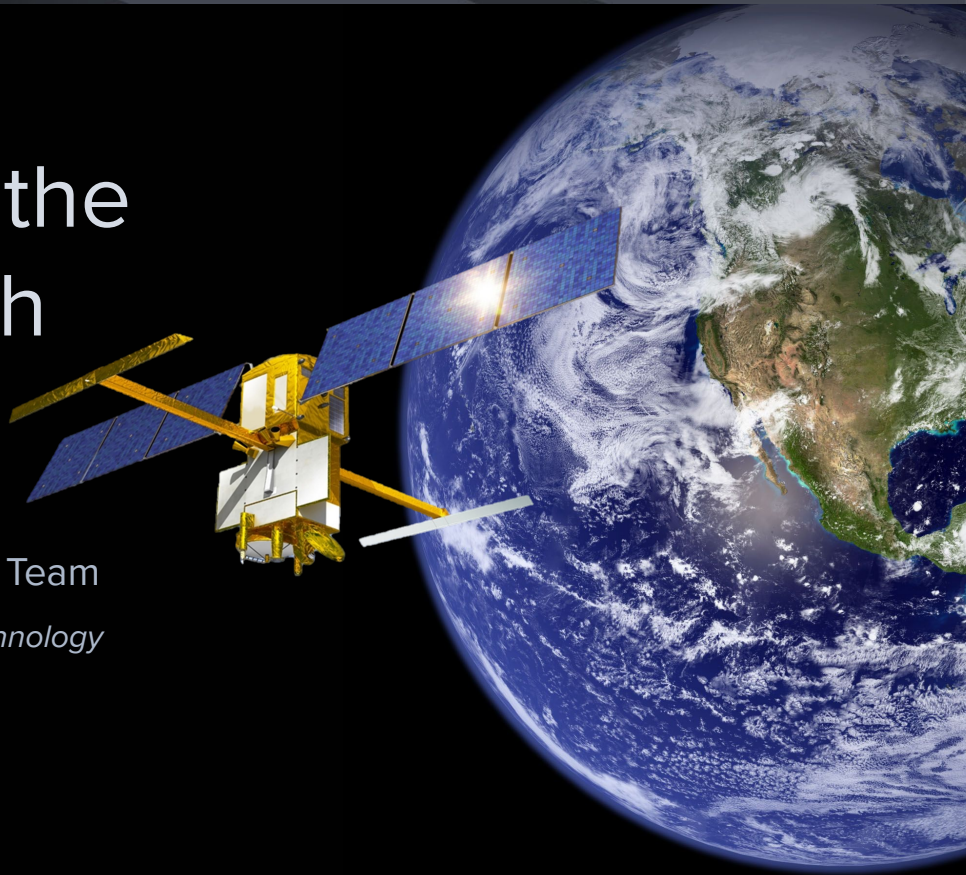
Jet Propulsion Laboratory
California Institute of Technology

podaac
Physical Oceanography Distributed Active Archive Center

Accessing Data for the World's Water with SWOT



Cassie Nickles, Celia Ou, & the PO.DAAC Team

Jet Propulsion Laboratory, California Institute of Technology

20 March 2024
NASA Earthdata Webinar

Credit: NASA Blue Marble

Introduction to PO.DAAC

- Physical Oceanography Distributed Active Archive Center (PO.DAAC)
- NASA Archive for Oceanography & Terrestrial Hydrology Data
- 1 of 12 discipline-specific NASA DAACs
    - DAACs ➔ data publication, access, & user support
- PO.DAAC is the NASA data archive and distribution of SWOT Mission data.

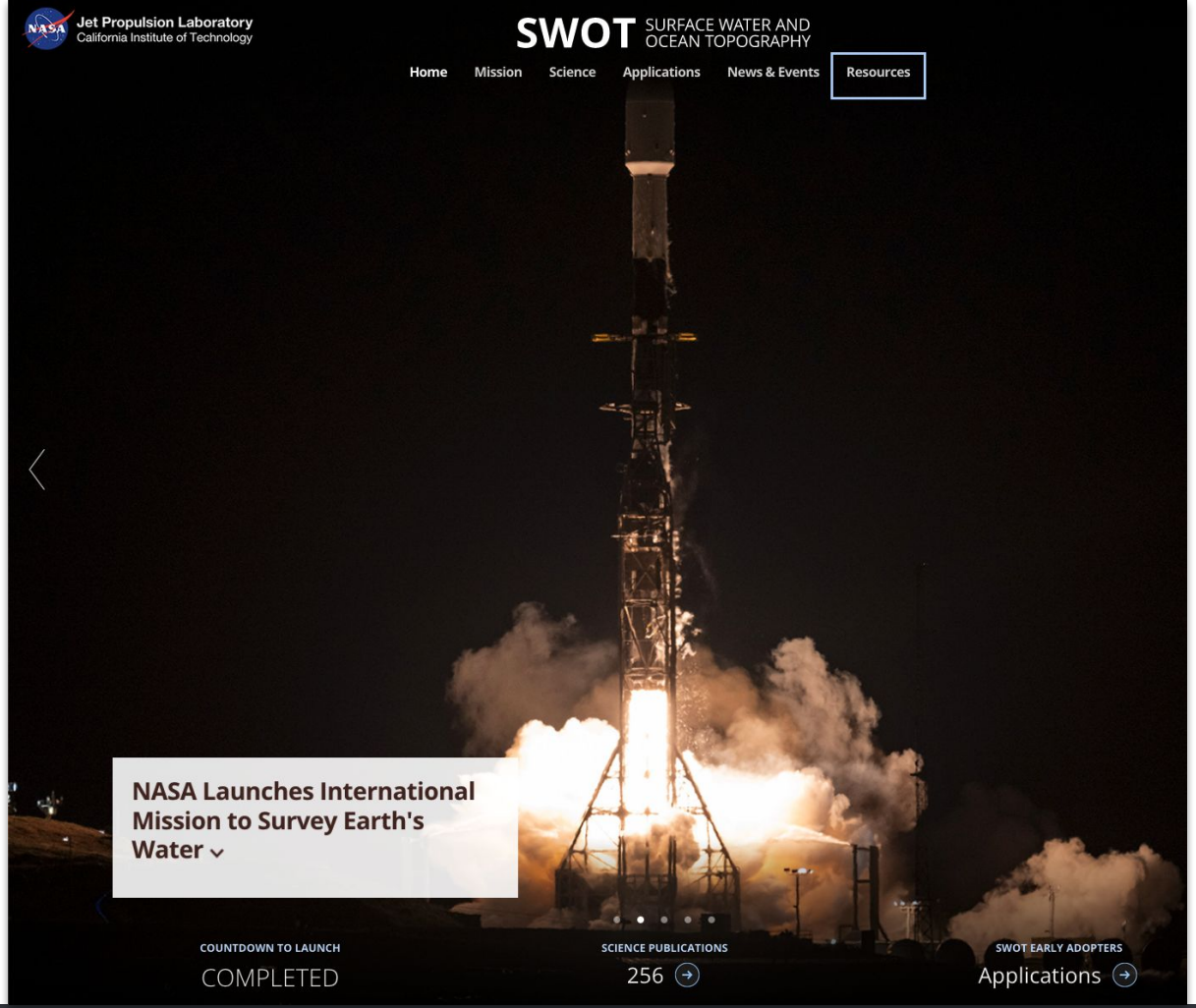
https://podaac.jpl.nasa.gov/

Our Missions

ADEOS-II ▪ AQUA ▪ AQUARIUS/SAC-D ▪ COWVR-TEMPEST ▪ CYGNSS ▪ ECCO ▪ GEOS-3 ▪ GHRSST ▪ GRACE ▪ GRACE-FO ▪ ISS-RAPIDSCAT ▪ JASON 1 ▪ JASON 3 ▪ LOCSS ▪ MEASURES-CCMP ▪ MEASURES-MUR ▪ MEASURES-PRE-SWOT ▪ MEASURES-SSH ▪ NSCAT ▪ OMG ▪ OPERA DSWx ▪ OSTM-JASON 2 ▪ QUIKSCAT ▪ S-MODE ▪ S-NPP ▪ SAILDRONE ▪ SEASAT ▪ SENTINEL-6 ▪ SMAP ▪ SPURS ▪ **SWOT** ▪ TERRA ▪ TOPEX-POSEIDON

The Surface Water and Ocean Topography (SWOT) Mission

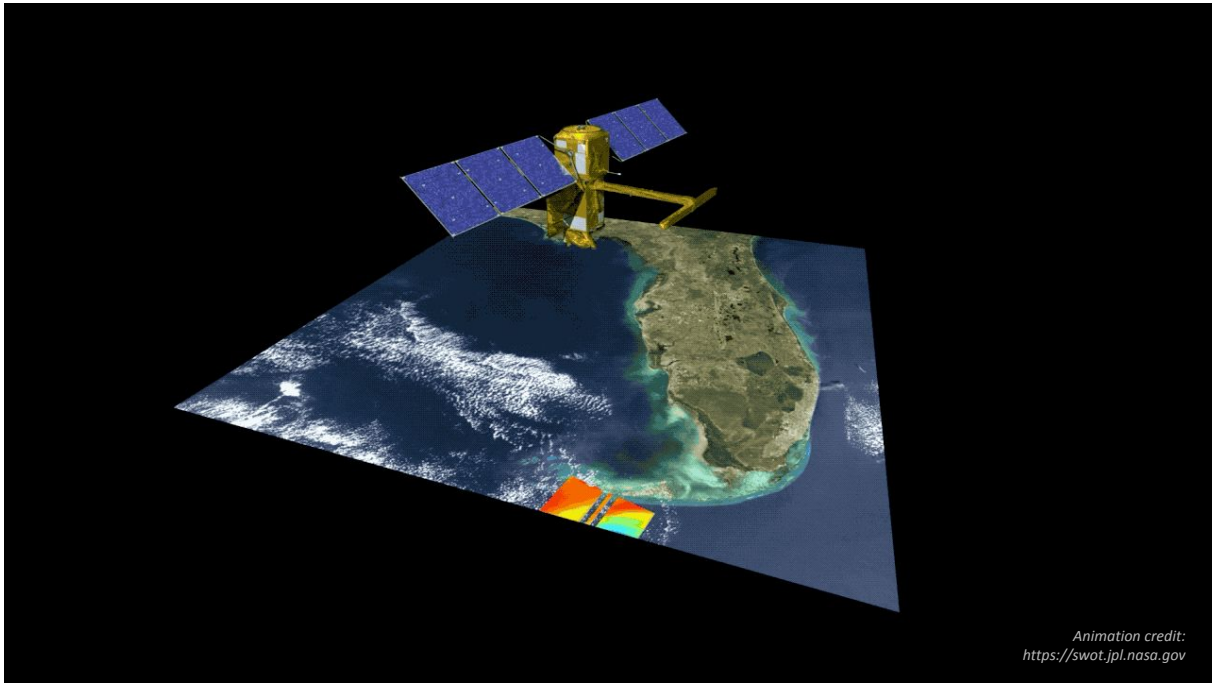
SWOT Launched Dec 2022!



