Civil & Construction Engineering

COLLEGE OF ENGINEERING

Empirical Analysis of ICESat-2 ATLAS's Bathymetric Mapping Capability

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20th Annual JALBTCX Airborne Coastal Mapping and Charting Technical Workshop

University of Notre Dame

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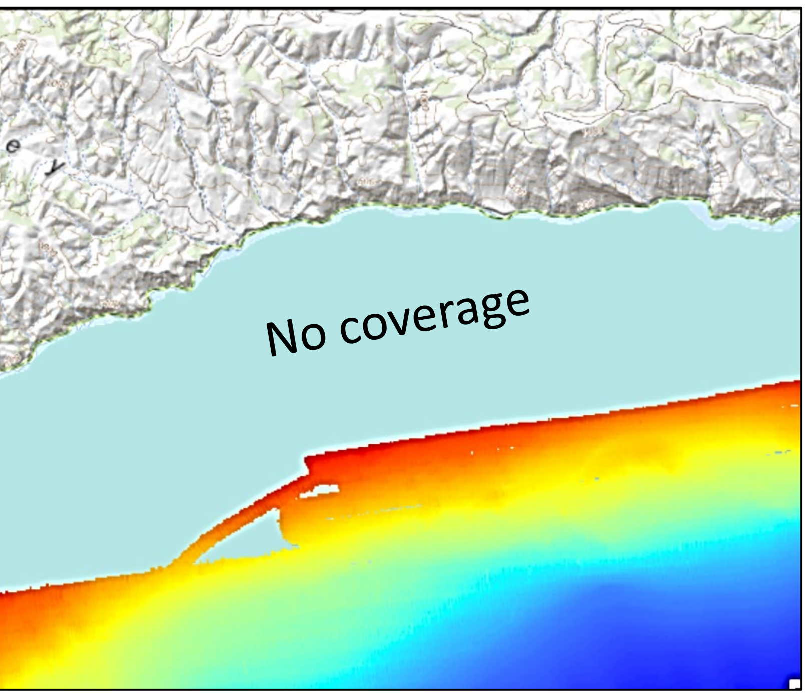
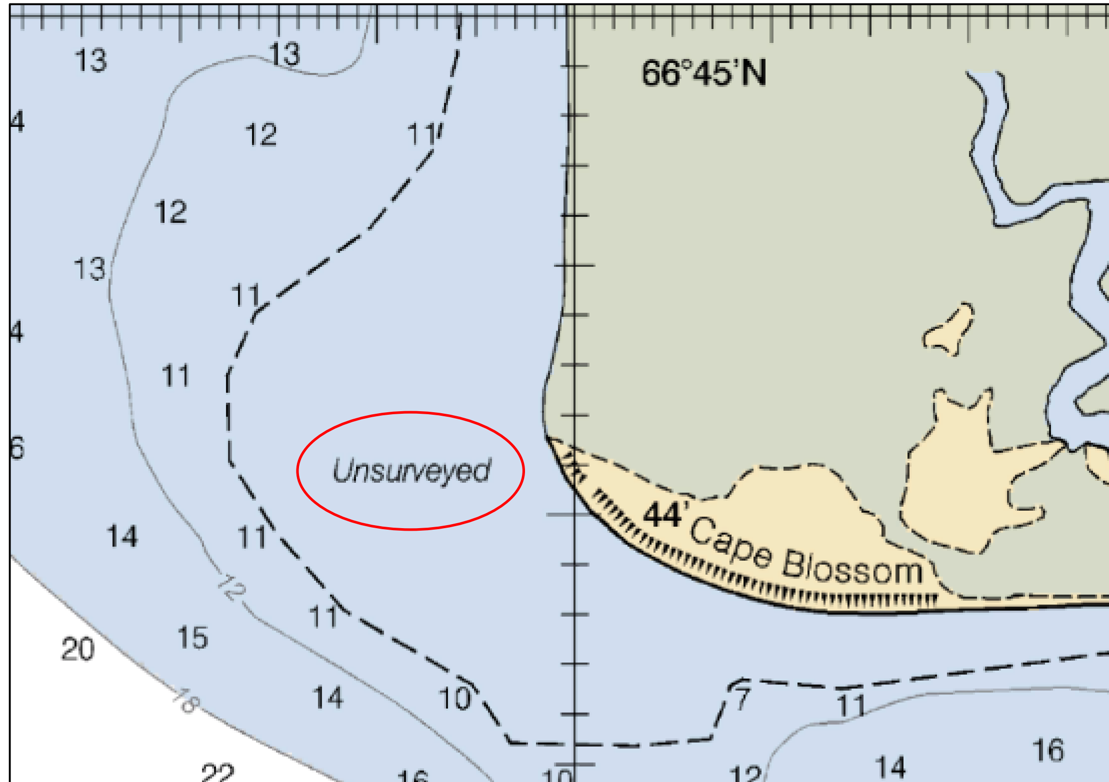
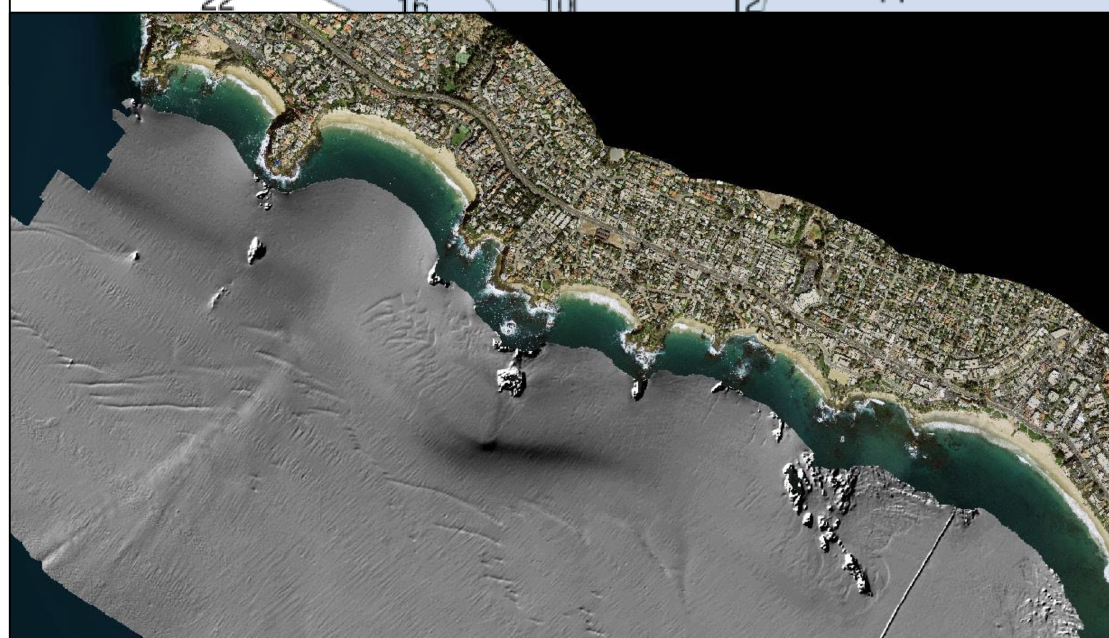
Nearshore data void: coastal "white ribbon"







Conventional (terrestrial) survey technologies (e.g., GNSS and total stations)

- Don’t work underwater!
- Can only survey as deep as you can wade
- Dangerous in high-energy environments

Ship- and boat-based technologies (e.g., sonar)

- NOAA defines the Navigable Area Limit Line (NALL) as the **offshore-most of the following**:
  - The seaward line which is offset horizontally by 0.8mm (from MHW) at the scale of the largest scale chart of the area
    - Ex: 64 meters for a 1:80,000 scale chart
  - The surveyed 3.5-meter depth contour
  - The inshore limit of safe navigation for the survey vessel (kelp, rocks, breaking waves, etc.) – subject to CO discretion

