
# Mapping and Monitoring Lakes and Reservoirs with Satellite Observations

Michael Jasinski and Sabrina Delgado Arias

February 23, 2021

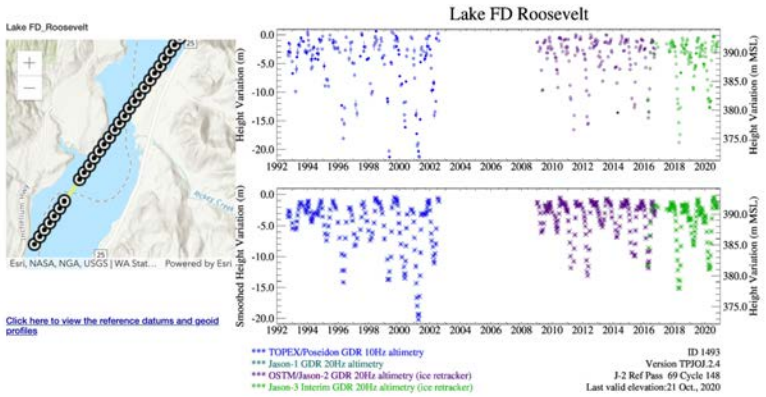
# Training Outline

February 9, 2021

Remote Sensing Observations for Monitoring Water Extent, Water Level Height, and Bathymetry in Lakes and Reservoirs

https://global-surface-water.appspot.com/#data

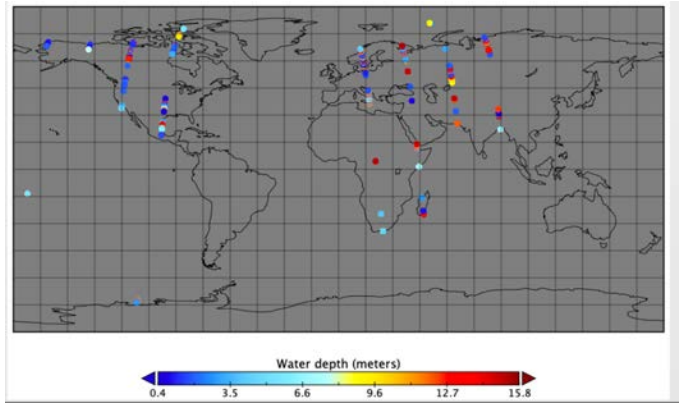
February 16, 2021




Water Level Height Data for Lakes and Reservoirs Using Radar Altimetry

https://ipad.fas.usda.gov/cropexplorer/global_reservoir/gr_regional_chart.aspx?regionid=us&reservoir_name=FD_Roosevelt

**February 23, 2021**




**Surface Water Heights and Bathymetry for Lakes, Reservoirs, Rivers and Coasts Using ICESat-2 Laser Altimetry**

https://nsidc.org/data/atl13

# Homework and Certificate

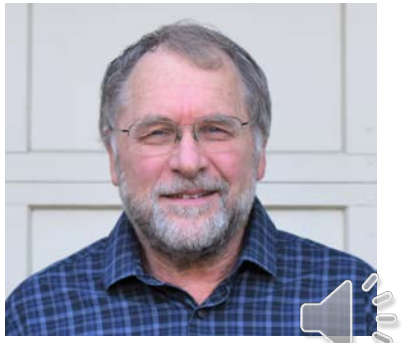
- One homework assignment:
  - Answers must be submitted via Google Form
  - Due date: March 23, 2021
- A certificate of completion will be awarded to those who:
  - Attend all live webinars
  - Complete the homework assignment by the deadline (access from website)
  - You will receive a certificate approximately two months after the completion of the course from: marines.martins@ssaihq.com

National Aeronautics and Space Administration

# Analysis of Surface Water Heights and Bathymetry for Lakes, Reservoirs, Rivers and Coasts Using ICESat-2

**Michael Jasinski**
**NASA Goddard Space Flight Center**

February 23, 2021



# Outline

- ICESat-2 mission overview and science data products
- Inland Water (ATL13) data products
- ICESat-2 Analysis Tools
- Example Case: Eagle Lake, CA, October 19, 2018
- Applications to 2-D bathymetry
- Summary

# Mission Overview

**Status**

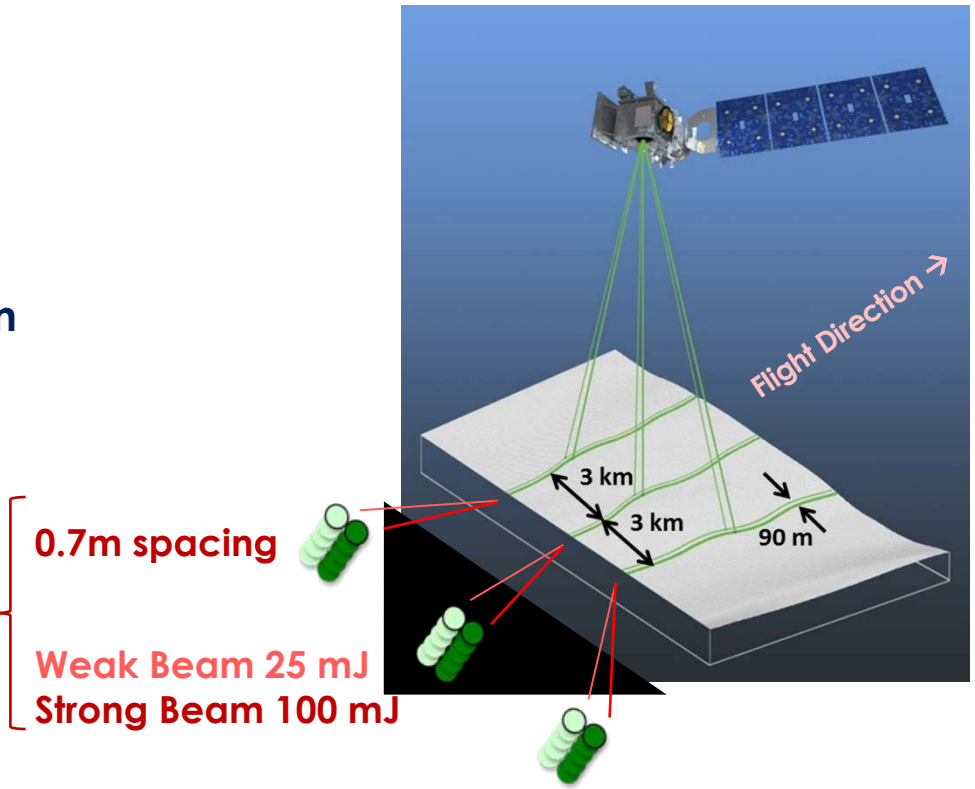
- Launched Sept 15, 2018
- Data products since Oct 15, 2018

**Instrument:**

- Advanced Topographic Laser Altimeter System (ATLAS)
- Micro-pulse 532 nm lidar, 10 kHz pulse rate, single-photon detection
- 6 beams: 3 pairs of "Strong"&"Weak" energy (100/25 mJ)
- Footprint: 11m
- Ground speed: 7000m/s

**Polar Orbit:**

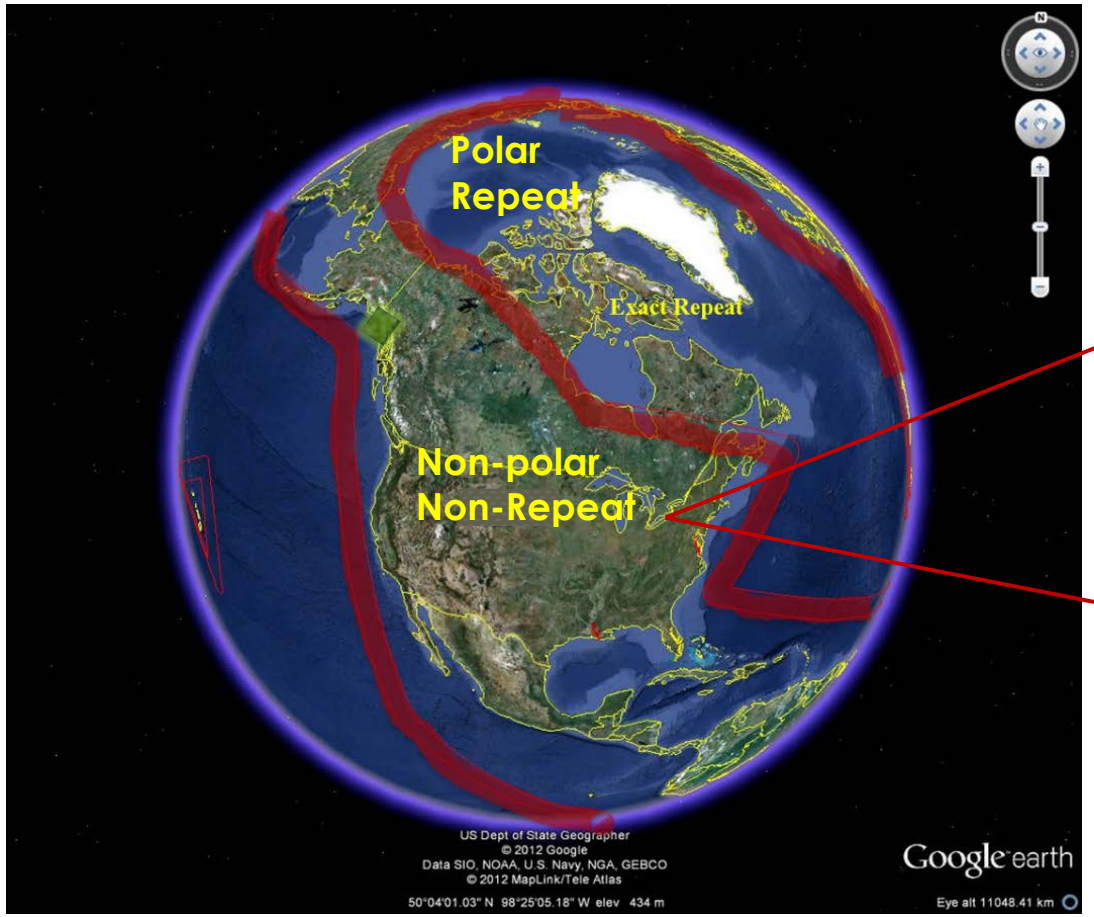
- 496 km, non-sun-sync, 92° inclination
- 91 day repeat cycle, ~30-day sub cycle
- Geolocation knowledge: 6.5 m



# ICESat-2 Data Products

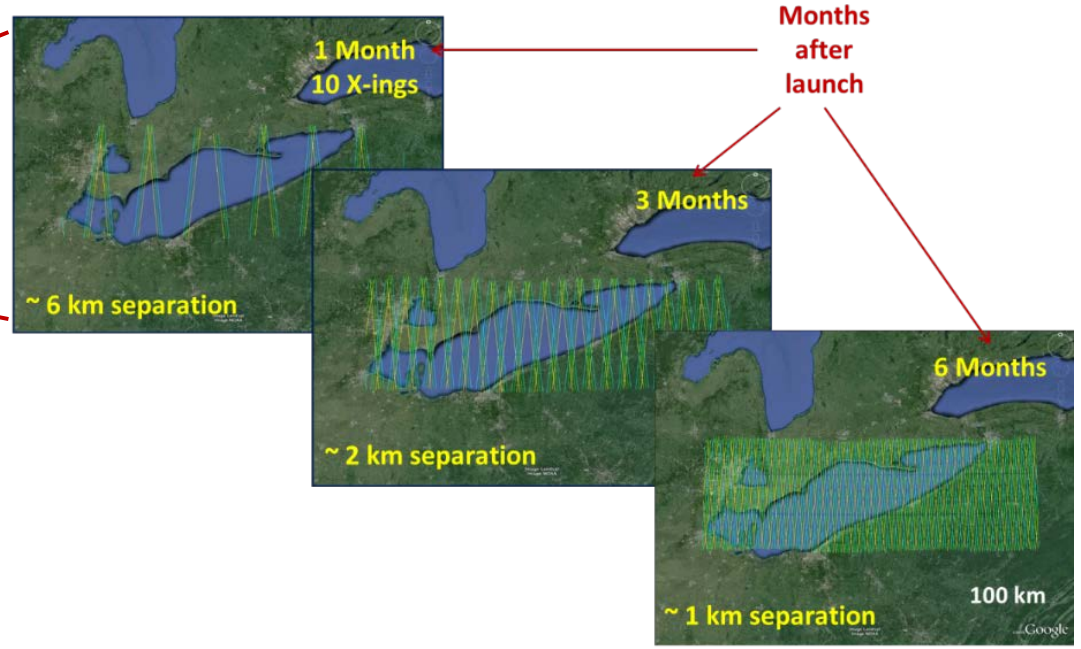
| | ID | NAME | DESCRIPTION |
|---|---|---|---|
| Along Track | ATL03 | Geolocated photons | Precise latitude, longitude and elevation for every received photon |
| | ATL04 | Uncalibrated Backscatter Profiles | Along-track atmospheric backscatter |
| | ATL06 | Land Ice Elevation | Surface height for each beam with along- and across-track slopes |
| | ATL07 | Arctic/Antarctic Sea Ice Elevation | Height of sea ice and open water leads at varying length scale |
| | ATL08 | Land and Vegetation Height | Height of ground including canopy surface & cover percentage |
| | ATL09 | Atmosphere Backscatter & Clouds | Along-track cloud and other atmosphere layer heights, blowing snow, optical depth. |
| | ATL10 | Arctic/Antarctic Sea Ice Freeboard | Sea ice freeboard @ specific spatial scales. Statistics of sea surface and sea ice heights. |
| | ATL11 | Antarctica / Greenland Ice Sheet Heights | Time series of height at points on the ice sheet, |
| | ATL12 | Ocean Elevation | Surface height at specific length scale, including height distribution |
| → | ATL13 | Inland Water Products | Along-track surface water height distribution and associated water properties |
| Gridded | ATL14 | Antarctica/Greenland Ice Sheet H(t) Gridded | Height maps of each ice sheet for each year based on all available elevation data. |
| | ATL15 | Antarctica/Greenland Ice Sheet dh/dt Gridded | Height change maps for each ice sheet, for each mission year |
| | ATL16 | ATLAS Atmosphere Weekly | Polar cloud fraction, blowing snow frequency, ground detection frequency. |
| | ATL17 | ATLAS Atmosphere Monthly | Polar cloud fraction, blowing snow frequency, ground detection frequency. |
| | ATL18 | Land/Canopy Gridded | Gridded ground surface height, canopy height, and canopy cover estimates. |
| | ATL19 | Mean Sea Surface (MSS) | Gridded ocean height product. |
| | ATL20 | Arctic / Antarctic Gridded Sea Ice Freeboard | Gridded sea ice freeboard. |
| | ATL21 | Arctic/Antarctic Gridded SSH w/in Sea Ice | Gridded monthly sea surface height inside the sea ice cover. |
| → | ATL22 | Mean Inland Water Body Products | Means for each water body ID type and transect. |

