Mission Satellitaire SWOT (Surface Water and Ocean Topography)

Pierre-Olivier Malaterre, Hind Oubanas, I.Y. Gejadze, Dylan Quittard, Isadora Rezende, Cécile Cazals

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(Surface Water and Ocean Topography)

Pierre-Olivier Malaterre[(1)], Hind Oubanas[(1)], Igor Gejadze[(1)]
Dylan Quittard[(1,2)], Isadora Rezende[(2,3,1)], Cécile Cazals[(4,2,1)]

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(2): CNES, (3): CLS, (4): CS

RÉPUBLIQUE FRANÇAISE
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INRAE

Plan

Objectifs de la Mission

Historique

Caractéristiques Techniques

- Instruments KaRIn, Poseidon 3C
- Orbite calval
- Orbite scientifique

Exemple de Données

Accès aux Données

Applications

Calculs des Débits des Fleuves

Perspectives et Suites

Conclusion

Satellite SWOT

Mission Franco Américaine (CNES + NASA), 2.4T, 1 B$, lancement 16/12/2022

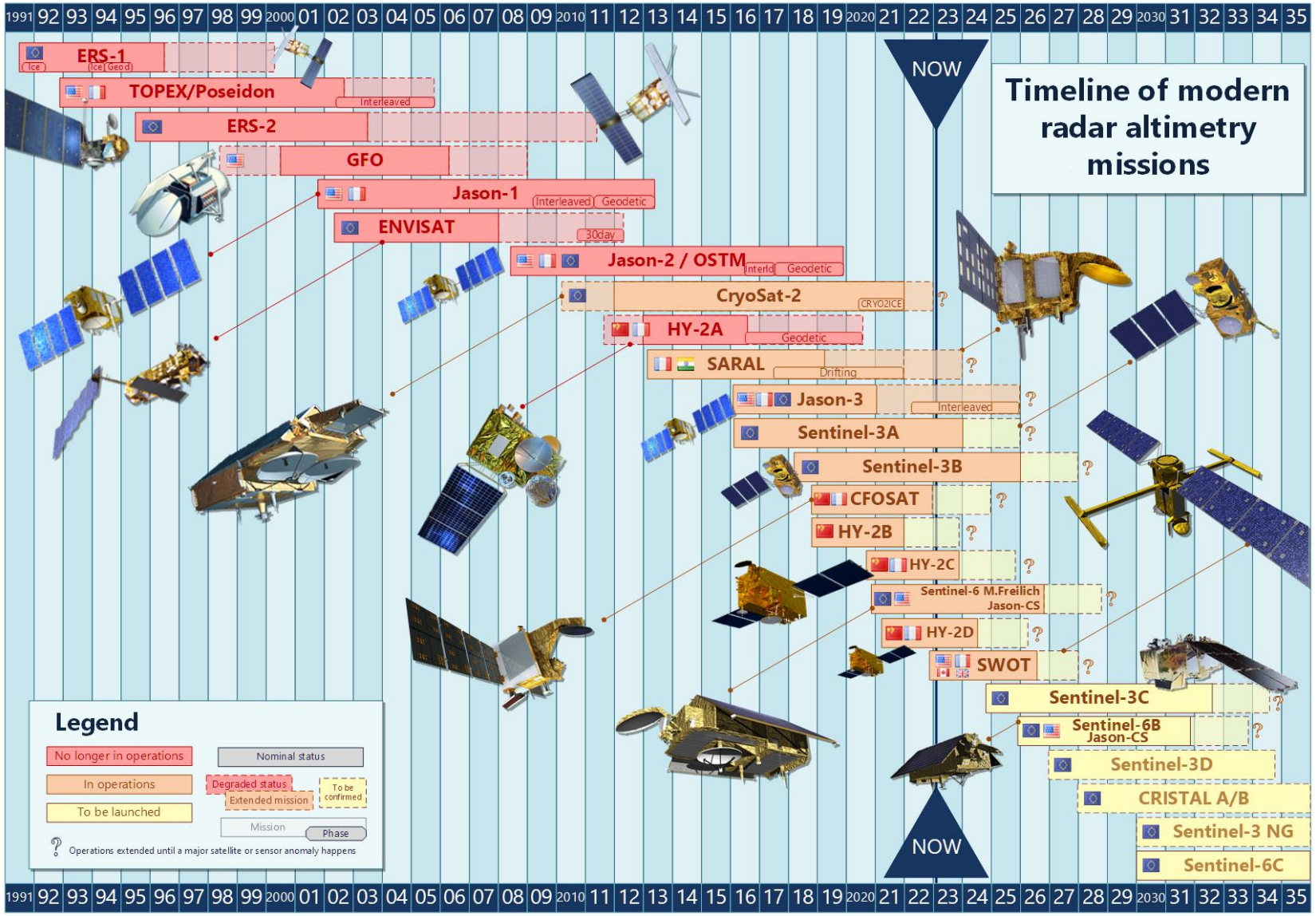
Objectifs de la mission SWOT

Hydrologie et Océanographie

- Mesure (globale) des hauteurs d'eau, largeurs et pentes des rivières/fleuves (>= 50m), hauteurs et surfaces des lacs et réservoirs (>= 1Ha) et zones inondées
- Hauteurs des océans, zones hauturières et côtières (étude de la méso-échelle)
- Estimation (globale) des débits des fleuves et des volumes stockés dans les lacs et réservoirs
- => Instrument de rupture technologique, un radar interférométrique large fauchée dénommé KaRIn
- Mission Scientifique (initialement pour une durée de 3-4 ans : mi 2026, mais probablement prolongé …)

