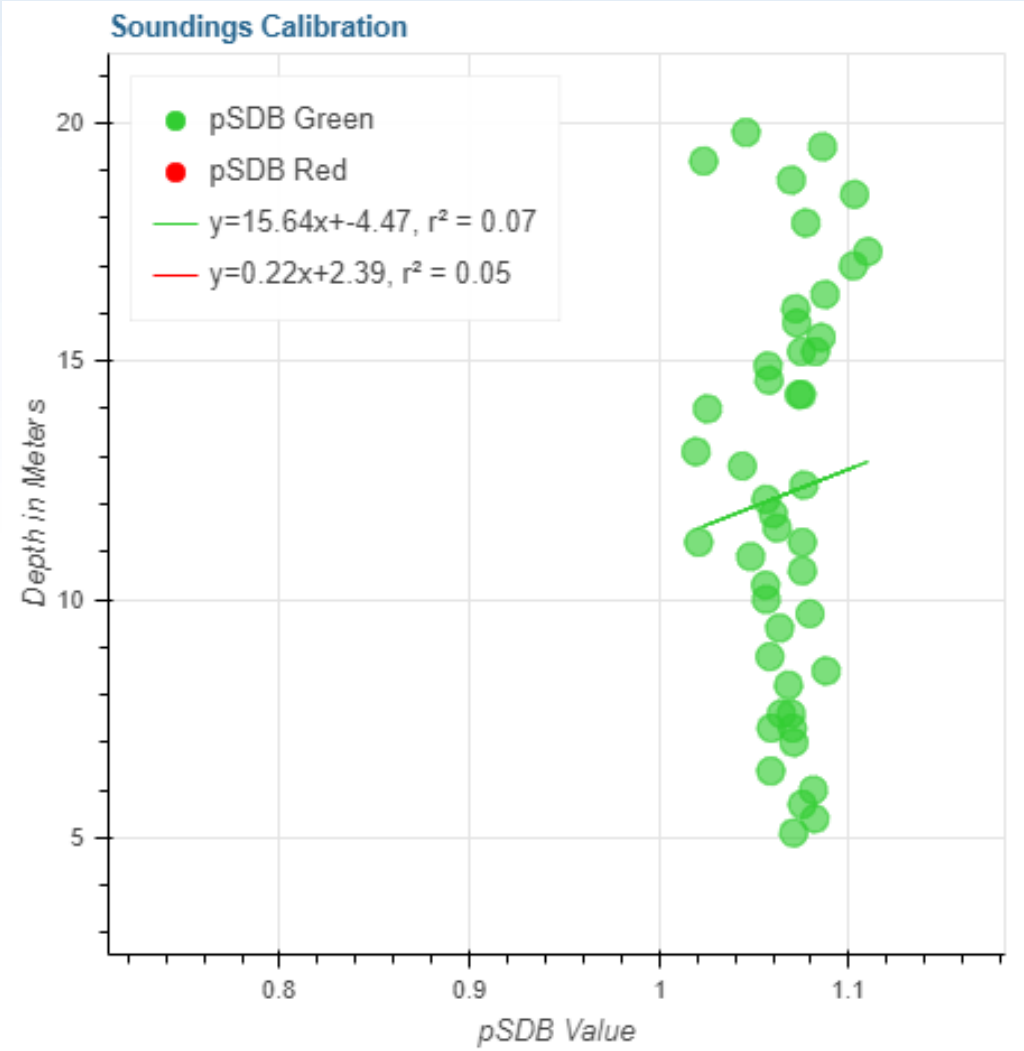


Select offset values closest to the shoreline (to zero); SDB = m_1*(pSDB-m_0)

Why NOAA moved to simplified calibration process: challenges and limitations with using charted soundings

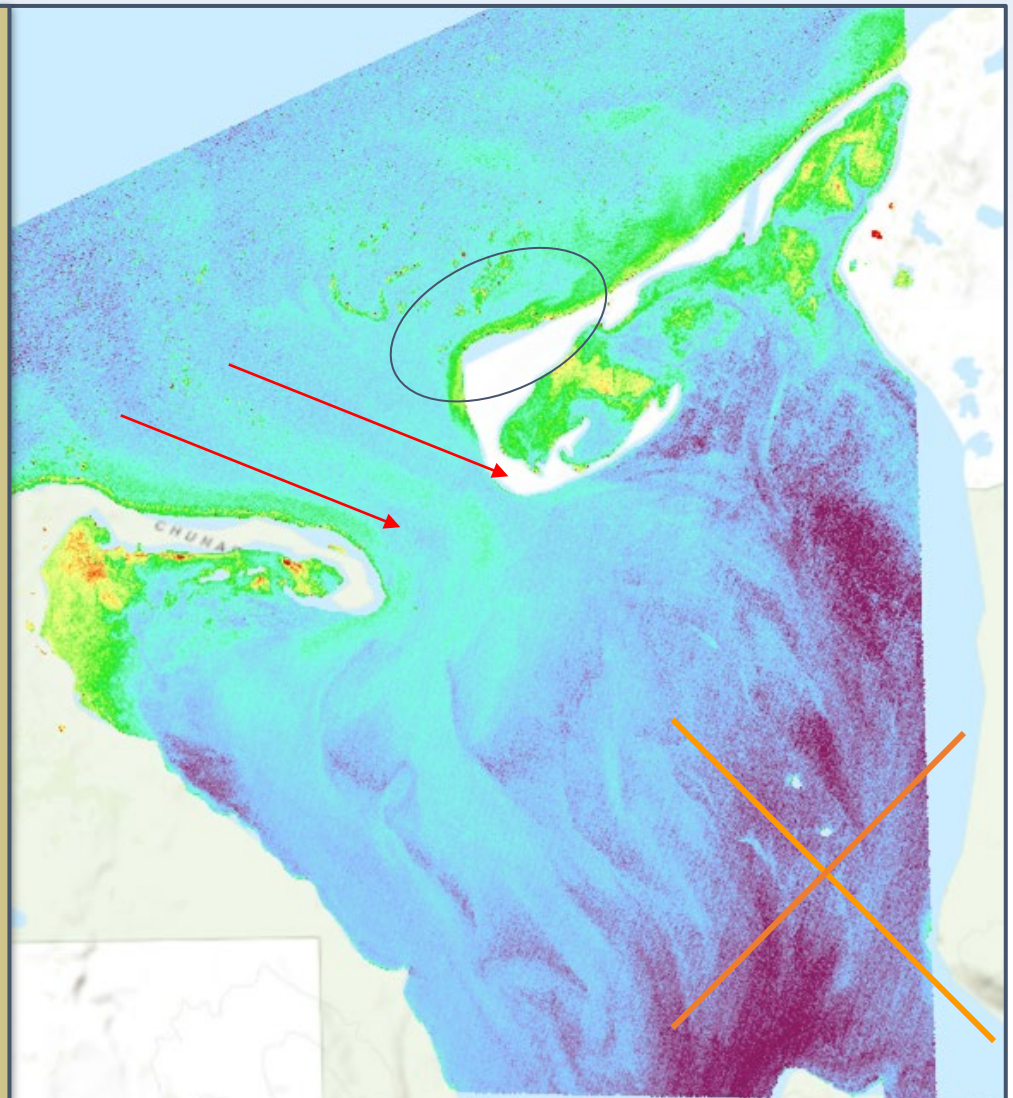
Limitations of previous calibration process

- **Locations where ENC/Lidar or MBES reference depths exist**
- Time (this is a combination manual/automated process)
- Possibility of poor linear regression results (see right)
- Lack of depths in shallow areas



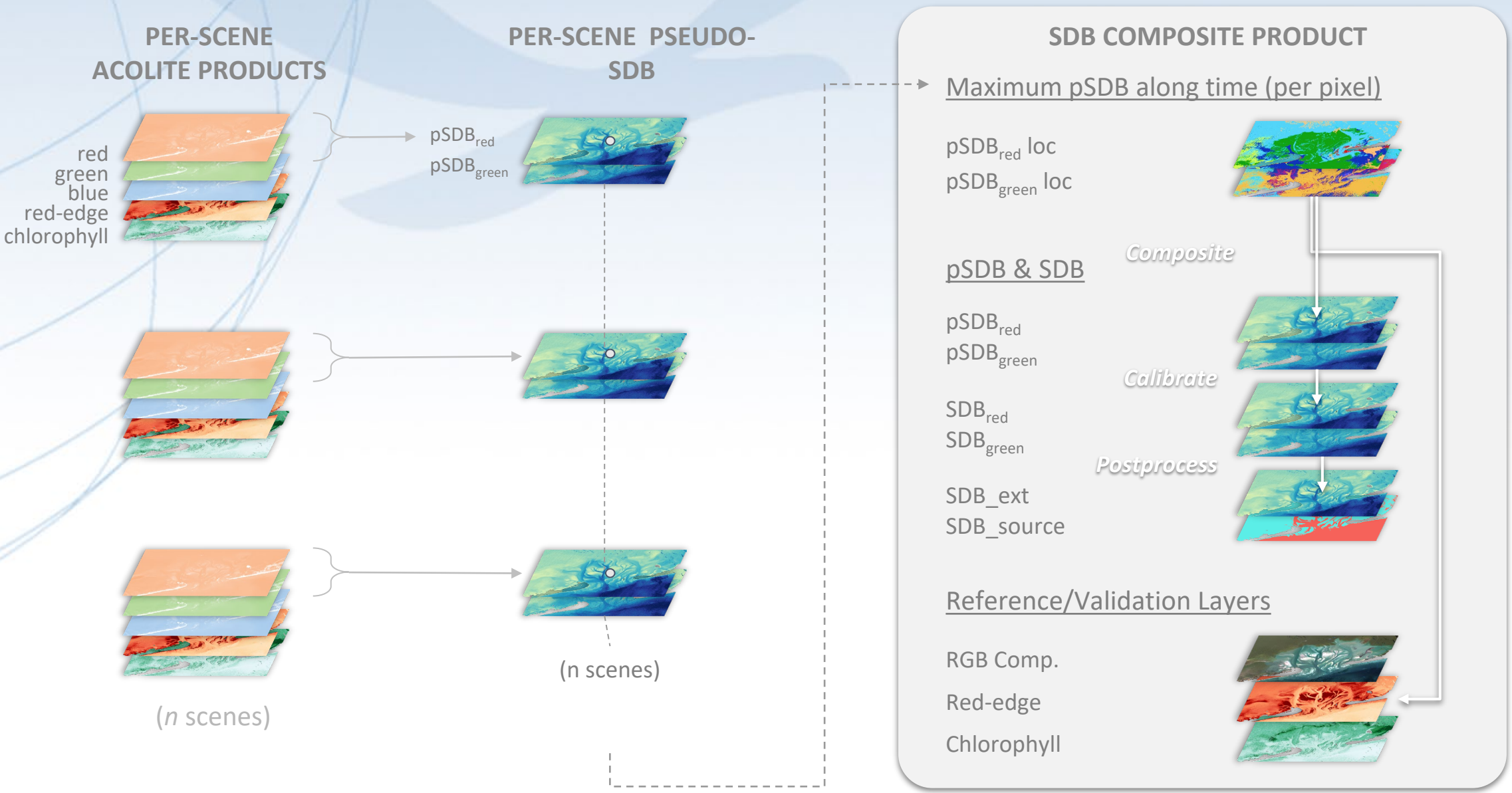
Example of poor linear regression result (R squared)