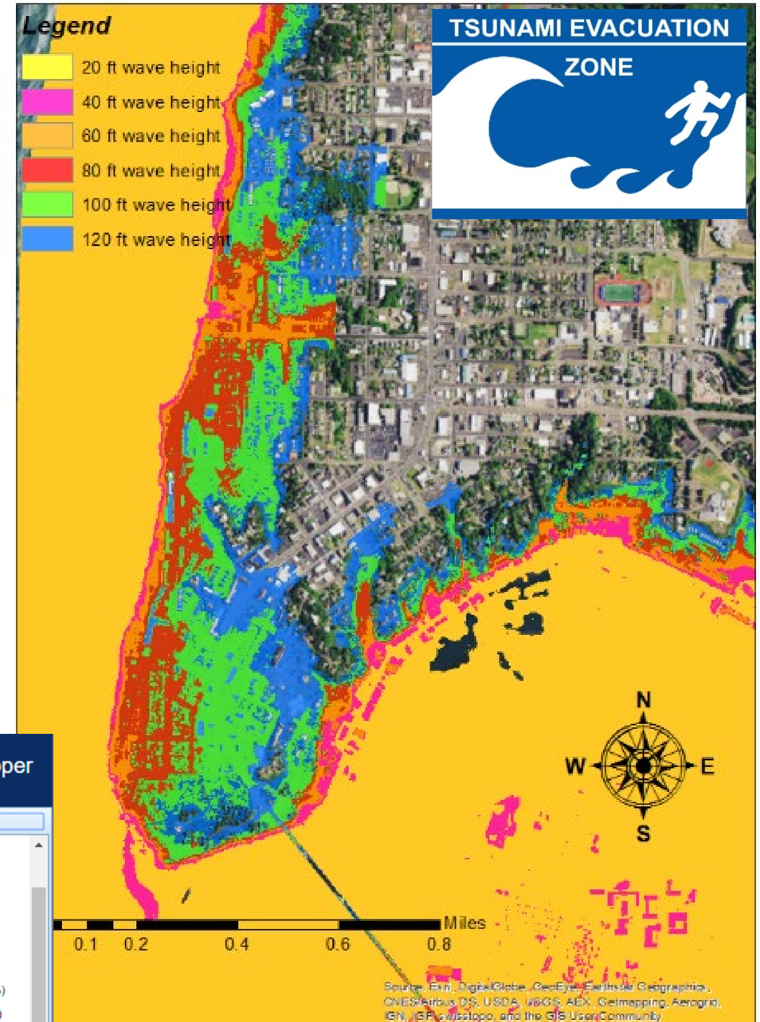
NOAA – Specs & Deliverables, 2018

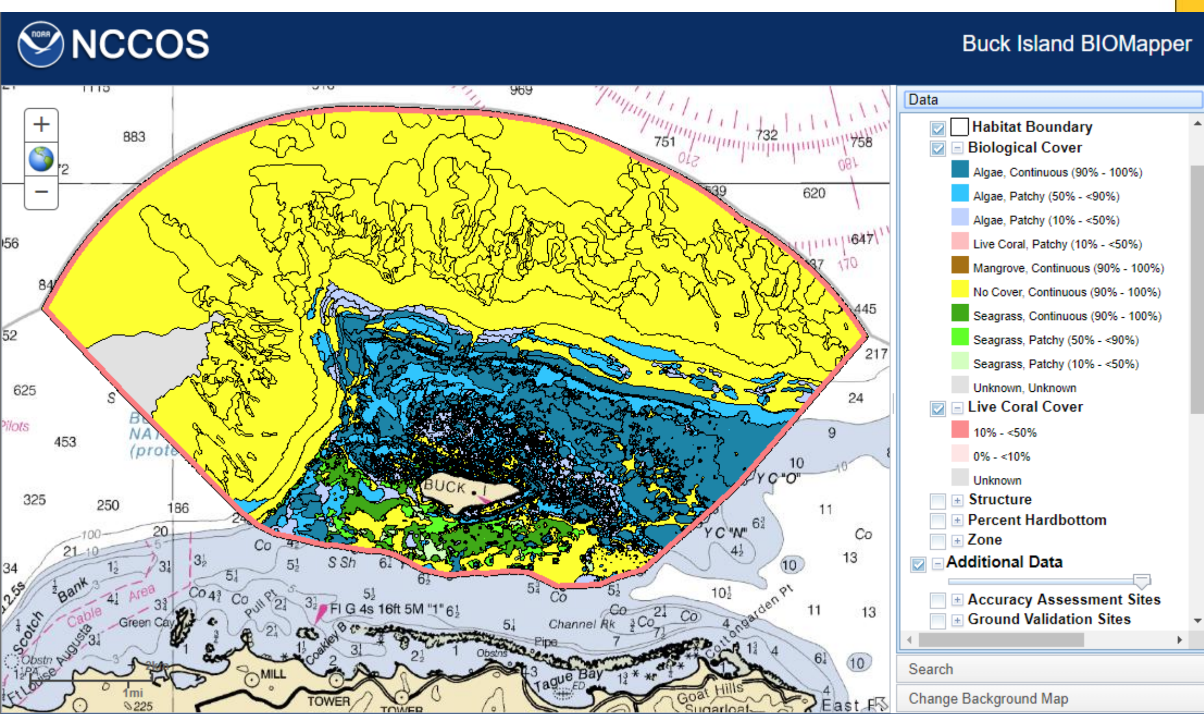
- MBES generally inefficient in shallow water

Large ships unlikely to be navigating shoreward of NALL!

Why we care about these shallow, nearshore areas:

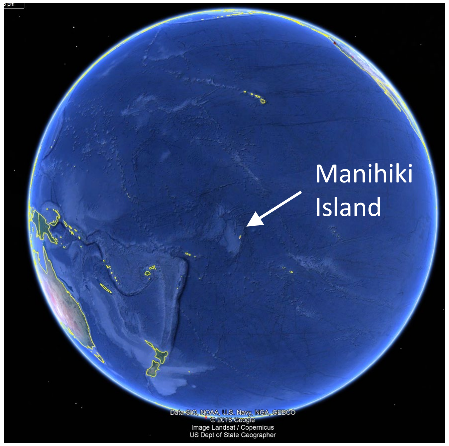
- Lack of nearshore coastal data hinders
  - Storm surge modeling
  - Benthic habitat mapping
    - Ex: coral reef habitat
  - Analysis of coastal hazards
  - Coastal resilience initiatives

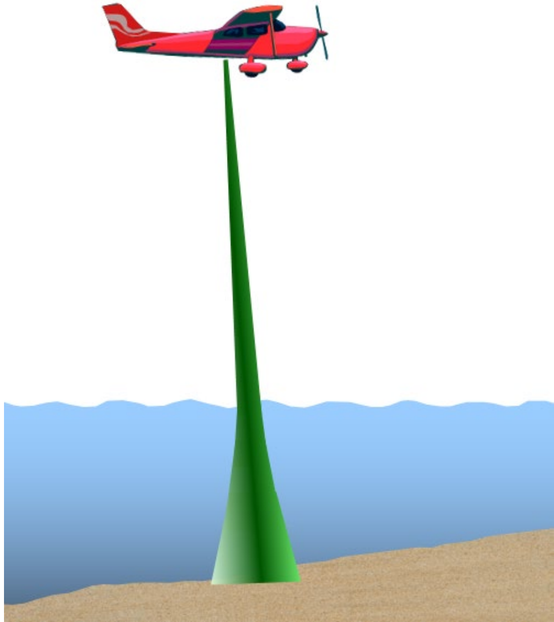




Why satellite-based approaches are of interest for filling nearshore data void

- ALB can be extremely effective technology for filling nearshore data void
  - But, expensive to deploy
    - Say you need bathymetry of Manihiki Island in the South Pacific (extremely remote)
  - Often you only get one chance to acquire data
    - What if water clarity happens to be poor at that particular time?
- Satellite-based approach
  - Avoids deploying aircraft and mission crew to remote coastal area
  - Revisit cycle allows many chances to get good water clarity

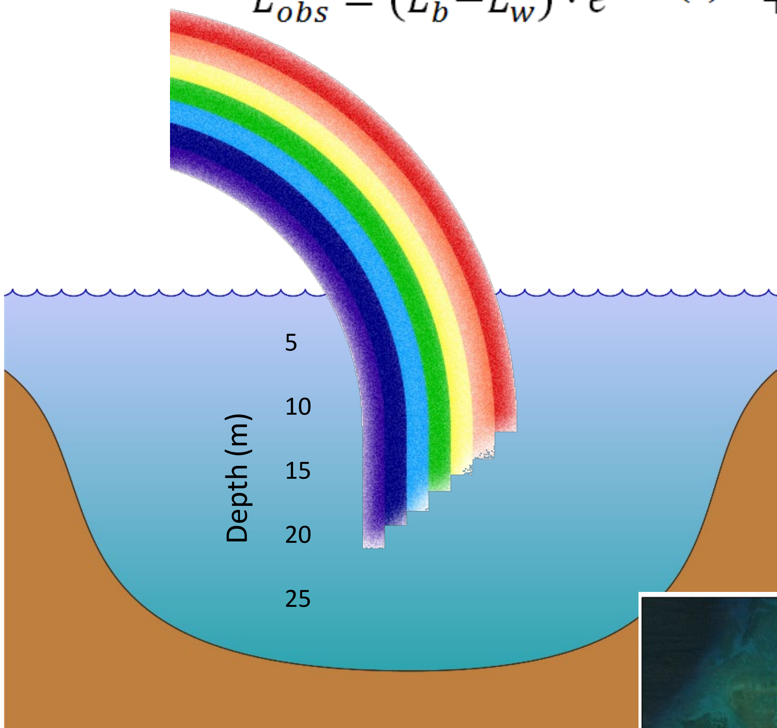


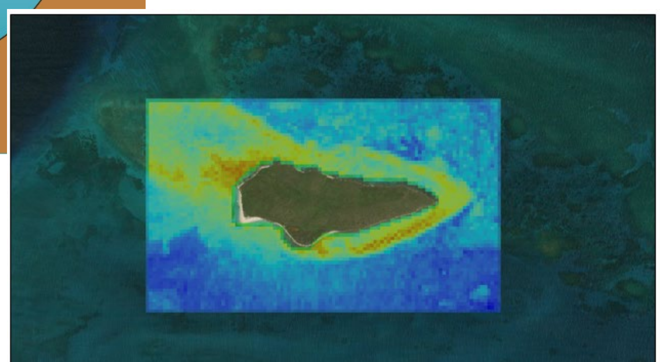


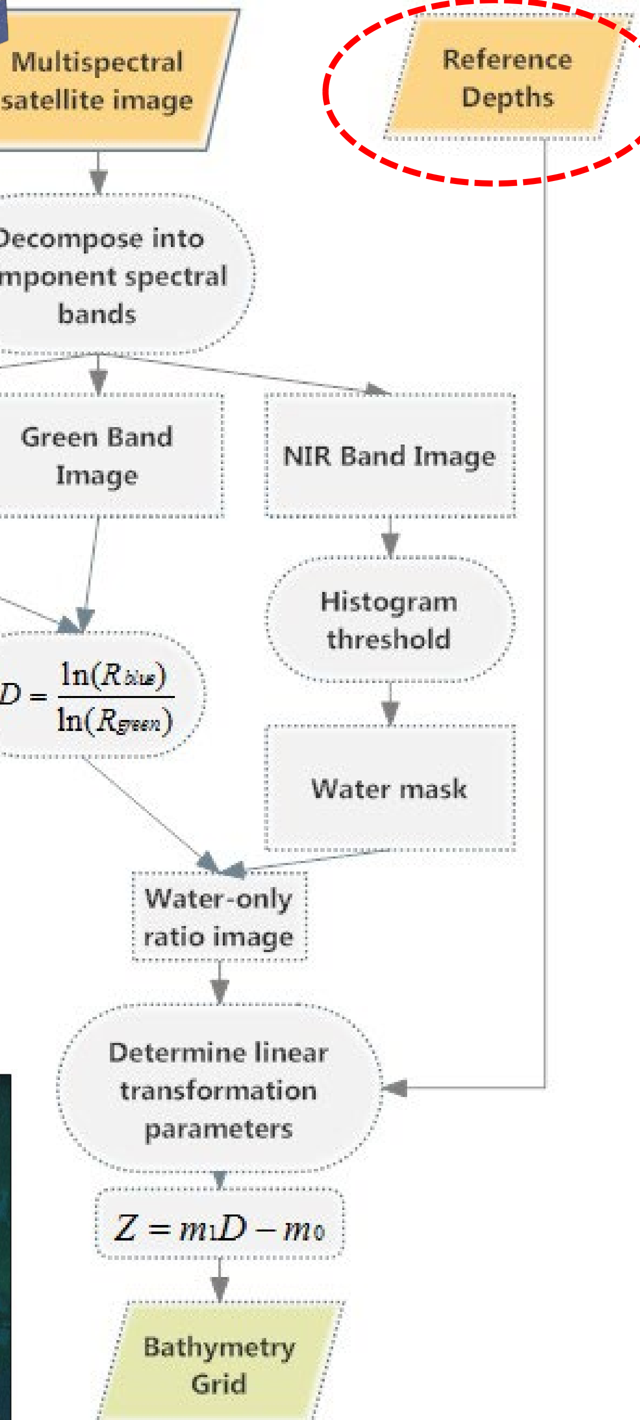
SDB

- Challenge is that it generally requires reference (or "seed") depths)

