SWOT HR River Discharge Products v3

Quick guide to SWOT discharge

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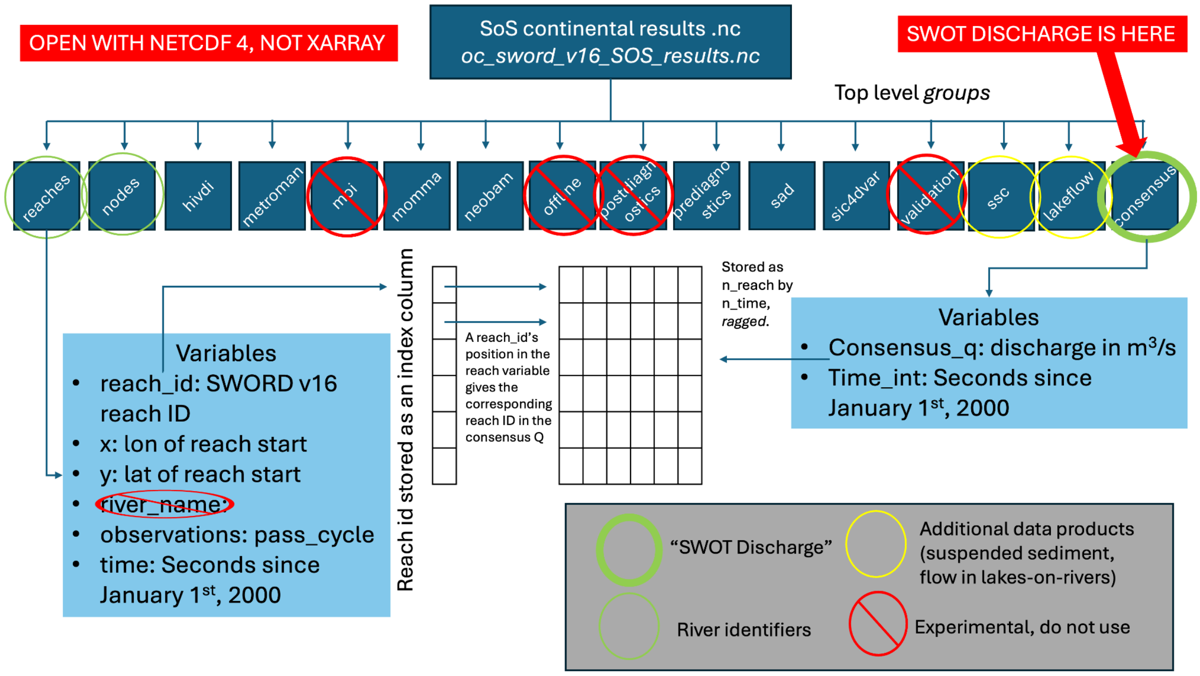
See https://www.youtube.com/@SWOTDAWG for visual guidance

- The data are provided as netCDFs per continent. They are *grouped* datasets, thus `ncdf4` is *strongly* recommended over `xarray` to open. See examples below.
- Within each file, there are 16 groups, each corresponding to a different data element. To access discharge time series, you need the following groups:
  - Consensus
    - Discharge is called ‘consensus_q’ : consensus -> consensus_q. It is in units of m^3/s
    - The time of each discharge is called ‘time_int’ consensus -> time_int. it is in units of seconds since January 1, 2000
    - Discharge is stored in a matrix with variable length columns. The row position indicates the reach id, to find the reach id you need to open the ‘reaches’ group
  - Reaches
    - Reach_id for SWORD 16 is found in reaches->reach_id. This is a single column vector of the same length as consensus_q. Mapping these together allows you to make hydrographs for reaches of interest.
- **DO NOT USE DATA FROM THE FOLLOWING GROUPS:**
  - MOI, offline, postdiagnostics, validation
  - These are experimental and incorrect in this version of the product
- The other groups are variables related to discharge
  - *hivdi*, *metroman*, *momma*, *neobam*, *sad*, and *sic4dvar* are all individual algorithms that are used to create the consensus from SWOT. Each has its own discharge elements, formats, output variables, and naming conventions you can find below
  - *SSC* is an estimate of suspended sediment made from HLS data on the same day as SWOT observations.
  - *Lakeflow* is an estimate of flow into/out of lakes connected to SWORD
  - *Prediagnostics* contains all of the information about how the input SWOT data were filtered before being used to estimate discharge
- Pseudocode to make a hydrograph at a reach of interest
  - Open netCDF, extract the reach ID’s from the reach group and the SWOT discharge from the consensus group, along with its time
  - Match the reach IDs to the rows of the consensus_q variable to assign reach ids
  - Plot time_int vs consensus_q for reach IDs of interest



[Visual](#) representation of the SWOT Discharge setup, corresponding to page 1 of this Quick User Guide.

