ATL24: A New Global ICESat-2 Bathymetric Data Product

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US Hydro Conference

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NASA

ICESat-2
ICE, CLOUD, AND LAND ELEVATION SATELLITE-2

The University of Texas at Austin
Center for Space Research
Cockrell School of Engineering

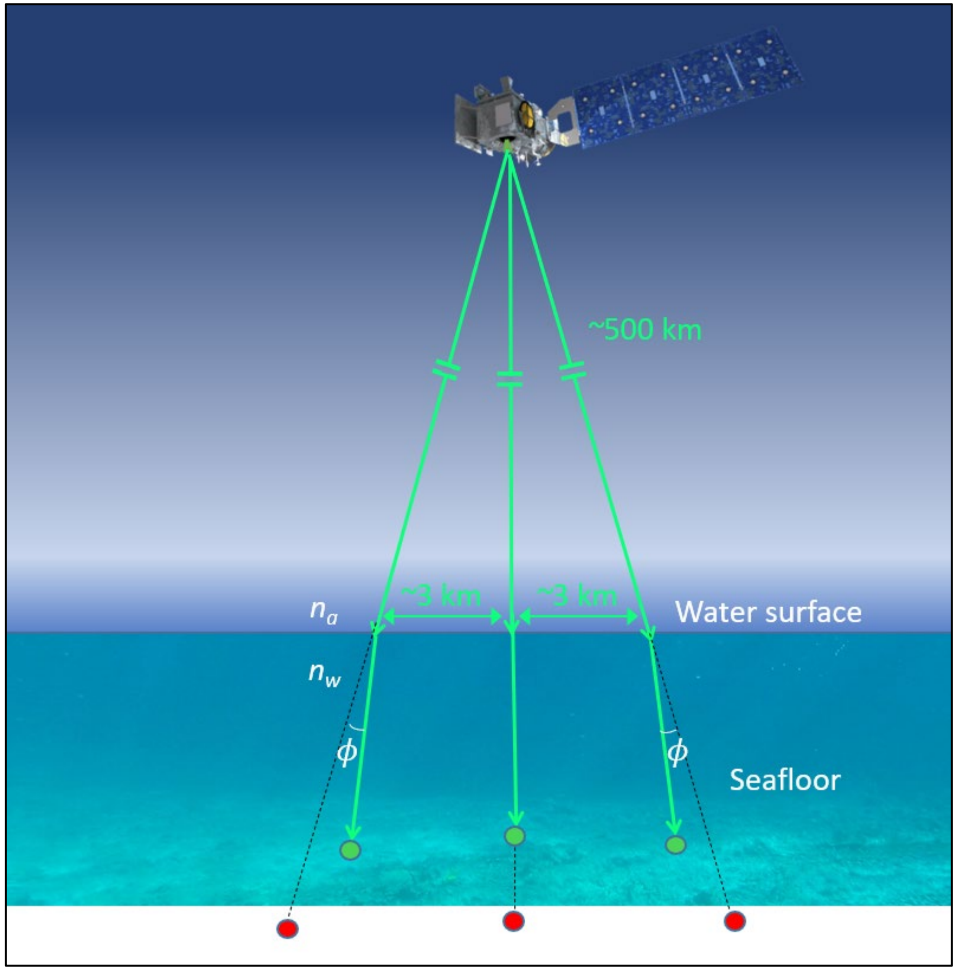
Oregon State University

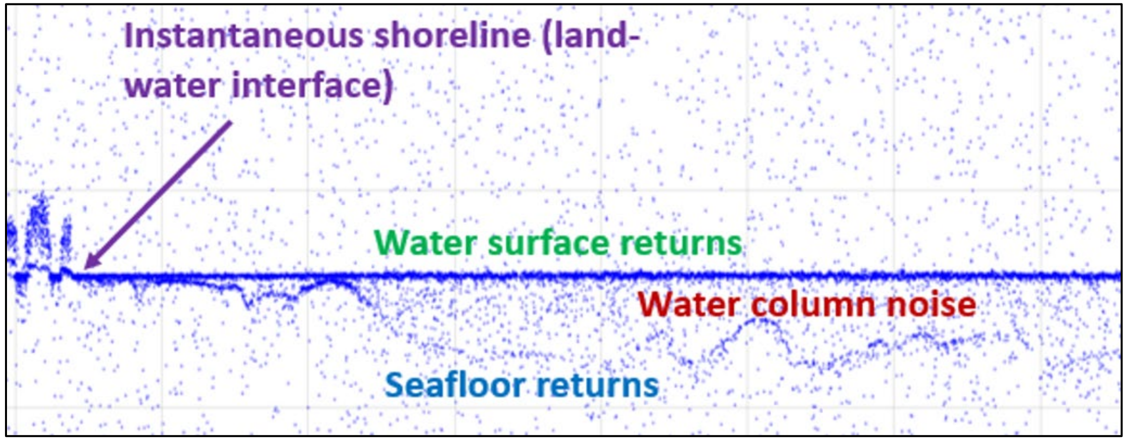
NASA's ICESat-2 (Ice, Cloud and land Elevation Satellite-2)

- Launched September 15, 2018
- Successor to ICESat (2003-2009) with new technology for laser altimeter acquisition
- Designed as a top priority in last Earth Science Decadal Survey
- Level 1 science goals for **cryospheric science** (land ice, sea ice), small scale feature monitoring and global **vegetation canopy** heights
- 496-km orbital altitude
- Single sensor: green-wavelength, photon-counting lidar, ATLAS
  - **To date: 2+ trillion laser pulses**