Preliminary final SDB product

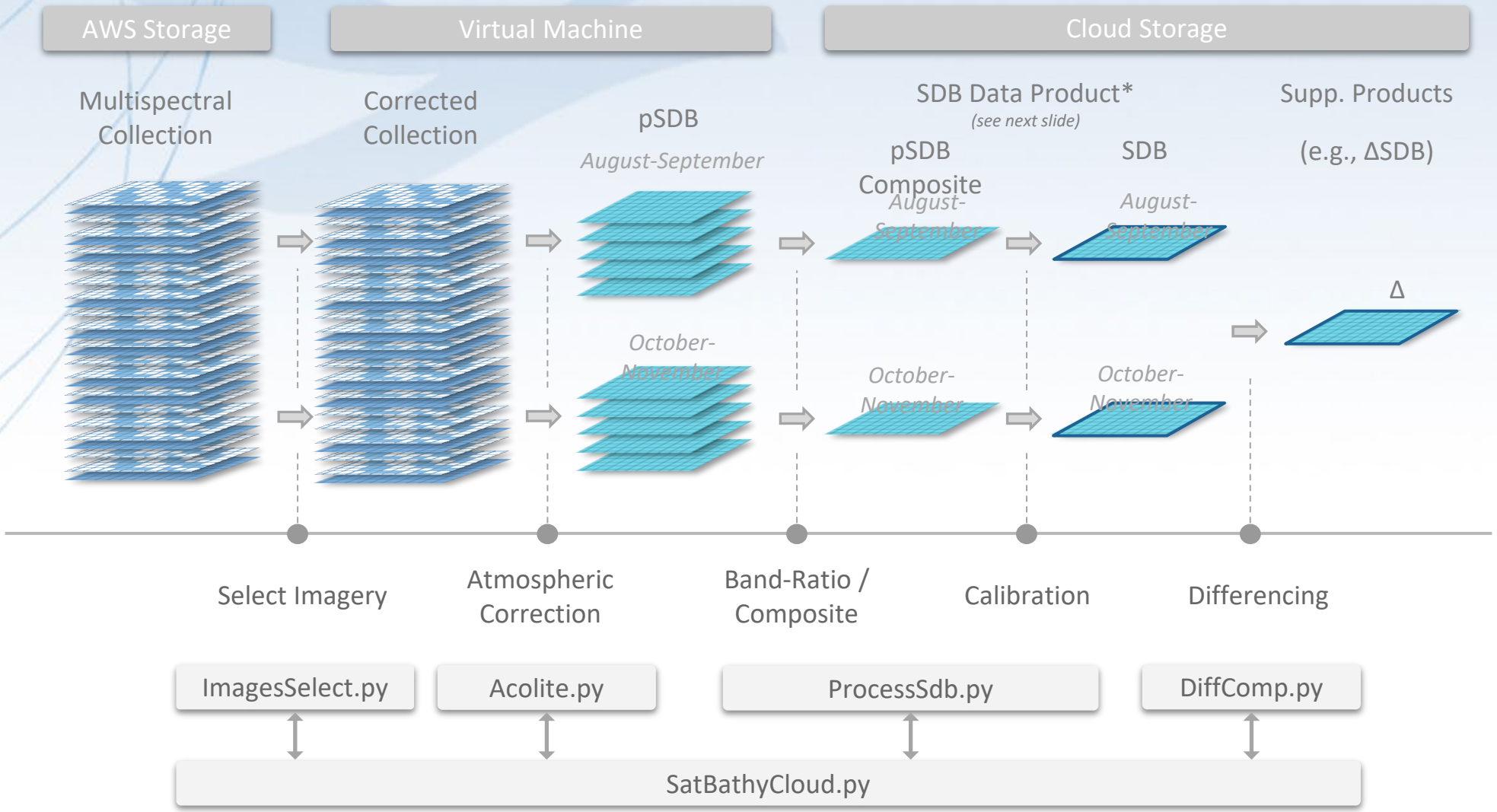


Evolution of SatBathy Framework

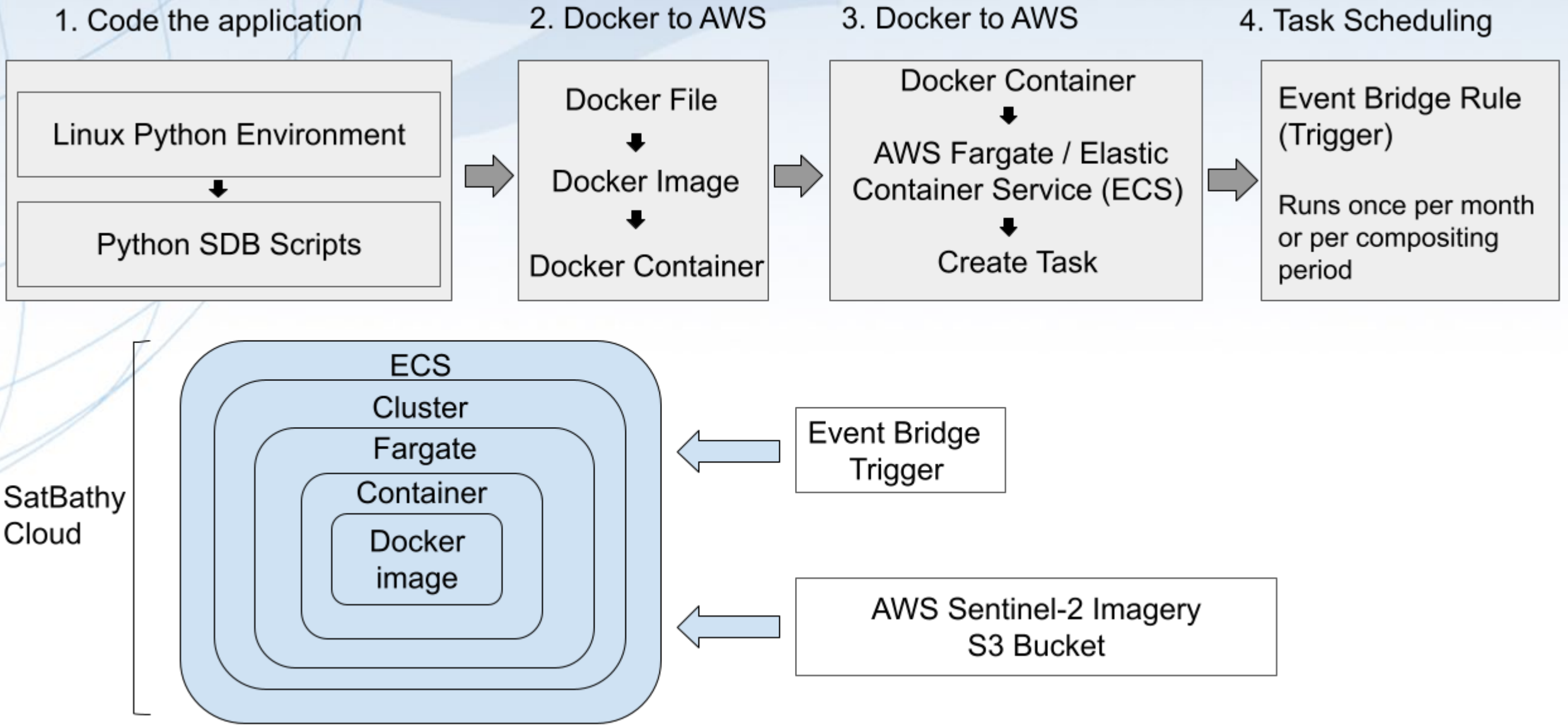
SDB Data Flow and Composite Product



An Example Cloud Workflow with Change Analysis



Vision for SatBathy Cloud



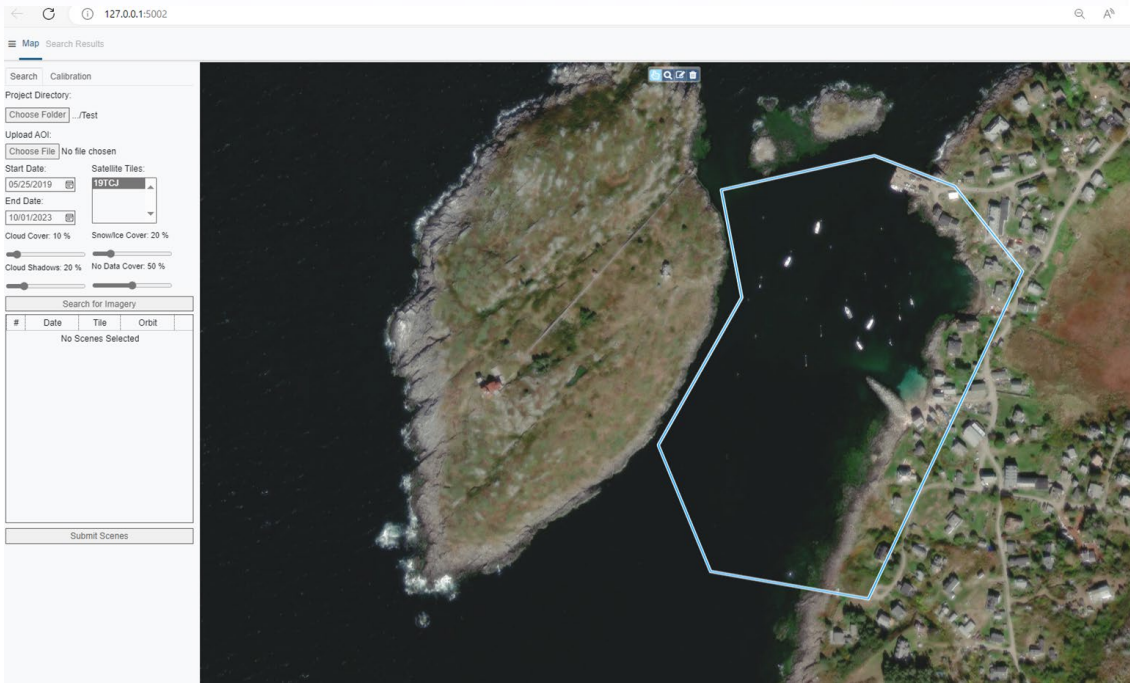
Updates & Latest capabilities

Updates

- Expanded data coverage
  - Sentinel-2 (S2) imagery source changed from the Google Cloud Platform (GCP) to Amazon Web Service (AWS) - GCP initiated rate restrictions - had to find a stable alternative
    - Credentials required to collect S2 imagery from AWS
    - Complete historical catalog from the European Space Agency (ESA) available
- Wider application of SatBathy
  - Atmospheric correction updated and parameters adjusted to more accurately process scenes of variable water quality from clear to turbid waters
- Developed strategies to support high tide areas

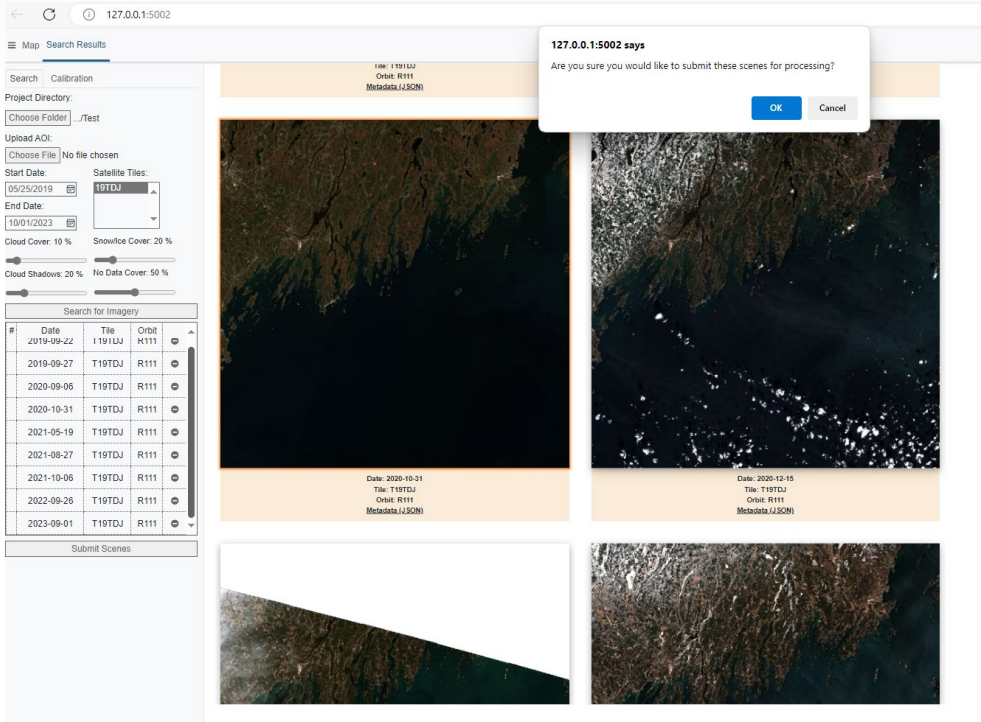
Updates (cont.)

- Additional personnel
  - Programming assistance from Keana Kief from OSU
  - RSD student, Brian Madore, from OSU researching change analysis
  - Matt Sharr from NOAA RSD working on machine learning for turbid areas, zero shoreline, etc.
  - All hands on universal calibration research (NCCOS, OSU and RSD)



Latest Capabilities

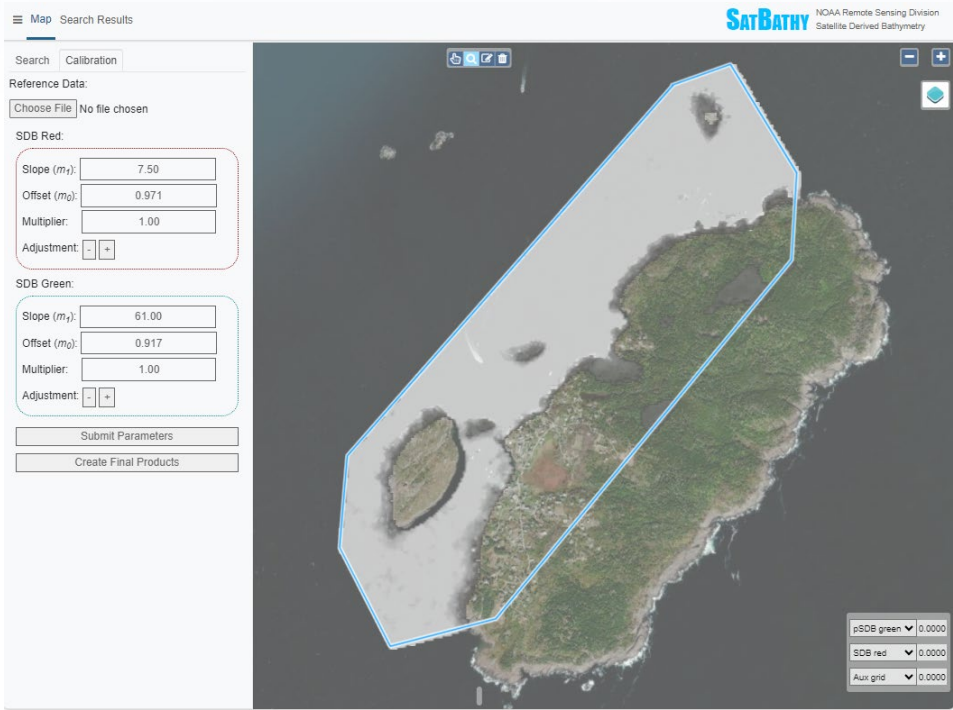
- New graphical user interface (GUI)
  - Transitioned the GUI from Python's Bokeh visualization library to the widely used and **customizable Flask web framework**
- Improved satellite image search and filtering utilities
  - Implemented a standardized, open source solution for searching and filtering S2 imagery via the SpatioTemporal Asset Catalog (STAC)
  - Cross-platform availability (Sentinel-2, Sentinel-3, Landsat, etc.)
  - Improved accuracy in snow/ice filtering – important for Alaska



Latest Capabilities (cont.)

