SWOT Discharge

The big picture

Hind Oubanas, Mike Durand, Colin Gleason, Pierre-Olivier Malaterre and Kévin Larnier
On behalf of the SWOT DAWG

SWOT Discharge Algorithm Working Group

Data

Here are datasets for use by the community.

Stage-discharge in situ data from Bangladesh

Data description (from Faisal Hossain): In followup to the SWOT Discharge WG telecon on May 15th, here is the database on current meter and ADCP-based Q measurement and

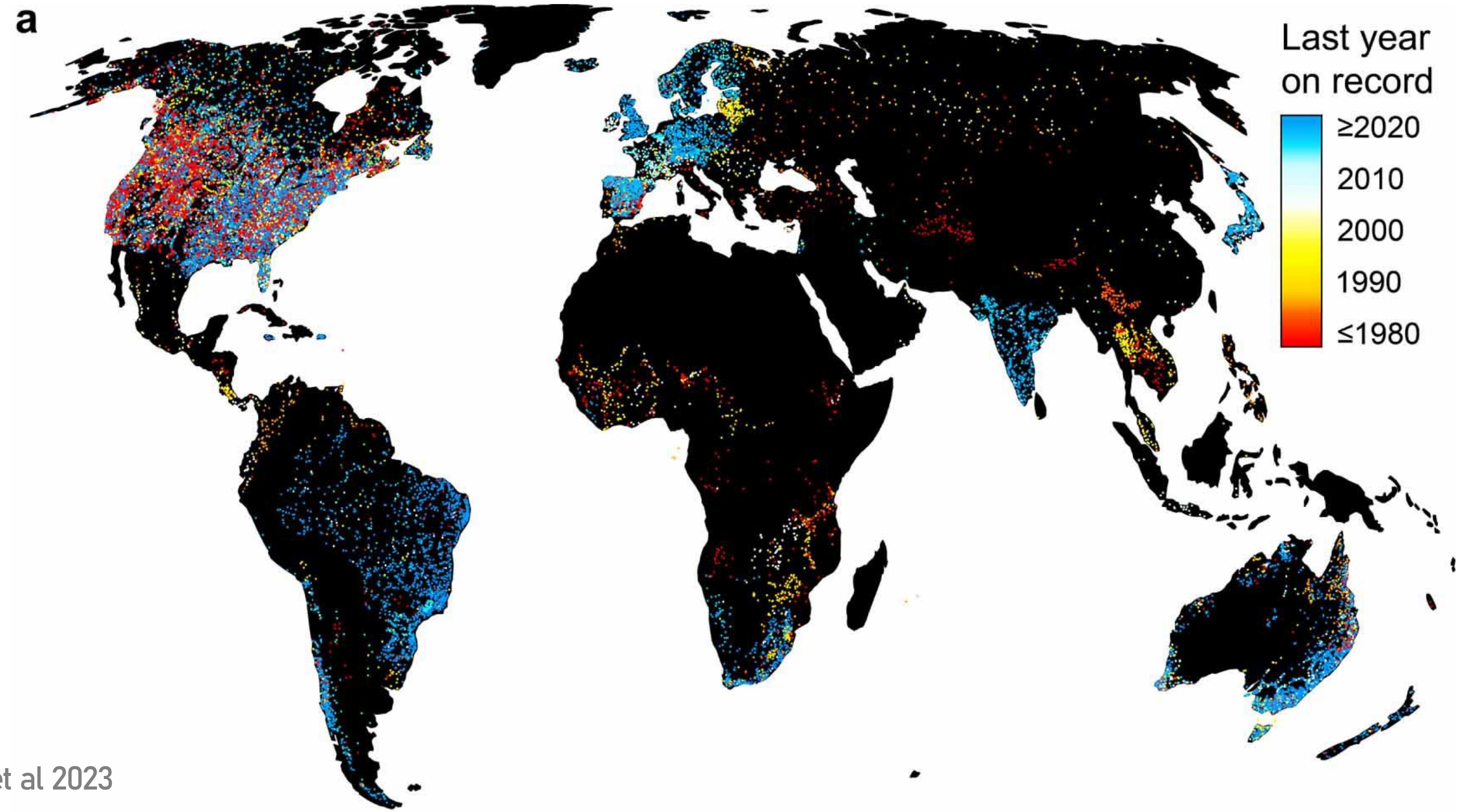
Search

Recent Posts

- June 7 Meeting
- May 10 Meeting
- Flow laws – a hypothesis
- April 12 Meeting
- March 29 Meeting

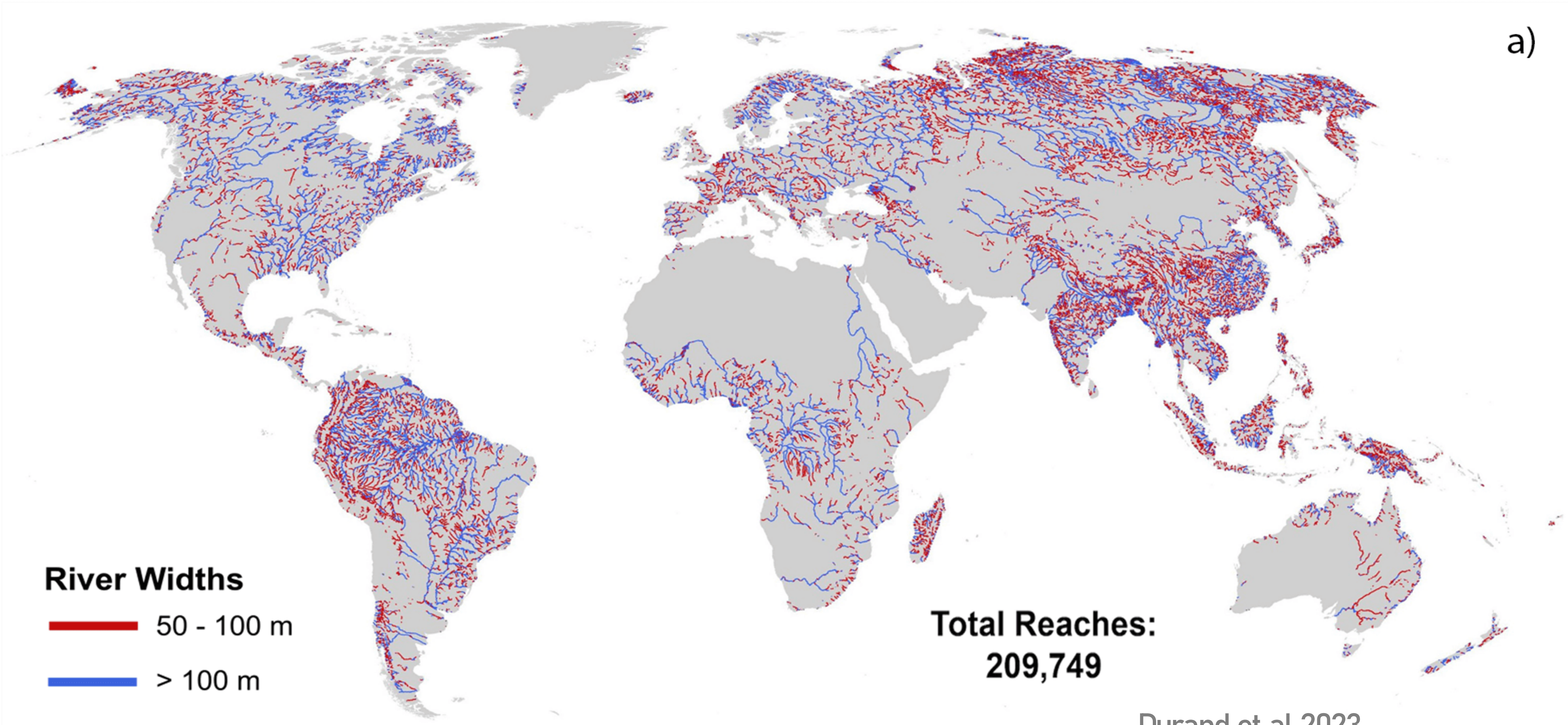
Recent Comments

Challenges : Ungauged Discharge



Riggs et al 2023

Challenges : Global Scale feasability



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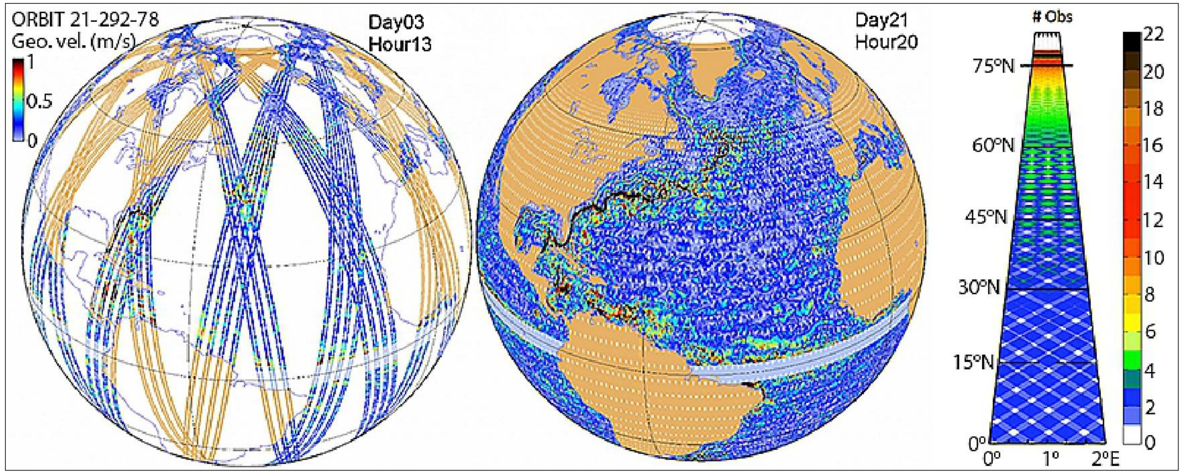
Challenges : Agencies Operational Framework