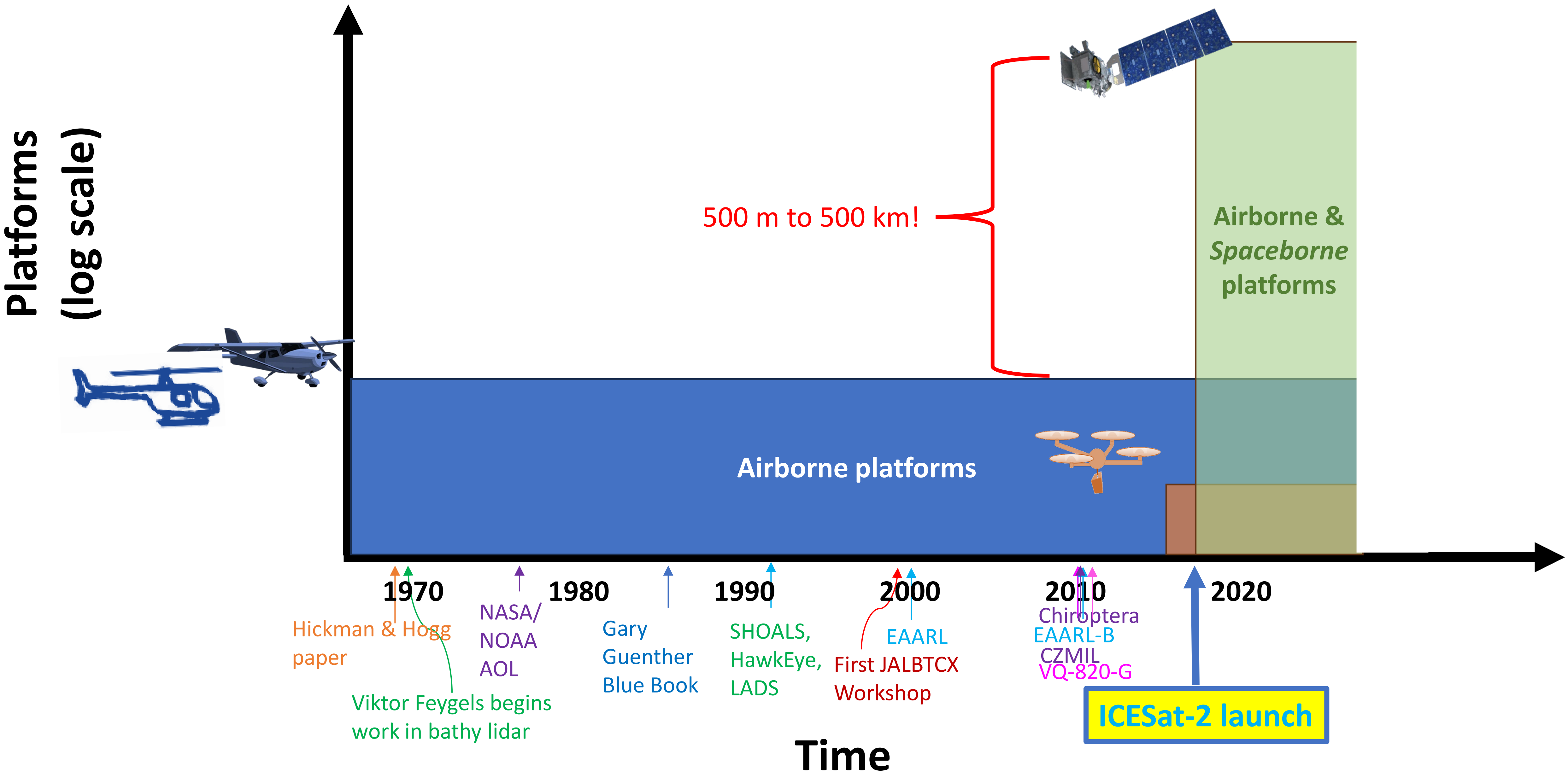
ICESat-2 Bathymetry

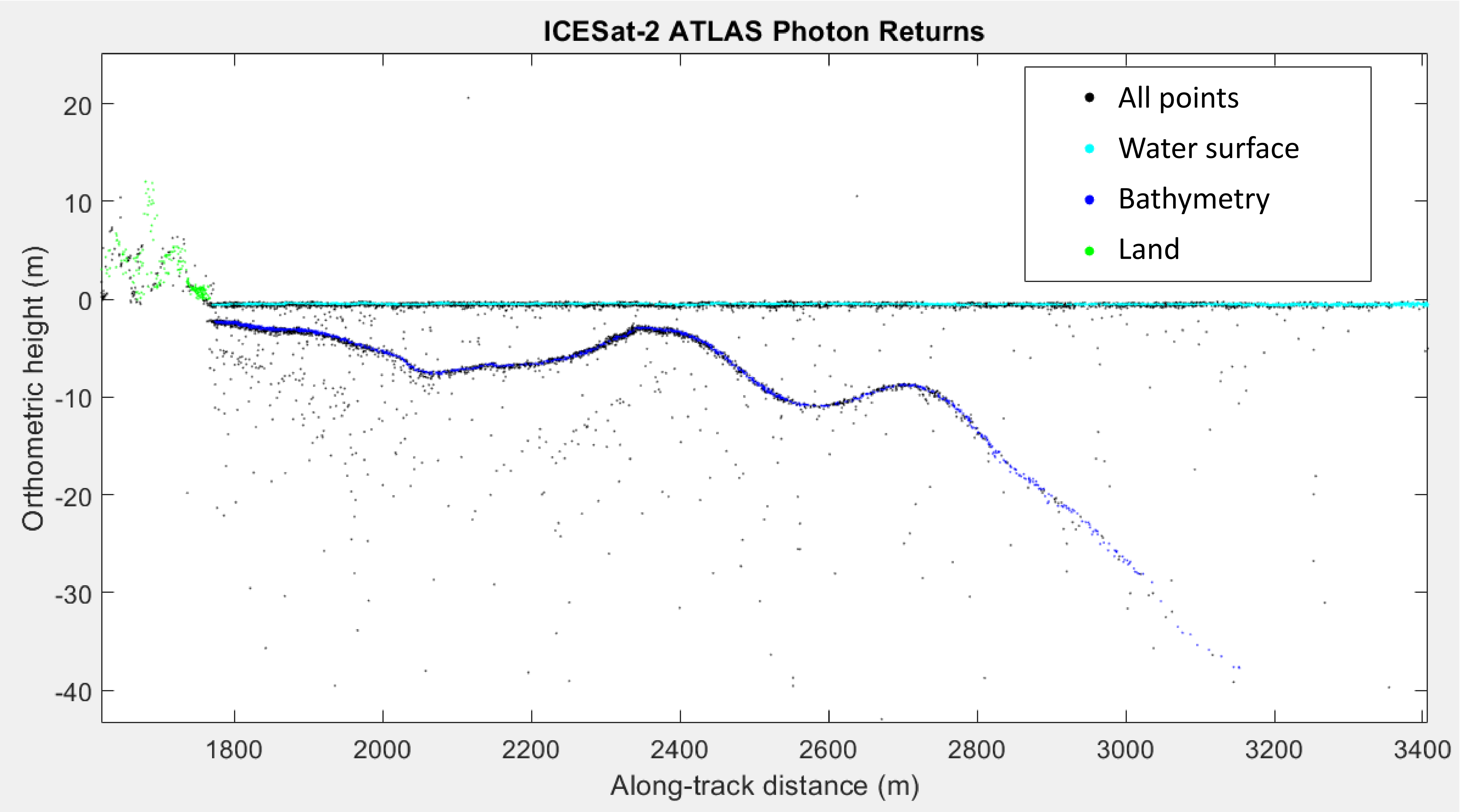
- ICESat-2 provides **bathymetric lidar measurements from space**!
- Bathymetry was not an initial mission requirement, but bathymetric measurement capabilities and response of user community have been remarkable:
    - Depths to ~1 Secchi depth or > 40 m in very clear waters
        - Better at night that during the day
        - Depends on seafloor reflectance, in addition to Kd
    - Near global coverage of coastal areas
    - Very complementary with SDB from multispectral imagery
    - Revisit cycle → many opportunities for overpass at time of suitable water clarity and to build up increasingly dense and accurate data over time
    - Has opened entirely new field of study!



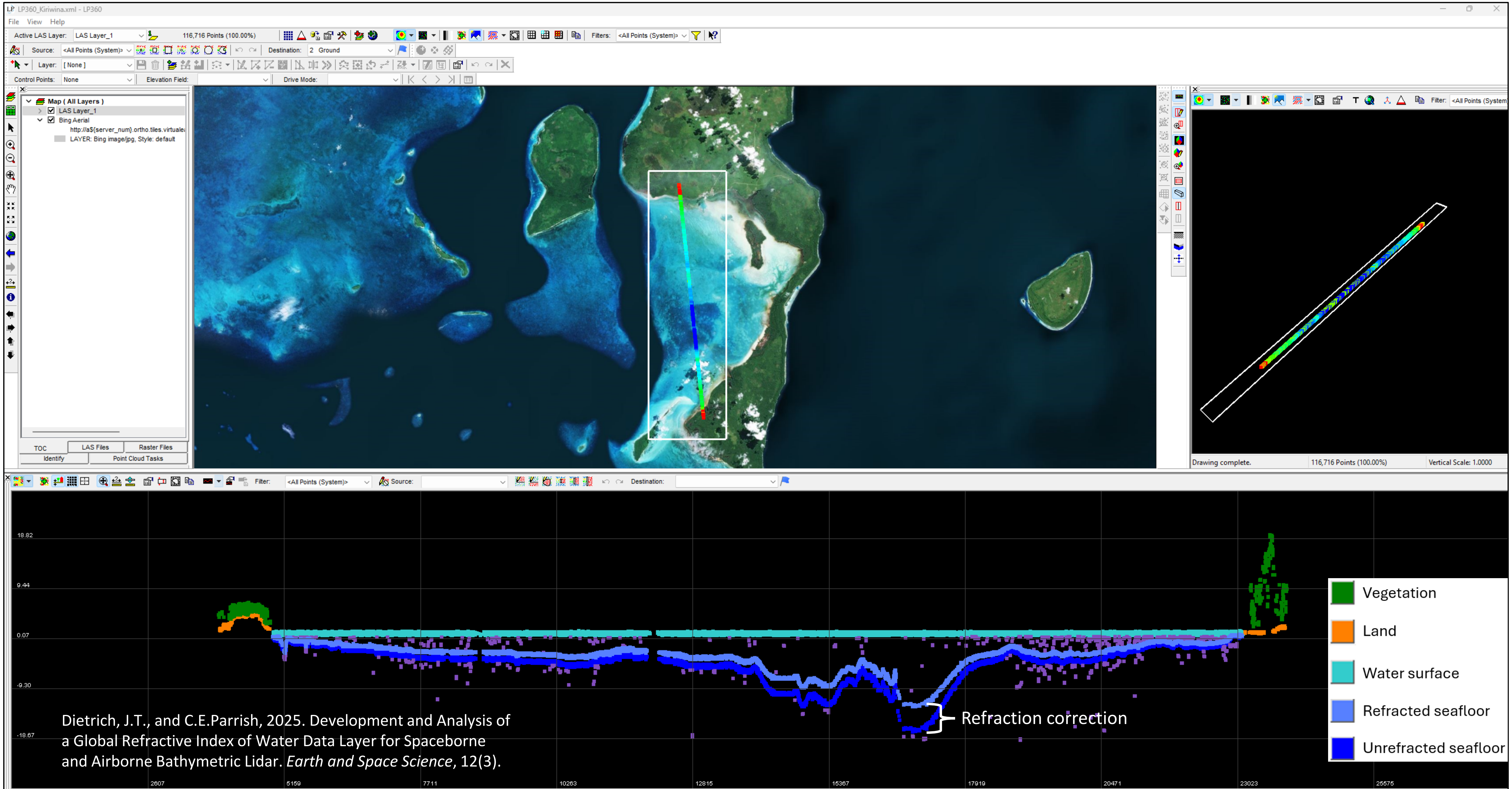


History and timeline of bathymetric lidar platforms



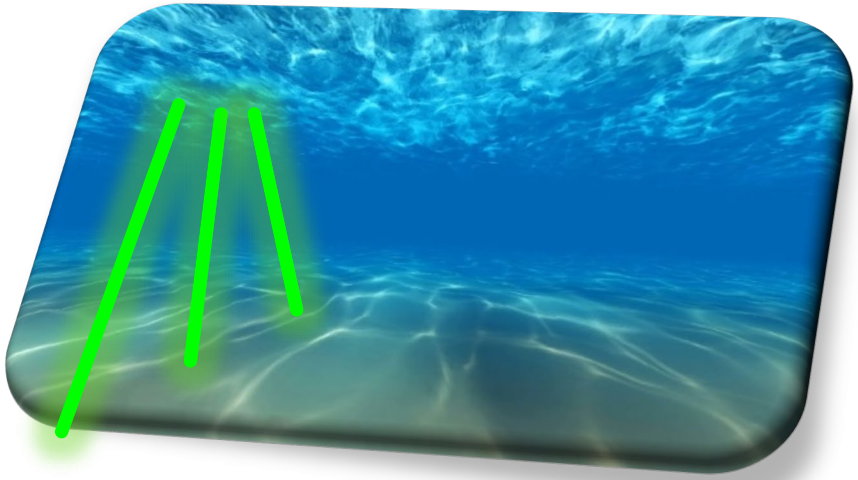

ICESat-2 ATLAS Photon Returns
All points
Water surface
Bathymetry
Land
Orthometric height (m)
Along-track distance (m)
20
10
0
-10
-20
-30
-40
1800
2000
2200
2400
2600
2800
3000
3200
3400

ICESat-2 Bathymetry Example: Kiriwina Island



Dietrich, J.T., and C.E.Parrish, 2025. Development and Analysis of a Global Refractive Index of Water Data Layer for Spaceborne and Airborne Bathymetric Lidar. *Earth and Space Science*, 12(3).