1. Products Description

1.1. Overview

The SWOT river discharge products are computed based on the parameters estimated by the 5 main algorithms dedicated to discharge inference – the so-called "Flow Law Parameters Estimation" (FLPE) algorithms are implemented in version 1: hivdi, metroman, neobam, sad, sic4dvar (for references about each algorithms, see section **algorithms references** in appendix). The objective of these FLPE algorithms is to provide parameters for the estimation of Level 2 discharge using Manning equation.

Because these algorithms rely on models of various complexity (from geomorphological laws to full shallow water equations), various spatiotemporal scales (from – fine - node scale to - medium - reach scale) and use different assimilation methods, they also can provide – as a by-product – discharge estimation that encompass more of the expertise of the algorithms development teams. This is why we – the Discharge Algorithm Working Group – decided to release these discharge estimation data as a Level 4 product.

1.2. Level 2 discharge products

- Available in SWOT_HR_L2_RiverSP products

- Table with attributes/variables description

1.3. Level 4 discharge products

1.3.1. Overview

The Level 4 discharge are expert products that are produced inside CONFLUENCE using the embedded models of each FLPE algorithm. These discharge estimations are distributed in the form of SoS (SWORD of Science) results files, one for each continent. These files are produced each time the CONFLUENCE toolchain is run.

1.3.2. Groups and attributes in SoS results products

SWOT Observations/Product Description document

Some information related to SWOT observations are replicated in the SoS results files in order to be able to process results using only the SoS results files. The two groups **/reaches** and **/nodes** are dedicated to this. Table XX lists all the variables in these /reaches group and Table XX lists all the variables in the node group

group	Variable	Description	unit
/reaches	**reach_id**	Taken from SWORD PDD: id of each reach.	
	x	longitude of the reach center decimal ranging from 180°E to 180°W	degrees_east
	y	latitude of the reach center decimal ranging from 90°S to 90°N	degrees_north
	river_name	all river names associated with a reach. If there are multiple names for a reach they are listed in alphabetical order and separated by a semicolon.	
	observations	Pass numbers associated with observations for each reach. Cycle passes are taken from shapefile name where a single cycle, pass combination is separated by an underscored (e.g., 112_386 representing cycle 112 and pass 386). Cycle, pass combinations are stored as strings with each cycle_pass element separated by a comma for each reach that has observations.	pass

	time	Taken from SWORD PDD: Time of measurement in seconds in the UTC time scale since 1 Jan 2000 00:00:00 UTC. [tai_utc_difference] is the difference between TAI and UTC reference time (seconds) for the first measurement of the data set. If a leap second occurs within the data set, the metadata leap_second is set to the UTC time at which the leap second occurs.	seconds since 2000-01-01 00:00:00.000
/nodes	**node_id**	Taken from SWORD PDD: id of each node.	
	reach_id	Taken from SWORD PDD: id of the reach each node is associated with.	
	x	longitude of each node ranging from 180°E to 180°W	degrees_east
	y	latitude of each node ranging from 90°S to 90°N	degrees_north
	river_name	all river names associated with a node. If there are multiple names for a node they are listed in alphabetical order and separated by a semicolon.	
	observations	Pass numbers associated with observations for each node. Cycle passes are taken from shapefile name where a single cycle, pass combination is separated by an underscored (e.g., 112_386 representing cycle 112 and pass 386). Cycle, pass combinations are stored as strings with each cycle_pass element separated by a comma for each node that has observations.	pass
	time	Taken from SWORD PDD: Time of measurement in seconds in the UTC time scale since 1 Jan 2000 00:00:00 UTC. [tai_utc_difference] is the difference between TAI and UTC reference time (seconds) for the first measurement of the data set. If a leap second occurs within the data set, the metadata leap_second is set to the UTC time at which the leap second occurs.	seconds since 2000-01-01 00:00:00.000

FLPE results

Results from FLPEs are raw outputs of FLPE algorithms, which in future versions will be *integrated* with the MOI. They are available in corresponding groups in the SoS results files. Table XX lists the groups and variables of these results. Table 1 lists the main variables of the FLPE results. This is an extract of Table 3 in appendix that list all the output variables of the FLPE algorithms.