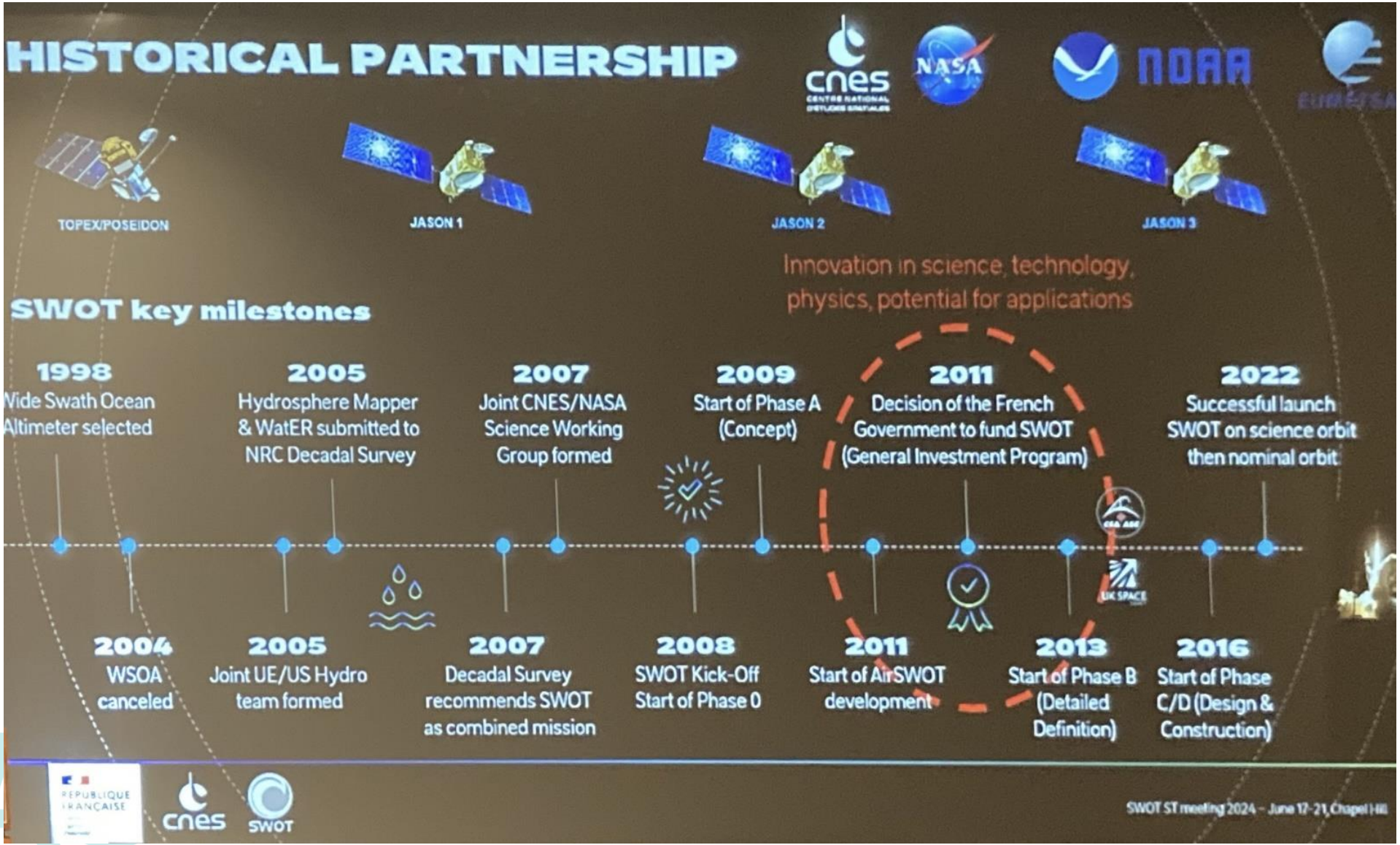
Historique

Missions altimétriques



Historique

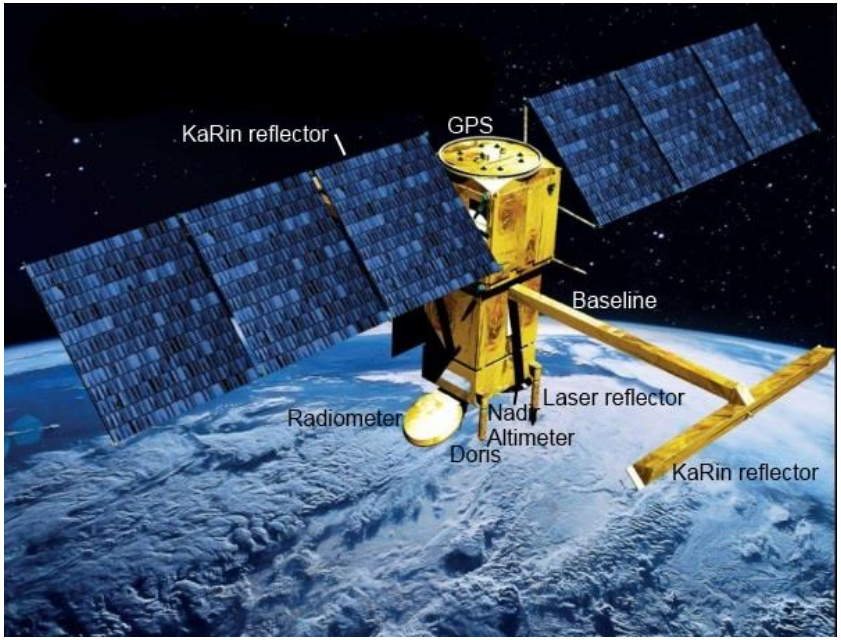
Dates clés pour SWOT



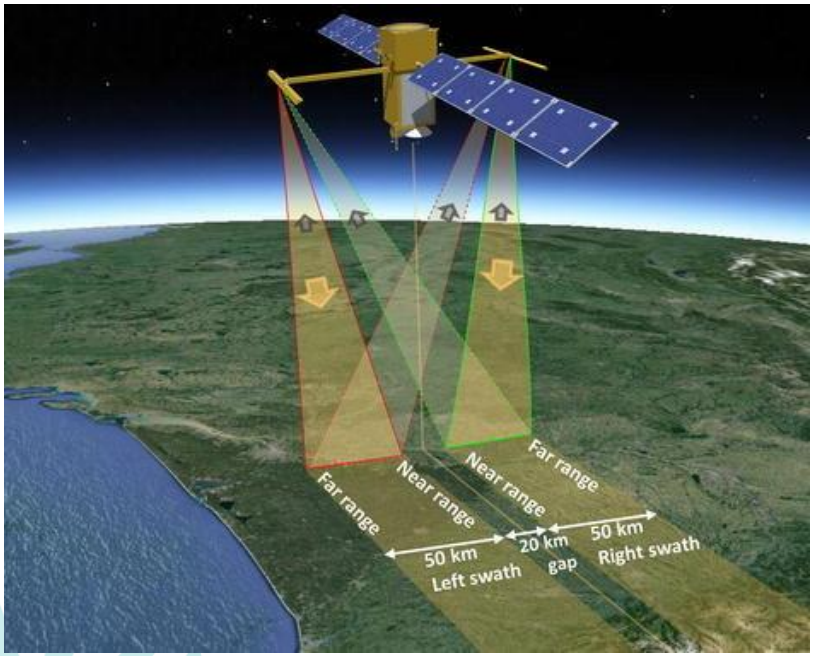
Historique

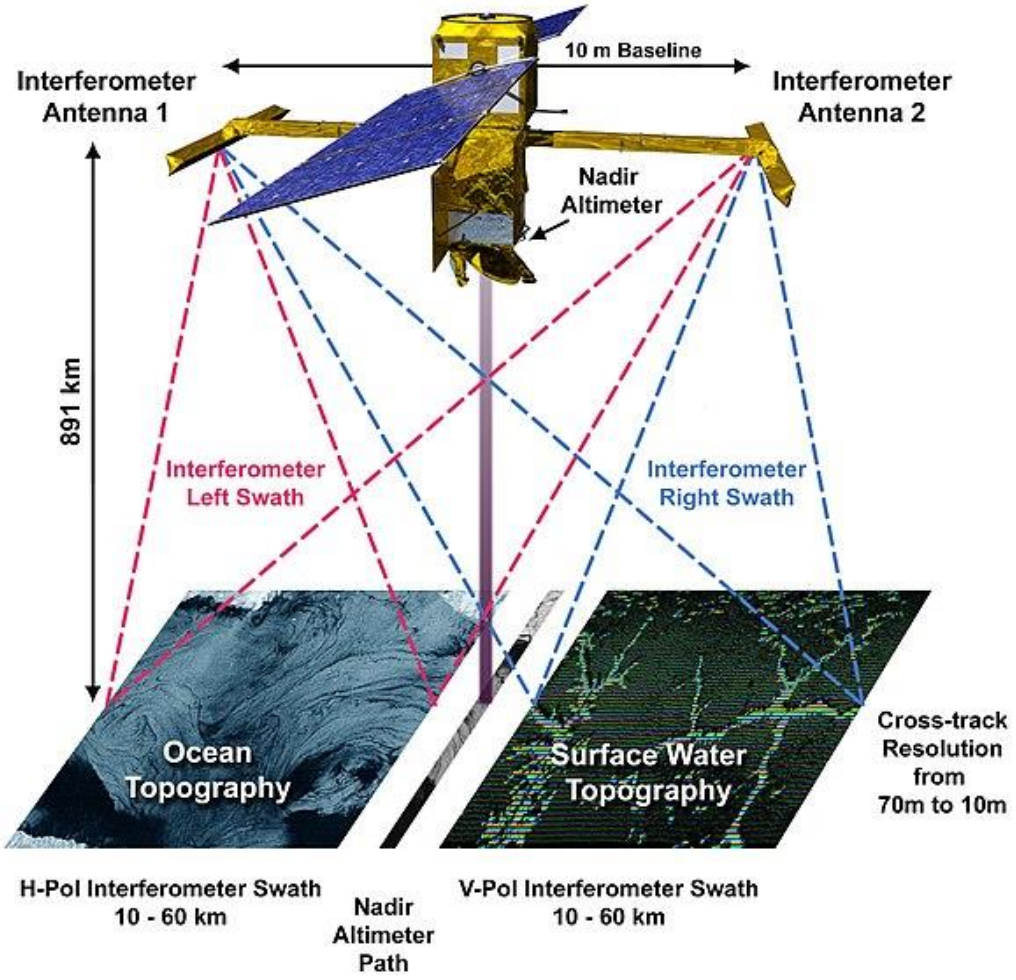
Dates clés

- Idées antérieures (dès 1998 WSOA, choix techno entre 4 options en 2004, WATER ESA mission 2005 abandonnée)
- 19 septembre 2008 : Début du programme SWOT
- Septembre 2009 : Début de la phase A du développement
- Novembre 2013 : Début de la phase B du développement