Coastal and Nearshore Along-Track Bathymetry Product (ATL24)



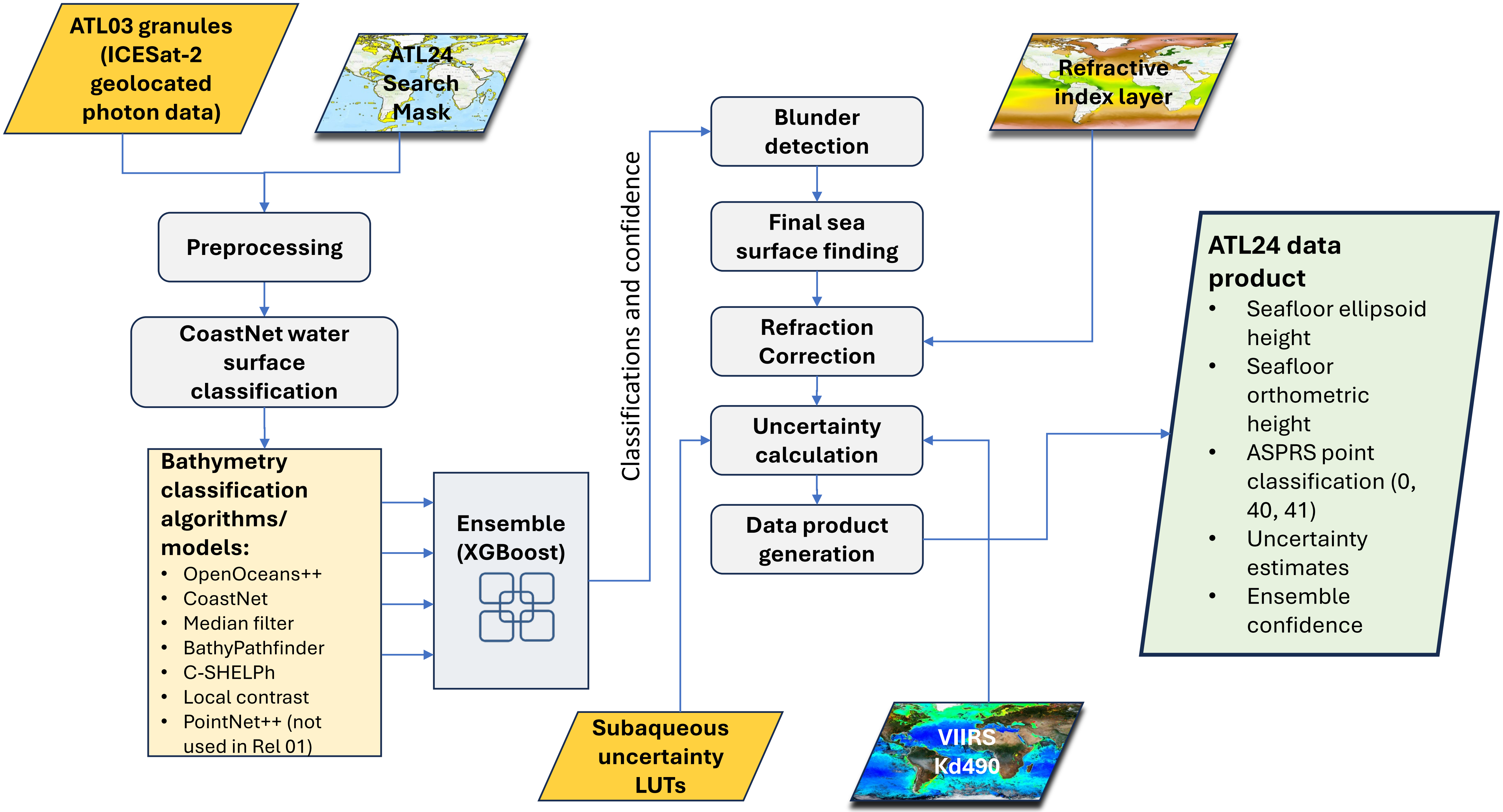
- Dedicated Coastal and Nearshore Along-Track Bathymetry Product
- Supported by ICESat-2 PSO as part of extended mission
- Provides
  - Photon-level classifications of seafloor and sea surface using ensemble ML model
  - Classification confidence values
  - Refraction-corrected seafloor elevations
 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

Oregon State University

THE UNIVERSITY OF TEXAS AT AUSTIN

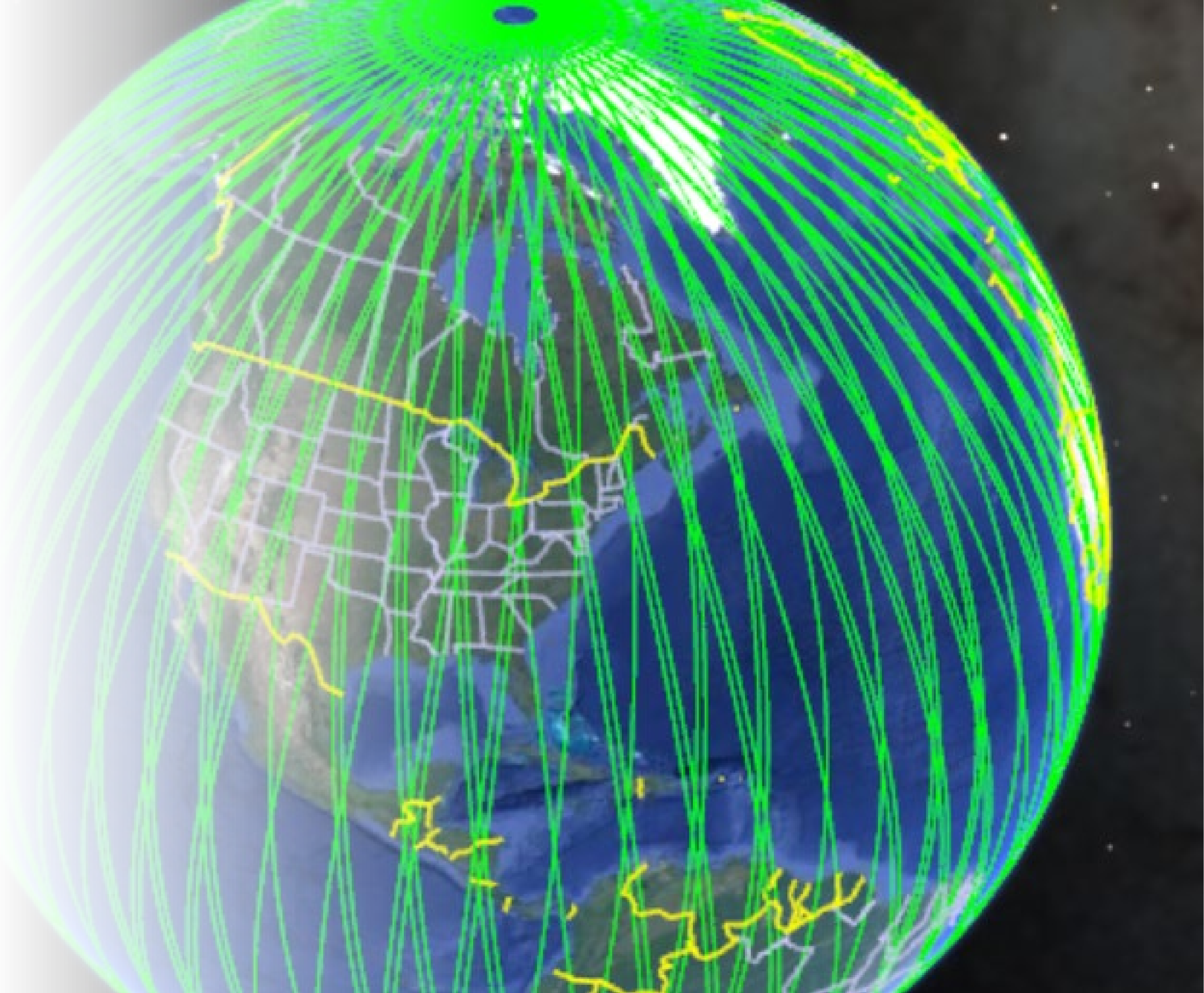
Amazing Team
UTA: Lori Magruder (UT PI), Jeff Perry, Matt Holwill, Jonathan Markel
OSU: Chris Parrish (OSU PI), Keana Kief, Forrest Corcoran
NASA GSFC: JP Swinski