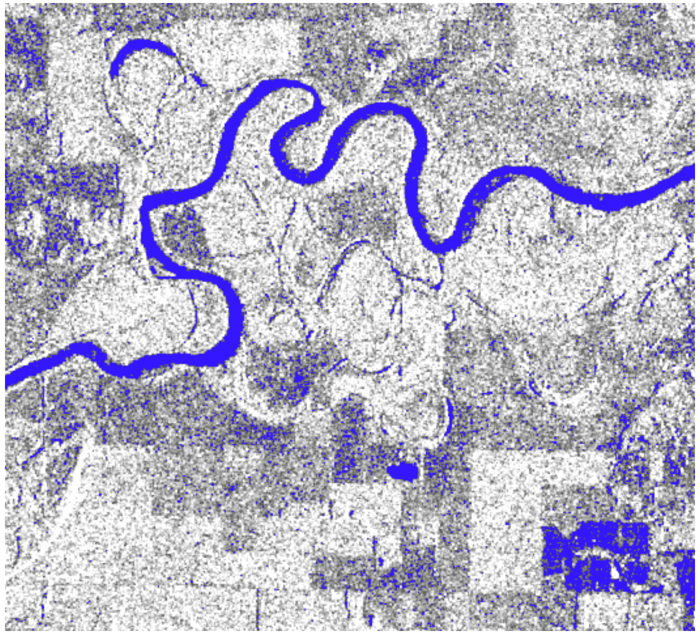
https://podaac.jpl.nasa.gov/SWOT

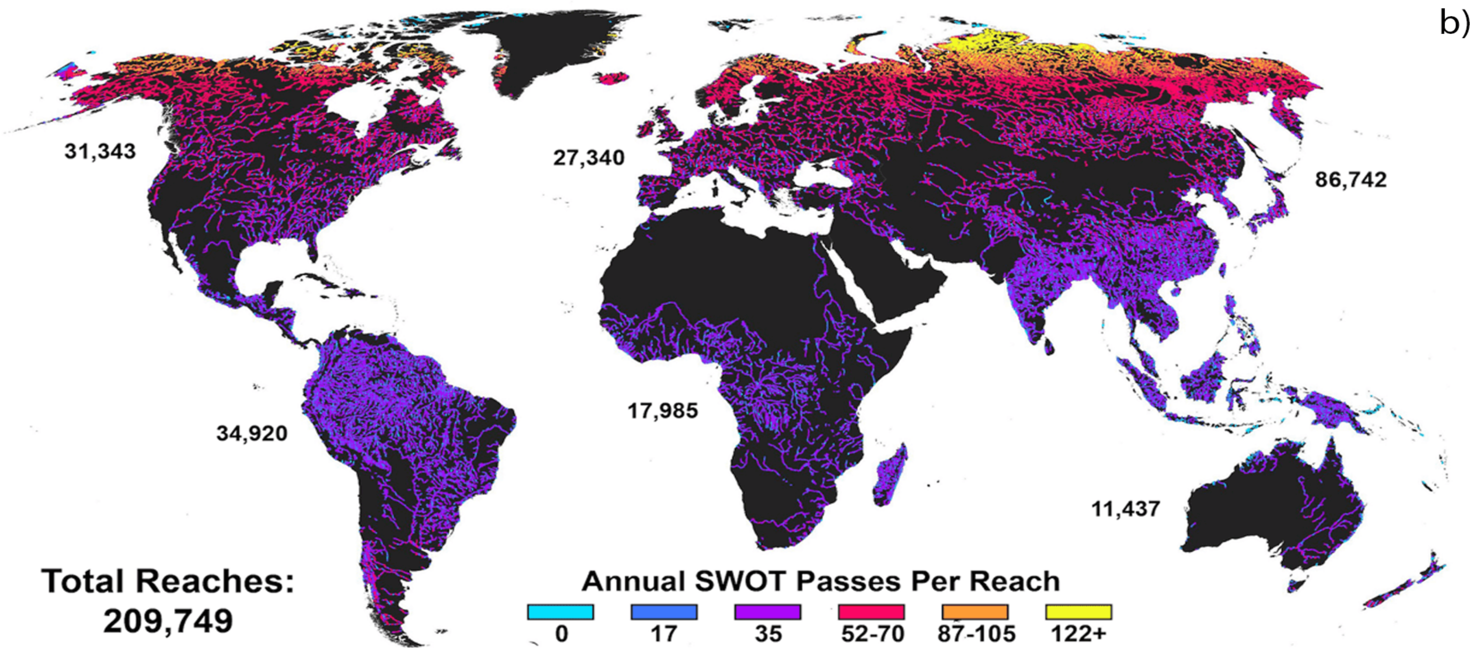
CENTRE NATIONAL D'ÉTUDES SPATIALES

Challenges : Nature of SWOT Observations

SWOT
SURFACE WATER & OCEAN TOPOGRAPHY







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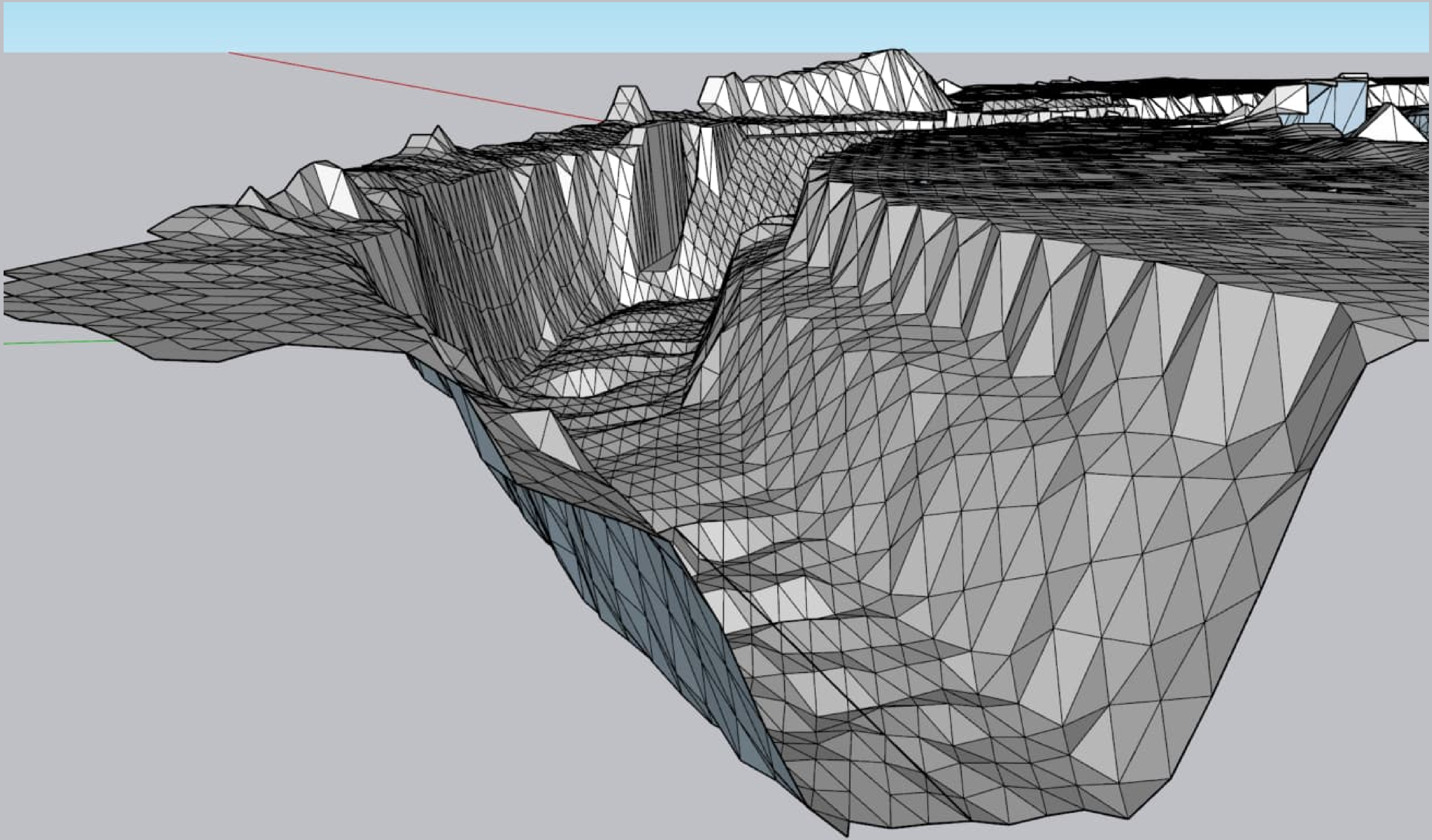
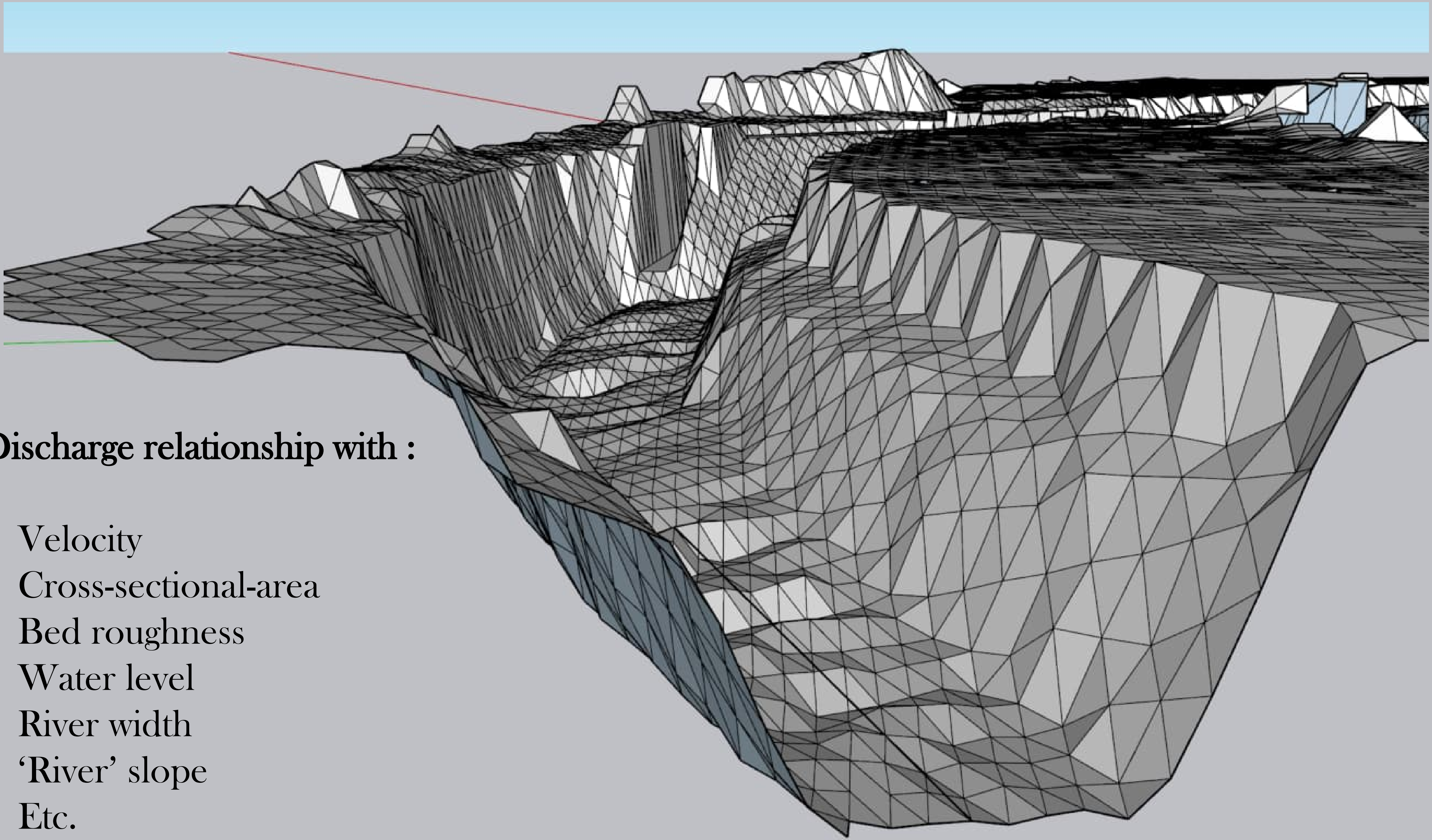
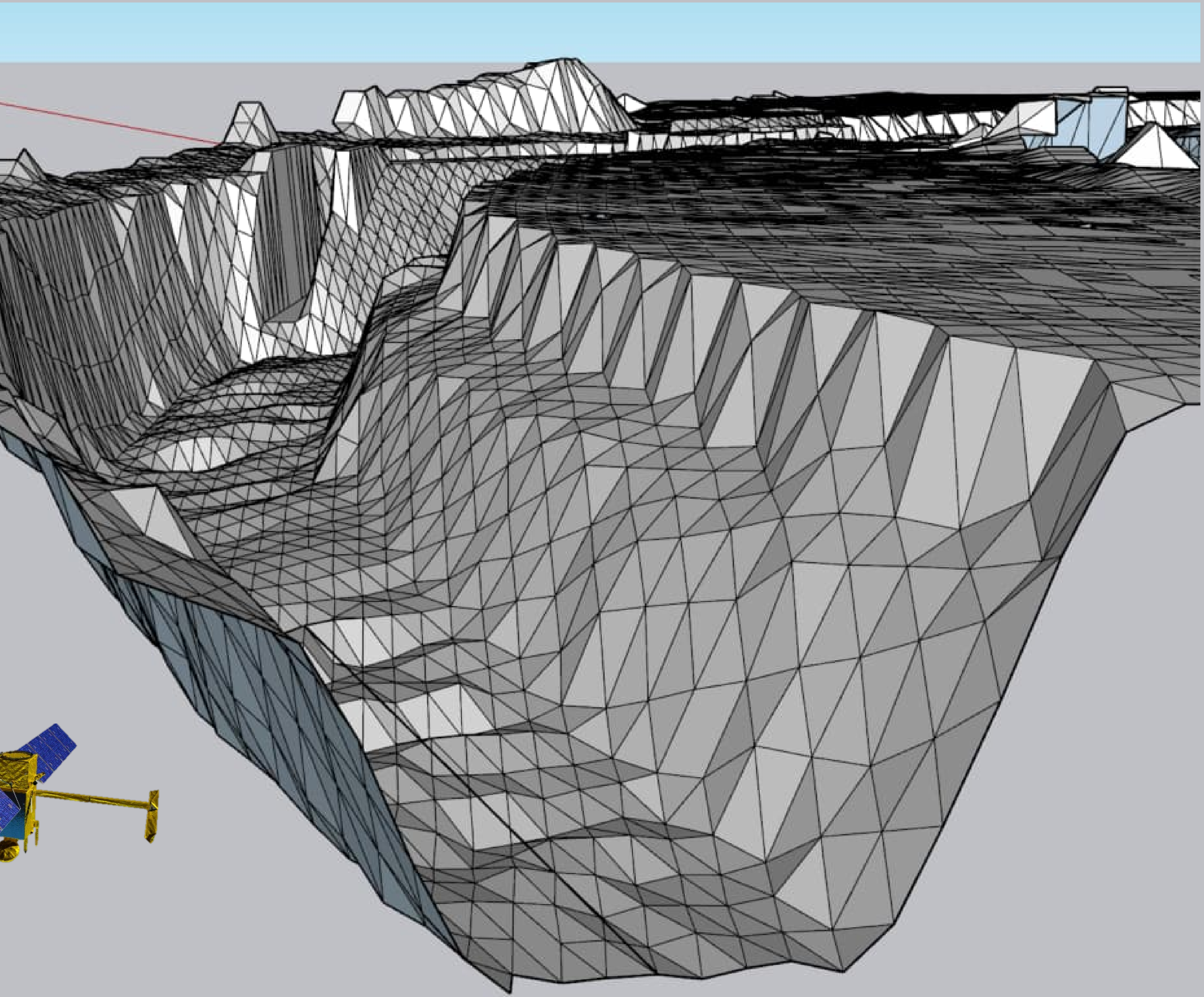




Discharge relationship with :

- Velocity
- Cross-sectional-area
- Bed roughness
- Water level
- River width
- ‘River’ slope
- Etc.



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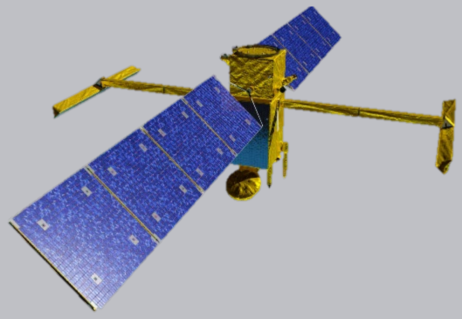

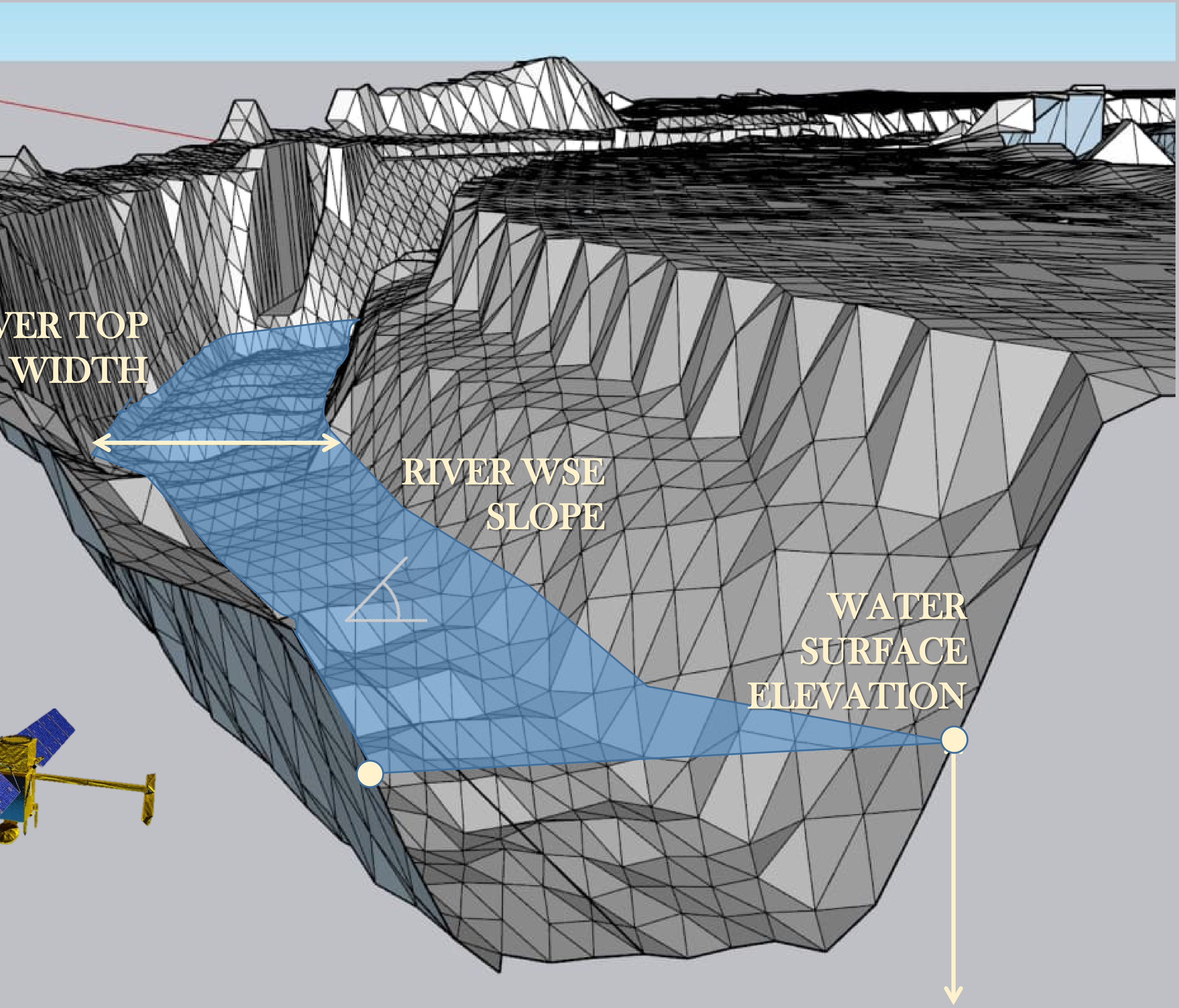

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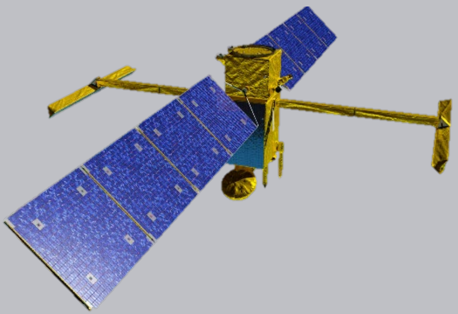

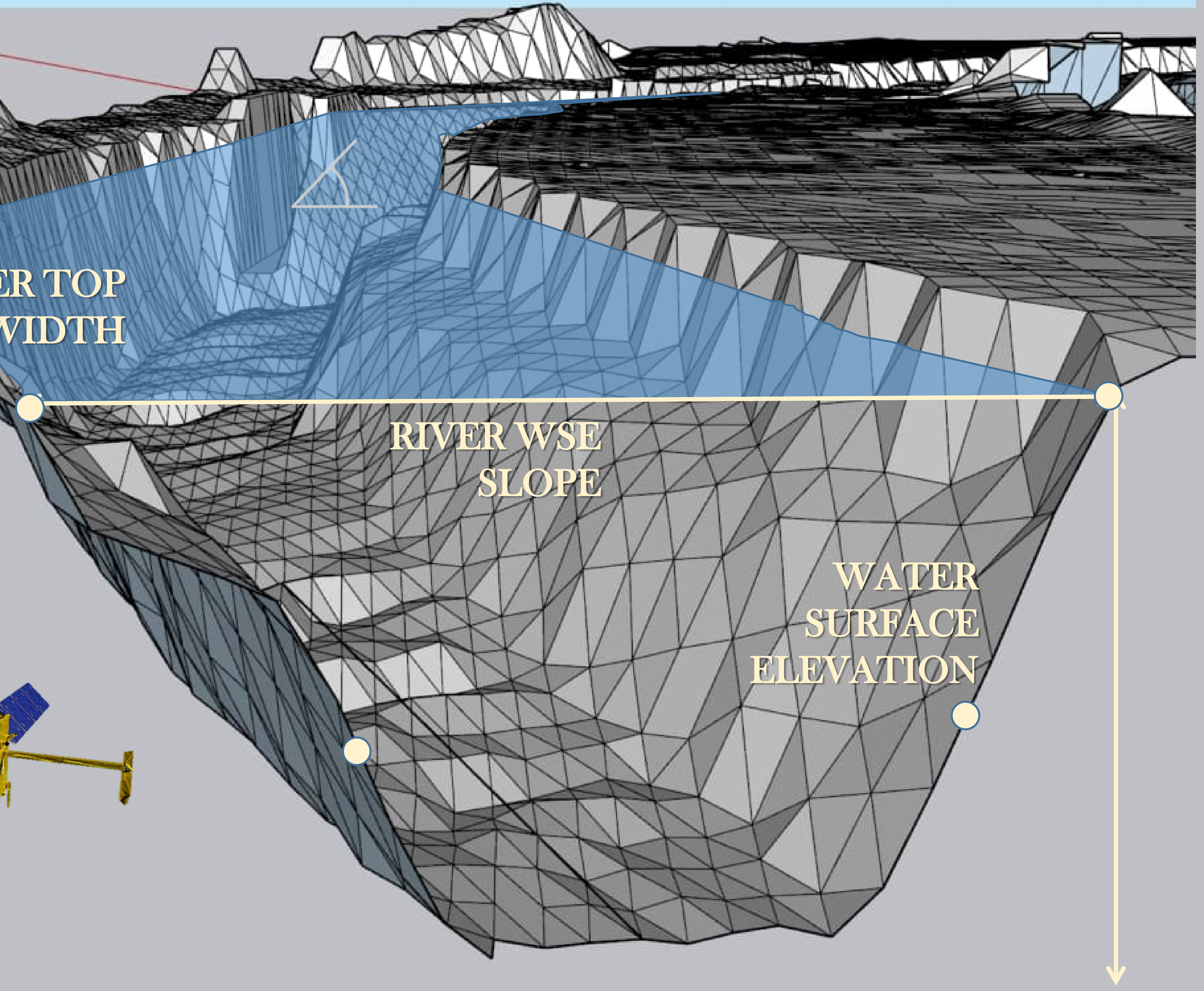

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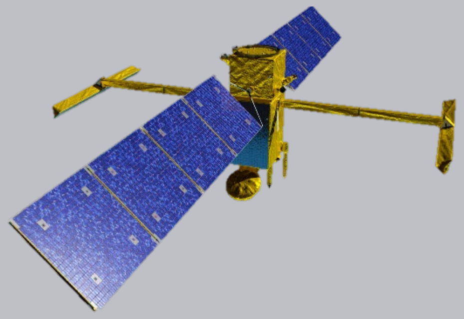

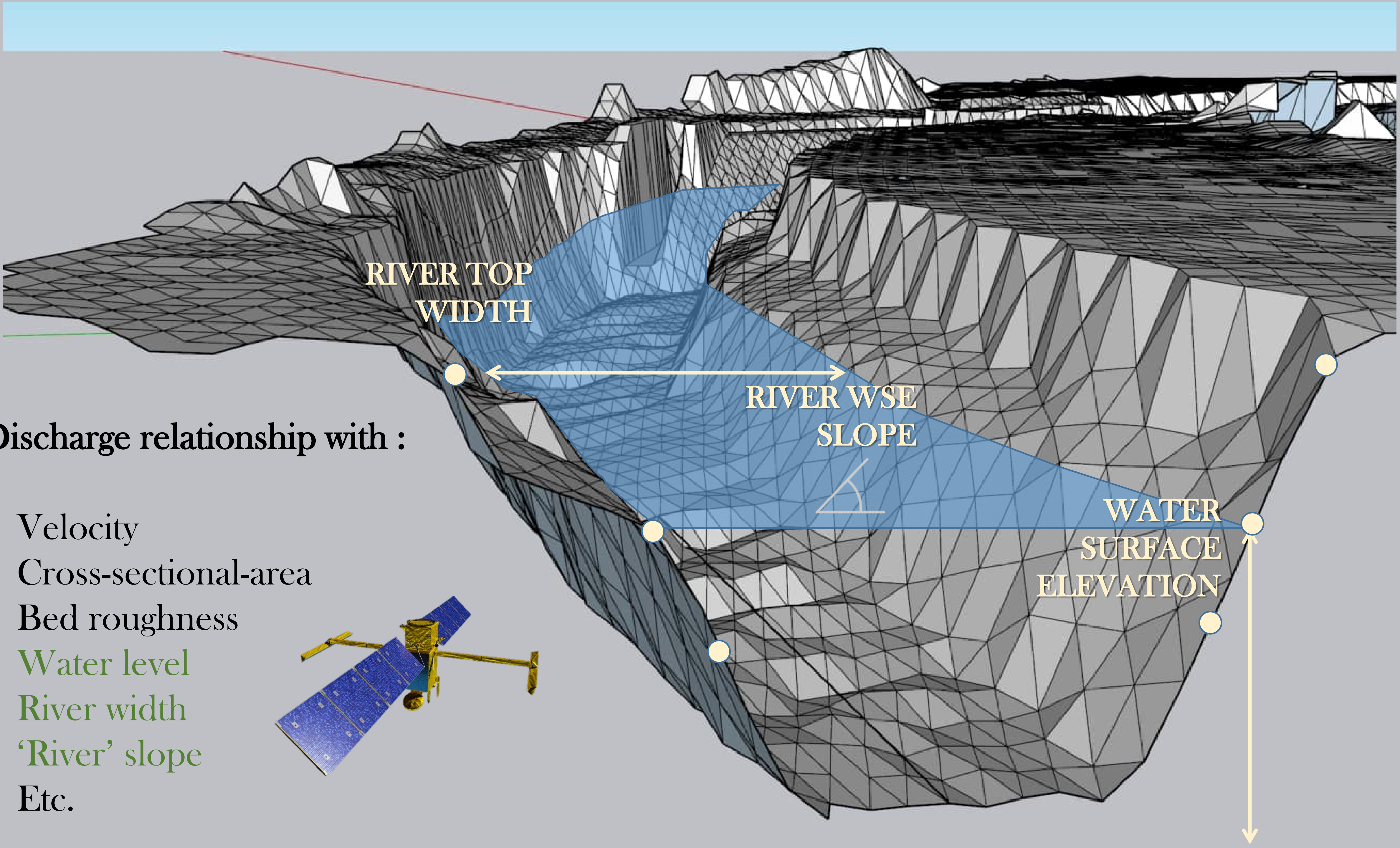

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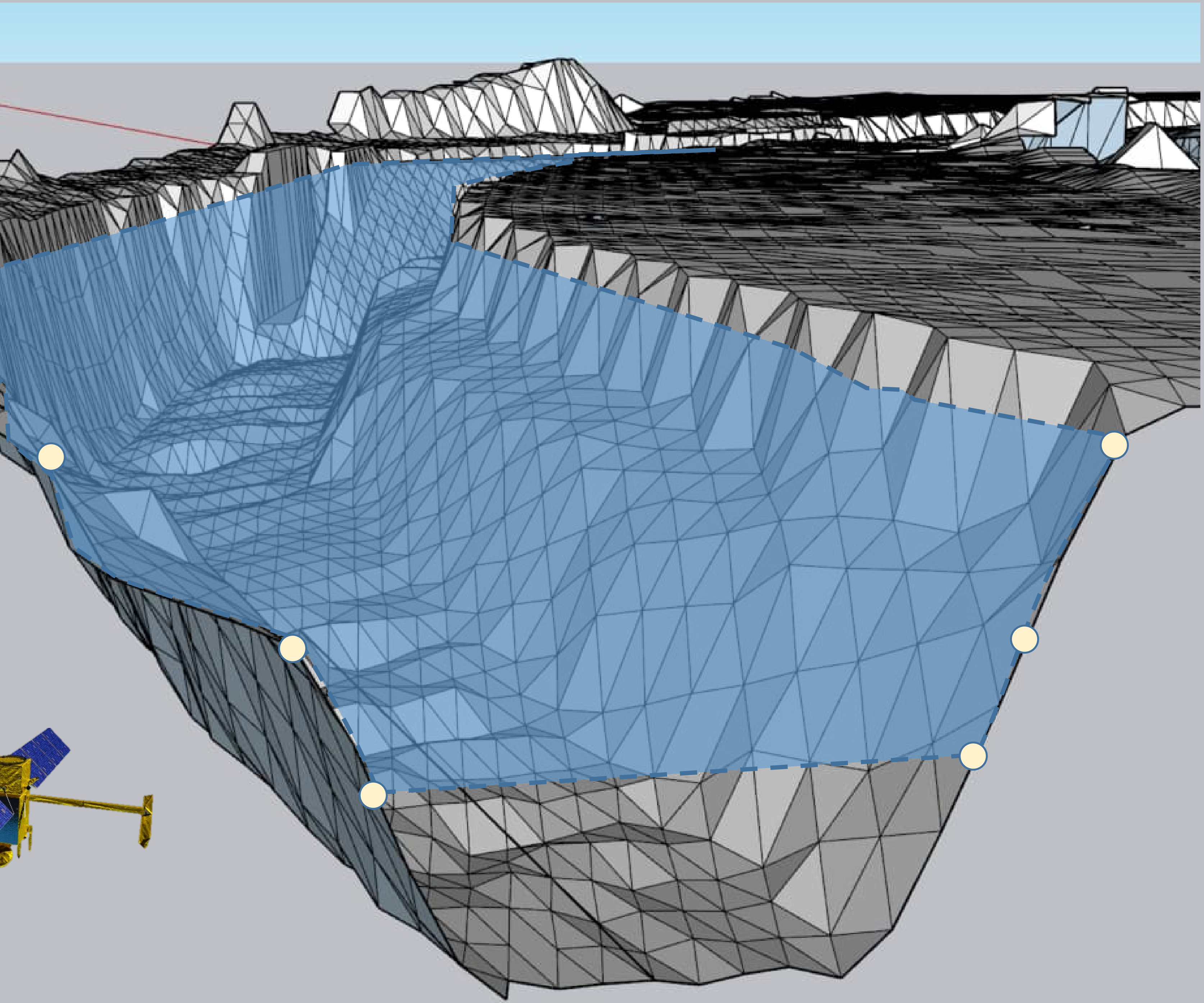