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

Ocean Hydro Coast

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

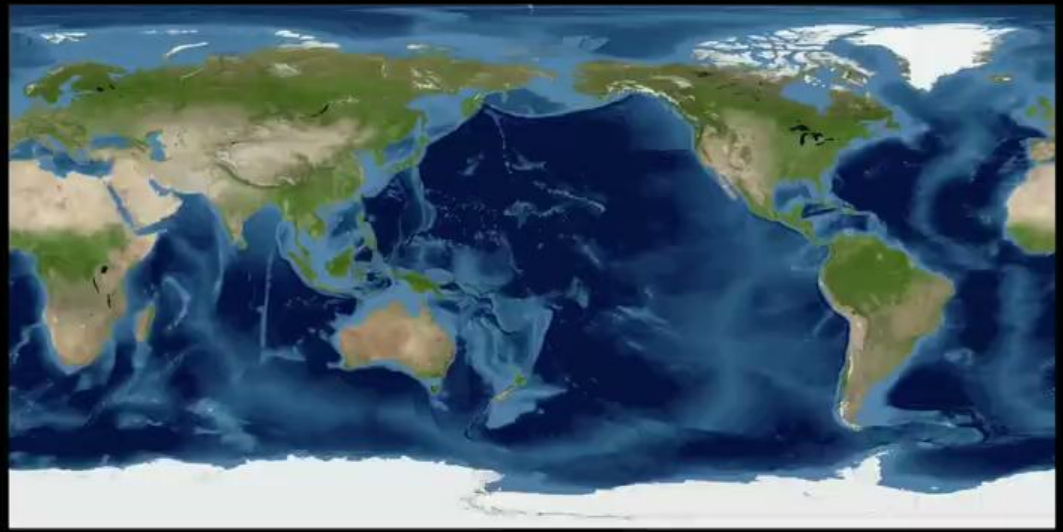


21-day orbit cycle (average 2 observations per cycle)

78° N/S coverage

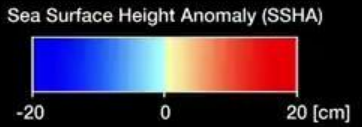
Oceanography

Sea surface height anomaly (SSHA) from SWOT Ka-band Radar Interferometer (KaRIn) over one full 21-day cycle
Same field, difference perspectives

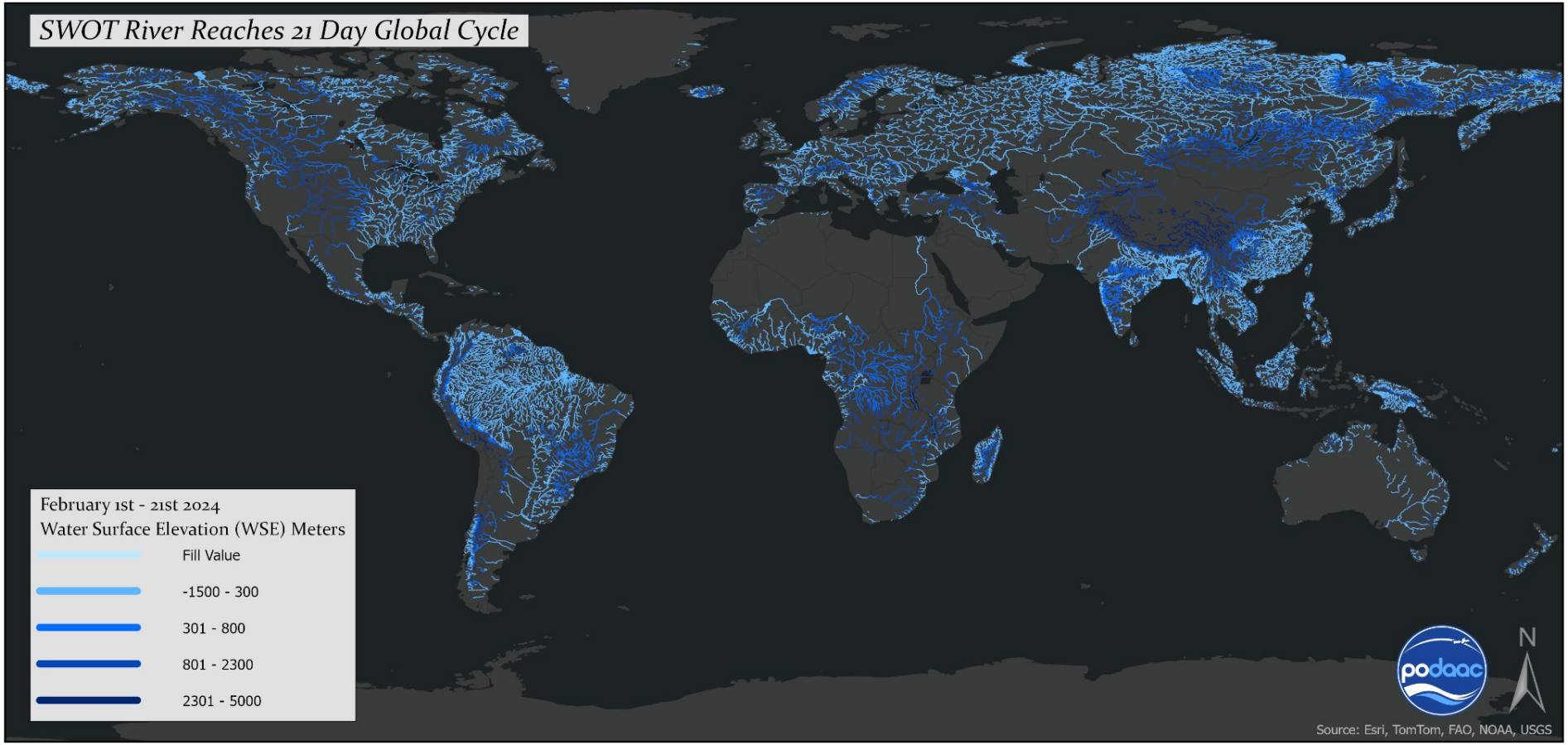


2023-08-11 02:19

Pass:

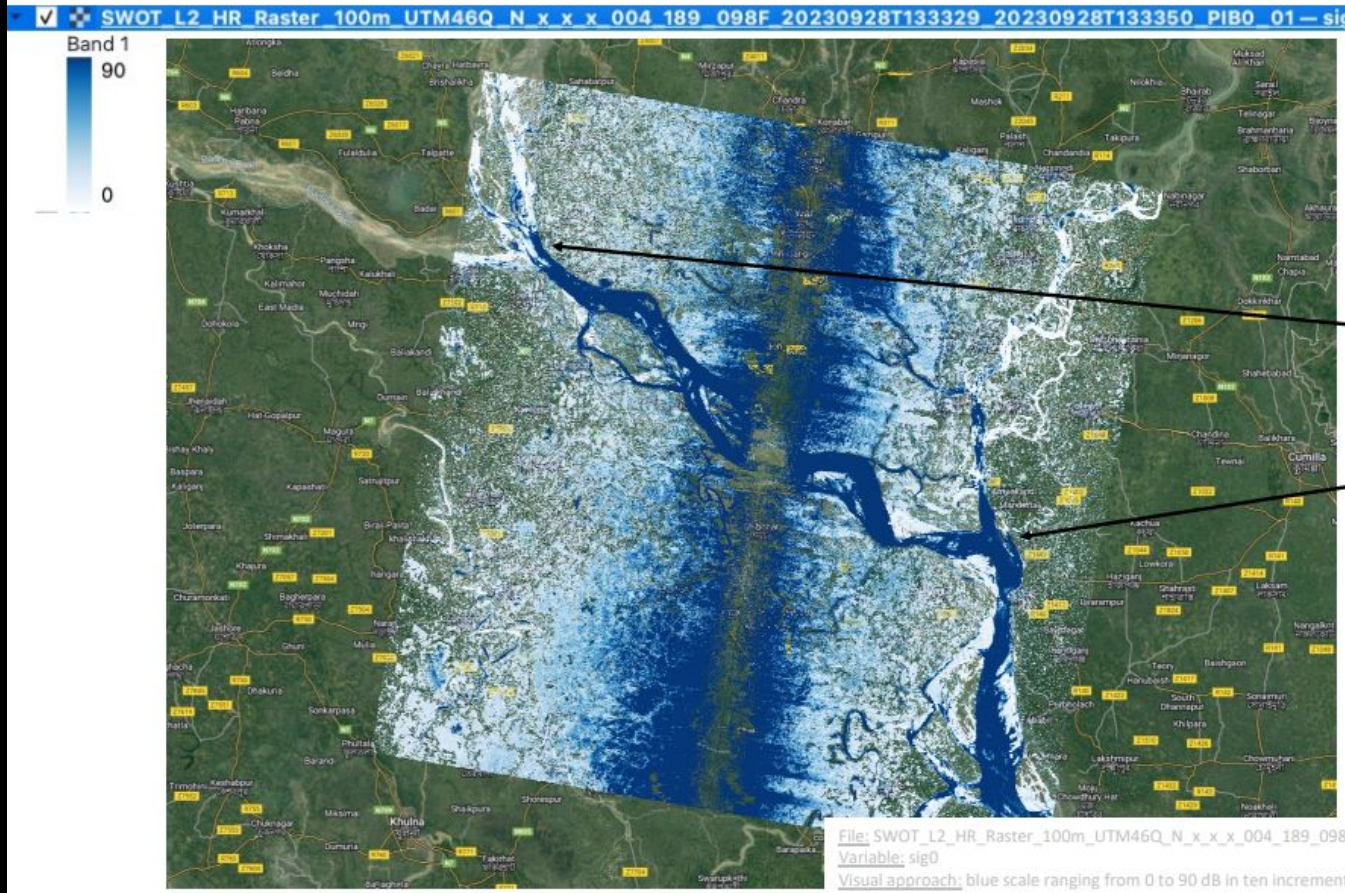


Credit: S. Suzuki



Credit: N. Tarpinian

Confluences of Ganges, Brahmaputra, and Meghna rivers in Bangladesh

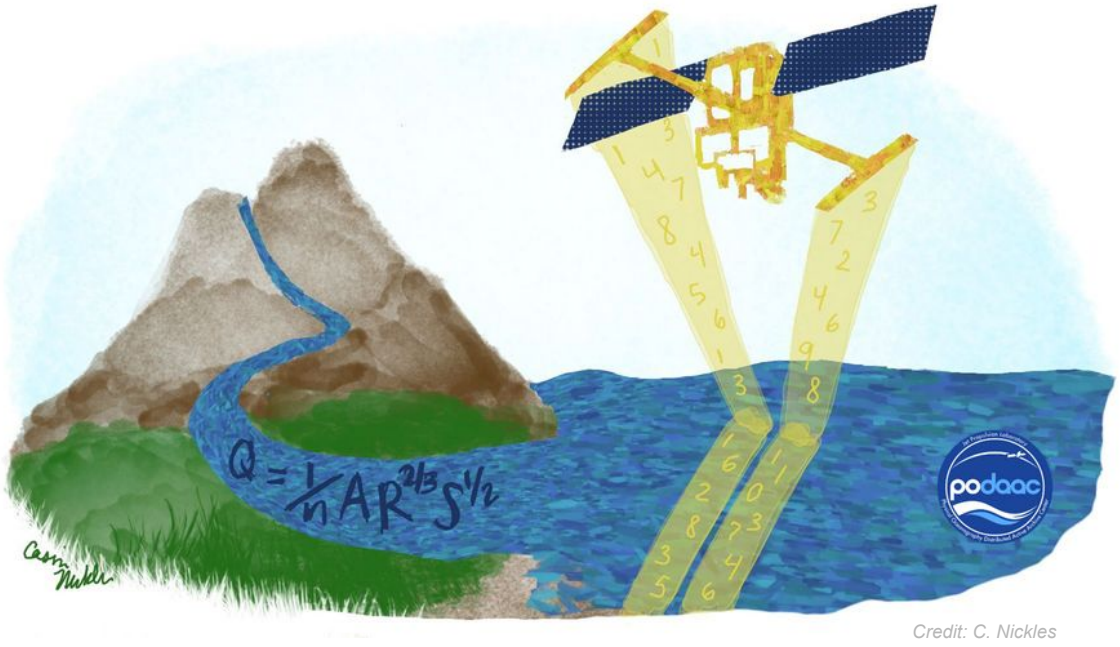


These are South Asia's biggest rivers and together flow to the Bay of Bengal. Flooding is guaranteed every year with the monsoon season

File: SWOT_L2_HR_Raster_100m_UTM46Q_N_x_x_x_004_189_098F_20230928T133329_20230928T133350_PIB0_01.nc
Variable: sig0
Visual approach: blue scale ranging from 0 to 90 dB in ten increments of 10 dB.