ATL24 *Simplified* Workflow



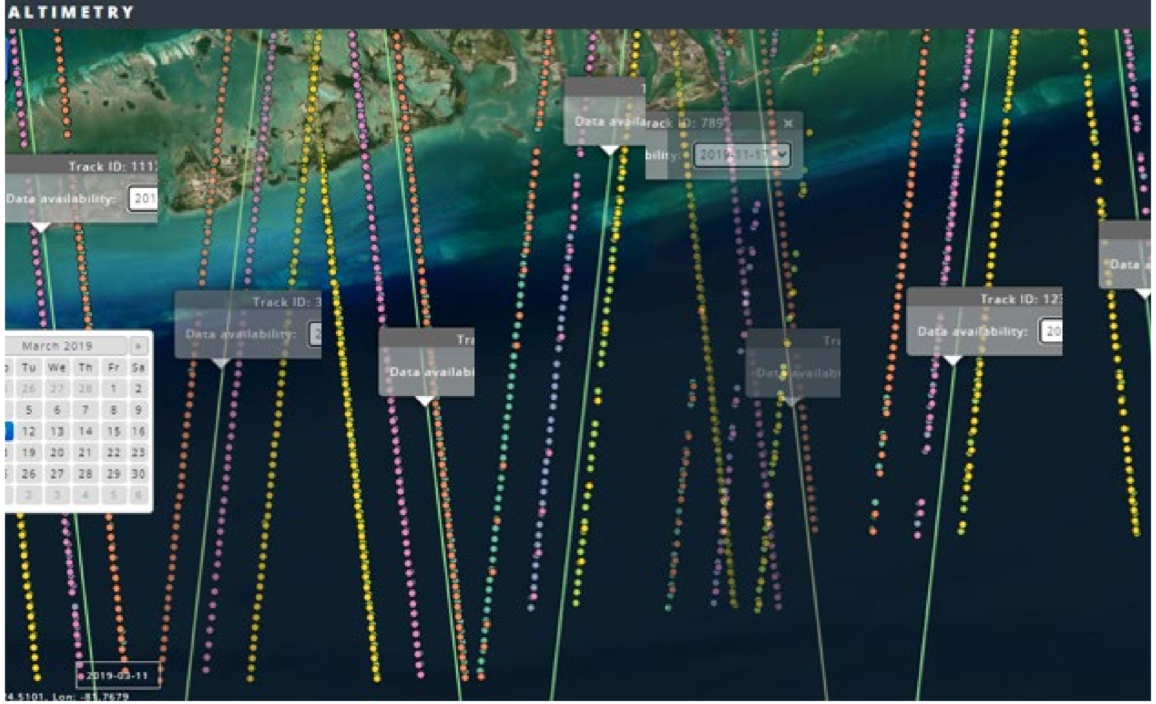
ATL24 Coverage

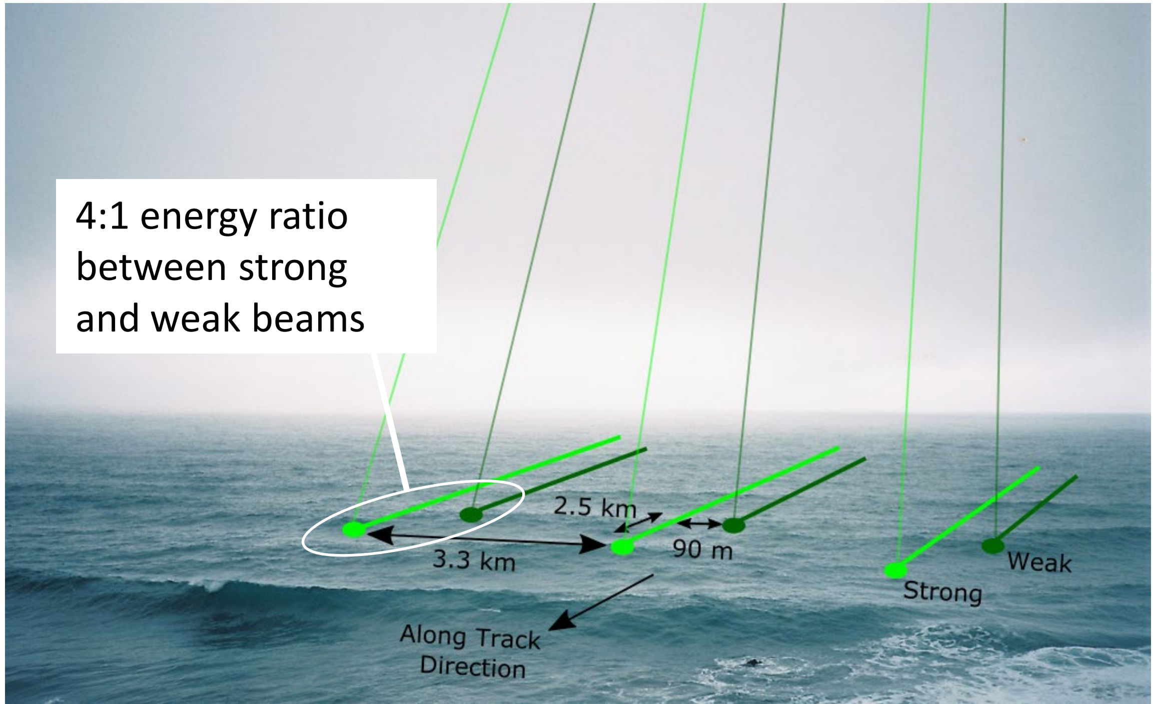
- Horizontal
  - 88° N to 88° S
- Vertical
  - Sea surface to depth of extinction
- Temporal
  - 2018 to present (and continuing throughout life of mission)



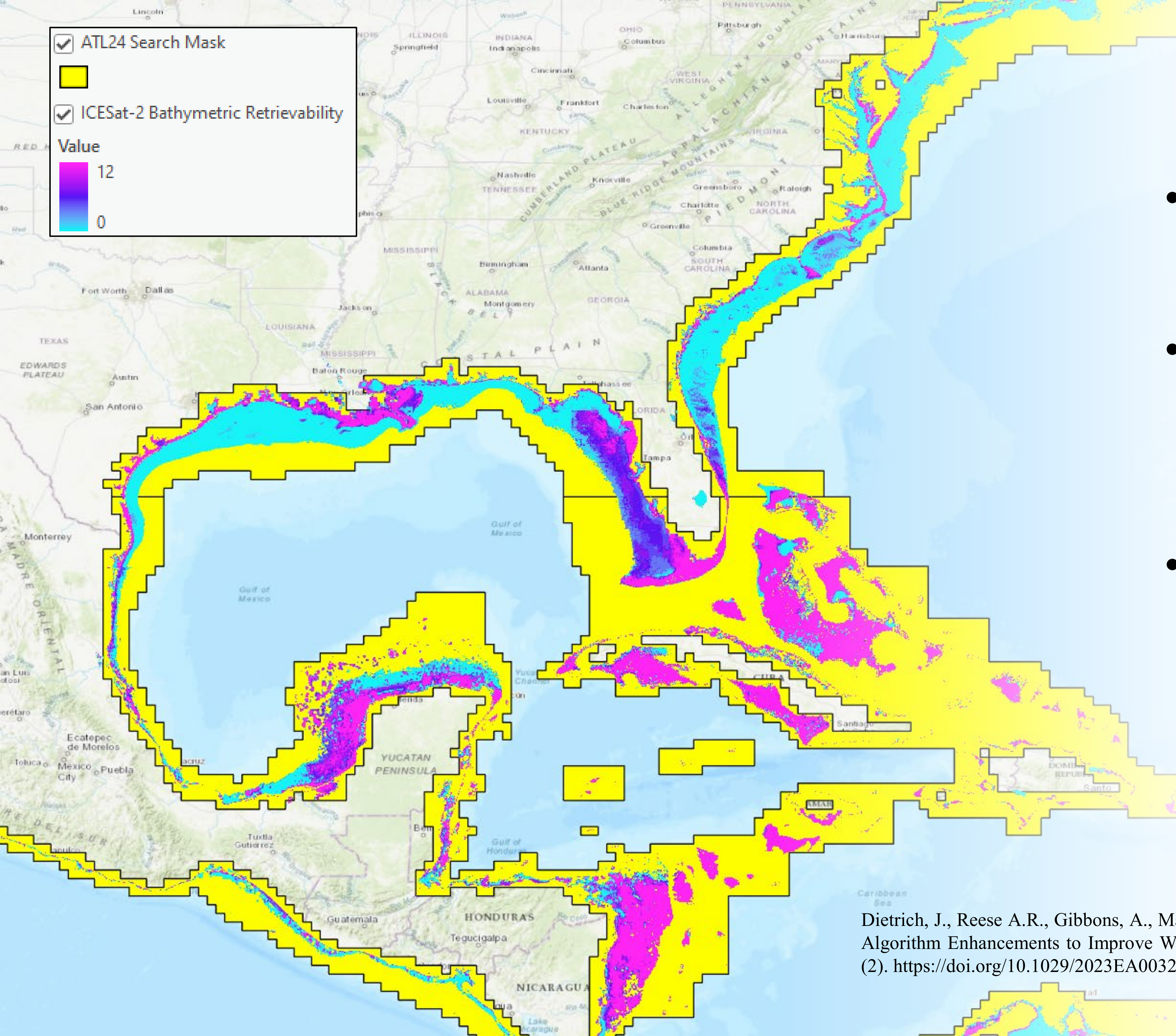
Spatial Resolution

- Profiling System
  - Provides data along tracklines (not “wall-to-wall” or “swath” coverage)
  - 6 beams arranged into 3 pairs of weak and strong beams
  - Spacing is ~70 cm in along track direction along each beam track
  - Cross-track spacing is coarser
    - Depends on water clarity (which, in turn, determines probability of successful bathymetric measurement on any given overpass) and how long a time window you consider
  - Footprint size on water surface: 11 m