- Mi-2016 : Début de la phase C/D du développement, début de la construction du satellite
- **Automne 2019 : Livraison des instruments Français : RFU, POSEIDON 3 et DORIS au JPL. Livraison du Centre de Contrôle SWOT au CNES**
- 2021/2022 : Assemblage et Intégration du satellite et Qualification Opérationnelle du système
- 16 décembre 2022 : Lancement du satellite SWOT par une Falcon 9 (Space X, Base de Vandenberg, Californie)



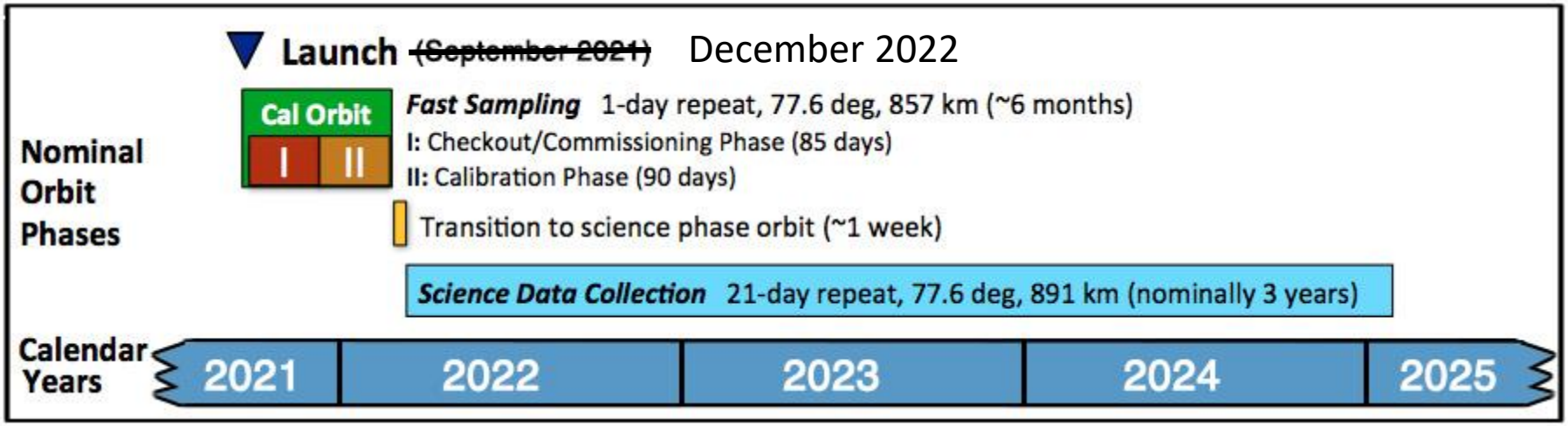
KaRIn
SAR, bande Ka (35 GHz) pour meilleure résolution et précision (qq m, qq cm)





