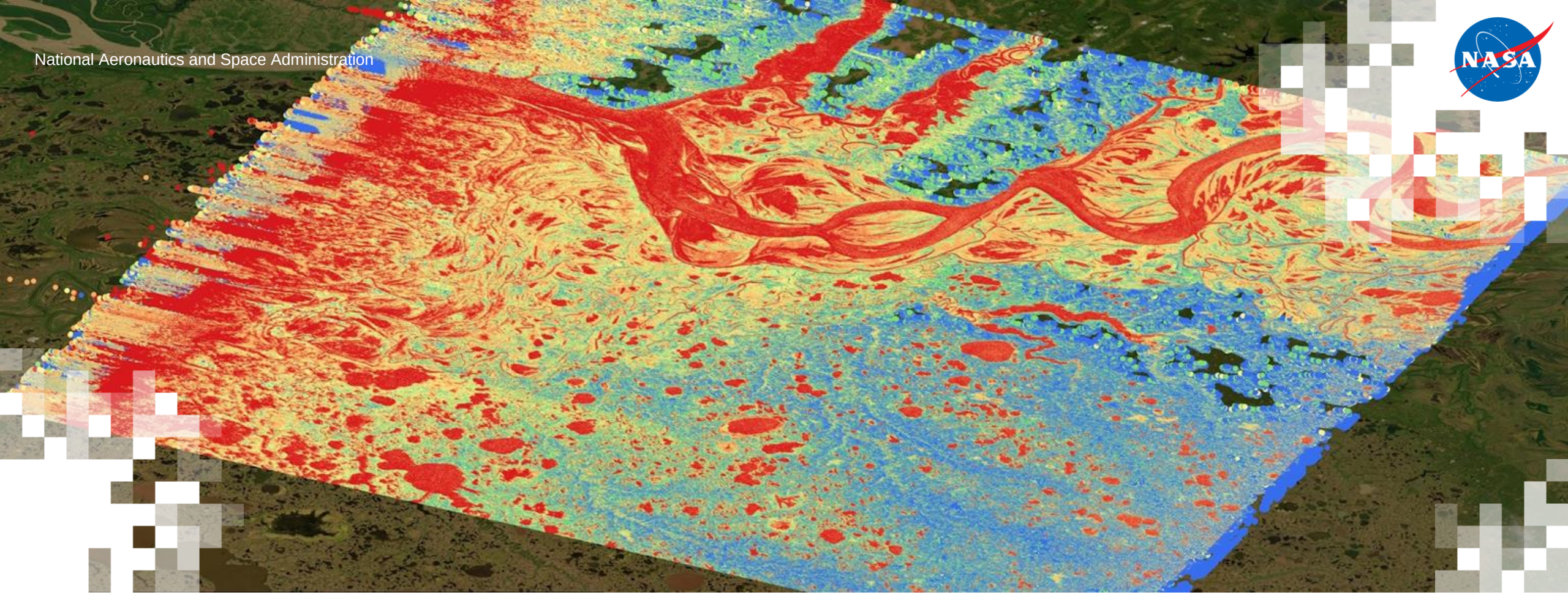
National Aeronautics and Space Administration

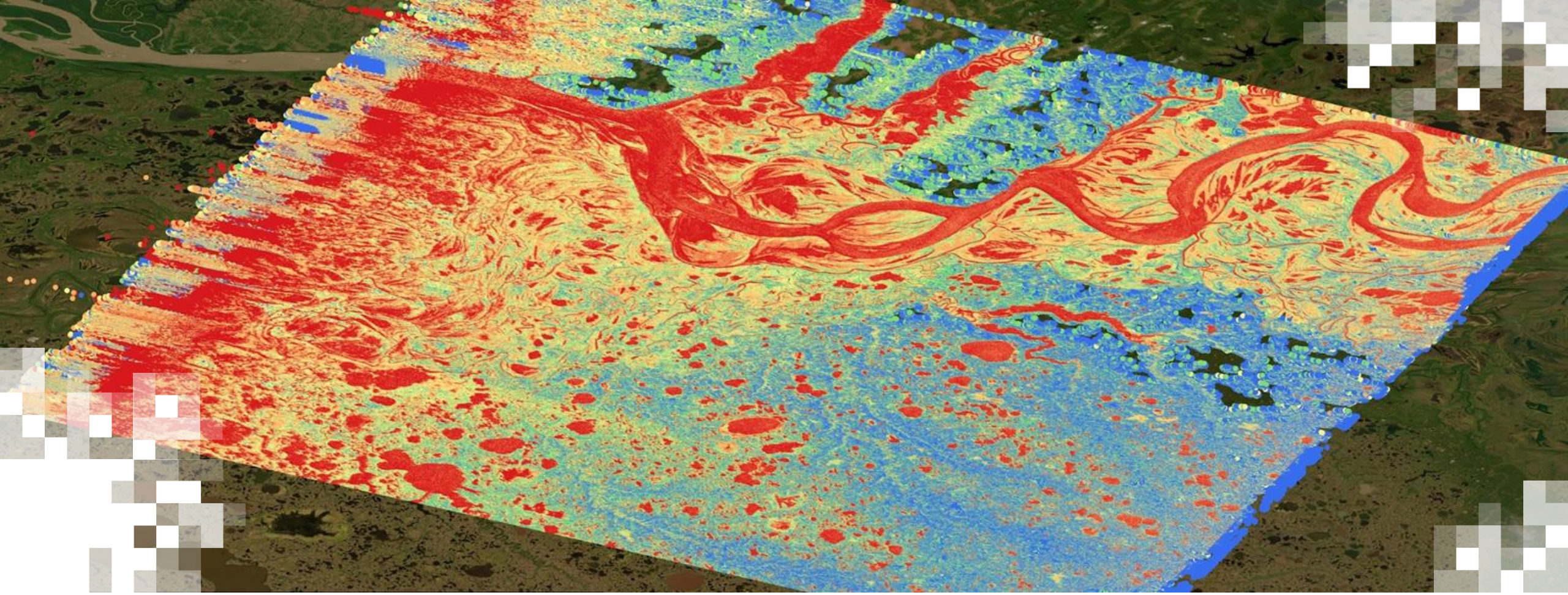


Monitoring Global Terrestrial Surface Water using Remote Sensing

Part 1: Overview of Remote Sensing Observations for Monitoring Global Terrestrial Surface Water in Large Rivers and Lakes

ARSET Instructors: Amita Mehta (612, GESTAR II), Sean McCartney (610, SSAI), Erika Podest (JPL, Caltech)
Guest Speaker: Matthew Bonnema (JPL, Caltech)

May 13, 2025



About ARSET

About ARSET

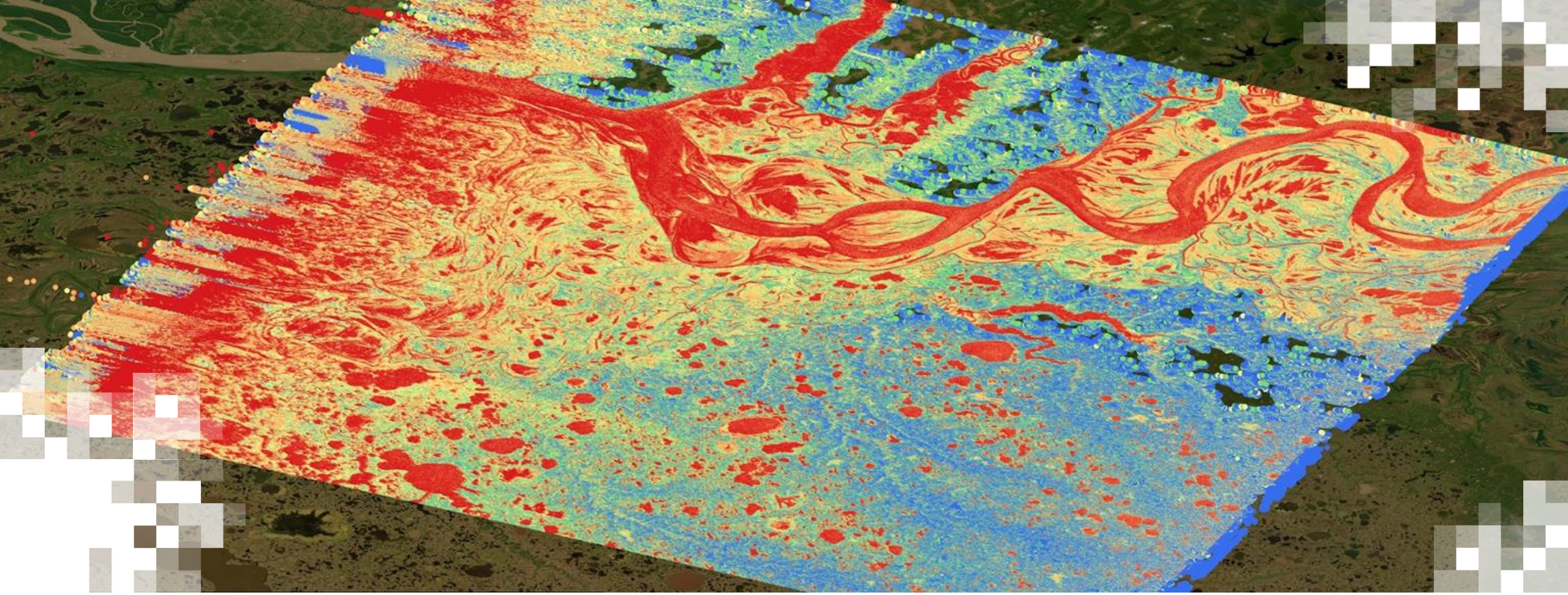
- **ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.**

- Trainings include a variety of applications of satellite data and are tailored to audiences with a variety of experience levels.

About ARSET Trainings

- Online or in-person
- Live and instructor-led or asynchronous and self-paced
- Cost-free
- Bilingual and multilingual options
- Only use open-source software and data
- Accommodate differing levels of expertise

- Visit the ARSET website to learn more.

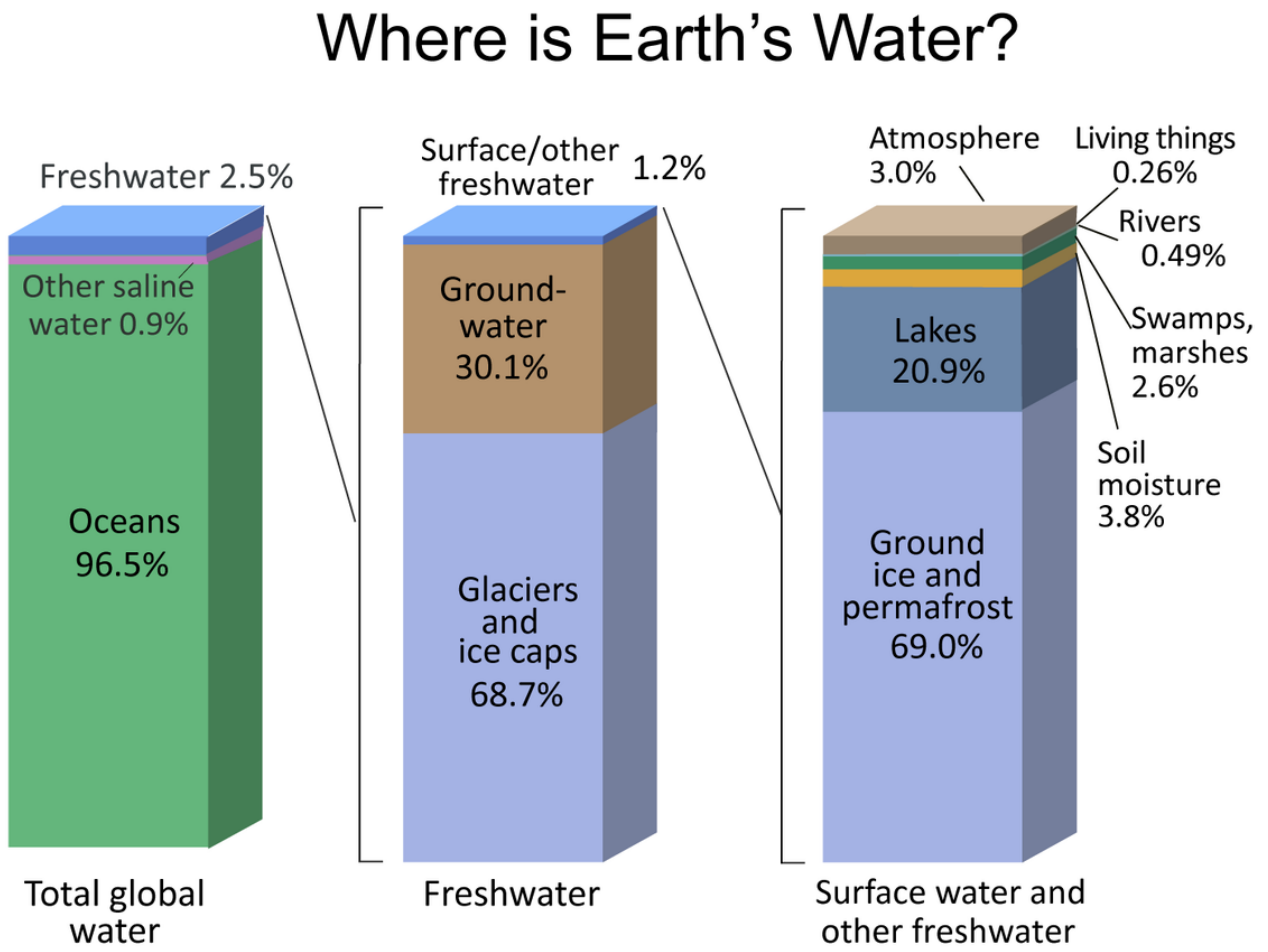


Monitoring Global Terrestrial Surface Water using Remote Sensing

Overview

Where is Terrestrial Surface Water?

- Surface water consists of all water bodies located above ground, including salt water (oceans) and fresh water (streams, rivers, lakes, wetlands).
- Freshwater lakes and rivers are primary sources of water supply for drinking, agriculture, energy, and transportation, and support aquatic ecosystems and wildlife.



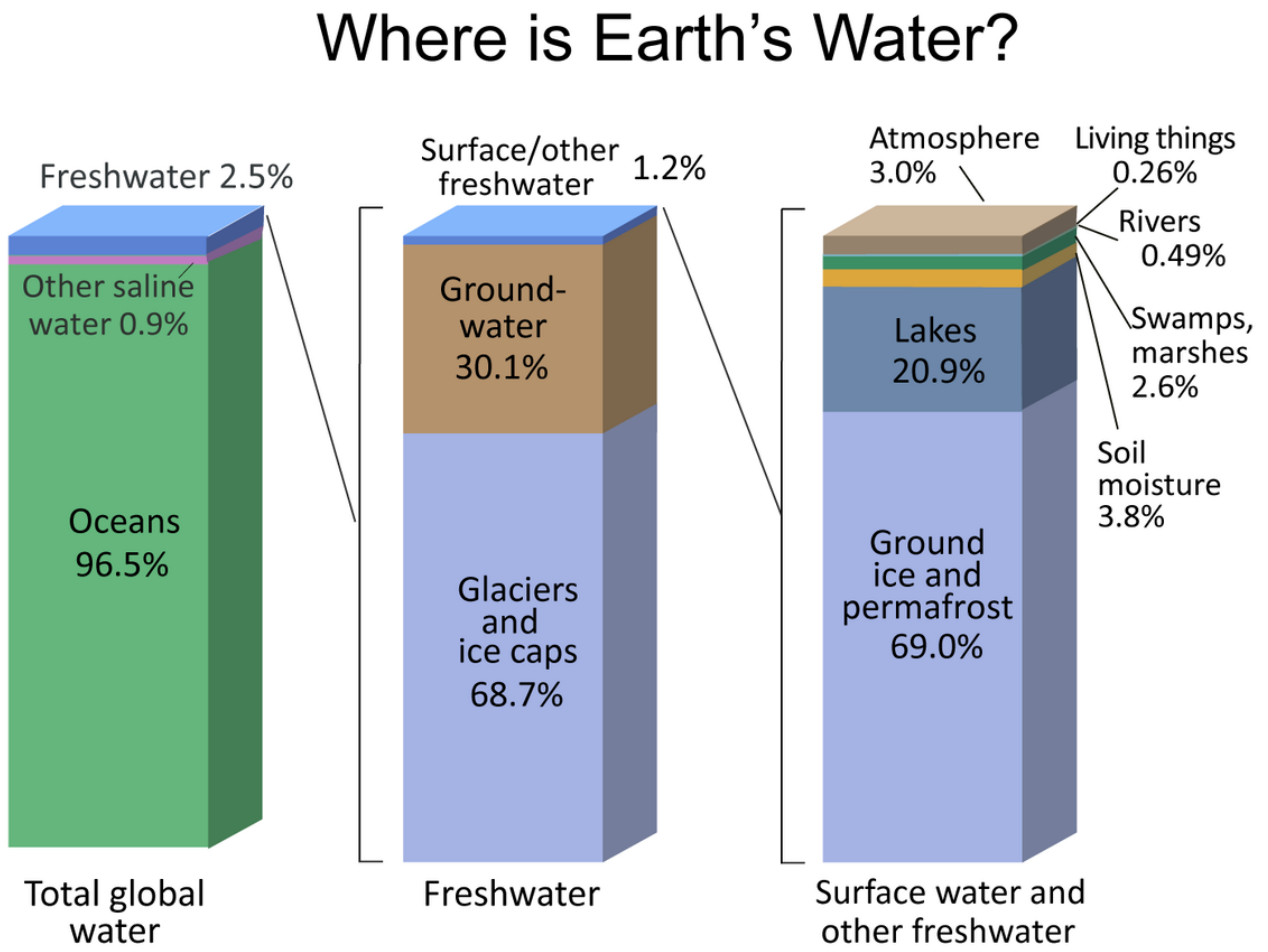
Credit: U.S. Geological Survey, Water Science School. https://www.usgs.gov/special-topic/water-science-school
Data source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources. (Numbers are rounded).

Image Source: USGS

Why Monitor Terrestrial Surface Water?

- Environmental changes, land use, and other water supply and demand changes affect these freshwater sources.
- Rivers spanning multiple countries or states within countries pose challenges in estimating water availability and usage.

Monitoring surface water extent and amount are crucial for sustainable water and disaster management.