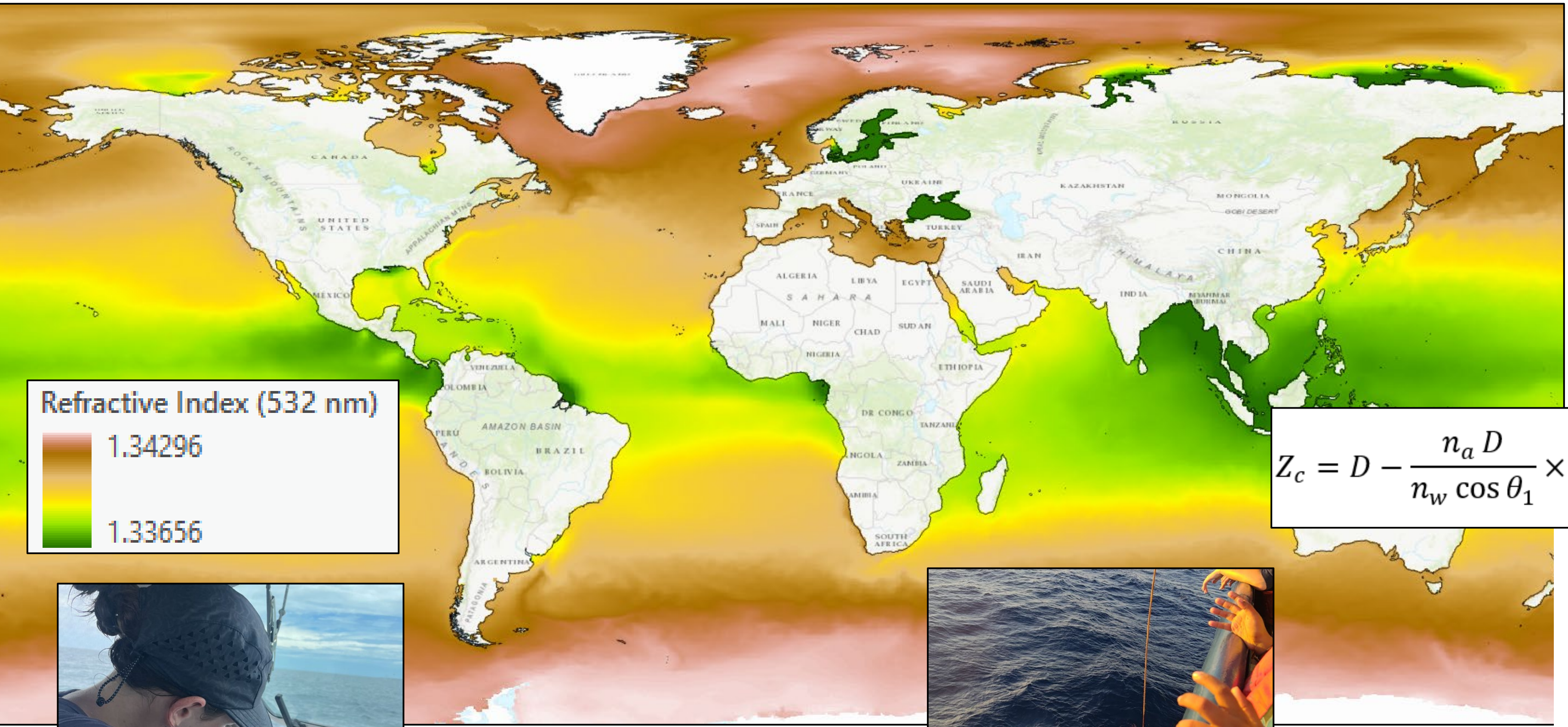
ATL24 Search Mask

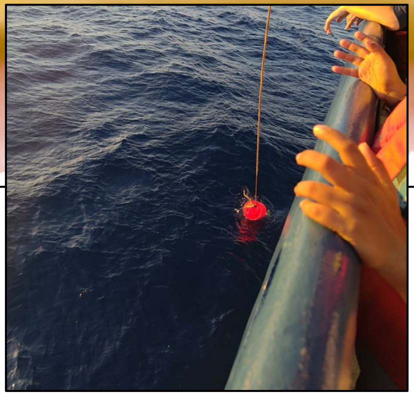


- Err on side of not missing previously-undiscovered bathymetry
- Considers
  - Best-available (but not great in many areas—hence the importance of ATL24!) global bathymetry
  - Water clarity (Kd490)
- Generous horizontal and vertical buffers to avoid missing bathymetry discoveries
  - Sea mounts
  - Reefs
  - Uncharted, migrating shoals
  - Etc.

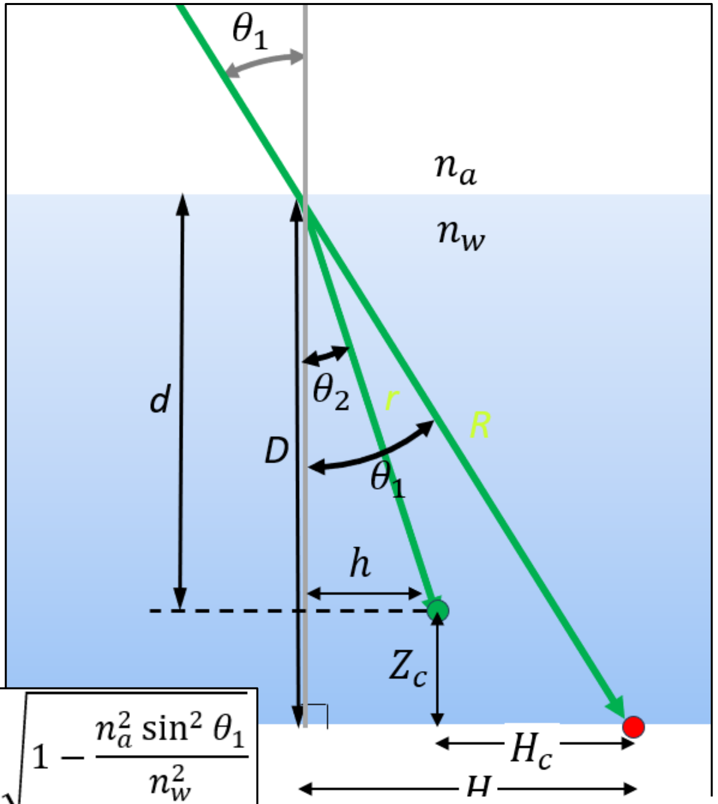
Dietrich, J., Reese A.R., Gibbons, A., Magruder, L., and Parrish, C. (2023) Analysis of ICESat-2 Data Acquisition Algorithm Enhancements to Improve Worldwide Bathymetric Coverage. *AGU Earth and Space Science,* Vol. 11 (2). https://doi.org/10.1029/2023EA003270

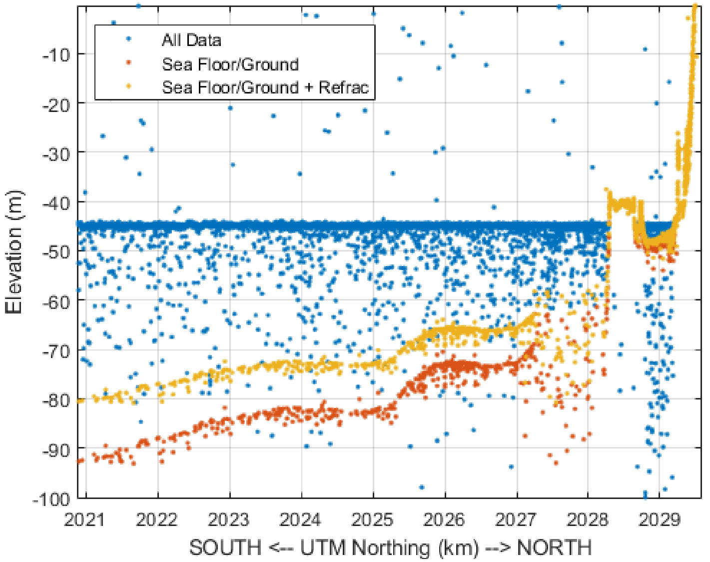
ATL24 Global Refractive index layer





$$Z_c = D - \frac{n_a D}{n_w \cos\theta_1} \times \sqrt{1 - \frac{n_a^2 \sin^2\theta_1}{n_w^2}}$$