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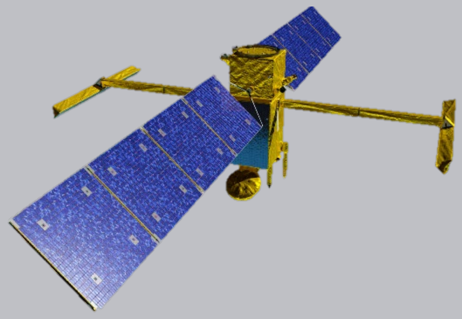

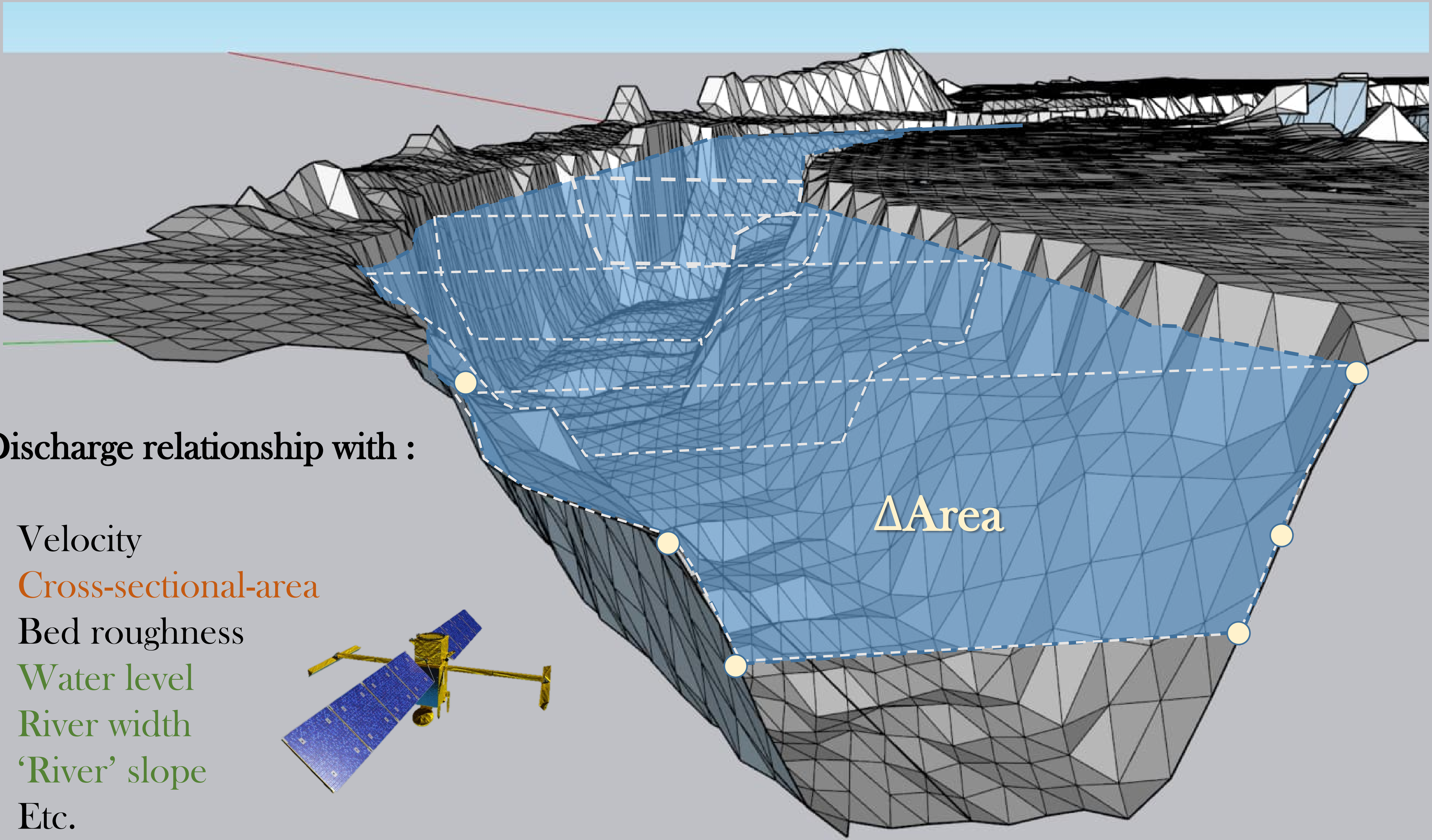

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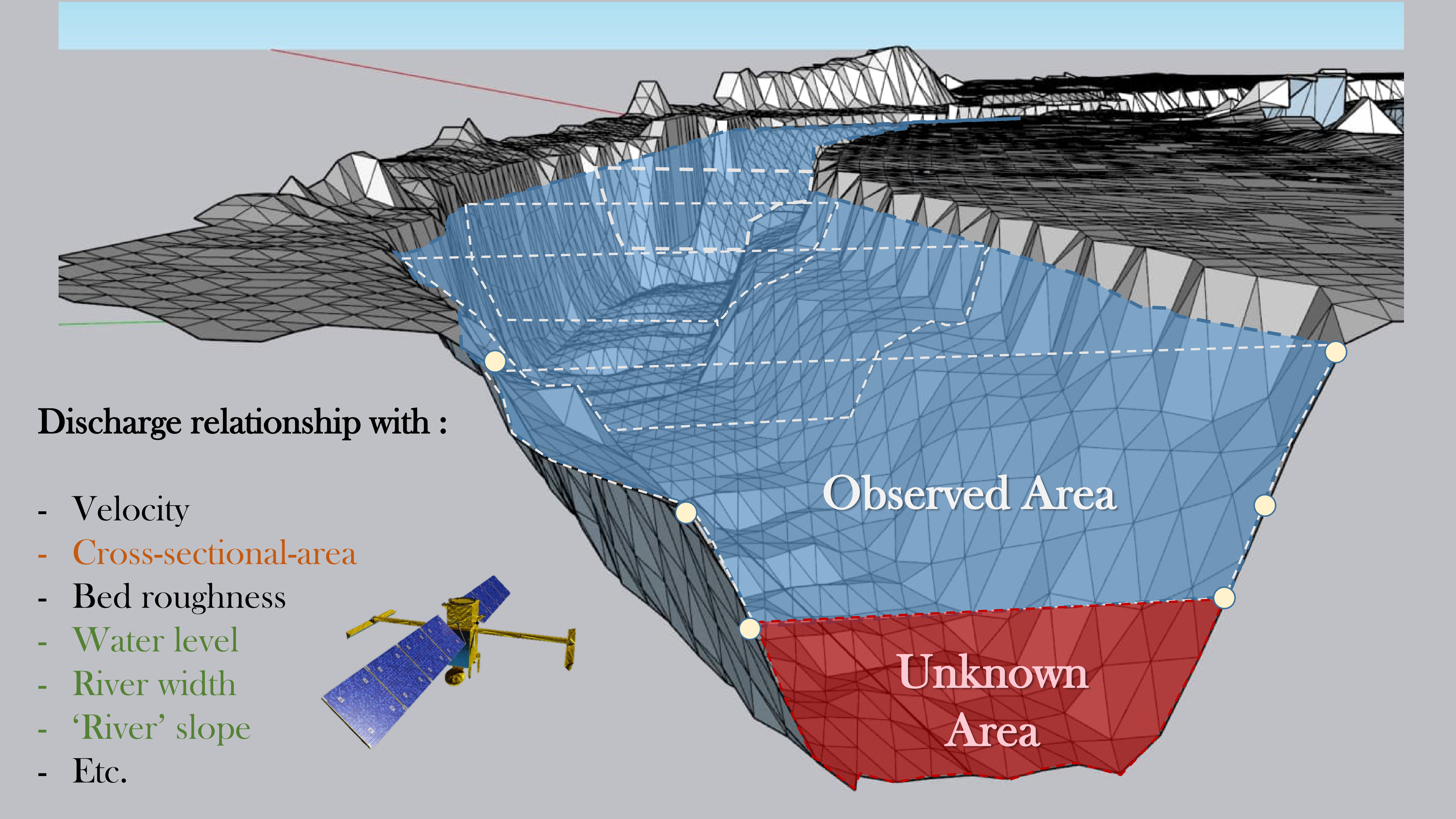
Discharge relationship with :
- Velocity
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- Bed roughness
- Water level
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- Etc.
Observed Area
Unknown Area

Discharge relationship with :

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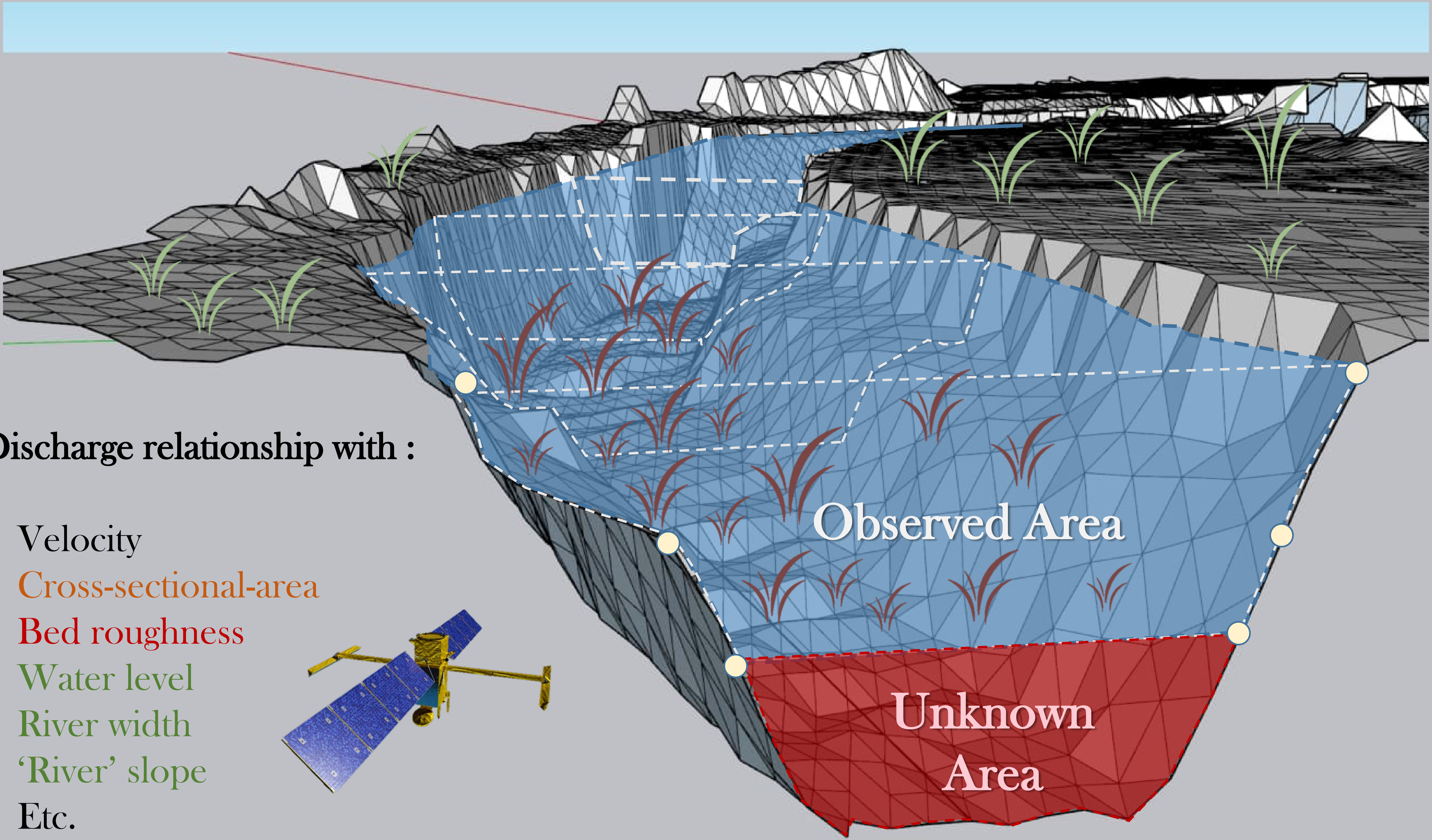

Example of the “Official” Discharge Product :

$$Q_i = \frac{1}{n}(\bar{A} + A'_t)^{\frac{5}{3}} W_i^{-\frac{2}{3}} S_i^{\frac{1}{2}}$$

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SWOT
Discharge
Algoritthms


Po River, Italy
Légende
- Nadir track
Pass 208 - Swath
Google Earth
N
10 km

SWOT Discharge

ALGORITHMS

SWOT

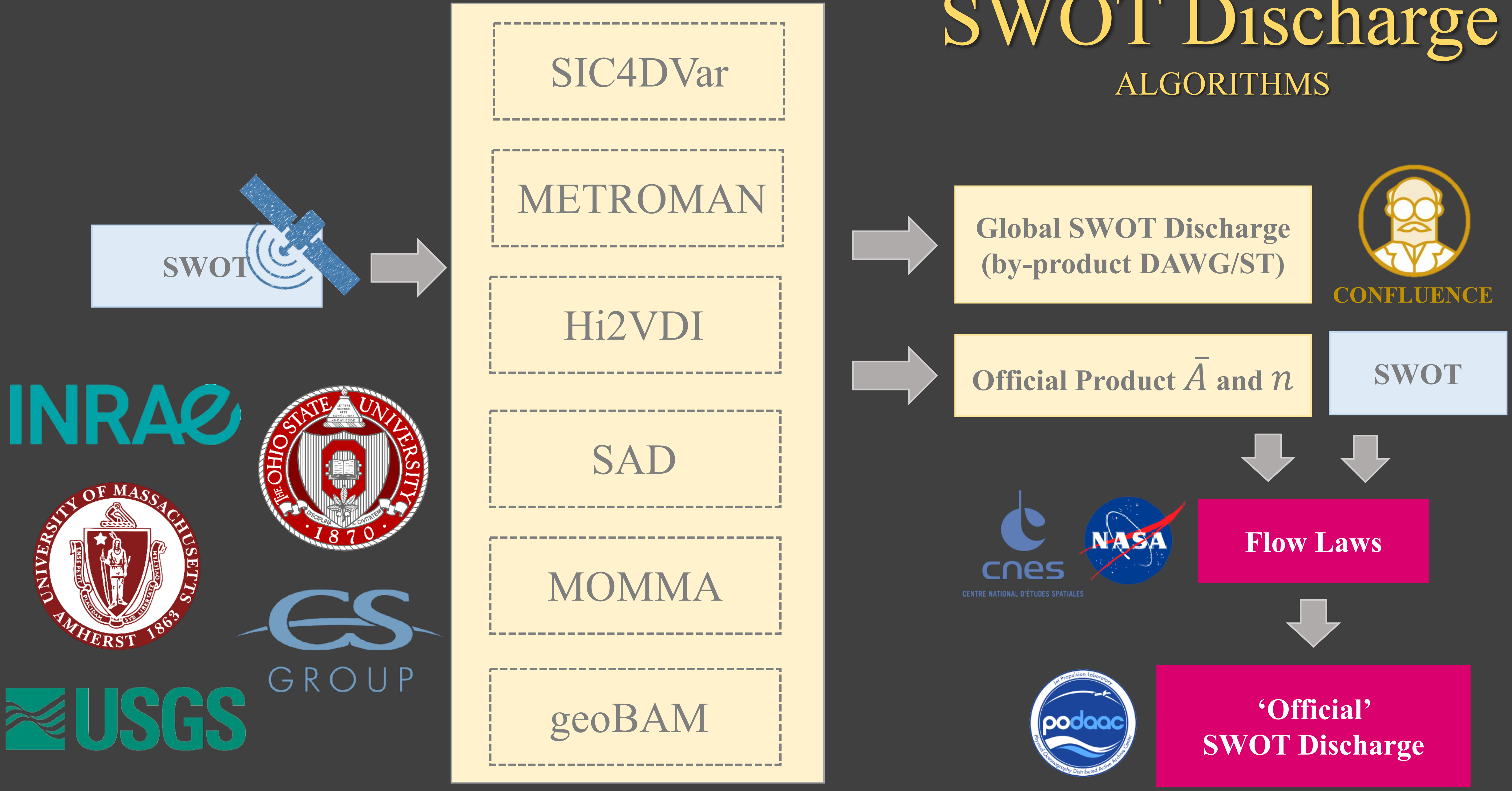
- SIC4DVar
- METROMAN
- Hi2VDI
- SAD
- MOMMA
- geoBAM

Global SWOT Discharge (by-product DAWG/ST)

Official Product $\bar{A}$ and n

SWOT Discharge

ALGORITHMS



SWOT Discharge

ALGORITHMS

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Global SWOT Discharge (by-product DAWG/ST)