Caractéristiques techniques

2 Orbites différentes :

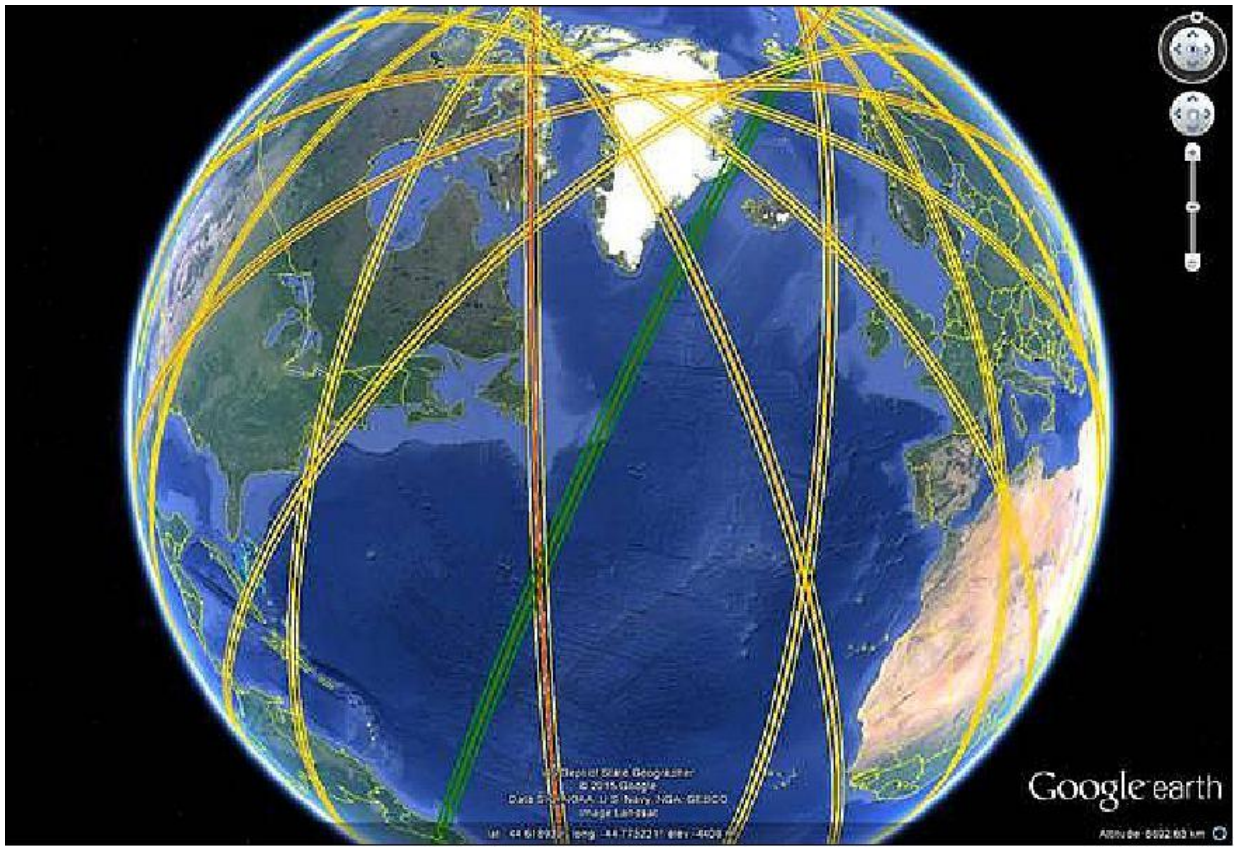


Orbite CalVal : 30 Mars 2023 -> 11 Juillet 2023

Orbite Scientifique : 21 Juillet 2023 -> Juillet 2026 ?

Caractéristiques techniques

Orbite calval (DT=1 jour)