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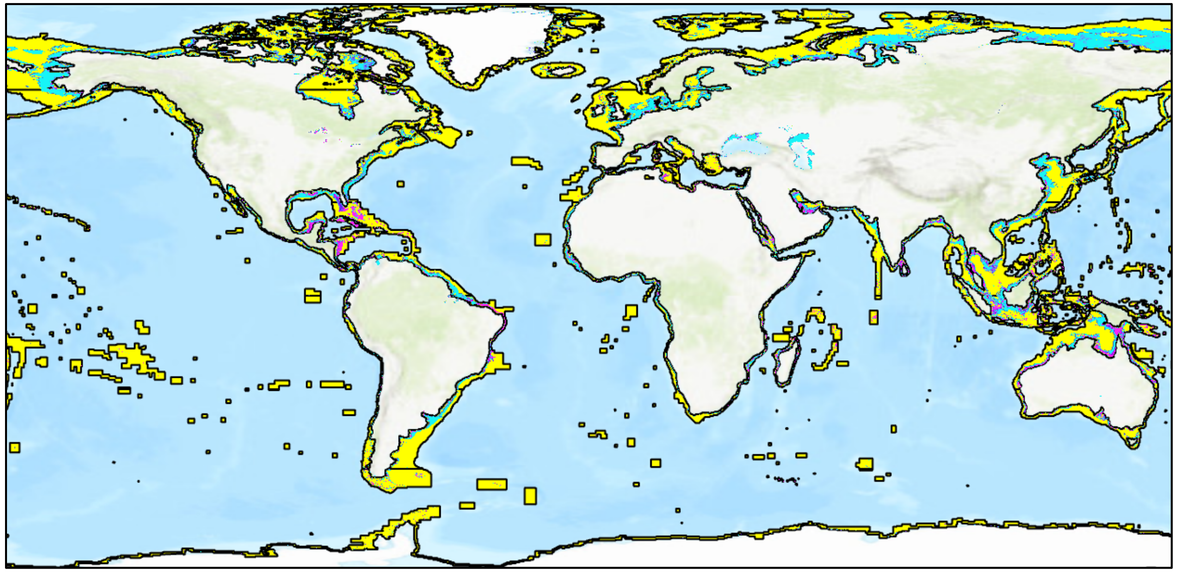
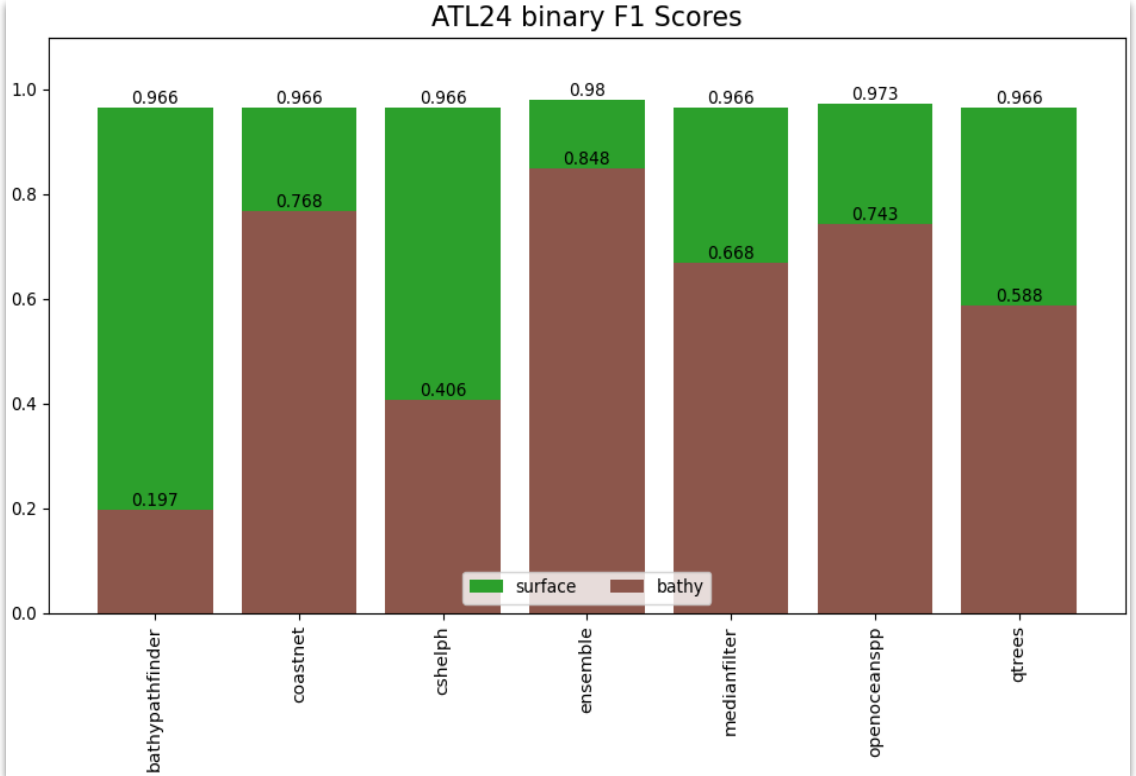
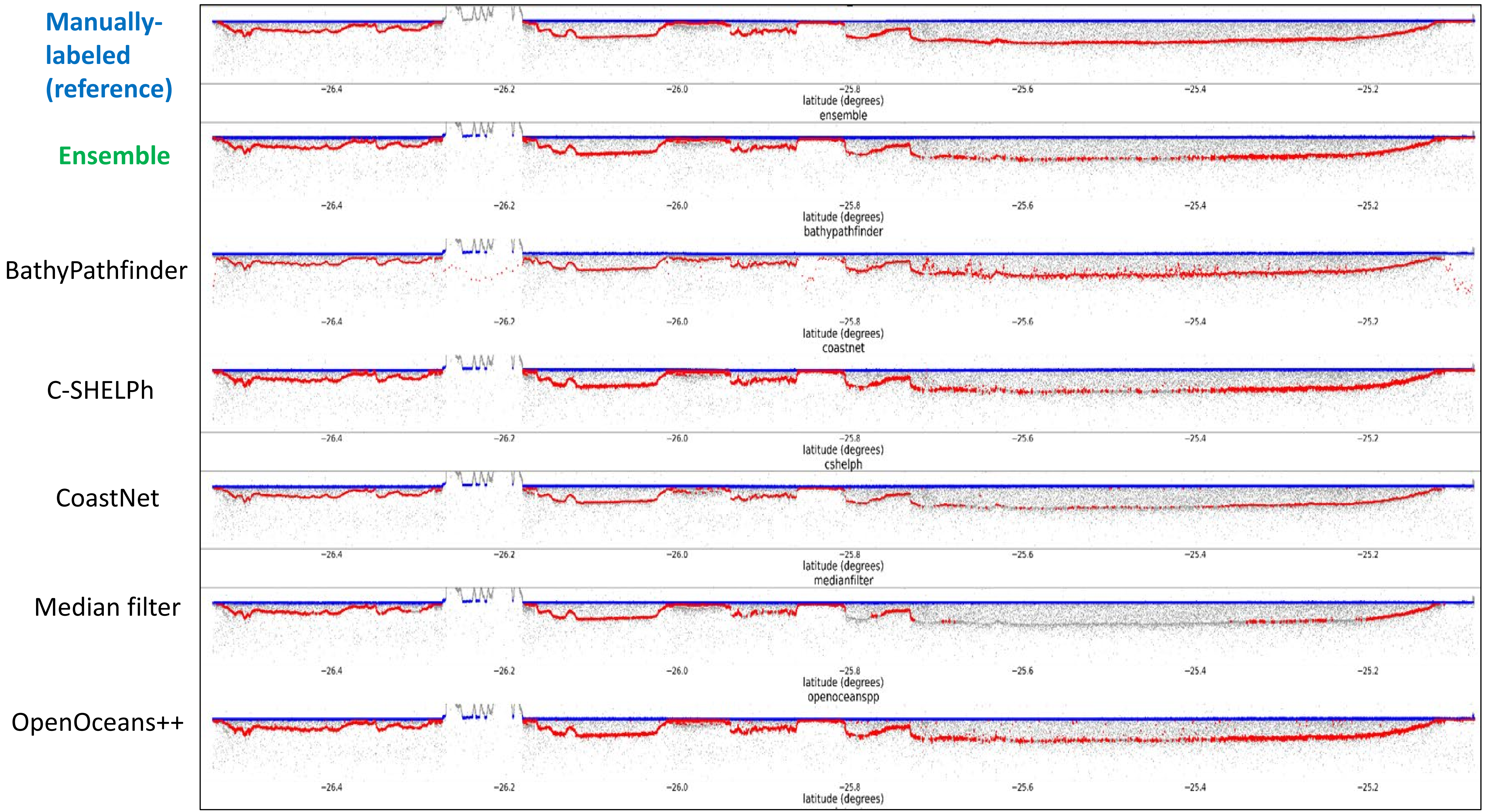
Ensemble Model for seafloor ans sea surface classification

- Why use an ensemble model?
  - Global nearshore coverage
    - Intersection of ATL24 Search Mask and ICESat-2 Retrievability Index > 0: **~ 5.6 million km^2**
    - Many different seafloor morphologies, cover types, wind, wave, and water characteristics
  - No single algorithm or model can provide good results across vast enormous extent
  - Ensemble leverages strengths of each base model/algorithm; outperforms any individual classifier
  - Another key factor: provides a **classification confidence score**