- Simplified calibration procedure
  - Quickly derives SDB products with consistent results
  - Adjustable parameters (previously derived as coefficients from linear regression with reference data)
    - Initial estimates are provided which are based on research from Richard Stumpf and Isabel Caballero

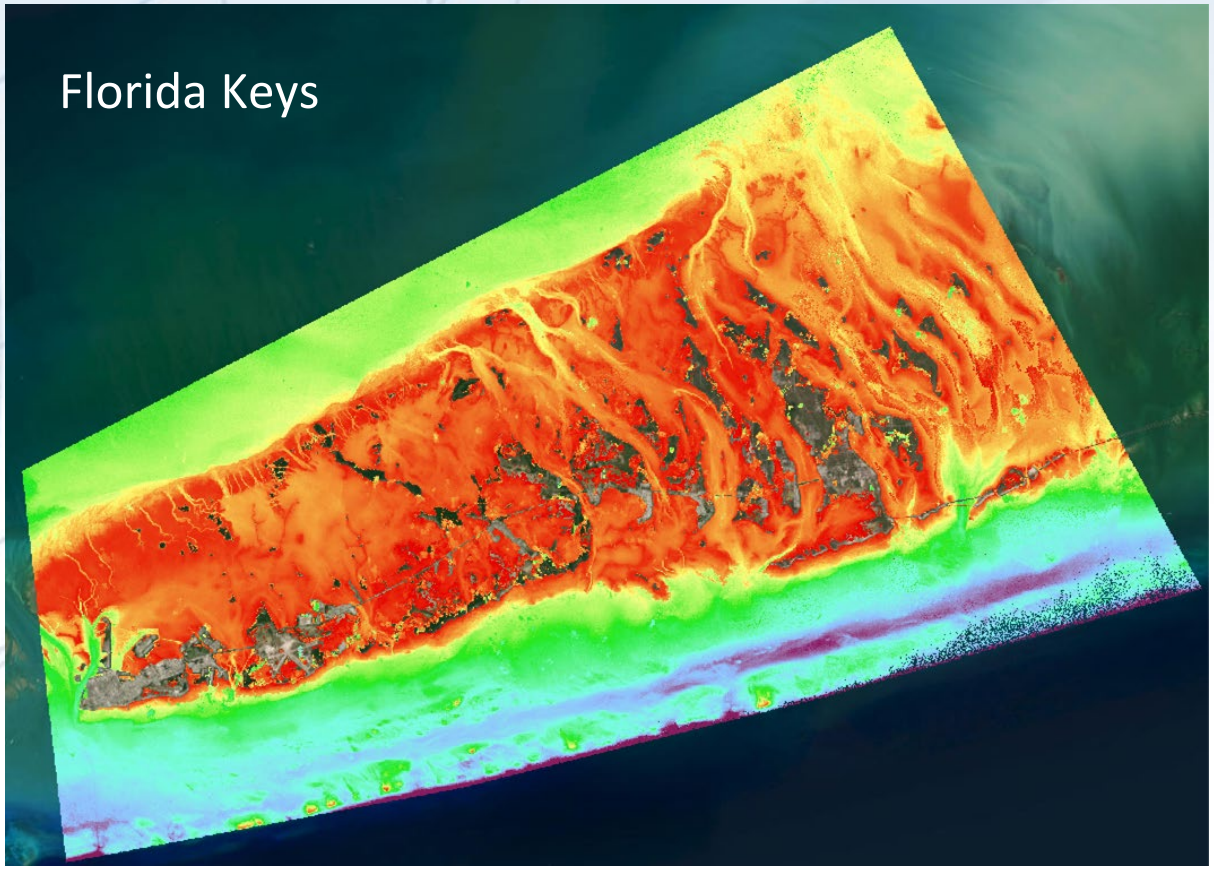
- Improvements to non-water masking
  - Use of machine learning techniques to identify true/false bathymetry
  - Thresholds on band indices including NDWI, NDVI, etc (experimental)

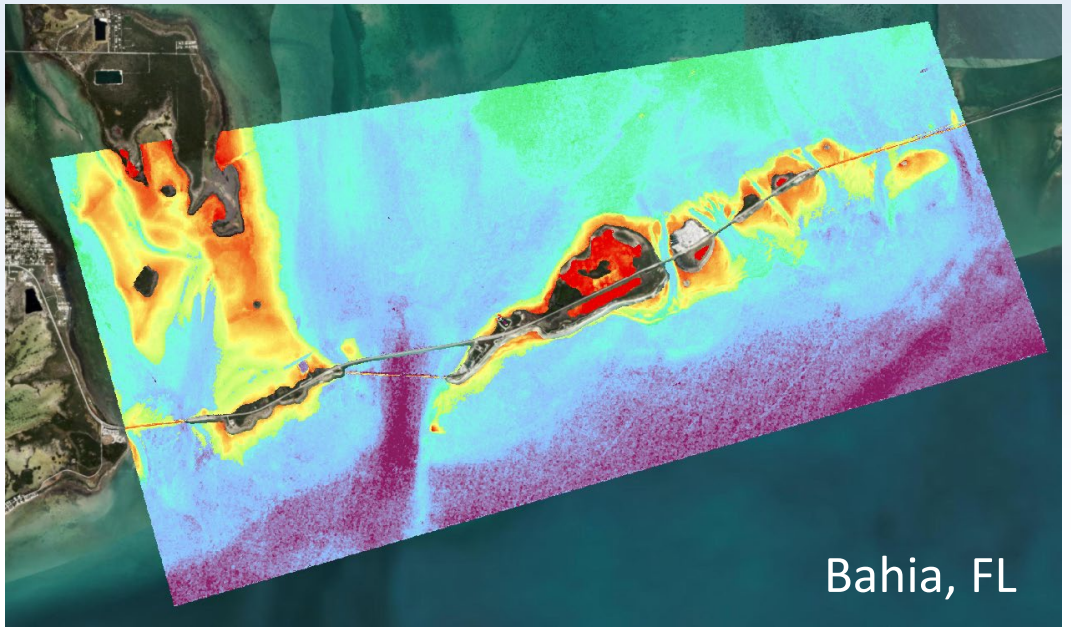


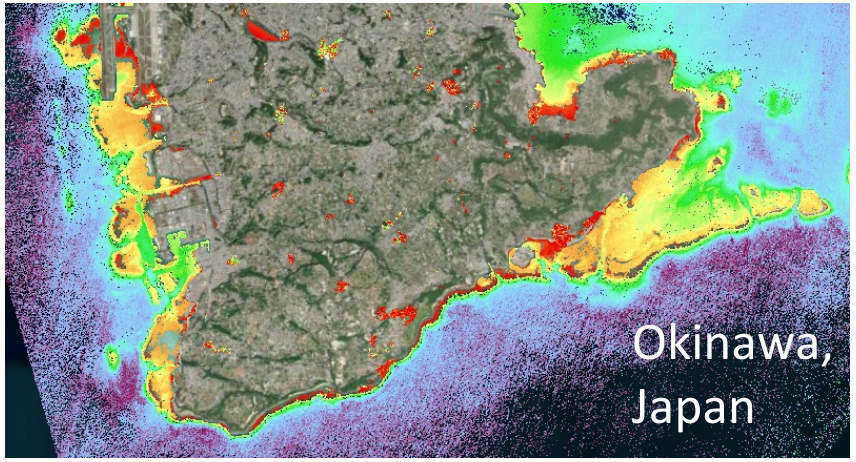
Latest Capabilities (cont.)

- Additional and improved composite products
  - Updated the S2 tile coverage with the latest acquisition paths from ESA , i.e. Mariana Islands
  - Increased SDB compositing time window for areas which are prone to poor water quality and/or frequent cloud cover, i.e. Alaska
  - All products are now written as cloud optimized GeoTIFFs (COGs)
- Many ‘under the hood’ improvements
  - refactored front-end HTML, JavaScript code
  - modular approach to back-end Python data processing scripts
  - Bug fixes (examples)
    - Fixed historical imagery issue (can now load 12-6-2016 and prior)
    - Fixed AOI subsetting when uploading shapefile
    - Path limit workaround for Windows