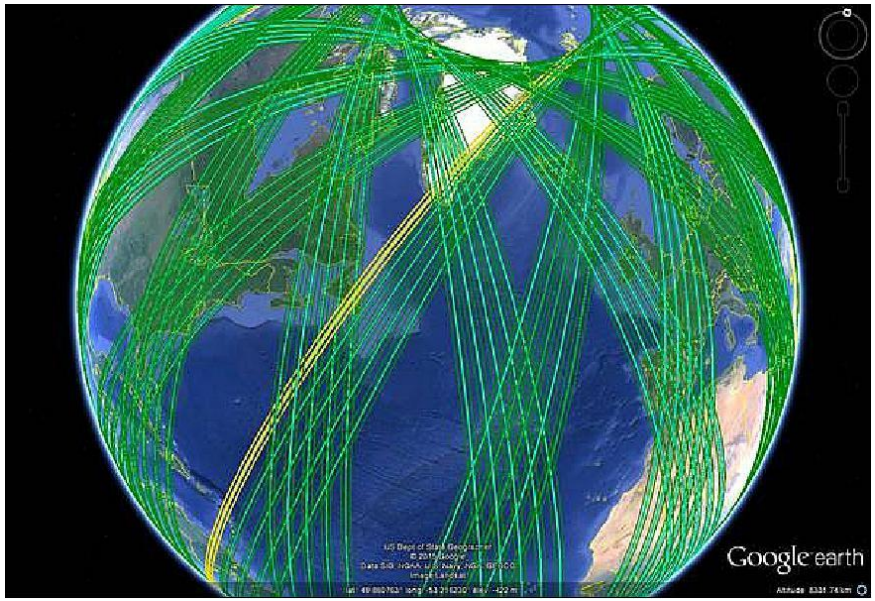
Caractéristiques techniques

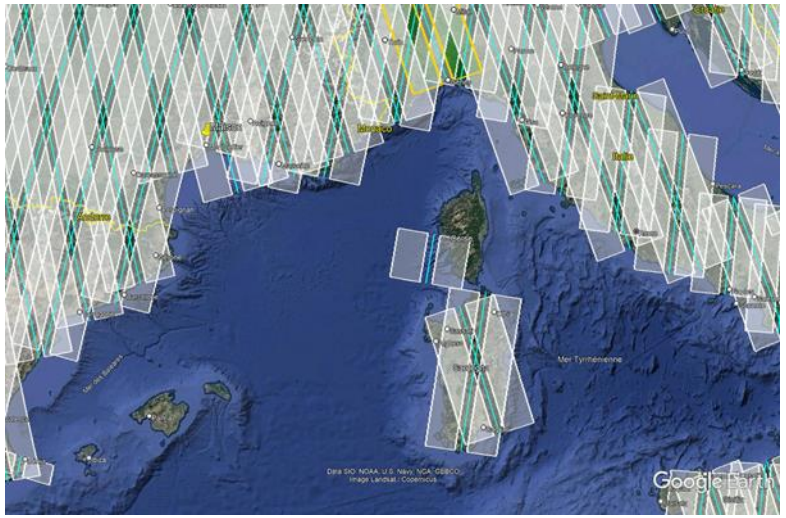
Sites calval (Calibration – Validation)

> 50 In-situ and Airborne Validation Sites in **2023** (ocean research campaigns, river, lake, delta, estuary validation, …)

Caractéristiques techniques

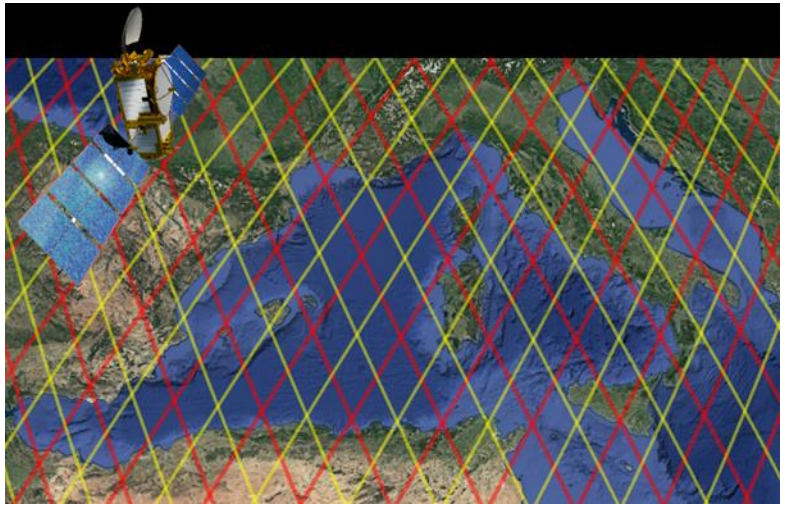
Orbite scientifique depuis le 21/07/2023





Fauchées SWOT

Jason 2 (jaune)
Jason 3 (rouge)