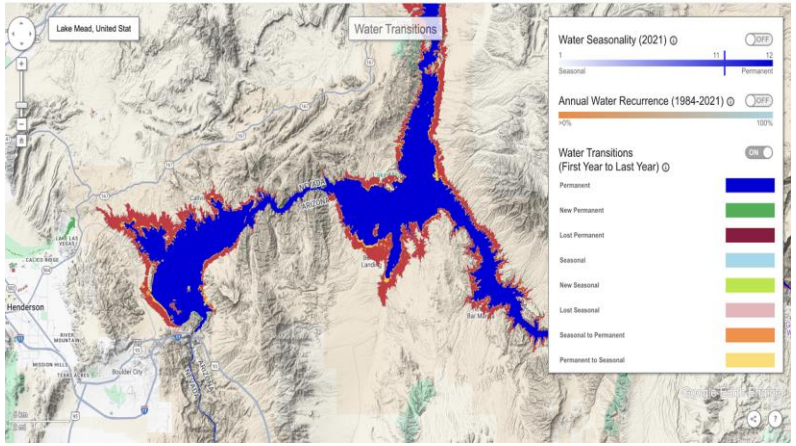
Credit: U.S. Geological Survey, Water Science School. https://www.usgs.gov/special-topic/water-science-school
Data source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources. (Numbers are rounded).

Image Source: USGS

Remote Sensing of Surface Water

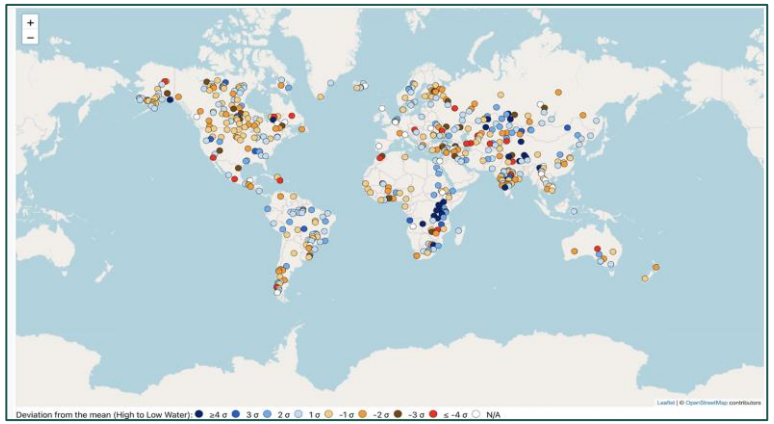
- Global surface water extent has been mapped by using optical satellite observations (e.g., from Landsat series, Aqua & Terra MODIS)[1].
- A series of NASA satellites launched from 1992 onwards with altimeter observations have been used to estimate ocean surface and inland lake (area > 50 km^2) surface heights[1].
- The latest NASA mission, **Surface Water and Ocean Topography (SWOT)**, launched on December 16, 2022, allows global surface freshwater mapping, including rivers, lakes, and wetlands, with high resolution measurements (~200 m).

Change in Lake Mead Surface Water Extent



Global Surface Water Explorer

Deviation in Lake Level Height



Global Water Measurements Portal

[1] ARSET - Mapping and Monitoring Lakes and Reservoirs with Satellite Observations

Training Learning Objectives

By the end of this training, participants will be able to:

- Identify available historic and current lake elevation data using satellite remote sensing.
- Recognize key science and technology advances behind how Surface Water and Ocean Topography (SWOT) measures surface water bodies.
- Identify ways to access SWOT data for water resources and disaster management applications, monitoring parameters such as elevation, slope, width, and discharge for global river reaches.
- Identify ways to apply SWOT data for water resources and disaster management applications.
- Learn how to utilize the SWOTviz and WISP data visualization tools.

Prerequisites

- Fundamentals of Remote Sensing
- Mapping and Monitoring Lakes and Reservoirs with Satellite Observations

Training Outline

Part 1

Overview of Remote Sensing Observations for Monitoring Global Terrestrial Surface Water in Large Rivers and Lakes

May 13, 2025

11:00–12:30 EDT (UTC-4)

Part 2

SWOT Mission Applications and Access for Retrieving, Visualizing, and Manipulating Data

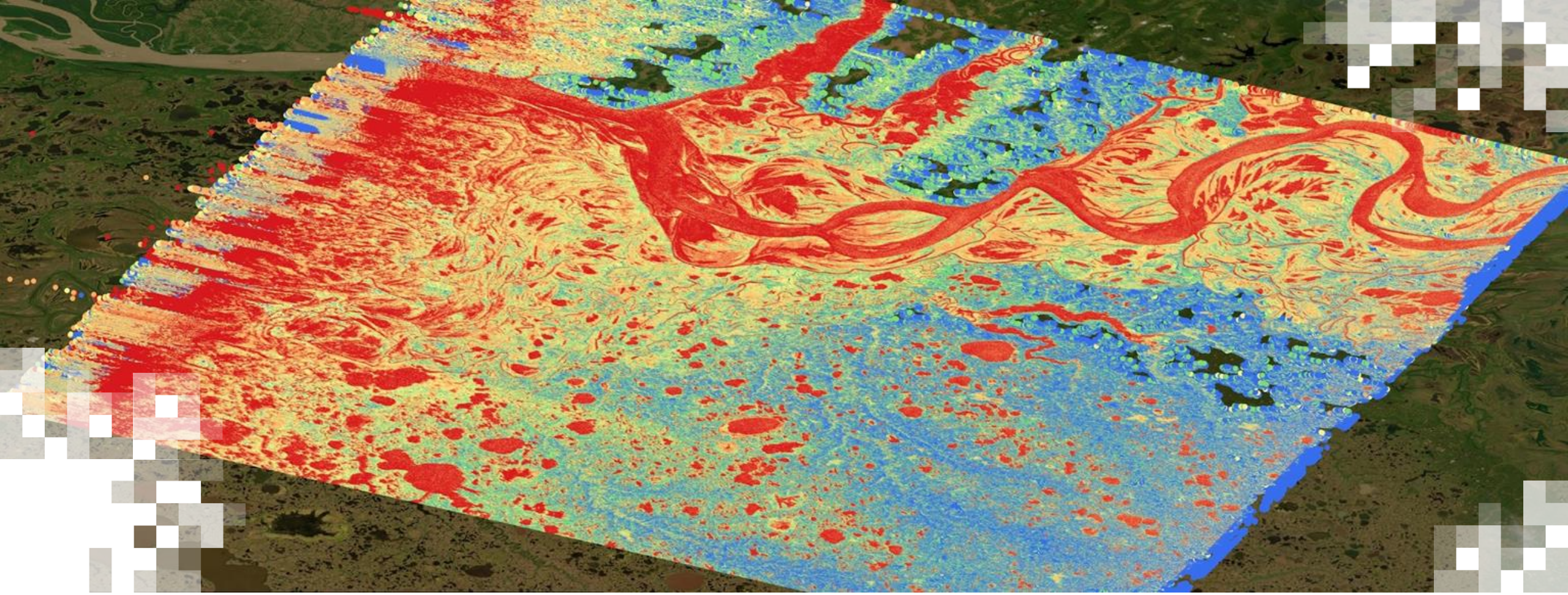
May 15, 2025

11:00–12:30 EDT (UTC-4)

Homework

Opens May 15 – **Due May 31** – Posted on Training Webpage

A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment before the given due date.



Monitoring Global Terrestrial Surface Water using Remote Sensing

Part 1: Overview of Remote Sensing Observations for Monitoring Global Terrestrial Surface Water in Large Rivers and Lakes

Part 1 Objectives

By the end of Part 1, participants will be able to:

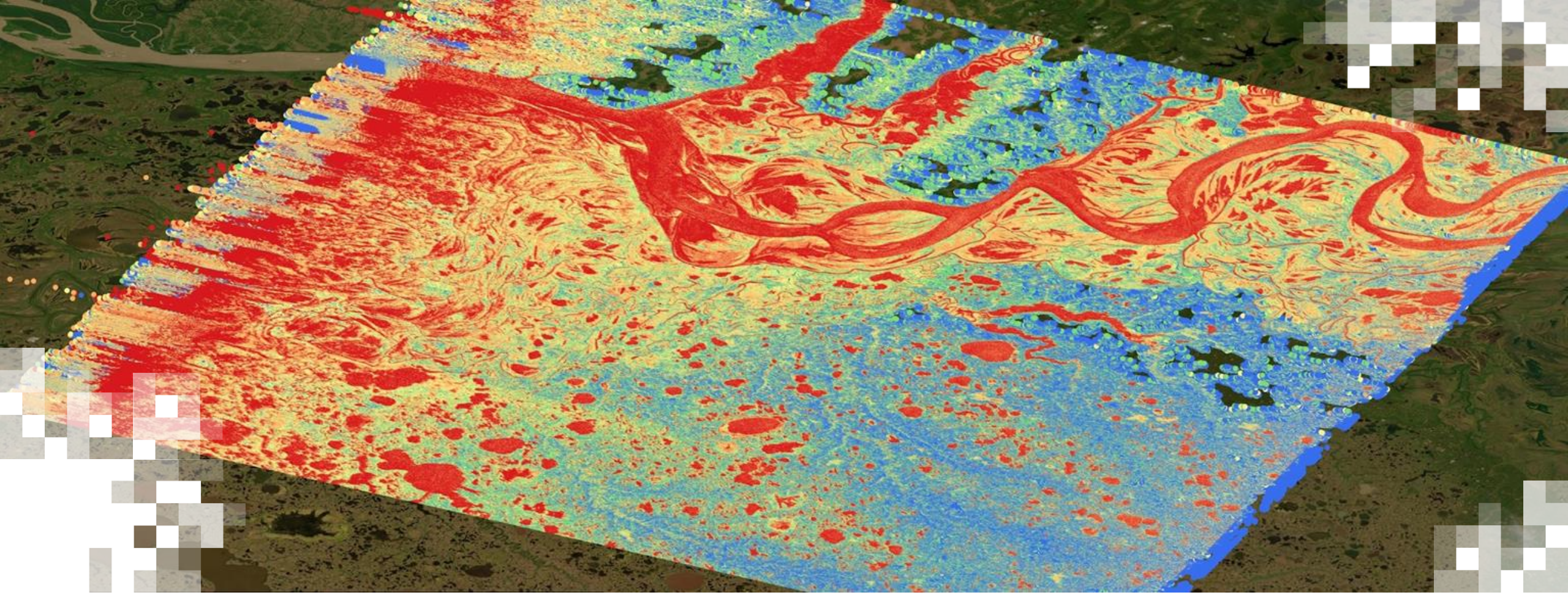
- Identify available historic and current lake elevation data using satellite remote sensing.
- Recognize key scientific and technological advances behind how SWOT measures surface water bodies.
- Identify ways to access SWOT data for water resources and disaster management applications.

Part 1 Outline

- Overview of Lake Level Elevation Data
  Demonstration: Global Water Meaurements
- Overview of SWOT Mission
- SWOT Data Products
- Demonstration: Data Access and Download
- SWOT Tools and Resources
- SWOT Applications

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 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.



Overview of Lake Level Elevation Data

What is an Altimeter?

- Altimetry is a technique for measuring height. A radar used for altimetry is called an altimeter.
- The time taken by a radar pulse to travel from the satellite antenna to the surface and back (radar echo), combined with precise satellite location data, is measured in altimetry.
- Satellite radar altimeters are used to get sea-surface heights, winds speed, and currents.

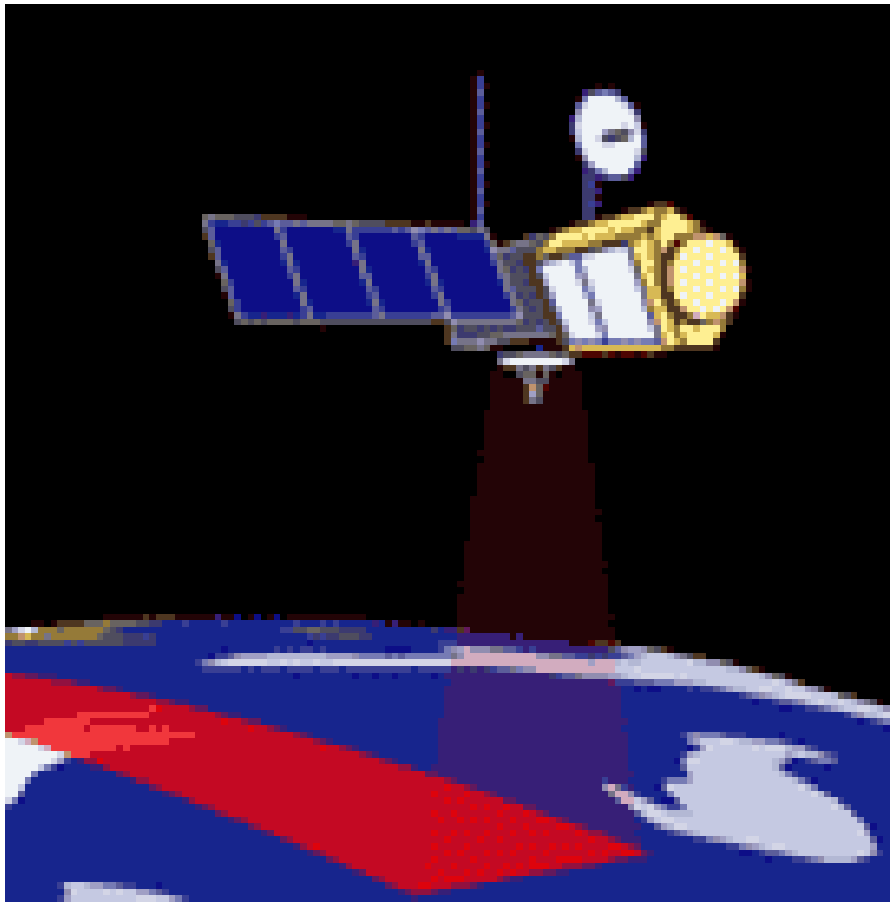


Image Source: JPL

Historical and Current Missions with Radar Altimeter

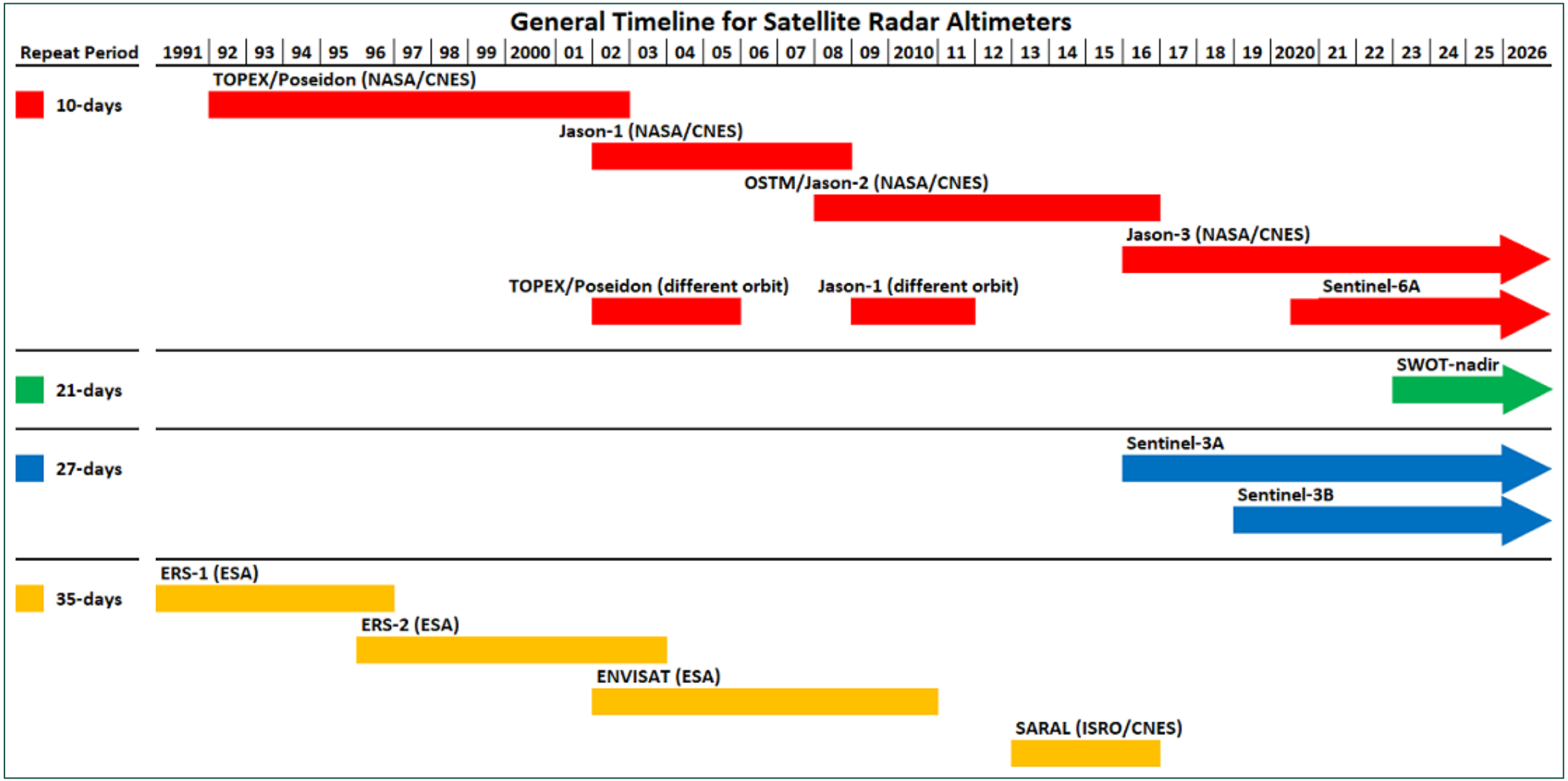


Image Source: USDA-FAS

Altimeter-Based Lake Level Height Data

- Derived from the difference between satellite orbit height and altimeter range (Birkett, 1995) with appropriate corrections for the Earth's tides.
- Generally, use Ku or Ka band Radar.
- Average height over a pixel is derived.
- Sensitive to satellite orbit accuracy, radar range accuracy, and lake surface conditions (e.g., calm and smooth, rough due to winds, icy).