2023 Testing and Training

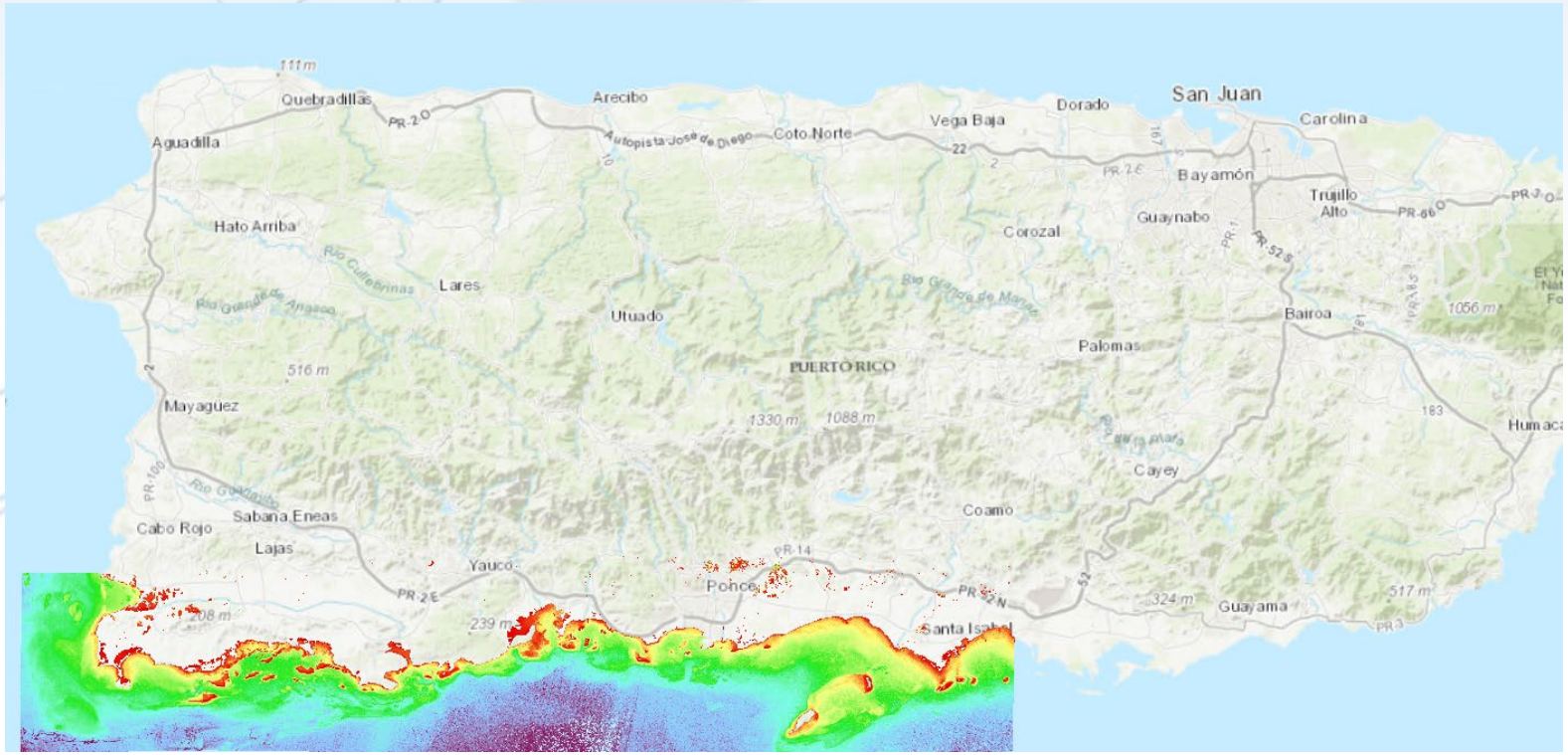




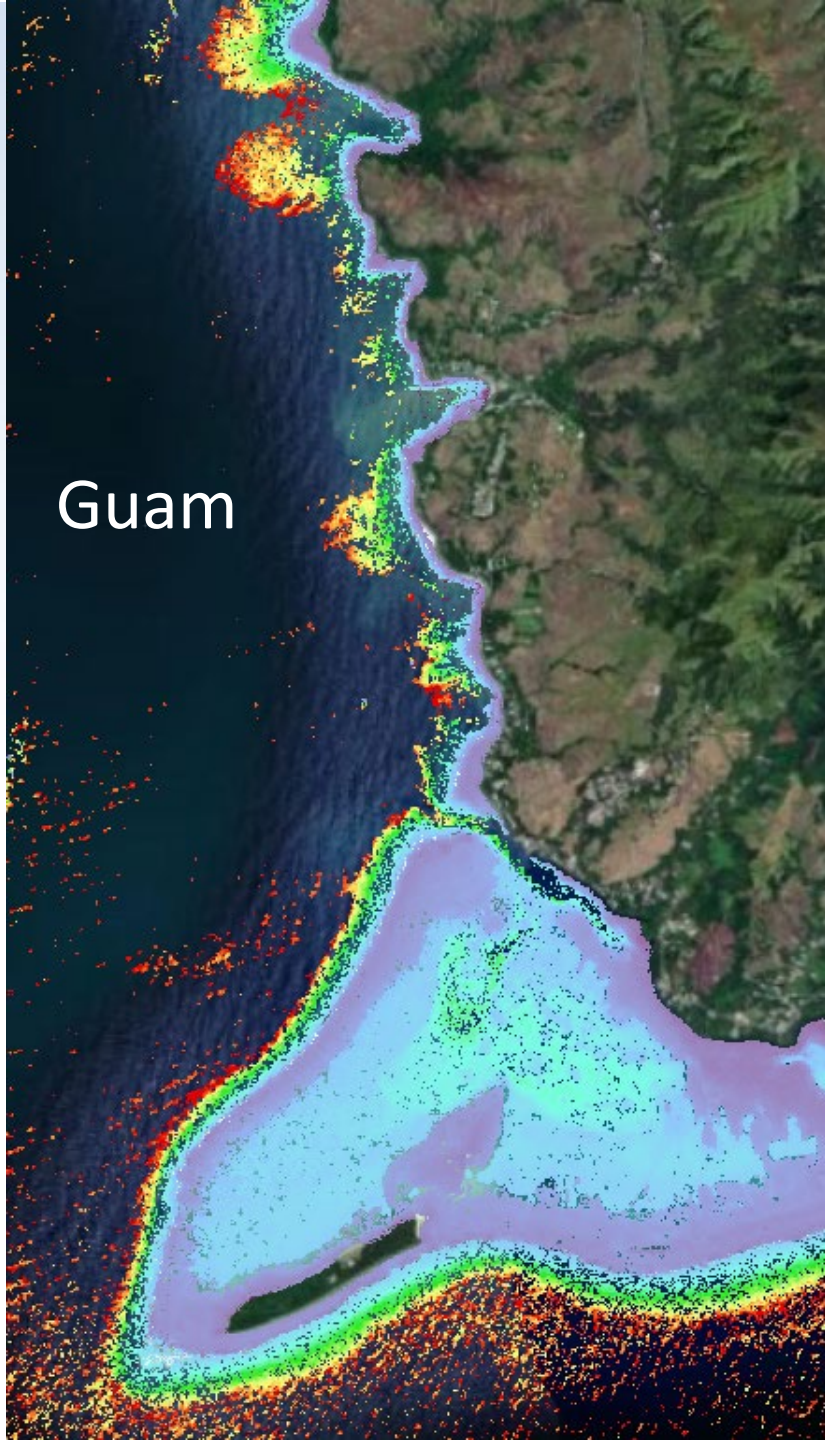


Testing and training areas for USGS, NGA, and USACE

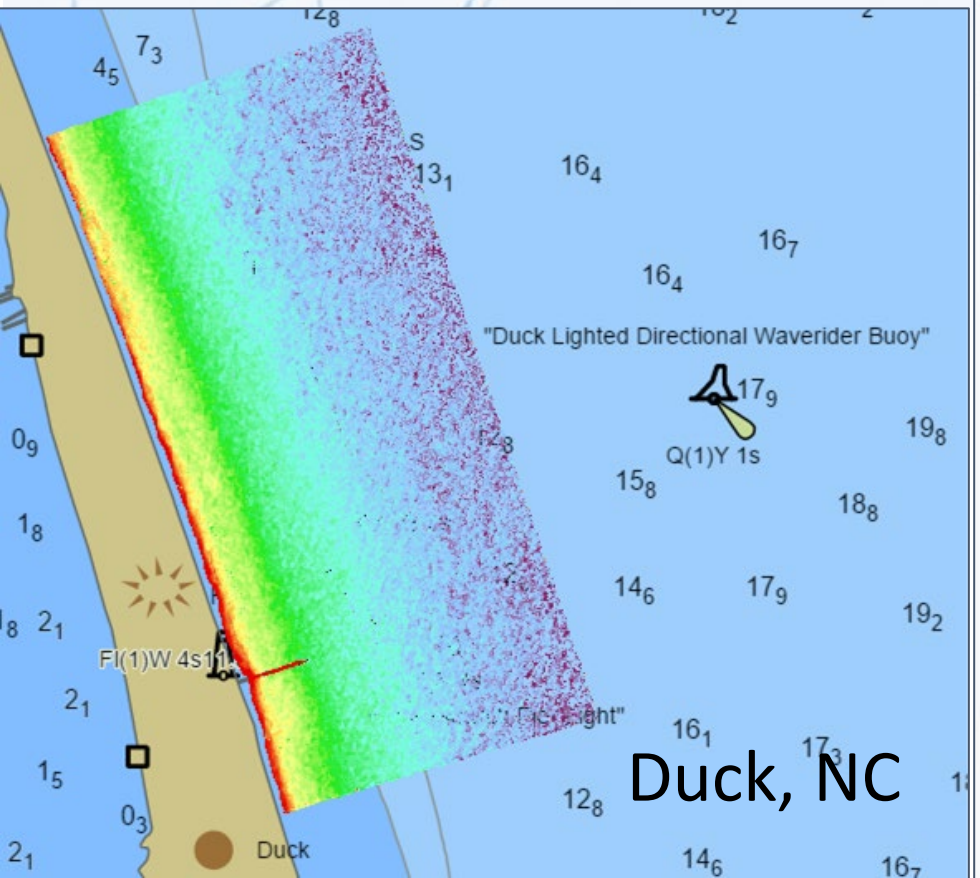
2023 Testing and Training



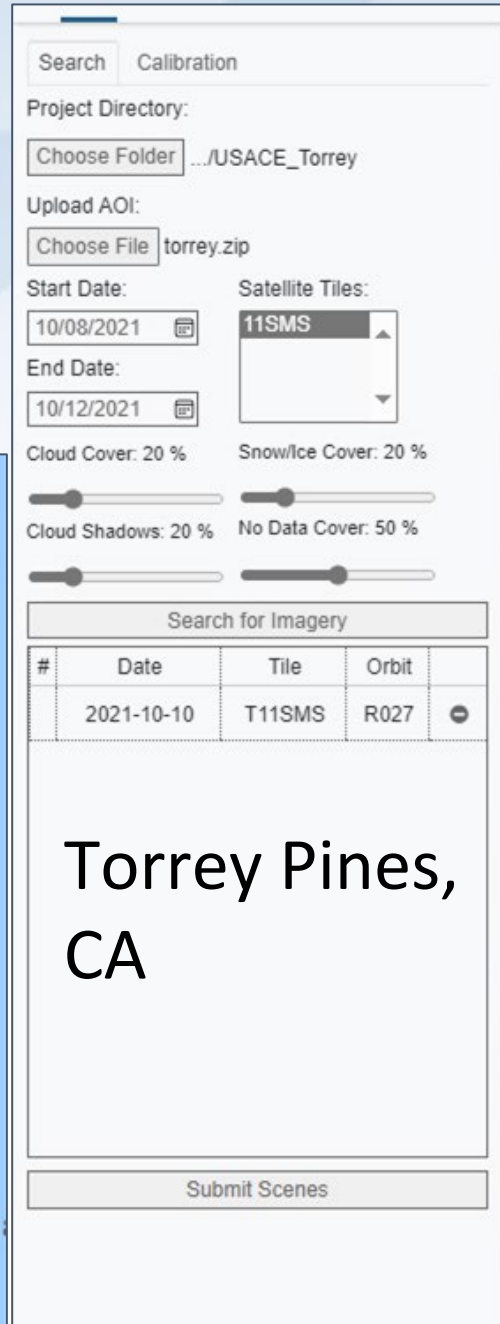
Puerto Rico



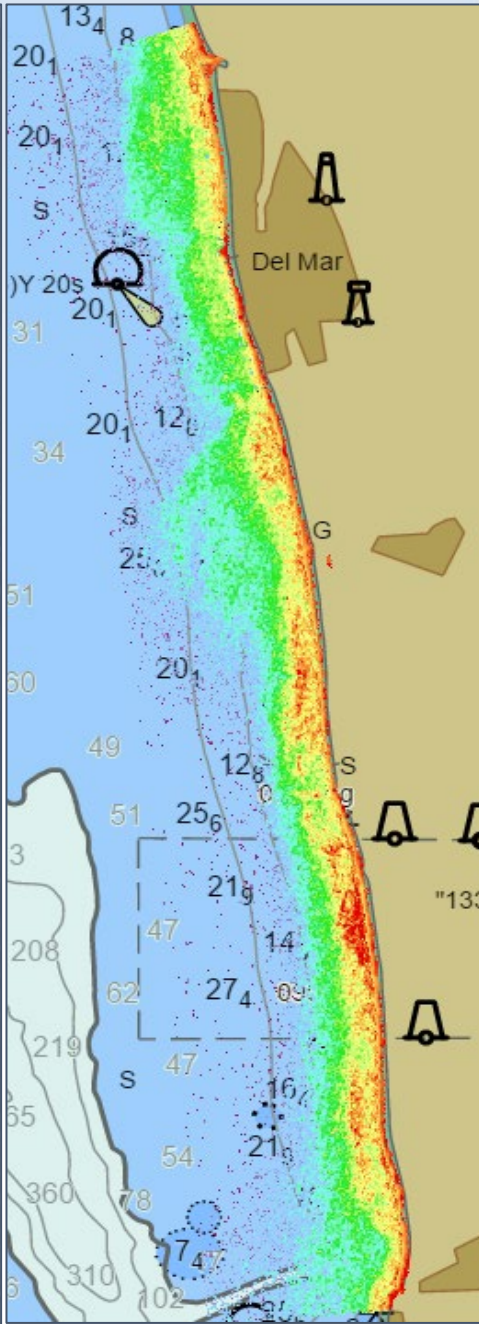
2023 Testing and Training



Duck, NC

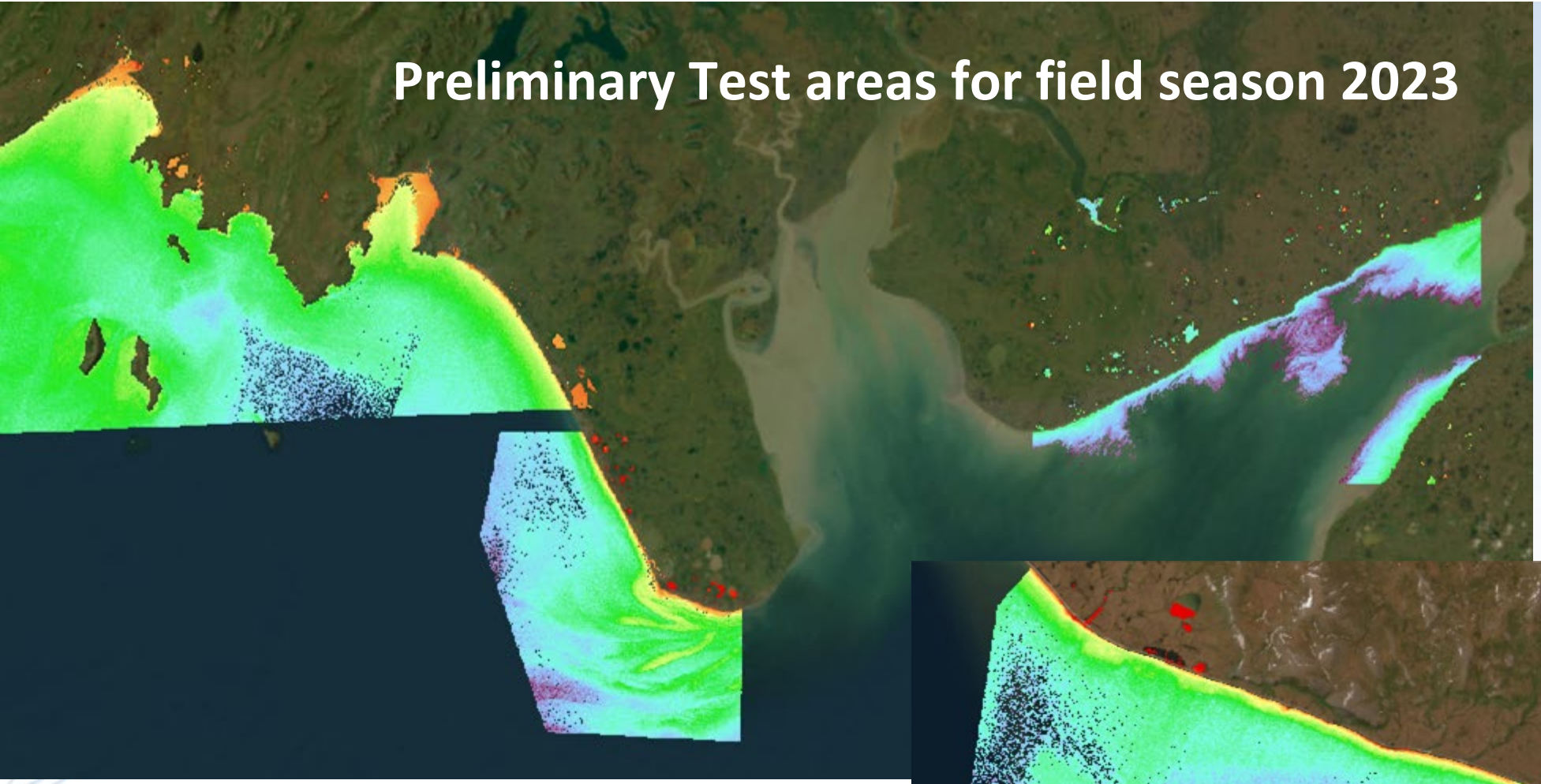


Torrey Pines, CA

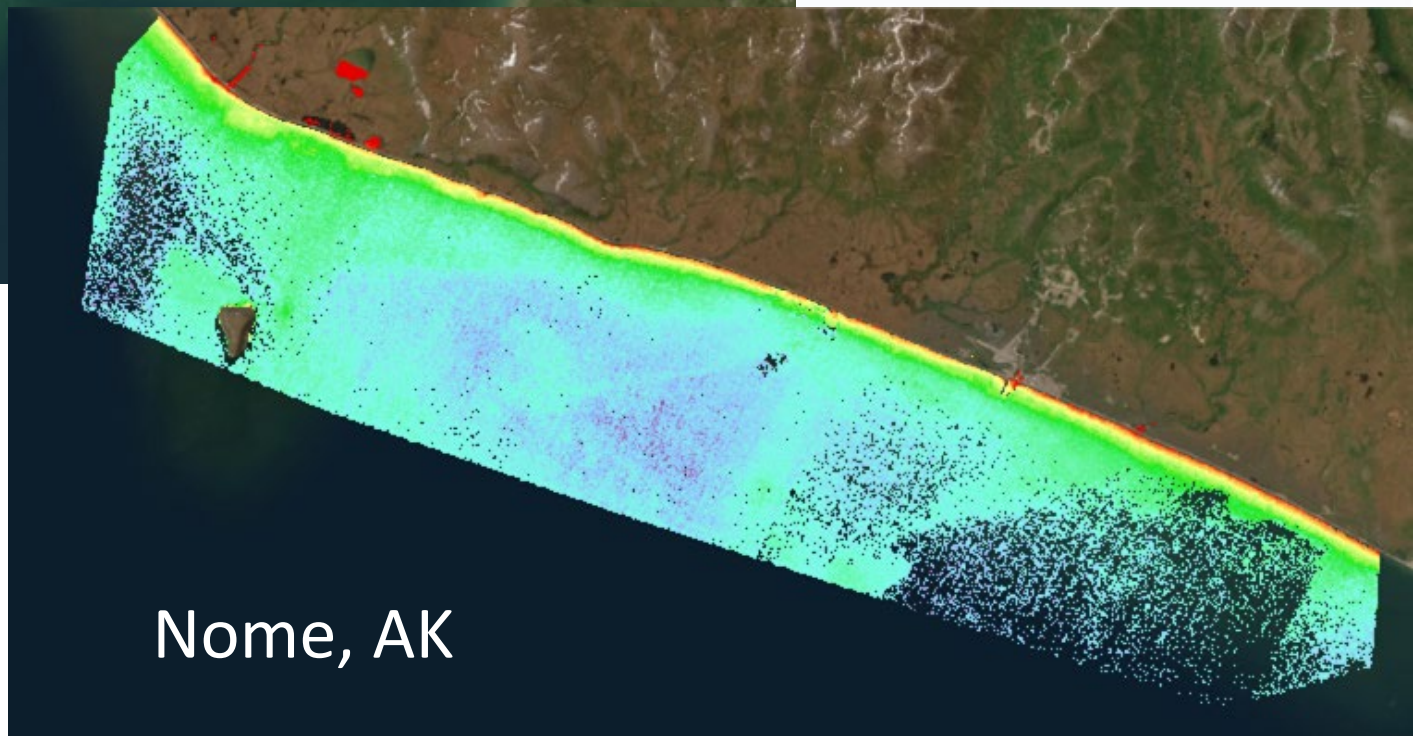


Reconnaissance for Operations

Preliminary Test areas for field season 2023



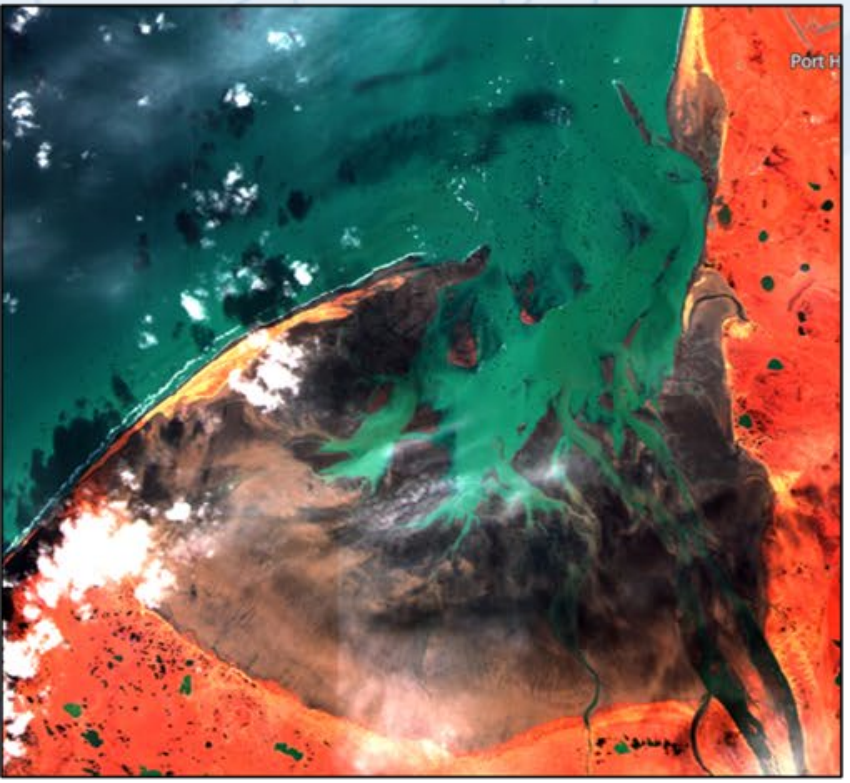
Bristol Bay, AK



Nome, AK

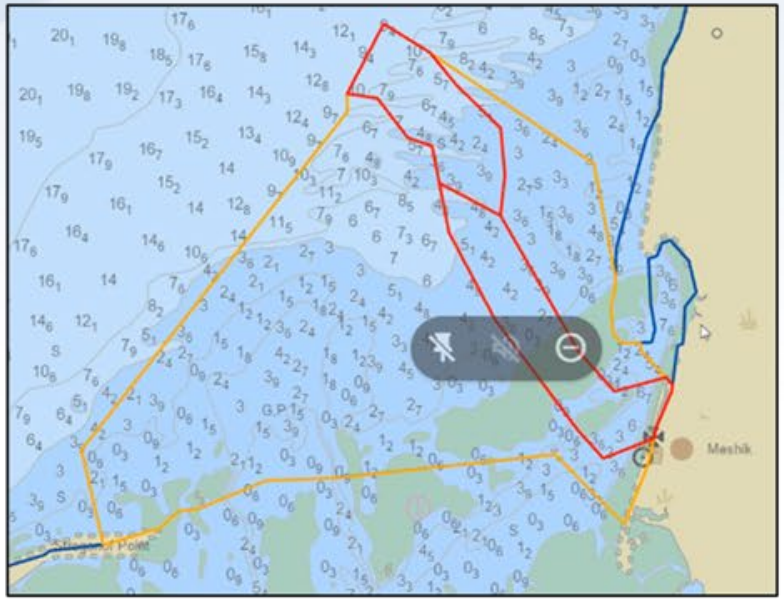
Develop Strategies to support high tide areas