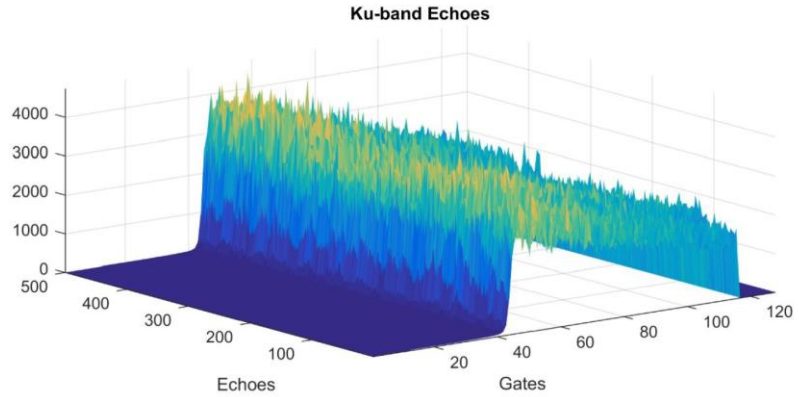
Exemples de données

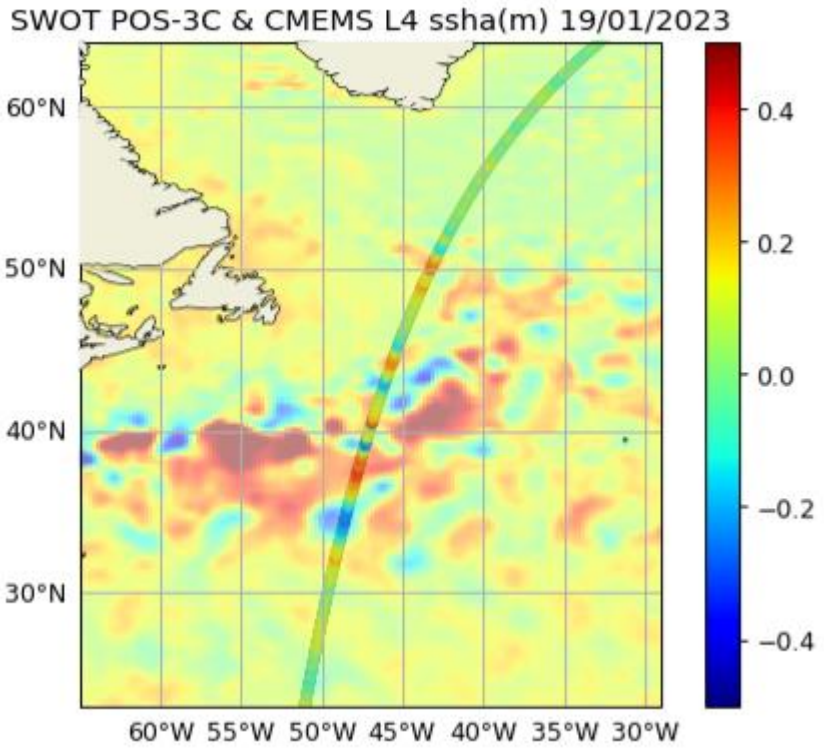
Allumage POSEIDON-3C

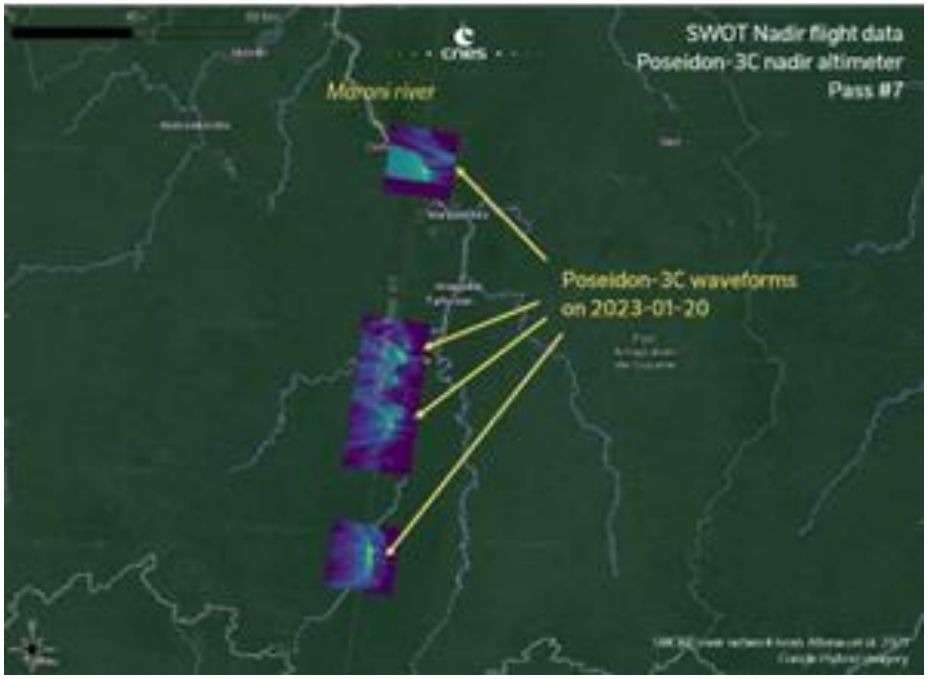
Premiers échos océans

Le 16/01/2023 10h56min59s

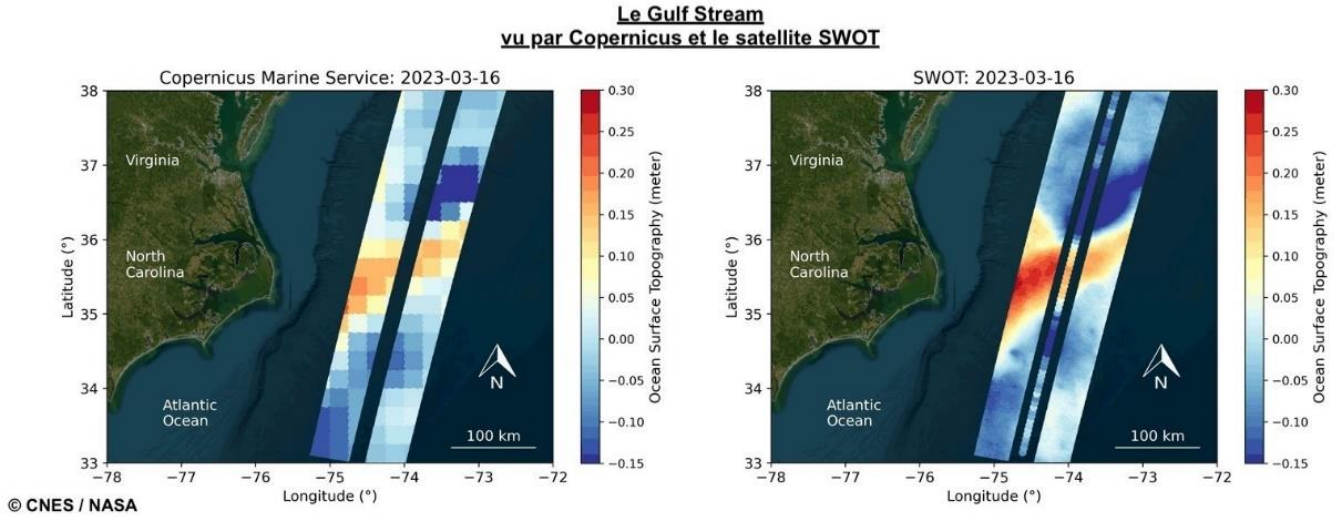
Premières données Nadir (Poseidon 3C)



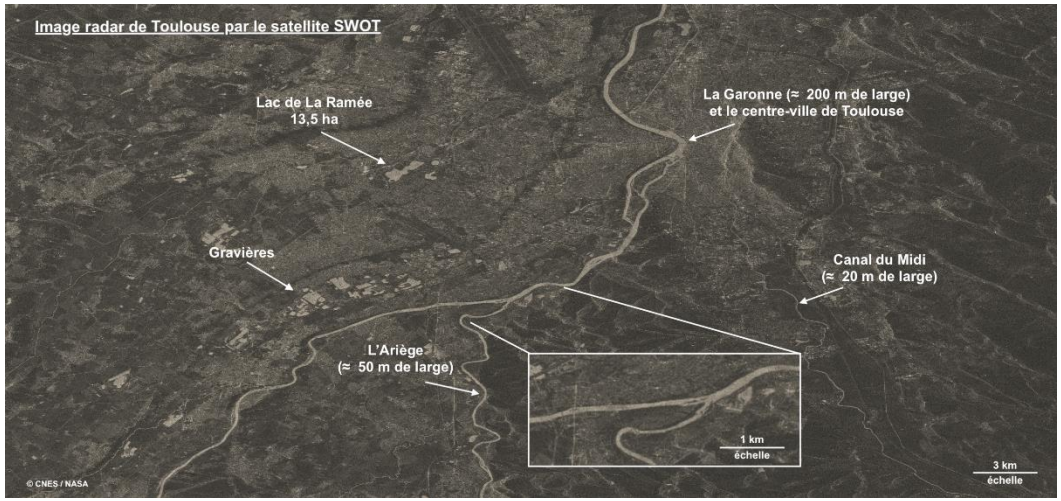




Premières données (Fauchées, KaRIn)