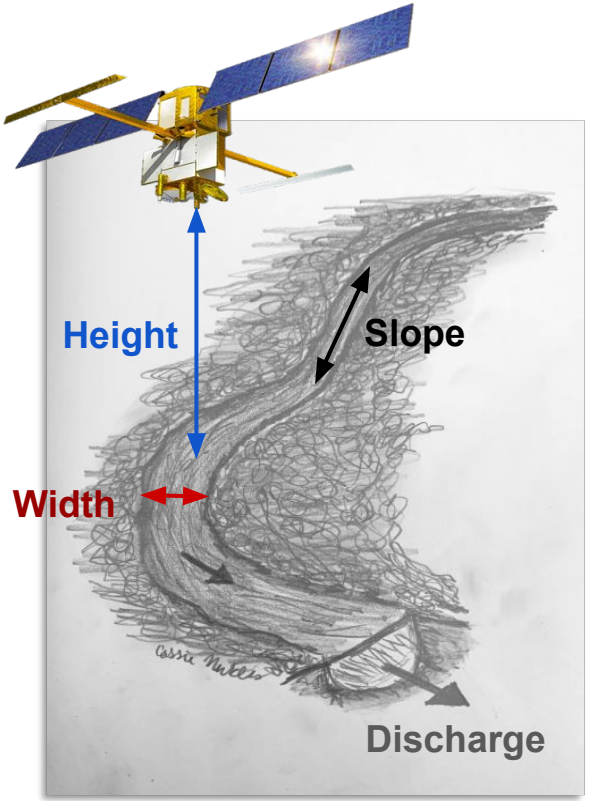
Credit: C. David, J. Wade, A. Cerbelaud, M. Tom

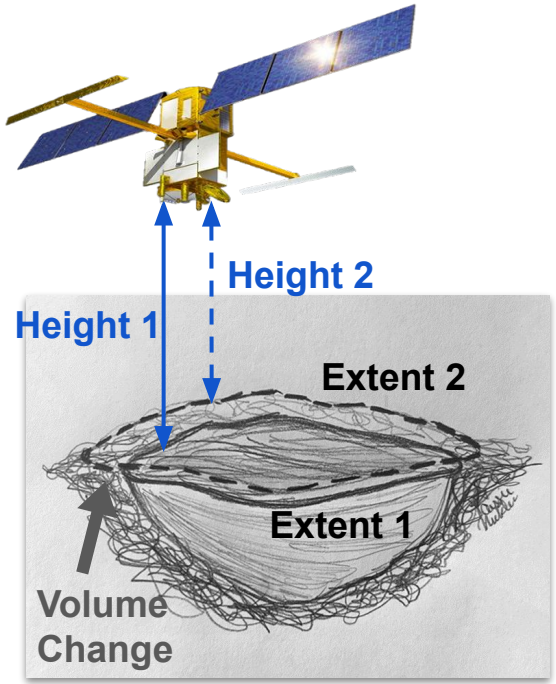
SWOT Data Products Overview



Credit: C. Nickles

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: C. Nickles

Hydrology-Relevant Level 2 SWOT Products

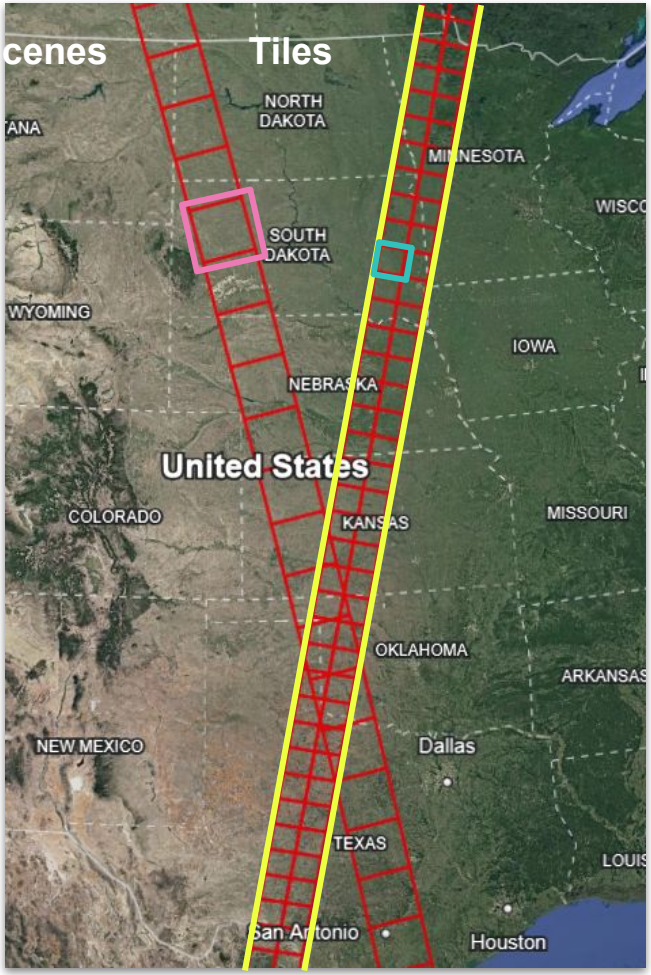
- **L2_HR_PIXC** Water Mask Pixel Cloud NetCDF
- **L2_HR_PIXCVec** Pixel Cloud Vector Attribute NetCDF
- **L2_HR_Raster** Raster NetCDF
- **L2_HR_RiverSP** River Vector Shapefile
- **L2_HR_LakeSP** Lake Vector Shapefile
- **L2_HR_RiverAvg** Cycle Average River Vector Shapefile
- **L2_HR_LakeAvg** Cycle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

* available ~2 years after launch

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

File Naming Conventions!

Product (organized by...)	File Naming Convention	Notes
L2_HR_RiverSP L2_HR_LakeSP (continent-level swaths)	PPP_CC	PPP = pass number (valid range: 001-584) CC = continent code (options listed below) AF - Africa EU - Europe and Middle East SI - Siberia AS - Central and Southeast Asia AU - Australia and Oceania SA - South America NA - North America and Caribbean AR - North American Arctic GR - Greenland *Ex: 013_NA = pass 013, North America*
L2_HR_PIXC L2_HR_PIXCVec L1B_HR_SLC (tiles)	PPP_TTTC	PPP = pass number (valid range: 001-584) TTT = tile number (valid range: 001-308) C = character L or R corresponding to left or right swaths *Ex: 001_120R = pass 001, right swath, tile 120*
L2_HR_Raster (scenes)	PPP_SSS	PPP = pass number (valid range: 001-584) SSS = scene number (valid range: 001-154) Scenes correspond to 2 x 2 sets of tiles **scene number x 2 = tile number** *Ex: 001_060 = pass 001, scene 60, corresponding to the same location as the PIXC/PIXCVec tile example above.*

Find this info in the PO.DAAC Cookbook:
https://podaac.github.io/tutorials/quarto_text/SWOT.html#tips-for-swot-hr-spatial-search

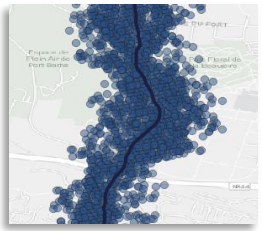
SWOT_L2_HR_PIXC (netCDF)

Description: Point cloud of water mask pixels (“pixel cloud”)

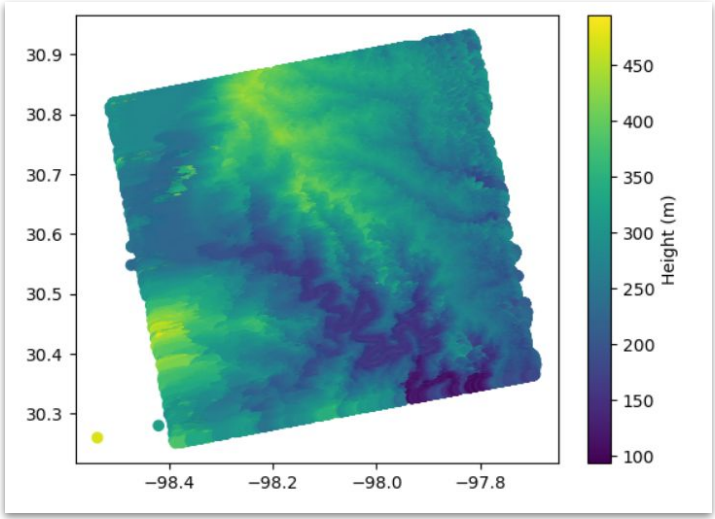
Spatial Extent Format: Tile (64x64 km^2)

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

Subcollections: N/A



Example river pixels



Colorado River near Austin, TX

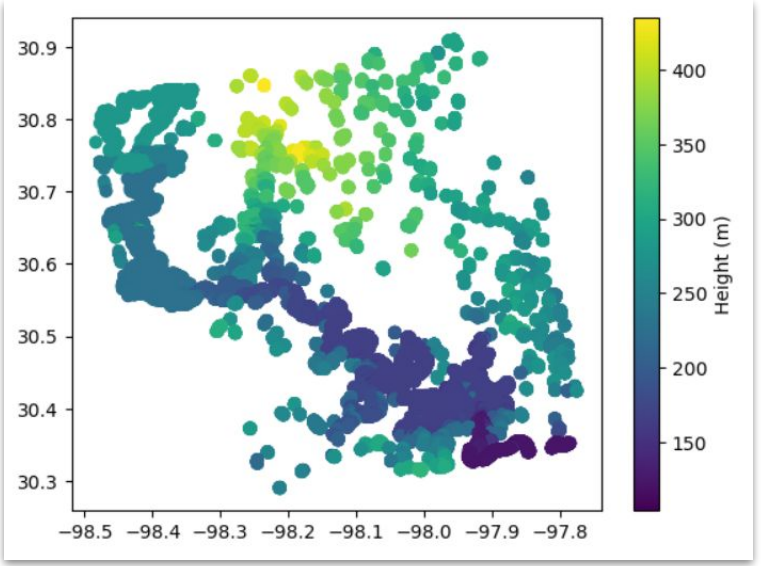
SWOT_L2_HR_PIXCVec (netCDF)

Description: Auxiliary info for pixel cloud product indicating water bodies pixels are assigned

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

Select Variables: height-constrained pixel geolocation after reach- or lake-scale averaging.

Subcollections: N/A



Colorado River near Austin, TX

SWOT_L2_Raster (netCDF)

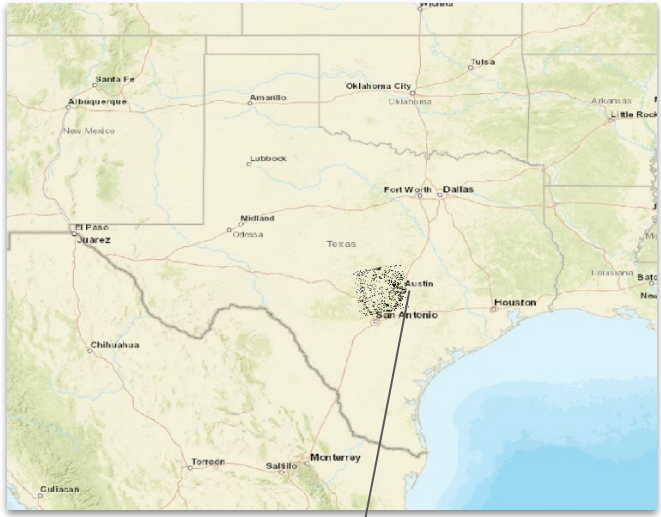
Description: Geographically fixed rasterized water surface elevation and inundation extent.

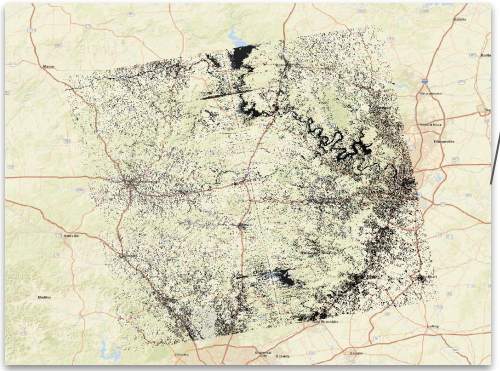
Spatial Extent Format: Scene (128x128 km^2)

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.