CONFLUENCE

Official Product $\bar{A}$ and n

SWOT

Flow Laws

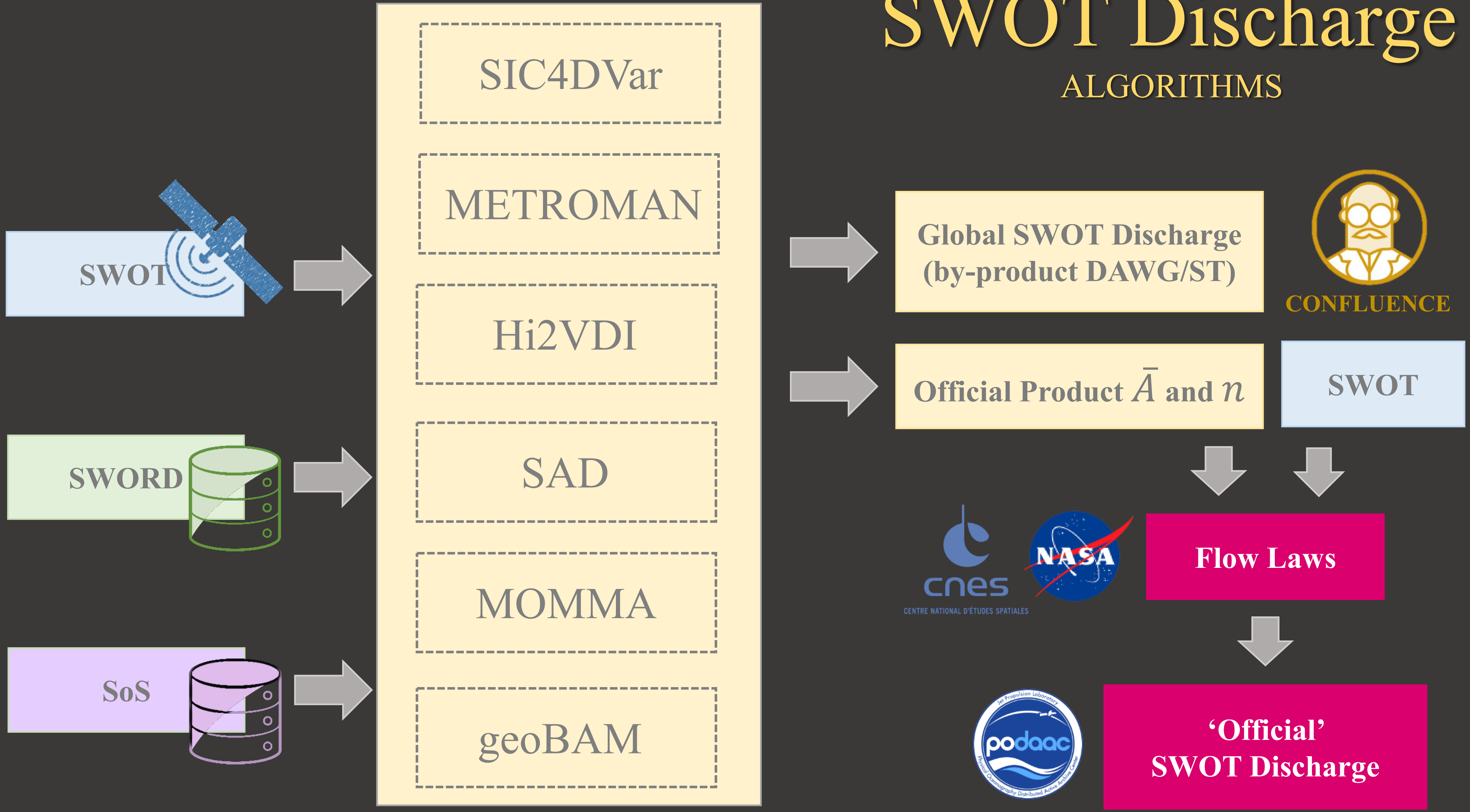
'Official' SWOT Discharge

GAUGED and **FULLY UNGAUGED** basins

Problem under high **uncertainty**

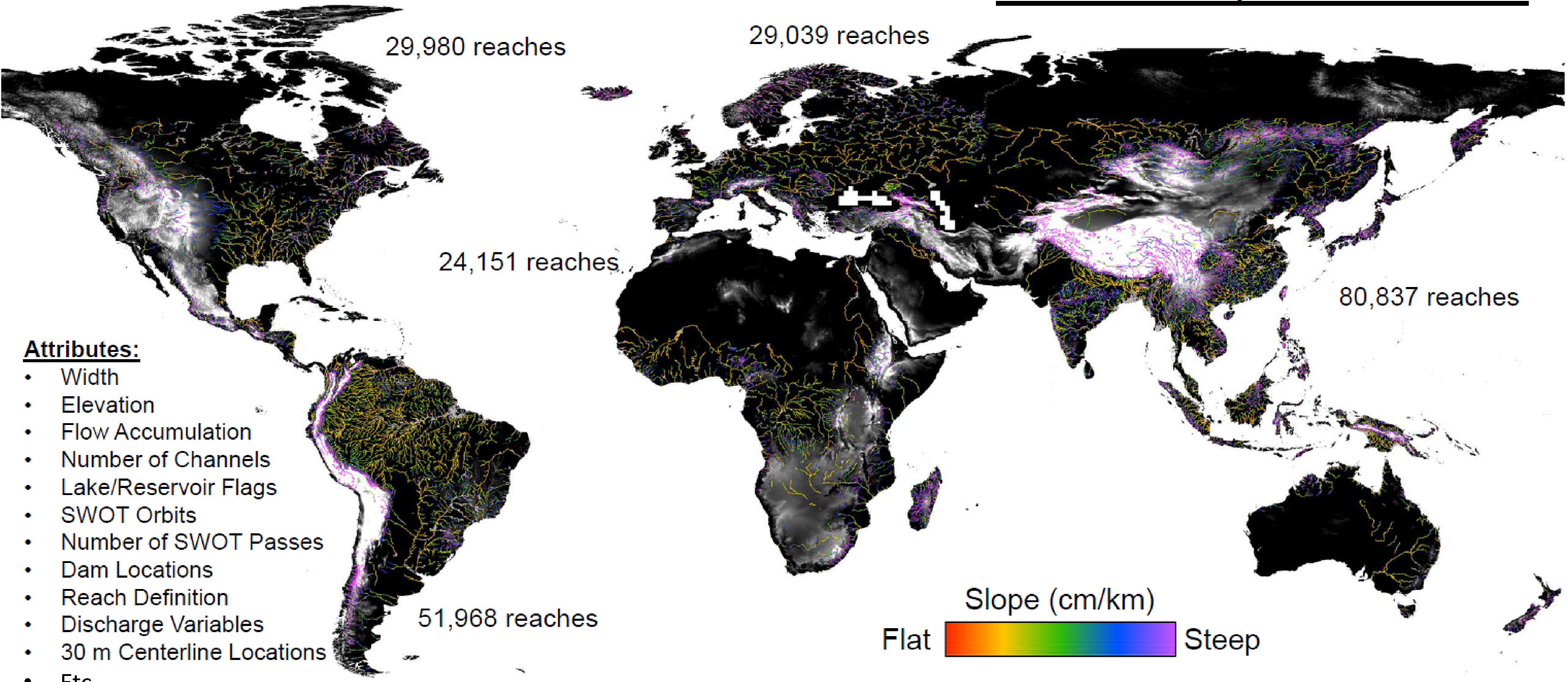
Strong **equifinality**

SWOT Discharge
ALGORITHMS



SWOT a priori River Database (SWORD)

GRWL + SRTM/HydroSHEDs + GRanD



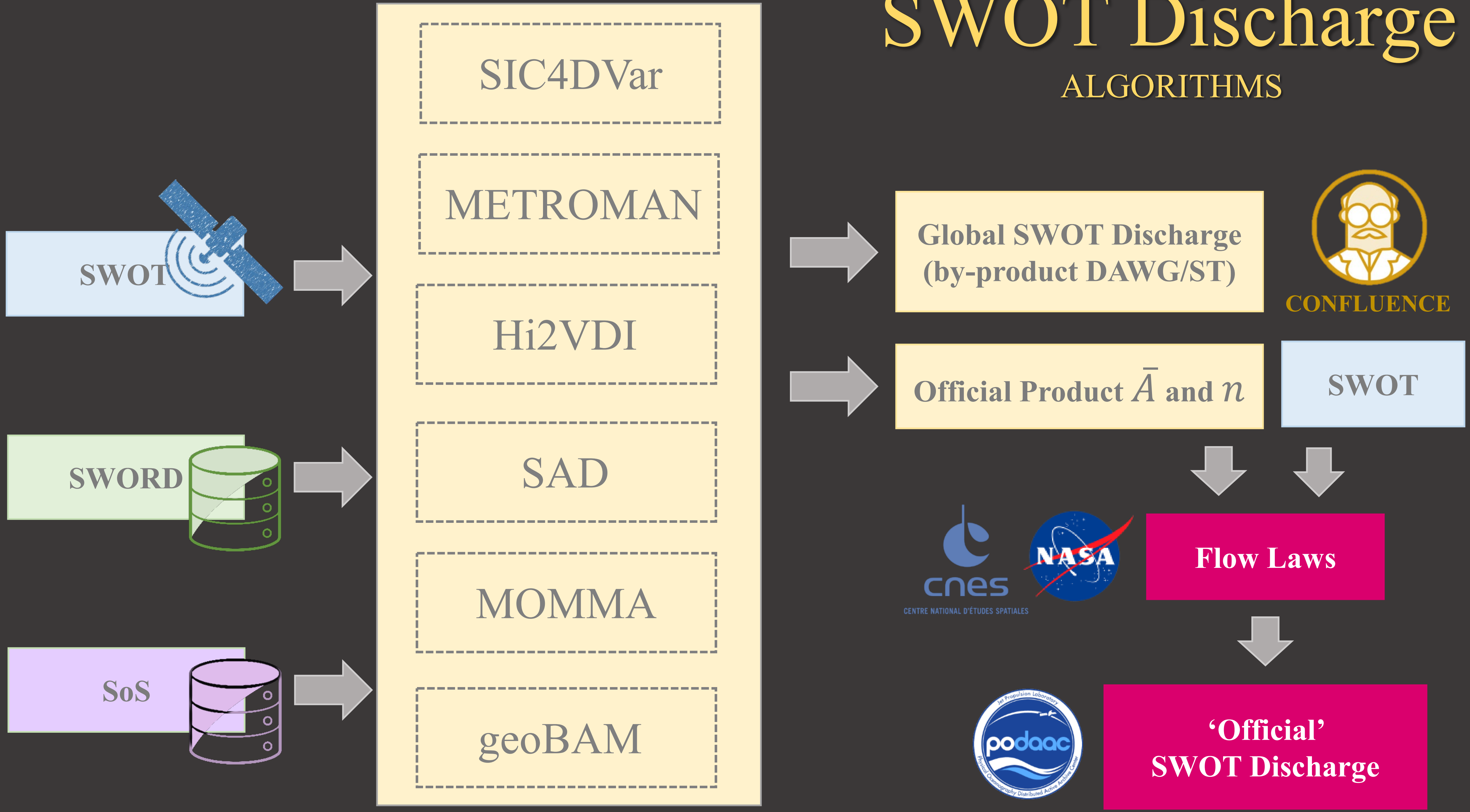
Attributes:

- Width
- Elevation
- Flow Accumulation
- Number of Channels
- Lake/Reservoir Flags
- SWOT Orbits
- Number of SWOT Passes
- Dam Locations
- Reach Definition
- Discharge Variables
- 30 m Centerline Locations
- Etc.

Frasson et al., 2019

SWOT Discharge

ALGORITHMS



SWOT Discharge

ALGORITHMS

McFLI

Mass Conserved Flow Law Inversion

- SIC4DVar
- **METROMAN**
- Hi2VDI
- SAD
- MOMMA
- **geoBAM**

DEVELOPERS

- **MetroMan**: M. Durand (OSU)
- **geoBAM**: C. Gleason (UMASS)

SWOT Discharge

ALGORITHMS

McFLI

Mass Conserved Flow Law Inversion

Calibration using flow laws

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- **MOMMA**: R. Dudley (USG)

SWOT Discharge

ALGORITHMS

McFLI
Mass Conserved Flow Law Inversion

Calibration using flow laws

Data Assimilation using Hydraulic Models

- SIC4DVar
- METROMAN
- Hi2VDI
- SAD
- MOMMA
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- **MetroMan**: M. Durand (OSU)
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- **Hi2VDI**: K. Larnier, J. Monnier, P.-A. Garambois
- **SAD**: K. Andreadis
- **SIC4DVar**: I. Gejadze, H. Oubanas, P.-O. Malaterre

SWOT Discharge

ALGORITHMS

McFLI
Mass Conserved Flow Law Inversion

Calibration using flow laws

Data Assimilation using Hydraulic Models

Machine Learning (surrogate)

SIC4DVar

METROMAN

Hi2VDI

SAD

MOMMA

geoBAM

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SWOT Discharge

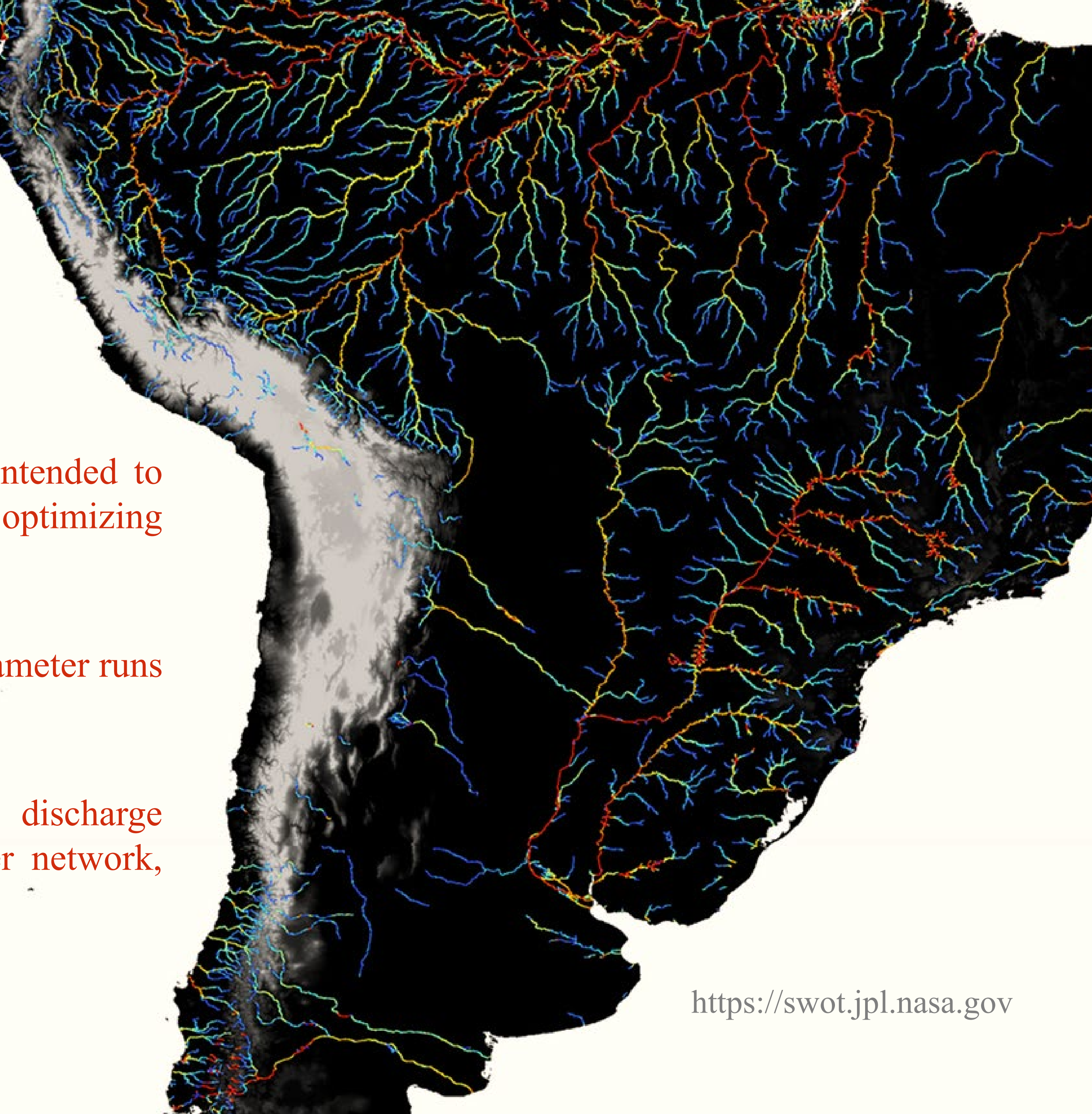
ALGORITHMS

Algorithm	Theoretical basis	SWOT data	Method
geoBAM	Hydraulic geometry + Manning's eq.	Water surface width (W), slope (S), cross-sectional area anomaly (dA)	Bayes
MetroMan	Manning's eq. w/o Q	Water surface height (H), W, S, dA	Bayes
Hi2VDI	1D Saint-Venant + Manning's eq.	H, W, S, δA	Assimilation Machine Learning
SAD	Gradually varied flow + Manning's eq. + hydraulic geometry	H, W, S	Assimilation
SIC4DVAR	1D Saint-Venant	H,W,S	Assimilation
MOMMA	Empirical form of Manning's eq.	H, W, S	Calibration

INTEGRATOR

"Integrators" make discharge algorithm results consistent across entire river networks.

- McFLI and VDA algorithms are generally intended to run across a small part of a river network, optimizing hydraulic parameters over just several reaches
- How to ensure consistency across McFLI parameter runs in different parts of the basin?
- Integrators take estimates of discharge or discharge parameters at different places within a river network, and ensure they obey continuity at large scale



https://swot.jpl.nasa.gov

Courtesy : Michael Durand

Steady flow optimization integrator (SFOI*)

McFLI and DA are generally too computational expensive to run across entire river networks. How to avoid mass imbalance at tributary junctions from inconsistent retrievals?

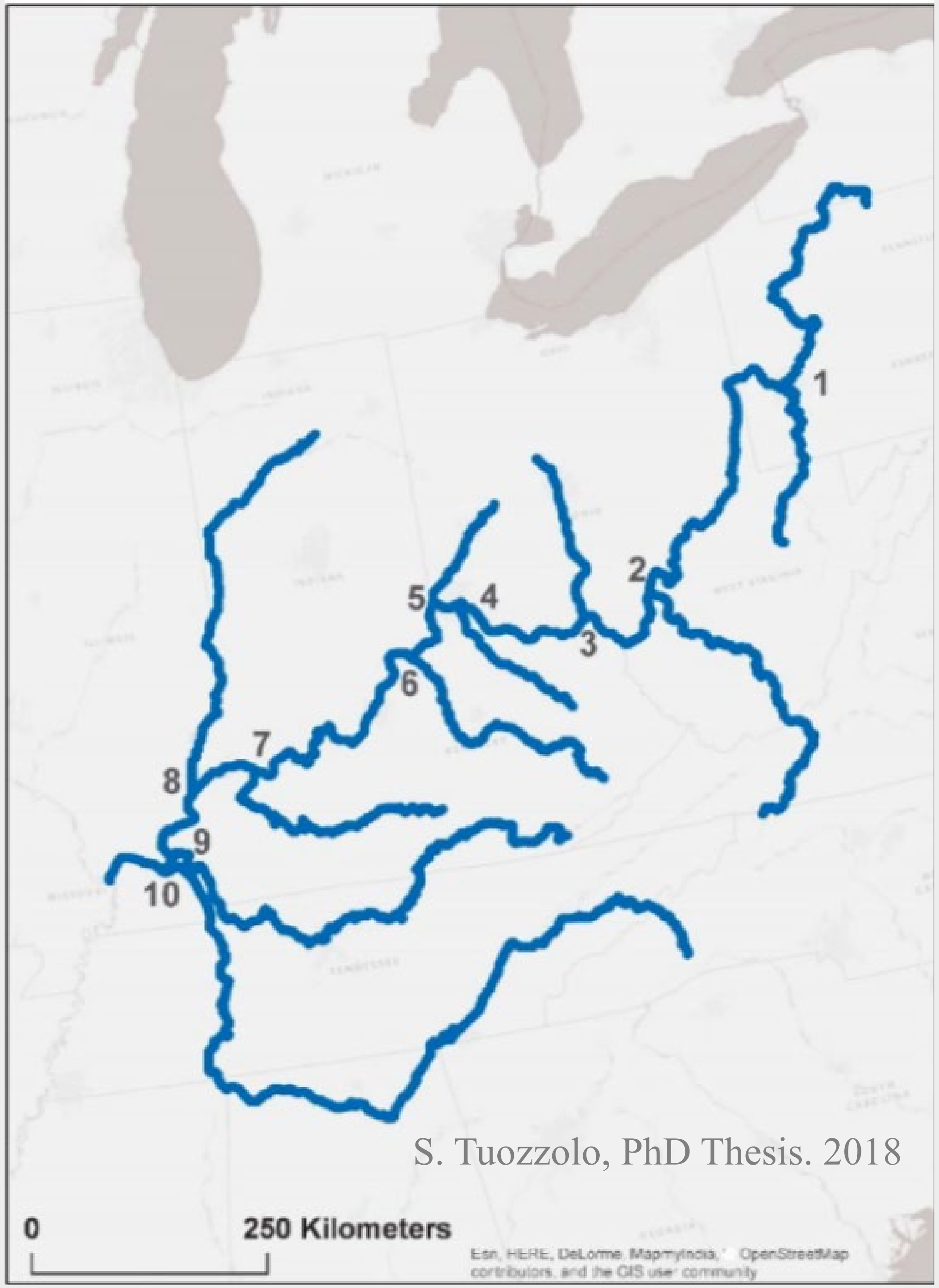
$$min_Q \sum_{reaches} \left[\frac{Q - \hat{Q}}{\sigma_Q}\right]^2$$

$\hat{Q}$: Estimated Q from SWOT discharge algorithms.