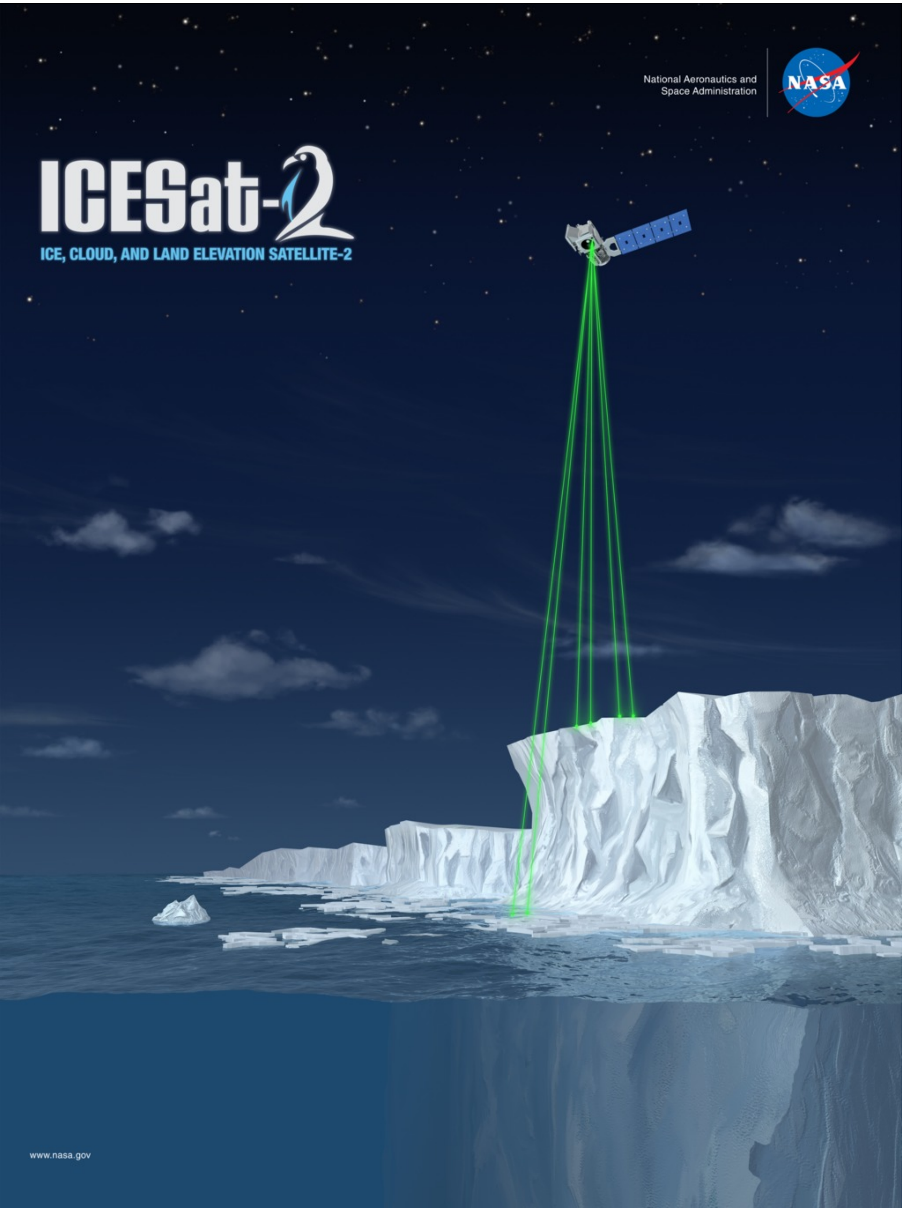
$$L_{obs} = (L_b - L_w) \cdot e^{-2K(\lambda) \cdot z} + L_w$$







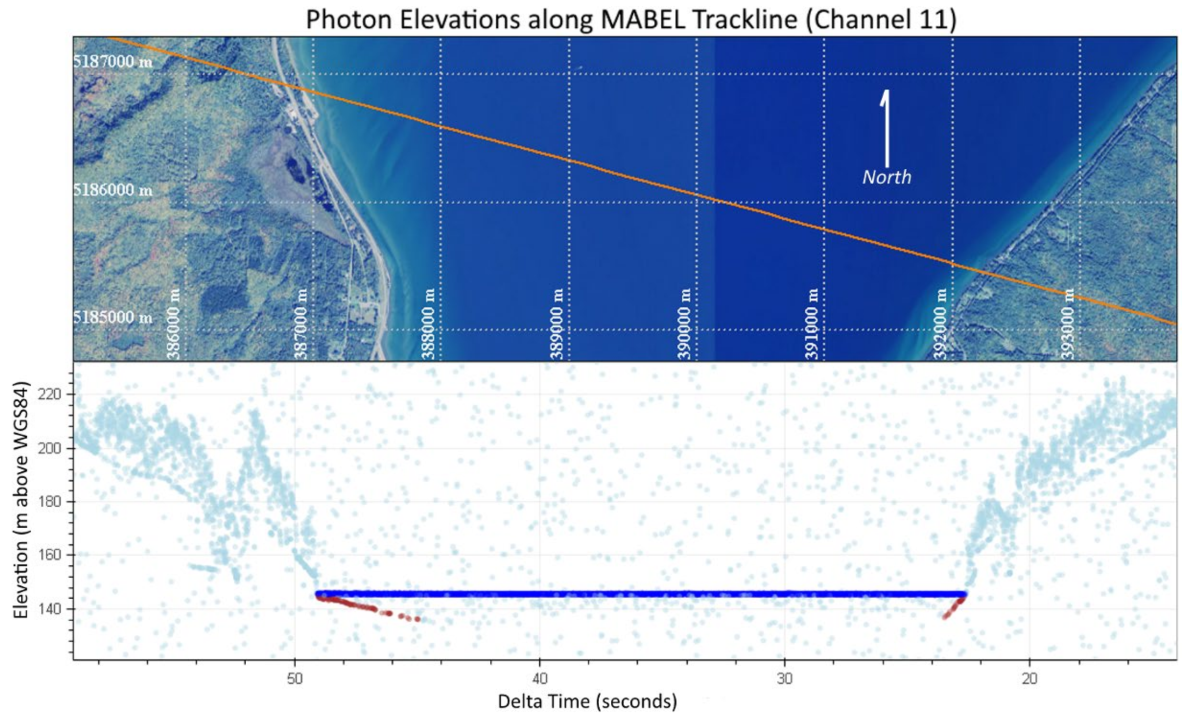
Can ICESat-2 ATLAS map bathymetry and assist in filling the nearshore data void?

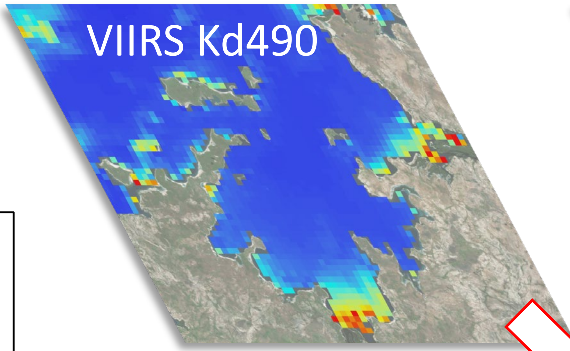


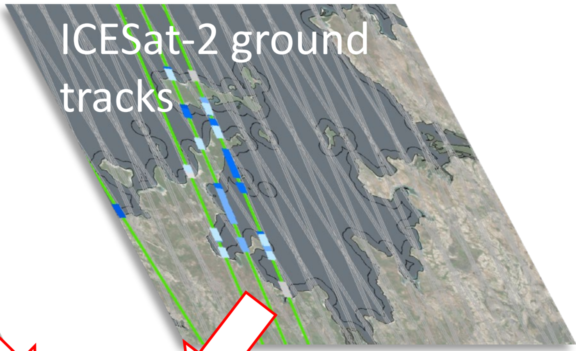
- Launched from Vandenberg AFB, Sept 15, 2018, 6:02 am (local)
- Carries single sensor: ATLAS – green (532 nm), photon-counting lidar

Summary of previous results (some presented at JALBTCX)

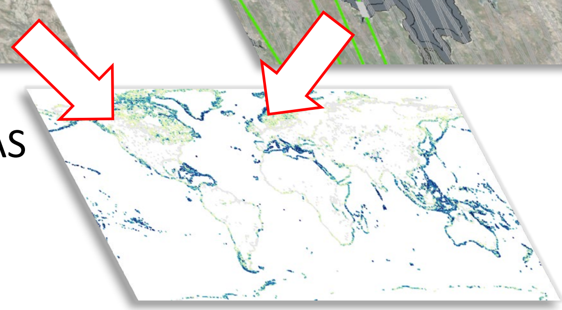
- NASA MABEL (high-altitude airborne emulator for ATLAS) capable of mapping bathymetry
  - Agrees with reference bathymetry to within 0.7 m RMS
- Visible Infrared Imaging Radiometer Suite (VIIRS) Kd490 useful in assessing utility of ATLAS for bathymetric mapping worldwide