Table 1 : List of all main variables in the SoS for the results of the FLPE algorithms

group	Variable	Description	unit
/hivdi	**Q**	Discharge timeseries	m^3/s
	A0	Part of the flow area that is below the lowest observation	m^2
	alpha	Coefficient of the Strickler law : K=alpha*h**beta	$m^{1/3}/s$
	beta	Exponent of the Strickler law : K=alpha*h**beta	
	n	Constant-in-time manning coefficient. Applicable to the conventional manning equation for estimating the L2 discharge	$s/m^{1/3}$
/metroman	**allq**	discharge of all times, including those outside inversion window	m^3/s
	A0hat	represented as the cross-sectional area of the initial time in the timeseries	m^2
	nahat	coefficient of the manning's equation power law	$m^{1/3}/s$
	x1hat	exponent for the manning coefficient power law	
	q_u	uncertainty calculated as the standard deviation of the Markov Chain	m^3/s
/momma	**Q**	For cases with complete SWOT-observed data (slope, width, elevation)	m^3/s
	Q_constrained	For cases when Qgage values are available and gage_constrained == TRUE	m^3/s
	zero_flow_stage	The zero flow stage (elevation of zero flow) is the stage below which the algorithm would return zero discharge, and serves as the stage defining the reach averaged bottom elevation from which mean depth of flow is referenced	m
	bankfull_stage	The bankfull stage is used to reference an in-bank and overbank segment (if this exists in the observational record) and is used to derive relative depths for calculation of the flow resistance in the algorithm.	m
	Qmean_momma	Mean of all discharge estimates for each SWOT observation	m^3/s
	Qmean_momma.constrained	Computed when gage_contrained == TRUE	m^3/s
/neobam/r	**mean**	r defined following Dingman 2007 JoH	
	sd	r defined following Dingman 2007 JoH	
/neobam/logn	**mean**	mean n from neobam	
	sd	sigma n from neobam	
/neobam/logDb	**mean**	mean bankfull depth from neobam	m
	sd	sigma bankfull depth from neobam	m

/neobam/logWb	**mean**	mean bankfull width	m
	sd	sigma bankfull width	m
/neobam/q	**q**	timeseries	m^3/s
	q_sd	sigma discharge	
/sad	**A0**	unobserved cross sectional area	m^2
	n	Manning's roughness coefficient	
	Qa	Mean discharge	m^3/s
	Q_u	Discharge standard deviation	m^3/s
/sic4dvar	**A0**	unobserved cross-sectional area	m^2
	n	Manning's roughness coefficient constant in time	$s/m^{1/3}$
	Q_mm	Discharge time series at reach level using SWOT reach observations output of optimization of modified Manning's equation	m^3/s
	Q_da	Discharge time series at node or reach level with improved observations output of Bayesian data assimilation	m^3/s
	width	Bed widths at each cross-section (dry observed bathymetry and wet estimated bathymetry)	m
	elevation	Bed levels at each cross-section (dry observed bathymetry and wet estimated bathymetry)	m

FLPE results after MOI

MOI IS CURRENTLY EXPERIMENTAL. INFORMATION IS FOR FUTURE VERSION INFORMATION ONLY

Table 2 : List of all variables in the SoS for the results of the FLPE algorithms after MOI

group	Variable	Description	unit
/moi/hivdi	**q**	timeseries of discharge for each SWOT overpass for MetroMan	m^3/s
	Abar	represented as the cross-sectional area at the time of the median WSE in the timeseries	m^2
	alpha	Coefficient of the Strickler law : K=alpha*h**beta	$m^{1/3}/s$
	beta	Exponent of the Strickler law : K=alpha*h**beta	
	qbar_reachScale	average of the timeseries of the reach scale (stage 1) discharge estimates	m^3/s
	qbar_basinScale	average of the timeseries of the basin scale (stage 2) discharge estimates	m^3/s