Subject to : $Q_{in,1} + Q_{in,2} = Q_{out}$

Step 1: Estimate Q for steady flow conditions (currently using mean flow and 33rd percentile)

Step 2: Back out the flow law parameters for each algorithm that match the steady flow estimates.

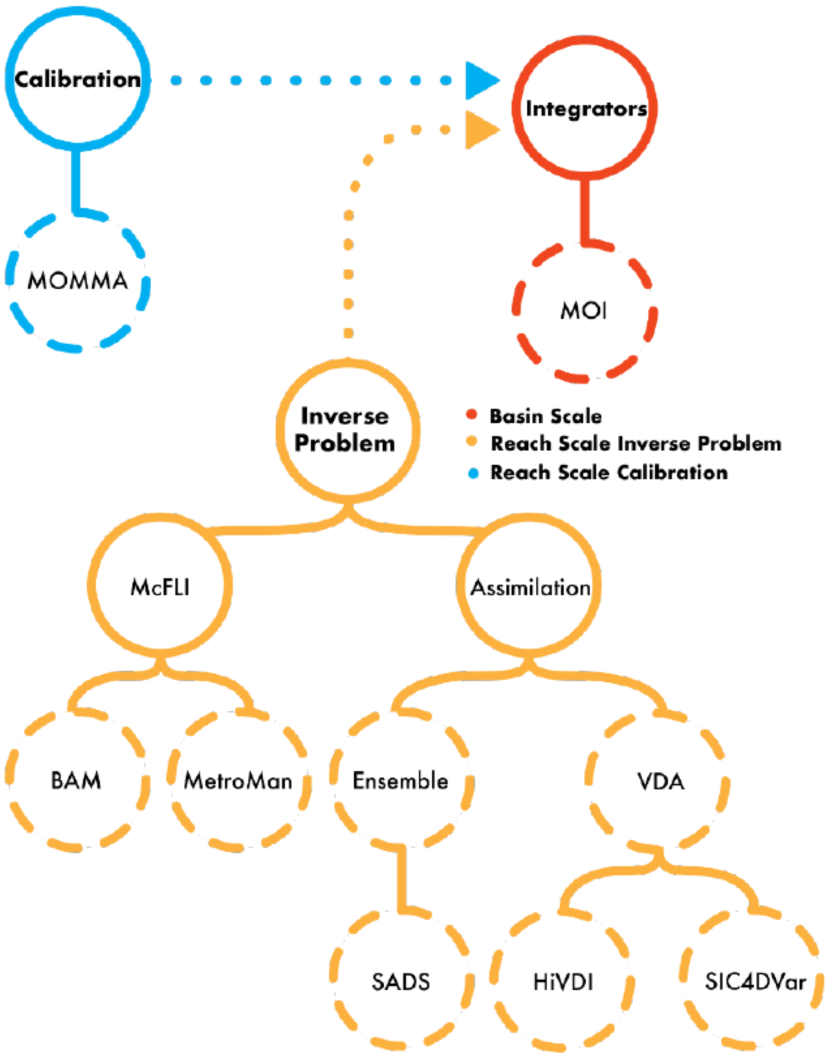


S. Tuozzolo, PhD Thesis. 2018

* SFOI used to be called MOI

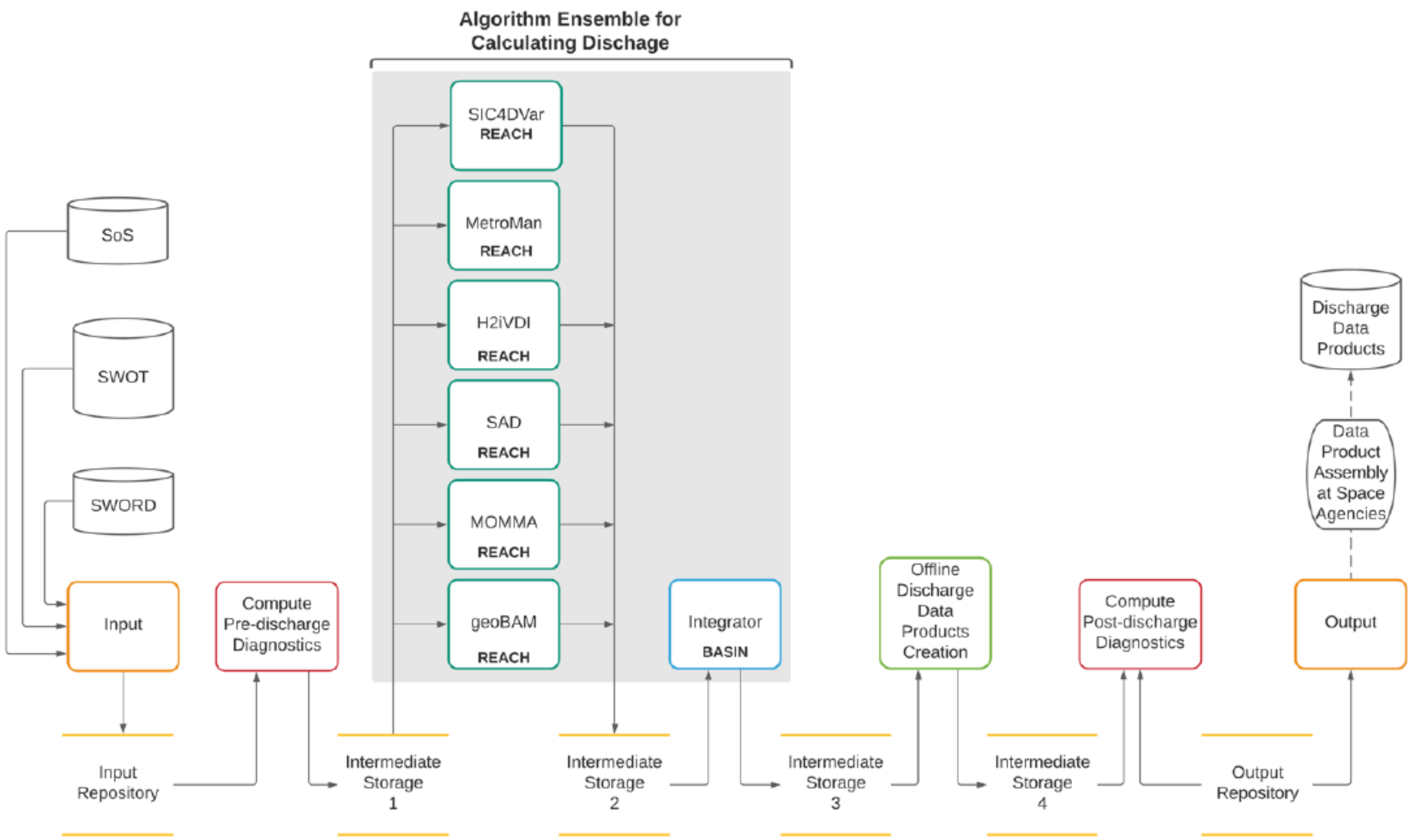
Courtesy : Michael Durand.

CONFLUENCE



Durand et al. 2023

CONFLUENCE

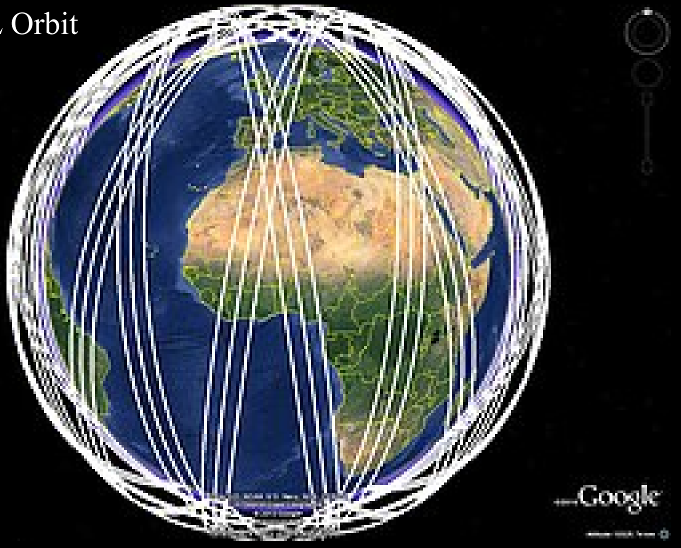


Durand et al. 2023

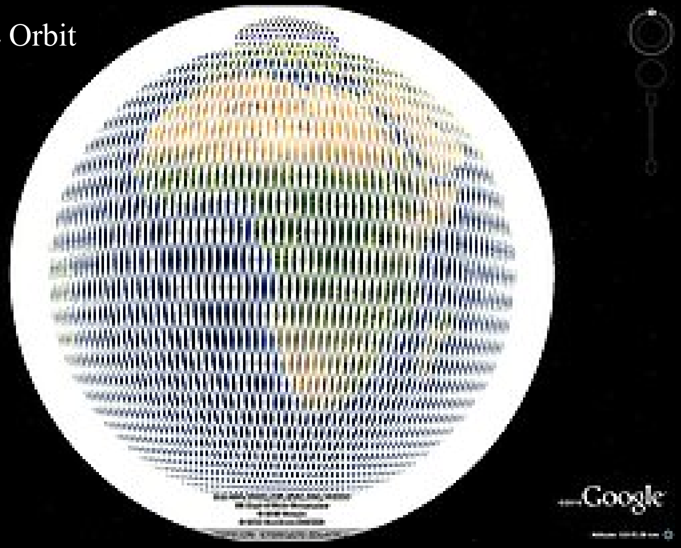
Courtesy : Nikki Tebaldi

Two Discharge Branches

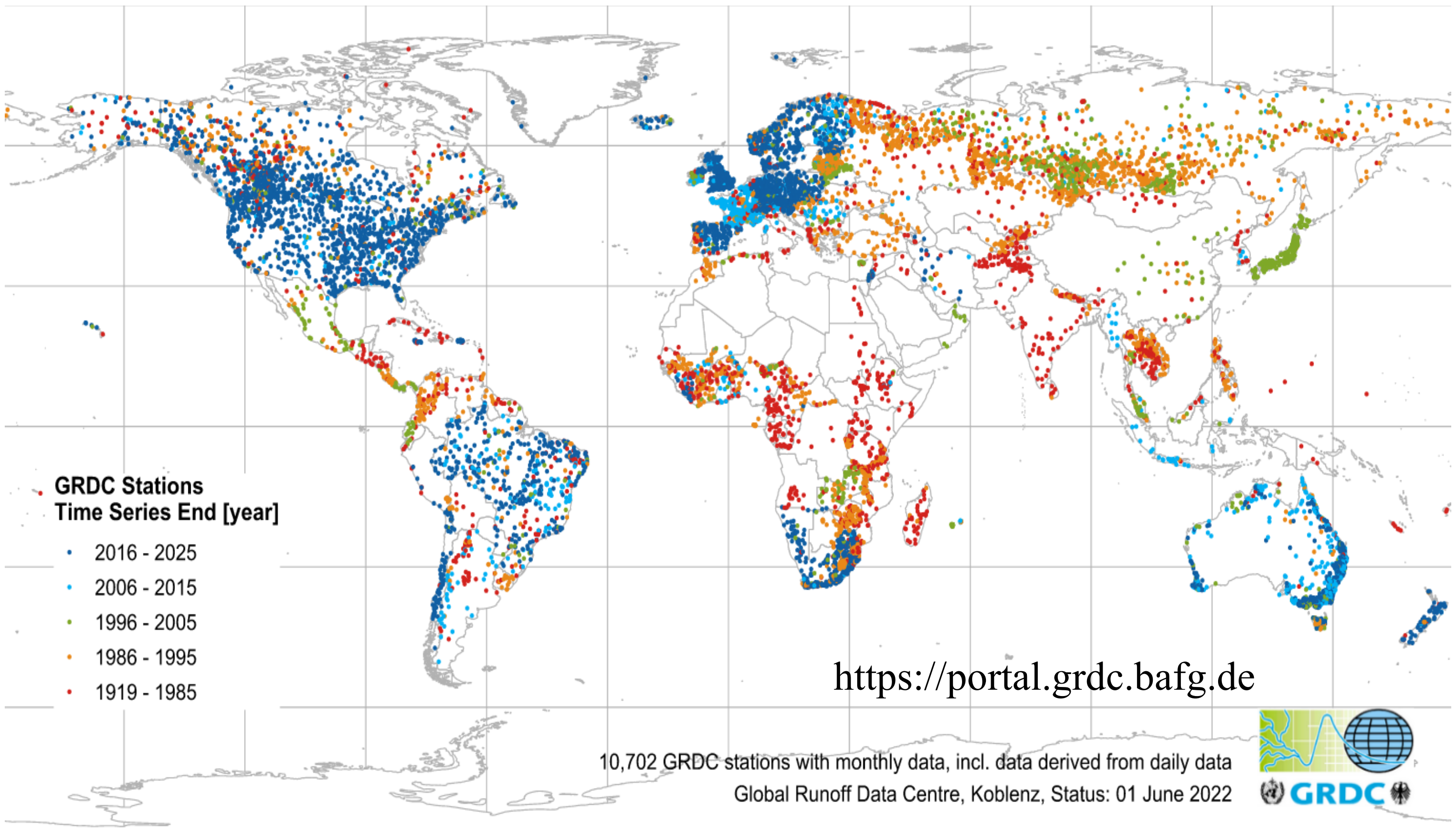
CALVAL Orbit



NOMINAL Orbit



https://aviso.altimetry.fr



Two Discharge Branches

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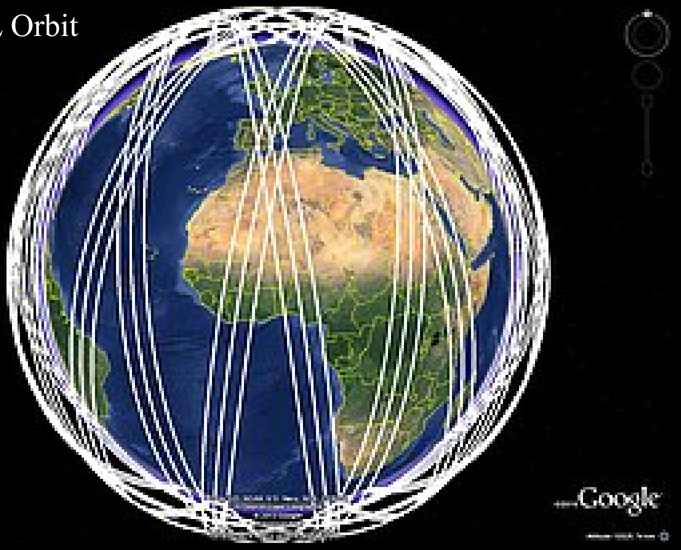

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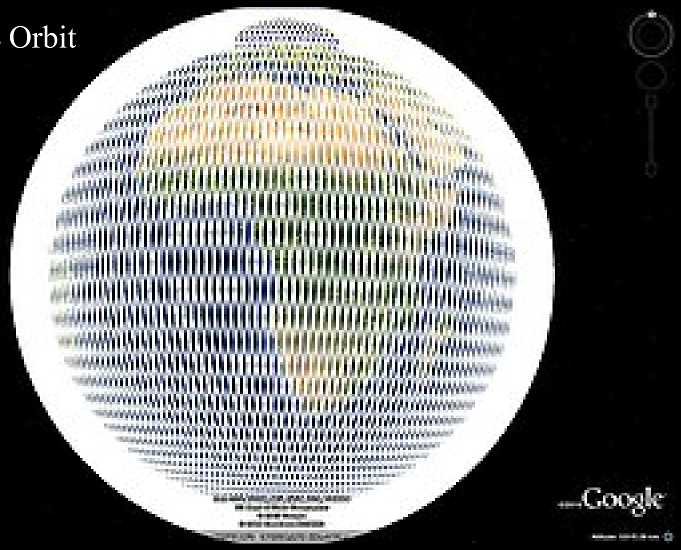