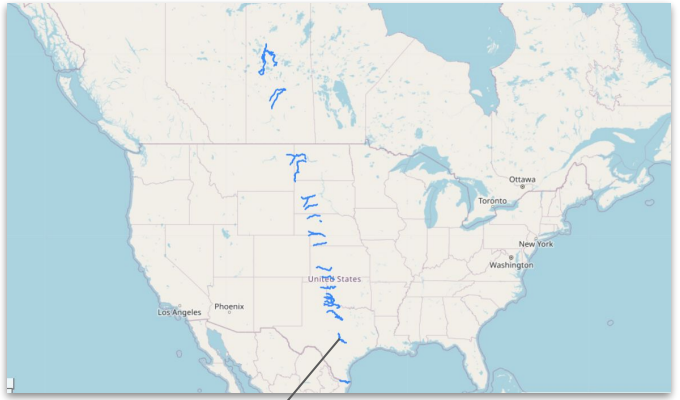
Extent Format: continent-scale swath

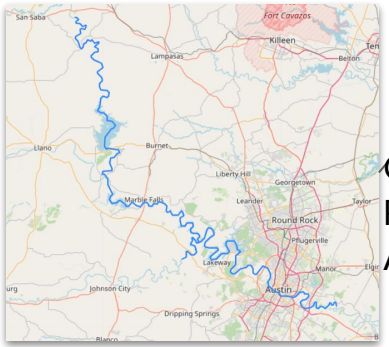
Variables: water surface elevation, slope, width, derived discharge*

Subcollections:

- SWOT_L2_RiverSP_reach
- SWOT_L2_RiverSP_node

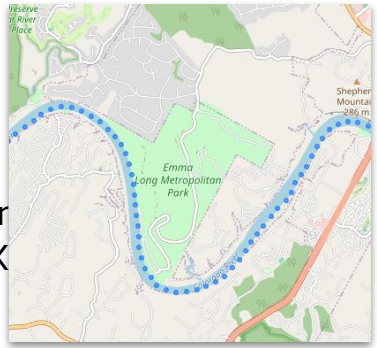
*included ~2 years after launch





Reach file

Colorado River near Austin, TX



Node file

SWOT_L2_LakeSP (shapefile)

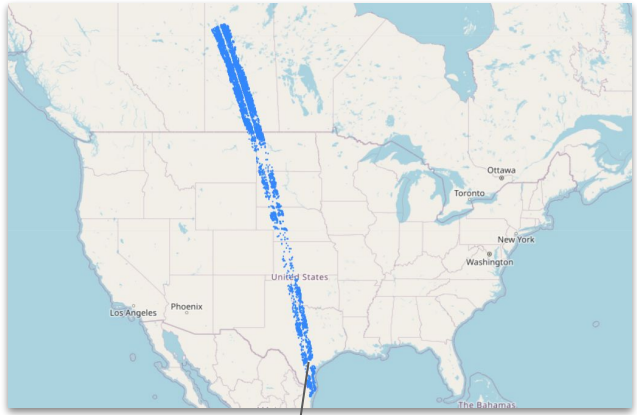
Description: Vectors of lakes in prior lake database and detected features not in the prior river or lake databases.

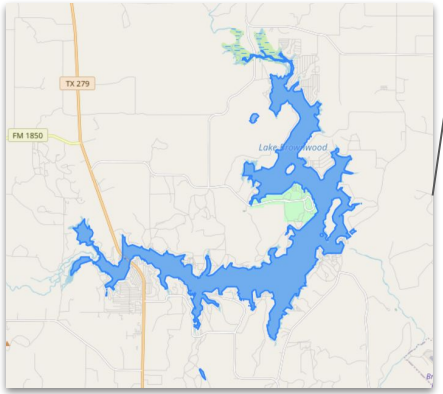
Extent Format: continent-scale swath

Select Variables: water surface elevation, area, derived storage change

Subcollections:

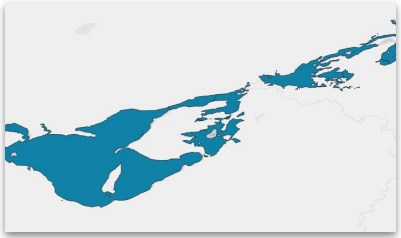
- SWOT_L2_LakeSP_obs
- SWOT_L2_LakeSP_prior
- SWOT_L2_LakeSP_unassigned

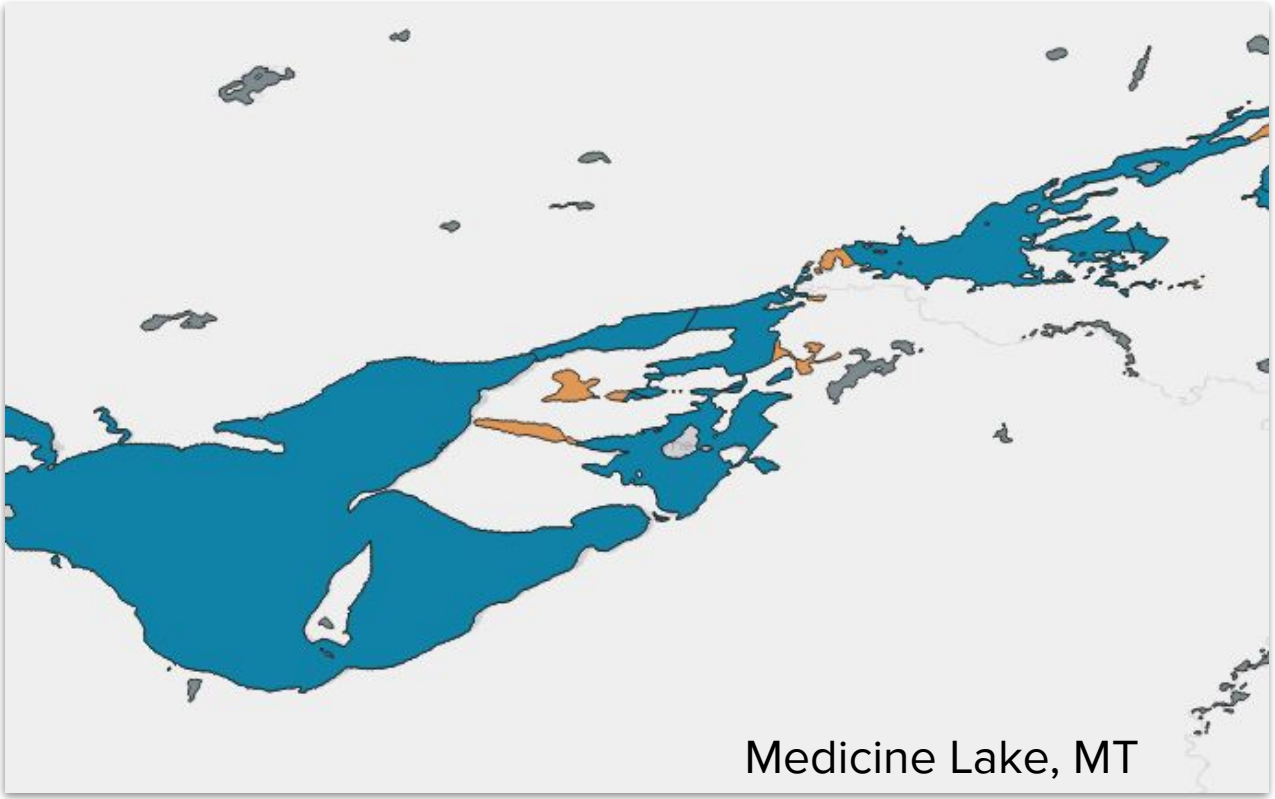




Lake Brownwood, TX

Observed, Prior & Unassigned Lakes





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

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

SWOT_L2_RAD_(O/I)GDR (netCDF)

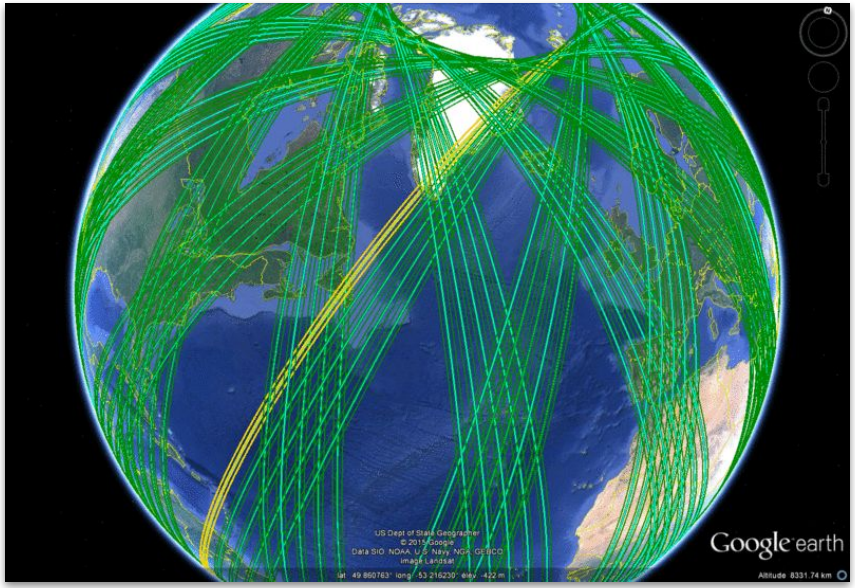
Description: Radiometer brightness temperature and troposphere correction data product - (operational/interim) geophysical data record

Spatial Extent Format: nadir track -

Left and right sides

Select Variables: radiometer wet troposphere correction

Subcollections: N/A



SWOT_L2_NALT_OGDR (netCDF)

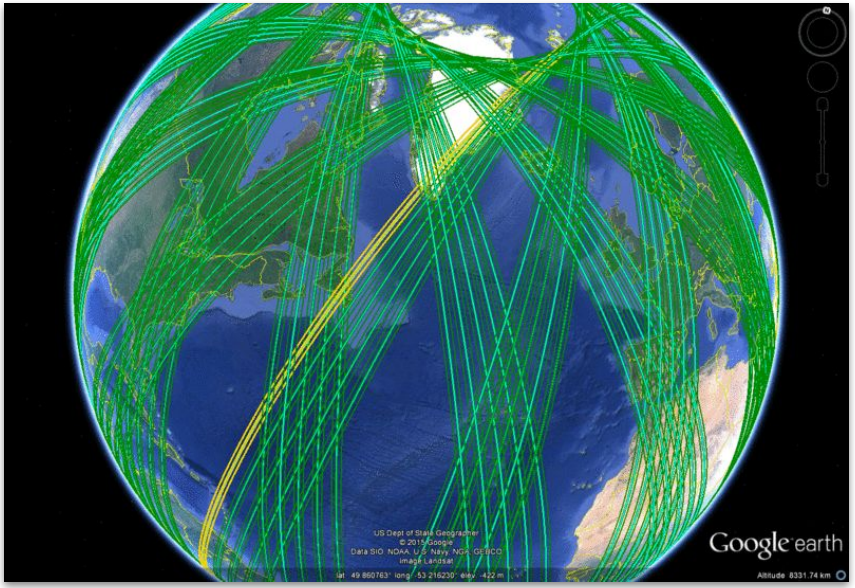
Description: Nadir altimetry operational geophysical data record

Spatial Extent Format: nadir track

Select Variables: sea surface height anomaly, significant wave height

Subcollections:

- SWOT_L2_NALT_OGDR_SSHA
- SWOT_L2_NALT_OGDR_GDR



SWOT_L2_NALT_IGDR (netCDF)