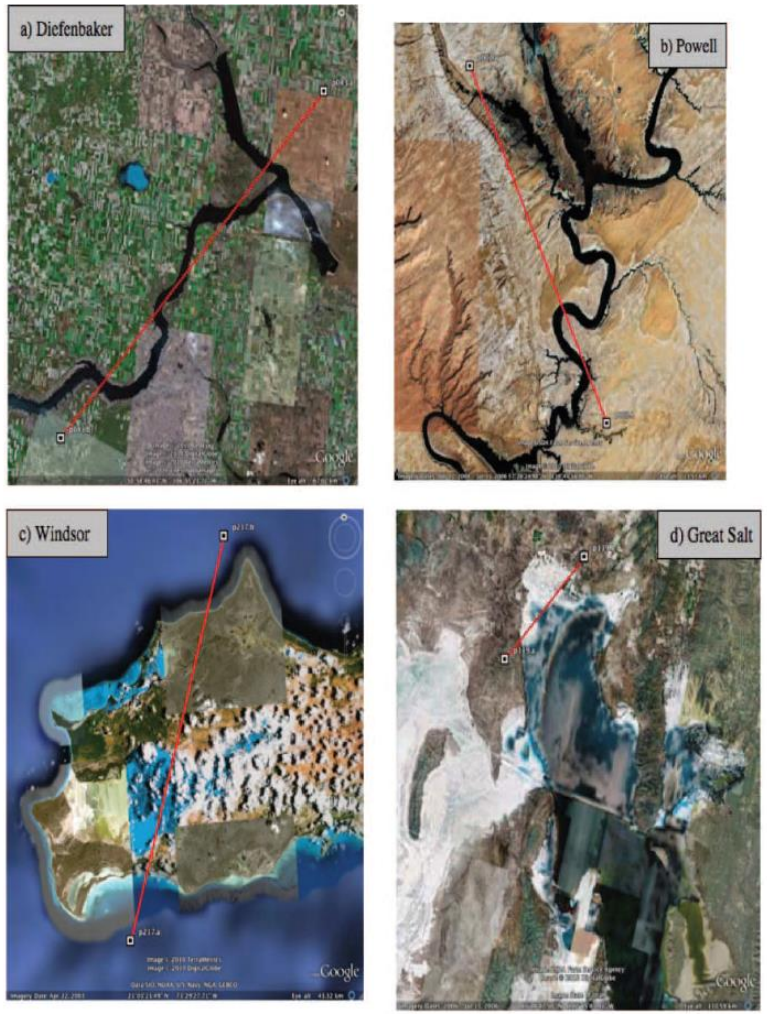


Figure 7. Satellite imagery depicting Jason-2/OSTM ground track locations (in red) across **(a)** Lake Diefenbaker, **(b)** the Powell reservoir region, **(c)** Lake Windsor, and **(d)** Great Salt Lake. Images are courtesy of the 2009 Google Earth software and Maps service.

Birkett and Beckley, 2010

ICESat-2 Laser Altimeter

Status:

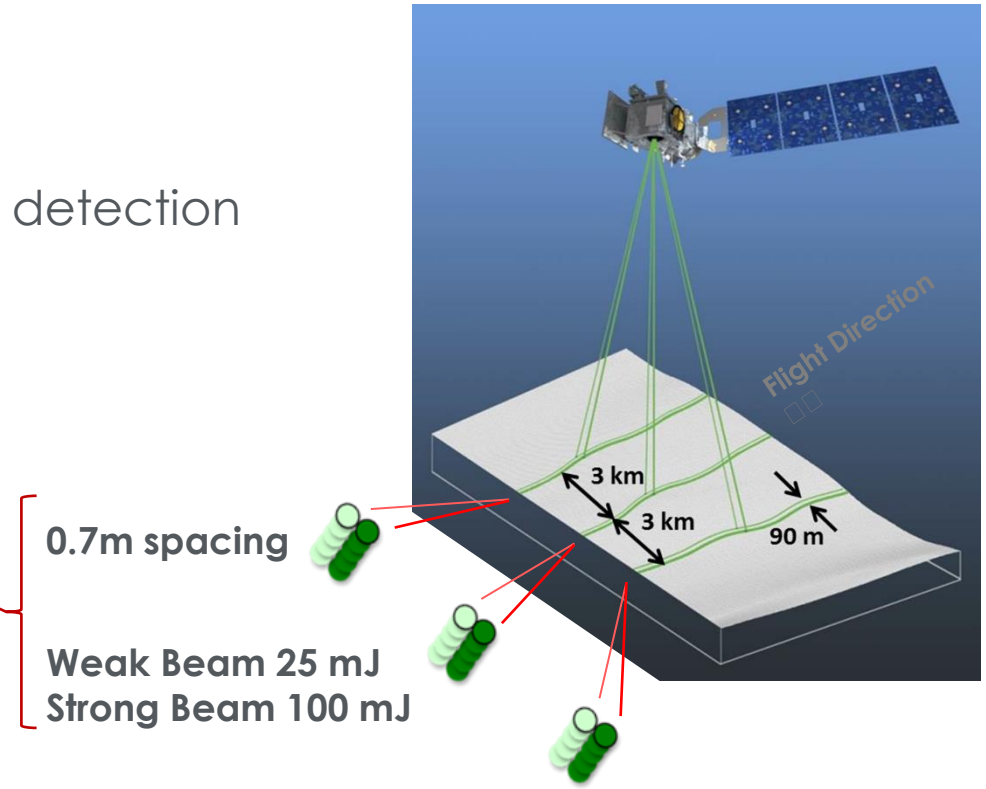
- Launched Sept 15, 2018
- Data products since Oct 15, 2018

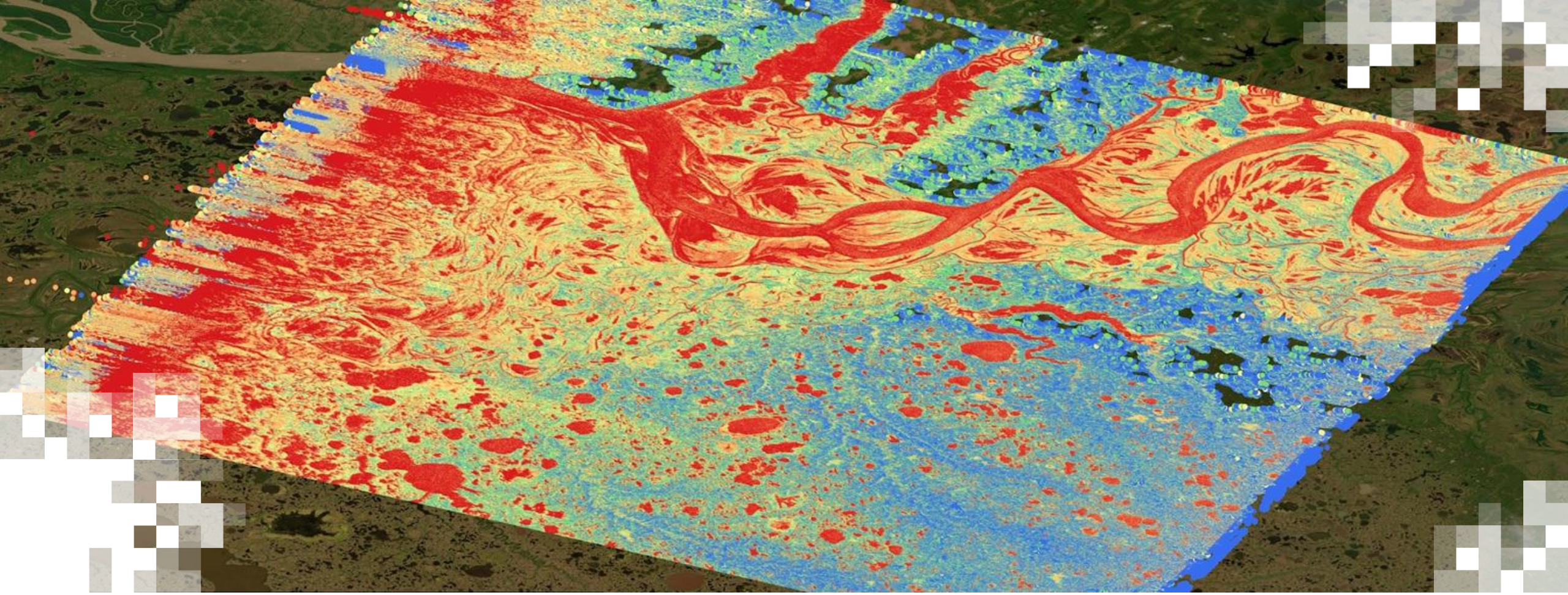
Instrument:

- **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-synchronous, 92° inclination
- 91 day repeat cycle, ~30-day sub cycle
- Geolocation knowledge: 6.5 m



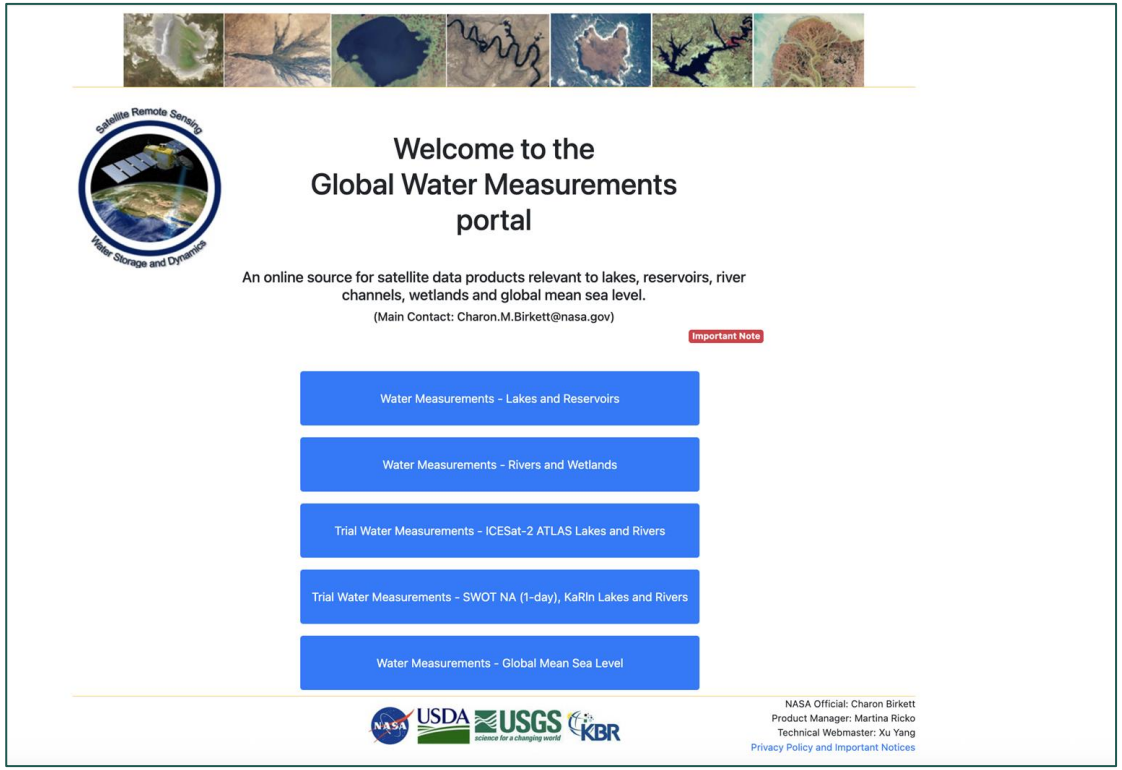


Demonstration

[Global Water Measurements]

Global Water Measurements: Monitor Lake Level Height and Area

- Demonstration: How to access, download, and visualize data
- Case Studies
  - Lake Powell, USA
  - Lake Nassar, South Egypt/North Sudan



[Global Water Measurements Website]

Part 1 – Trainers

Matthew Bonnema, PhD

SWOT Mission Applications Lead

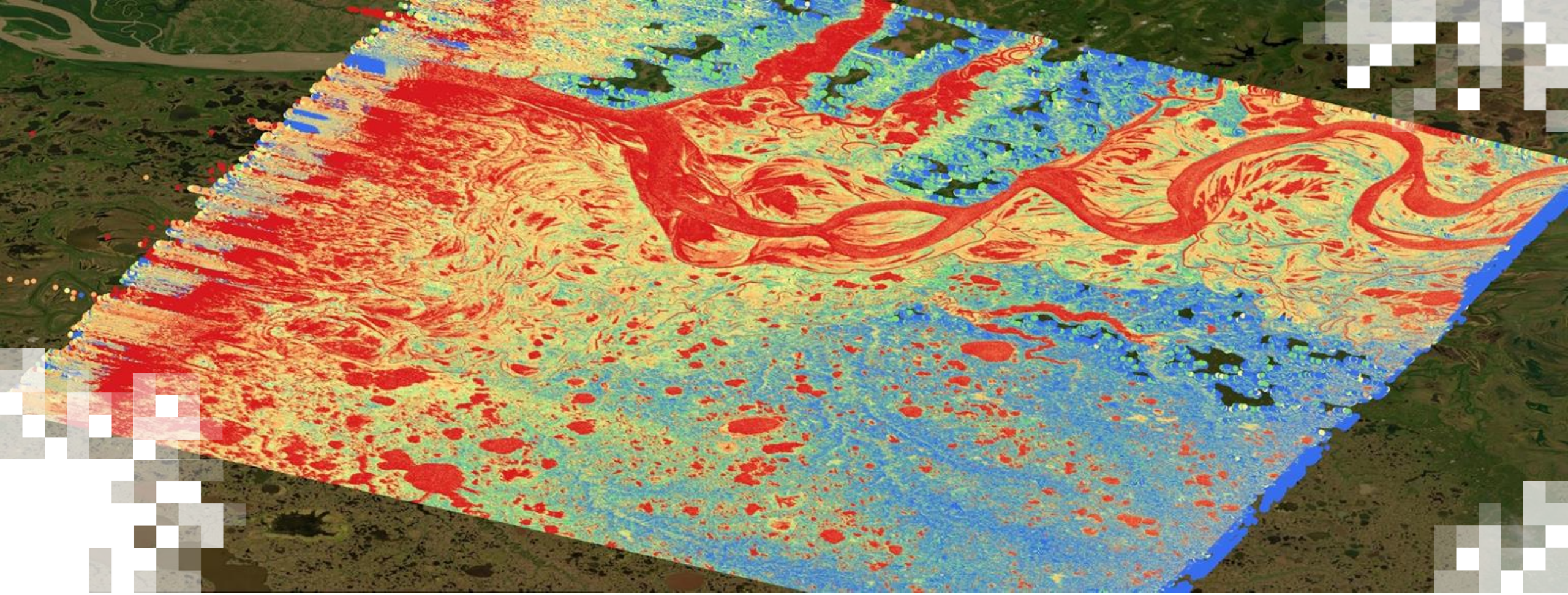
NASA JPL, Caltech

Angelica Rodriguez, PhD

SWOT Project Applications Lead

NASA JPL, Caltech

SWOT Training Coordinator



Overview of SWOT Mission

SWOT measures global **ocean** surface topography and **land surface water** extents & elevation with great accuracy using interferometry.