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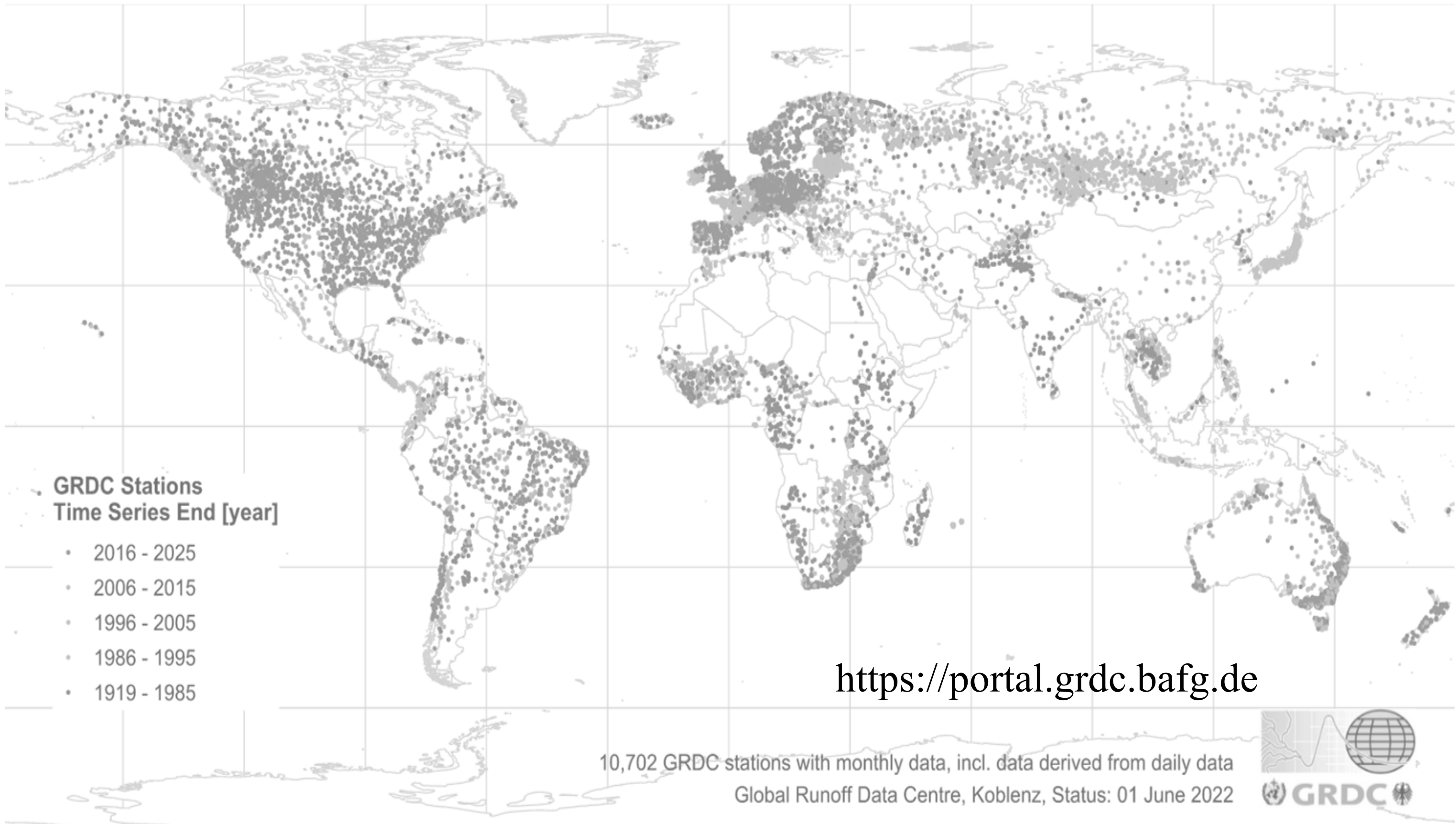
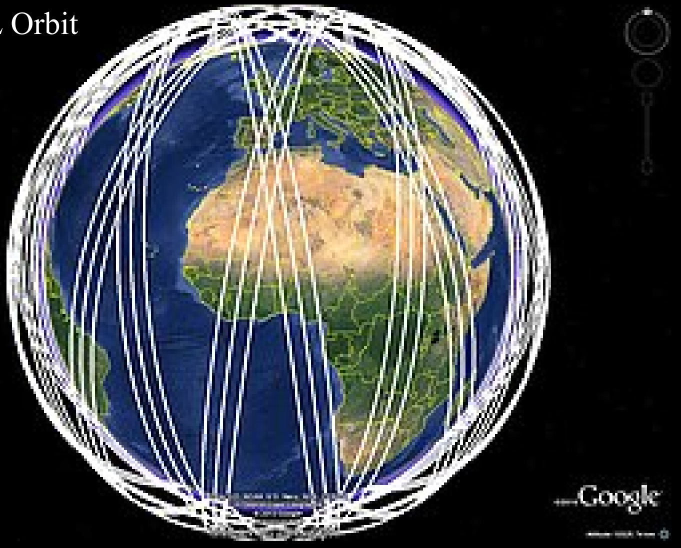


https://portal.grdc.bafg.de

1. Gage-unconstrained: DOES NOT USE stream gage data to constrain SWOT discharge.

Two Discharge Branches

CALVAL Orbit



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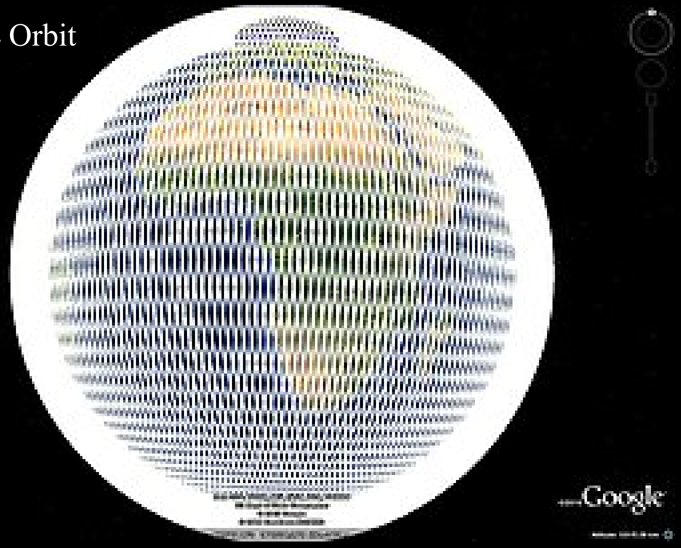

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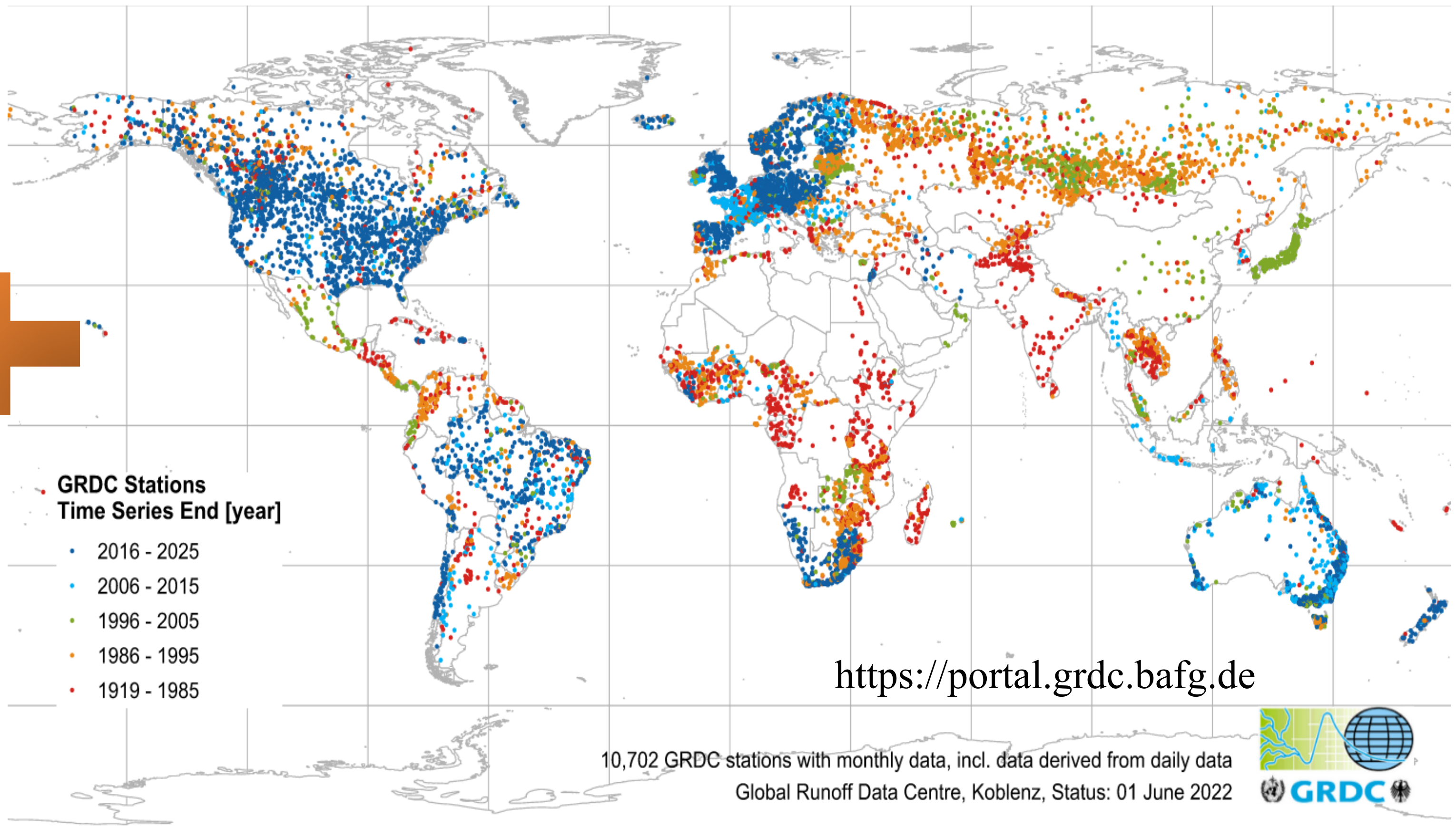


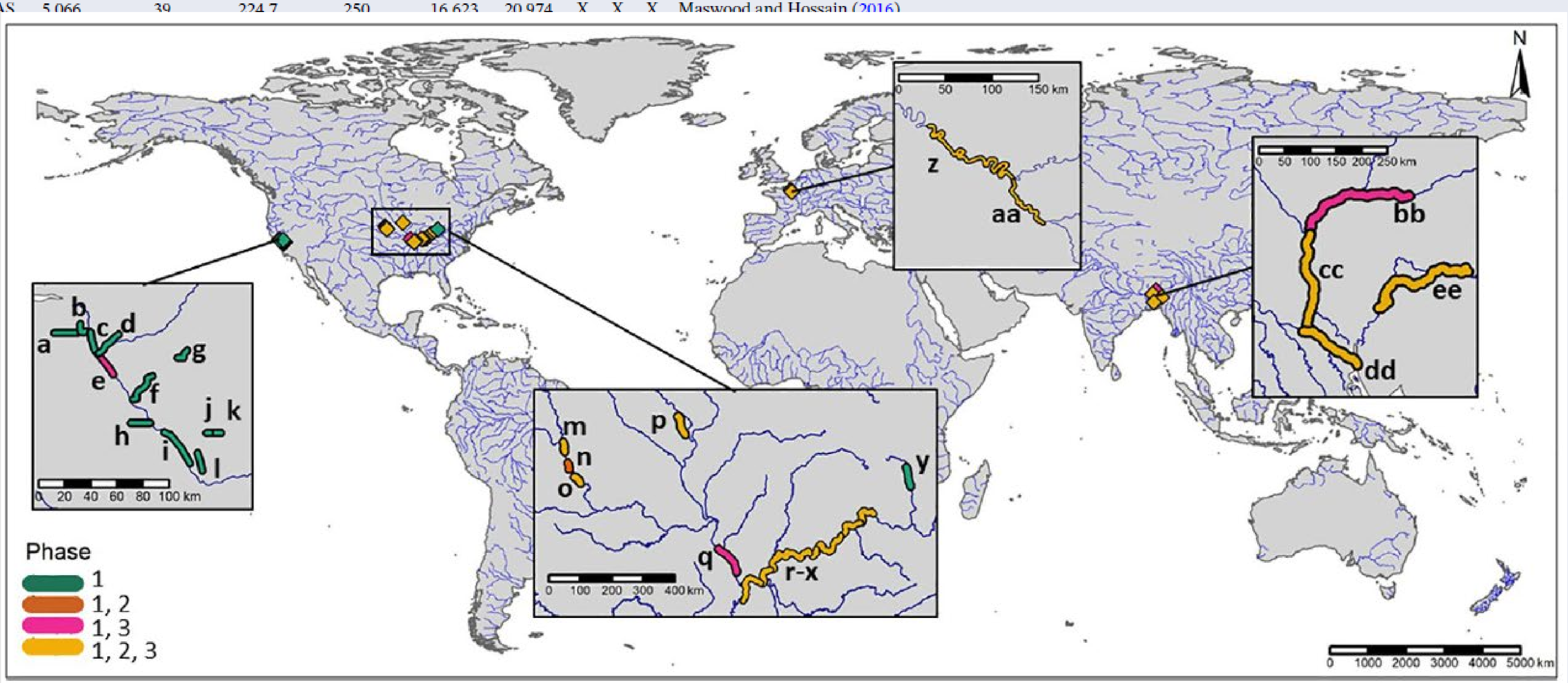
1. Gage-unconstrained: DOES NOT USE stream gage data to constrain SWOT discharge.

2. Gage-constrained: USES stream gage data to constrain SWOT discharge (SWOT Algorithms).

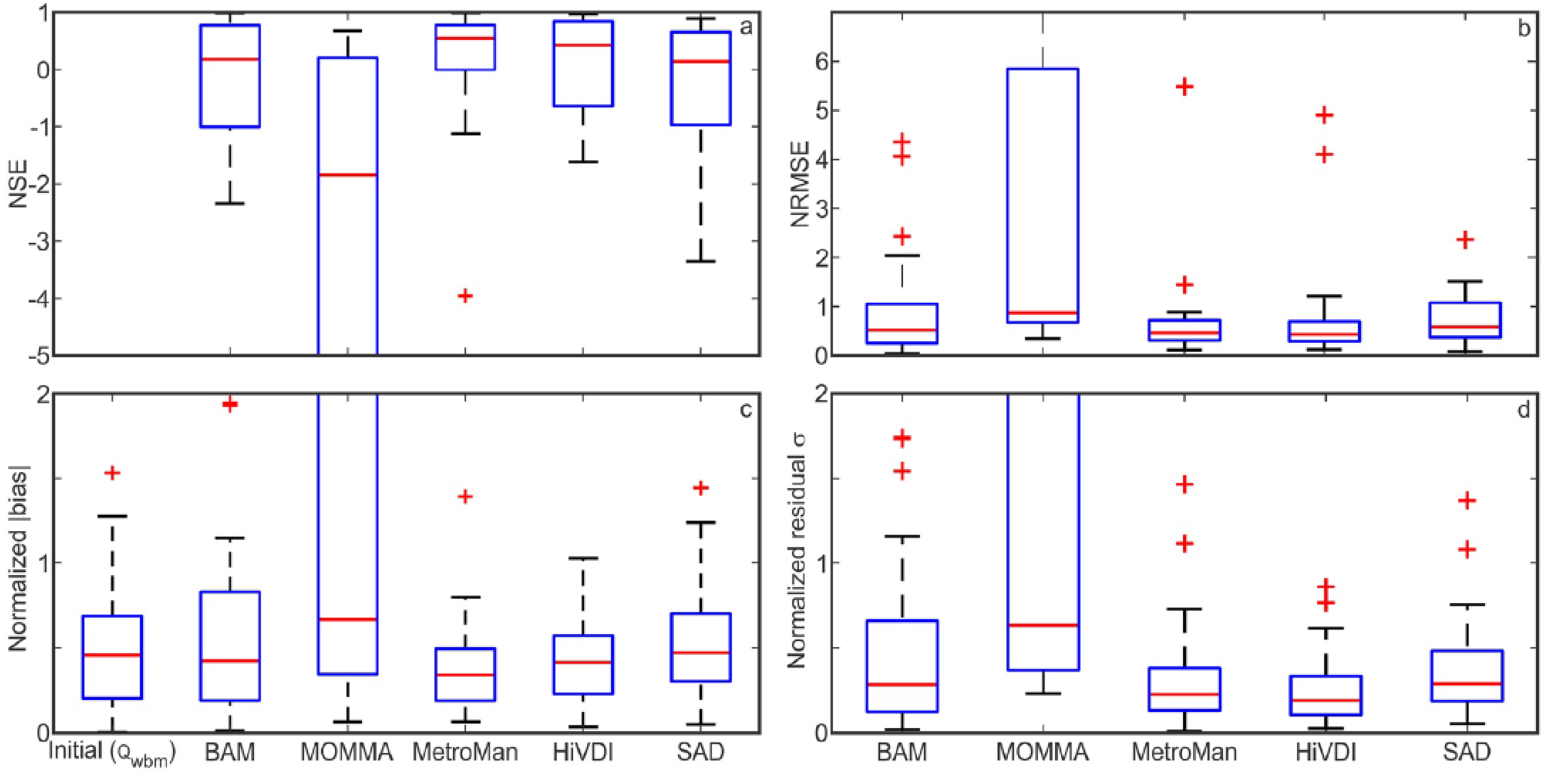
Test/Validation Cases

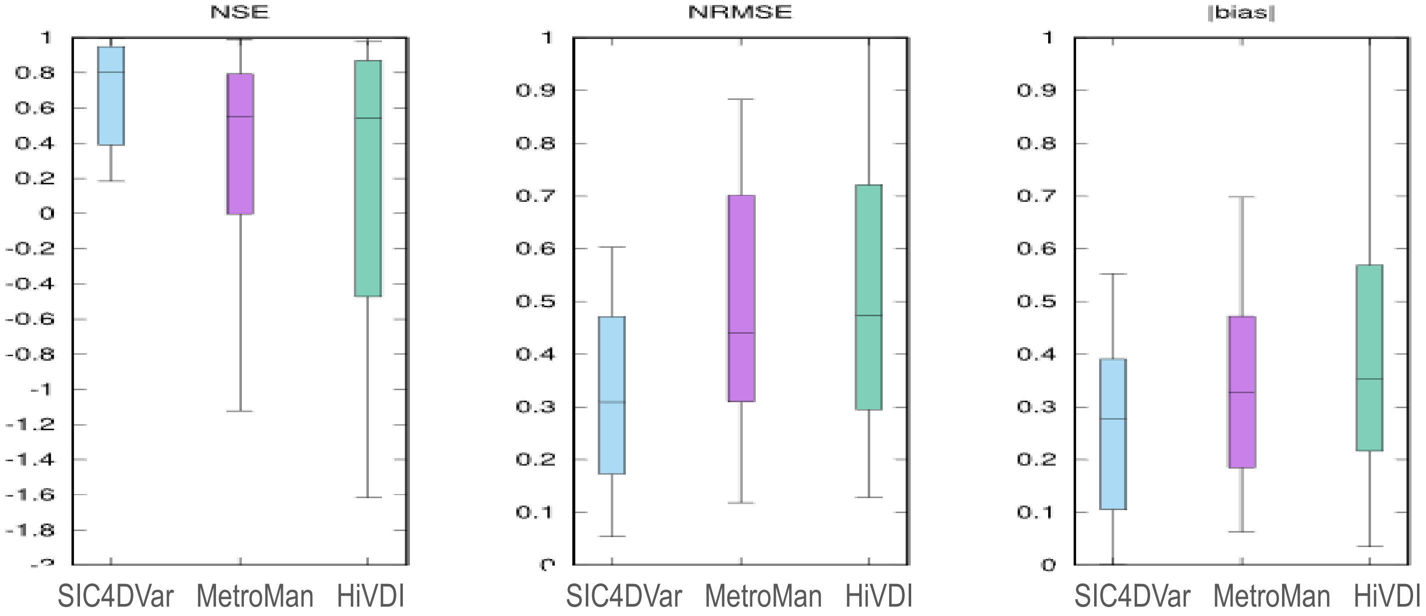
- Test Cases : 19 Rivers (Benchmark 1)
- Blind Test Cases : 32 Rivers (Benchmark 2)

	Test case name	Hydraulic model	Width (m)	Number of cross-sections	Length (km)	Simulation length (days)	WBM (m^3/s)	True (m^3/s)	1	2	3	Reference
1	Ash Slough	HEC-RAS	56	53	7.7	12	36	38	X			Rogers (2014)
2	Berenda Slough	HEC-RAS	43	62	11.4	12	36	16	X			Rogers (2014)
3	Brahmaputra	HEC-RAS	2,275	39	250.0	107	5,162	2,039	X		X	Maswood and Hossain (2016)
4	Chowchilla Canal	HEC-RAS	78	74	26.1	12	36	21	X			Rogers (2014)
5	Fresno River	HEC-RAS	52	61	16.2	12	46	52	X			Rogers (2014)
6	Grant Line Canal	HEC-RAS	200	34	12.5	12	244	212	X			Rogers (2014)
7	Iowa River	HEC-RAS	157	201	32.3	366	147	158	X	X	X	Gilles et al. (2012)
8	Jamuna	HEC-RAS	5,066	39	224.7	250	16,623	20,974	X	X	X	Maswood and Hossain (2016)
9	Kushiyara	HEC-R										
10	Mariposa Bypass	HEC-R										
11	Merced River	HEC-R										
12	Middle River	HEC-R										
13	Mississippi	HEC-R										
14	Missouri upstream	HEC-R										
15	Missouri midsection	HEC-R										
16	Missouri downstream	HEC-R										
17	Ohio section 1	HEC-R										
18	Ohio section 2	HEC-R										
19	Ohio section 3	HEC-R										
20	Ohio section 4	HEC-R										
21	Ohio section 5	HEC-R										
22	Ohio section 7	HEC-R										
23	Ohio section 8	HEC-R										
24	Olentangy	HEC-R										
25	Padma	HEC-R										
26	San Joaquin	HEC-R										
27	San Joaquin 2	HEC-R										
28	Seine Downstream	ProSe										
29	Seine Upstream	ProSe										
30	Stanislaus River	HEC-RAS	114	55	24.3	12	155	101	X			Rogers (2014)
31	Tuolumne River	HEC-RAS	386	32	10.0	12	155	228	X			Rogers (2014)



Frasson et al. 2021





Test/Validation Cases

- Test Cases : 19 Rivers (Benchmark 1)
- Blind Test Cases : 32 Rivers (Benchmark 2)

- Rivers of various hydraulic conditions, including braided and multi-channel rivers, dam effects, backwater, and other effects.