(Where we don't have Vdatum …yet)

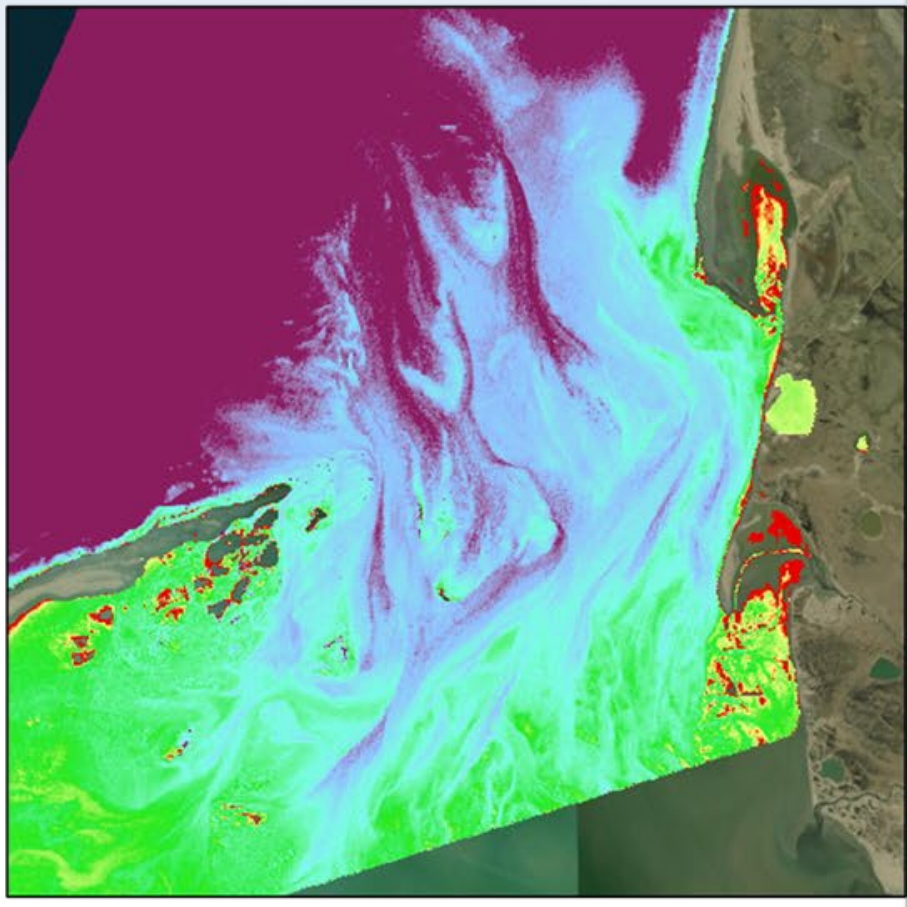


Low water S2 image, developing product for turbid areas with high tide range
- Shows where you want to be careful even at high tide

Port Heiden, AK

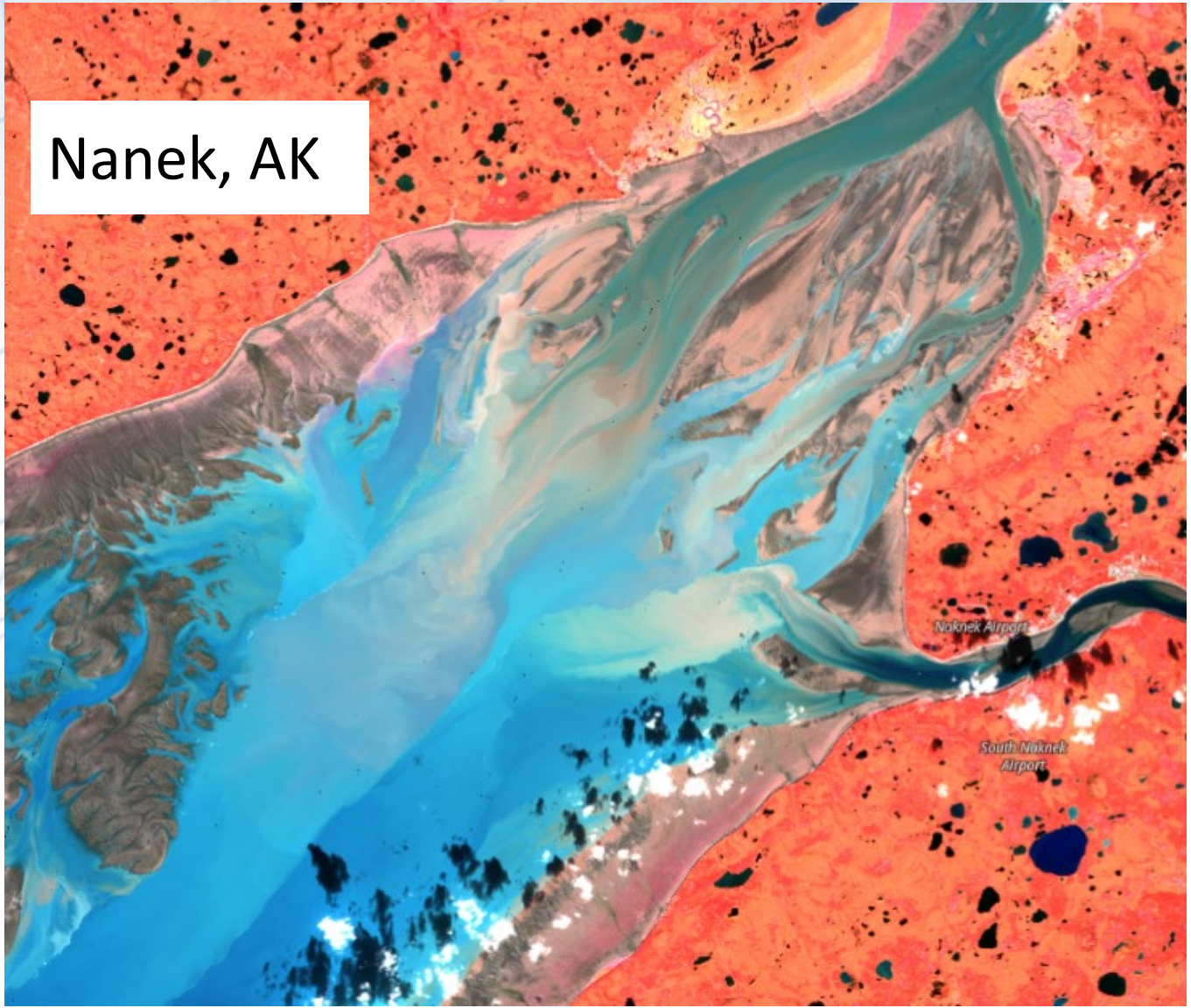


Hydro project (orange) – possible transit area to Meshik (red)



SDB Red using multi-low water images to show where there may be safe passage (dark and light purple) and where it may be too shallow (red)

Analyzing these areas show us the value in automating low tide selection for high tide areas



S2B/MSI 2022-09-30 21:59:06
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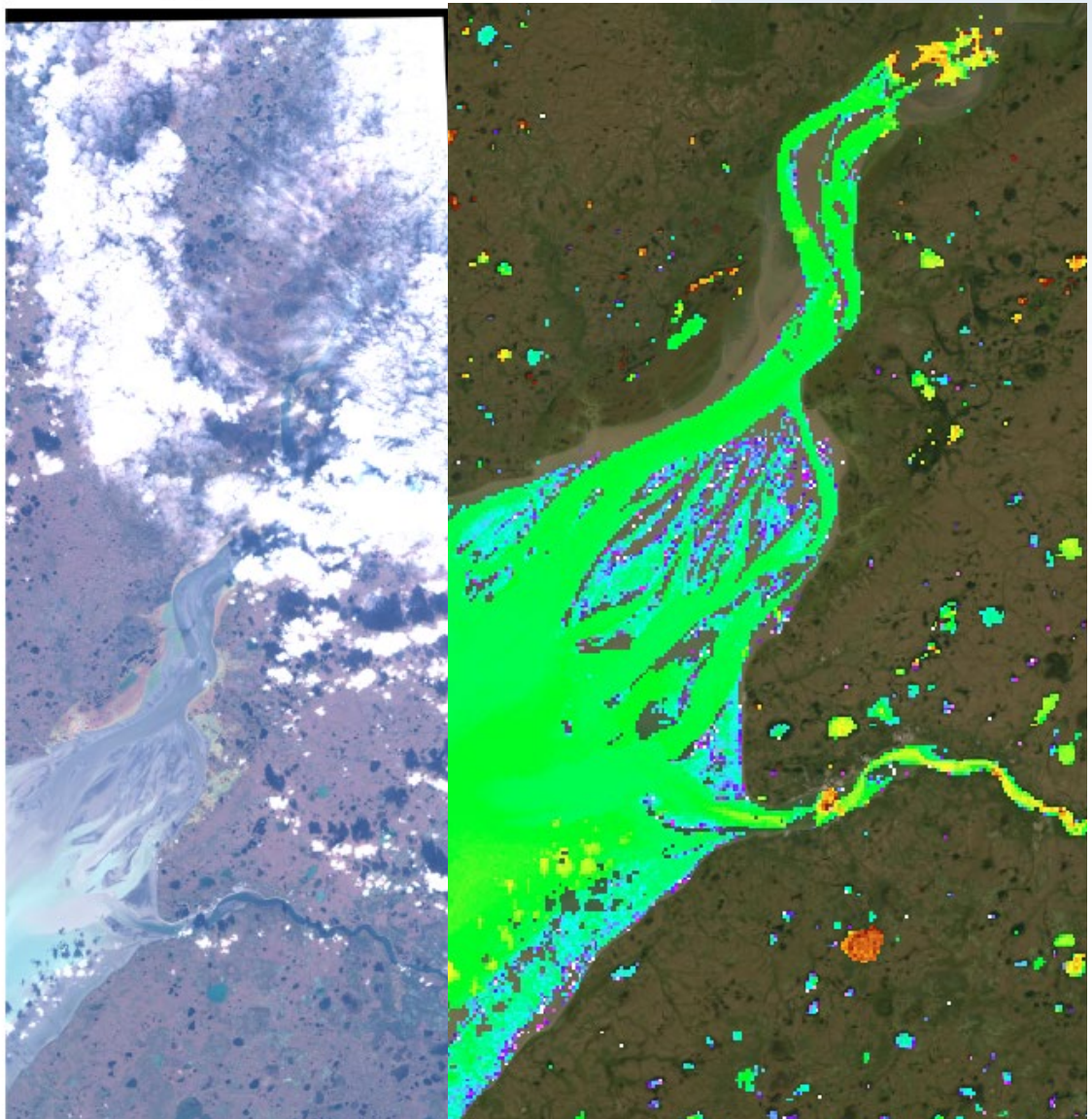