# ICESat-2 Observation Strategy for Polar vs Non-Polar Regions




## Observations in non-polar regions

E.g., Lake Erie, USA ~42 deg N

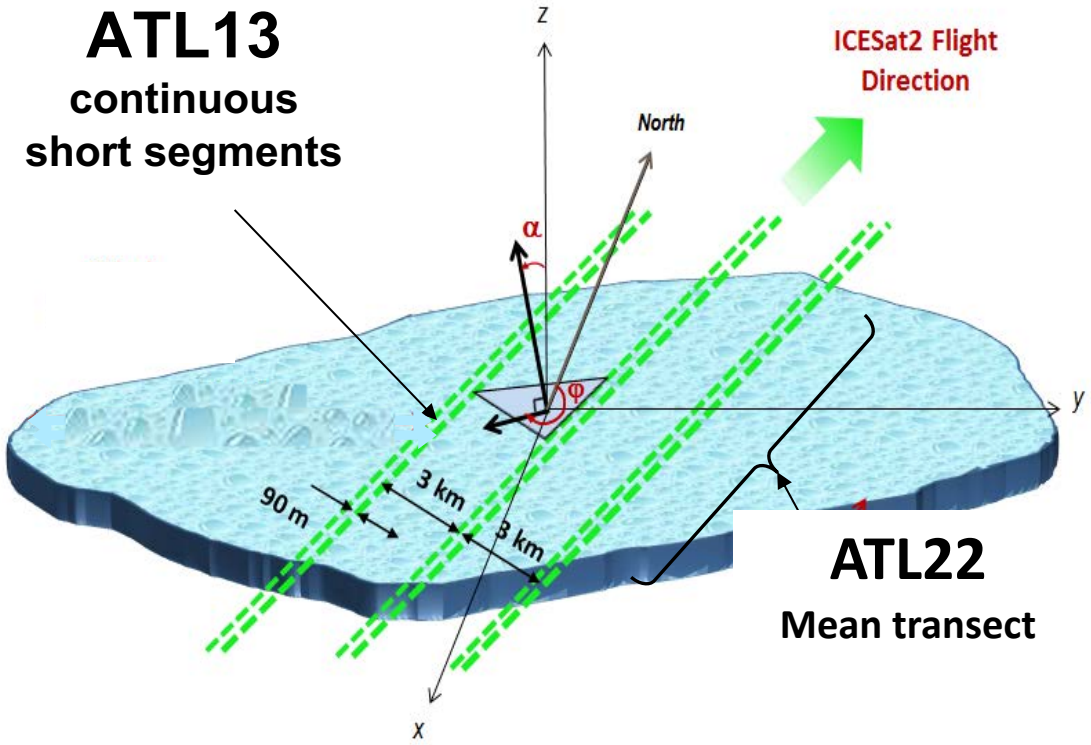


# ATL13 & ATL22
# Operational Inland Water Products

## Main Geophysical Products

| Name | Units |
|---|---|
| ht_water_surf | m |
| ht_ortho | m |
| subsurface_attenuation | $m^{-1}$ |
| segment_slope_trk_bdy | - |
| stdev_water_surf | m |
| sig_wv_ht | m |
| water_depth | m |
| u_derived | m/s |

**ATL13**
**continuous short segments**



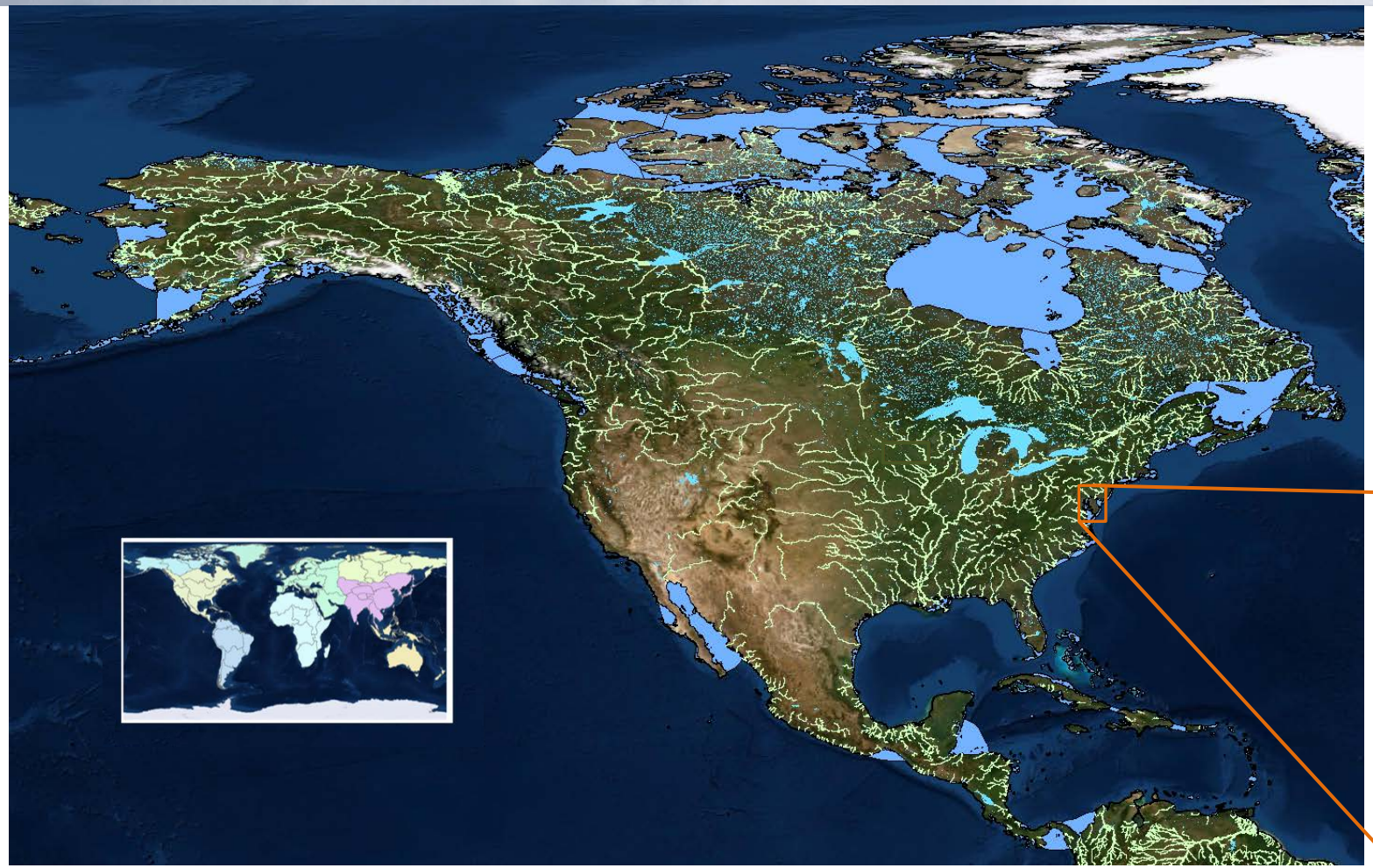

**ATL22**
**Mean transect**

## Quality Flags

| Name | Units |
|---|---|
| QF_lwP | - |
| QF_Cloud | - |
| QF_Bckgrd | - |
| Ice_Flag | - |
| QF_Ice | - |
| QF_Subsurf_Anom | - |
| QF_Bias_Fit | - |
| QF_Bias_EM | - |
| QF_Spec_Width | - |
| QF_Sseg_Length | - |
| QF_Lseg_Length | - |
| met_wind10_ATL09 | m/s |
| met_wind10_ATL13 | m/s |
| met_ts_ATL09 | K |
| snow_ice_ATL09 | - |
| Cloud_Flag_ASR_ATL09 | - |
| Cloud_Flag_Atm_ATL09 | - |
| Layer_Flag_ATL09 | - |

Access Page: https://nsidc.org/data/ATL13

# ATL13 Domain
# Global Inland Water Coverage



## Water Body Types

- Lakes and Reservoirs ≥ 0.1 $km^2$
- Rivers > ~ 100 m
- Transitional water including estuaries, bays & near coast


## Identification

**ATL13 inland water mask defined by ~ 1.4 M shapes defined, each w/unique ID (derived from HydroLAKES, GRWL, GSHHG Shoreline, etc )**

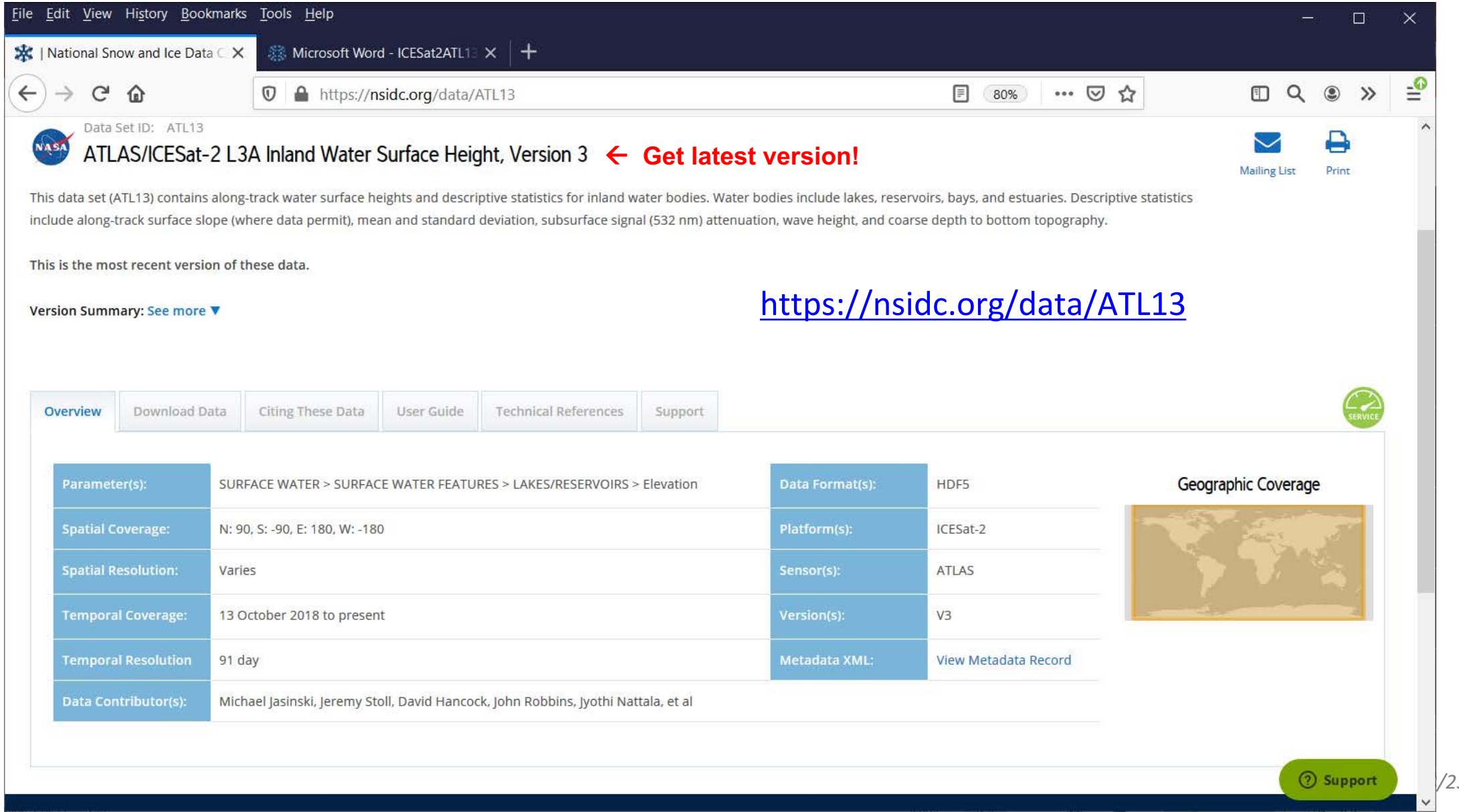
# Evolution of the ATL13 Operational Product

| Version | Release Date | Water Body Types (Number of unique IDs) | Description and Principal/Added Features |
|---|---|---|---|
| 1 | May 2019 | Lakes & reservoirs > 10 $km^2$ (19,634) | - Surface water height statistics (mean, StdDev, slope), subsurface attenuation, and supporting variables at short segment length<br>- Employs GLWD (Lehner & Doll 2004) |
| 2 | November 2019 | Lakes & reservoirs ≥ 10 $km^2$ (19,800)<br>Estuaries, bays, and near shore 7 km buffer (~3500) | - Employs HydroLAKES (Messager & Lehner, 2016)<br>- Adds transitional waters;<br>Named Marine Water Bodies (ESRI)<br>GSHHG Shoreline (Wessel et al, 1996)<br>- Adds significant wave height<br>- coarse bathymetry algorithm<br>- Adds dynamic shore finding |
| 3 | March 2020 | Lakes & reservoirs ≥ 0.1 $km^2$ (~1,400,000)<br>Estuaries, bays, near shore buffer (7m) (~3500)<br>Rivers ≥ ~50-100 m wide (10,300) | - Adds river mask using GRWL (Allen and Pavelsky, 2018)<br>- Adds wind speed for all crossings<br>- Adds Ice on/off flag from multi-sensor NOAA product<br>- Corrects first photon bias error<br>- Adds cloud confidence flag |
| 4 | Dec 2021 | All water bodies | - Improves photon classification<br>- Refines parameter estimates<br>- Added DEMs |
| ATL22 Ver 1 | Dec 2021 | All water bodies | - Transect mean quantities and supporting parameters |

Current version -
Data Oct 2018 thru March 2021

New in 2021!