/moi/metroman	**q**	timeseries of discharge for each SWOT overpass for MetroMan	m^3/s
	Abar	represented as the cross-sectional area at the time of the median WSE in the timeseries	m^2
	na	coefficient of the manning's equation power law	$m^{1/3}/s$
	x1	exponent for the manning coefficient power law	
	qbar_reachScale	timeseries average of discharge estimated from reach scale (stage 1) FLPE	m^3/s
	qbar_basinScale	Stage 2 algorithm requires average flows to be positive	m^3/s
/moi/momma	**q**	timeseries of discharge from stage 2	m^3/s
	B	bottom of the river elevation calculated in stage 2 algorithms	m
	H	bank height elevation calculated in stage 2 algorithms	m
	Save	average of the slope measurements from SWOT	m/m
	qbar_reachScale	average of the timeseries of the reach scale (stage 1) discharge estimates	m^3/s
	qbar_basinScale	average of the timeseries of the basin scale (stage 2) discharge estimates	m^3/s
/moi/neobam	**q**	timeseries of discharge for each SWOT overpass for geoBAM	m^3/s
	a0	represented as the cross-sectional area at the time of the median WSE in the timeseries	m^2
	n	time-constant Manning's n	$s/m^{1/3}$
	qbar_reachScale	timeseries average of discharge estimated from reach scale (stage 1) FLPE	m^3/s
	qbar_basinScale	Stage 2 algorithm requires average flows to be positive	m^3/s
/moi/sad	**q**	timeseries of discharge from stage 2	m^3/s
	a0	unobserved cross sectional area	m^2
	n	Manning's roughness coefficient	$s/m^{1/3}$
	qbar_reachScale	average of the timeseries of the reach scale (stage 1) discharge estimates	m^3/s
	qbar_basinScale	average of the timeseries of the basin scale (stage 2) discharge estimates	m^3/s
/moi/sic4dvar	**q**	timeseries of discharge from stage 2	
	a0	unobserved cross-sectional area	m^2
	n	Manning's roughness coefficient constant in time	$s/m^{1/3}$

	qbar_reachScale	average of the timeseries of the reach scale (stage 1) discharge estimates	m^3/s
	qbar_basinScale	average of the timeseries of the basin scale (stage 2) discharge estimates	m^3/s

Consensus product

2. Data providers

2.1. NASA PO.DAAC

You can discover and access these data through the NASA Earthdata SWOT site https://www.earthdata.nasa.gov/data/platforms/space-based-platforms/swot.

Data Tools and Resources as well as data tutorials can found in the PO.DAAC Cookbook – SWOT Chapter: https://podaac.github.io/tutorials/quarto_text/SWOT.html

3. Exploring the data

3.1. Using Python

In this section we present several examples to handle the SoS results products to analyze discharge timeseries using standard libraries.

Plot stage 1 Metroman results

```
import matplotlib.pyplot as plt
import netCDF4 as nc
import numpy as np

# Open SoS results file for Europe
sos_results = nc.Dataset("eu_sword_v16_SOS_results.nc", "r")

# Retrieve /reaches and /metroman (stage1) groups
reaches_group = sos_results.groups["reaches"]
metroman_group = sos_results.groups["metroman"]

# Retrieve index of the considered reach
reach_index = int(np.ravel(np.argwhere(reaches_group.variables["reach_id"][:] == 21601000091))[0])

# Retrieve datetimes
times = reaches_group.variables["time"][reach_index][:]
valid_times = times > -99999999999.0
datetimes = np.array([np.datetime64("2000-01-01") + np.timedelta64(int(dt), "s") for dt in times[valid_times]])

# Retrieve MetroMan discharge results
Q_metroman = metroman_group.variables["allq"][reach_index][:]
Q_metroman[Q_metroman == metroman_group.variables["allq"].missing_value] = np.nan
Q_metroman[Q_metroman <= -99999999999.0] = np.nan
```

```
Q_metroman = Q_metroman[valid_times]

plt.plot(datetimes, Q_metroman)
plt.show()

sos_results.close()
```