Where and when ATLAS bathymetric mapping may be feasible



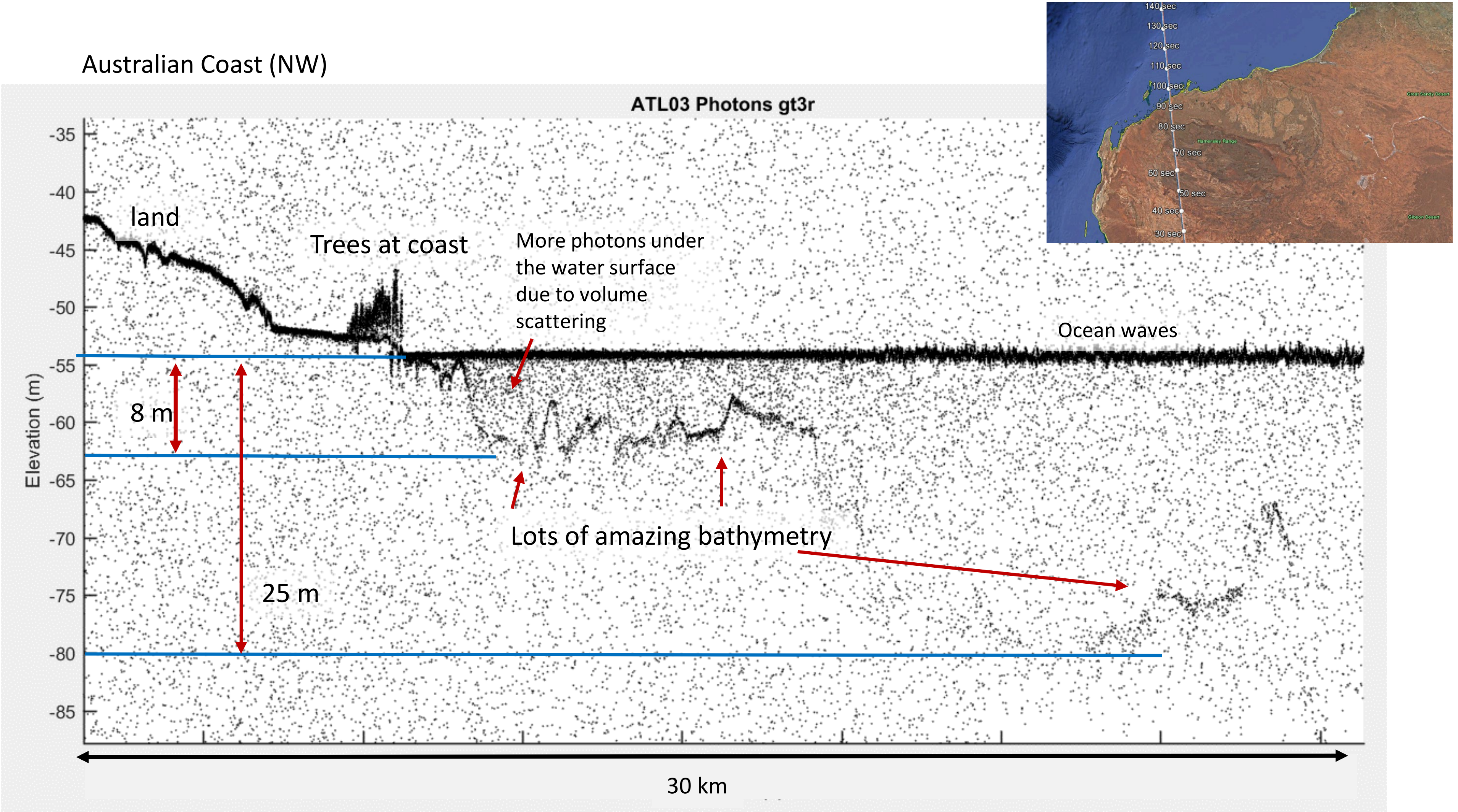
1. Forfinski-Sarkozi, N.A., and C.E. Parrish, 2016. Analysis of MABEL Bathymetry in Keweenaw Bay and Implications for ICESat-2 ATLAS. *Remote Sensing*, Vol. 8, No. 9.
2. Forfinski-Sarkozi, N.A., and C.E. Parrish, 2019. Active-Passive Spaceborne Data Fusion for Mapping Nearshore Bathymetry. *Photogrammetric Engineering and Remote Sensing*, Vol. 85, No. 4, pp. 281-295.

Objectives of current (post-launch) research

1. Identify examples of ICESat-2 ATLAS bathymetry
2. Empirically assess bathymetric mapping accuracy through comparison against reference data
3. Assess ATLAS's maximum depth penetration capability as a function of K_d and Secchi depth through analysis at multiple locations around the globe

With ICESat-2 now on orbit, many examples of bathymetry

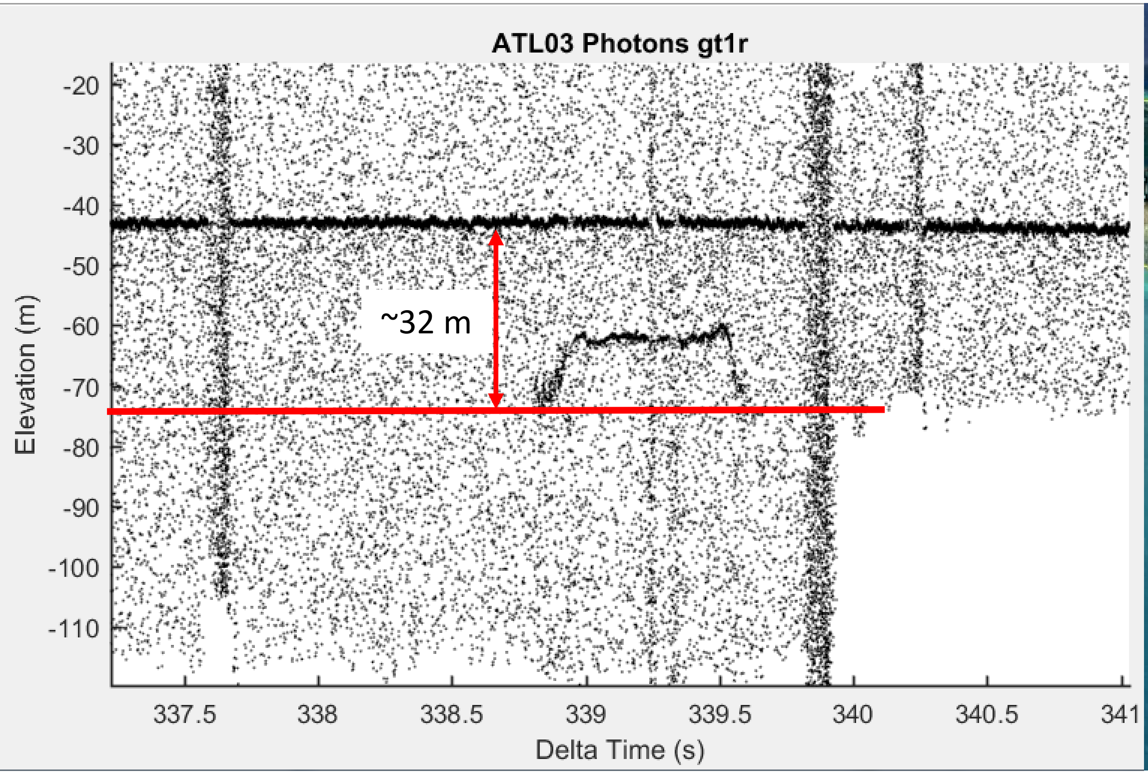
Australian Coast (NW)



Amy Neuenschwander, U Texas

More examples

ATL03_20181019195533_03240101_200_01.h5



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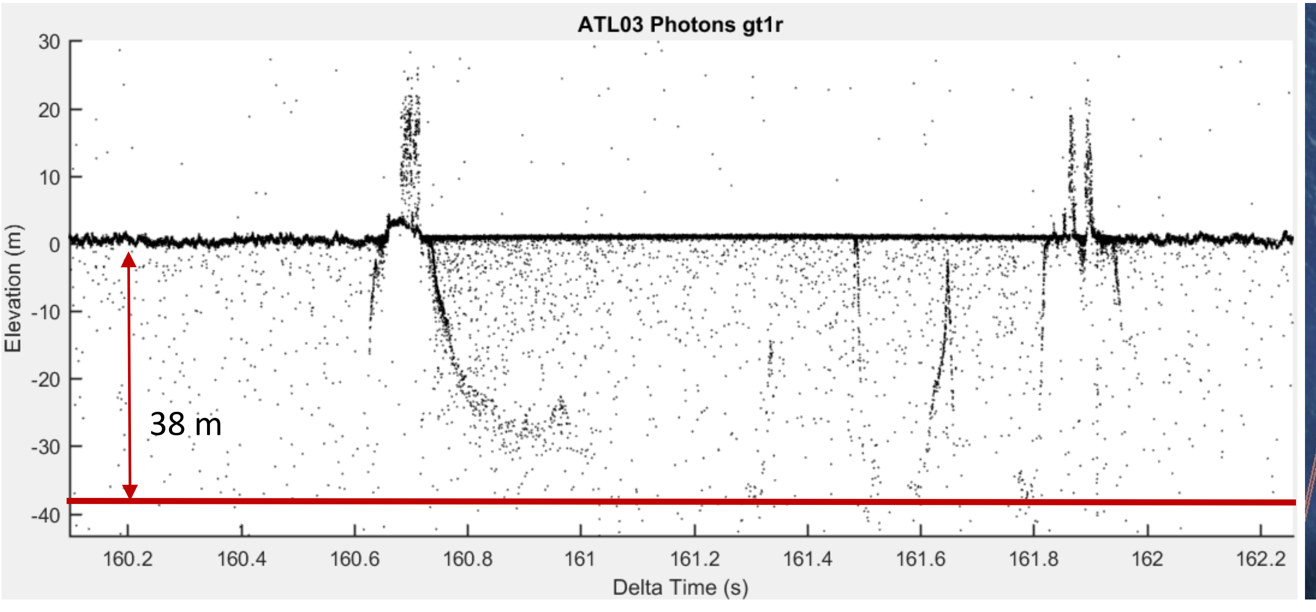
More examples