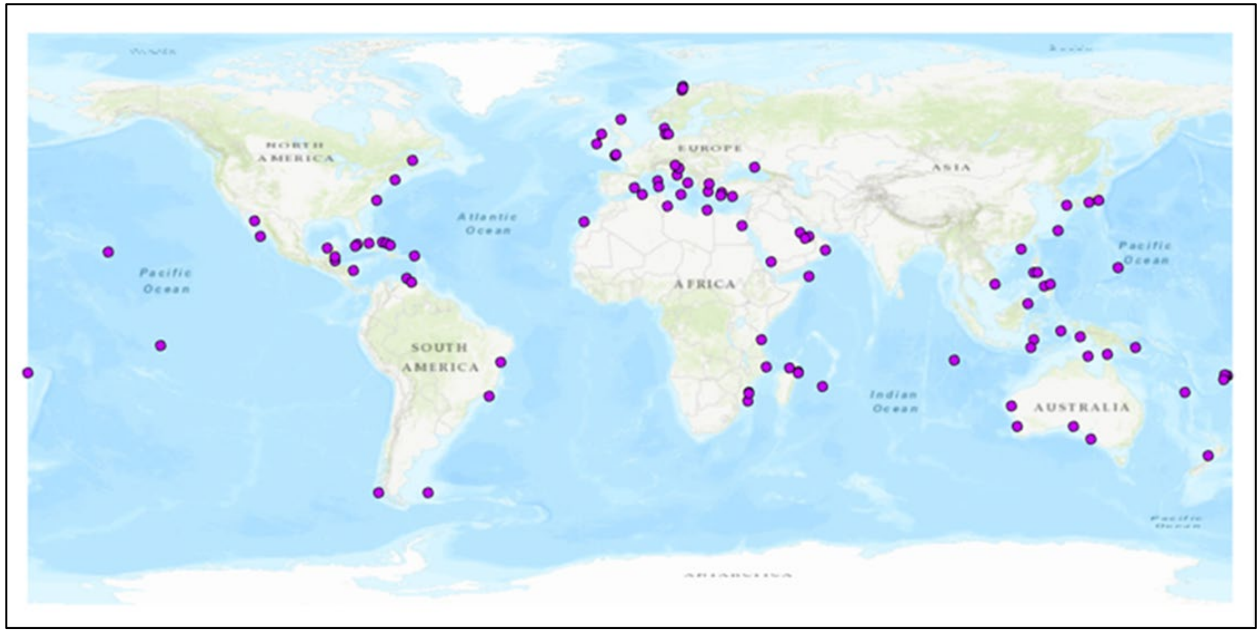


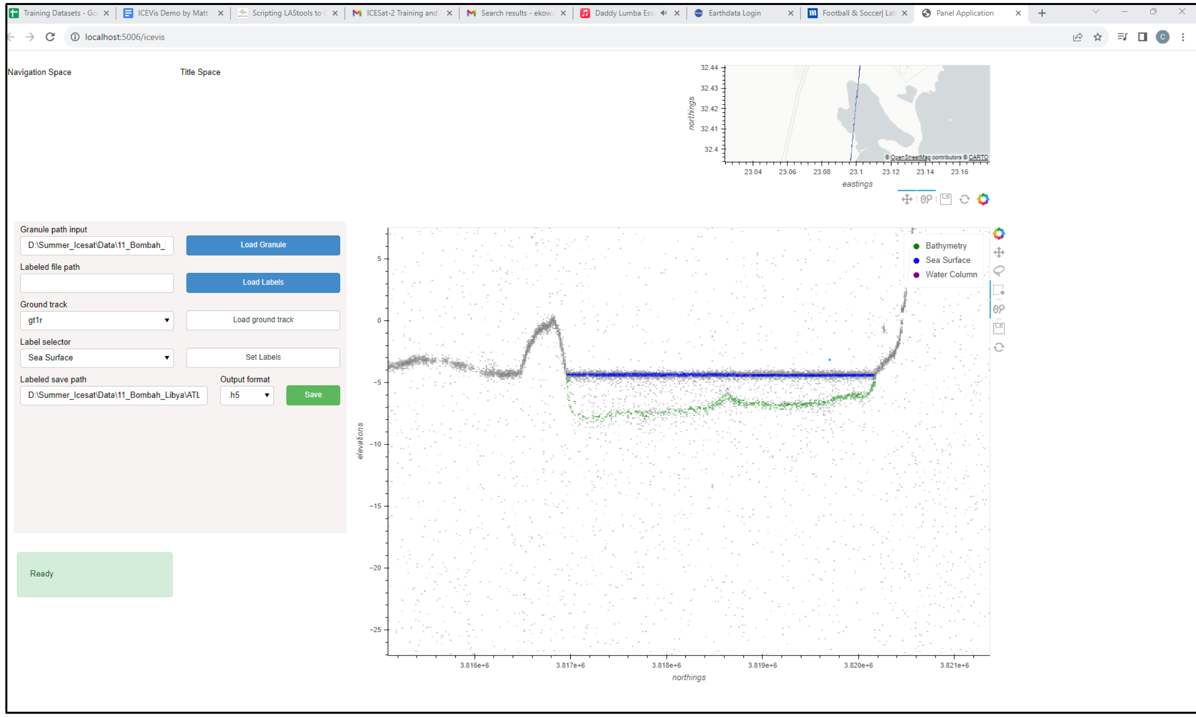



Manually-labeled (reference)
Ensemble
BathyPathfinder
C-SHELPh
CoastNet
Median filter
OpenOceans++
−26.4
−26.2
−26.0
−25.8
−25.6
−25.4
−25.2
latitude (degrees)
ensemble
bathypathfinder
coastnet
cshelph
medianfilter
openoceanspp

ICESat-2 Seafloor and Sea Surface Classification Training & Testing Database

- As part of ATL24 development efforts, we needed large training and testing database of ATL03 (geolocated photon clouds) data with sea surface and seafloor points accurately labeled
- Database of >150 sites developed by our team
- Wide variation in seafloor morphology and composition, substrate and cover types, and other environmental parameters





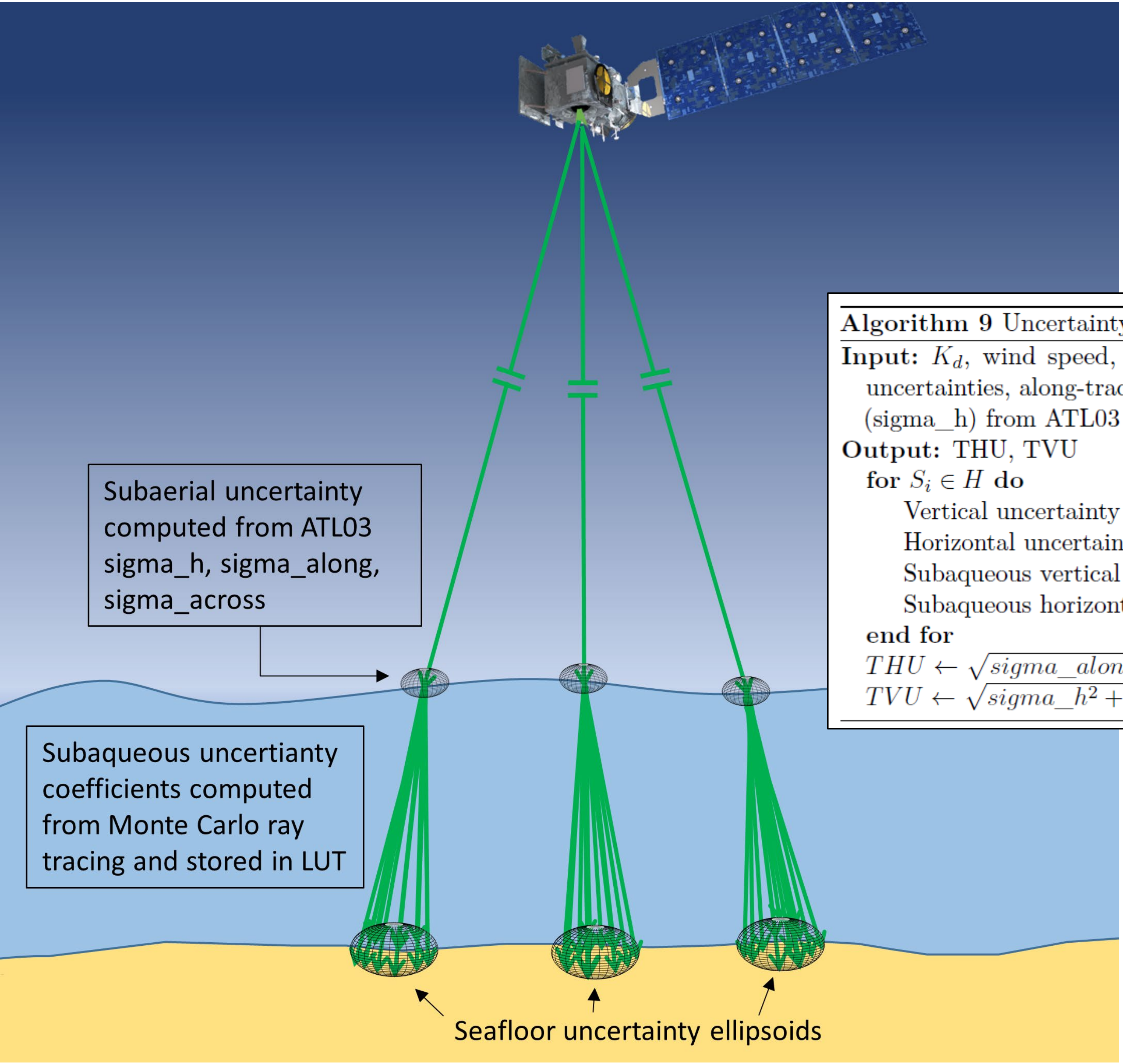
Disseminated via **ScholarsArchive@OSU**