OCS Request for Reconnaissance

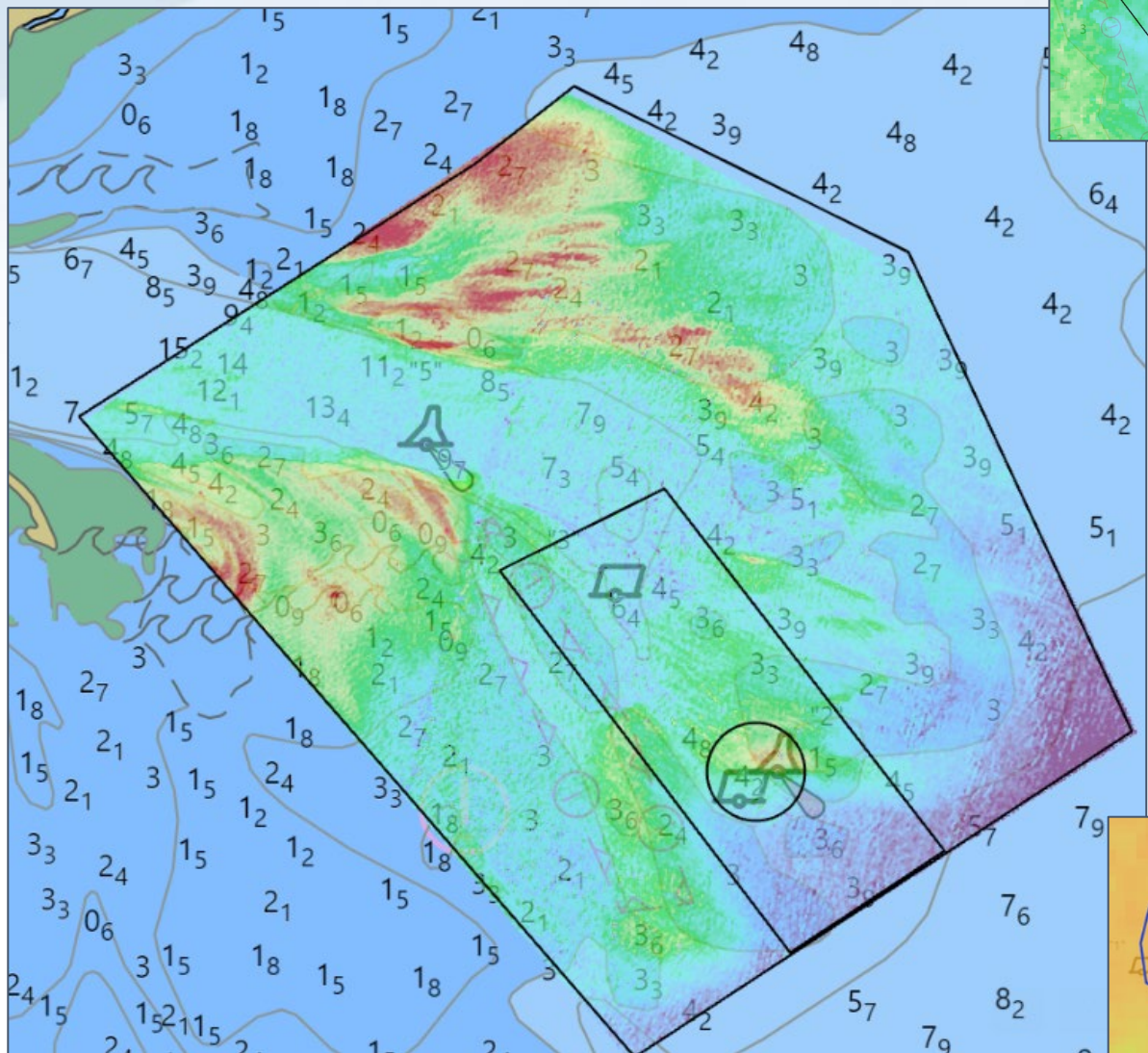
St. Catherines Sound, GA

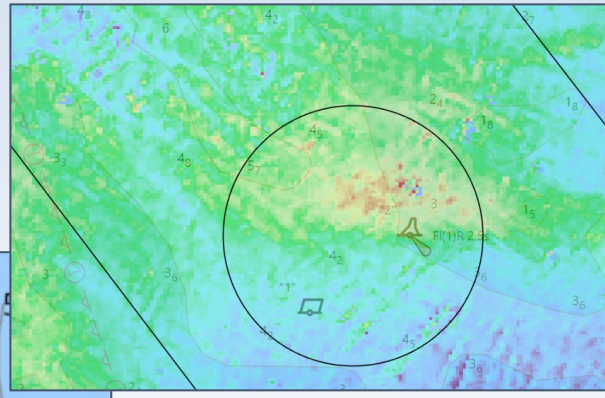
Vessel hit shoal (circled area)

NOAA's SatBathy team provided requested relative SDB to confirm dangerous rock/shoal location

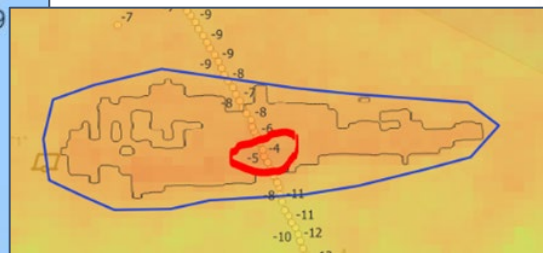
Area is very turbid but RSD used the clearest & most recent Sentinel-2 imagery

USCG notified and Coast Survey Navigation Response Team is going to survey this area next year to provide depths to update NOAA chart





External Source Data validation for depth confirmation

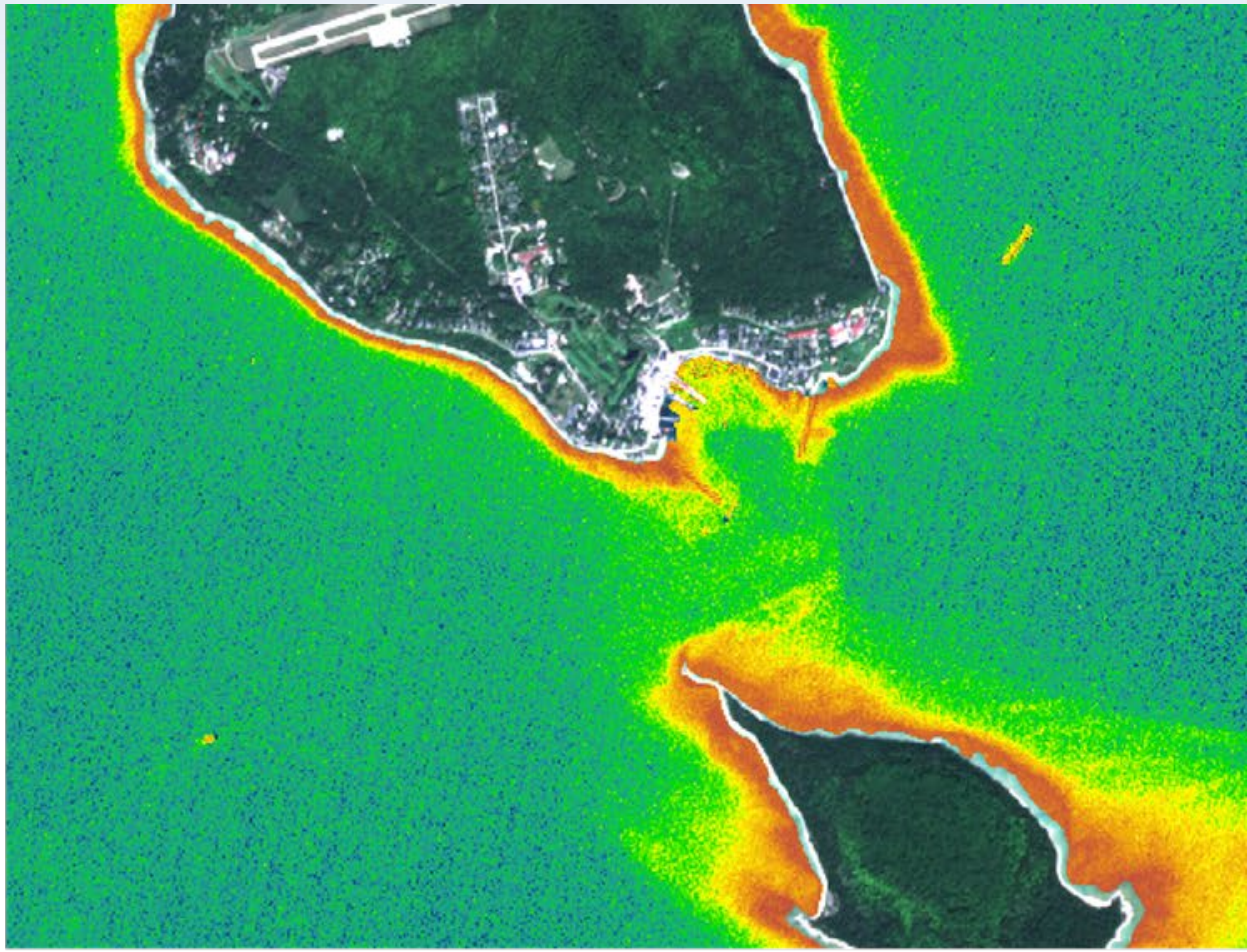


Research

Research

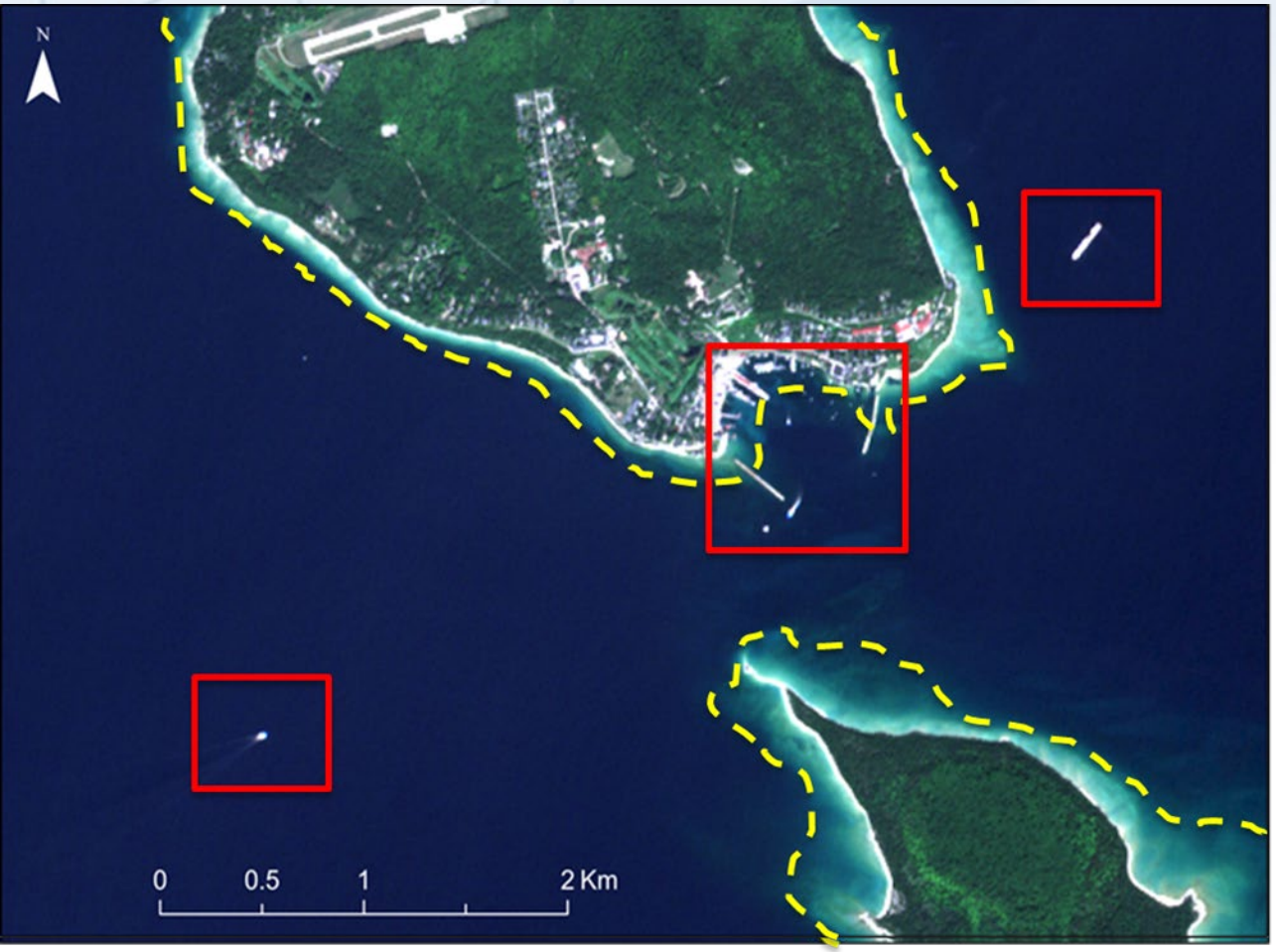
Automated Classification of Valid and Erroneous Depths in Satellite Derived Bathymetry