ATL03_20181016140809_02740108_200_01.h5

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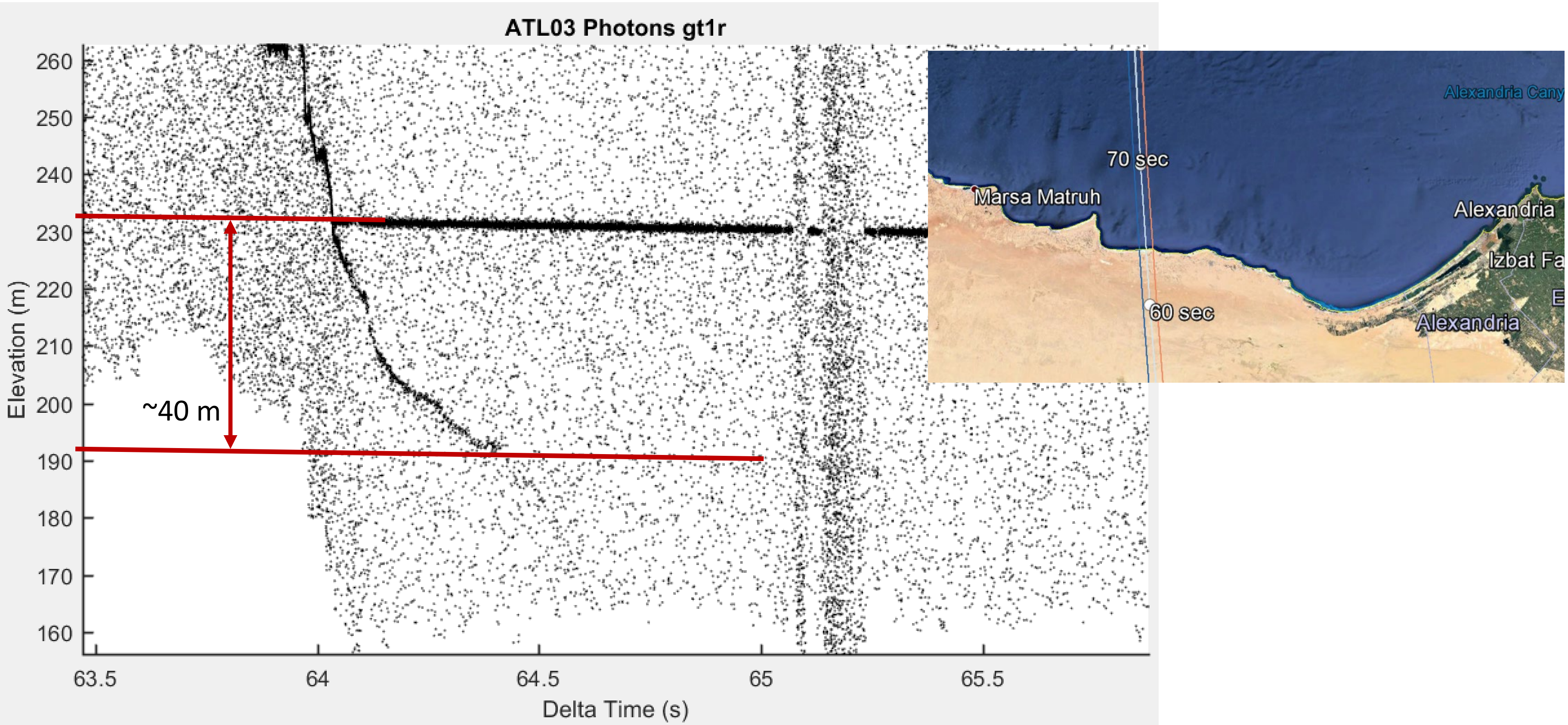
More examples

ATL03_20181016132807_02740102_200_01.h5



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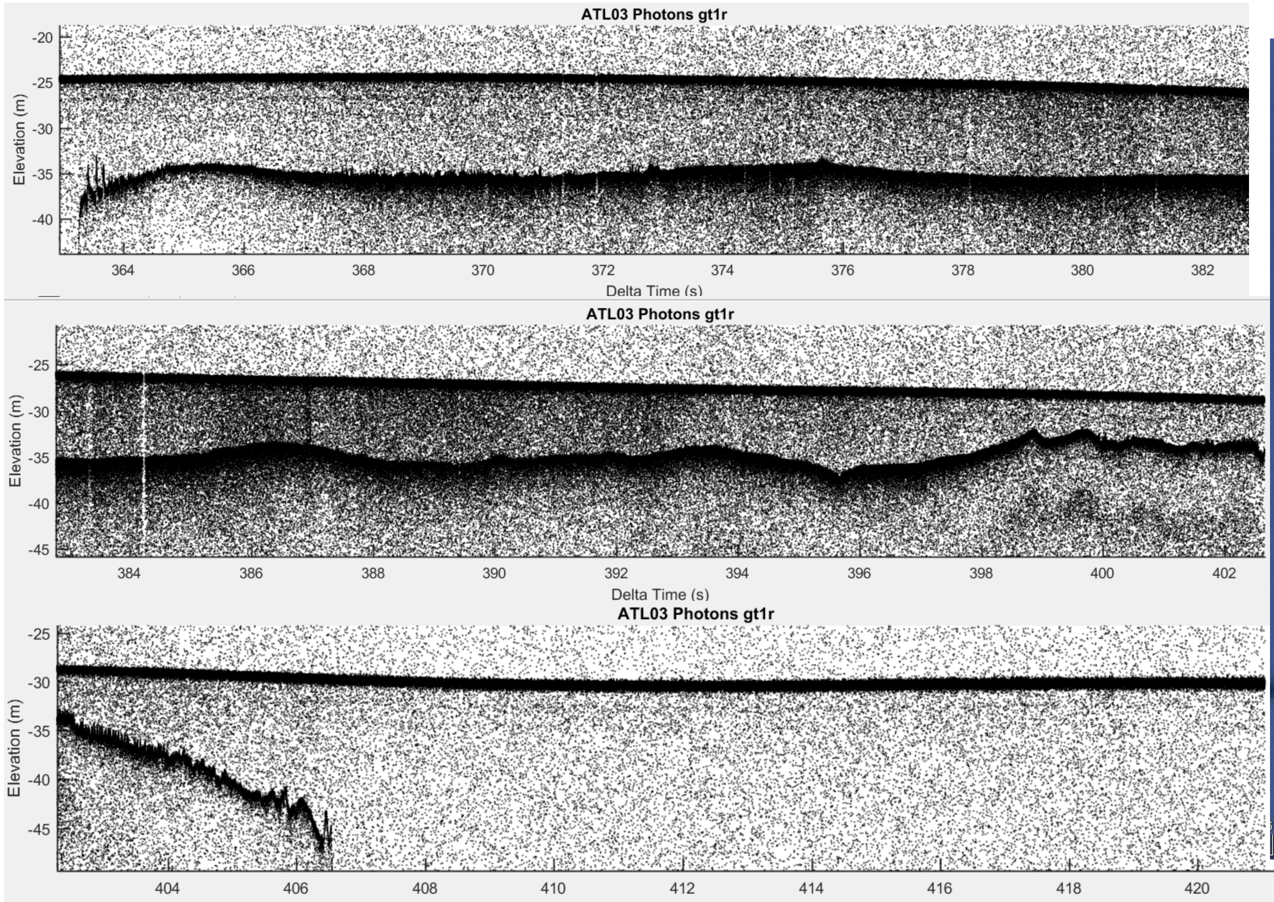
More examples

Great Bahama Bank

316 km of continuous bathymetry!



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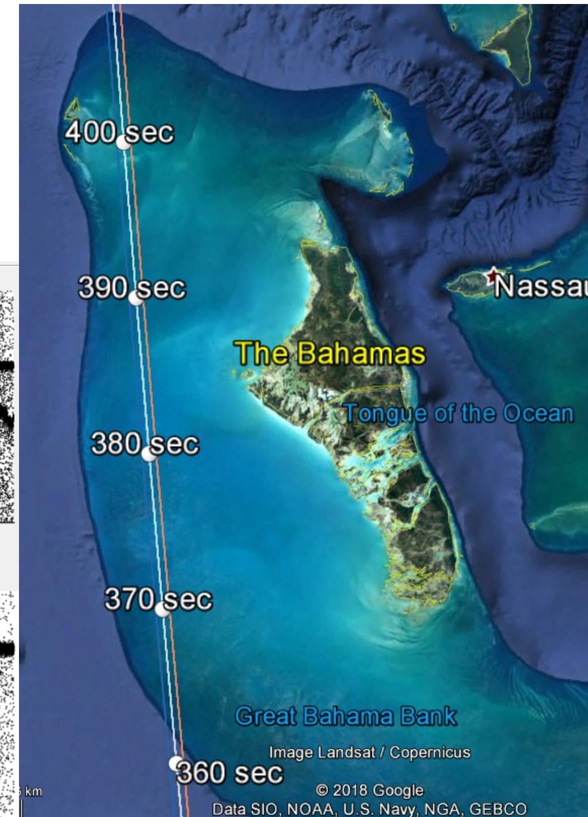