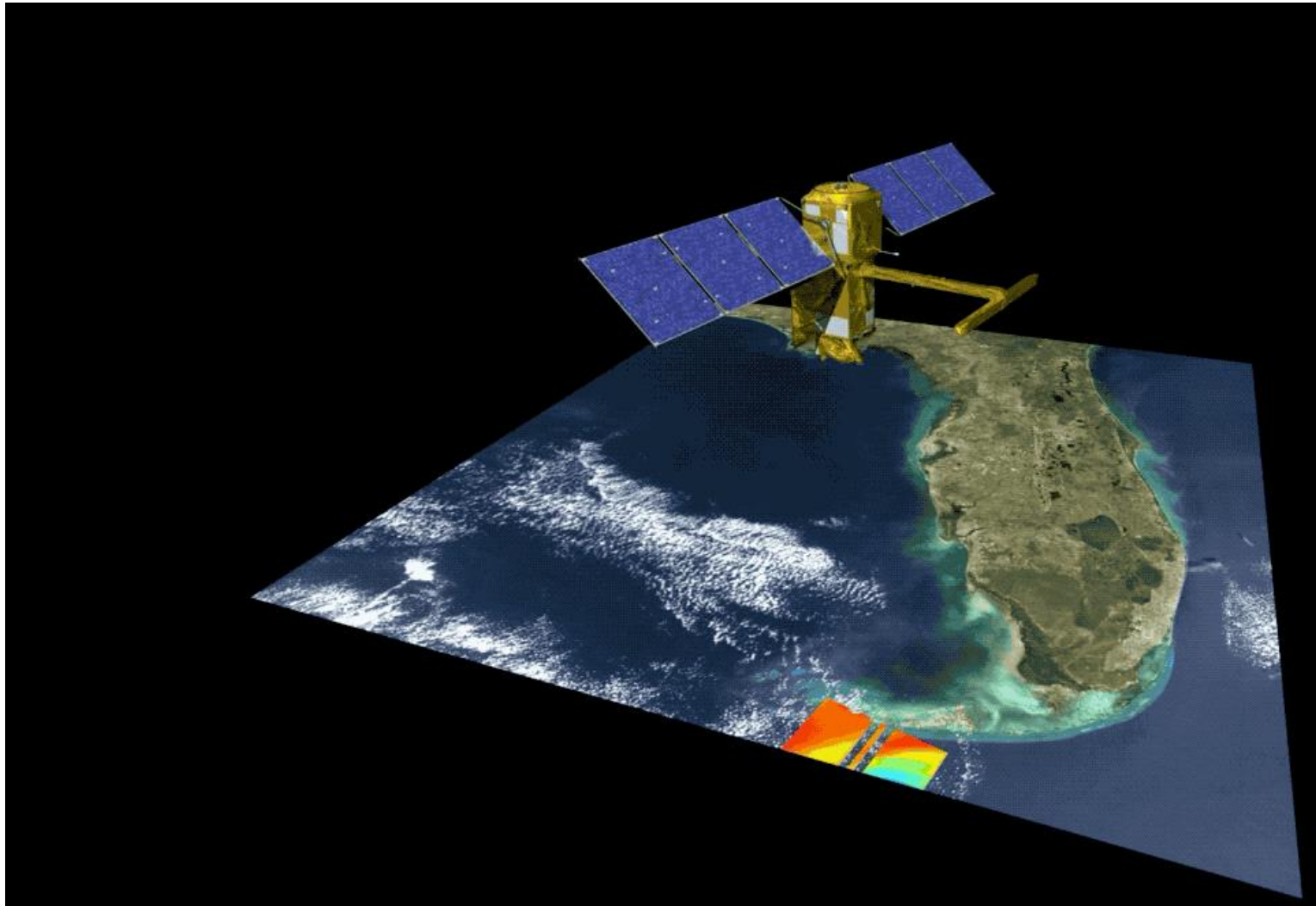


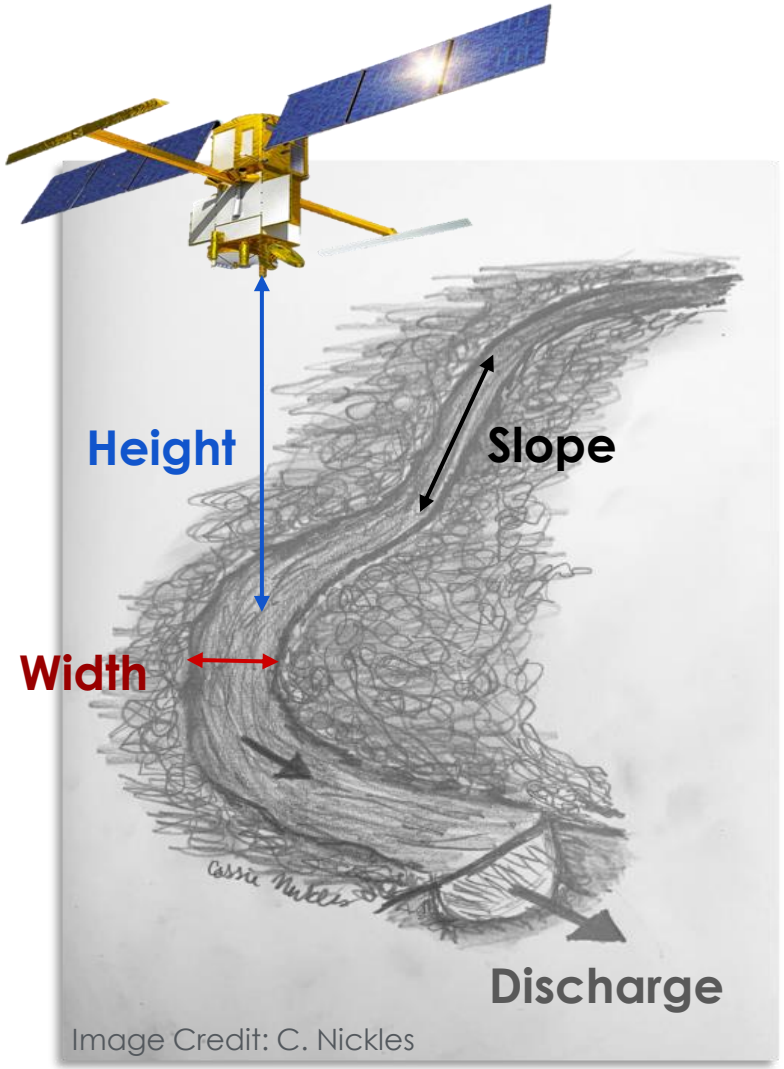
Image Credit: https://swot.jpl.nasa.gov

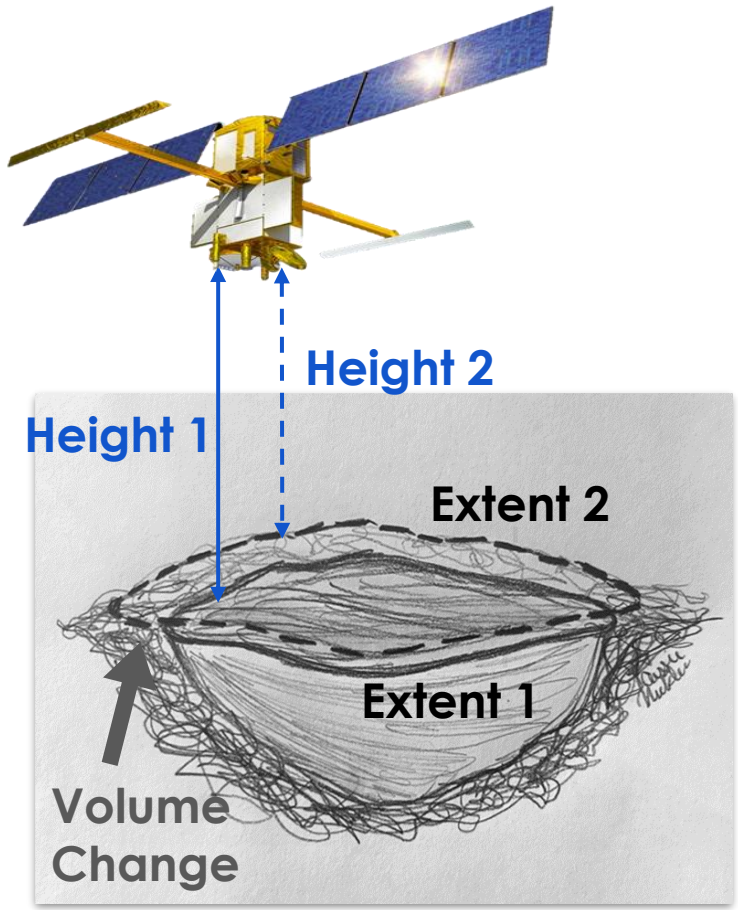
SWOT Launched Dec 2022!

21-Day Orbit Cycle (Average 2 observations per cycle)

78° N/S Latitudinal Coverage

Hydrology Measurements Simplified





Requirements:
Rivers > 100 m wide
Lakes > 250 m^2

Future Derived Products:

- River Flow (i.e., Discharge)
- Lake/Reservoir Volume Change

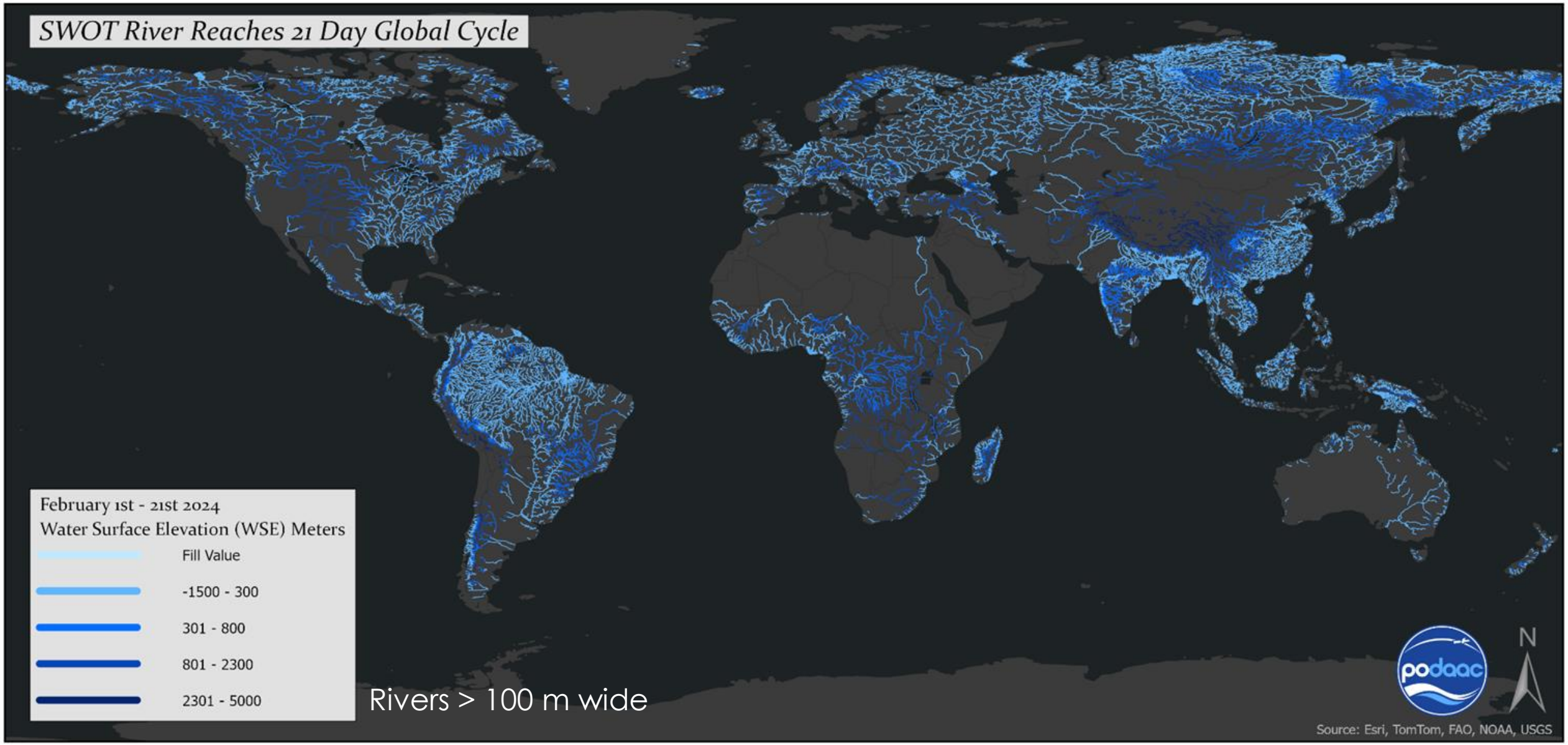
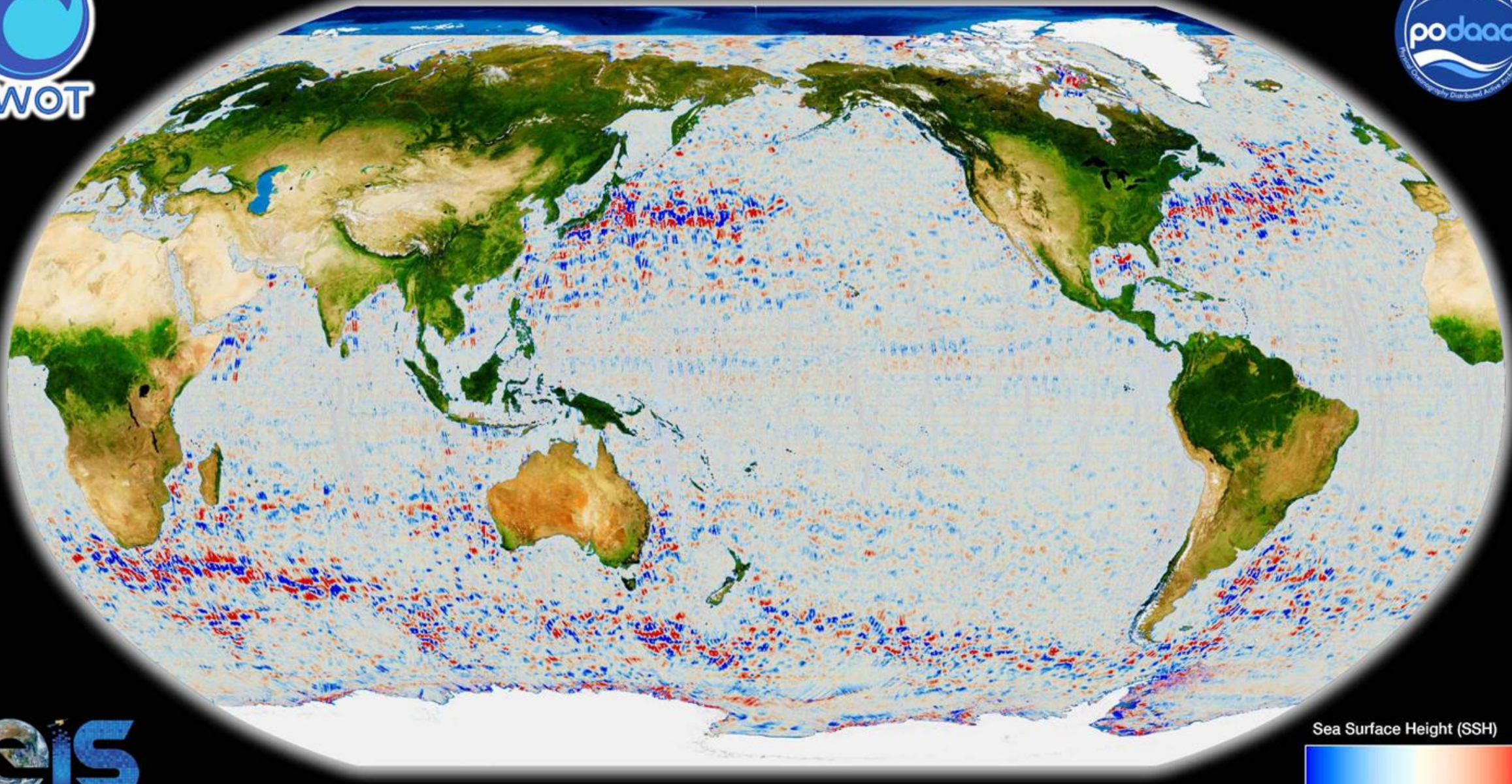


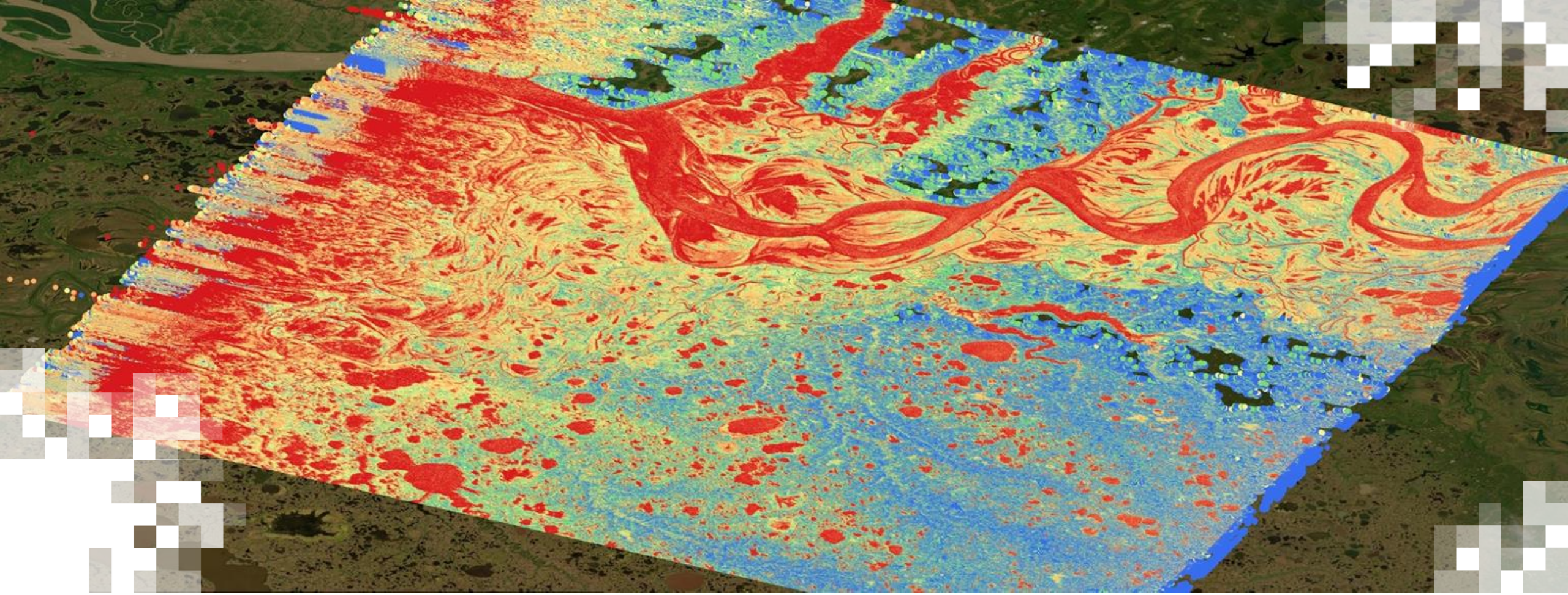
Image Credit: N. Tarpinian

Oceanography – Sea Surface Height



Resolutions below 10 km!

Data start: 2023-07-26T14:12:39
end: 2023-08-16T14:17:18



SWOT Data Products, Data Access, and Download

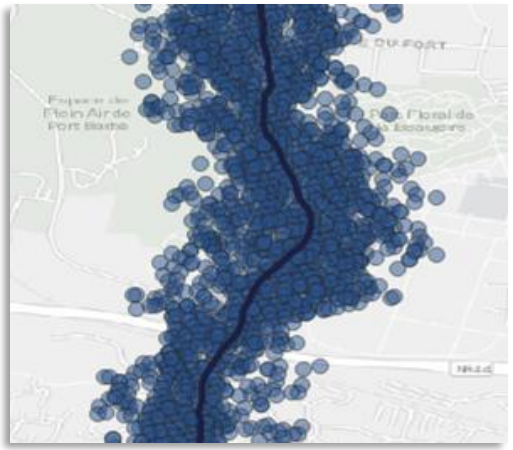
Hydrology-Relevant Level 2 SWOT Products

• Water Mask Pixel Cloud NetCDF	**L2_HR_PIXC**
• Pixel Cloud Vector Attribute NetCDF	**L2_HR_PIXCVec**
• Raster NetCDF	**L2_HR_Raster**
• River Vector Shapefile	**L2_HR_RiverSP**
• Lake Vector Shapefile	**L2_HR_LakeSP**
• Cycle Average River Vector Shapefile	**L2_HR_RiverAvg**
• Cycle Average Lake Vector Shapefile	**L2_HR_LakeAvg**
• Floodplain Digital Elevation Model	**L2_HR_FPDEM***