- Temporal dynamics usually captured, but oftentimes, large biases were present.

- Results are **not sensitive** to temporal sampling and observation error (intrinsic to SWOT), but **are sensitive** to how accurate modified Manning's equation fits true discharge.

Frasson et al. 2021

Gejadze et al. 2022

OHIO Verify Experiment

- SWOT-like observations.
- SWOT temporal frequency and spatial distribution.
- Realistic representation of the errors.
- Test Cases: 215 River reaches.
- Sets of reaches (from 2 to 10).
- 16 USGS stations

Durand et al. 2023

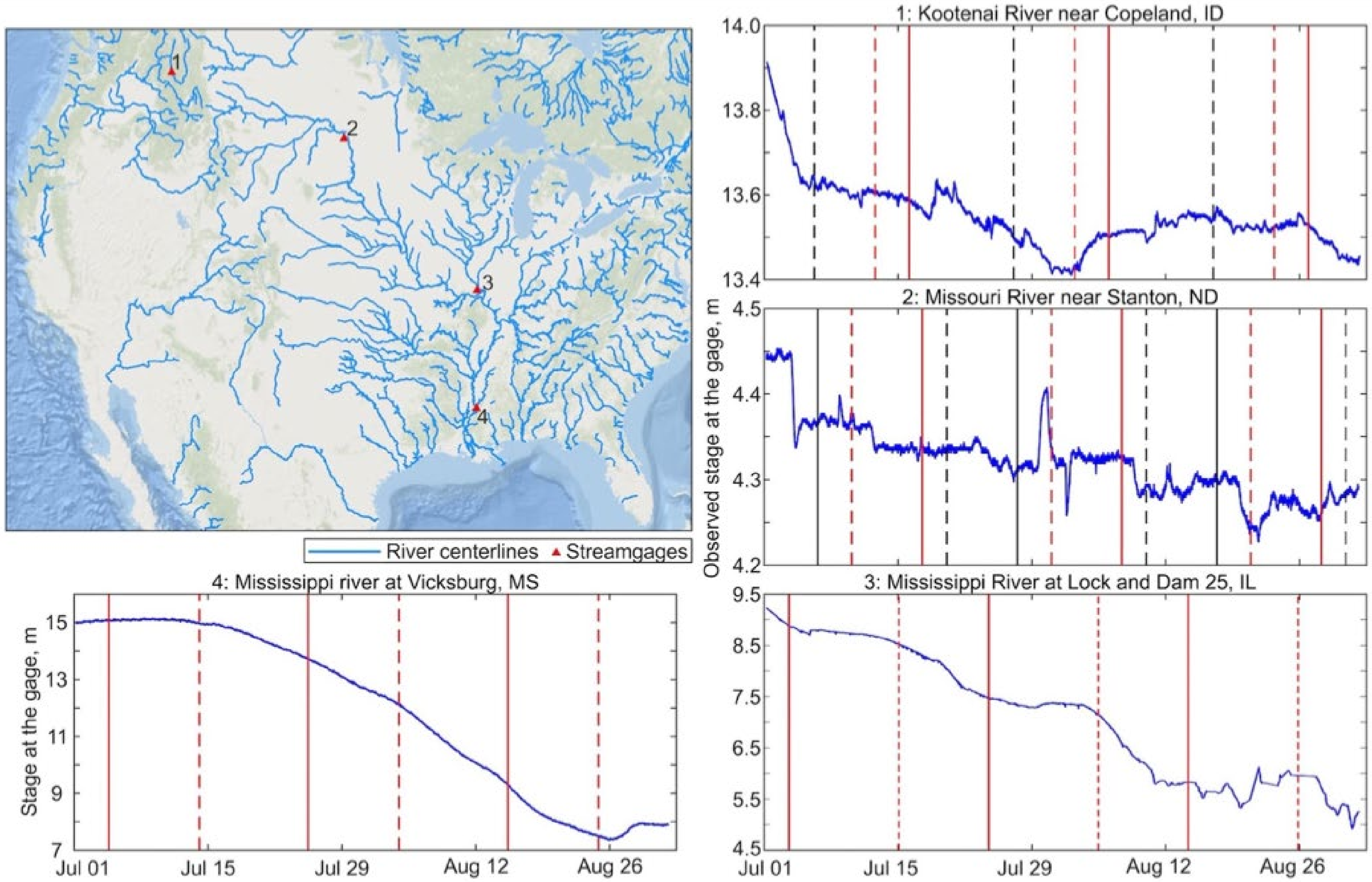


Figure 4. Illustration of Surface Water and Ocean Topography (SWOT) temporal sampling at four arbitrary gages (see panels 1–4) in the United States (see map for gage locations), adapted from Frasson (2021). The vertical lines indicate SWOT overpass timing, where each pass is represented by a different line style. The timing of each pass assumes an arbitrary mission start day of January 1 chosen for illustration purposes.

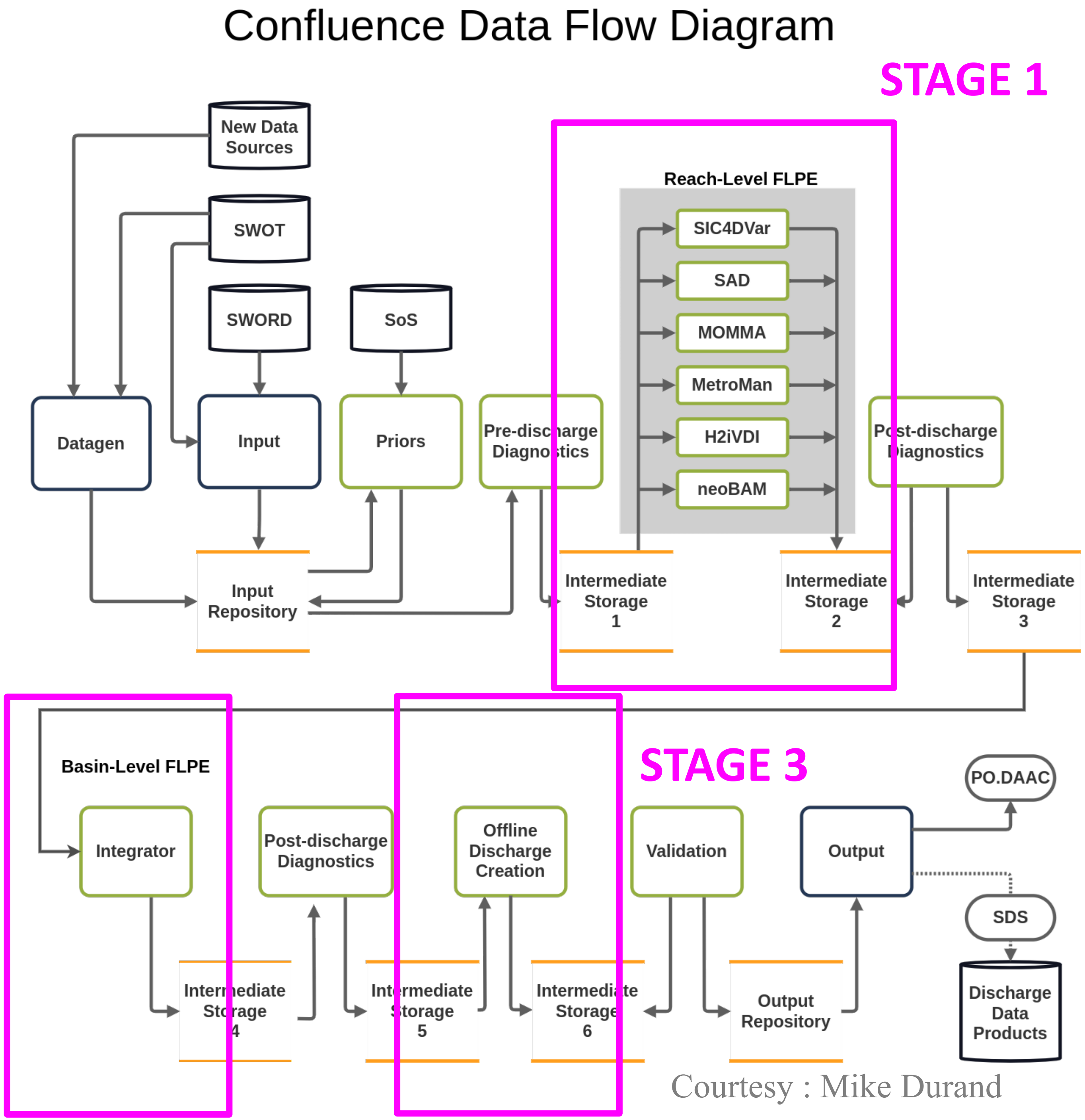
Durand et al. 2023

Confluence run status: Proposed Nomenclature

- Stage 1: Reach-scale FLPE
- Stage 2: Basin-scale FLPE (Integrator)
- Stage 3: "Offline" Discharge creation: Use Flow Laws, flow law parameters (from stage 2) and SWOT observations

Note: Confluence's "offline" module mimics the discharge creation by the SDS

STAGE 2



Courtesy : Mike Durand

Stage 1 & 2

Table 2
Example Flow Law Parameter Estimates for Seven Reaches on the Mississippi River for the Gage-Constrained Branch of the Surface Water and Ocean Topography (SWOT) Discharge Estimates

	Reach-scale flow law parameters			Basin-scale flow law parameters		
HiVDI	Abar	alpha	beta	Abar	alpha	beta
Reach #						
74270100211	2,774.84	85.35	–0.05	2,825.41	679.80	–0.84
74270100221						
74270100231						
74270100191						
74270100171						
74270100151						
74270100131						

BAM	Db	*n*	*r*	A0	*n*	–
Reach #						
74270100211	8.33	0.02	5.07	4,617.83	0.01	–
74270100221	–	–	–	5,520.33	0.01	–
74270100231						
74270100191						
74270100171						
74270100151						
74270100131						

MetroMan	Abar	Ninf	*b*	Abar	ninf	*b*
Reach #						
74270100211	10,848.53	0.03	1.04	9,045.63	392.21	–4.76
74270100221	10,548.05	0.03	1.50	10,556.17	37.07	–3.25
74270100231	11,107.28	0.03	1.75	8,832.68	3,759.82	–5.48
74270100191	11,073.69	0.03	0.92	11,112.76	0.43	–0.89
74270100171	11,298.95	0.03	1.06	11,333.25	1.62	–1.54
74270100151	9,027.99	0.03	0.64	9,043.53	0.070	0.14
74270100131	11,305.57	0.03	1.61	10,434.40	3,741.31	–4.97

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Stage 3 : Gauge-constrained

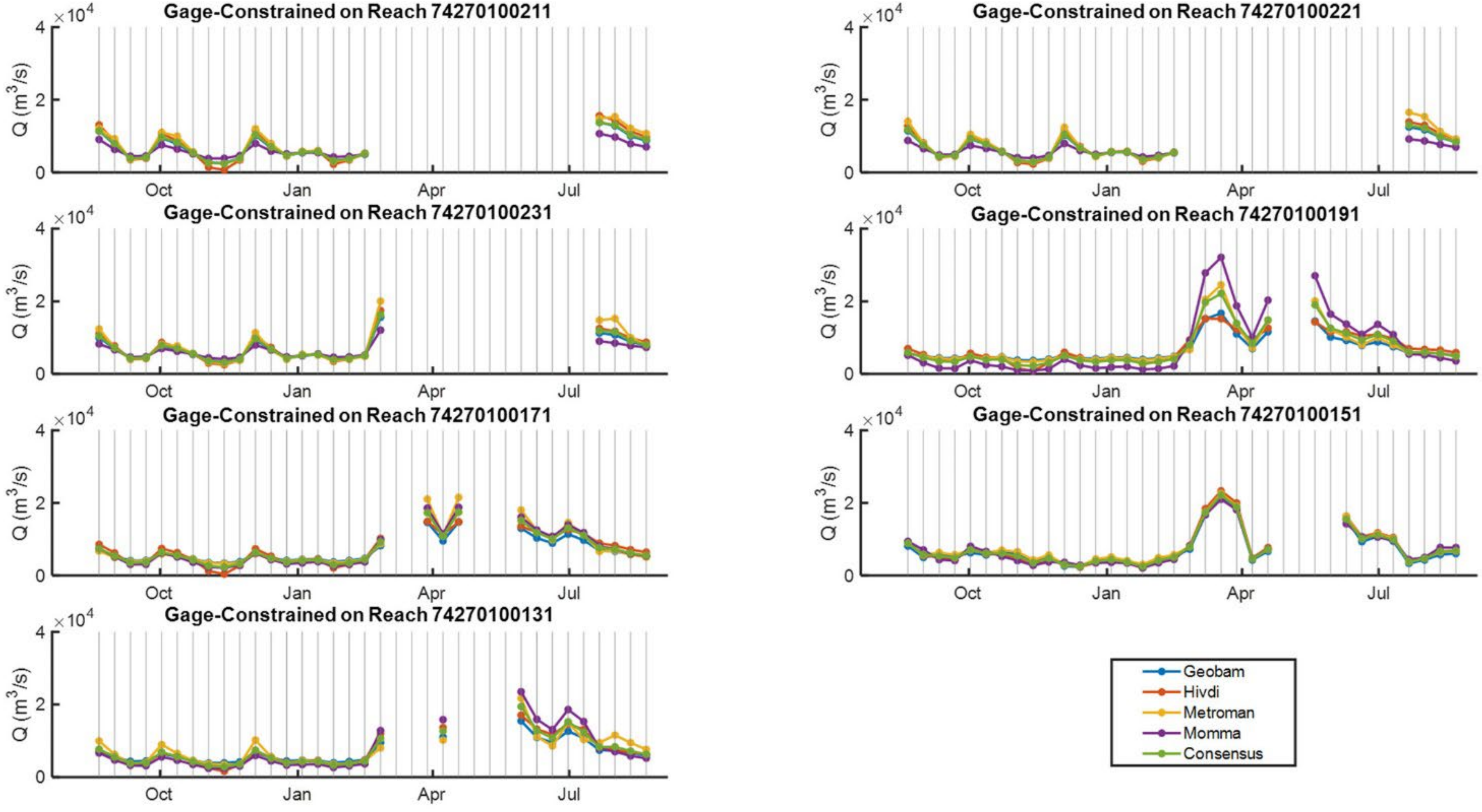

Figure 7. Example simulated Surface Water and Ocean Topography (SWOT) discharge (Q) results mimicking Agency-led data products for seven reaches on the Mississippi River. Branch (i.e., either gage-constrained or unconstrained) and SWOT mission river database (SWORD) reach IDs are shown in titles of each subplot. The various colored lines indicate each flow law parameter estimation algorithm, and are labeled in the figure legend. Note that some values exceed *Y* axis limit.

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Stage 3: Gauge-Unconstrained

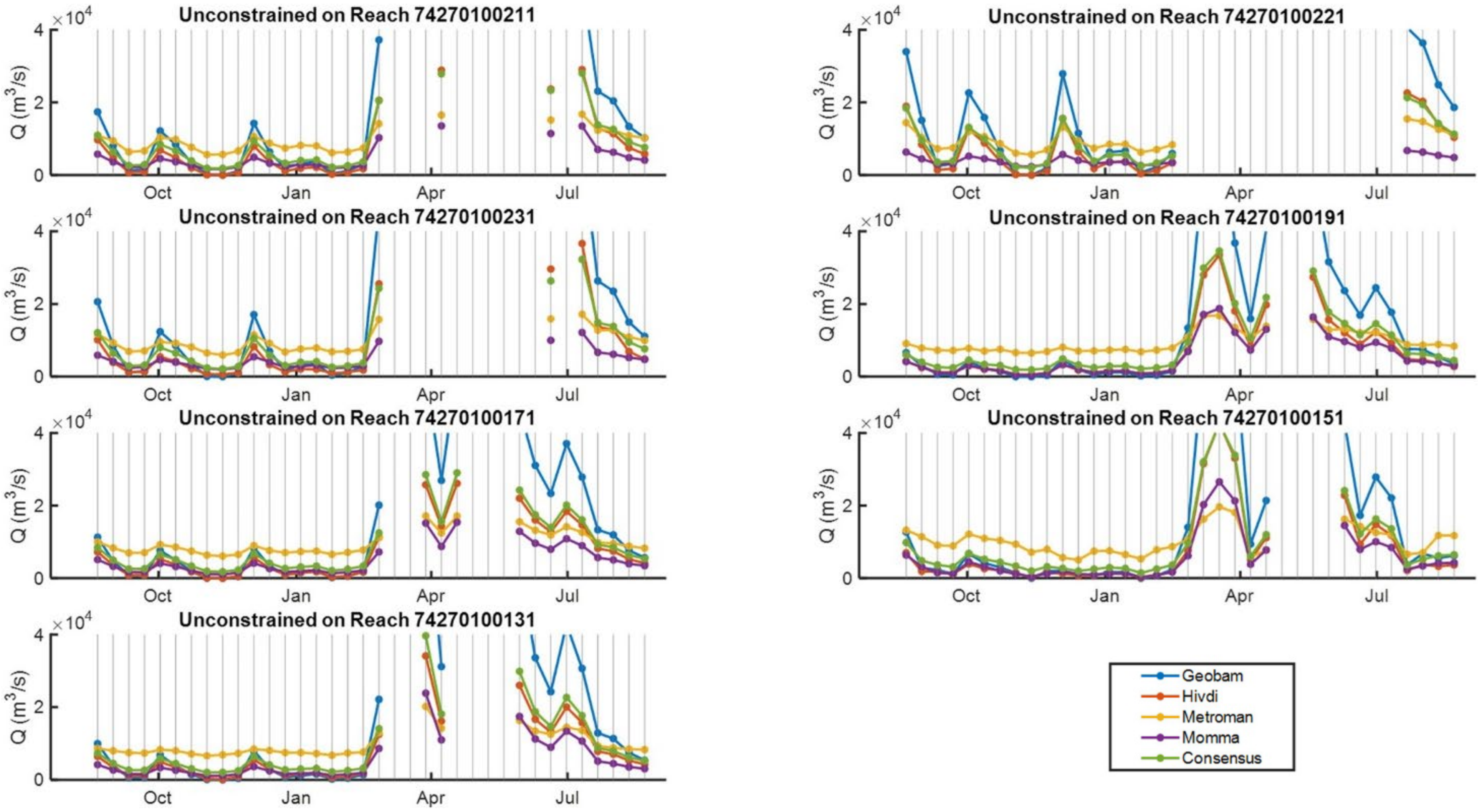


Figure 7. Example simulated Surface Water and Ocean Topography (SWOT) discharge (Q) results mimicking Agency-led data products for seven reaches on the Mississippi River. Branch (i.e., either gage-constrained or unconstrained) and SWOT mission river database (SWORD) reach IDs are shown in titles of each subplot. The various colored lines indicate each flow law parameter estimation algorithm, and are labeled in the figure legend. Note that some values exceed *Y* axis limit.