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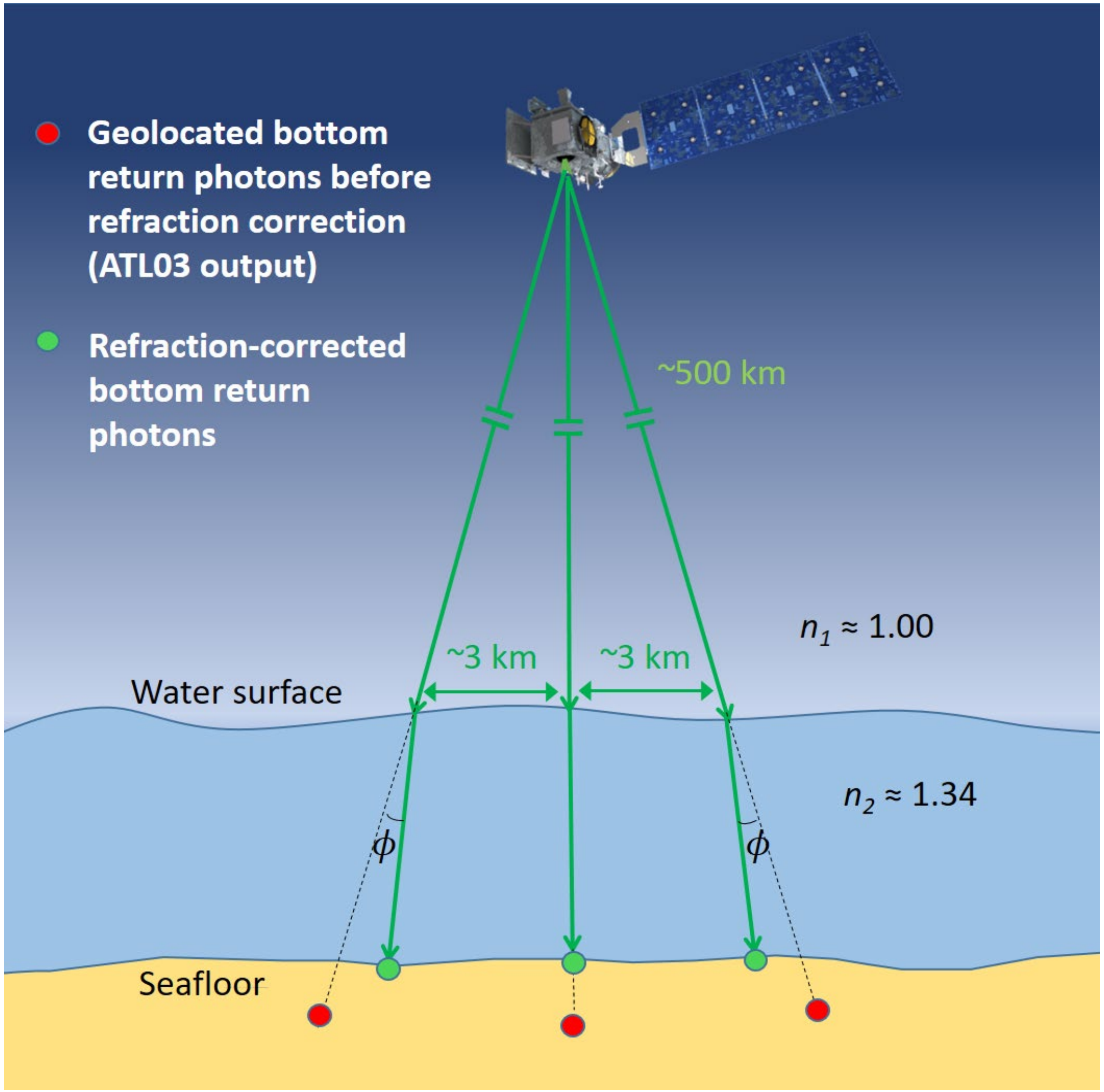
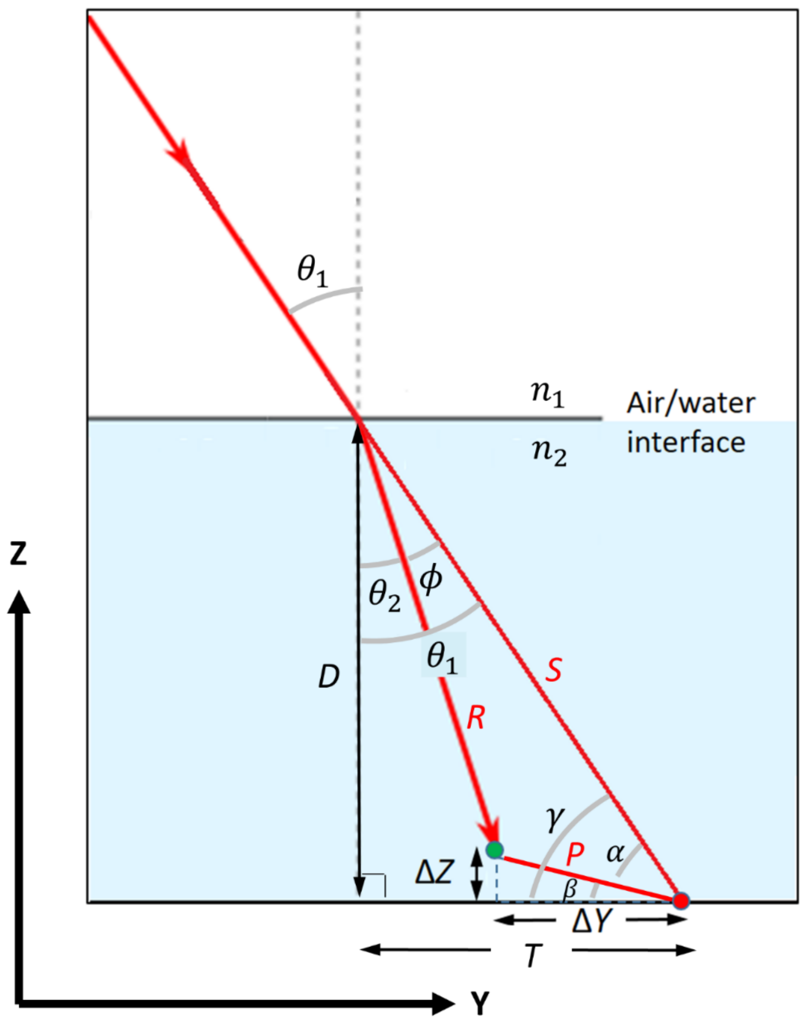
But…small problem: what we've been calling bathymetry is not really bathymetry, because geolocated seafloor photon returns are in wrong spot



Refraction correction algorithm:



Input:

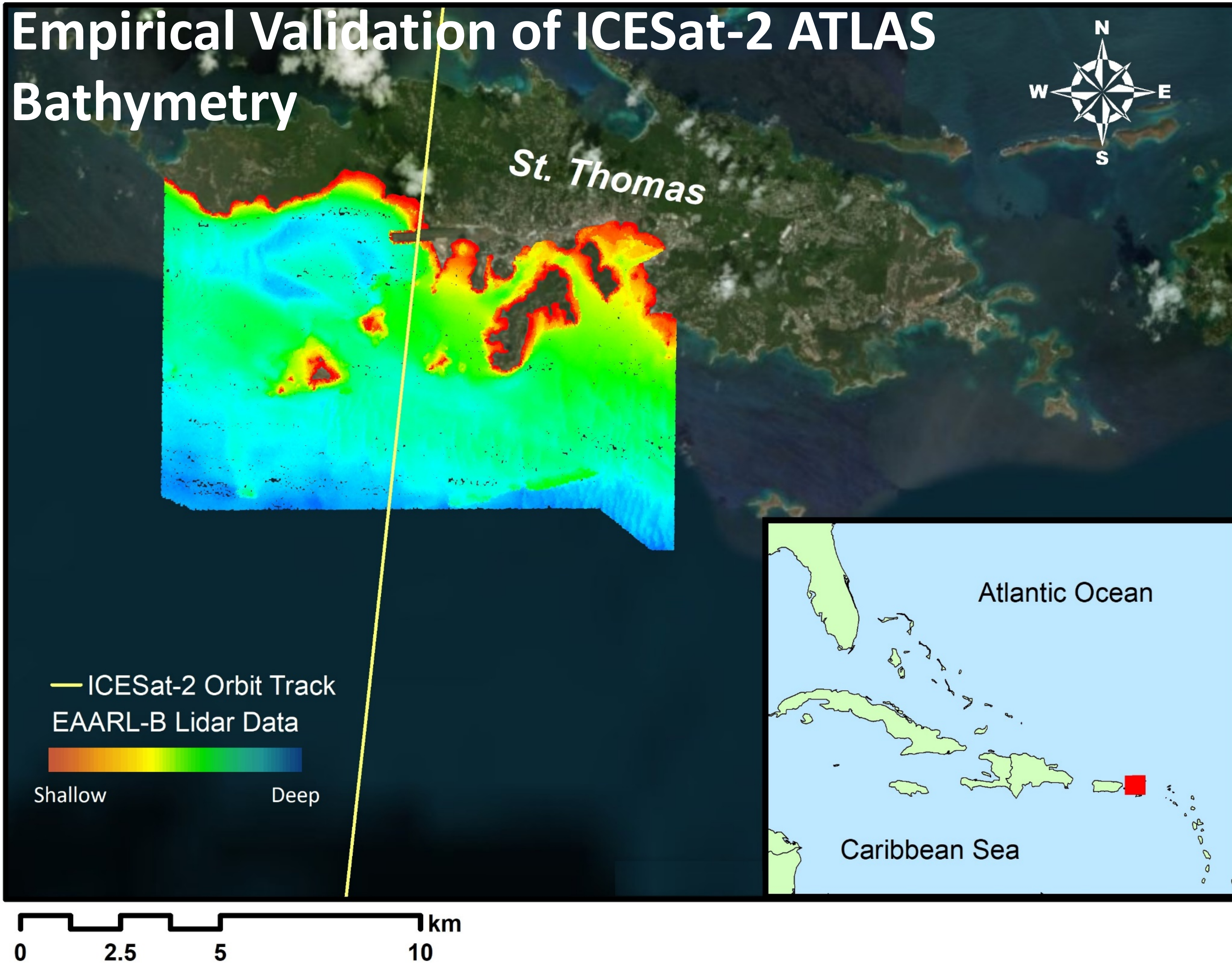
- Geolocated seafloor photon returns
- Water surface model
- Refractive indices of air and water
- Angle of incidence of photon
- Azimuth of unit pointing vector

For each seafloor photon return {

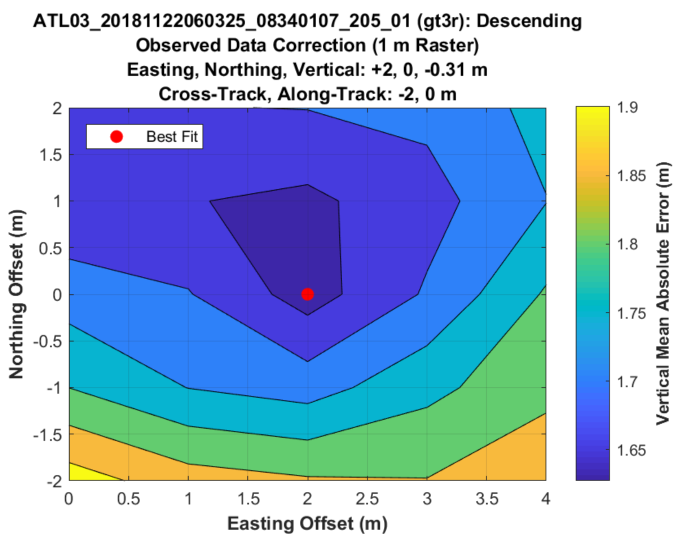
- Compute horizontal and vertical offsets ΔY, ΔZ (as shown in figure) from simple geometry
- Project the horizontal offset, ΔY, onto the (E, N) axes using azimuth of unit pointing vector
- Apply ΔE, ΔN, ΔZ to unrefracted photon coordinates