DOI for the dataset:

https://doi.org/10.7267/j3860g66d

https://ir.library.oregonstate.edu/concern/datasets/j3860g66d

ATL24 Uncertainty Model



Algorithm 9 Uncertainty Algorithm

Input: K_d, wind speed, orthometric height (H), pointing angle, along track and across track uncertainties, along-track (sigma_along), across-track (sigma_across), and vertical uncertainties (sigma_h) from ATL03

Output: THU, TVU

for $S_i \in H$ **do**

  Vertical uncertainty coefficients and offsets $(A_v, B_v, C_v) \leftarrow K_d$, wind speed, pointing angle

  Horizontal uncertainty coefficients and offsets $(A_h, B_h, C_h) \leftarrow K_d$, wind speed, pointing angle

  Subaqueous vertical uncertainty $(SVU) \leftarrow A_v S_i^2 + B_v S_i + C_v$

  Subaqueous horizontal uncertainty $(SHU) \leftarrow A_h S_i^2 + B_h S_i + C_h$

end for

$THU \leftarrow \sqrt{sigma\_along^2 + sigma\_across^2 + SHU^2}$

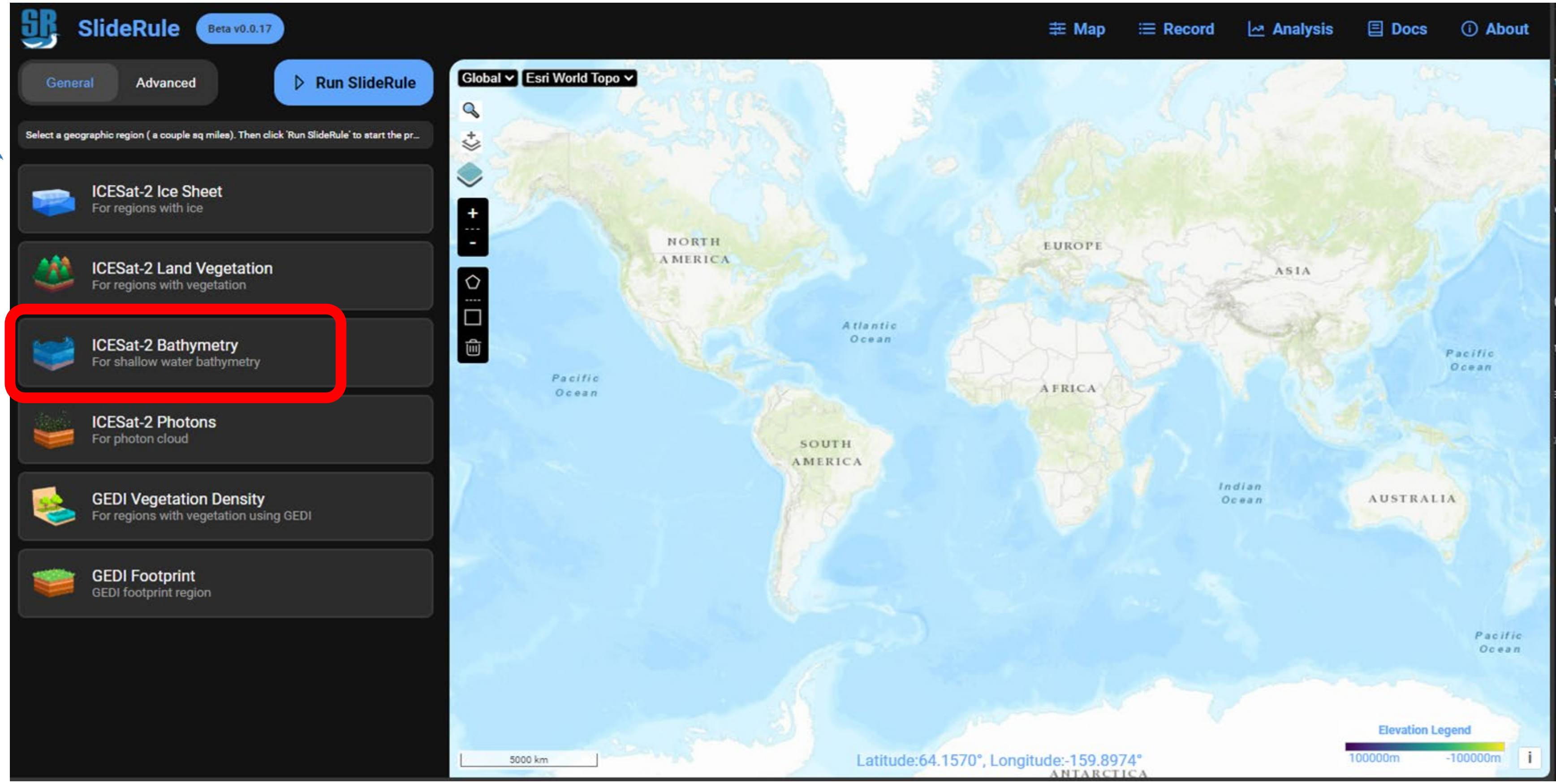
$TVU \leftarrow \sqrt{sigma\_h^2 + SVU^2}$

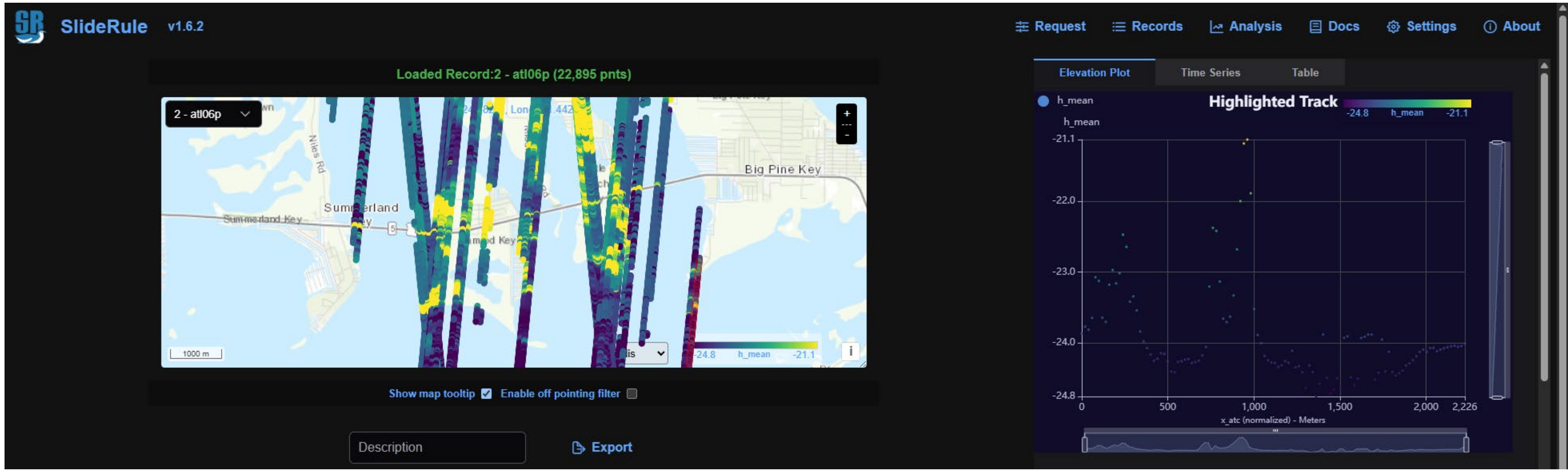
Update: current version uses linear model, rather than quadratic

Eren, F., Jung, J., Parrish, C.E., Sarkozi-Forfinski, N. and Calder, B.R., 2019. Total vertical uncertainty (TVU) modeling for topo-bathymetric LIDAR systems. *Photogrammetric Engineering & Remote Sensing*, *85*(8), pp.585-596.

Slide Rule Web Map Interface

- Open-source API for on-demand processing of NASA science data in the cloud
- Will enable parameter customization based on use case
- Many output formats, including LAS and CSV





ATL24 Accuracy Test Sites

- NOAA or USACE ALB data collected within ±6 months of ICESat-2 granule
- Range of seafloor morphologies, substrate and cover types, wind, wave, and water clarity characteristics

Status and Next Steps

- Official ATL24 release via NASA National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC)
  - **April 1, 2025!!**
- SlideRule release shortly thereafter
- Planned enhancements for future releases
  - Multiple upcoming papers
  - Create series of training videos
  - Possible enhancements over time (future releases)
    - Periodically retrain base models and ensemble
    - Add additional algorithms/base models
    - Support integration with cloud-based data catalogs
    - Improve uncertainty model
    - Refine confidence value

Questions?

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