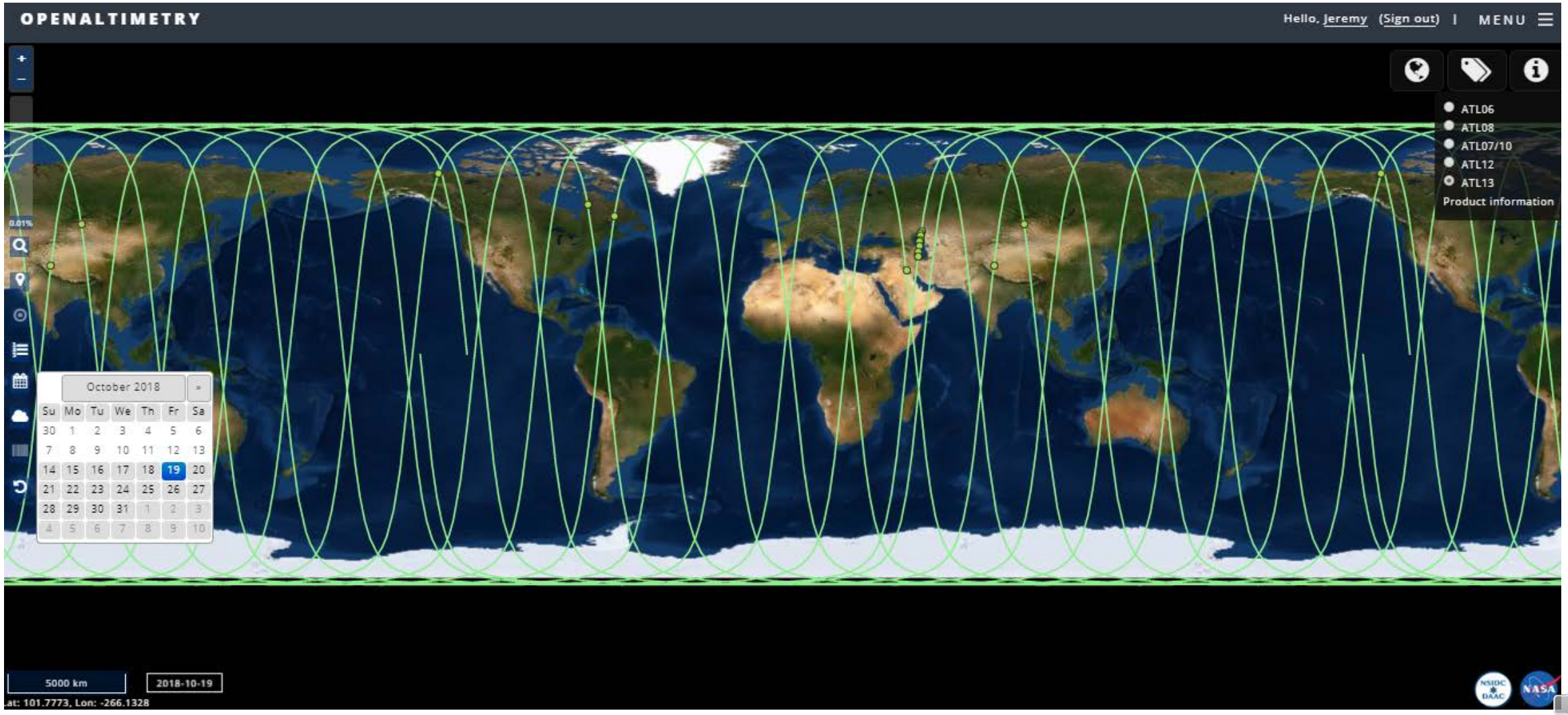
# ATL13 Inland Water Data Access



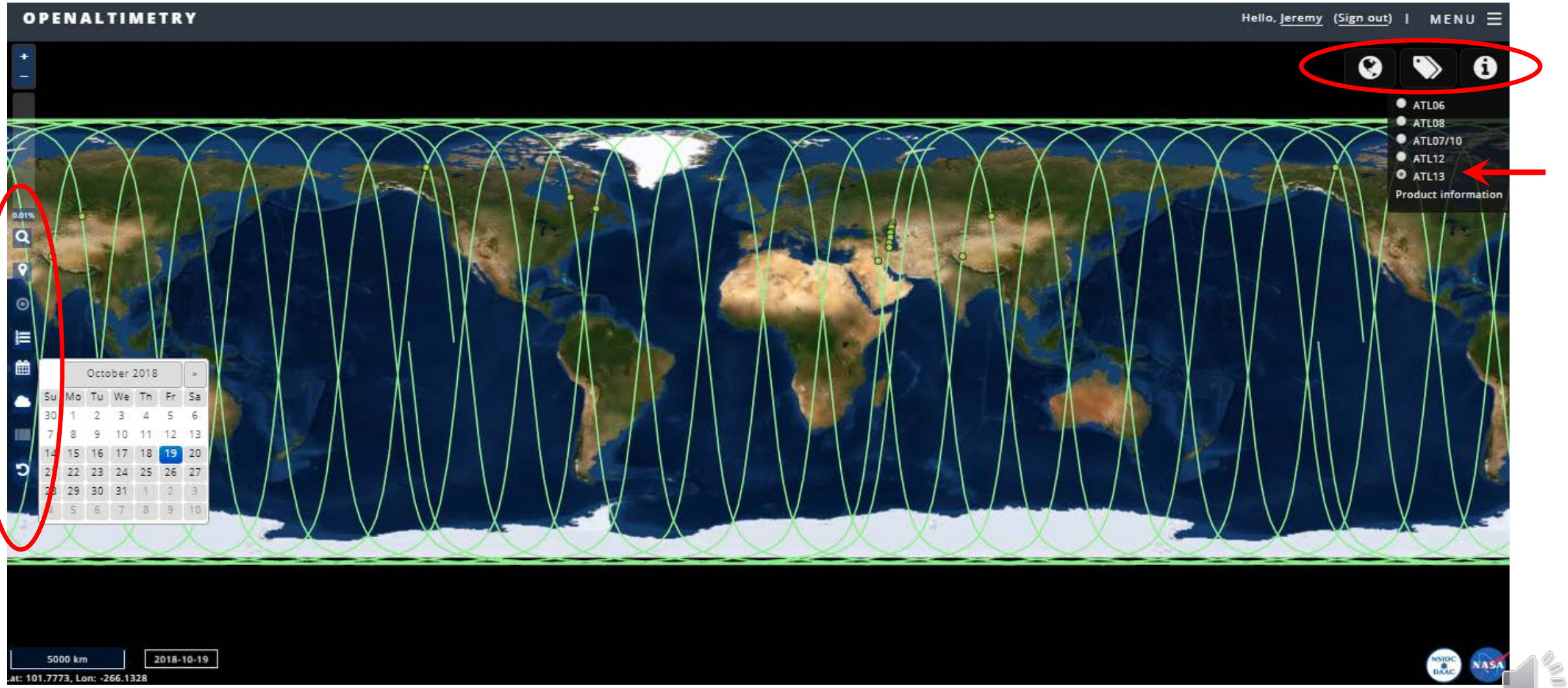
# ICESat-2 Analysis Tools

| Name | Description | Access Type | Service Outputs | Source |
|---|---|---|---|---|
| OpenAltimetry | Discover, access, and visualize ICESat and ICESat-2 data. Key functions include on-the-fly plotting of segment elevations and photon clouds based on date and region of interest, ground track filtering and visualization, and data access in CSV or subsetted HDF5 format. | Web application | •Downloadable elevation and photon plots<br>•Spatially subsetted HDF5 data<br>•CSV output of key parameters | A NASA funded collaborative project between the Scripps Institution of Oceanography, San Diego Supercomputer Center, NSIDC DAAC, and UNAVCO. |
| NASA Earthdata Search | Search, visualize, and access data across thousands of Earth science data sets, including ICESat, IceBridge, and ICESat-2. Customization services are available for most ICESat-2 data sets, including subsetting and reformatting. | Web application | •Data access via shell script and zip links<br>•Visit this page for details on subsetting and reformatting services available for each ICESat-2 data set. | NASA EOSDIS, supported by NSIDC DAAC. |
| Data Subscription | Subscribe to have new ICESat-2 data automatically delivered to you as they become available at NSIDC. Customization services including subsetting and reformatting can be applied to your subscription request. | Online subscription request form | •Automated emailed data delivery<br>•Visit this page for details on subsetting and reformatting services available for each ICESat-2 data set. | NSIDC DAAC |
| Data Access and Service API | The NSIDC DAAC's Application Programming Interface, or API, provides spatial and temporal filtering as well as customization options as a single access command, without the need to script against our data directory structure. | API | •Visit this page for details on subsetting and reformatting services available for each ICESat-2 data set. | NSIDC DAAC |
| NSIDC DAAC Data Access Jupyter Notebook | A Jupyter notebook exploring data coverage, size, and customization service availability along with direct data download utilizing the NSIDC DAAC's access and service API. | Downloadable tool | •Visit this page for details on subsetting and reformatting services available for each ICESat-2 data set. | NSIDC DAAC |
| Panoply | Plot arrays and geo-referenced data from NetCDF and HDF files. | Downloadable tool | •Downloadable plots as GIF, JPEG, PNG, TIFF bitmap images, PDF, or PostScript graphics files, as well as lon-lat map plots as KMZ files.<br>•Animations as MP4 video or as a collection of individual frame images. | NASA Goddard Institute for Space Studies |
| HDFView | Browse, visualize, and edit HDF (HDF5 and HDF4) files. Key functions include viewing HDF file hierarchy in a tree structure, opening data and metadata arrays, image creation, and HDF file modification. | Downloadable tool | •Save data values to a text or binary file<br>•Save HDF image to JPEG, GIF, PNG, or BMP file | The HDFGroup |

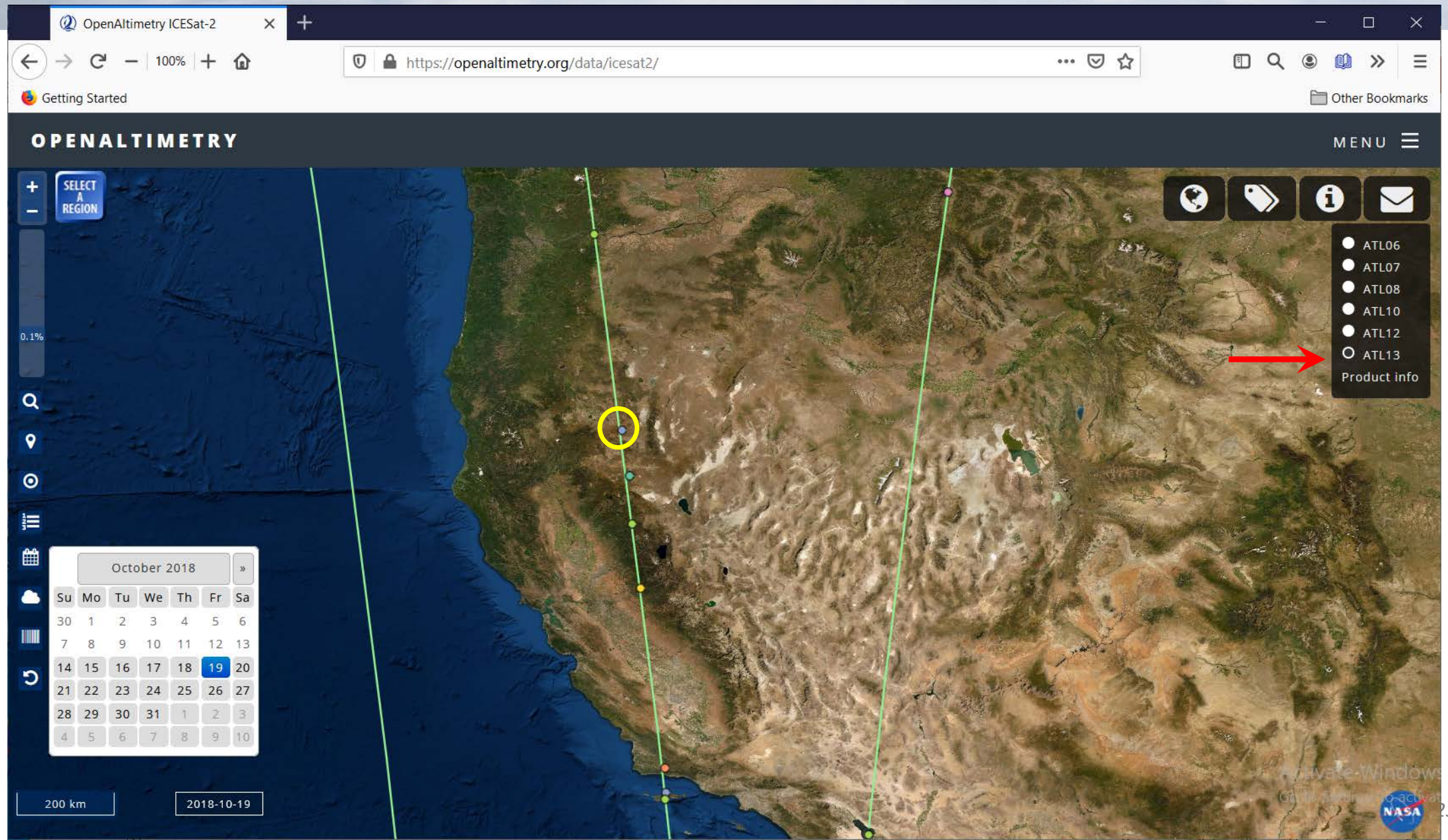
# Data Access:
# https://openaltimetry.org/



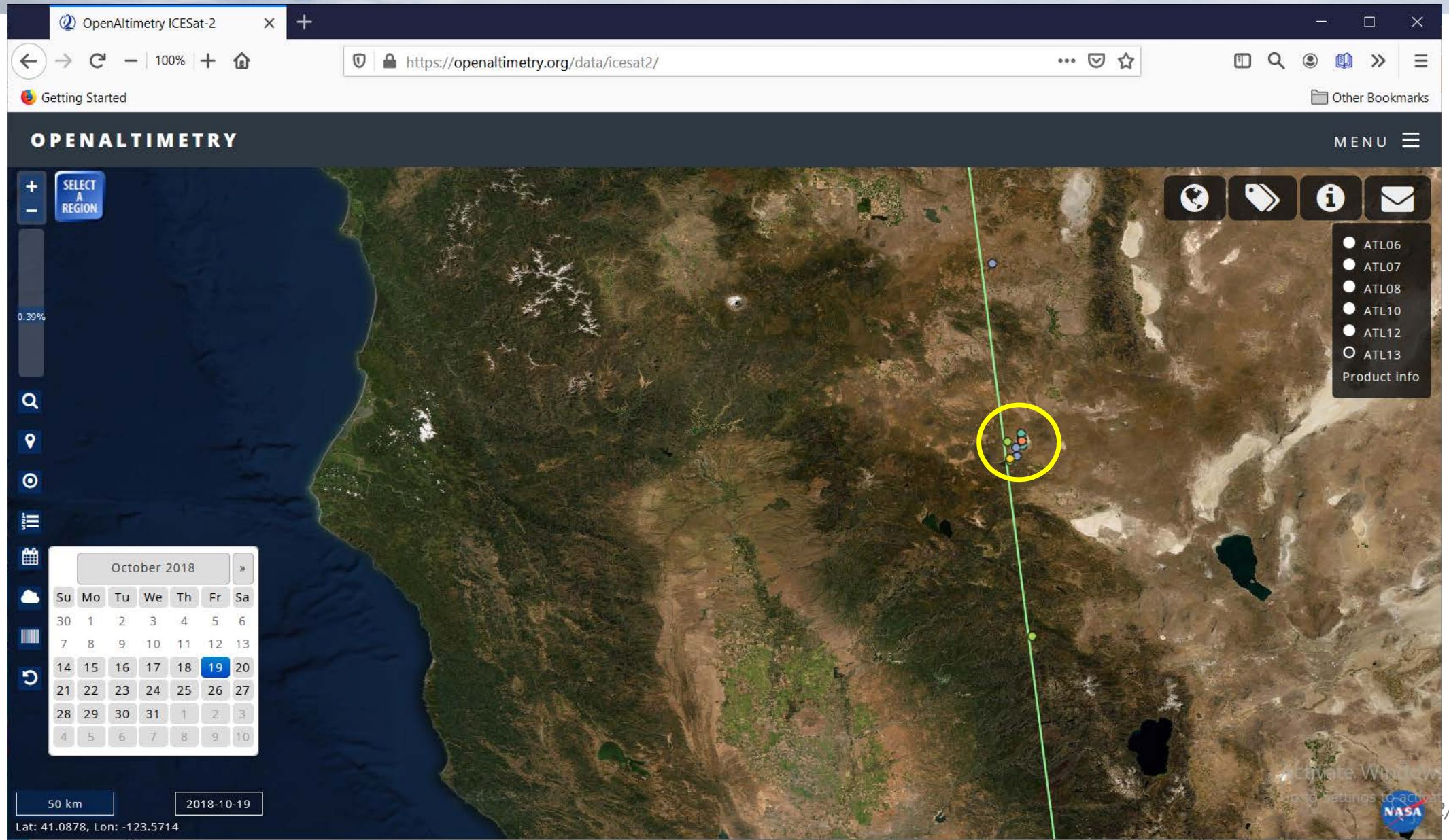
# Data Access:
# https://openaltimetry.org/