Résolution 10* meilleure
Cours d'eau de 10m de large sont vus (Canal du Midi)

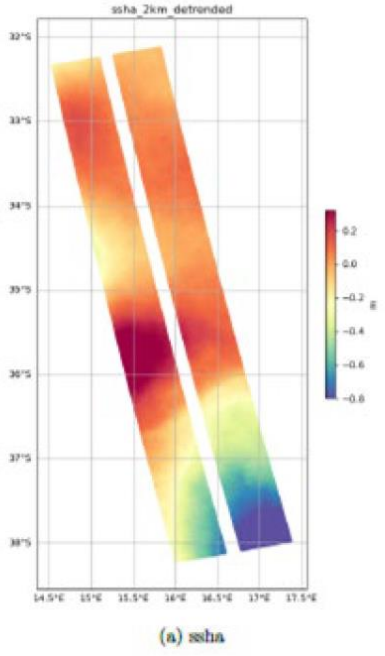


Exemples de données

Océans

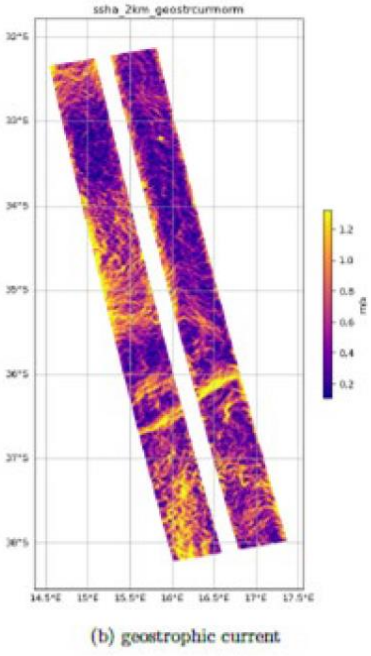
SWOT : a new 2D vision of ocean currents – waves – winds at km scale

2 km SSHA



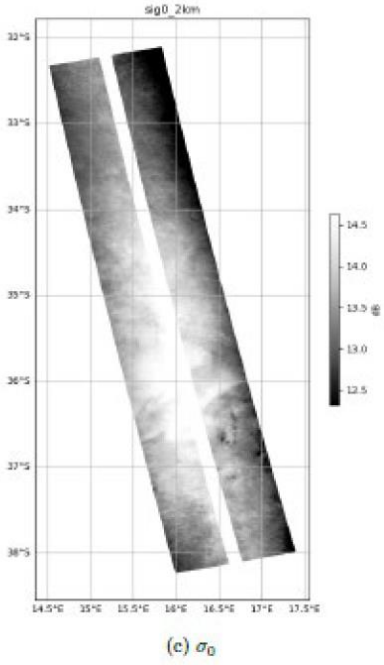
(a) ssha

2 km geostrophic vel



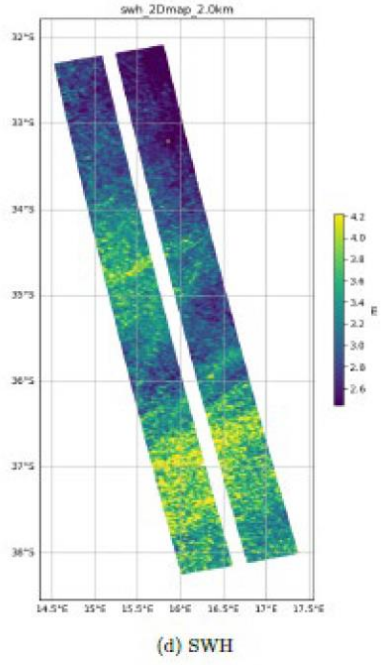
(b) geostrophic current

2 km SAR sigma-0



(c) σ_0

2 km SWH



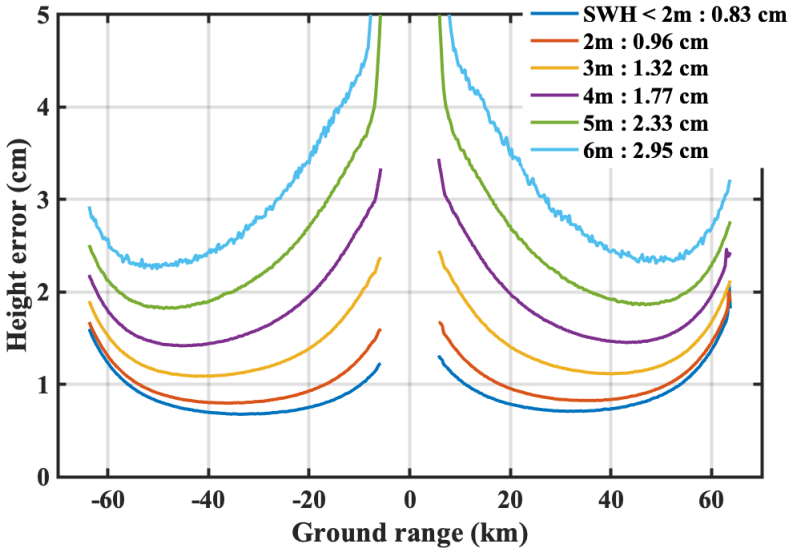
(d) SWH

SWOT provides 2D simultanous maps at km scale of **ocean surface topography** (-> geostrophic **courants**), de surface backscatter (dominated by the **wind**, & other physical signatures) & **waves (**significant wave height) :
- air-sea interaction studies.