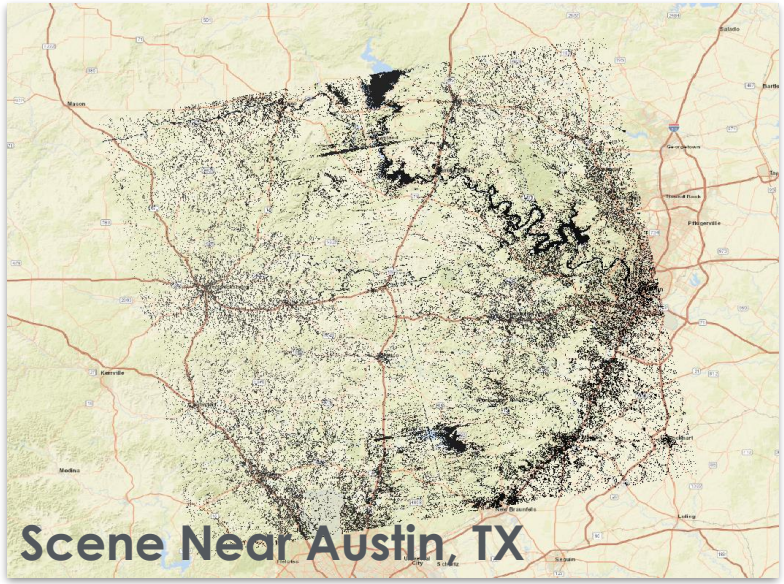
* Available >2 years after launch

Hydrology-Relevant Level 2 SWOT Products

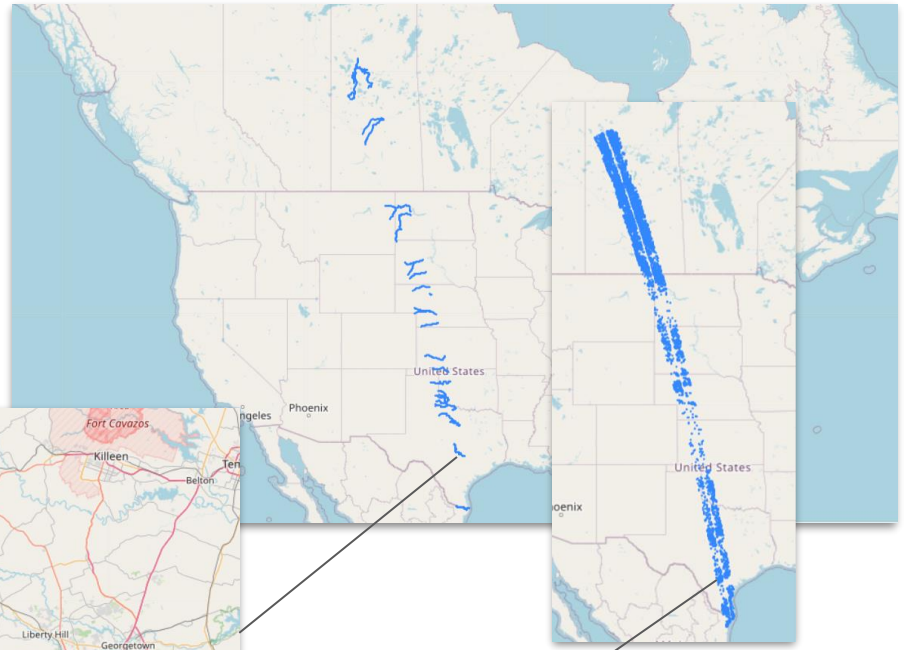
Pixel Cloud NetCDF

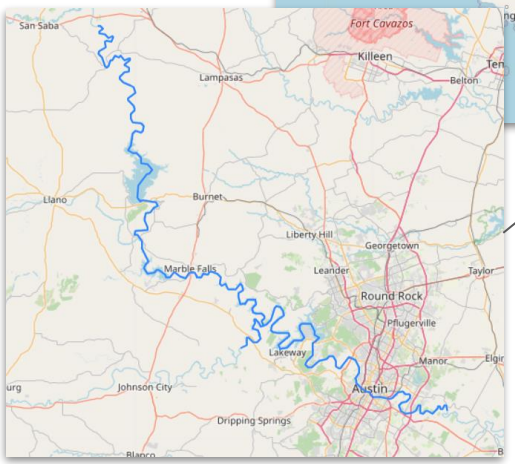


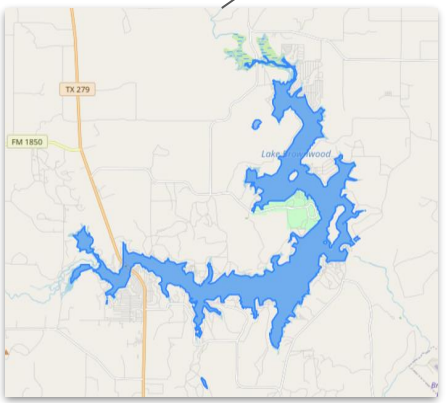
Raster NetCDF



River Vector Shapefile





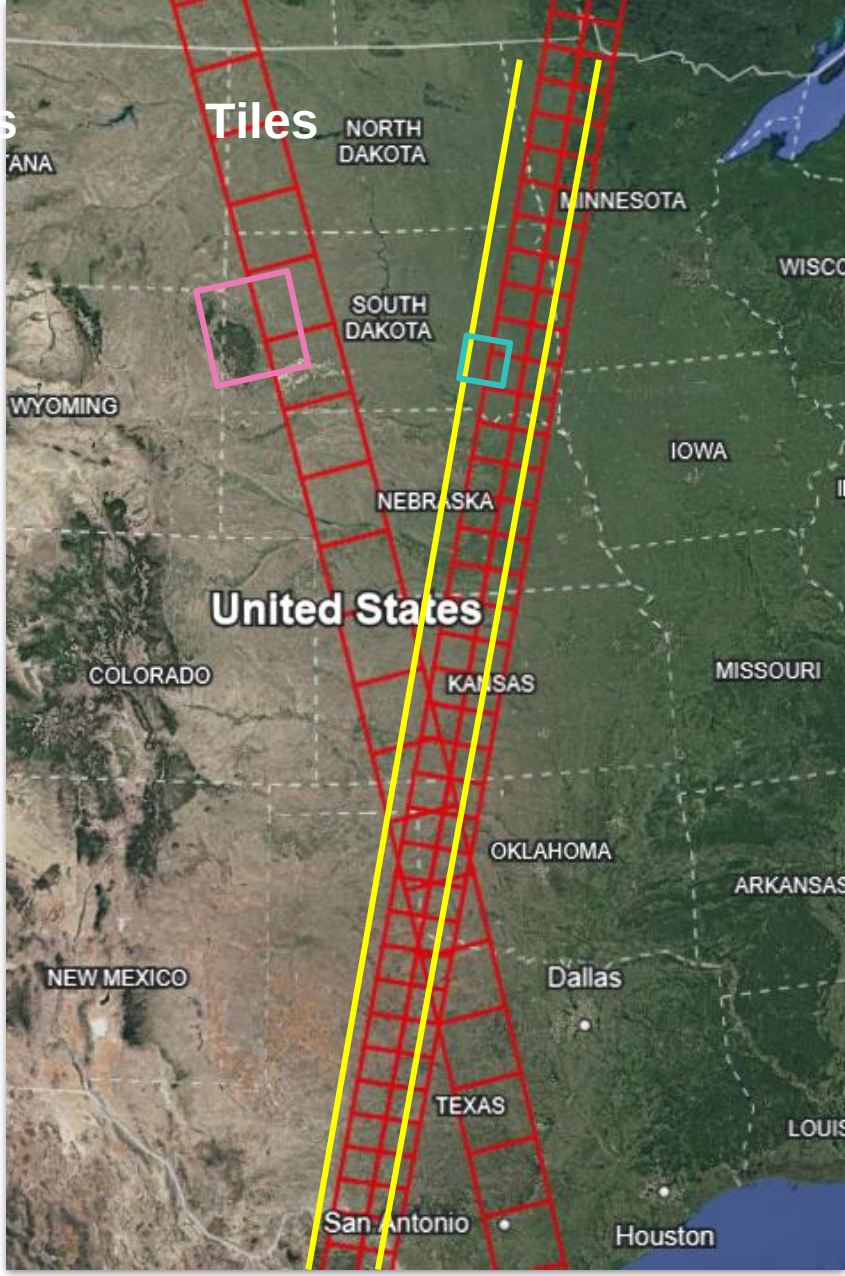


Lake Vector Shapefile

Spatial Extent Formats

- Swath – Half-Globe Orbit Track
- Tile – 64x64 km^2; Half Swath Width
- Scene – 128x128 km^2, Georeferenced; Full Swath Width
  - Scene Number x 2 = Tile Number

Tip: More Here
https://podaac.github.io/tutorials/quarto_text/SWOT.html#tips-for-swot-hr-spatial-search



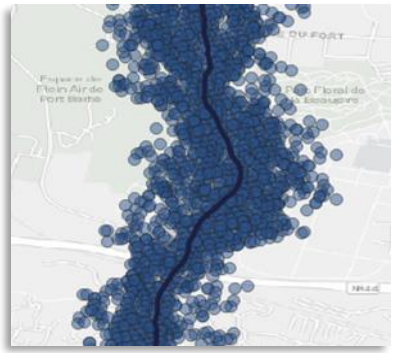
SWOT_L2_HR_PIXC (NetCDF)

Description: Point cloud of water mask pixels ("pixel cloud")

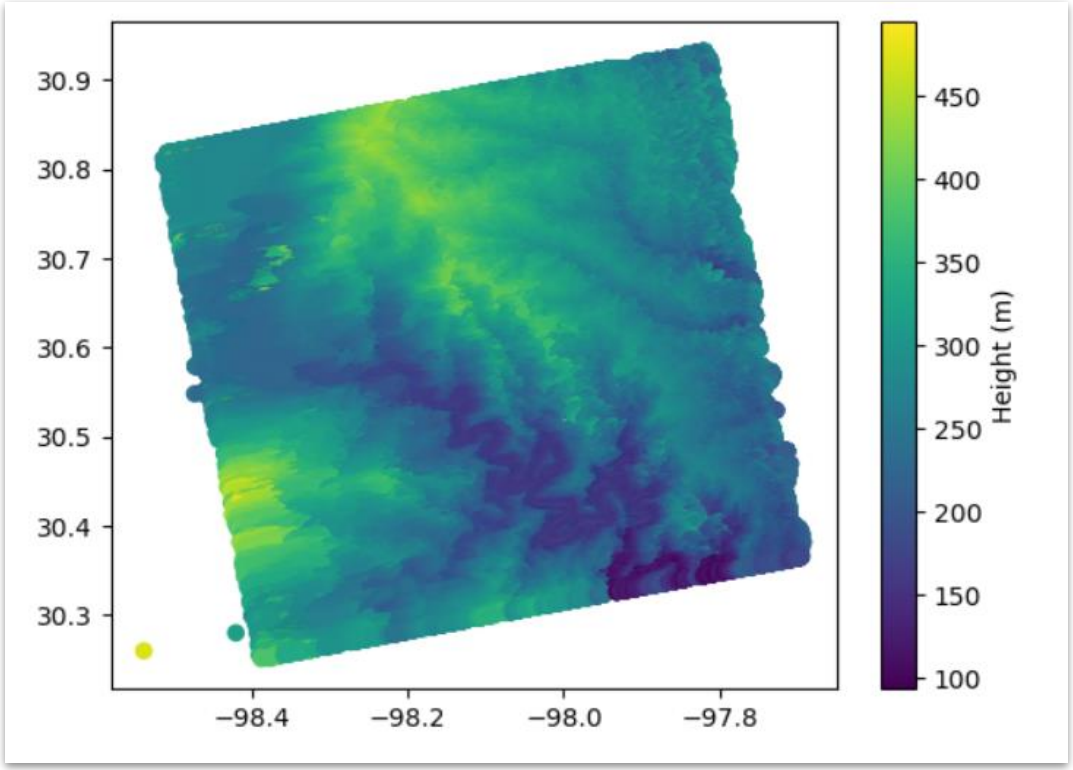
Spatial Extent Format: Tile (64x64 km^2)

Select Variables: Geolocated heights, backscatter, geophysical fields, and flags

Subcollections: N/A



Example River Pixels



Colorado River Near Austin, TX

SWOT_L2_Raster (NetCDF)

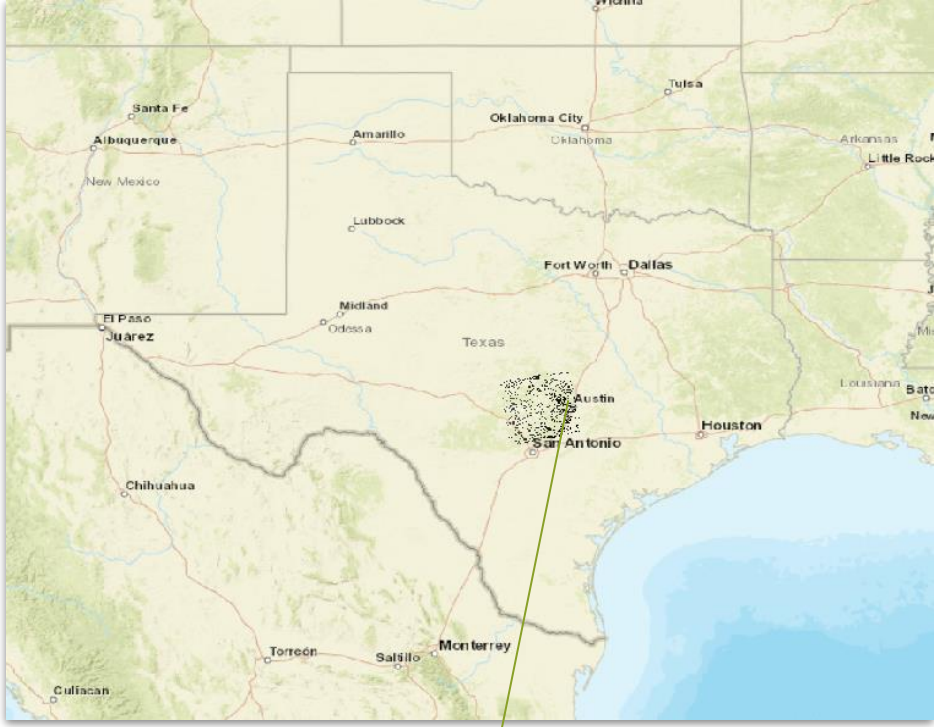
Description: Geographically fixed rasterized water surface elevation and inundation extent.

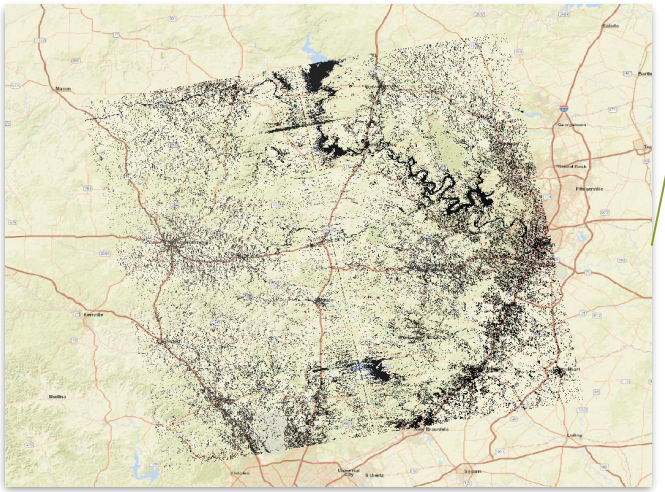
Spatial Extent Format: Scene (128x128 km^2)

Select Variables: Water Surface Elevation, Area, Water Fraction, Backscatter, Geophysical Information

Subcollections:

- SWOT_L2_Raster_100m
- SWOT_L2_Raster_250m





Scene Near Austin, TX

SWOT_L2_RiverSP (Shapefile)

Description: Vectors of river reaches (~10 km long) and nodes (~200 m spacing) in prior river database.

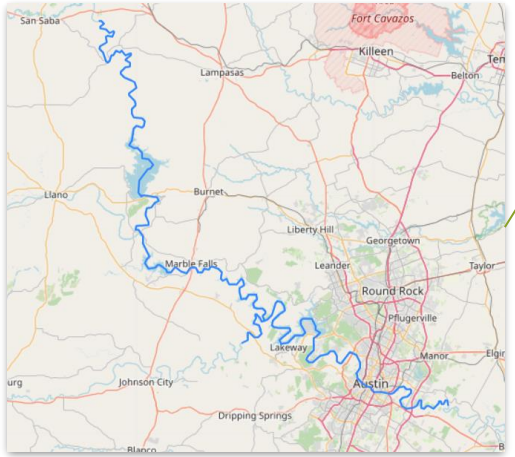
Extent Format: Continent-Scale Swath

Variables: Water Surface Elevation, Slope, Width, Derived Discharge*

Subcollections:

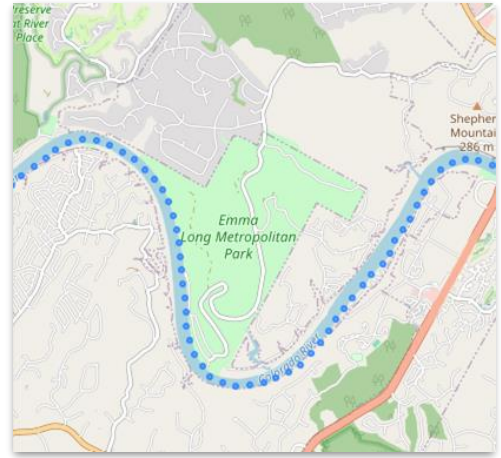
- SWOT_L2_RiverSP_reach
- SWOT_L2_RiverSP_node

* Included ~2 years after launch



Reach File

Colorado River near Austin, TX



Node File

SWOT_L2_LakeSP (Shapefile)

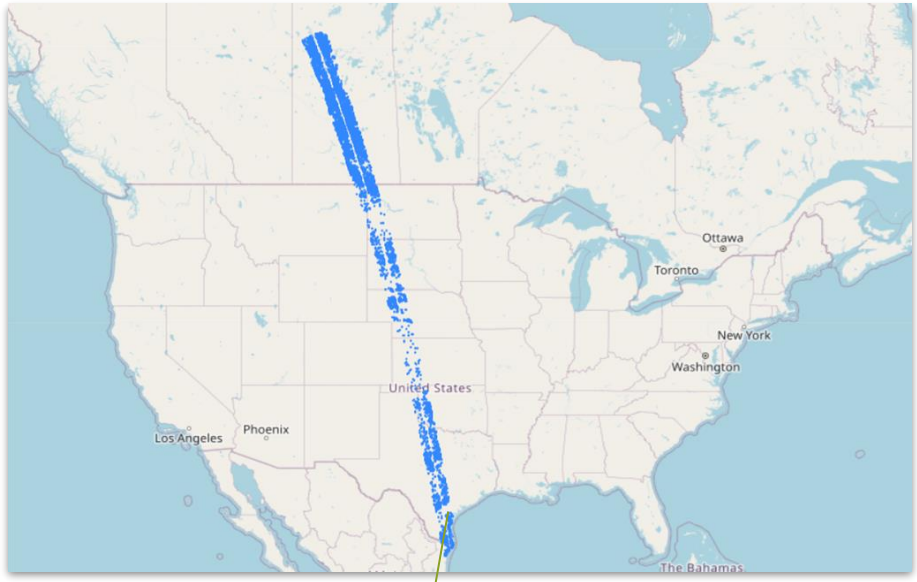
Description: Vectors of lakes in prior lake database and detected features not in the prior river or lake databases.