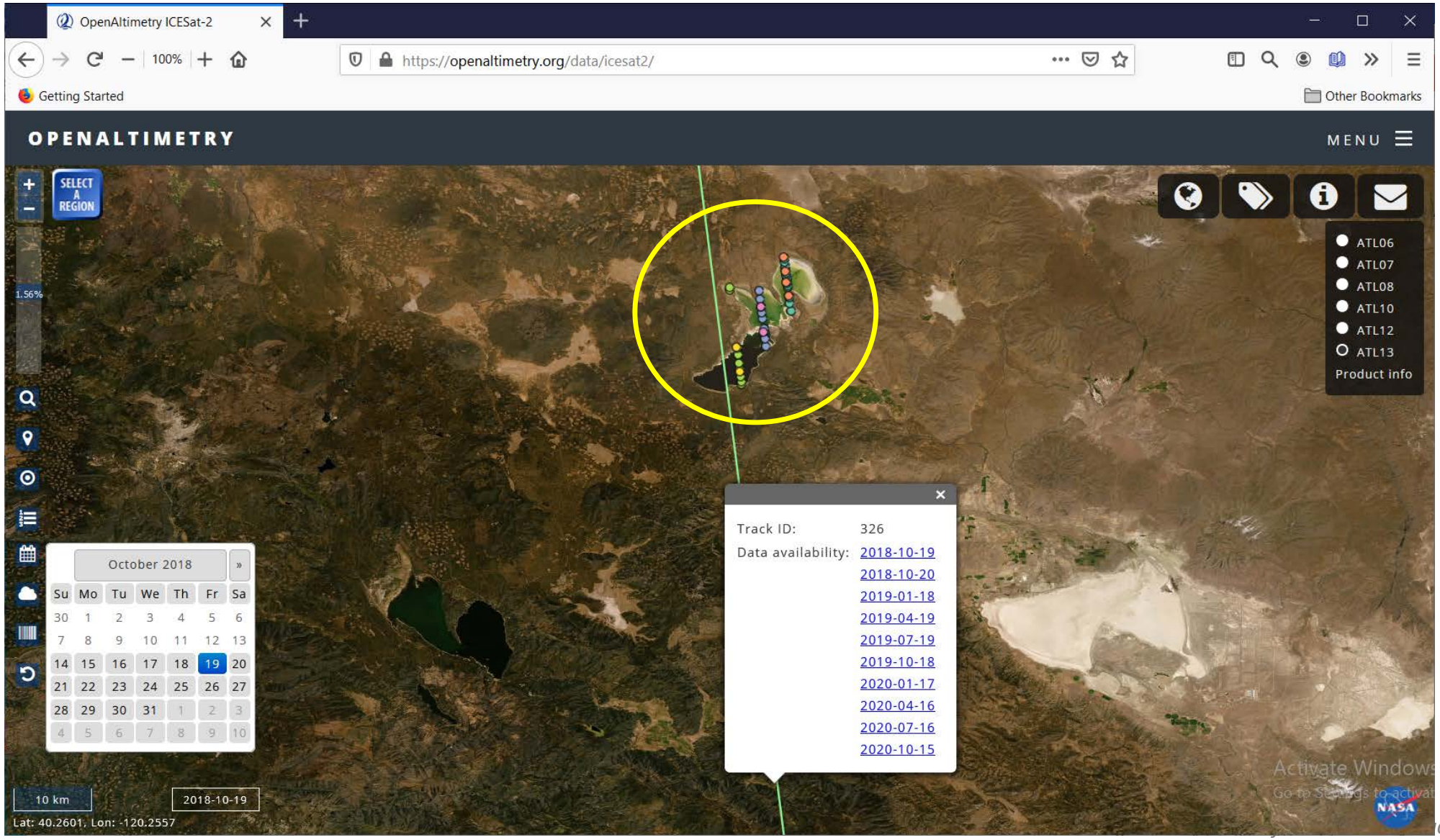
# Example: Eagle Lake CA, October 19, 2018



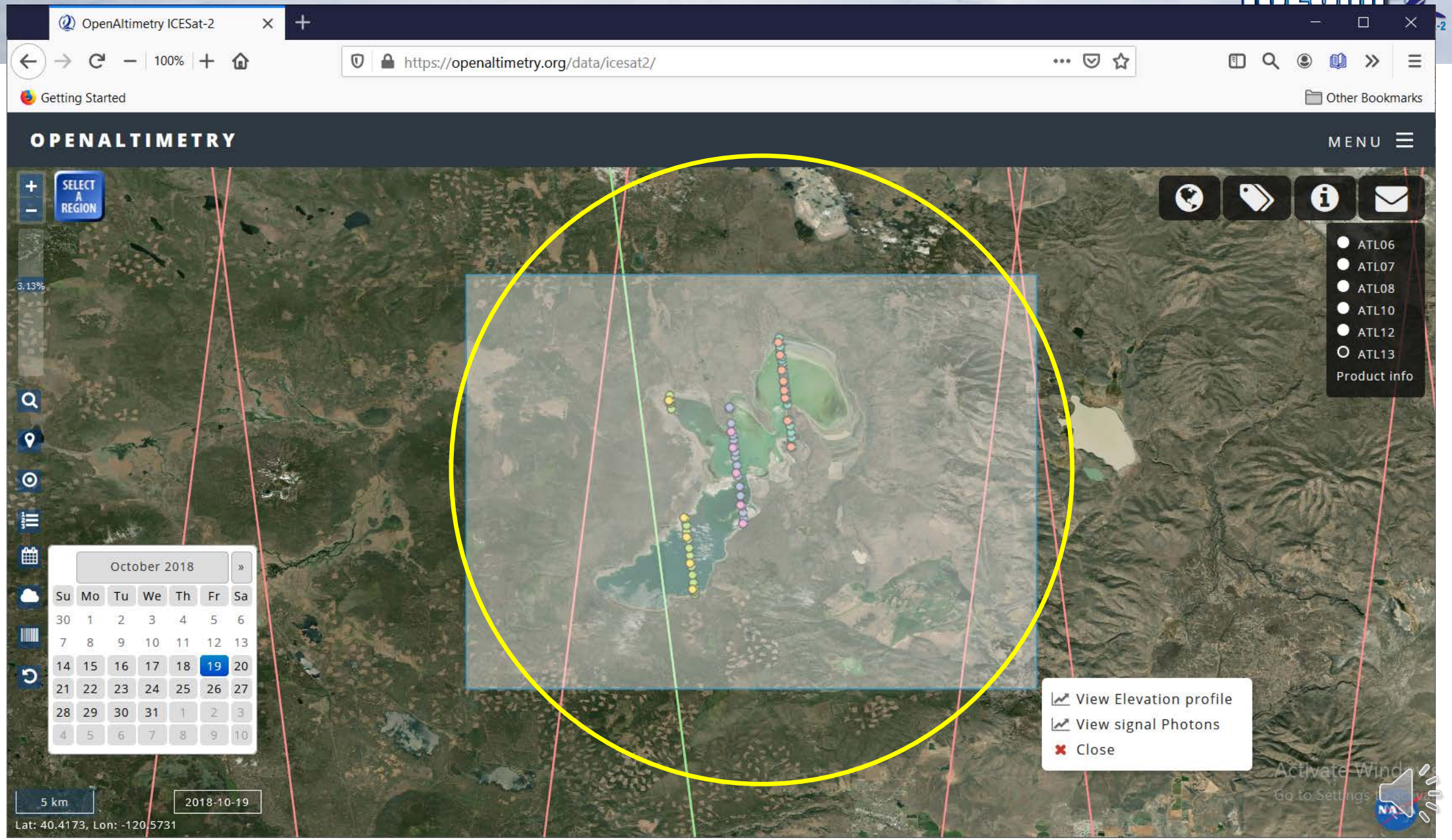
# Example: Eagle Lake CA, October 19, 2018



# Example: Eagle Lake CA, October 19, 2018



# Data Access:


OpenAltimetry ICESat-2
https://openaltimetry.org/data/icesat2/
Getting Started
Other Bookmarks
OPENALTIMETRY
MENU
SELECT A REGION
ATL06
ATL07
ATL08
ATL10
ATL12
ATL13
Product info
October 2018
Su Mo Tu We Th Fr Sa
30 1 2 3 4 5 6
7 8 9 10 11 12 13
14 15 16 17 18 19 20
21 22 23 24 25 26 27
28 29 30 31 1 2 3
4 5 6 7 8 9 10
View Elevation profile
View signal Photons
Close
5 km
2018-10-19
Lat: 40.4173, Lon: -120.5731

# OpenAltimetry:
# ATL13 Data Browsing:

OPENALTIMETRY MENU

Date: 2018-10-19 | 2018-10-20 | 2019-01-18 | 2019-04-19 | 2019-07-19 | 2019-10-18 | 2020-01-17 | 2020-04-16 | 2020-07-16 | 2020-10-15

Overpass Dates

ELEVATION PROFILE | ATL03 PHOTON HEIGHTS

Select ATLAS beam gt3r (strong) | gt3l (weak) | gt2r (strong) | gt2l (weak) | gt1r (strong) | gt1l (weak)

Beams

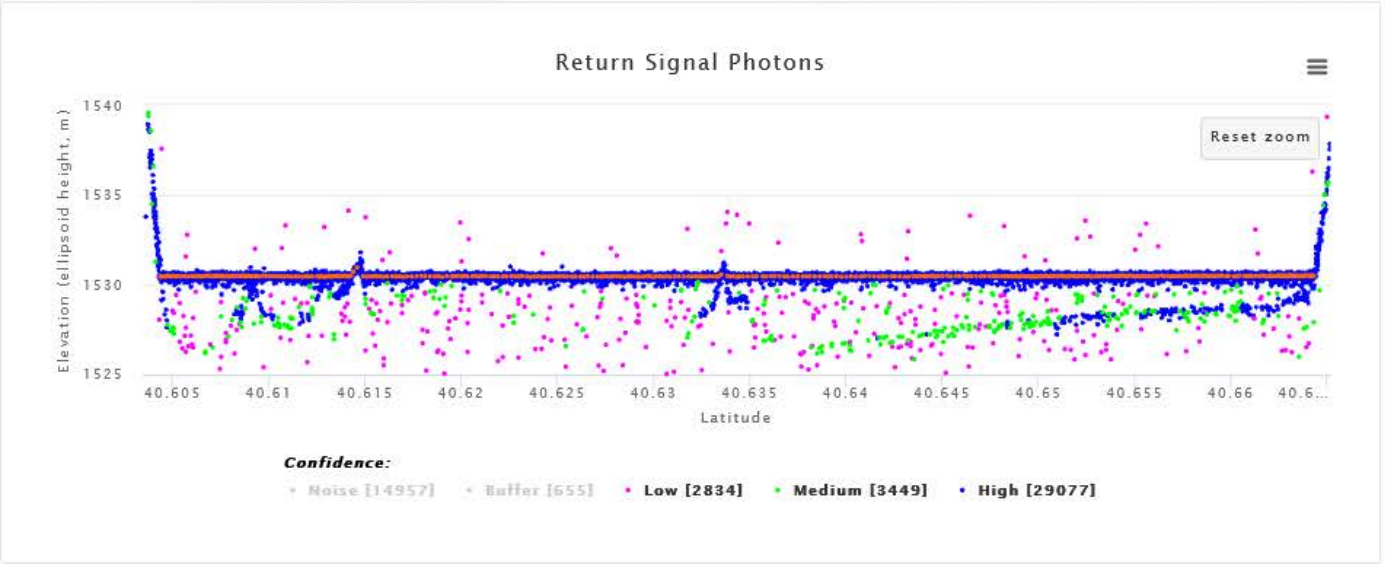
Track ID: 326 - Beam: gt2r - Showing 33.33% data sample rate - View all data (Requires Login)

Total number of photons: 152,915 - Total segments: 1,502 - Segment range: [224,703 - 226,204]

Overlay L3A ATL13 inland water height (WG

Drag zoom on the plot below to view more detail.