RGB Color Composite



SDB – Value for every pixel in the scene

Research

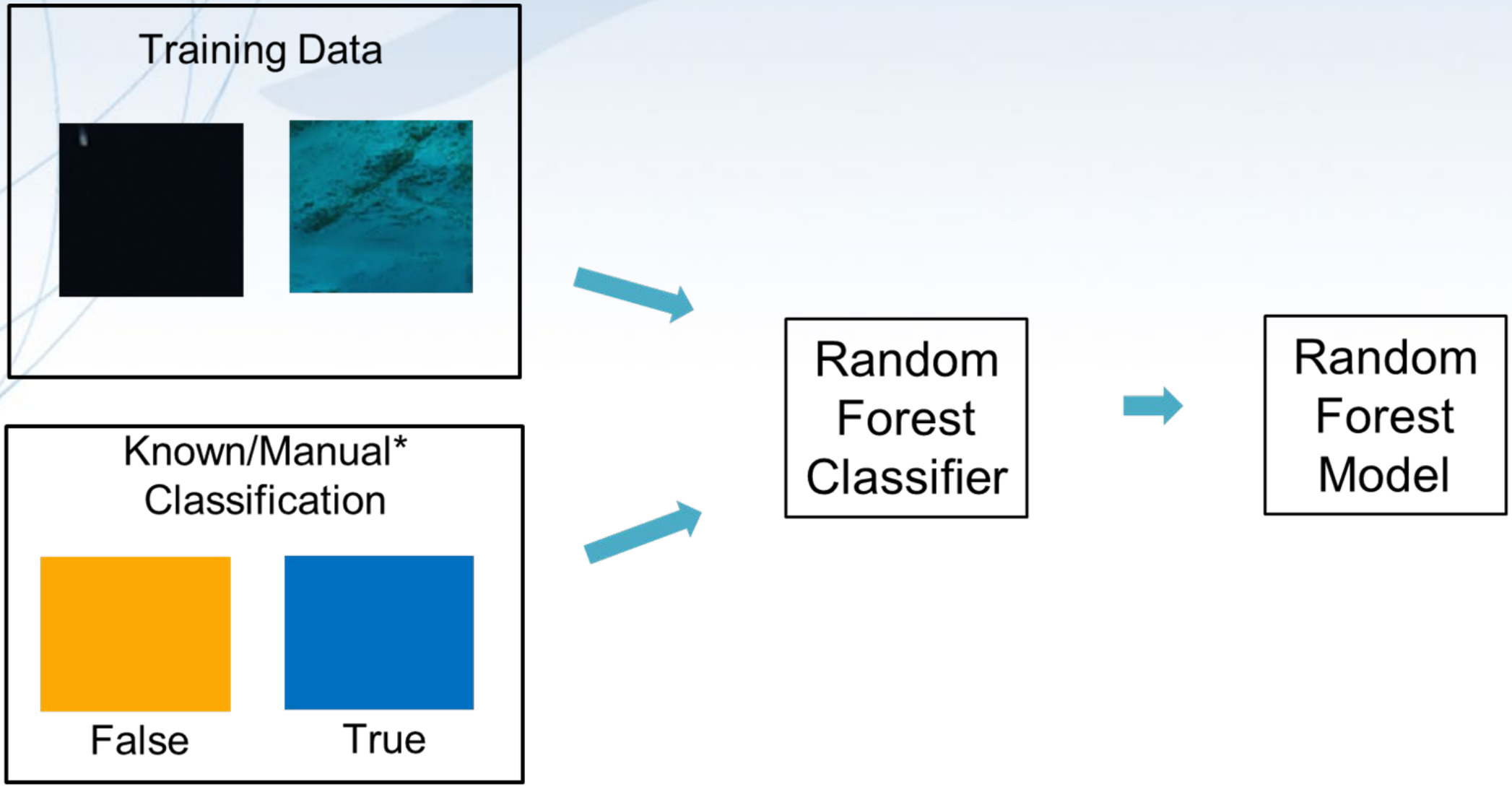


RGB Color Composite

Goal

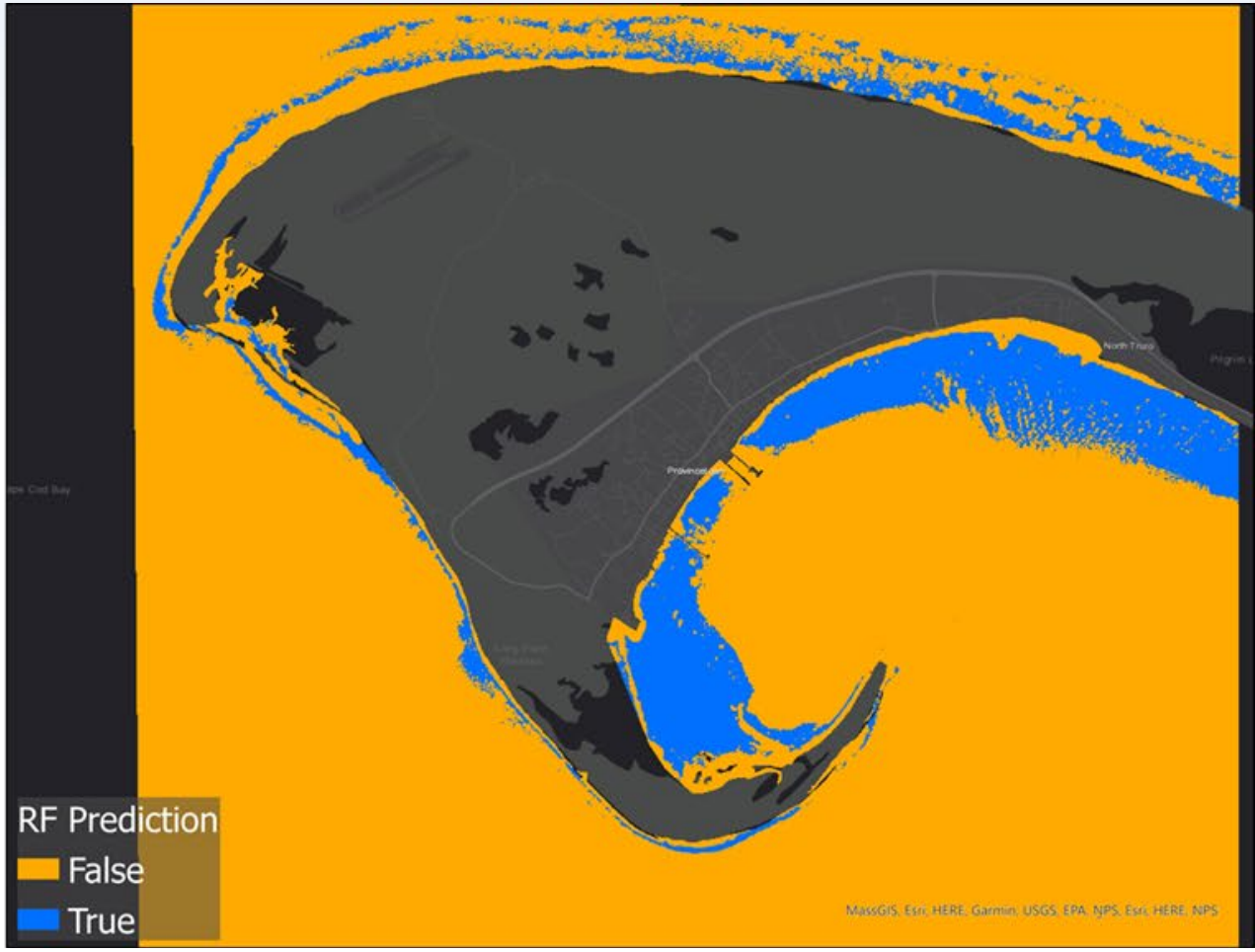
Research

Supervised Learning



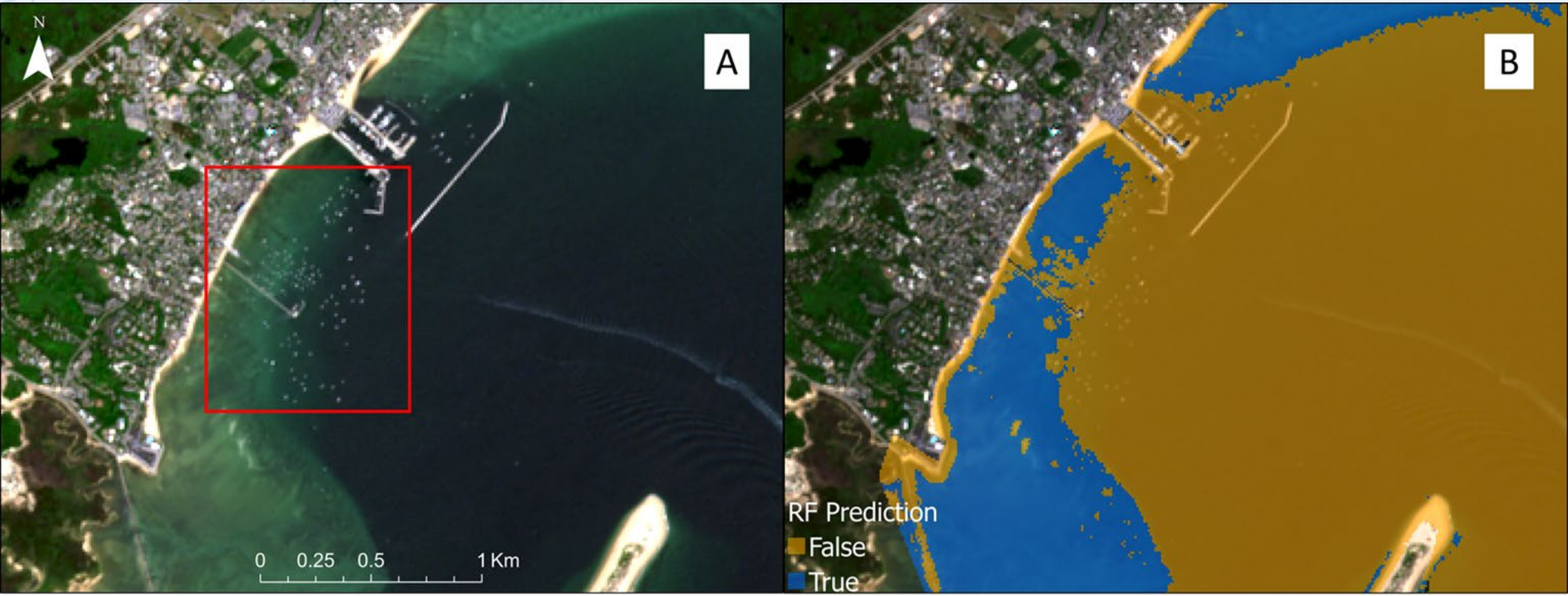
Research

Provincetown Harbor, MA



Research

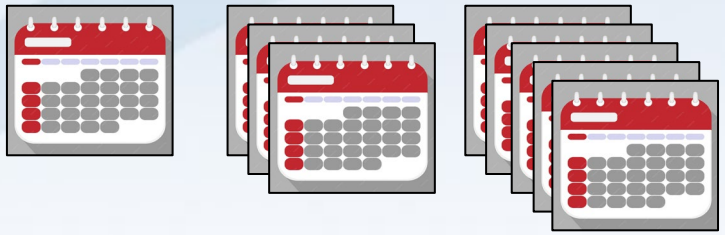
Provincetown Harbor, MA



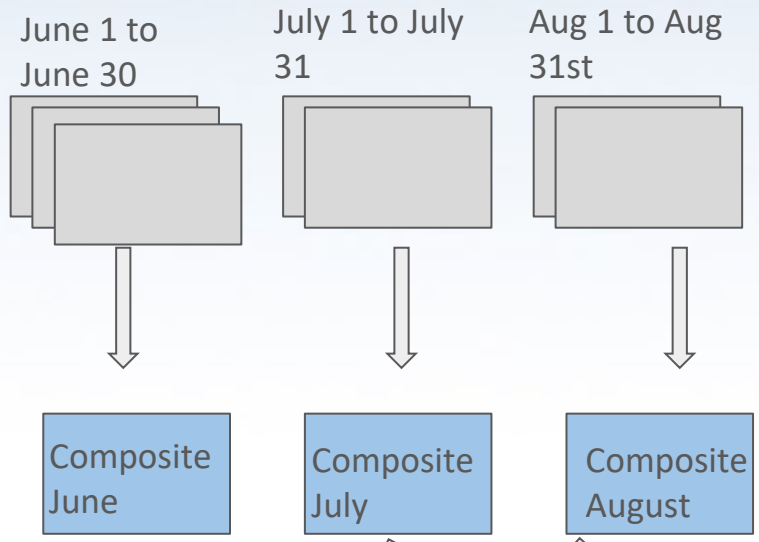
Research

Determine Reference Dataset or Event (July 16th example)

Test Various Temporal Windows from Reference Date



Create Monthly SDB Composites using SatBathy Tool Method (deepest depth) (3 month example)



SDB Change Analysis

Compare Results of Various Temporal Means with Reference Data/Event

Reference Lidar Dataset

Δ

3 Month Mean
4 Month Mean
5 Month Mean Composite

Mean (median?) SDB of monthly composites

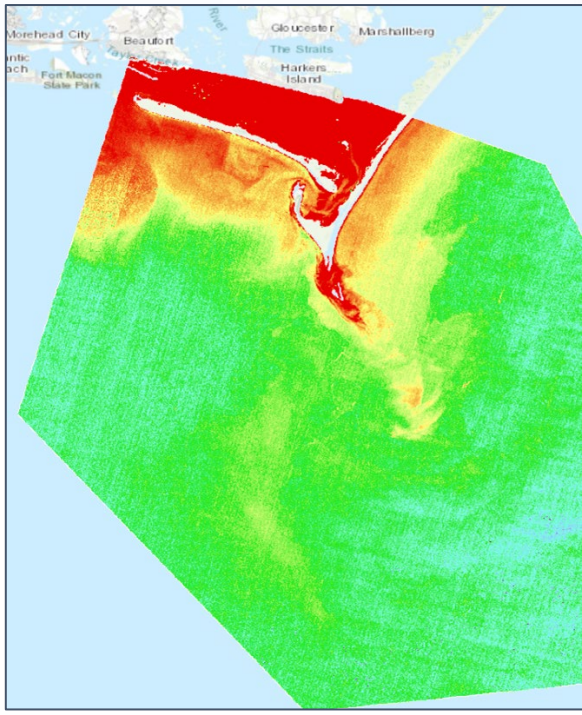
Average SDB Composites over Temporal Window

Research

Temporal Composites for SDB Change Analysis

Thesis/Research Question - Can the error associated with SDB be reduced using a temporal composite over a certain period of time when performing change analysis between 2 epochs?