Plot stage 1 Metroman and Metroman + MOI results

```
import matplotlib.pyplot as plt
import netCDF4 as nc
import numpy as np

# Open SoS results file for Europe
sos_results = nc.Dataset("eu_sword_v16_SOS_results.nc", "r")

# Retrieve /reaches, /metroman (stage1) and /moi/metroman groups
reaches_group = sos_results.groups["reaches"]
metroman_group = sos_results.groups["metroman"]
moi_metroman_group = sos_results.groups["moi"].groups["metroman"]


# Retrieve index of the considered reach
reach_index = int(np.ravel(np.argwhere(reaches_group.variables["reach_id"][:] == 21601000091))[0])

# Retrieve datetimes
times = reaches_group.variables["time"][reach_index][:]
valid_times = times > -999999999999.0
datetimes = np.array([np.datetime64("2000-01-01") + np.timedelta64(int(dt), "s") for dt in times[valid_times]])

# Retrieve MetroMan discharge results
Q_metroman = metroman_group.variables["allq"][reach_index][:]
Q_metroman[Q_metroman == metroman_group.variables["allq"].missing_value] = np.nan
Q_metroman[Q_metroman <= -999999999999.0] = np.nan
Q_metroman = Q_metroman[valid_times]

# Retrieve MetroMan+MOI discharge results
Q_moi_metroman = moi_metroman_group.variables["q"][reach_index][:]
Q_moi_metroman[Q_moi_metroman == moi_metroman_group.variables["q"].missing_value] = np.nan
Q_moi_metroman[Q_moi_metroman <= -999999999999.0] = np.nan
Q_moi_metroman = Q_moi_metroman[valid_times]

plt.plot(datetimes, Q_metroman, label="MetroMan - stage 1")
plt.plot(datetimes, Q_metroman, label="MetroMan + MOI")
plt.legend()
plt.show()

sos_results.close()
```

3.2. Using hydroviz

Coming soon. Stay tuned.

4. Appendix

List of all variables in the SoS results for stage 1 FLPE outputs

Table 3 : List of all variables in the SoS for the results of the FLPE algorithms from stage 1

group	Variable	Description	unit
/hivdi	**Q**	Discharge timeseries	m^3/s
	A0	Part of the flow area that is below the lowest observation	m^2
	alpha	Coefficient of the Strickler law : K=alpha*h**beta	$m^{1/3}/s$
	beta	Exponent of the Strickler law : K=alpha*h**beta	
	n	Constant-in-time manning coefficient. Applicable to the conventional manning equation for estimating the L2 discharge	$s/m^{1/3}$
/metroman	**allq**	discharge of all times, including those outside inversion window	m^3/s
	A0hat	represented as the cross-sectional area of the initial time in the timeseries	m^2
	nahat	coefficient of the manning's equation power law	$m^{1/3}/s$
	x1hat	exponent for the manning coefficient power law	
	q_u	uncertainty calculated as the standard deviation of the Markov Chain	m^3/s
/momma	**stage**	Datum defined by SWOT	m
	width	Reach surface water area divided by the reach length	m
	slope	Upstream and downstream water-surface elevations divided by the reach length	
	Qgage	The ground gage is an independent discharge measuring point within the reach obtained from an existing streamgage network	m^3/s
	seg	seg = 1, below bankfull stage. seg = 2, equal to or above bankfull stage	
	n	Represents the resistance to flow within the reach when using the Manning equation to describe the mean flow	
	Y	Mean depth of flow in the reach excluding zones of zero flow and is not directly measured	m
	v	Computed from the mean depth, slope, and flow resistance. not measured	m/s
	Q	For cases with complete SWOT-observed data (slope, width, elevation)	m^3/s