Sampling Profile




Zoomable Quick-Look

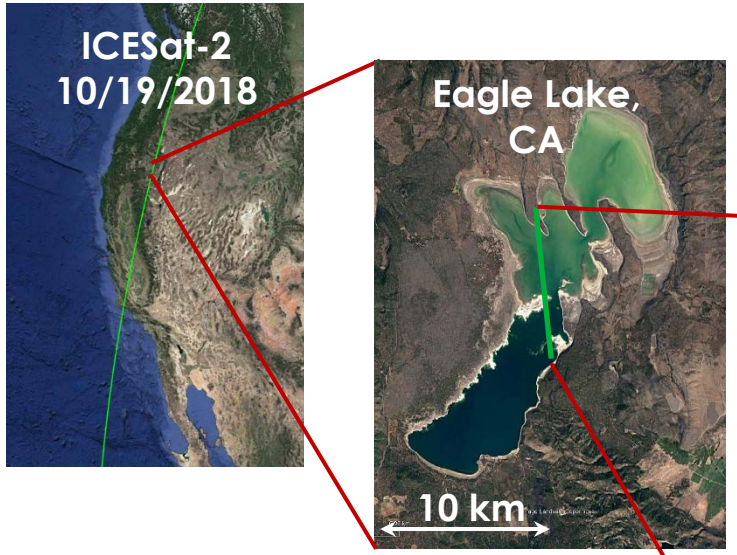
Signal Confidences

Download data as CSV Download subsetted HDF5 (via NSIDC) (Requires Login)

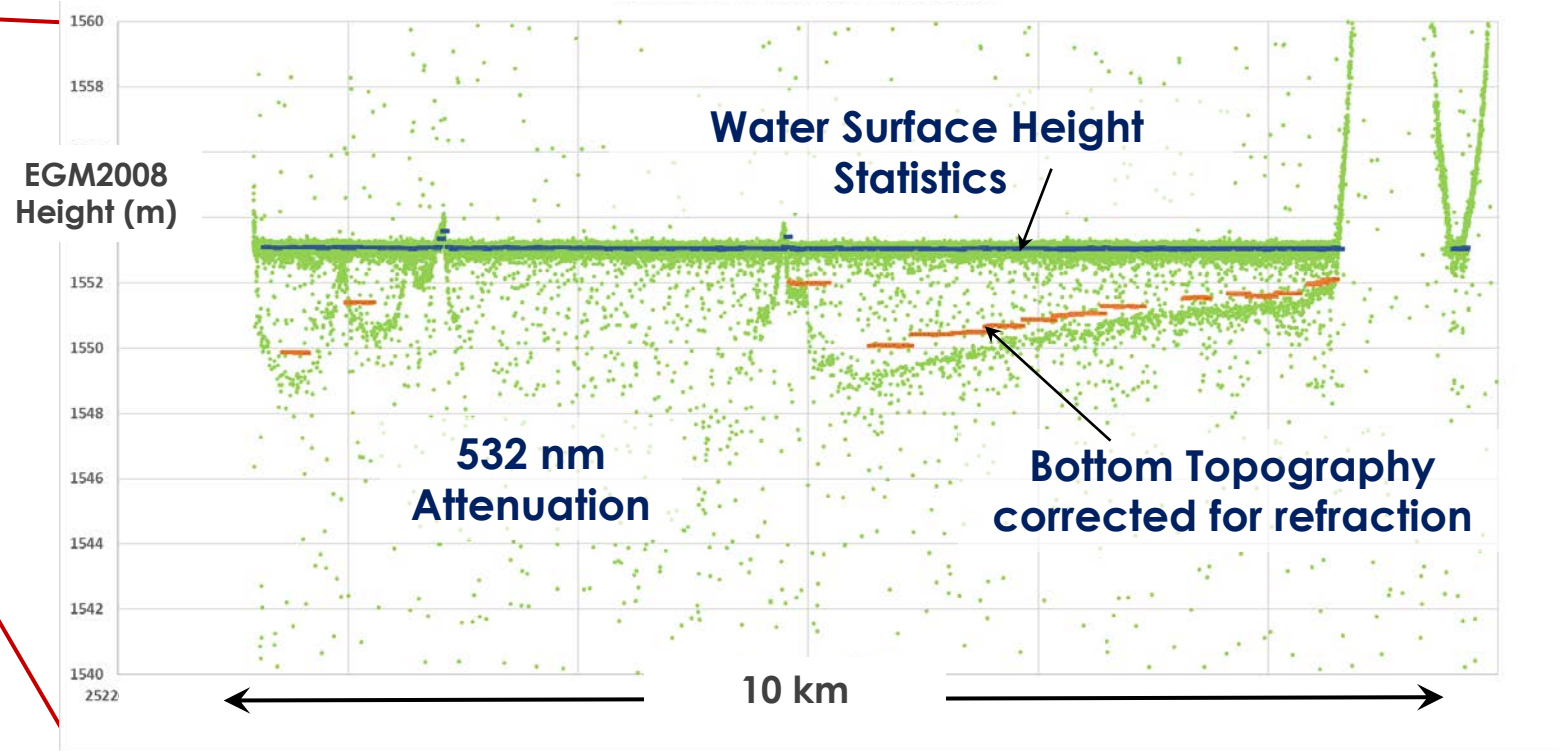
Get API URL (Binder example) 3D Viewer

Acquisition Optior

# Results - ATL13 Operational Products



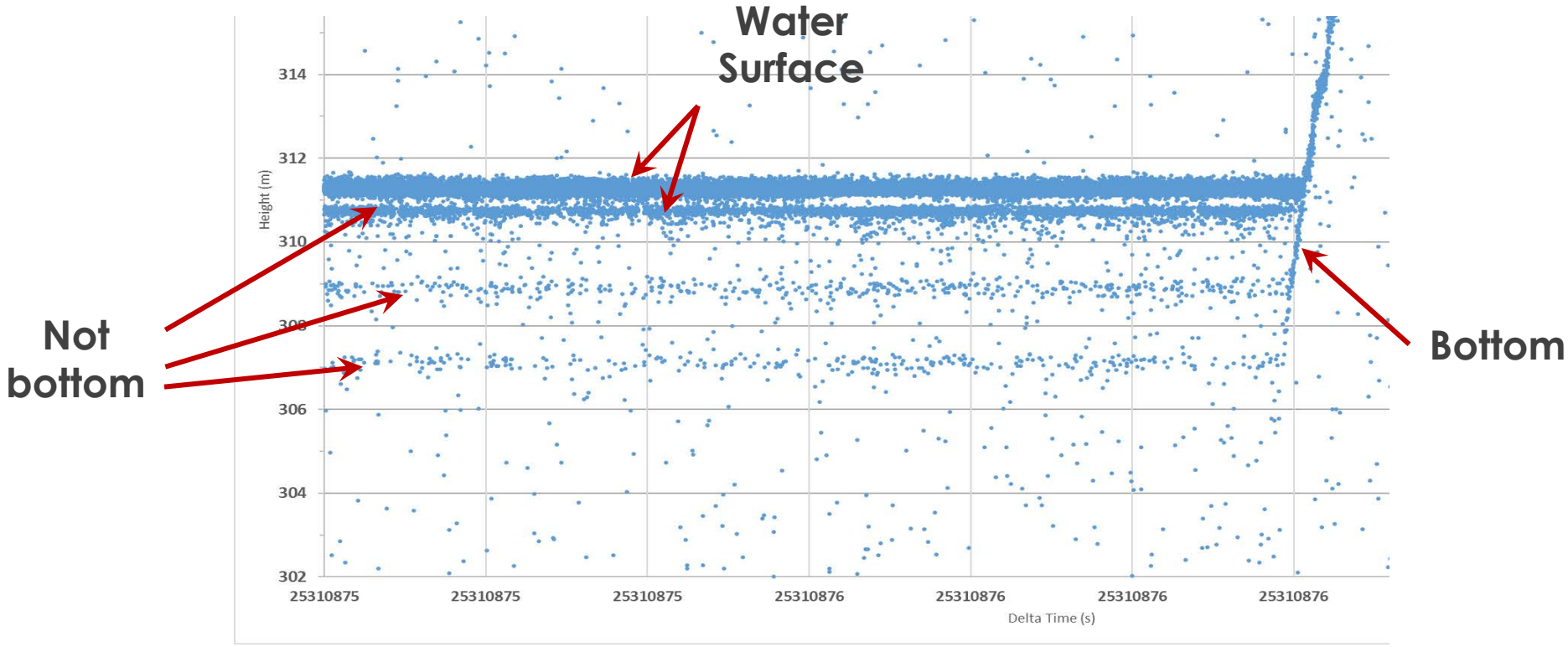

## Results for beam gt2r on 10/19/2018



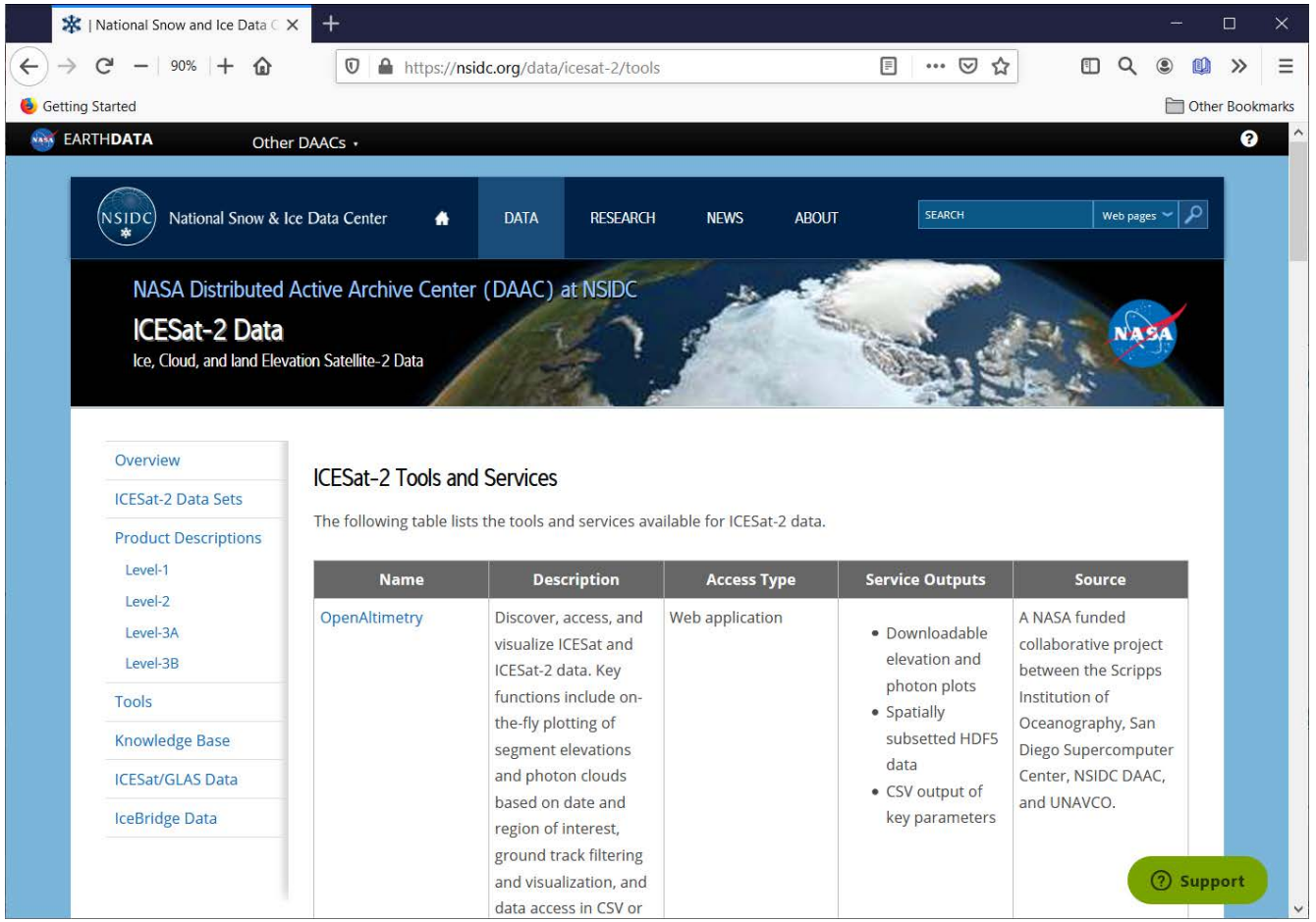

Jasinski, Stoll, and Coauthors. 2020: *ICESat-2 Inland Water ATBD,*
https://doi:10.5067/L870NVUK02YA

*Water Surface Height RMSE < 0.058m when compare against in situ data over two years

# Known ATLAS Instrument Issue: Occasional extra photons

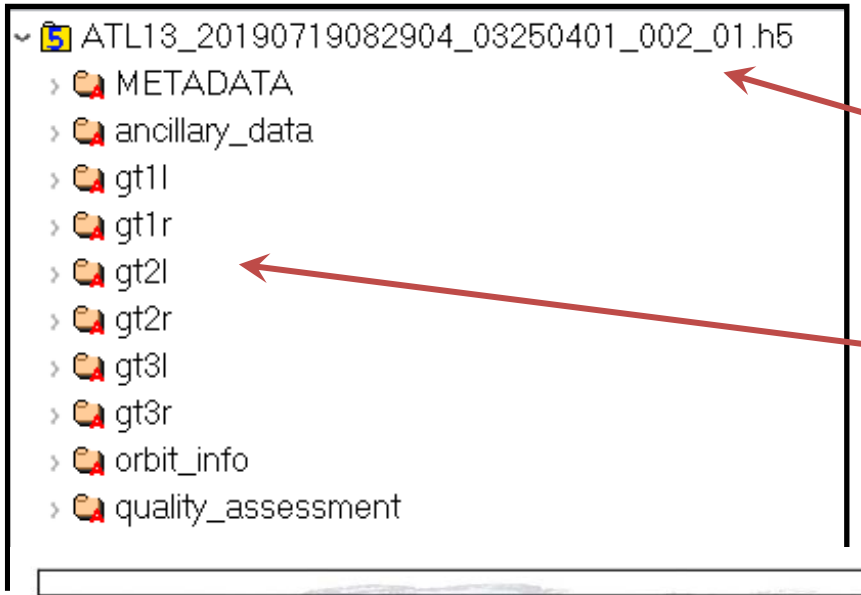


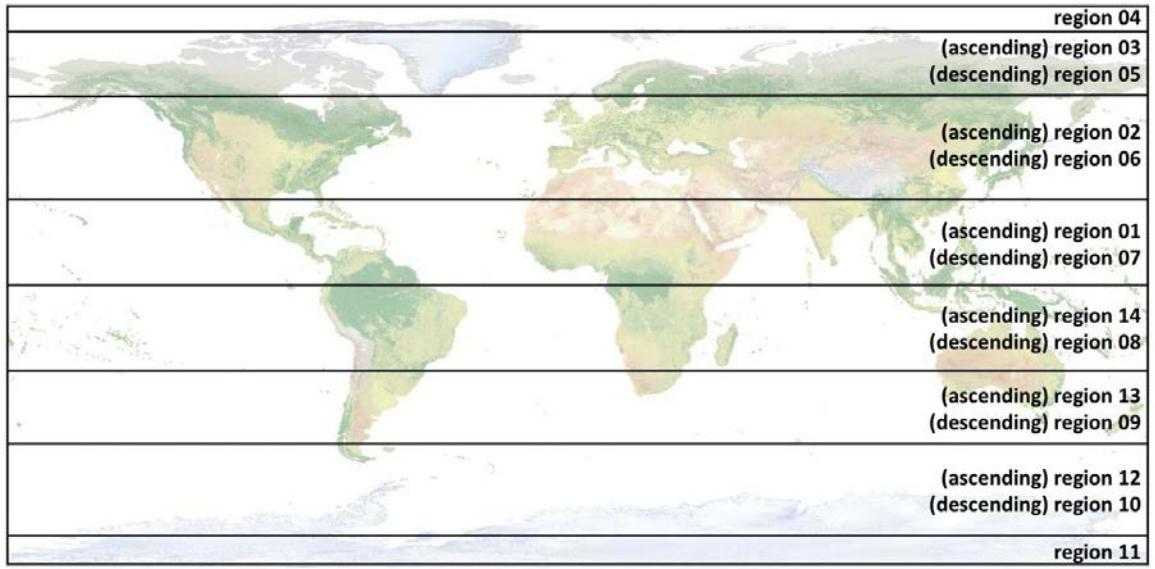
# ICESat-2 Tools & Services: https://nsidc.org/data/icesat-2/tools