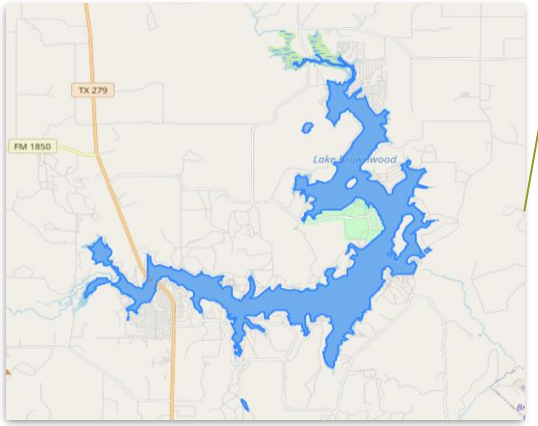
Extent Format: Continent-Scale Swath

Select Variables: Water Surface Elevation, Area, Derived Storage Change

Subcollections:

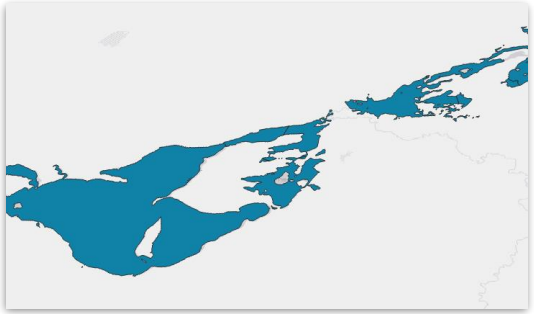
- SWOT_L2_LakeSP_obs
- SWOT_L2_LakeSP_prior
- SWOT_L2_LakeSP_unassigned





Lake Brownwood, TX

Observed, Prior, & Unassigned Lakes



SWOT Level-2 Data

L2_HR_RiverAvg (Shapefile)
Cycle average and aggregation of river reach pass data within predefined hydrological basins.

L2_HR_LakeAvg (Shapefile)
Cycle average and aggregation of lake pass data within predefined hydrological basins.

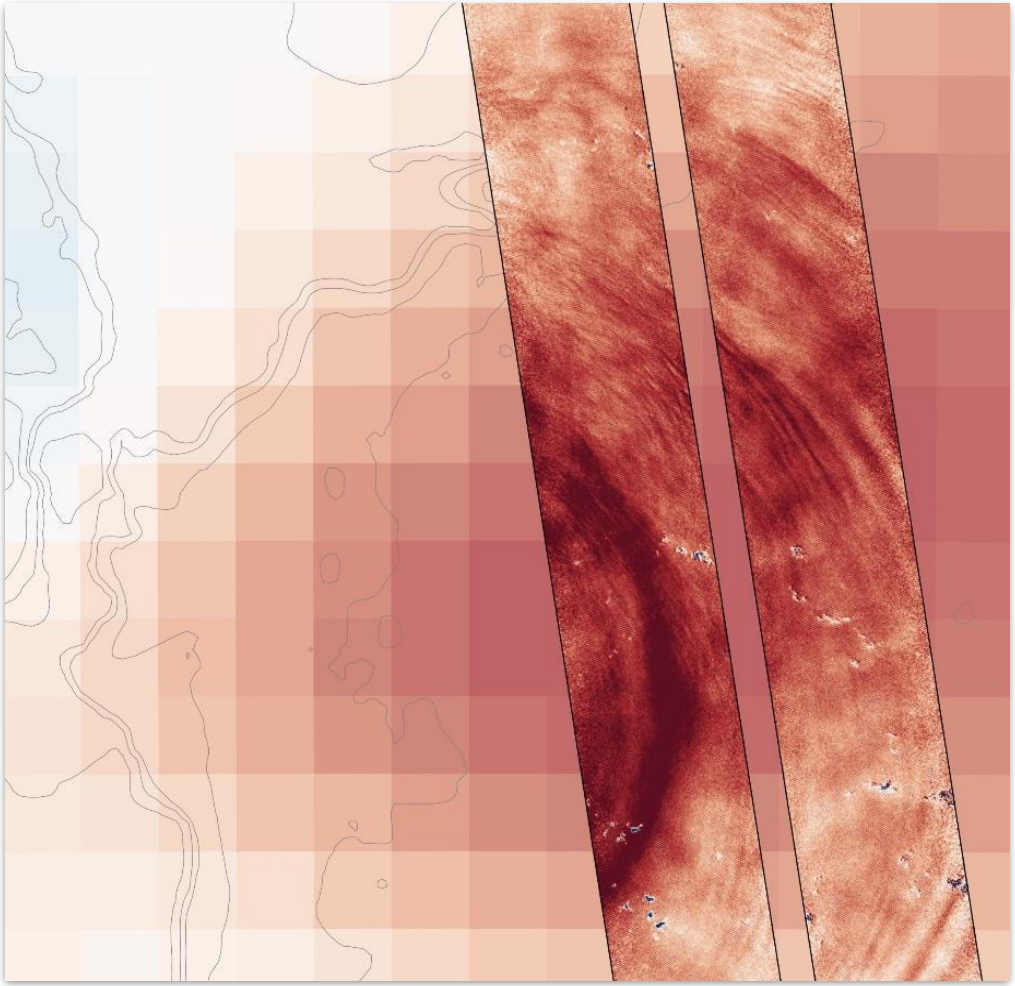
L2_HR_FPDEM* (NetCDF)
Flood Plain Digital Elevation Map in raster format, derived from multiple cycles of SWOT acquisitions (~50m resolution). Provides height and quality flag for each pixel.

* Available >2 years after launch

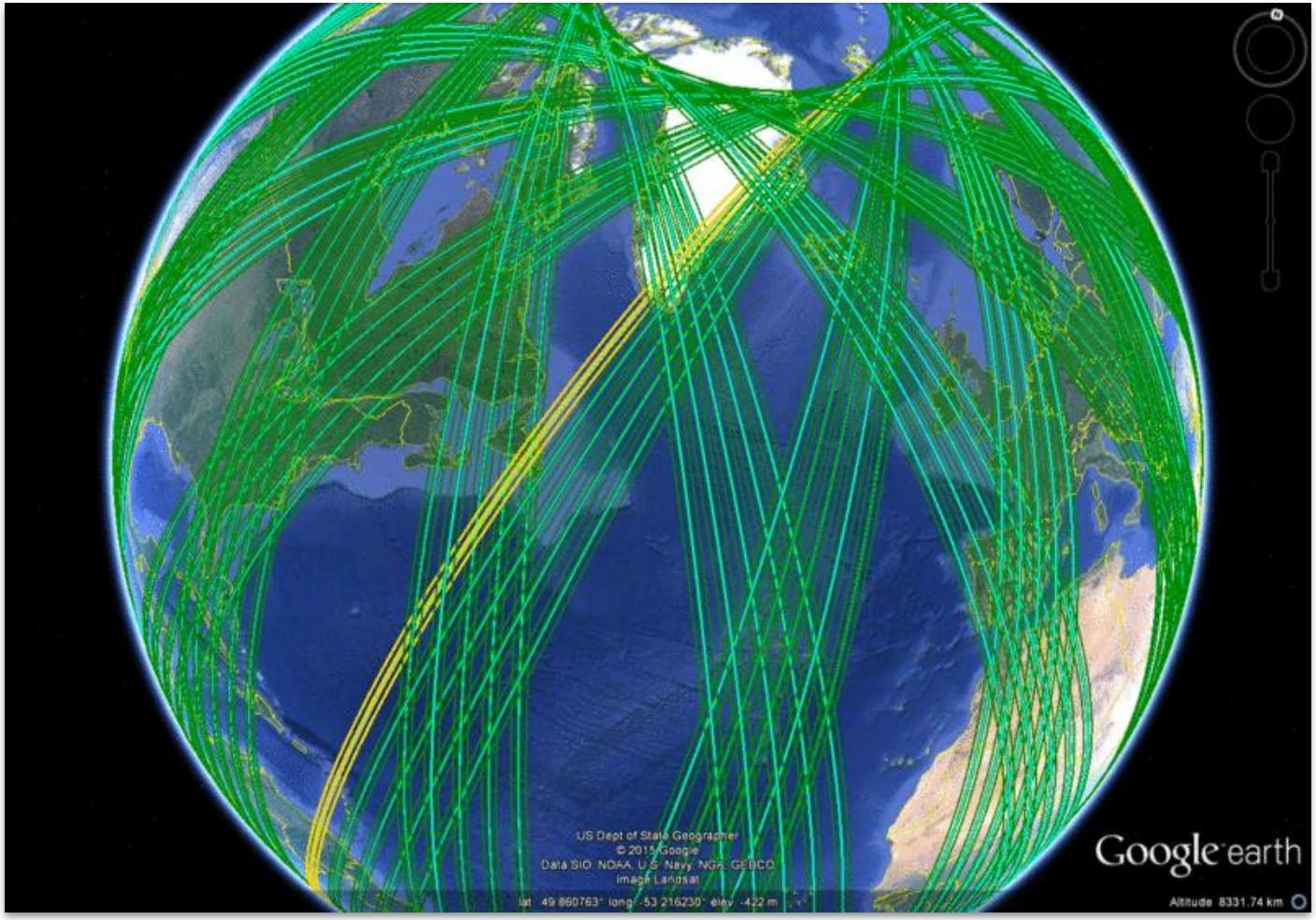
Oceanography-Relevant SWOT Products

- Operational Radiometer NetCDF **L2_RAD_OGDR**
- Interim Radiometer NetCDF **L2_RAD_IGDR**
- Radiometer NetCDF **L2_RAD_GDR**
- Operational Nadir Altimetry NetCDF **L2_NALT_OGDR**
- Interim Nadir Altimetry NetCDF **L2_NALT_IGDR**
- Nadir Altimetry NetCDF **L2_NALT_GDR**
- KaRIn Sea Surface Height NetCDF **L2_LR_SSH**

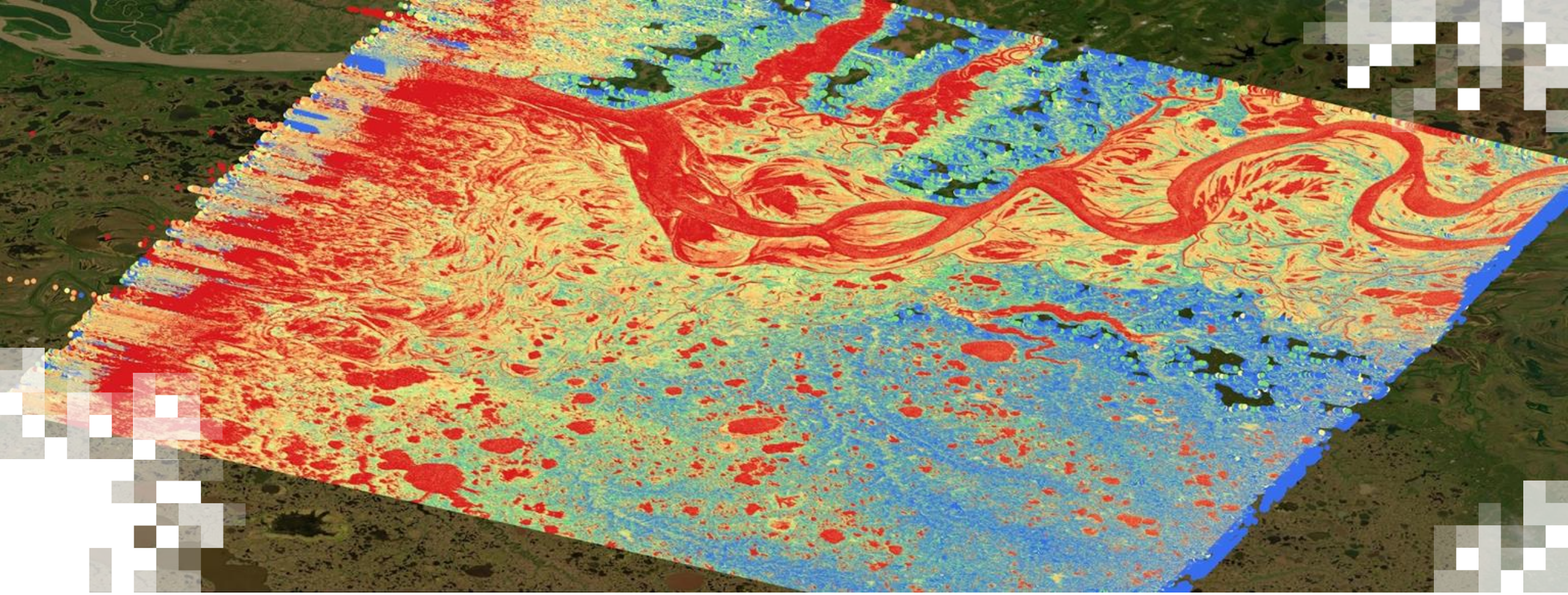
Oceanography-Relevant SWOT Products



KaRIn Sea Surface Height



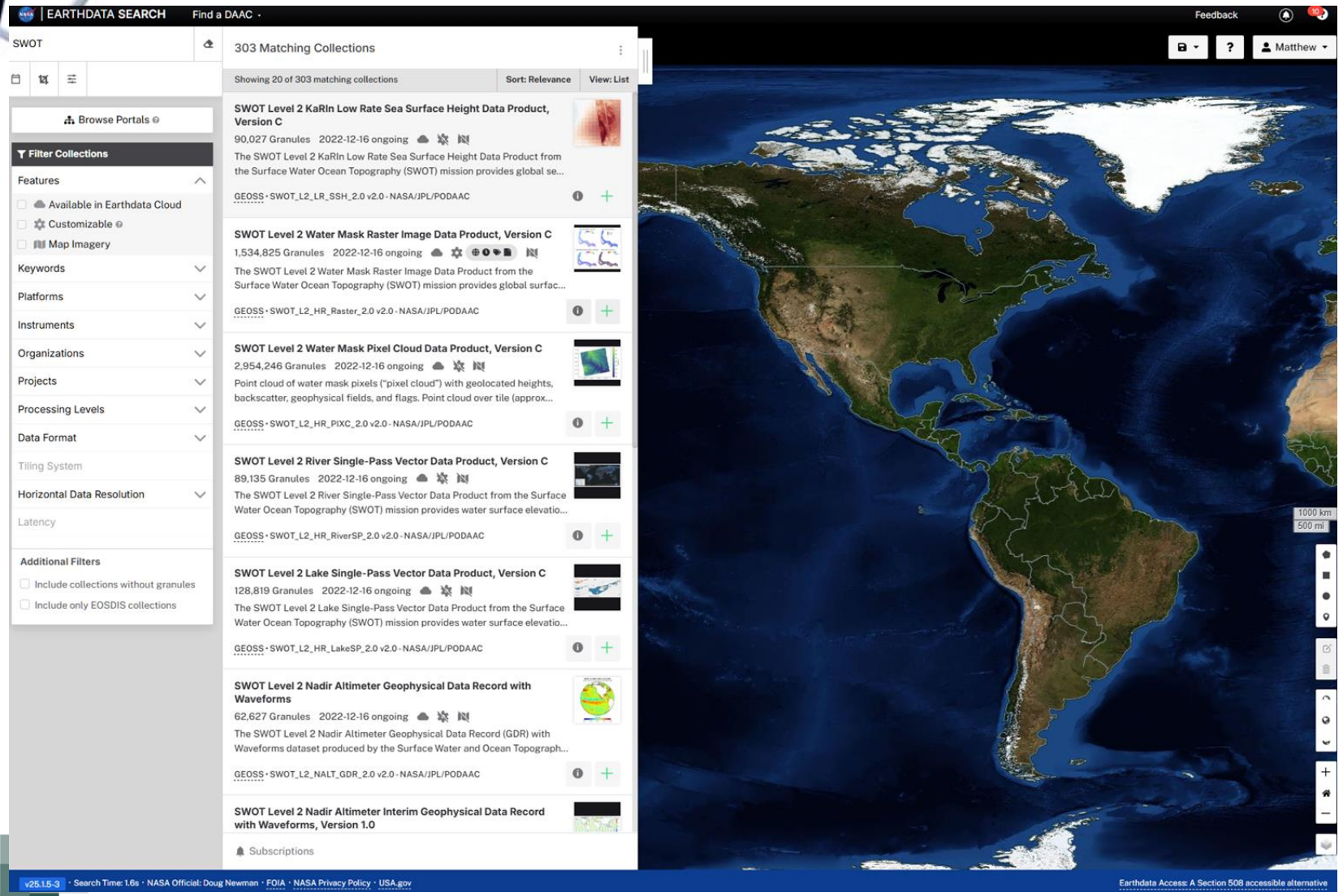
Radiometer & Nadir products



SWOT Data Access Demos

SWOT Data from Earth Data Search

https://search.earthdata.nasa.gov/search

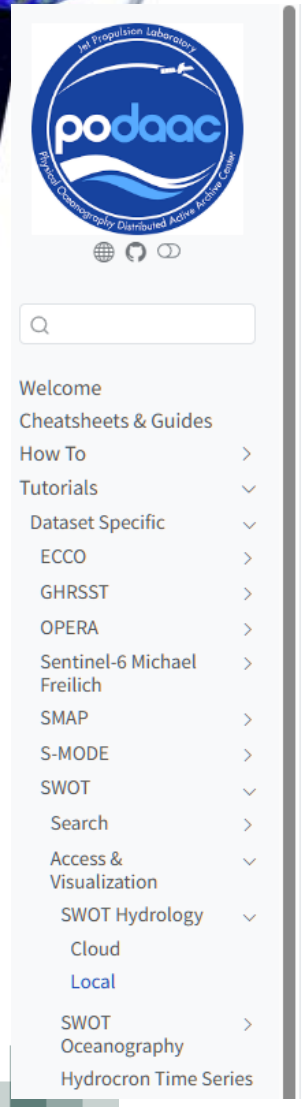


Web-Based User Interface:

- Search for datasets
- Subset by time and spatial extent
- Download selected products

Download and Visualize using Python

https://podaac.github.io/tutorials/quarto_text/SWOT.html



Tutorials > Dataset Specific > SWOT > Access & Visualization > SWOT Hydrology > Local

PO.DAAC Contribution

> From the PO.DAAC Cookbook, to access the GitHub version of the notebook, follow this link.

SWOT Hydrology Dataset Exploration on a local machine

Accessing and Visualizing SWOT Datasets

Requirement:

Local compute environment e.g. laptop, server: this tutorial can be run on your local machine.