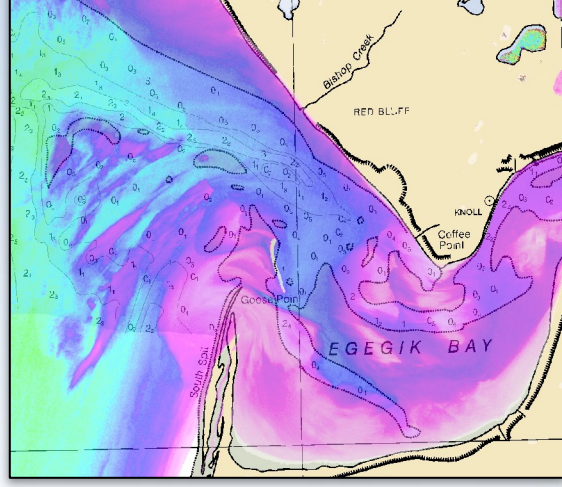
- What is the time window(s) that leads to the greatest reduction in error
- What compositing methods are best at reducing the error
  - Mean, median, turbidity detection



Methods (rough)

- Use NOAA's SatBathy tool to perform individual monthly composites
- Create various temporal averages around epoch 1 and 2
- Compute RMSE of the different temporal averages between the epochs

Research



Temporal Composites for SDB Change Analysis (cont.)

Challenges

- Dealing with turbidity, especially when limited satellite imagery for a particular month
- Tidal range and differences between scenes and monthly composites
- Adapting pre-existing code to automate process

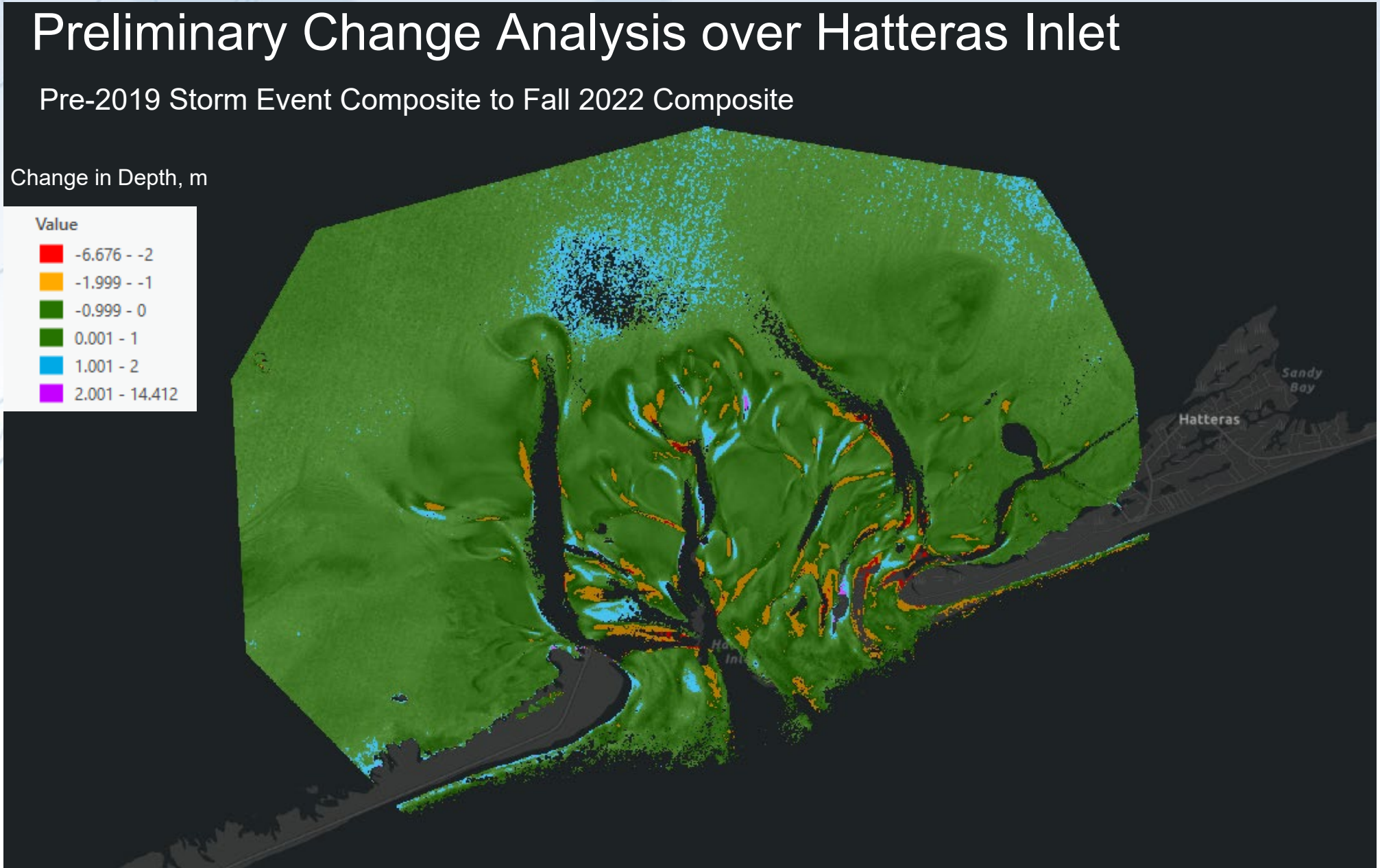
Long Term Outlook

- Implementation of research into SatBathy tool with an automated process
- Using research/results to create storm event change analysis tool
  - Rapid vs long-term results
- Creation of best practices for conducting SDB change analysis when a multitude of scenes are available

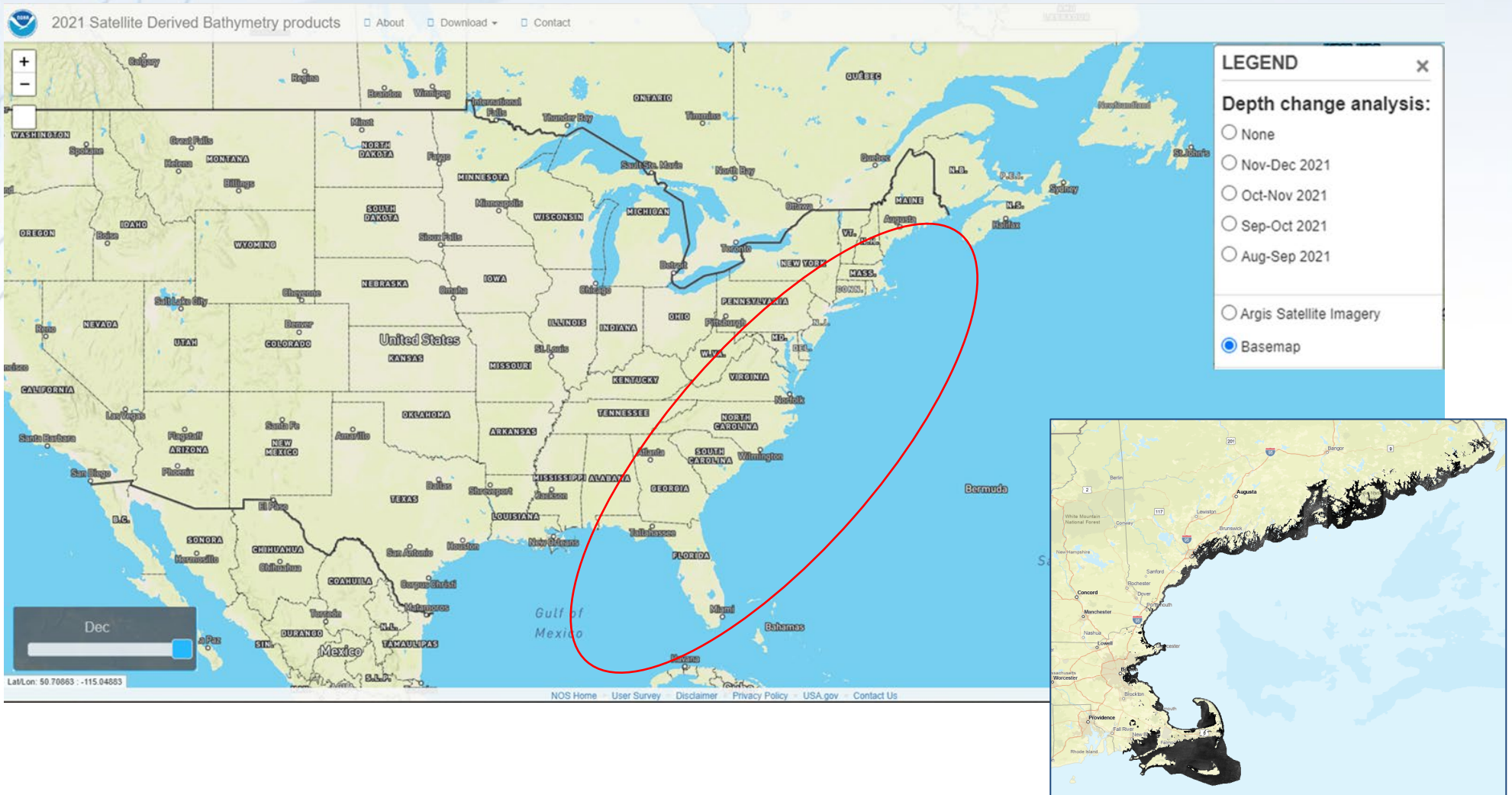
Research

Preliminary Change Analysis over Hatteras Inlet

Pre-2019 Storm Event Composite to Fall 2022 Composite



SatBathy Vision for Processing Large Areas



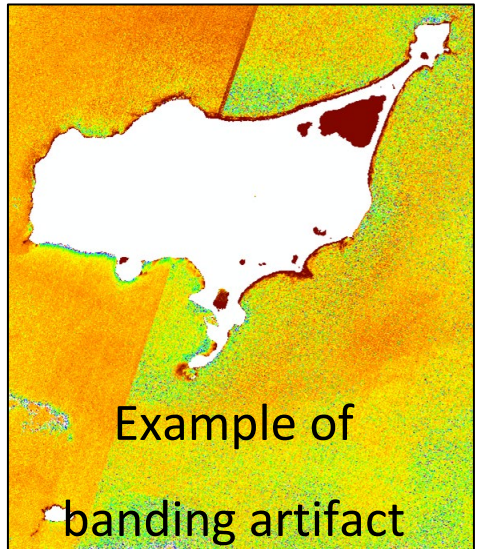
Challenges and Limitations

- Cannot support both a desktop and large scale/area processing effort with current resources
    - Plan to phase out SatBathy desktop tool once large scale/area processing effort is live
- Make sure everything users require in the tool is kept for the large scale/area processing effort
- Best practices for creating SDB using multiple adjacent S2 scenes
    - calibration
    - merge tile/swath boundaries
    - tides
    - UTM zone crossover
- Removing noise

Long-term Items to Fix/Add

- Continue to transition to cloud computing/large scale processing
- S2 Banding Artifacts (>AK)/Noise - S/N
- High cloud issue and sunglint filter
- AOIs crossing over multiple UTM zones
- Implement ICESat-2
- Change analysis
- Enhance extinction depth clipping
- Automate removal of fliers/outliers in final product for NOAA's National Bathymetric Source

- Universal calibration method
- Automate imagery selection
- Develop robust uncertainty
- Tides for composites
- Shoreline extraction



*Completed
Work in need of resources
Products

Phases for NOAA SatBathy tool

Phase3:
Public facing Cloud app

- NBS, e-hydro, ICESat-2 – ref. depths added

V1.0 (TBD)

NOAA use & federal mapping partners

Phase 2:
Cloud application

- Cloud operations
- Robust Extinction depth research
- Tides/WL ref. research
- ICESat-2
- Planet? calibration research
- Robust uncertainty

Beta V2.1.6 (Nov 2023)

Beta V1.0 (Jan 2022)

RSD use & OCS POCs Testing/limited operations

- 1st approx. Extinction depth research
- GEE Replacement!

RSD use & OCS POCs testing

Alpha V1.0 (July 2021)

Phase 1:
Desktop application

- Automate scripts from NCCOS
- Add manual imagery selection
- 1st Approx. uncertainty

- Relative SDB
- Single image SDB with ref depths
- Relative Composite SDB
- Composite SDB with ref depths

Pre-Alpha V1.0 (Mar)

RSD testing/ use only

Publications

● Isabel Caballero, Richard P. Stumpf, 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, doi/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.

● 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.

Publications

● 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.

● 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.

● 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.

Thank you!