**NISDC DAAC tutorial video (YouTube):** https://bit.ly/2rHdQz7

# Data Format: Product Layout




**GRANULE DELINEATION**

- ~5 files per day (several RGTs)
- data exist only over water bodies

**NAMING CONVENTION**

- date+time, RGT, cycle, segment, release, version

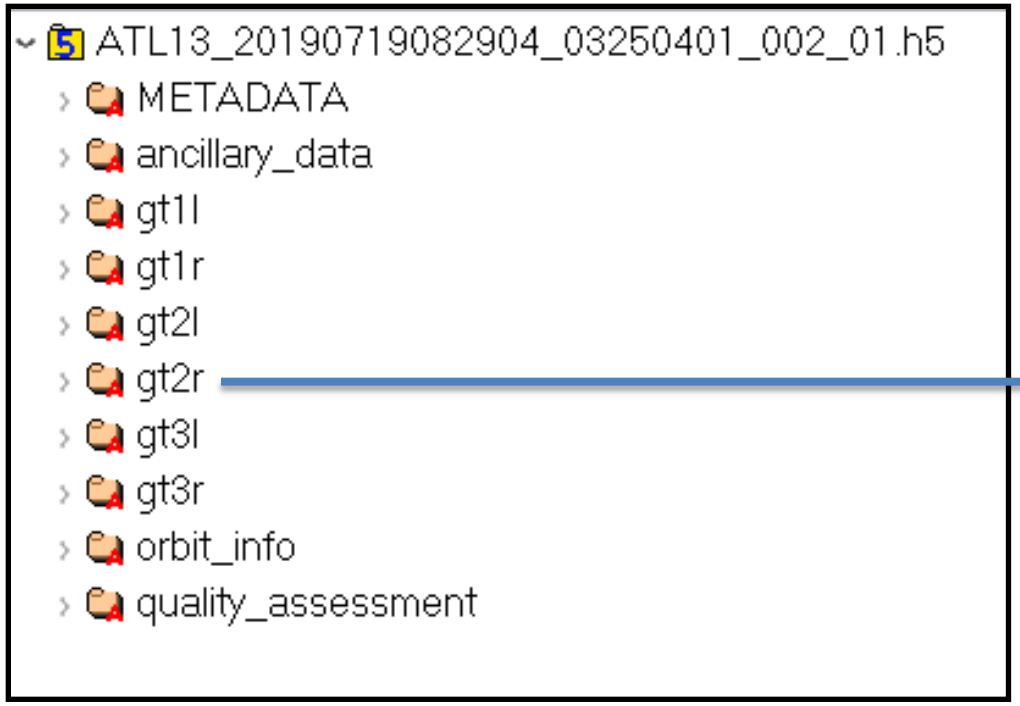
**6-BEAM STRUCTURE**

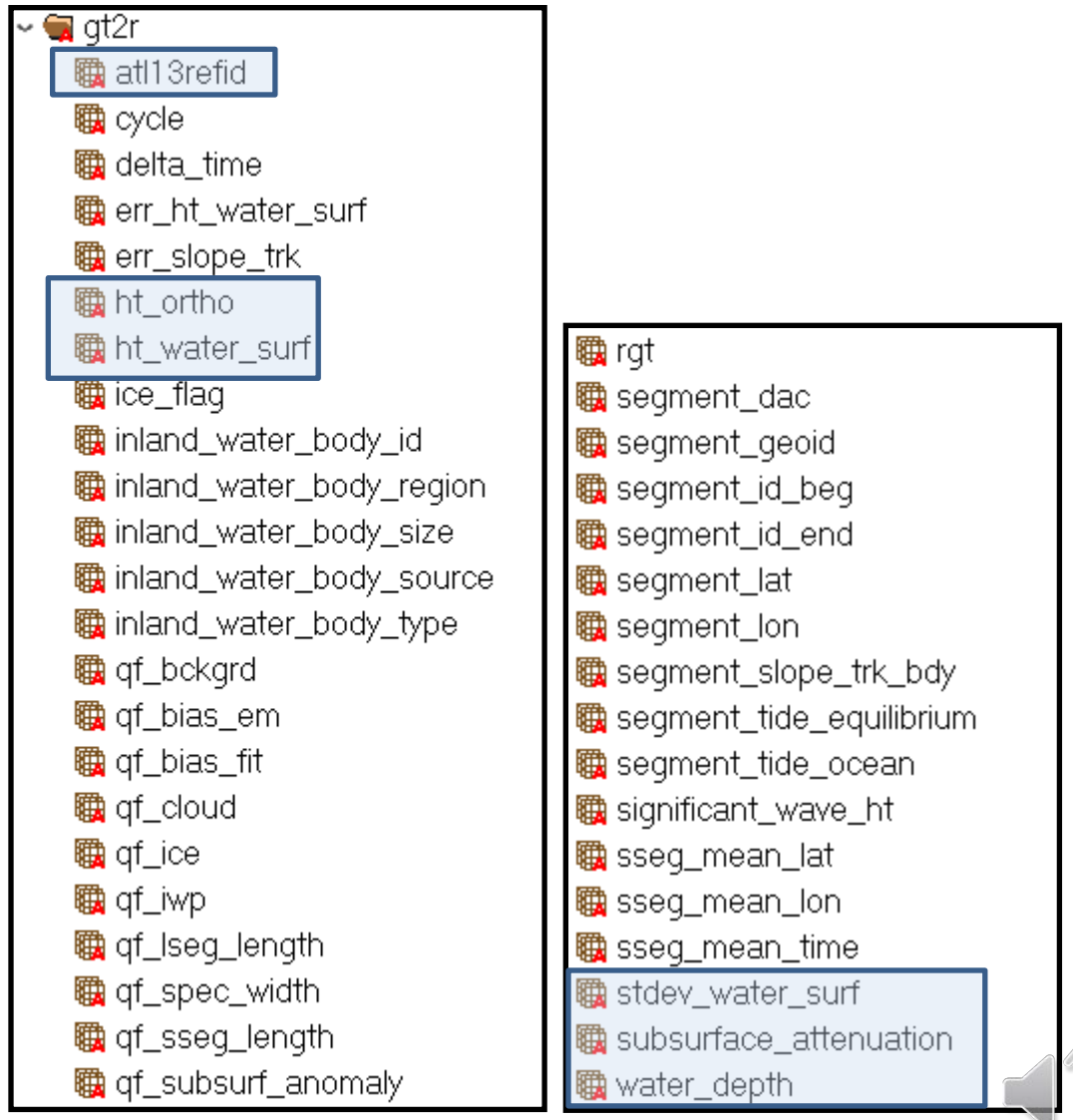
- along-track hierarchy

**IMPORTANT METADATA**

- ancillary_data > RGT, time start & end
- orbit_info > sc_orient

# Data Format: Product Layout




**Product Highlights**

| | |
|---|---|
| atl13refid | Unique water body identifier |
| ht_ortho | Water ht above EGM2008 |
| ht_water_surf | Water ht above WGS84 |
| stdev_water_surf | Water surface standard dev |
| subsurface_attenuation | Water profile ph attenuation |
| water_depth | [ht – corrected bottom ht] |

# Data Format: Product Rate

| | ATL13refid | ht_ortho | stdev_water_surf |
|---|---|---|---|
| 81 | 1410003682 | 237.68318 | 3.4028235E38 |
| 82 | 1410003682 | 237.65822 | 3.4028235E38 |
| 83 | 1410002095 | 23.176842 | 0.065 |
| 84 | 1410002095 | 23.179201 | 0.065 |
| 85 | 1410002095 | 23.164207 | 0.065 |
| 86 | 1410002095 | 23.173082 | 0.065 |
| 87 | 1410002095 | 23.140081 | 0.065 |
| 88 | 1410002095 | 23.16066 | 0.065 |
| 89 | 1410002095 | 23.16881 | 0.065 |
| 90 | 1410002095 | 23.1775 | 0.065 |
| 91 | 1410002095 | 23.172443 | 0.065 |
| 92 | 1410002095 | 23.184858 | 0.065 |
| 93 | 6033000122 | 0.13068293 | 0.125 |
| 94 | 6033000122 | 0.18919733 | 0.125 |

- Short Segment rate
- 1-D arrays
- Mapped by ATL13refid
- Long Segment-derived products repeat

# Summary

ATL13 delivers:

- water surface elevation RMSE ~ < 5-10 cm under most conditions:
- other ATL13 products are consistent w/above
- bathymetry products retrieved mainly in clear waters and near shorelines
    - best examples in coastal zones ~ 20-30 m
    - good cases for reservoirs ~10-15 m
    - full 2-D bathymetry requires merging with multispectral imagery

- ATL13 continuous products → suitable for detailed hydrologic analysis

- ATL22 transect mean products → More useful to applied science users
- especially water resources applications
- calibration of other satellite altimeters including radar

# *Thank you!*

## Acknowledgements

**ATL13 Team:**
**Jeremy Stoll (SSAI)**
**John Robbins (Craig Technologies)**
**David Hancock (KBR)**
**Jyothi Nattala (SSAI)**

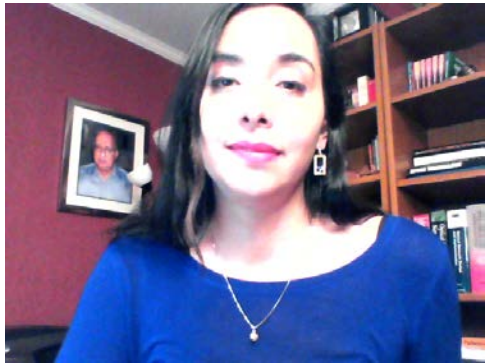
**ICESat-2 Project Office, NASA GSFC**
**NASA Cryosphere Program**

National Aeronautics and Space Administration

# ICESat-2 Applications Program

Sabrina Delgado Arias (SSAI, NASA GSFC)
on behalf of ICESat-2 Applications Team

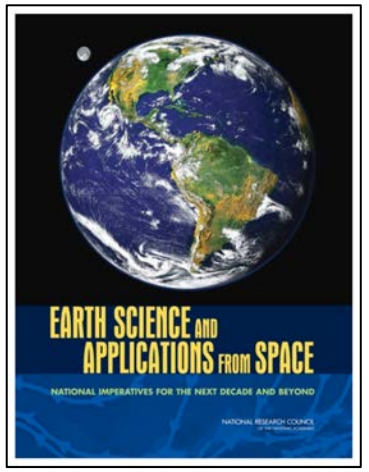
February 23, 2021



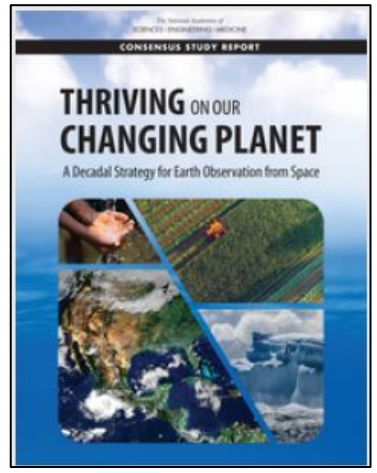
# NASA Mission Applications

## Why Mission Applications?

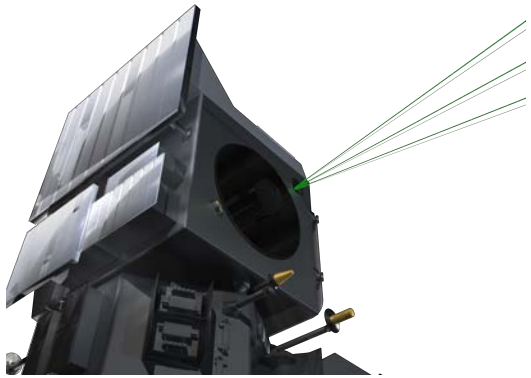
- Key component of the NASA Applied Sciences program
- Recommended as a priority by first Decadal Survey for Earth Science in 2007
- Recommended as a priority by second Decadal Survey for Earth Science in 2018


*National Research Council Decadal Survey Report,* **Earth Science and Applications from Space (2007)**



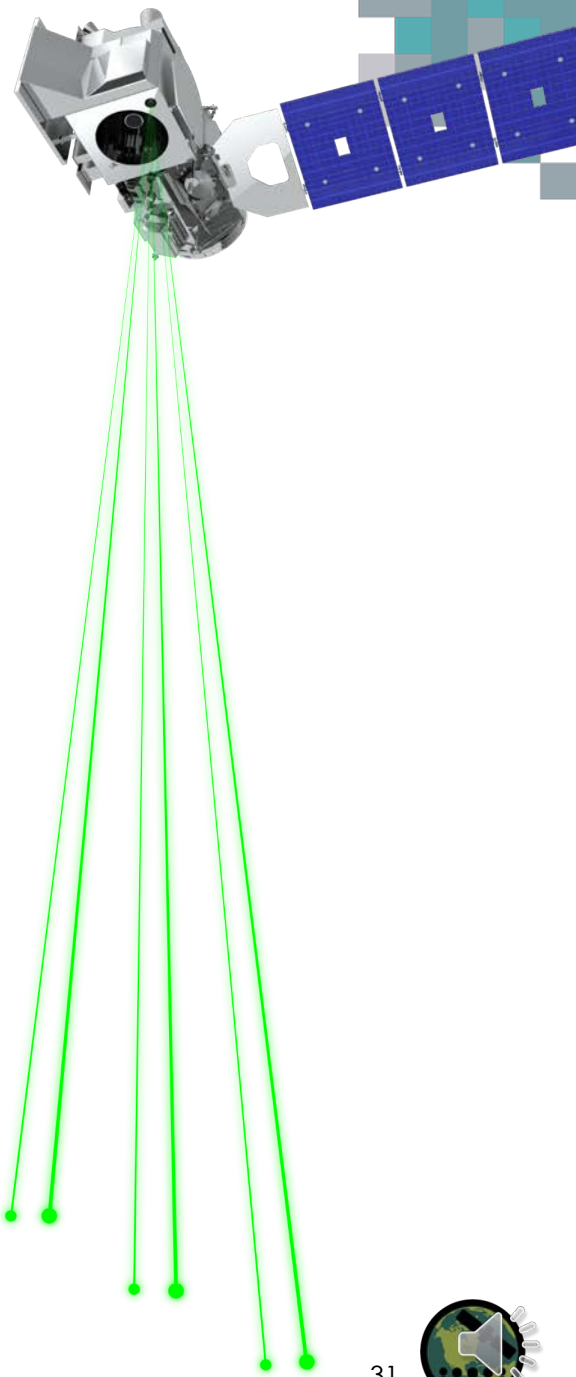

National Research Council Decadal Survey Report, **Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space (2018)**