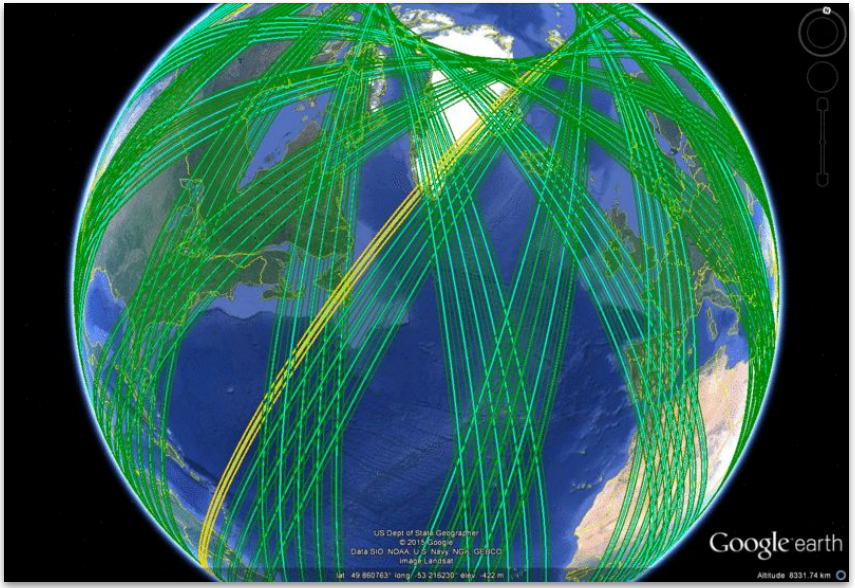
Description: Nadir altimetry interim geophysical data record

Spatial Extent Format: nadir track

Select Variables: sea surface height anomaly, significant wave height

Subcollections:

- SWOT_L2_NALT_IGDR_SSHA
- SWOT_L2_NALT_IGDR_GDR
- SWOT_L2_NALT_IGDR_SGDR



SWOT_L2_NALT_GDR (netCDF)

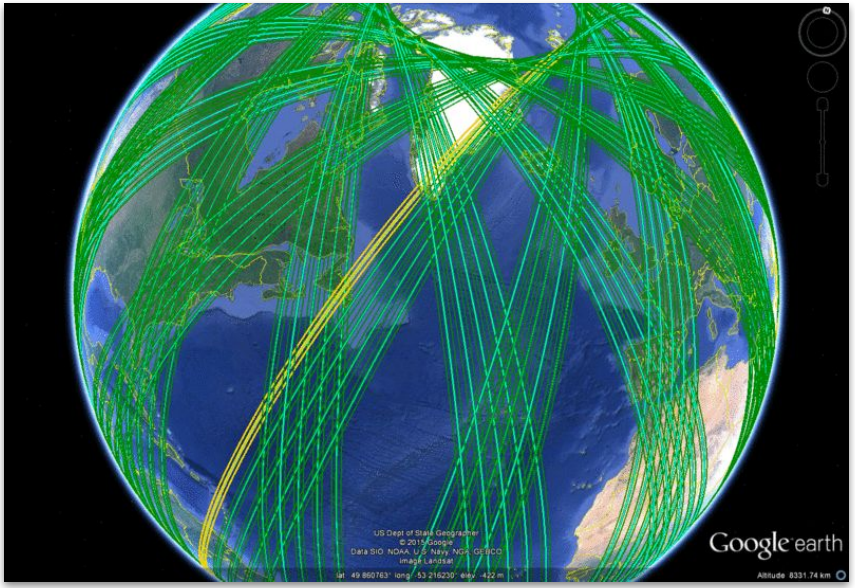
Description: Nadir altimetry geophysical data record

Spatial Extent Format: nadir track

Select Variables: sea surface height anomaly, significant wave height

Subcollections:

- SWOT_L2_NALT_GDR_SSHA
- SWOT_L2_NALT_GDR_GDR
- SWOT_L2_NALT_GDR_SGDR



SWOT_L2_LR_SSH (netCDF)

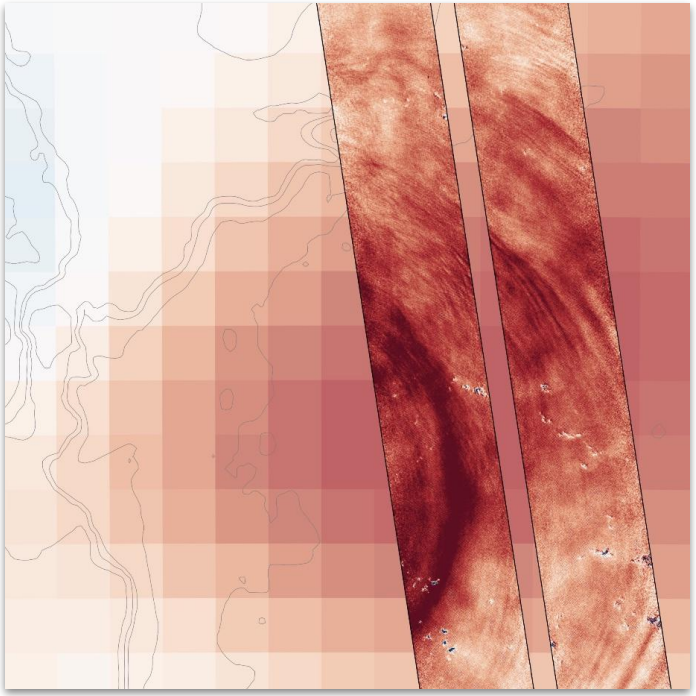
Description: Sea surface height (SSH) and significant wave height (SWH) over oceans

Spatial Extent Format: 2 km fixed-grid swath (and unsmoothed; 250 m native grid)

Select Variables: SSH, SWH

Subcollections:

- SWOT_L2_LR_SSH_Basic
- SWOT_L2_LR_SSH_WindWave
- SWOT_L2_LR_SSH_Expert
- SWOT_L2_LR_SSH_Unsmoothed



Thumbnail image credit: M. Archer

Quality Flags!

SWOT Product	Quality Flag Identifier	Values and Meanings
L2_HR_RiverSP L2_HR_RiverAvg	Var + '_q' Overall Quality Variables: 'reach_q' or 'node_q' Bitwise: Var + '_q_b'	0 = good 1 = suspect - may have large errors 2 = degraded - likely to have large errors 3 = bad - may be nonsensical and should be ignored *For discharge parameters: (e.g., 'dschg_c_q')* 0 = valid 1 = questionable 2 = invalid
L2_HR_LakeSP L2_HR_LakeAvg	Overall quality Variable: 'quality_f'	0 = good 1 = bad
L2_HR_Raster	Var + '_qual' Ex: 'wse_qual' Bitwise: Var + '_qual_bitwise'	0 = good 1 = suspect - may have large errors 2 = degraded - likely to have large errors 3 = bad - may be nonsensical and should be ignored
L2_NALT_GDR L2_NALT_IGDR L2_NALT_OGDR L2_RAD_GDR L2_RAD_IGDR L2_RAD_OGDR L2_FPDEM	Var + '_qual' Ex: 'rad_water_vapor_qual'	0 = good 1 = bad
L2_LR_SSH L2_HR_PIXC L1B_HR_SLC L1B_LR_INTF	Var + '_qual'	Varies, see PDDs

Find this info in the PO.DAAC Cookbook:

https://podaac.github.io/tutorials/quarto_text/SWOT.html#tips-for-quality-flags

More Detailed Information

Product Description Documents (PDDs)

Dataset	Description	Coverage	Format	Product Description Document (PDD)	Algorithm Theoretical Basis Document (ATBD)
L2_HR_PIXC	Point cloud of water mask pixels ("pixel cloud") with geolocated heights, backscatter, geophysical fields, and flags.	Point cloud over tile (approx 64x64 km^2); half swath (left or right side of full swath)	netCDF	L2_HR_PIXC Product Description Document	L2_HR_PIXC Algorithm Theoretical Basis Document

...

https://podaac.jpl.nasa.gov/SWOT?tab=datasets-information&sections=about

March 6, 2024 SWOT Data Release, v2.0

https://podaac.jpl.nasa.gov/announcements/2024-03-06-SWOT-KaRIn-Science-Data-Products-Release

Forward stream and reprocessed SWOT KaRIn Science Data Products Release:

Encourage users to review the **Release Note** closely to familiarize themselves with the details of the release.

Section 6: Known Features and Issues - Helpful!

*Tip: **these** are data product shortnames!*

This release includes:

1. **Reprocessed global low rate (LR)** ocean products spanning **Nov 23, 2023 – Jan 25, 2024 and forward processing** from the science phase (21-day orbit).
2. **Forward processing reprocessed global high rate (HR)** hydrology products from **Jan 25, 2024 onward** from the science phase (21-day orbit).
3. Reprocessing of science data products from March 30, 2023 to January 25, 2024 is ongoing and will be released as they become available.

The LR products include:

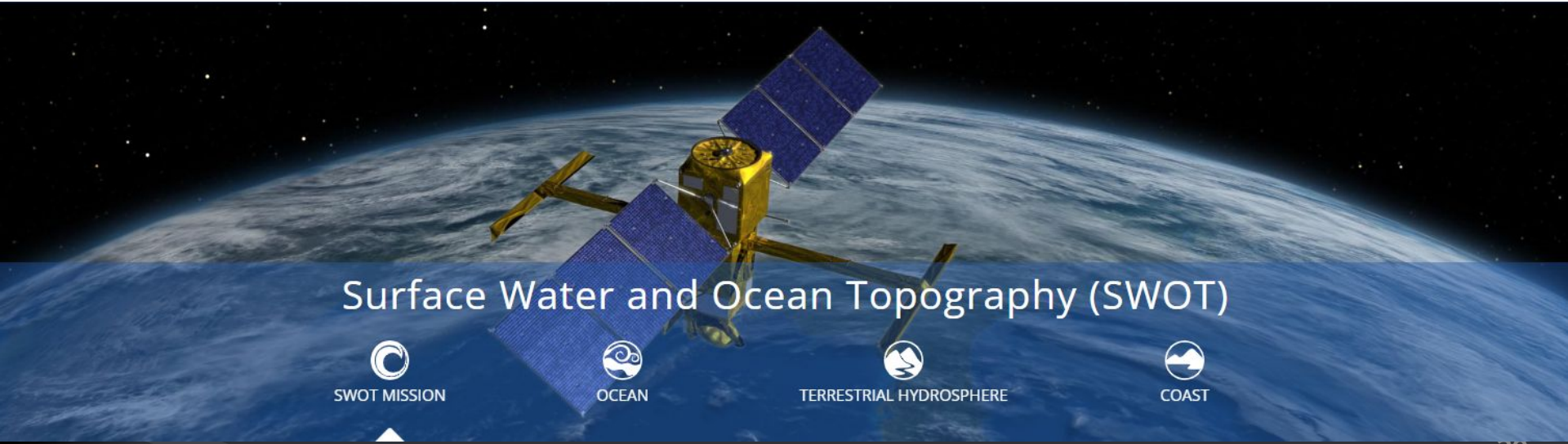
1. Level 1B KaRIn Low Rate Interferogram Data Product (**SWOT_L1B_LR_INTF_2.0** (DOI: 10.5067/SWOT-INTF-2.0))
2. Level 2 KaRIn Low Rate Sea Surface Height Data Product (**SWOT_L2_LR_SSH_2.0** (DOI: 10.5067/SWOT-SSH-2.0))

The HR products include:

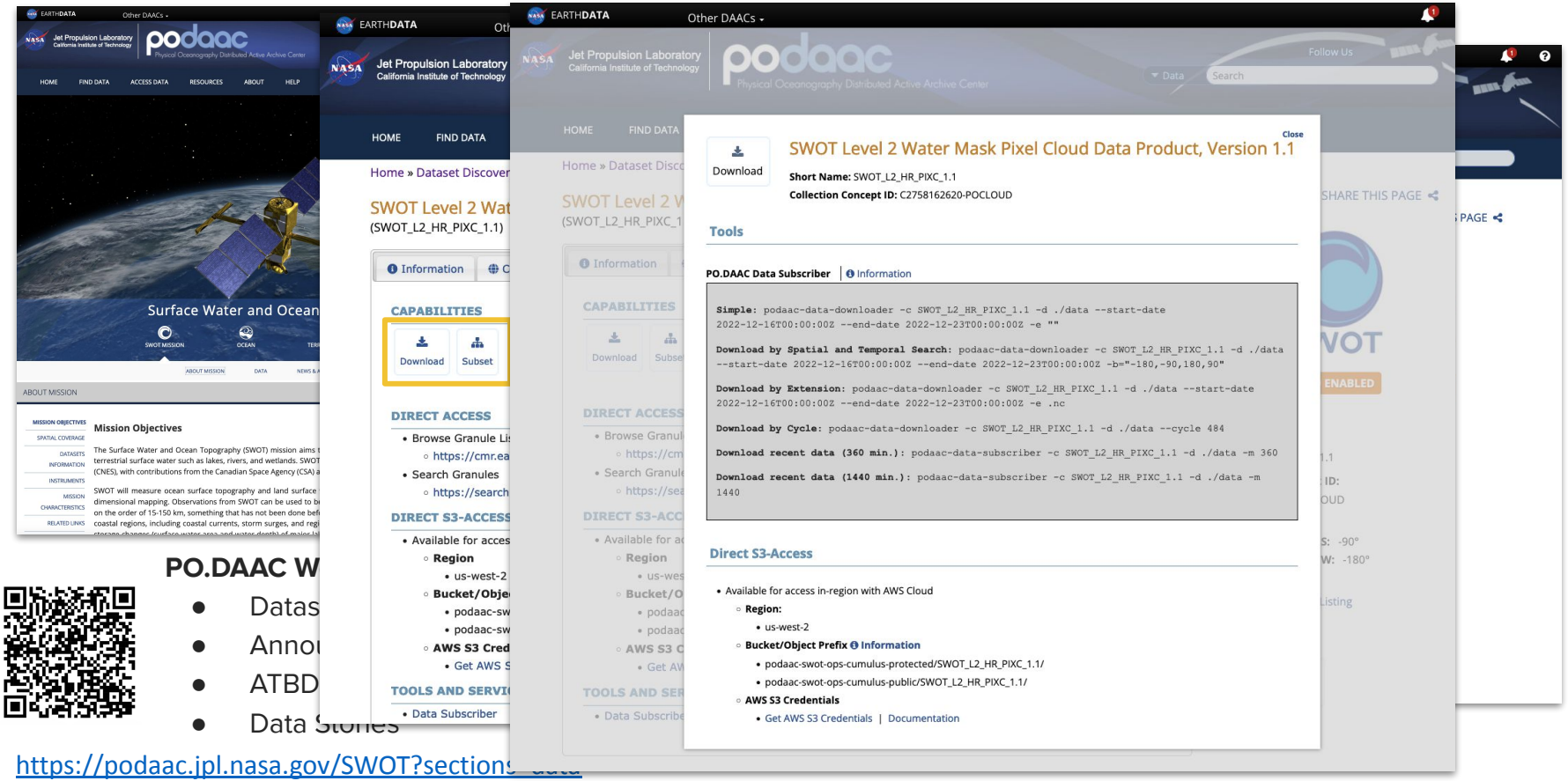
1. Level 1B KaRIn High Rate Single Look Complex Product (**SWOT_L1B_HR_SLC_2.0** (DOI: 10.5067/SWOT-SLC-2.0))
2. Level 2 KaRIn High Rate Water Mask Pixel Cloud Product (**SWOT_L2_HR_PIXC_2.0** (DOI: 10.5067/SWOT-PIXC-2.0))
3. Level 2 KaRIn High Rate Water Mask Pixel Auxiliary Cloud Product (**SWOT_L2_HR_PIXCVec_2.0** (DOI: 10.5067/SWOT-PIXCVEC-2.0))
4. Level 2 KaRIn High Rate River Single Pass Vector Product (**SWOT_L2_HR_RiverSP_2.0** (DOI: 10.5067/SWOT-RIVERSP-2.0))
5. Level 2 KaRIn High Rate Lake Single Pass Vector Product (**SWOT_L2_HR_LakeSP_2.0** (DOI: 10.5067/SWOT-LAKESP-2.0))
6. Level 2 KaRIn High Rate Raster Product (**SWOT_L2_HR_Raster_2.0** (DOI: 10.5067/SWOT-RASTER-2.0))
7. Level 2 KaRIn High Rate River Average Vector Product (**SWOT_L2_HR_RiverAvg_2.0** (DOI: 10.5067/SWOT-RIVERAVG-2.0))
8. Level 2 KaRIn High Rate Lake Average Vector Product (**SWOT_L2_HR_LakeAvg_2.0** (DOI: 10.5067/SWOT-LAKEAVG-2.0))
9. Level 2 KaRIn High Rate Floodplain DEM Product* (**SWOT_L2_HR_FPDEM_2.0**
   *available after one year of science orbit products released

Timeline to data

- ✓ v1.1 - Beta Pre-Validated released November 2023
- ✓ v2.0 - Pre-Validated released March 2024
- Validated data to be released no sooner than June 2024



PO.DAAC Access to SWOT data: **Search**



PO.DAAC W

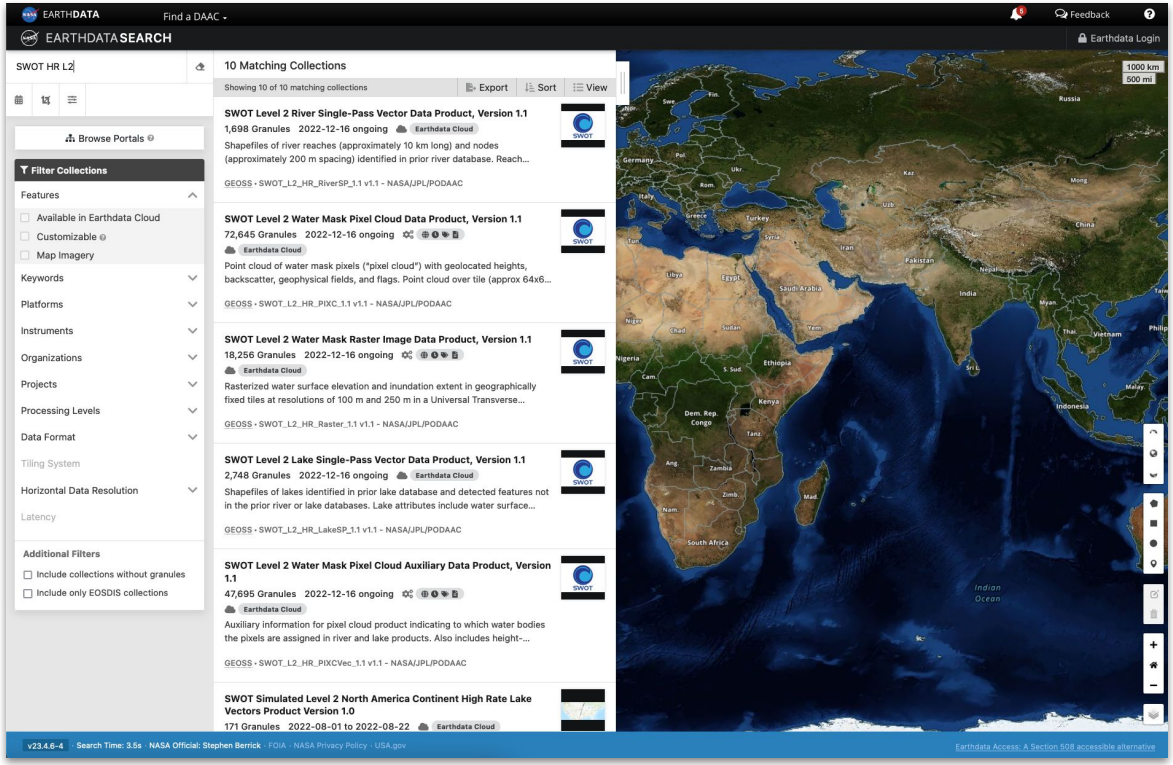
- Datas
- Anno
- ATBD
- Data S

https://podaac.jpl.nasa.gov/SWOT?sections=data

PO.DAAC Access to SWOT data: **Search**

Earthdata Search

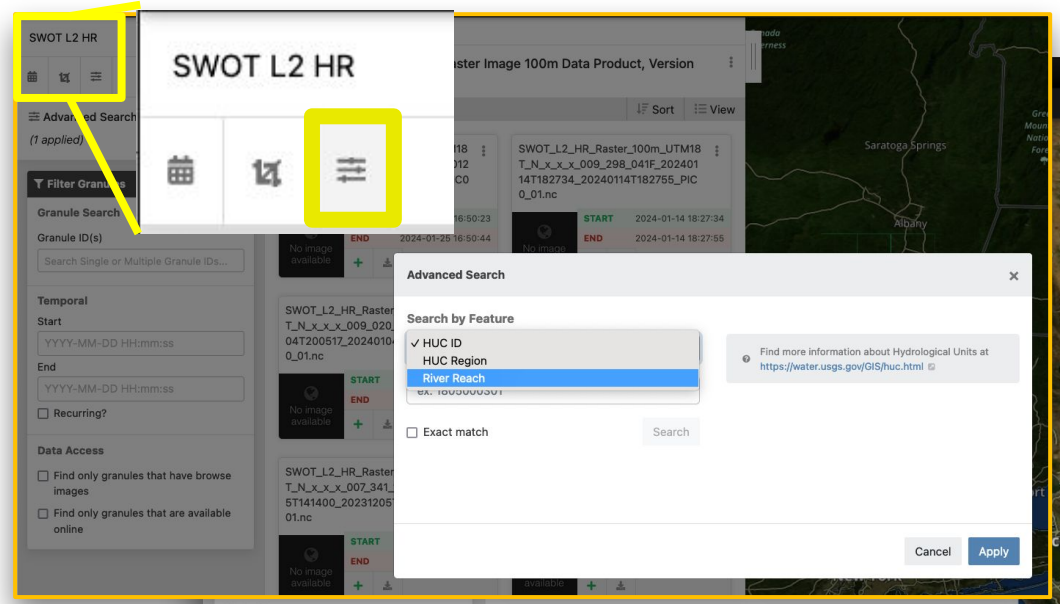
- Search and Discover SWOT and NASA EO data, metadata
- Faceted search to identify dataset per needs
- To download, need to log in with Earthdata Login
- **https** and **s3** data access links