Learning Objectives:

- Access SWOT HR data products (archived in NASA Earthdata Cloud) by downloading to local machine
- Visualize accessed data for a quick check

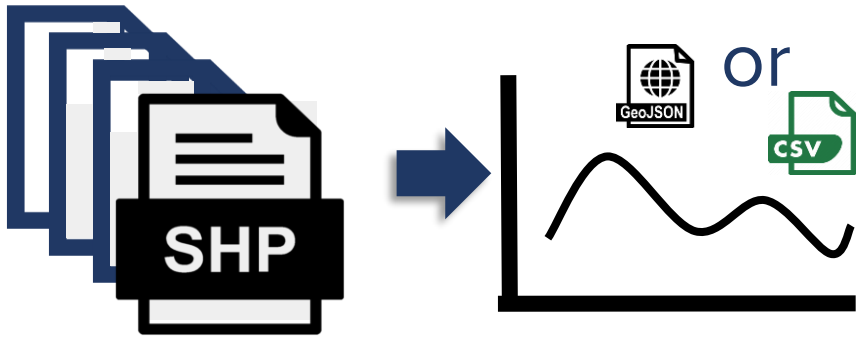
SWOT Level 2 KaRIn High Rate Version C (aka 2.0) Datasets:

1. **River Vector Shapefile** - SWOT_L2_HR_RIVERSP_2.0
2. **Lake Vector Shapefile** - SWOT_L2_HR_LAKESP_2.0
3. **Water Mask Pixel Cloud NetCDF** - SWOT_L2_HR_PIXC_2.0
4. **Water Mask Pixel Cloud Vector Attribute NetCDF** - SWOT_L2_HR_PIXCVec_2.0
5. **Raster NetCDF** - SWOT_L2_HR_Raster_2.0
6. **Single Look Complex Data product** - SWOT_L1B_HR_SLC_2.0

Jupyter Notebook:

- Python library for searching and downloading data from NASA Earth Data
- Visualization of downloaded SWOT data products

Hydrocron Timeseries API

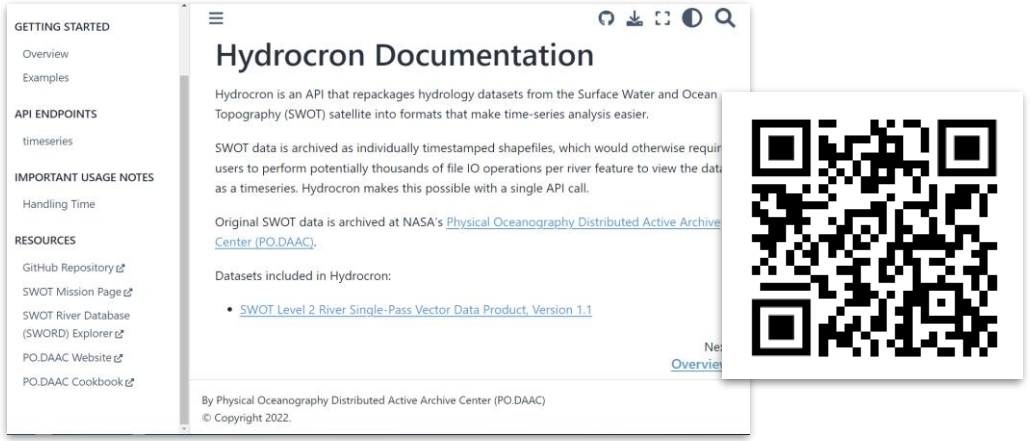


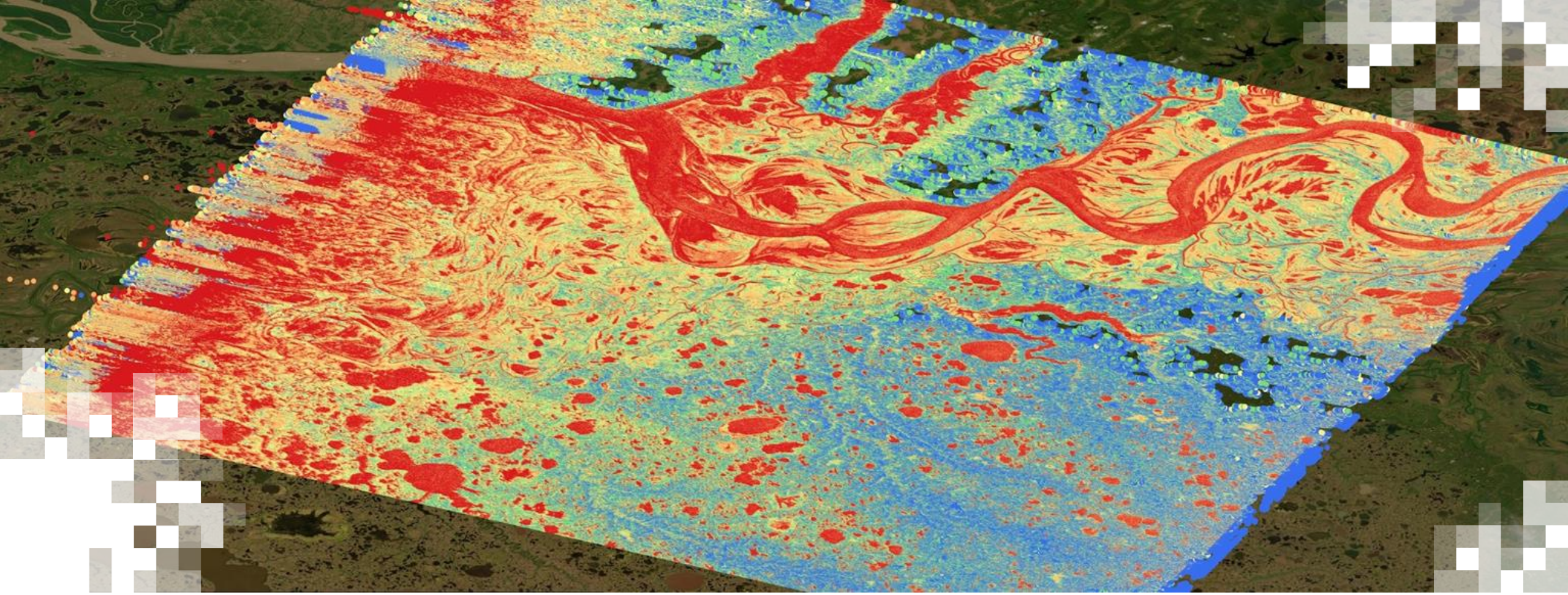
podaac/hydrocron

Input: Water Feature ID (SWOT River Reach, Node) Future: Lake ID, or Geospatial Bounding Box

Output: Timeseries in CSV or GeoJSON

Example Applications: Populate time series in a web dashboard for a river reach, ingest time series into models, faster analysis in programmatic workflows





SWOT Tools and Resources

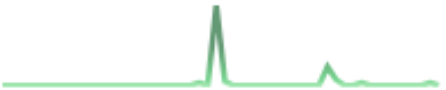
GitHub Collaboration Space

SWOT Community

This is a code space for the global SWOT mission community. We share experience, code, research and much more. Our mission is to increase the value of SWOT.

SWOT-OpenToolkit Public

Community codes for processing SWOT data. This is a community code repo, does not include the algorithms that belong to the project.



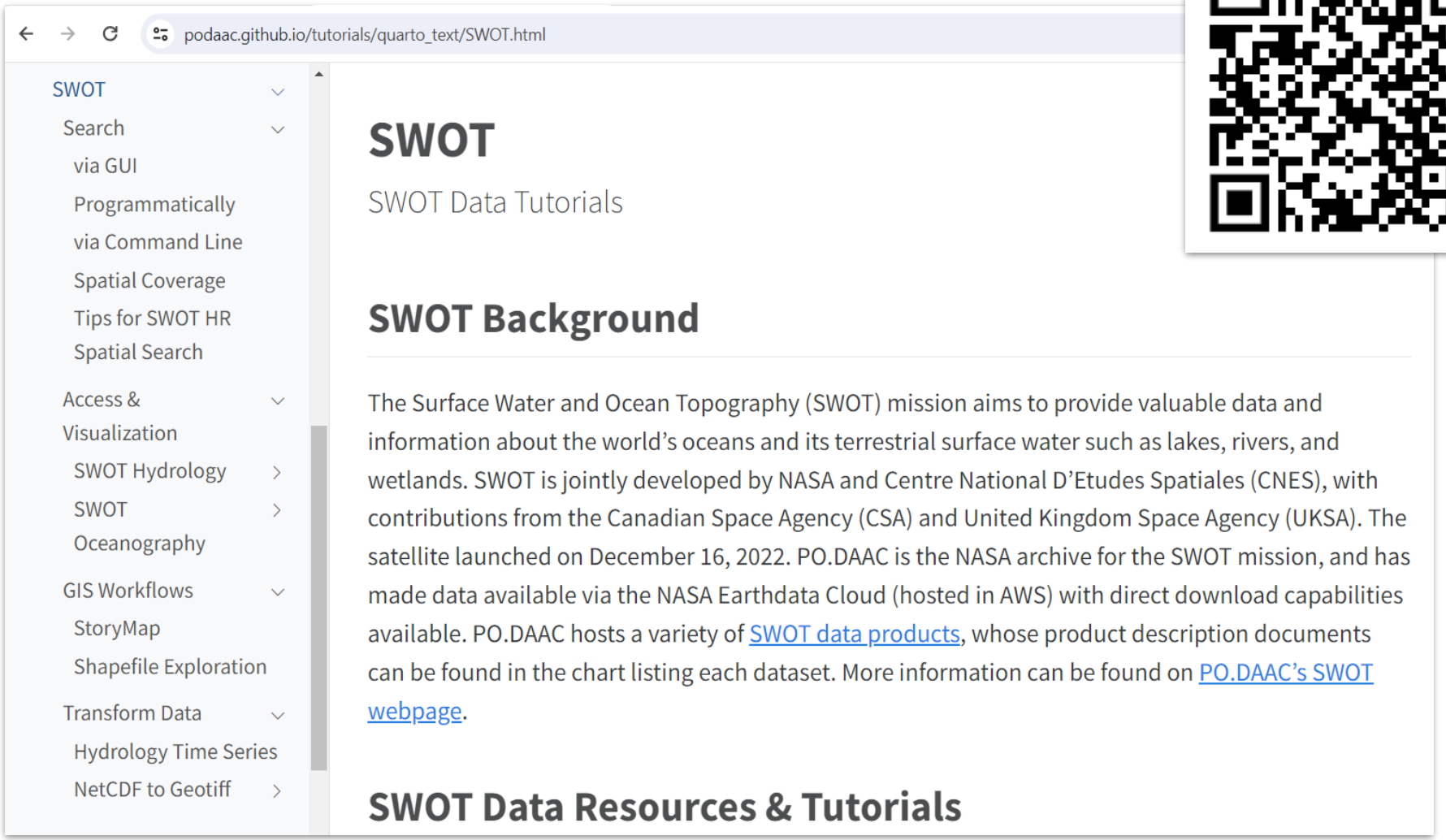
Python 29 Apache-2.0 7 0 1 Updated 2 weeks ago

CNES-AVISO Public

Jupyter Notebook 7 BSD-3-Clause 1 0 0
Updated 3 weeks ago

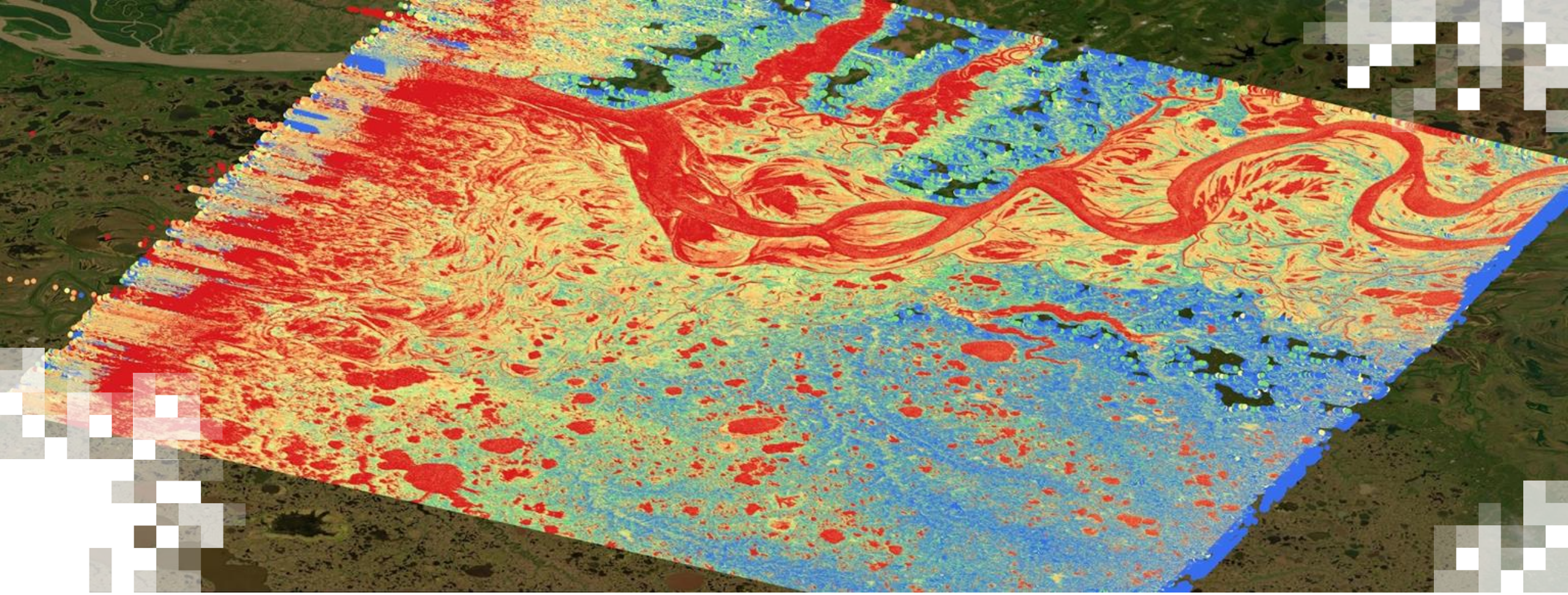
https://github.com/SWOT-community

Resources, Tips, & Tutorials!



PO.DAAC Cookbook: SWOT Chapter

https://podaac.github.io/tutorials/quarto_text/SWOT.html



SWOT Applications

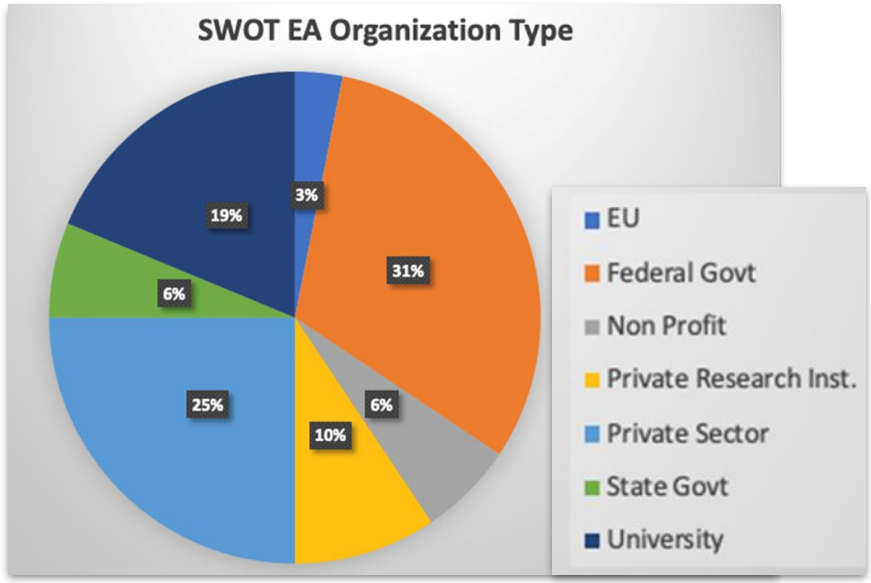
SWOT Applications Areas

https://swot.jpl.nasa.gov/applications/applications-areas/

SWOT Early Adopters Program

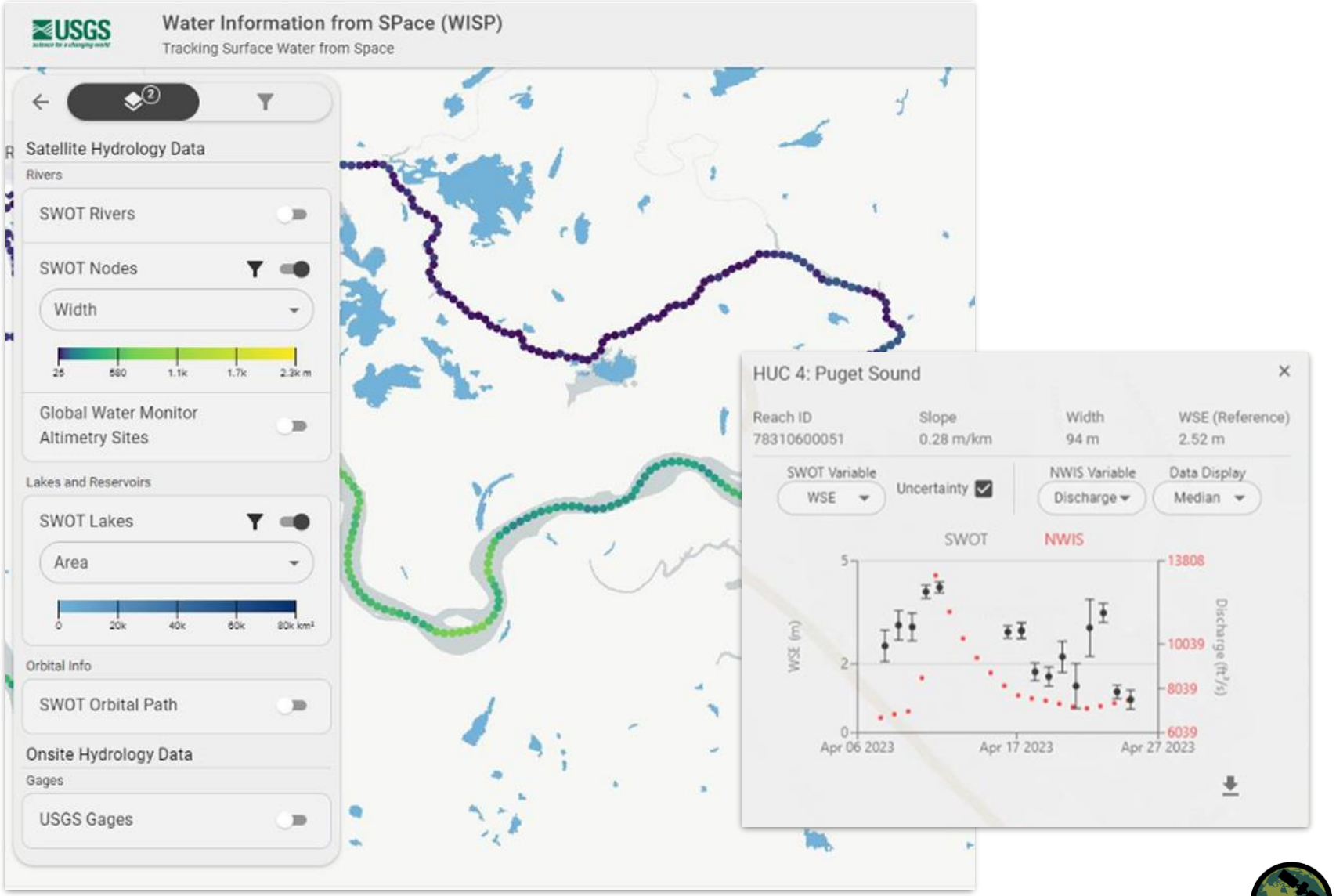
- SWOT Applications Program Since 2012
- 40 SWOT Early Adopters
- U.S. and International leadership – NASA/CNES