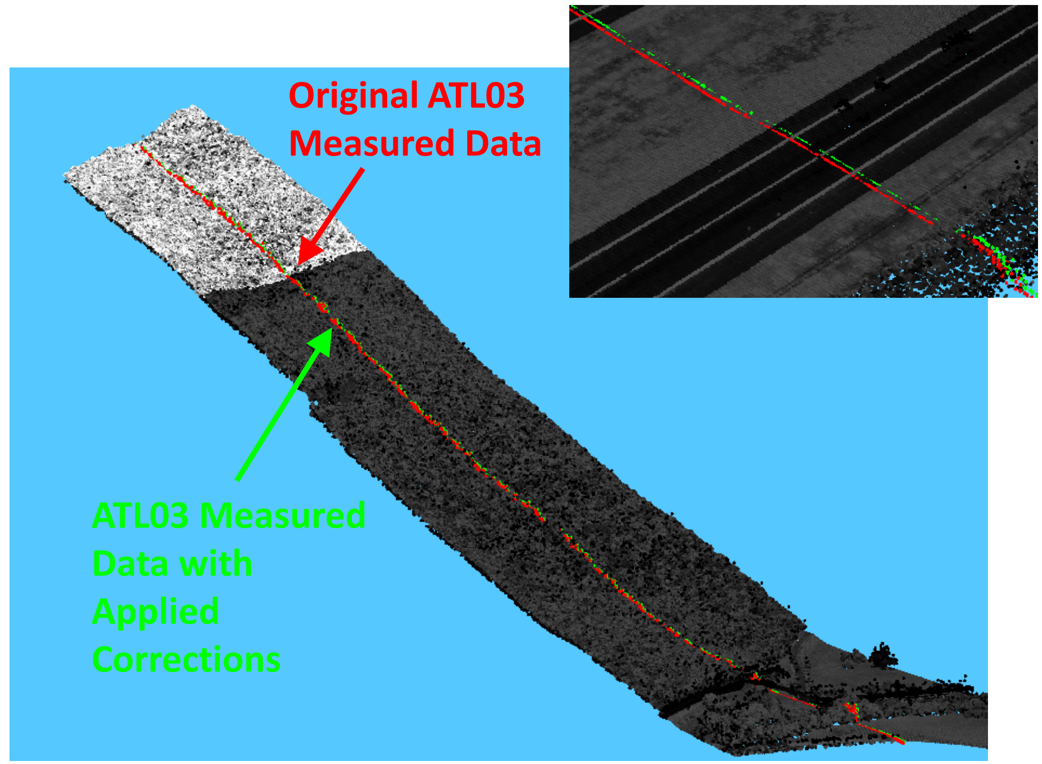
}

Optional: Earth curvature correction (corrects for Earth curvature across ATLAS's swath)

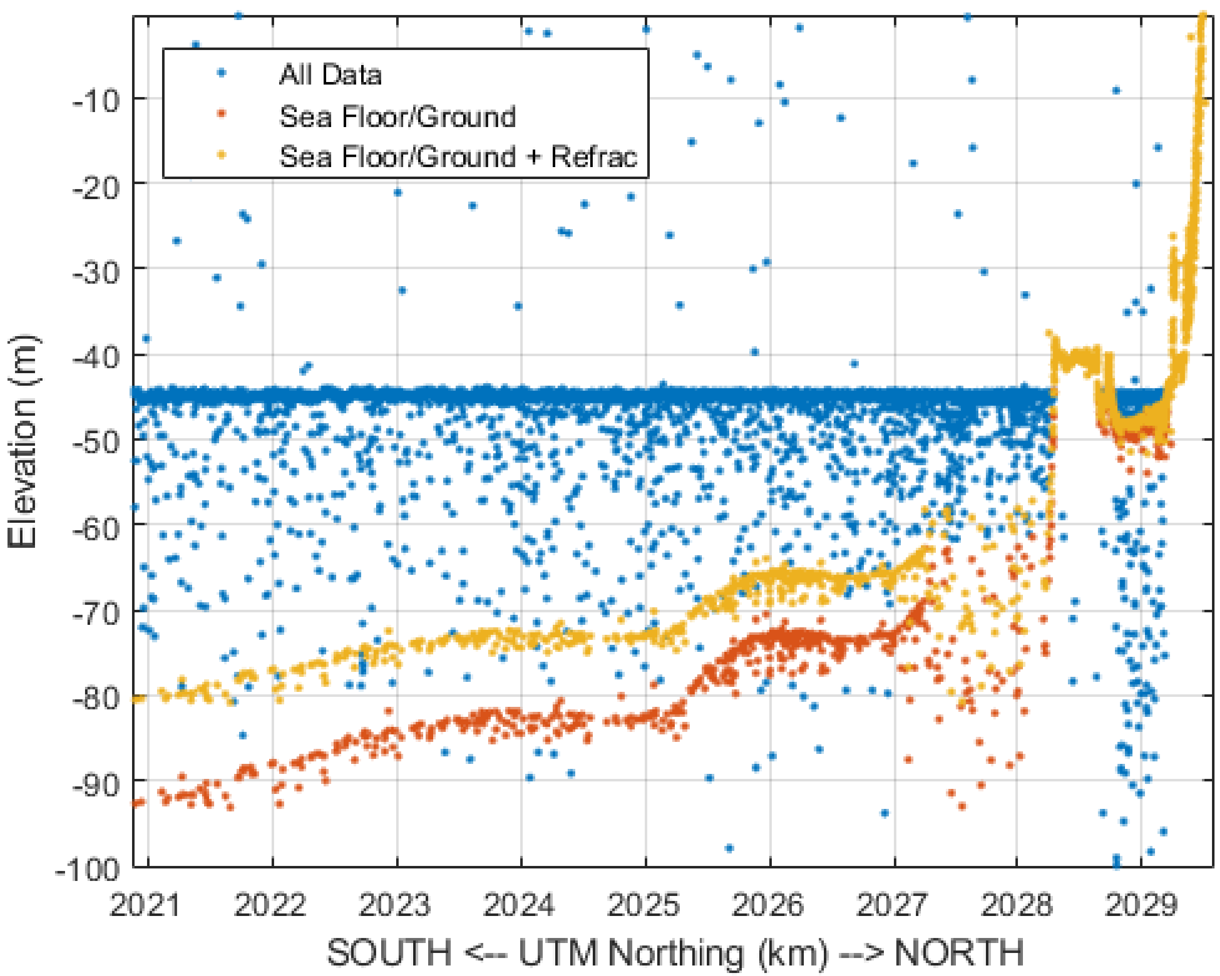

Empirical Validation of ICESat-2 ATLAS Bathymetry
N
W
E
S
St. Thomas
ICESat-2 Orbit Track
EAARL-B Lidar Data
Shallow
Deep
Atlantic Ocean
Caribbean Sea
0
2.5
5
10
km

Find Measurement XYZ Biases with Topographic Lidar (R205)