Durand et al. 2023

SWOT CALVAL

Steve will reveal the first results

Directions

Directions

Know SWOT better :

Improve SWOT discharge algorithms based on SWOT data

Directions

Know SWOT better :

Improve SWOT discharge algorithms based on SWOT data

Learn from SWOT about Water

What SWOT tells us about daily dynamics
What SWOT reveals about inland water uses
How SWOT monitors large rivers
How SWOT captures small rivers and tributaries
Quantify SWOT accuracy and uncertainty in discharge

Directions

Know SWOT better :

Improve SWOT discharge algorithms based on SWOT data

Learn from SWOT about Water

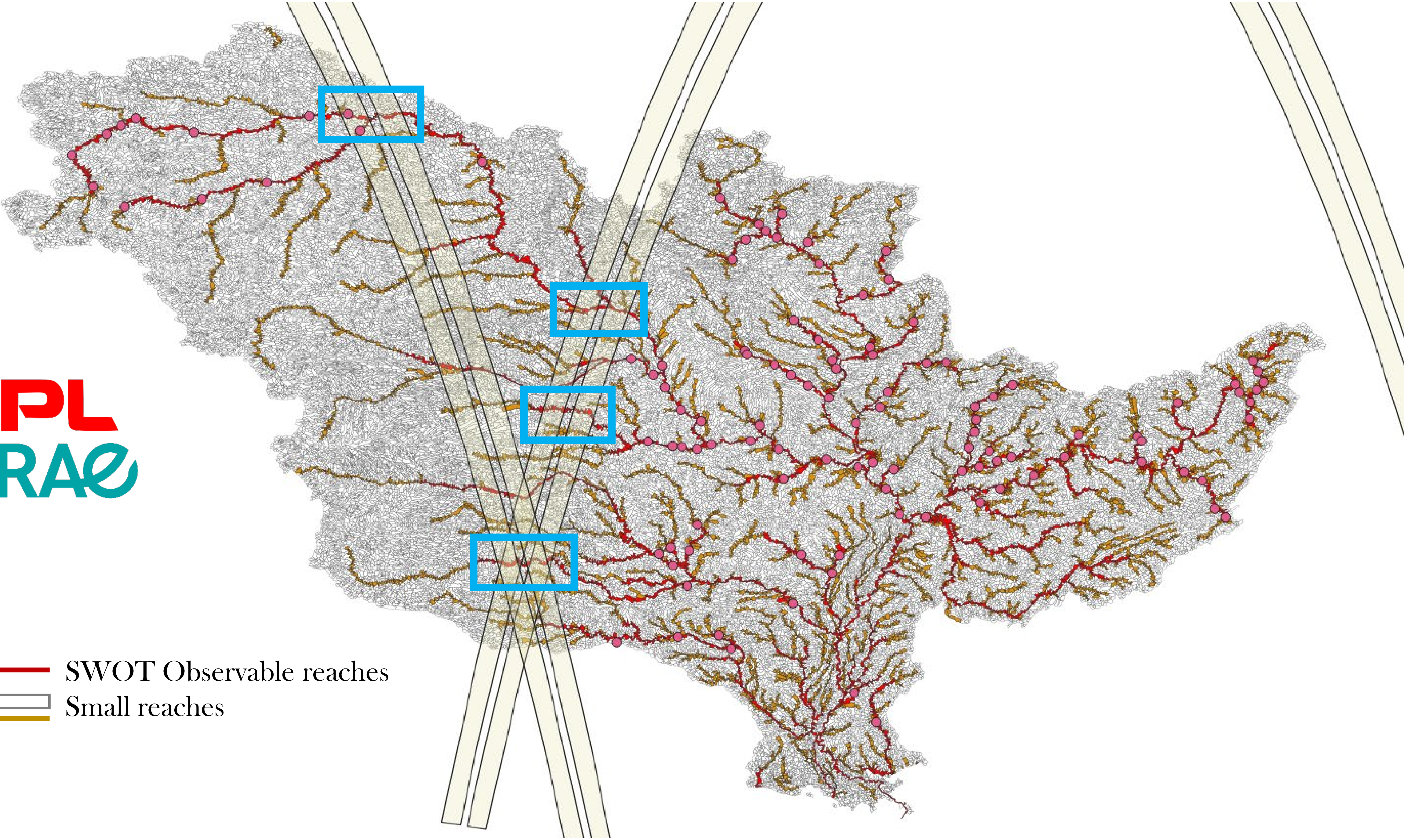
What SWOT tells us about daily dynamics
What SWOT reveals about inland water uses
How SWOT monitors large rivers
How SWOT captures small rivers and tributaries
Quantify SWOT accuracy and uncertainty in discharge

Make use of SWOT to :

Complement other satellite missions.
Know about smaller rivers (not observed by SWOT).

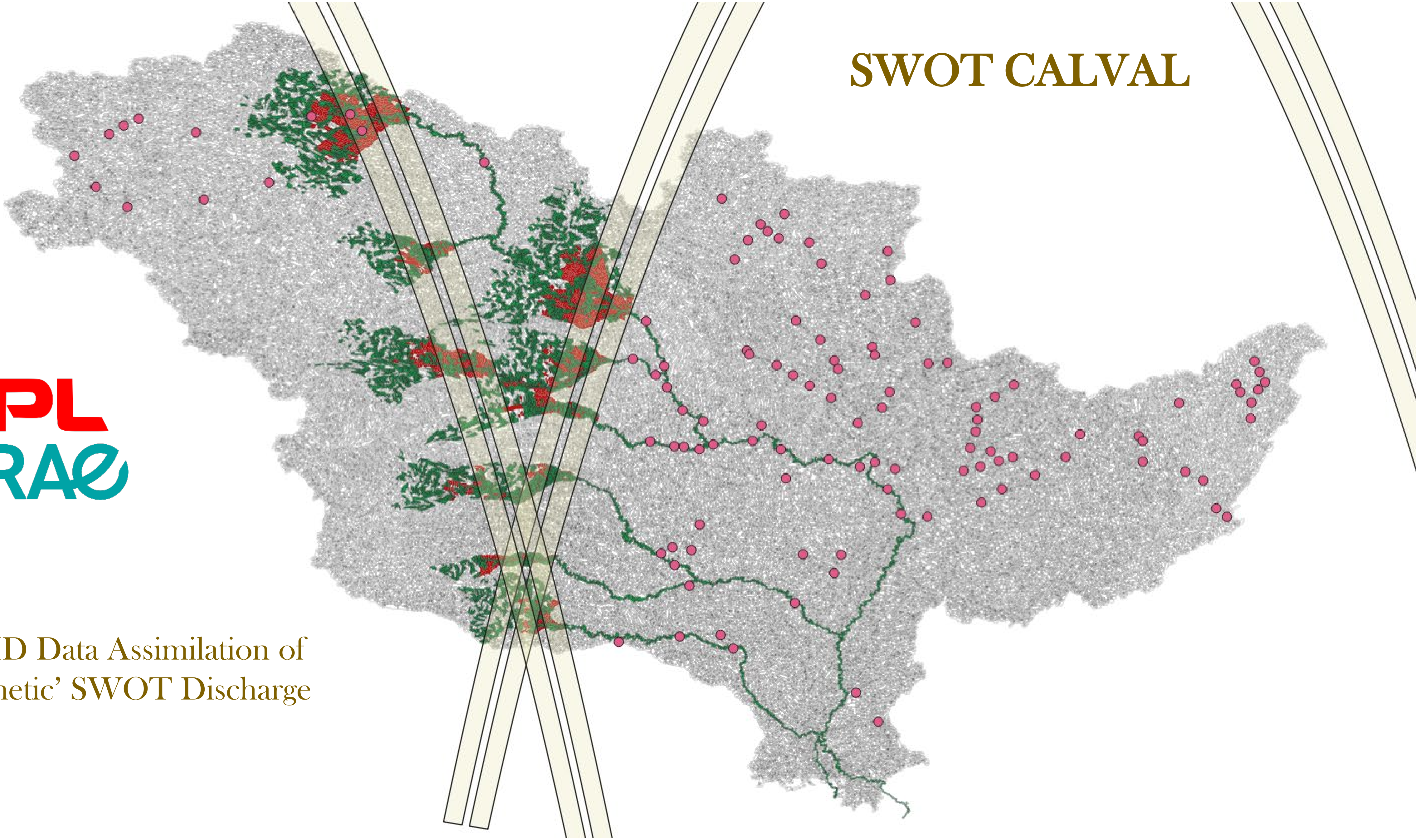
DAWG hand in hand with Global Modelling

JPL
INRAE



SWOT Observable reaches
Small reaches

SWOT CALVAL

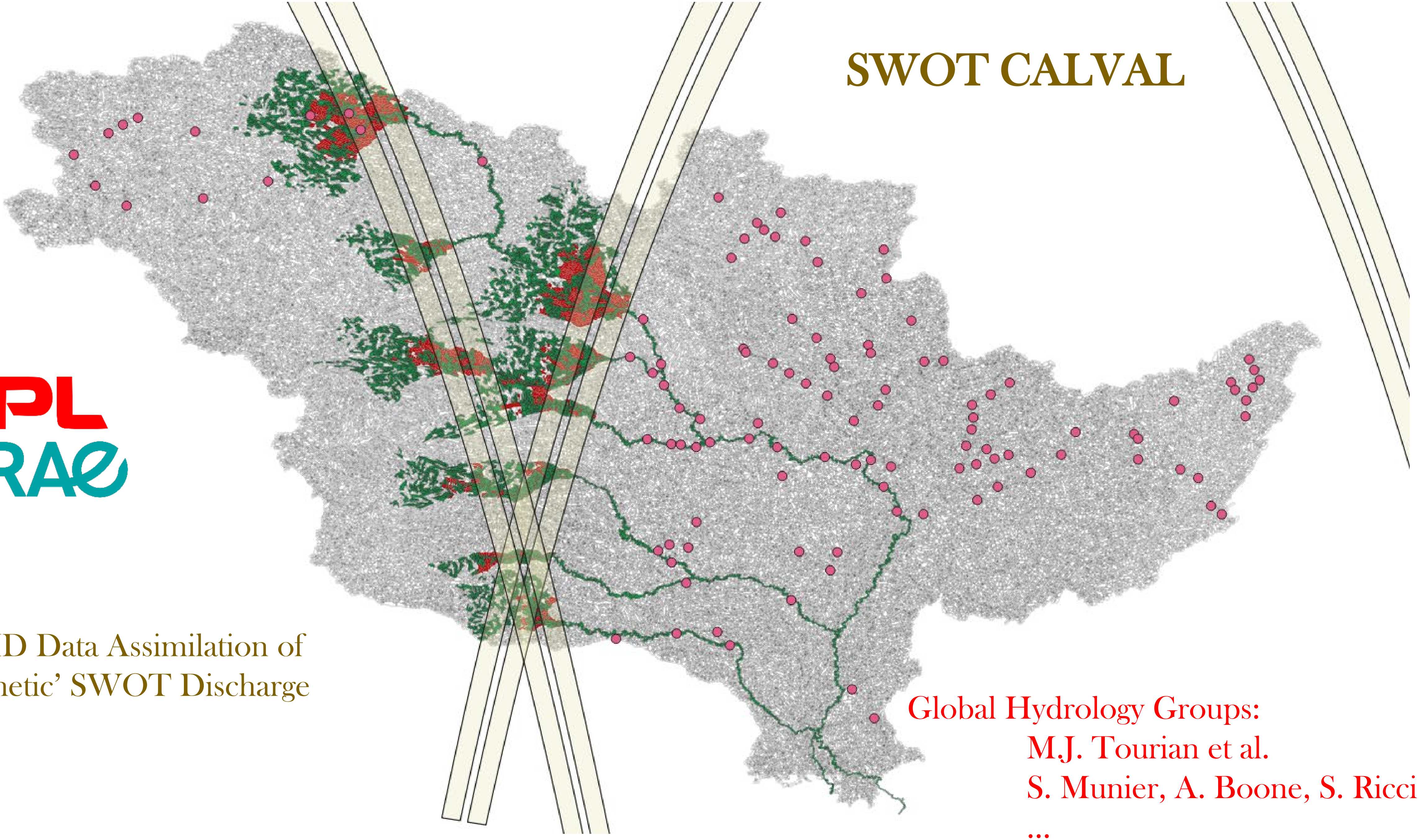


JPL
INRAE

RAPID Data Assimilation of
'Synthetic' SWOT Discharge

SWOT CALVAL

JPL
INRAE



RAPID Data Assimilation of
'Synthetic' SWOT Discharge

Global Hydrology Groups:
M.J. Tourian et al.
S. Munier, A. Boone, S. Ricci
...

Merci!

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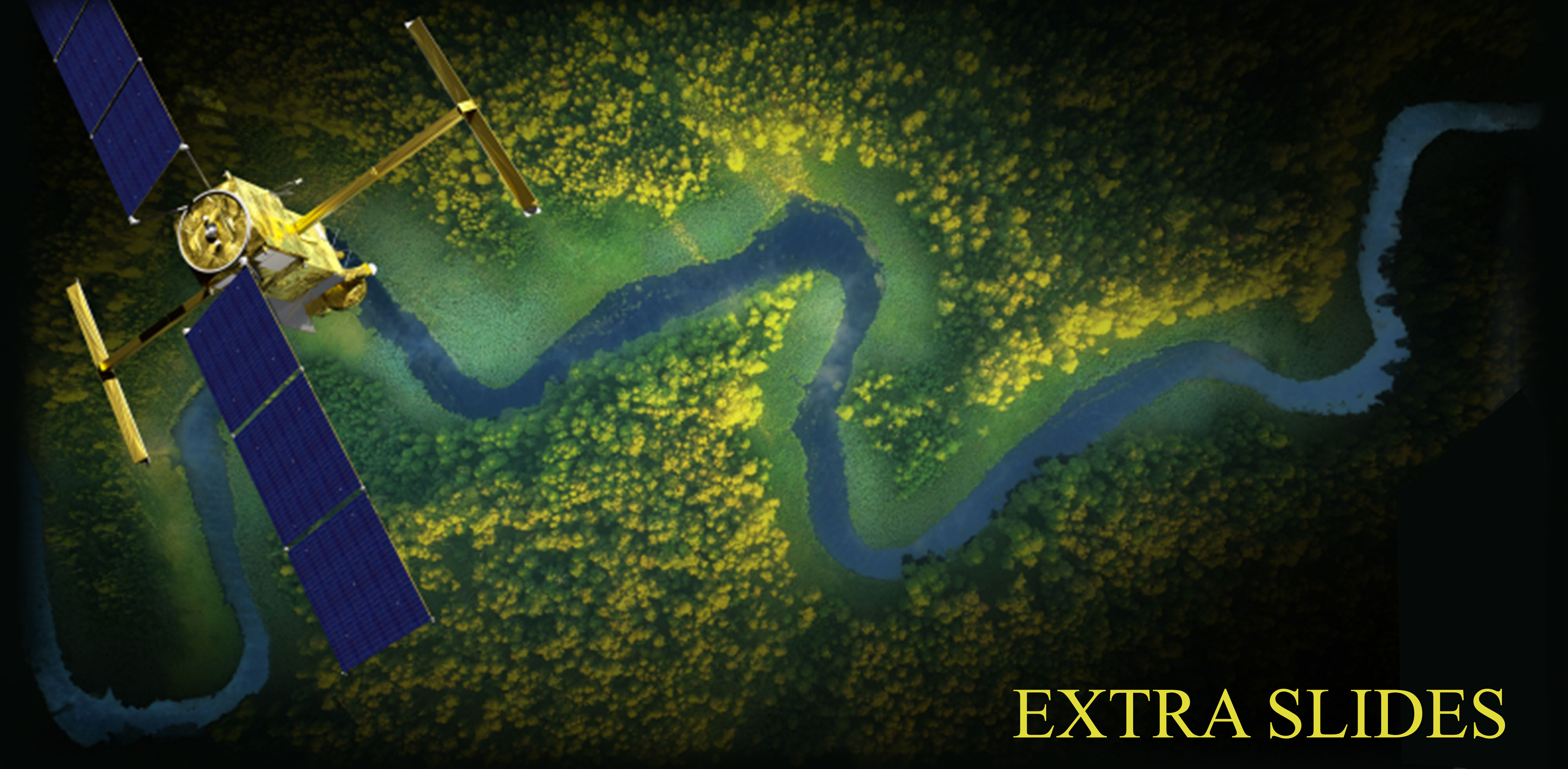
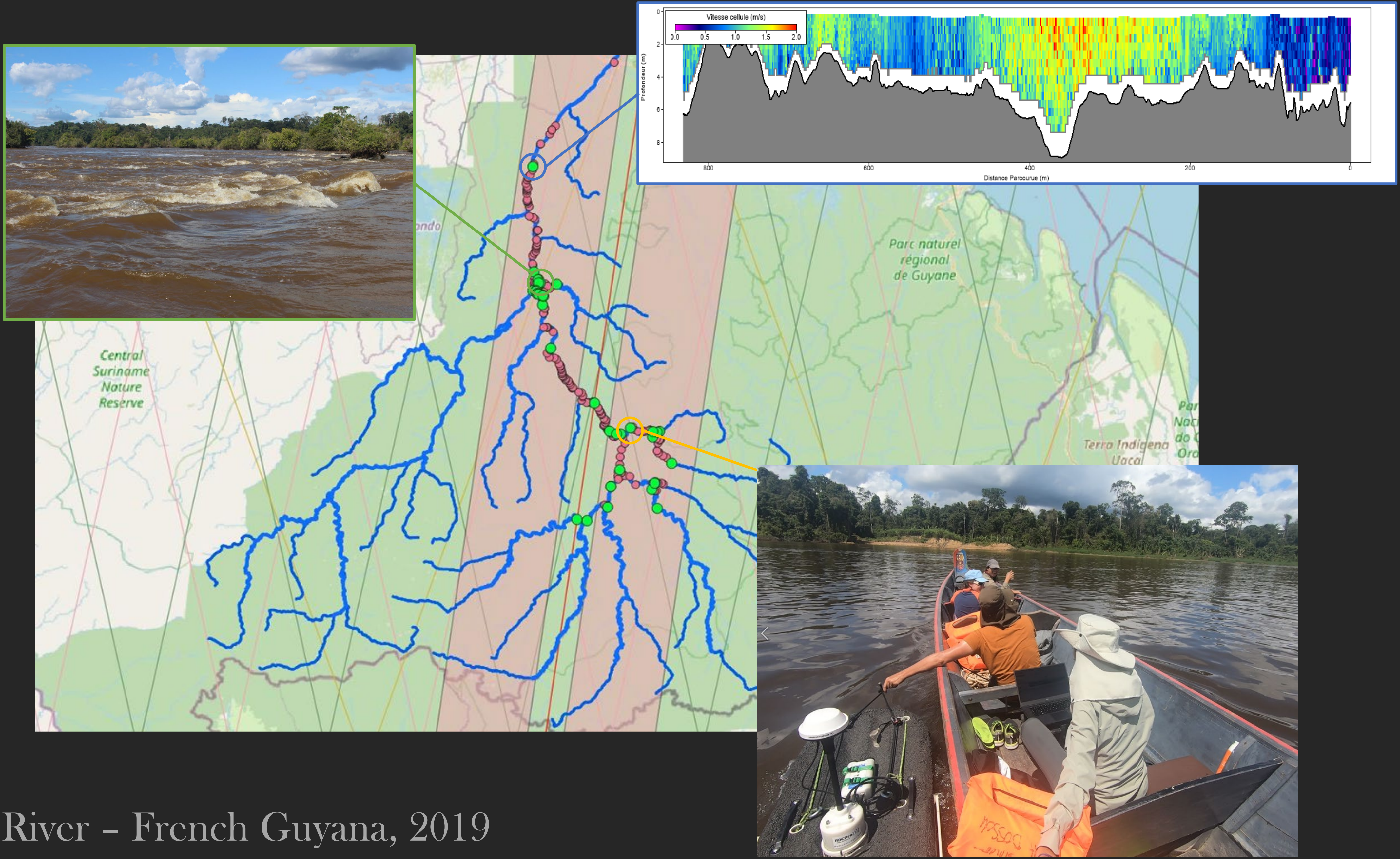
SWOT DAWG Members



EXTRA SLIDES



Maroni River – French Guyana, 2019