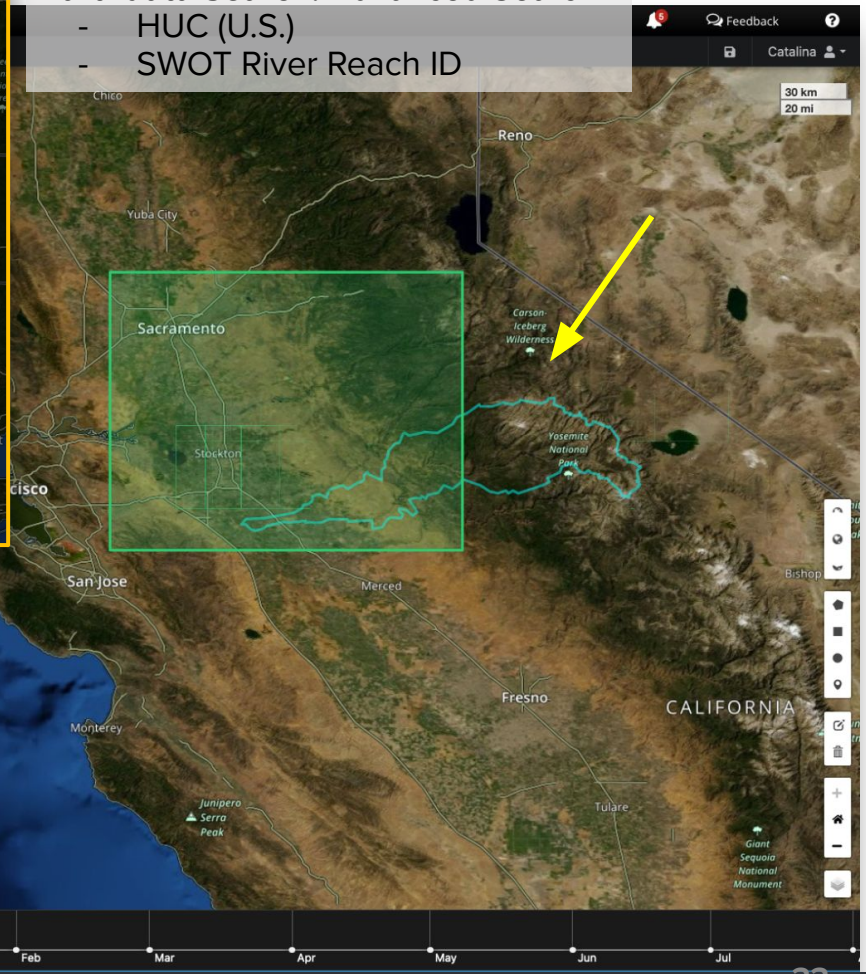


https://search.earthdata.nasa.gov/search?fpj=SWOT

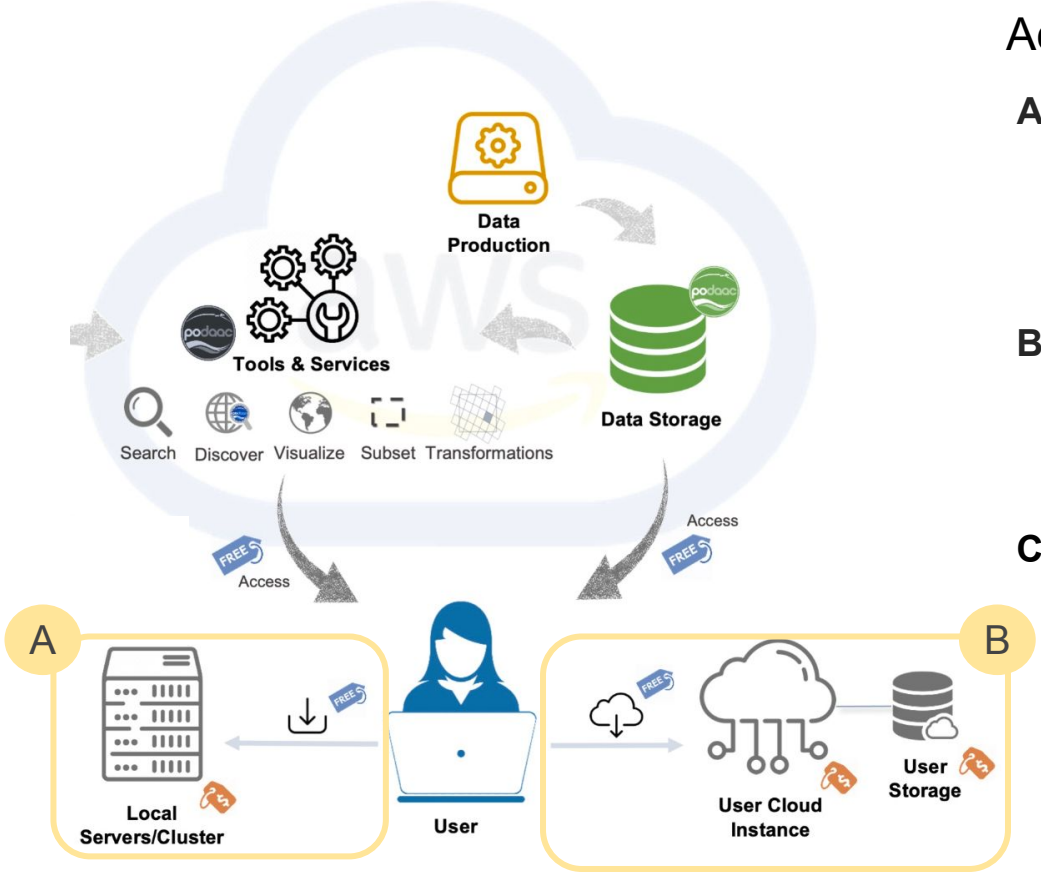
Earthdata Search: Advanced Search

- HUC (U.S.)
- SWOT River Reach ID





Accessing SWOT data from PO.DAAC



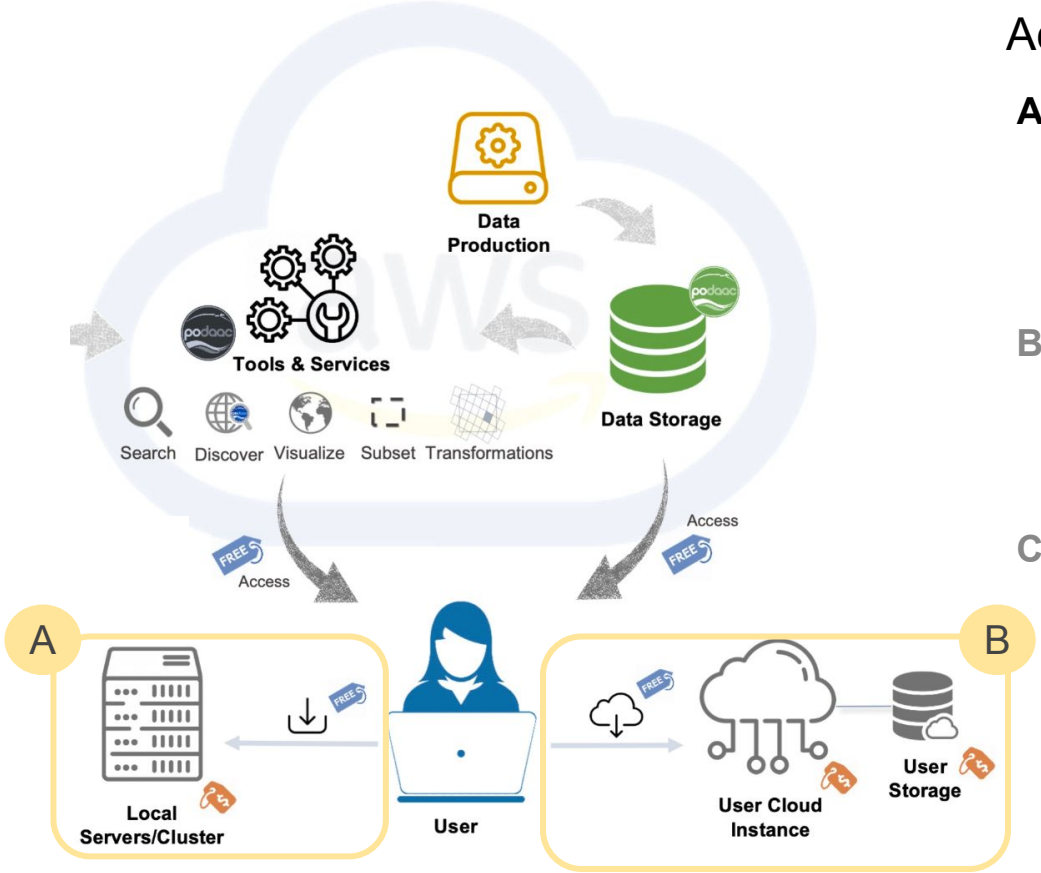
Access pathways (not exhaustive)

A. **Download** to local computer, laptop, server
- *E.g. subscriber/downloader CLI tool*
- *E.g. programmatic (python, notebook)*
- *E.g. via graphic user interface:* ***HiTIDE***

B. **In-cloud access** workflows (no download)
- *E.g. programmatic (python, notebook)*

C. **API**/Web Service (“streaming data”)
- *E.g. GIS tools*
- *Hydrocron API*
- `In development`

Accessing SWOT data from PO.DAAC



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B. **In-cloud access** workflows (no download)
- *E.g. programmatic (python, notebook)*

C. **API**/Web Service (“streaming data”)
- *E.g. GIS tools*
- *In development*

HiTIDE Demonstration

- Explore Level 2 swath data for ocean
- A tool for download workflow
- View data coverage compared to a regional box
- Preview data values
- **Subset** the data (not only spatial search)

https://hitide.podaac.earthdatacloud.nasa.gov/

DEMO

HiTIDE

High-level

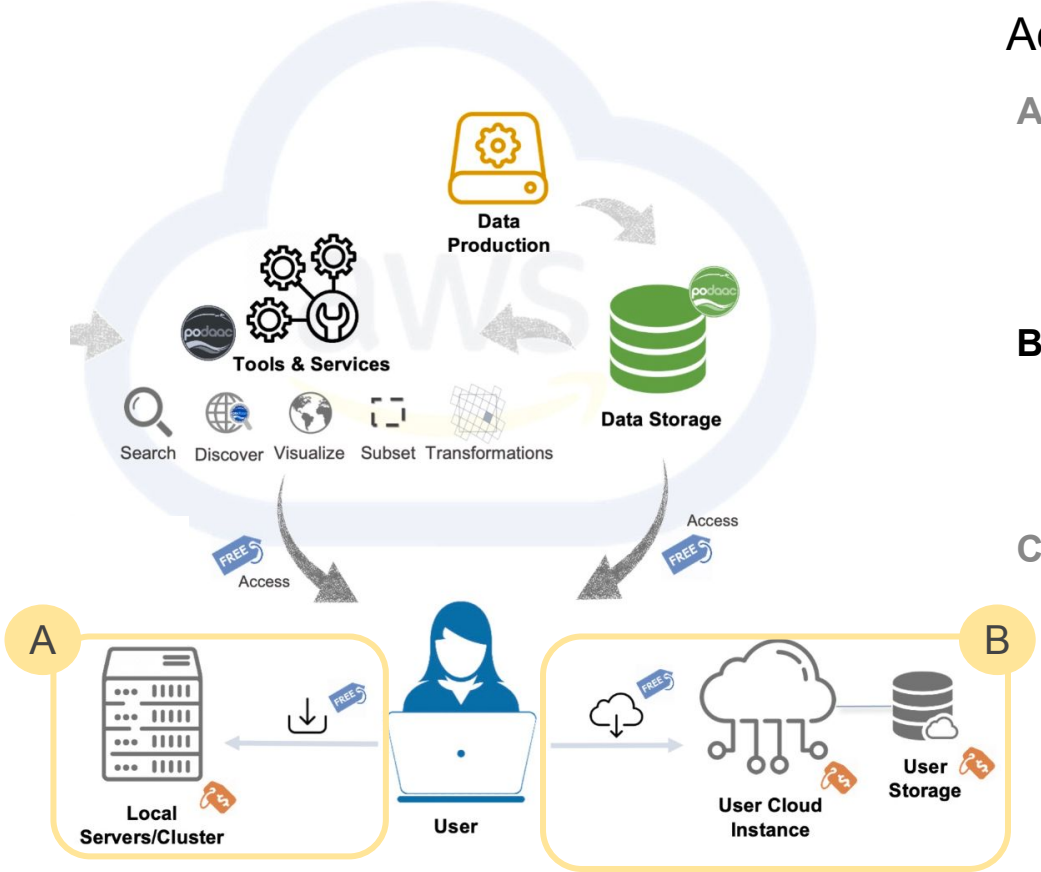
Tool for

Interactive

Data

Extraction

Accessing SWOT data from PO.DAAC



Access pathways (not exhaustive)

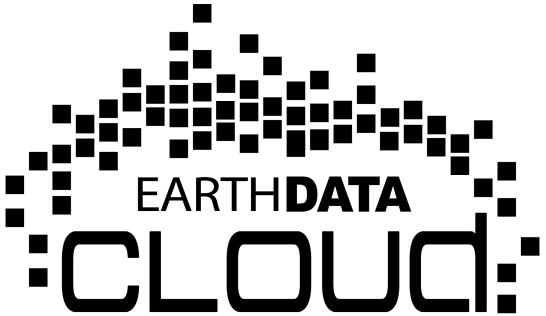
A. **Download** to local computer, laptop, server
   - *E.g. subscriber/downloader CLI tool*
   - *E.g. programmatic (python, notebook)*
   - *E.g. graphic user interface: HiTIDE*

B. **In-cloud access** workflows (no download)
   - *E.g. programmatic (python, notebook)*

C. **API**/Web Service (“streaming data”)
   - *E.g. GIS tools*
   - *In development*

Jupyter Notebook Demonstration

in the AWS Cloud



B. Accessing SWOT data in the cloud

Demo quick preview

Requirement:

This tutorial can only be run in an **AWS cloud instance running in us-west-2**: NASA Earthdata Cloud data in S3 can be directly accessed via `earthaccess` python library; this access is limited to requests made within the US West (Oregon) (code: `us-west-2`) AWS region.