Q_constrained	For cases when Qgage values are available and gage_constrained == TRUE	m^3/s
gage_constrained	Set to TRUE if Qgage values are available for calibration	
input_Qm_prior	Prior calibration target contained and hosted in the SWORD database	m^3/s
input_Qb_prior	Prior calibration target contained and hosted in the SWORD database	m^3/s
input_Yb_prior	Prior calibration target contained and hosted in the SWORD database	m
input_known_ezf	If known, a provided (prior) value of the bottom elevation of the reach channel relative to stage datum	m
input_known_bkfl_stage	If known, a provided (prior) value of the bankfull stage of the reach channel relative to stage datum	m
input_known_nb_seg1	If known, a provided (prior) value of the base n-value below bankfull	
input_known_x_seg1	If known, a provided (prior) value of the resistance exponent below bankfull	
Qgage_constrained_nb_seg1	Computed when gage_contrained == TRUE	
Qgage_constrained_x_seg1	Computed when gage_contrained == TRUE	
input_known_nb_seg2	If known, a provided (prior) value of the base n-value above bankfull	
input_known_x_seg2	If known, a provided (prior) value of the resistance exponent above bankfull	
Qgage_constrained_nb_seg2	Computed when gage_contrained == TRUE	
Qgage_constrained_x_seg2	Computed when gage_contrained == TRUE	
n_bkfl_Qb_prior	Computed if input_Qb_prior is available (not NA)	
n_bkfl_slope	Estimated using the mean of all slope values from SWOT observations in the Bray and Davar equation https://il.water.usgs.gov/proj/nvalues/equations.shtml?equation=09-bray1	
vel_bkfl_Qb_prior	Computed if input_Qb_prior is available (not NA)	m/s
Froude_bkfl_diag_Smean	The value for the diagnostic Froude number is computed from equation (9) found in Bjerklie et al., 2018 (https://doi.org/10.1016/j.jhydrol.2018.04.005)	
width_bkfl_solved_obs	the computed bankfull width may not be the highest value in the record if an overbank segment is identified or if it is not associated with the identified bankfull stage	m
depth_bkfl_solved_obs	the relation between the stage and width squared is used to define a parabolic channel cross-section shape defining the bottom stage for the channel. Alternative cross-section geometry assumptions are possible.	m

	depth_bkfl_diag_Wb_Smean	the value for the diagnostic bankfull depth is computed from equation (20) found in Bjerklie 2007 (https://doi:10.1016/j.jhydrol.2007.04.011). is used as a diagnostic comparison with MOMMA estimated bankfull depth	m
	zero_flow_stage	The zero flow stage (elevation of zero flow) is the stage below which the algorithm would return zero discharge, and serves as the stage defining the reach averaged bottom elevation from which mean depth of flow is referenced	m
	bankfull_stage	The bankfull stage is used to reference an in-bank and overbank segment (if this exists in the observational record) and is used to derive relative depths for calculation of the flow resistance in the algorithm.	m
	Qmean_prior	Prior calibration target contained and hosted in the SWORD database. same as input_Qm_prior	m^3/s
	Qmean_momma	Mean of all discharge estimates for each SWOT observation	m^3/s
	Qmean_momma.constrained	Computed when gage_contrained == TRUE	m^3/s
	width_stage_corr	Pearson correlation coefficient	
/neobam/r	**mean**	r defined following Dingman 2007 JoH	
	sd	r defined following Dingman 2007 JoH	
/neobam/logn	**mean**	mean n from neobam	
	sd	sigma n from neobam	
/neobam/logDb	**mean**	mean bankfull depth from neobam	m
	sd	sigma bankfull depth from neobam	m
/neobam/logWb	**mean**	mean bankfull width	m
	sd	sigma bankfull width	m
/neobam/q	**q**	timeseries	m^3/s
	q_sd	sigma discharge	
/sad	**A0**	unobserved cross sectional area	m^2
	n	Manning's roughness coefficient	
	Qa	Mean discharge	m^3/s
	Q_u	Discharge standard deviation	m^3/s
/sic4dvar	**A0**	unobserved cross-sectional area	m^2
	n	Manning's roughness coefficient constant in time	$s/m^{1/3}$
	Q_mm	Discharge time series at reach level using SWOT reach observations output of optimization of modified Manning's equation	m^3/s
	Q_da	Discharge time series at node or reach level with improved observations output of Bayesian data assimilation	m^3/s

	width	Bed widths at each cross-section (dry observed bathymetry and wet estimated bathymetry)	m
	elevation	Bed levels at each cross-section (dry observed bathymetry and wet estimated bathymetry)	m

FLPE Algorithms references