MISSIONS & APPLICATIONS

# ICESat-2 Applications Team

| Role in ICESat-2 Mission | Members | Affiliation |
|---|---|---|
| ICESat-2 Program Applications Coordinator | Sabrina Delgado Arias | Science Systems and Applications Inc (SSAI), NASA's Goddard Space Flight Center (GSFC) |
| ICESat-2 Program Applications Scientist | Molly Brown | University of Maryland |
| ICESat-2 Science Team Member (Hydrology) & ST Applications Liaison | Michael Jasinski | NASA GSFC |
| ICESat-2 Project Scientist | Tom Neumann | NASA GSFC |
| ICESat-2 Science Team Leader | Lori Magruder | University of Texas |
| NASA Headquarters Program Applications Lead | Woody Turner | NASA Headquarters (HQ) |



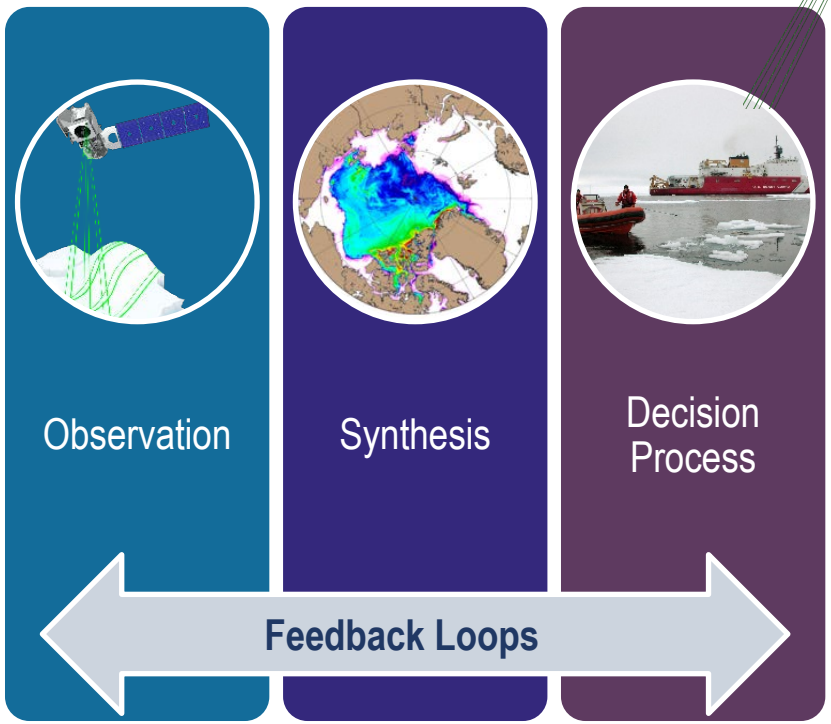
# NASA ICESat-2 Applications

## Program Overview

- Applications research provides fundamental knowledge of how mission data products can be scaled and integrated to inform resource management, policy development, and decision making.

- We define applications as **innovative uses** of mission data products in **decision-making** activities for **societal benefit**

Identify and strengthen links between:




https://icesat-2.gsfc.nasa.gov/applications

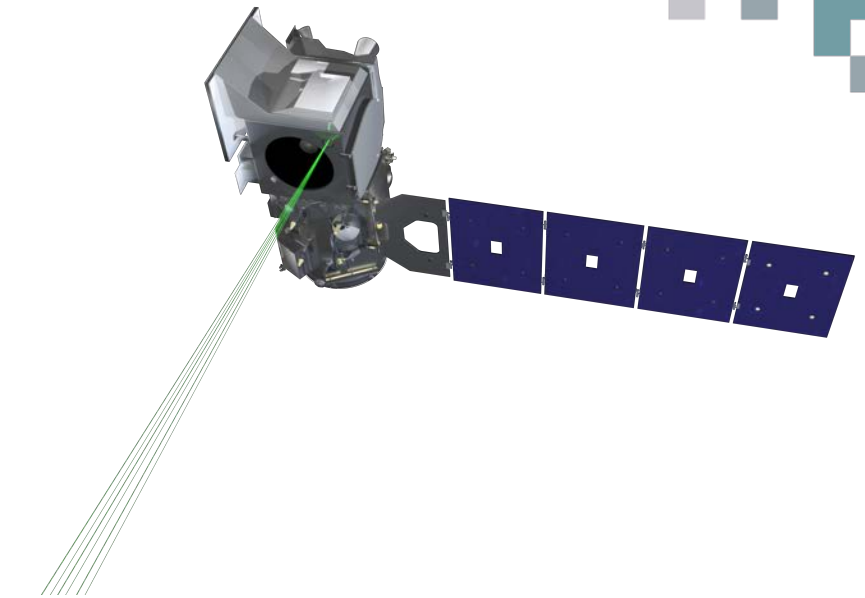
**Enhance Applications Research | Increase Collaboration | Accelerate Applications**

# ICESat-2 Key Data Characteristics

**Lifetime:** 3 years, with consumables for 5+
- Fuel should not be a limiting factor
- Operating on primary laser at energy level 4
- Equipped with redundant laser

**Resolution:** 6 beams, arranged in 3 pairs
- Single-photon sensitive detection, 532 nm wavelength
- 10 kHz pulse-rep. rate
- 11 m footprint
- spaced 0.7m along-track (1 measurement every 70 cm)
- Height accuracy currently better than 10 cm

**Data Latency:** 45 days for higher level data products

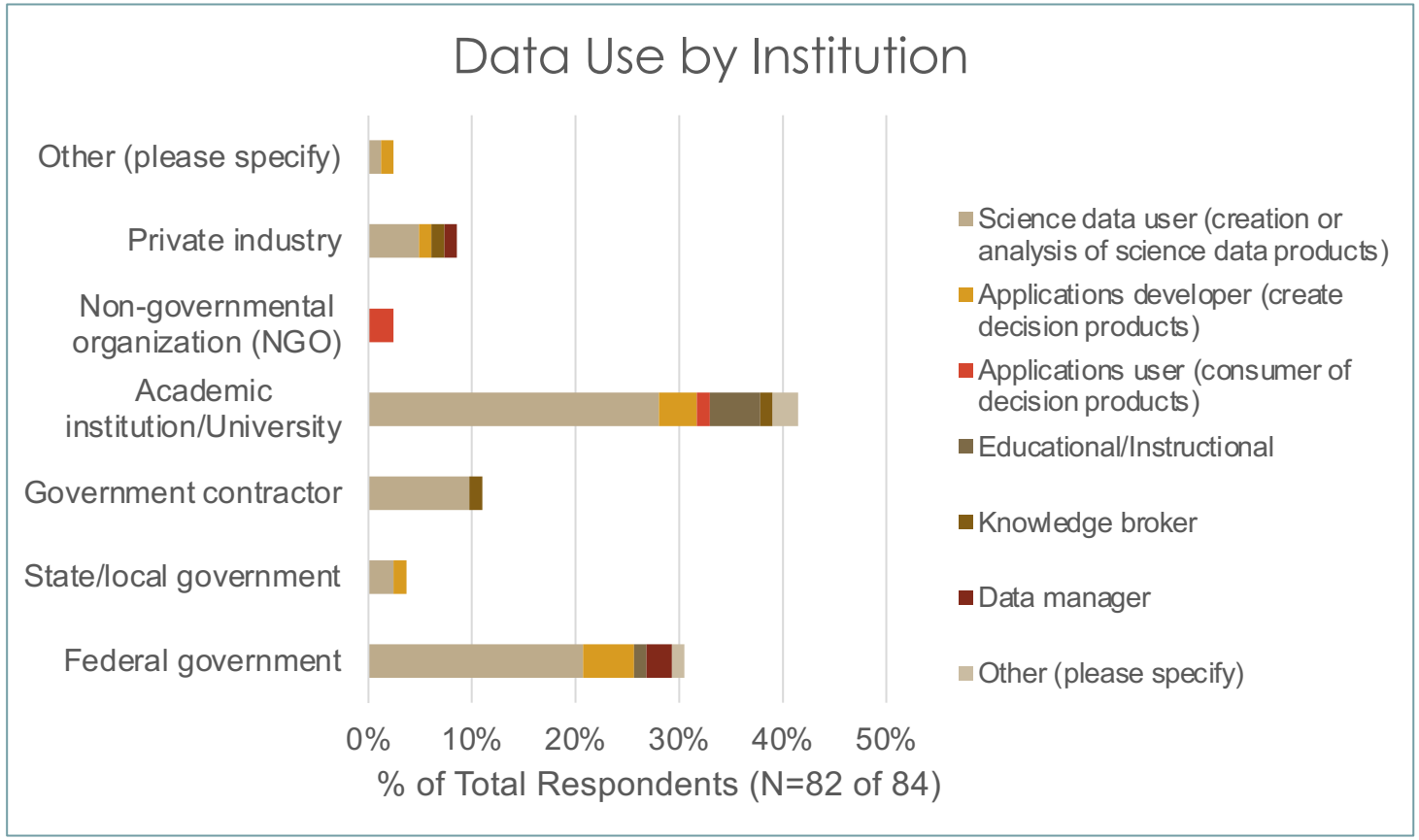


**What opportunities and challenges exist in integrating ICESat-2 data for your application?**

# ICESat-2 Applications Community

https://lists.nasa.gov/mailman/listinfo/icesat-2-applications/

- The ICESat-2 Applications community consists of 651 individuals who have expressed interest in the practical use of ICESat-2 data by either signing up to the community mailing list or through actual engagement with the mission via the various outreach events and the Early Adopter/Applied Users programs.

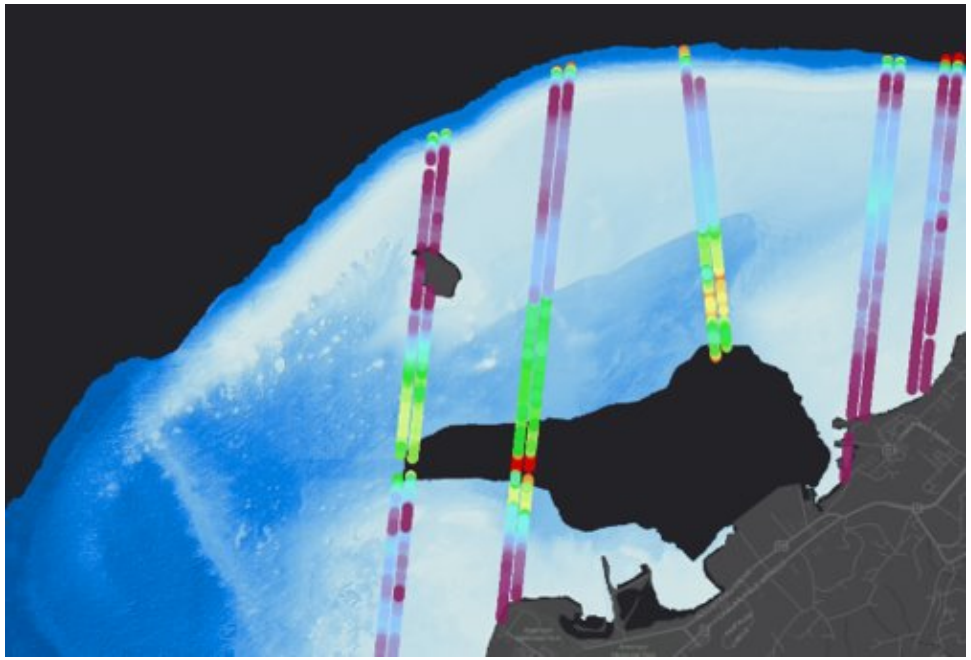



**Join our ICESat-2 Applications Community!**

# ICESat-2 Applications Examples

## Applied User Spotlight: PI – Ross Smith, TCarta

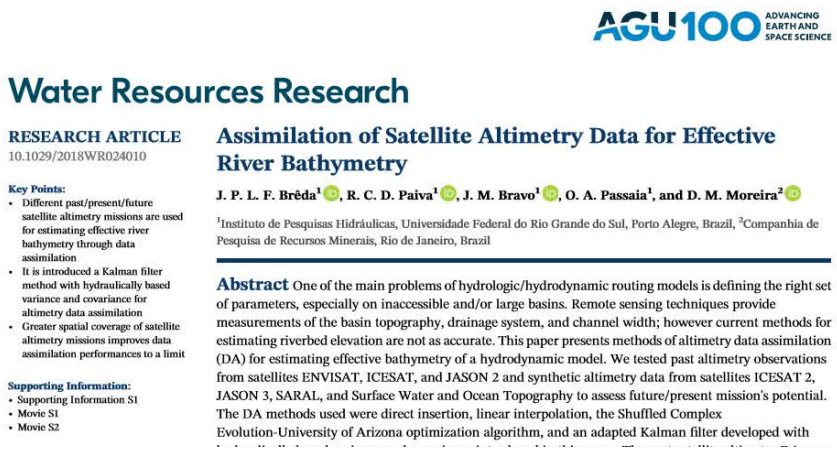
- TCarta Marine, a global provider of marine maps, is using machine learning and artificial intelligence to estimate seafloor depth using data from ICESat-2.
- ICESat-2 has mapped over 147,925 km² of coastal regions, gauging seafloor depths down to 100 ft with a +/- 1.2 ft accuracy. Using this new tool, TCarta derived over 10.8 million depth measurements in over 45 locations around the world during 2020.