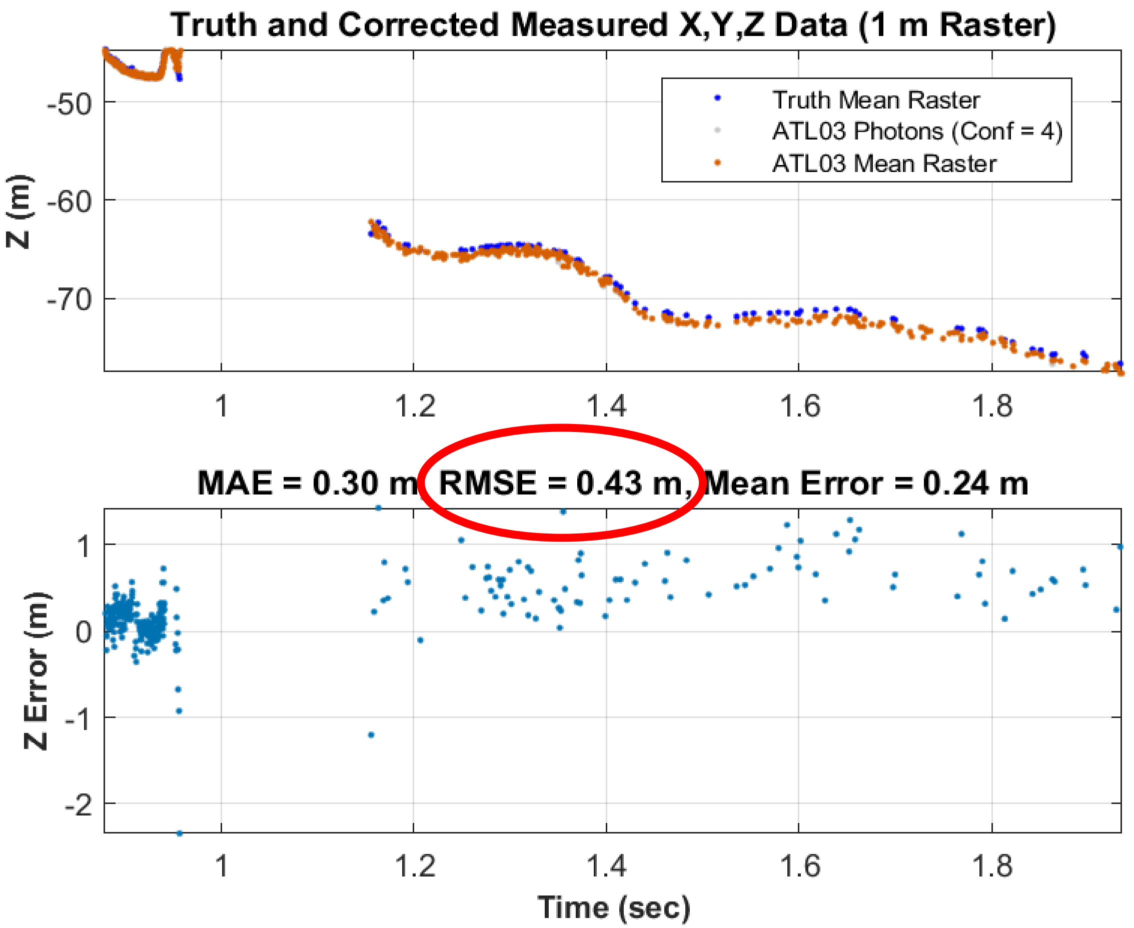




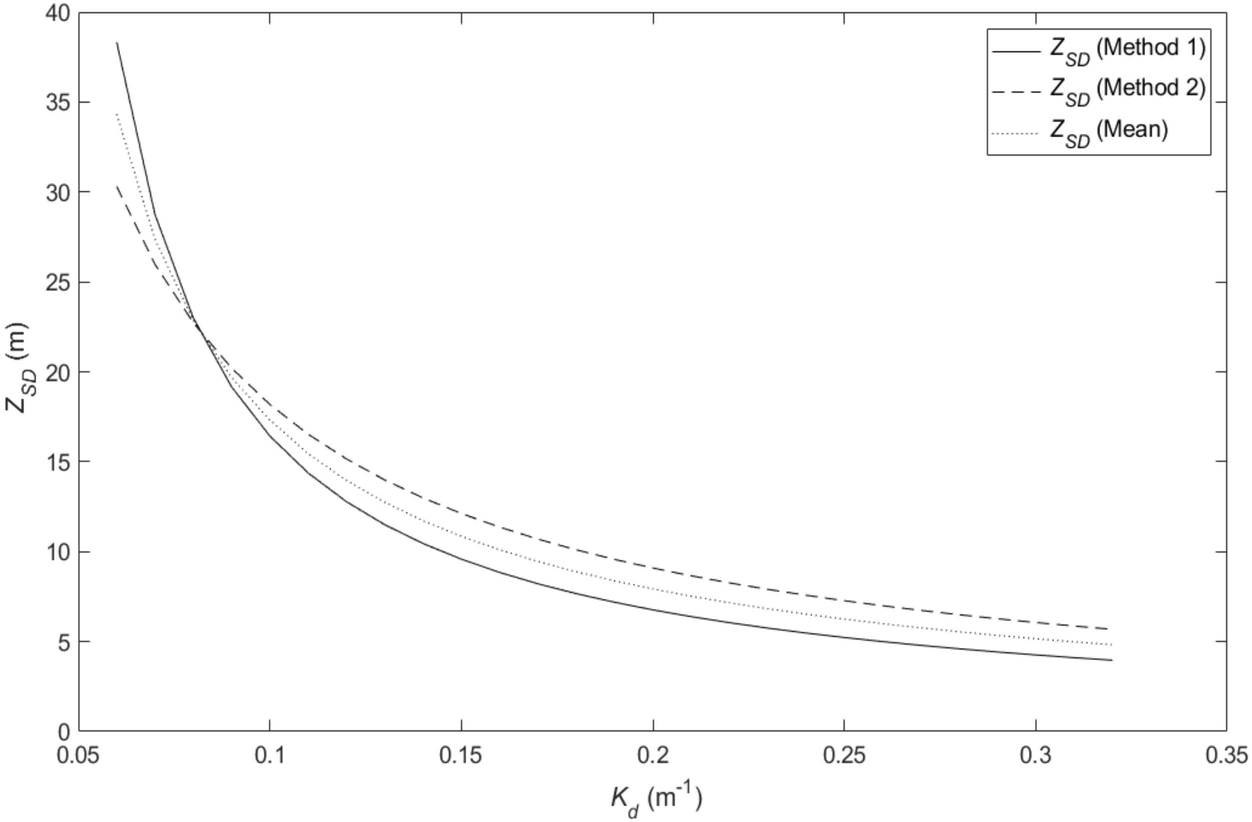
Perform Refraction Correction

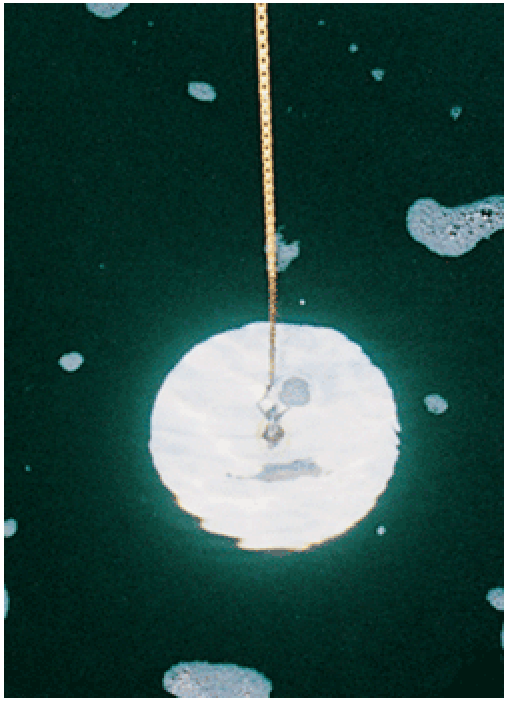


Comparison against EAARL-B reference data



Visible Infrared Imaging Radiometer Suite (VIIRS) Kd(490) ↔ Secchi depth (Empirical estimates)





Estimating Secchi Depth from K_d

No exact conversion exists or is possible, but many have been discussed (sometimes debated) at JALBTCX Workshops

$$Z_{SD} = \frac{1.15}{K_d - 0.03}$$

Guenther, 1985

$$Z_{SD} = \frac{4.80 - \ln R}{K_d + c}$$

Feygels et al., 2014

$$Z_{SD} = \frac{1.7}{K_d}$$

Guenther, 1985, citing Poole-Atkins

Quick aside regarding Secchi depth measurements

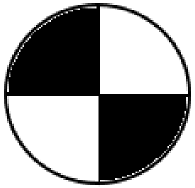
Proc. SPIE 9262, Lidar Remote Sensing for Environmental Monitoring XIV, 92620X
(26 November 2014); doi: 10.1117/12.2069871

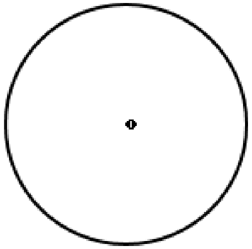
Particularities of hydro lidar missions in the Asia-Pacific region

Viktor I. Feygels [*a], Yuri Kopilevich [b], Joong Yong Park [a], Minsu Kim [a], Jennifer Aitken [a],
[a] Optech, Inc.
7225 Stennis Airport Drive, Kiln, Mississippi, 39556, USA

"…in several studies no difference was found between large and small disks visibility range. Generally speaking, the Secchi depth for disk is expected to exceed that for white one, but in very clear waters, according to experiments, both the pure white and black-and-white disks disappear not due to a loss of contrast but because the decrease in the disk's angular size makes it too small to be seen" (Feygels et al., 2014).

Meaning: it doesn't matter which type of disk you use?! *





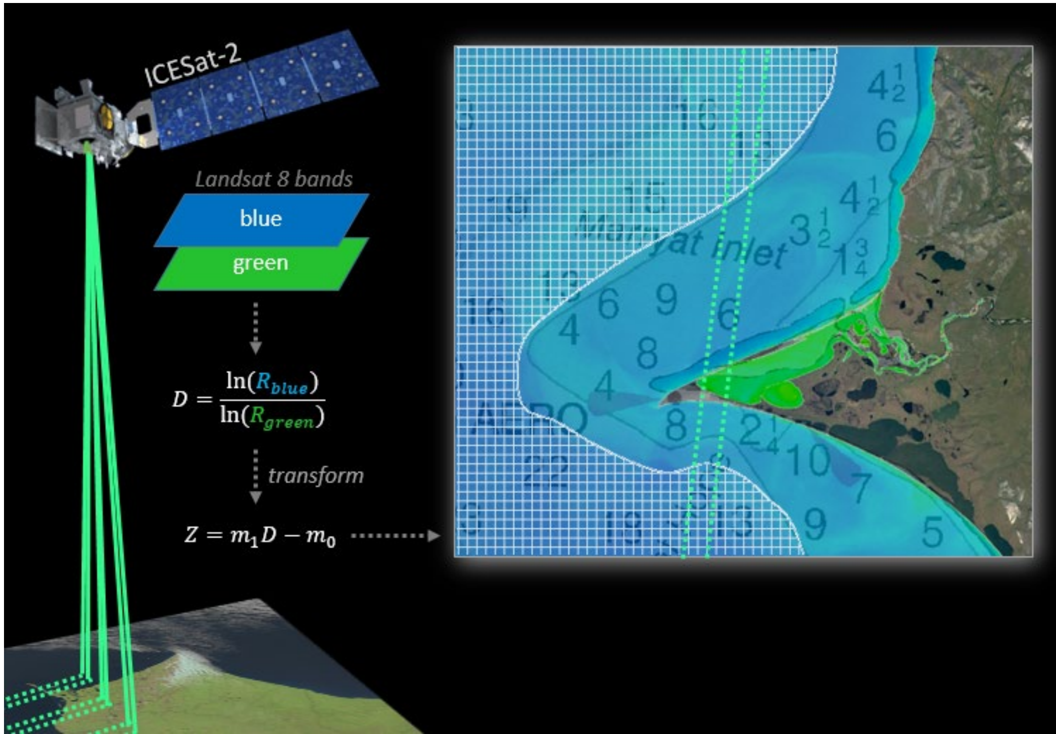
* In clear water

ICESat-2 ATLAS maximum depth mapping capability analysis

Site	Maximum depth, D_{max} [m]	VIIRS Kd(490) [m^{-1}]	Secchi depth, Z_{SD} [m]	Max Depth Penetration in Secchi Depths	Maximum optical depth, $K_d D_{max}$
Turks and Caicos	24	0.075	25.1	0.95	1.79
North West Australia (western Pilbara region)	19	0.099	17.6	1.08	1.87
Great Bahama Bank	13	0.123	13.6	0.96	1.60
St. Thomas	38	0.053	32.1	0.84	2.01
Mean	**24**	**0.087**	**22.1**	**0.96**	**1.82**

Next Steps

- Continue to test in additional areas
- TPU for ICESat-2 ATLAS bathymetry
- Active-passive fusion-based bathymetric mapping approach using ICESat-2 ATLAS and Landsat 8 OLI and/or Sentinel 2 MSI
- WebGIS containing nearshore bathymetry
  - To be developed in Summer 2019 with funding from AmericaView (USGS)
  - Will be made public



Conclusions

- ICESat-2 ATLAS can reliably map bathymetry
  - Agreement with EAARL-B data to within 0.5 m RMS
  - Depth penetration to ~1 Secchi depth
- Great potential for filling nearshore data void, especially when combined with SDB
- Recommendations
  - Future dedicated bathymetric mapping satellite mission
  - Proposed name change:

JASLBTCX

spaceborne

Reference

remote sensing

MDPI

Article

Validation of ICESat-2 ATLAS Bathymetry and Analysis of ATLAS's Bathymetric Mapping Performance

Christopher E. Parrish [1,*], Lori A. Magruder [2], Amy L. Neuenschwander [2], Nicholas Forfinski-Sarkozi [1], Michael Alonzo [2] and Michael Jasinski [3]

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Abstract: NASA's Ice, Cloud and Land Elevation Satellite-2 (ICESat-2) was launched in September, 2018. The satellite carries a single instrument, ATLAS (Advanced Topographic Laser Altimeter System), a green wavelength, photon-counting lidar, enabling global measurement and monitoring

Parrish, C.E., L.A. Magruder, A.L. Neuenschwander, N. Forfinski-Sarkozi, M. Alonzo, and M. Jasinski, 2019. Validation of ICESat-2 ATLAS Bathymetry and Analysis of ATLAS's Bathymetric Mapping Performance. *Remote Sensing* (in reveiew)

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THE END

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