Figure 2. *Forty SWOT Early Adopter teams span the globe with a wide range of operational and applied science project topics. Visit swot.jpl.nasa.gov/applications/early-adopters/ for information about all SWOT EA projects.*



Water Information from SPace (WISP) Dashboard

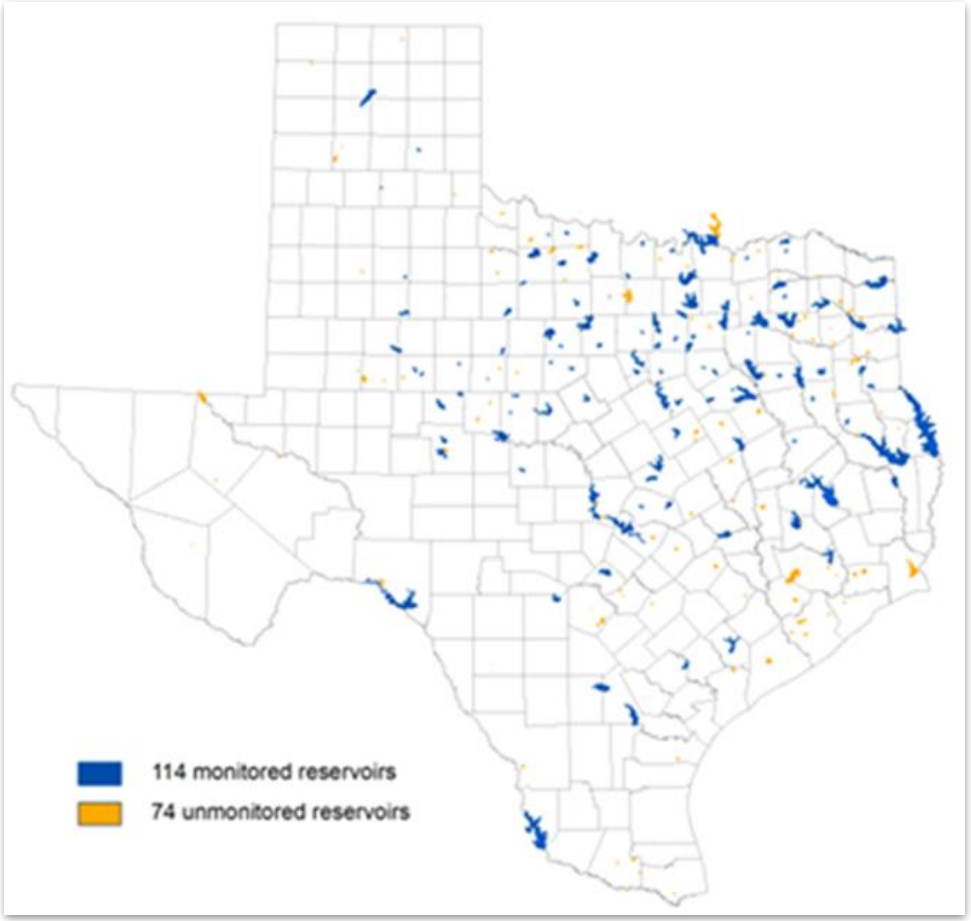
- SWOT River data timeseries alongside USGS gauge data
- Uses Hydrocron tool developed by PO.DAAC
- Not yet publicly available, but in the works!



Texas Water Development Board (TWDB), Austin, TX

- Estimation of Volumetric Evaporative Water Loss from Unmonitored Reservoirs in Texas
- SWOT provides surface area for reservoirs and TWDB plans to compute “statewide” evaporation losses (evaporation - precipitation)
- Leads: Nelun Fernando & John Zhu

Major Texas reservoirs (capacity is greater than 5,000 acre-feet); ~200.



Indian Institute of Technology - Bombay

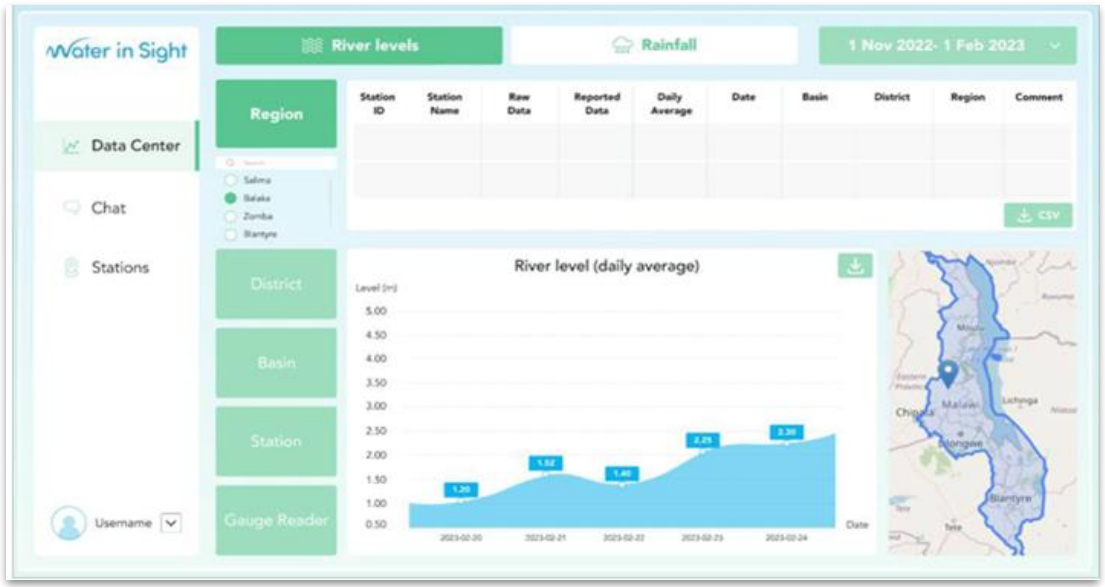
Work in Progress:

- Lake Data Inventory
- Floods on Indian Rivers through Discharge Estimation
- Extending historical gauge network over Indian river reaches
- Hydrologic model calibration over the Indian Basin
- Sentinel-1 based Inland water dynamics Mapping System (SIMS) Toolkit
  Leads: Indu Jaya & Manu Soman

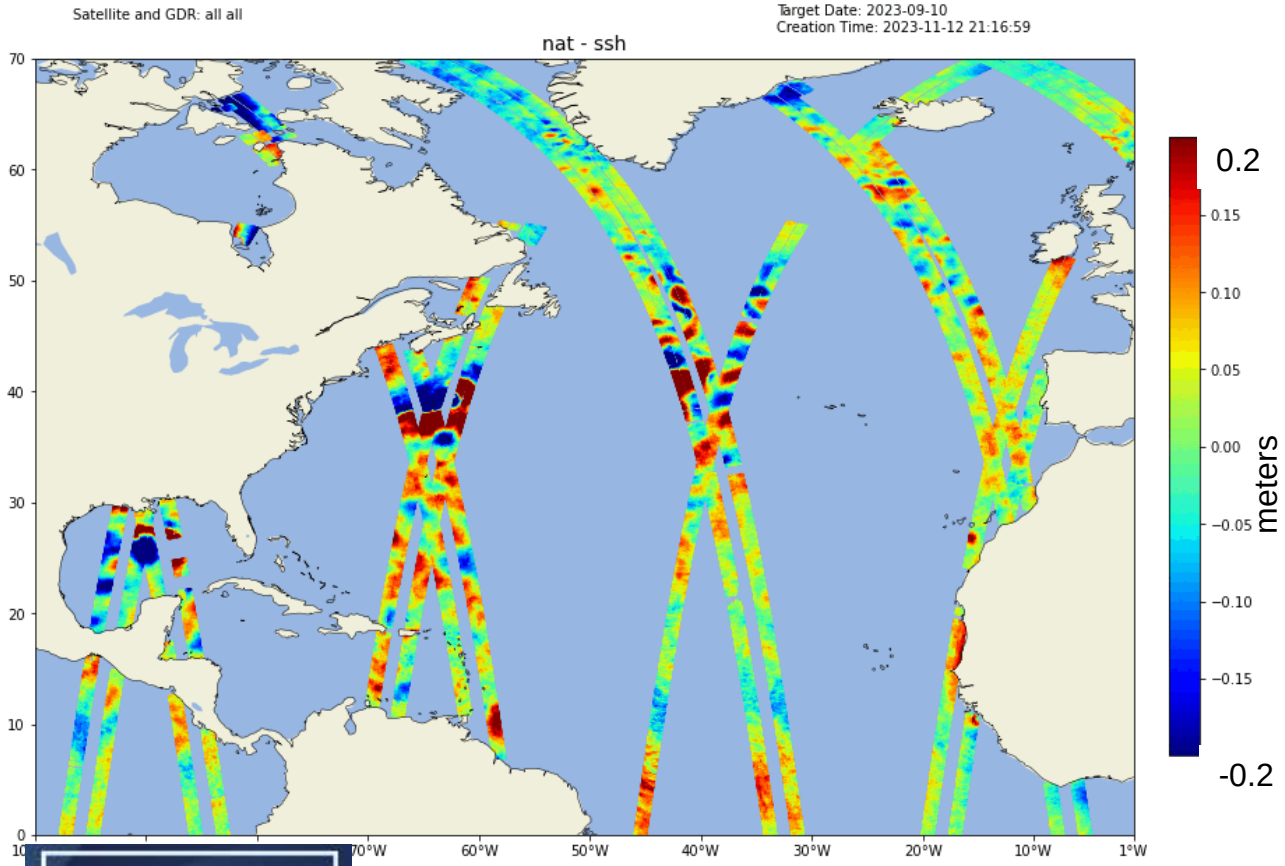
Water in Sight

Swedish Startup

- Developed SMS & WhatsApp for hydro gauge readers in Least Developed Countries (LDC)
- SWOT EA project area – Africa (Malawi, Mozambique, Sierra Leone)
- Smartphone observations of river & rainfall levels sent to database for govt operational agencies, compare to SWOT
- Flood thresholds & equipment inventory



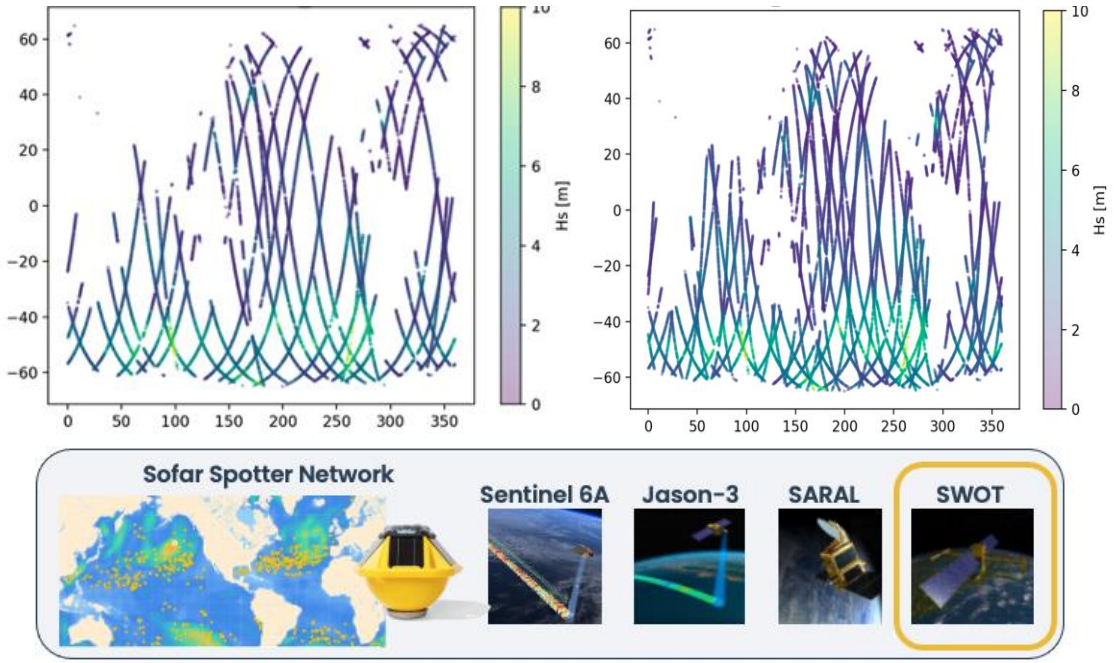
SWOT Ocean Early Adopters



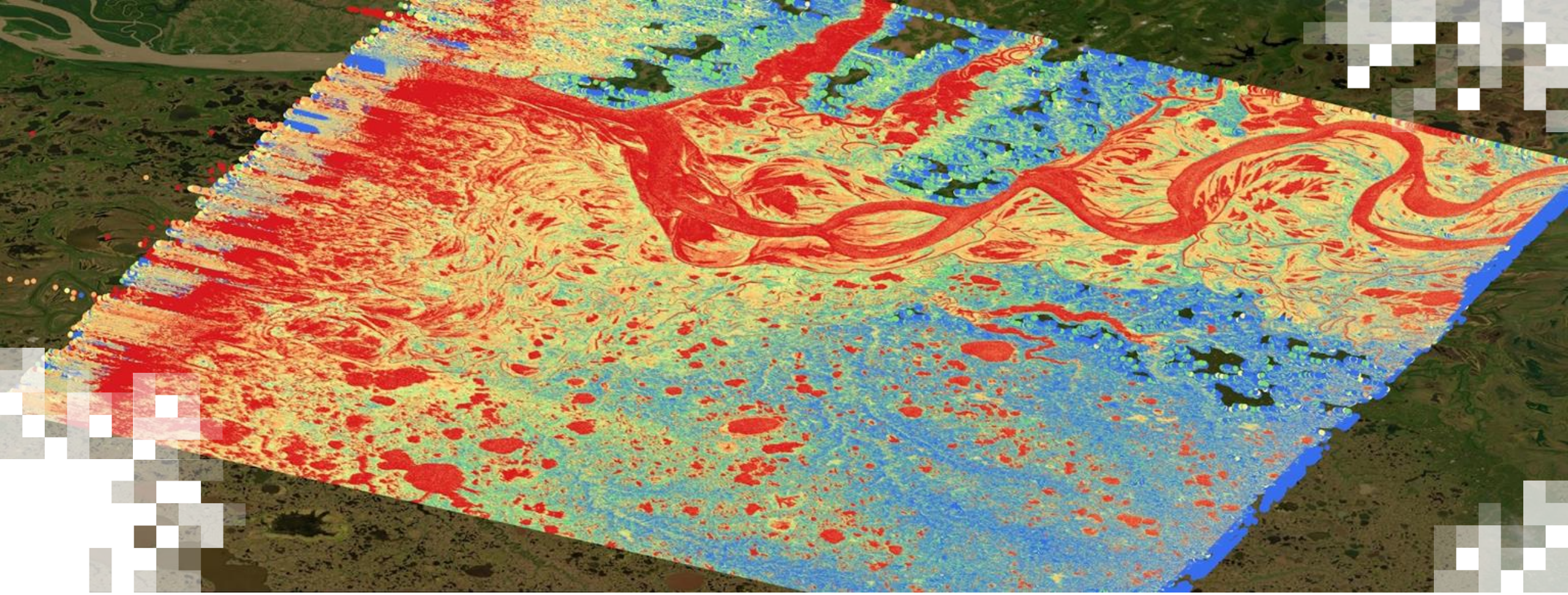
- SWOT Ocean swath data and nadir data already integrated!

24 hrs Altimeter Data
11,962 obs

24 hrs Altimeter Data
with SWOT
19,303 obs



- Ocean weather forecasts to reduce fuel and emissions for maritime shipping
- Adding SWOT gives 50-100% more observations



Part 1
Summary

Summary

- Review of Altimeter-Based Lake Level Height Data from Historical and Current Missions
  - Data Access: Global Water Measurements
- Overview of SWOT Mission and Data Products:
  - Hydrology Relevant Level-2 Data
- Data Access:
  - NASA Earthdata Search
  - Hydrocron API
- SWOT Applications and Early Adopters Program

Missions

Topex/Poseidon
Jason-1
Jason-2/OSTM
Jason-3
Sentinel-6A Michael Freilich
ERS-1 and ERS-2
ENVISAT
SARAL
Sentinel-3
SWOT
ICESat-2

Looking Ahead to Part 2

- Identify SWOT data for water resources and disaster management applications.
- Recognize how to utilize the SWOT rivers data visualization tools such as SWOTviz and WISP to monitor water availability and flooding potential.

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on May 15, 2025
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by May 31, 2025**

- **Certificate of Completion:**
  - Attend all live webinar sessions (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.

Acknowledgement

Matthew Bonnema

SWOT Mission Applications Lead

NASA JPL, Caltech

Angelica Rodriguez

SWOT Project Applications Lead

NASA JPL, Caltech

SWOT Training Coordinator

Perry Oddo

Program Coordinator, Water Resources Program

NASA Earth Science Division

Contact Information

Trainers:

- Matthew Bonnema
  - matthew.g.bonnema@jpl.nasa.gov
- Angelica Rodriguez
  - angelica.rodriguez@jpl.nasa.gov
- Amita Mehta
  - amita.v.mehta@nasa.gov
- Sean McCartney
  - sean.mccartney@nasa.gov
- Erika Podest
  - erika.podest@jpl.nasa.gov

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- DEVELOP

Resources

Birkett, C.M. (1995). The contribution of TOPEX/POSEIDON to the global monitoring of climatically sensitive lakes, J. Geophys. Res., 100, 25,179–25,204. https://doi.org/10.1029/95JC02125

Birkett, C.M., & Beckley, B. (2010). Investigating the Performance of the Jason-2/OSTM Radar Altimeter over Lakes and Reservoirs. *Marine Geodesy*, *33*(sup1), 204–238. https://doi.org/10.1080/01490419.2010.488983


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Thank You!