*ICESat-2 paths off the coast of Saipan measure seafloor depth, used to calibrate & validate a 2-meter satellite-derived bathymetry model using Maxar WorldView-2 and other satellites. Learn more: NSF Story Map*

# ICESat-2 Applications Examples

## Early Adopter Spotlight: PI – Rodrigo Paiva, Hydraulic Research Institute, Federal University of Rio Grande do Sul, Brazil



AGU100 ADVANCING EARTH AND SPACE SCIENCE

Water Resources Research

RESEARCH ARTICLE
10.1029/2018WR024010

**Assimilation of Satellite Altimetry Data for Effective River Bathymetry**

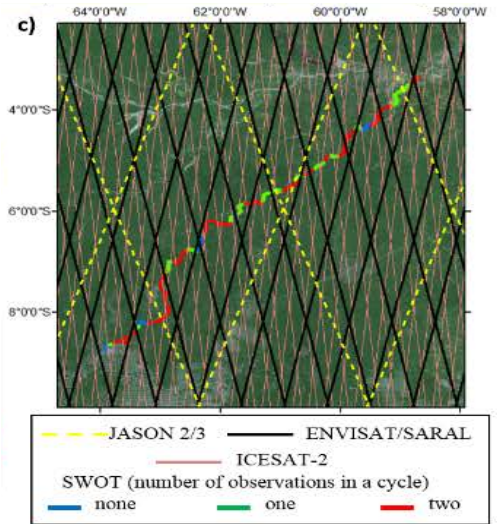
J. P. L. F. Brêda[1], R. C. D. Paiva[1], J. M. Bravo[1], O. A. Passaia[1], and D. M. Moreira[2]

[1]Instituto de Pesquisas Hidráulicas, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil, [2]Companhia de Pesquisa de Recursos Minerais, Rio de Janeiro, Brazil

Key Points:
- Different past/present/future satellite altimetry missions are used for estimating effective river bathymetry through data assimilation
- It is introduced a Kalman filter method with hydraulically based variance and covariance for altimetry data assimilation
- Greater spatial coverage of satellite altimetry missions improves data assimilation performances to a limit

Supporting Information:
- Supporting Information S1
- Movie S1
- Movie S2

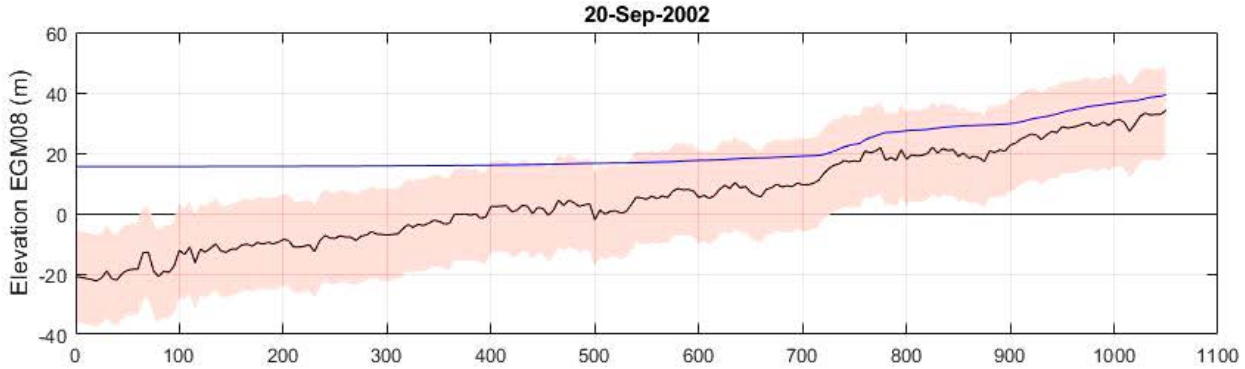
**Abstract** One of the main problems of hydrologic/hydrodynamic routing models is defining the right set of parameters, especially on inaccessible and/or large basins. Remote sensing techniques provide measurements of the basin topography, drainage system, and channel width; however current methods for estimating riverbed elevation are not as accurate. This paper presents methods of altimetry data assimilation (DA) for estimating effective bathymetry of a hydrodynamic model. We tested past altimetry observations from satellites ENVISAT, ICESAT, and JASON 2 and synthetic altimetry data from satellites ICESAT 2, JASON 3, SARAL, and Surface Water and Ocean Topography to assess future/present mission's potential. The DA methods used were direct insertion, linear interpolation, the Shuffled Complex Evolution-University of Arizona optimization algorithm, and an adapted Kalman filter developed with

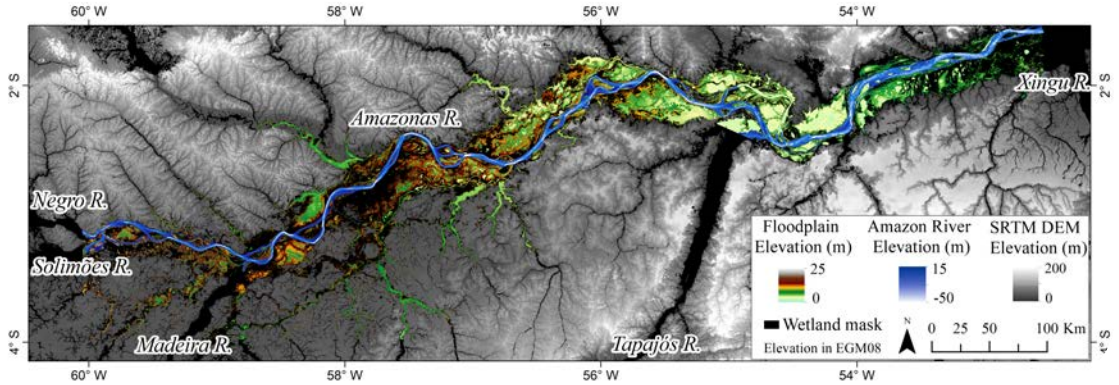



***"High resolution mapping of floodplain bathymetry from space: a case study in the Amazon"***

Fassoni-Andrade A., Paiva,RCD, Rudorff,C. et al Remote Sensing of Environment, https://doi.org/10.1016/j.rse.2020.112065

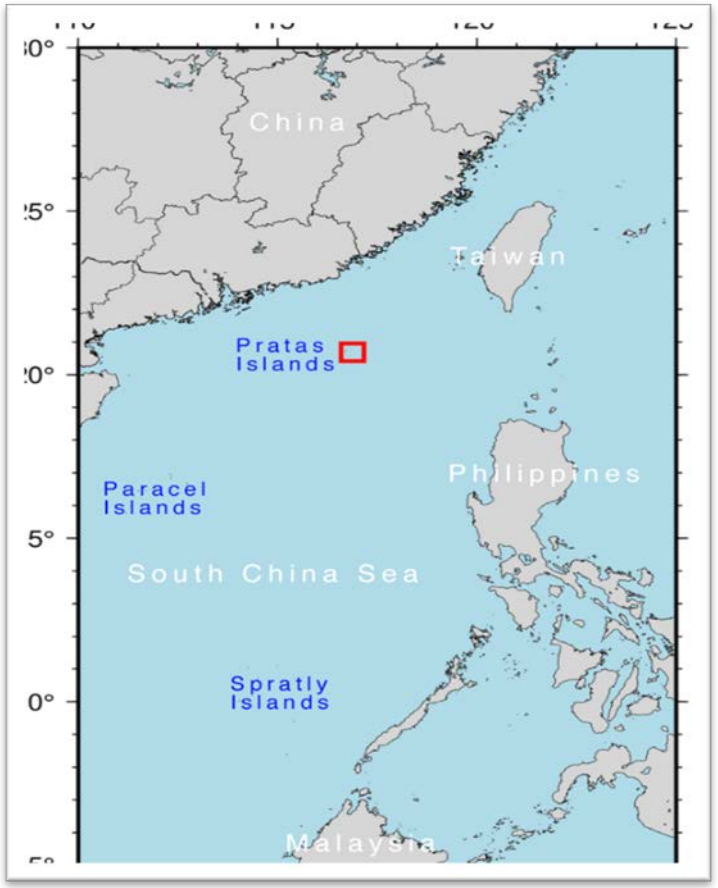
## Madeira River Profile

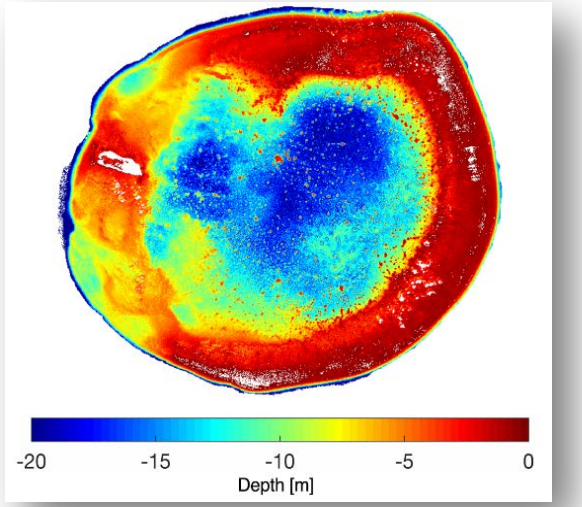


# ICESat-2 Applications Examples

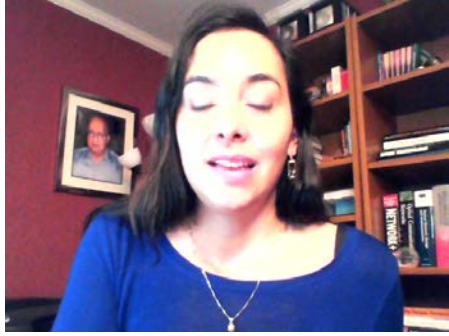
## Early Adopter Spotlight: PI – Steven Kuo-Hsin Tseng, Taiwan National Central University, Center for Space and Remote Sensing Research



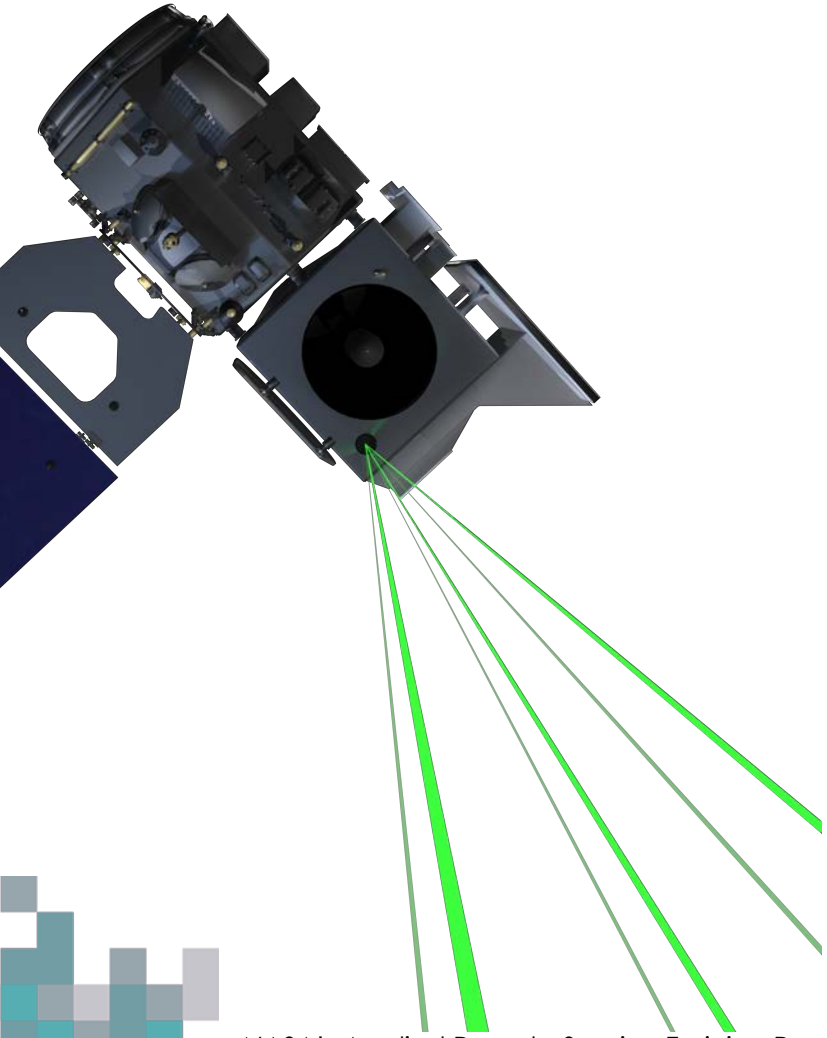




- How can we improve Electronic Navigation Charts for navigation in South China Sea if we integrate water depth data from ICESat-2 with optical imagery from Sentinel-2?
- Water clarity in the South China Sea allows for penetration of photons down to 20-30 meters making it possible to model underwater terrain.

# Get Involved!



## ICESat-2 Applied Users Program



**Partner with ICESat-2 mission scientists in your discovery of ICESat-2 data.**

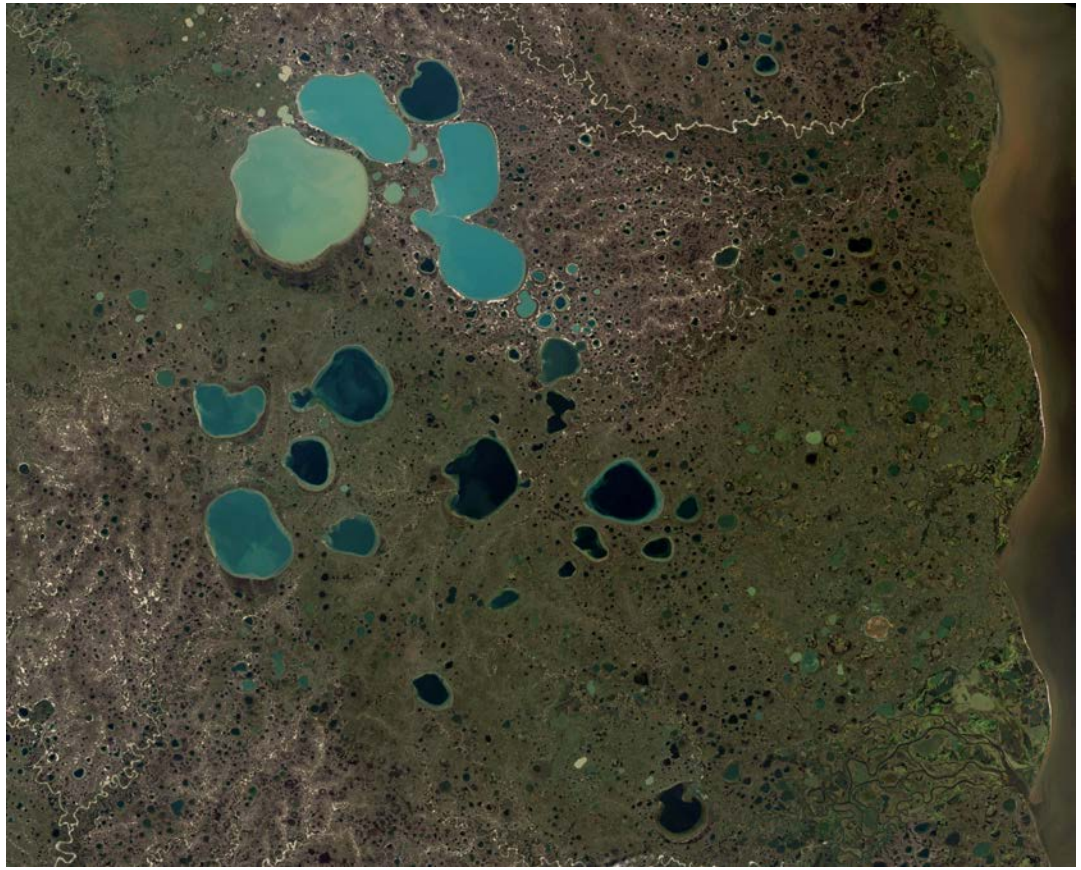
*YOUR BENEFITS*

- Get support from a Science Definition Team (SDT) or Project Science Office (PSO) member
- Participate in quarterly webinars
- Be in the know about ICESat-2
- Get access to calibration and validation (cal/val) data
- Reference lessons learned

***POC: sabrina.delgadoarias@nasa.gov***
***https://icesat-2.gsfc.nasa.gov/get_involved***

# Questions

- Please enter your questions in the Q&A box. We will answer them in the order they were received.
- We will post the Q&A to the training website following the conclusion of the webinar.



https://earthobservatory.nasa.gov/images/6034/pothole-lakes-in-siberia

# Contact

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    michael.f.jasinski@nasa.gov
  - Sabrina Delgado
    sabrina.delgadoarias@nasa.gov
- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/mapping-and-monitoring-lakes-and-reservoirs-satellite-observations

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