Learning Objectives:

- Access SWOT HR data prodcuts (archived in NASA Earthdata Cloud) within the AWS cloud, without downloading to local machine
- Visualize accessed data for a quick check

SWOT Level 2 KaRIn High Rate Version 1.1 (where available) Datasets:

1. **River Vector Shapefile** - SWOT_L2_HR_RIVERSP_1.1
2. **Lake Vector Shapefile** - SWOT_L2_HR_LAKESP_1.1
3. **Water Mask Pixel Cloud NetCDF** - SWOT_L2_HR_PIXC_1.1
4. **Raster NetCDF** - SWOT_L2_HR_Raster_1.0
5. **Single Look Complex Data product** - SWOT_L1B_HR_SLC_1.1

0

Libraries Needed

Use this while SWOT data has restricted access: need to install the dev version for earthaccess

```
import s3fs
import fiona
import xarray as xr
import pandas as pd
import geopandas as gpd
import numpy as np
import matplotlib.pyplot as plt
import hvplot.xarray
import earthaccess
```

1

Earthdata Login

An Earthdata Login account is required to access data, as well as discover restricted data, from the NASA Earthdata system. Thus, to access NASA data, you need Earthdata Login. If you don't already have one, please visit https://urs.earthdata.nasa.gov to register and manage your Earthdata Login account. This account is free to create and only takes a moment to set up. We use `earthaccess` to authenticate your login credentials below.

```
auth = earthaccess.login()
```

2

Search for the data of interest

```
#Retrieves granule from the day we want, in this case by passing to `earthdata.search_data` function
river_results = earthaccess.search_data(short_name = 'SWOT_L2_HR_RIVERSP_1.1',
                                        temporal = ('2023-04-08 00:00:00', '2023-04-25 23:59:59'),
                                        granule_name = '*Reach*_013_NA*', # here we filter by Reach
                                        count=2000) #for restricted datasets, need to specify count
```

3

Set up an `s3fs` session for Direct Cloud Access

`s3fs` sessions are used for authenticated access to s3 bucket and allows for typical file-system style operations. Below we create session by passing in the data access information.

```
fs_s3 = earthaccess.get_s3fs_session(results=river_results)
```

Direct in-cloud access *without* moving, storing or downloading files

4

Create Fiona session to work with zip and embedded shapefiles in the AWS Cloud

The native format for this data is a **.zip** file, and we want the **.shp** file within the .zip file, so we will create a Fiona AWS session using the credentials from setting up the s3fs session above to access the shapefiles within the zip files. If we don't do this, the alternative would be to download the data to the cloud environment (e.g. EC2 instance, user S3 bucket) and extract the .zip file there.

```
fiona_session=fiona.session.AWSSession(
        aws_access_key_id=fs_s3.storage_options["key"],
        aws_secret_access_key=fs_s3.storage_options["secret"],
        aws_session_token=fs_s3.storage_options["token"]
    )
```

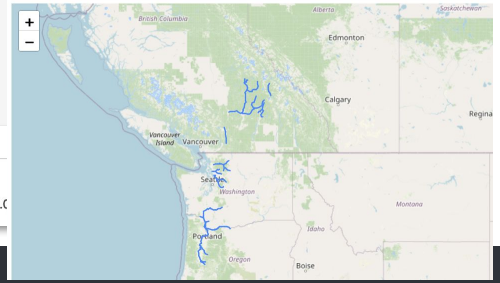
```
# We use the zip+ prefix so fiona knows that we are operating on a zip file
river_shp_url = f"zip+{river_data[0]}"

with fiona.Env(session=fiona_session):
    SWOT_HR_shp1 = gpd.read_file(river_shp_url)

#view the attribute table
SWOT_HR_shp1
```

reach_id	time	time_tai	time_str	p_lat	p_lon	river_name
100900135	-1.000000e+12	-1.000000e+12	no_data	46.159638	-123.070171	Columbia River

1. earthaccess.login()
2. earthaccess.search_data()
3. earthaccess.get_s3fs_session()
4. Fiona & zip+ (if needed)
5. Plot

5 **Quickly plot the SWOT river data**

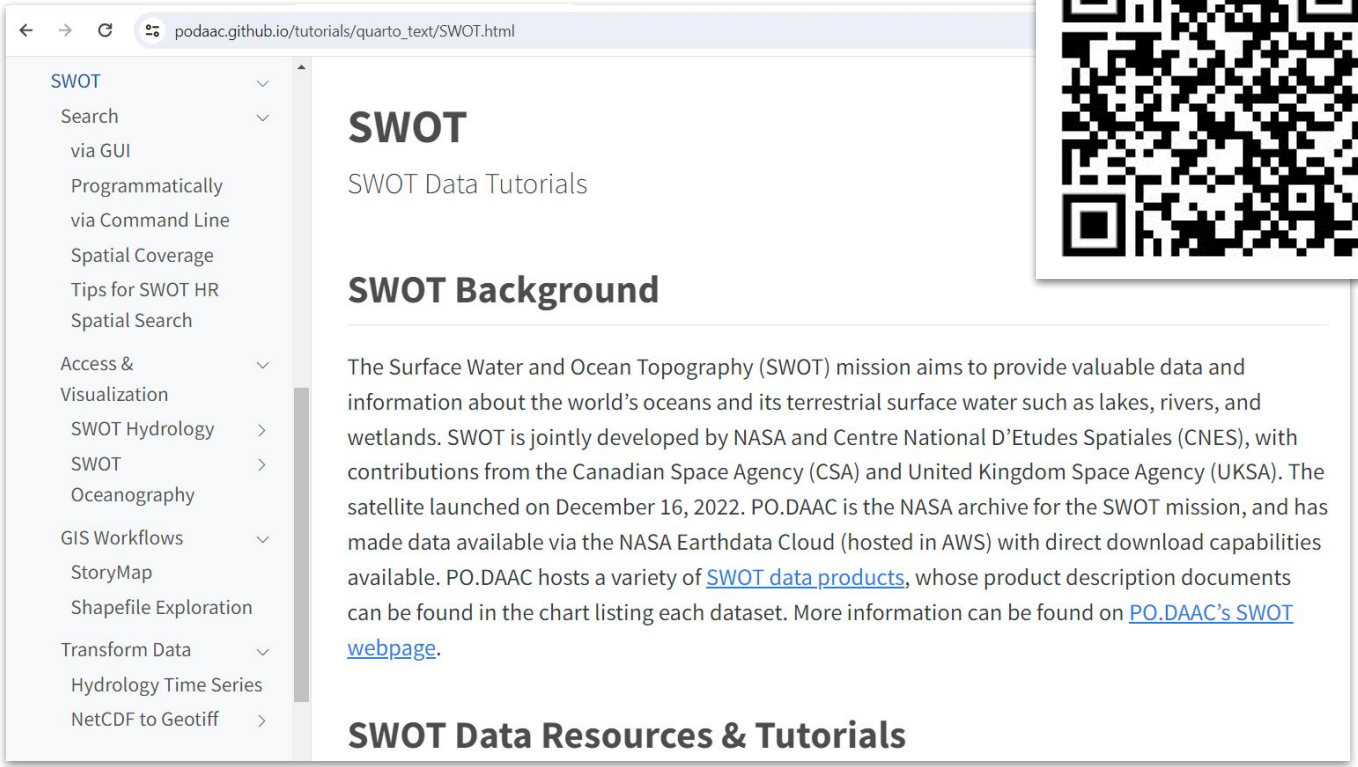
```
# # Another way to plot geopandas dataframes is with `explore`, which also plots a basemap
SWOT_HR_shp1.explore()
```



Resources & Tutorials!

PO.DAAC Cookbook: SWOT Chapter

Let's explore!



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

Tools for accessing SWOT data - Cheatsheet

Ocean Hydro Coast

REF

Learn/Information

- PO.DAAC Dataset Mission Page and Landing Pages https://podaac.jpl.nasa.gov/SWOT?sections=data

Find Data - Map GUI interface

- Search & Access in *Earthdata Search* https://search.earthdata.nasa.gov/search?q=SWOT%20HR&long=-0.0703125

Access - Command line/automated scripts

- Subscriber/Downloader https://podaac.github.io/tutorials/quarto_text/SWOT.html

Access & Subset - GUI

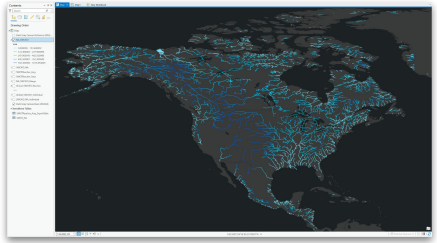
- HiTIDE https://hitide.podaac.earthdatacloud.nasa.gov/

Access - Cloud native, Big data, ML

- in-cloud access available: example for LR ocean, example for HR hydro

Access & Explore - In development or planning phase:

- Hydrocron Timeseries API - *in development (Beta, Spring 2024)*
- SWODLR On-demand Raster - *in development (Beta, Spring 2024)*
- GIS-friendly, e.g. web services (e.g. WFS) - *in development (Beta, mid-2024)*
- QGIS and ArcGIS - local: download and open - *works now*
- Exploratory Analysis in SOTO by Worldview - *early 2025*



Thank you! Questions?

Cassie Nickles – PO.DAAC Applied Science System Engineer
Celia Ou – PO.DAAC Data Publication Engineer

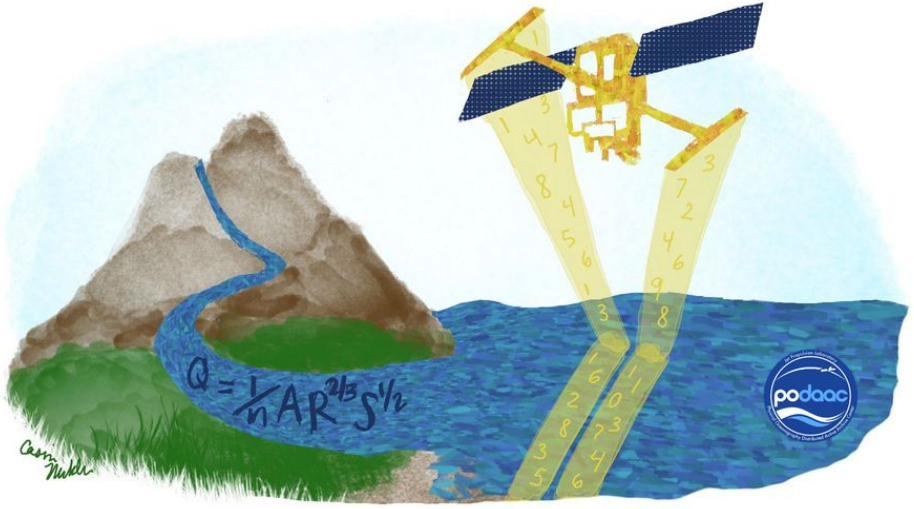
Contact PO.DAAC via:
podaac@podaac.jpl.nasa.gov

Questions?
Check out the Earthdata Forum!
https://forum.earthdata.nasa.gov/
SWOT Data Product User Feedback:
https://forum.earthdata.nasa.gov/viewtopic.php?t=5270

Subscribe to PO.DAAC Mailing List

https://podaac.jpl.nasa.gov/swot

PO.DAAC Cookbook - SWOT Chapter
Tutorials and Resources



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