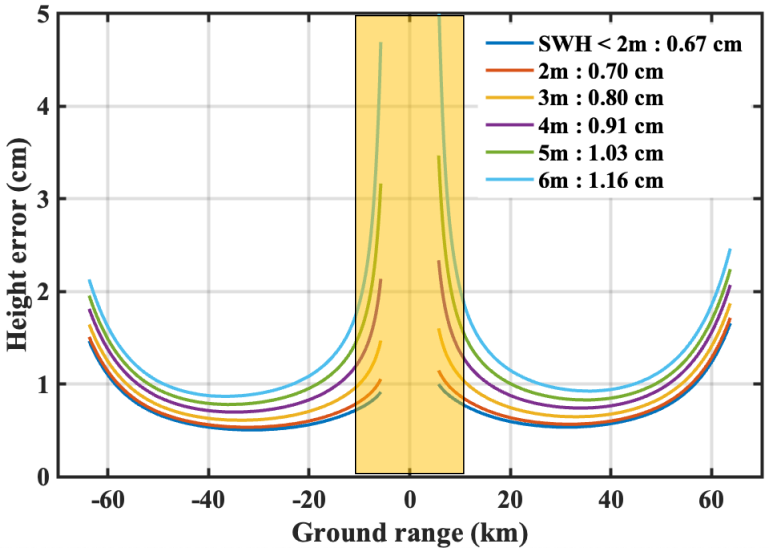
Credit : A Bohe, 2024

Résumé des performances de l'instrument KaRIn (sur les océans)

Total height error in 1km² pixels
Requirement: 2.5cm @ SWH 2m



Random height error in 1km² pixels from decorrelation

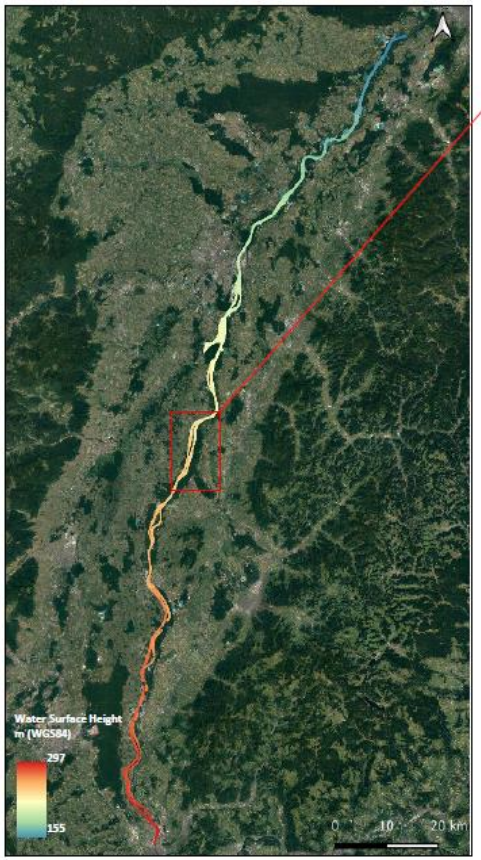


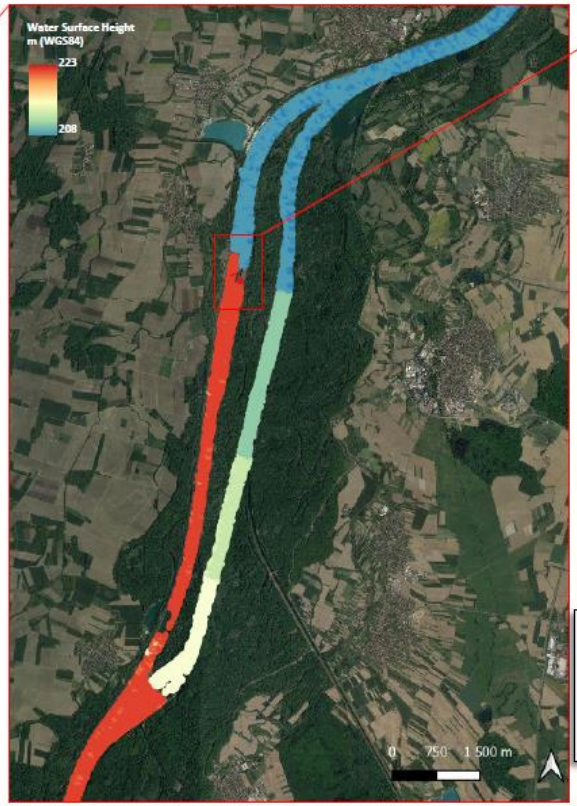
KaRIn's performance remains nominal with high SNR margin and excellent random performance

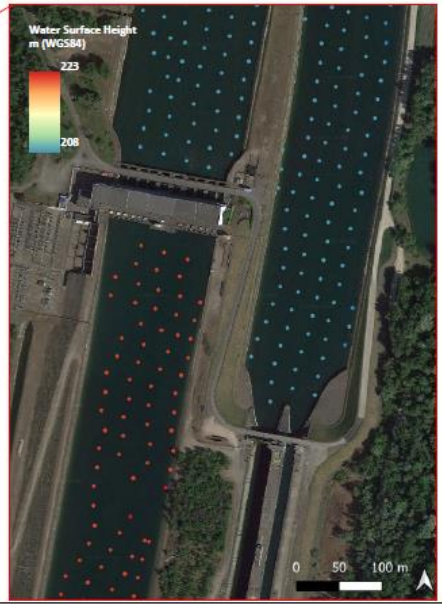
Divers types de données (rivières & lacs)

Pixel Cloud

SWOT PIXC L2 HR PGC0 - Class 4 - Cycle 540



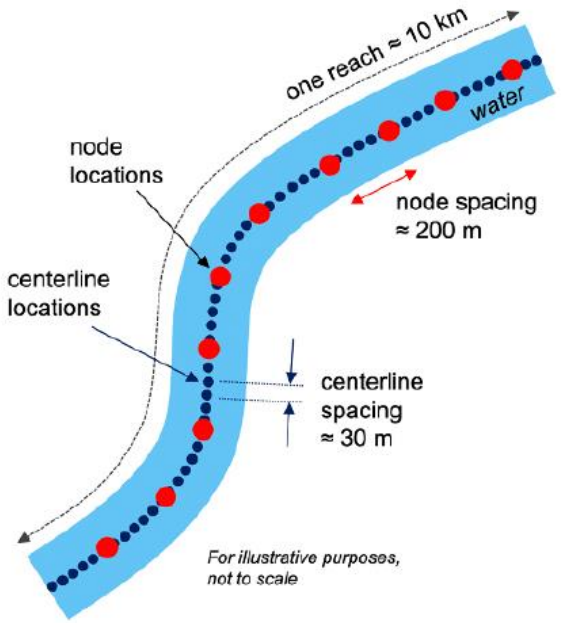




- Global slope of the Rhine well illustrated
- Identification of the weirs, locks and dams

Divers types de données (rivières)

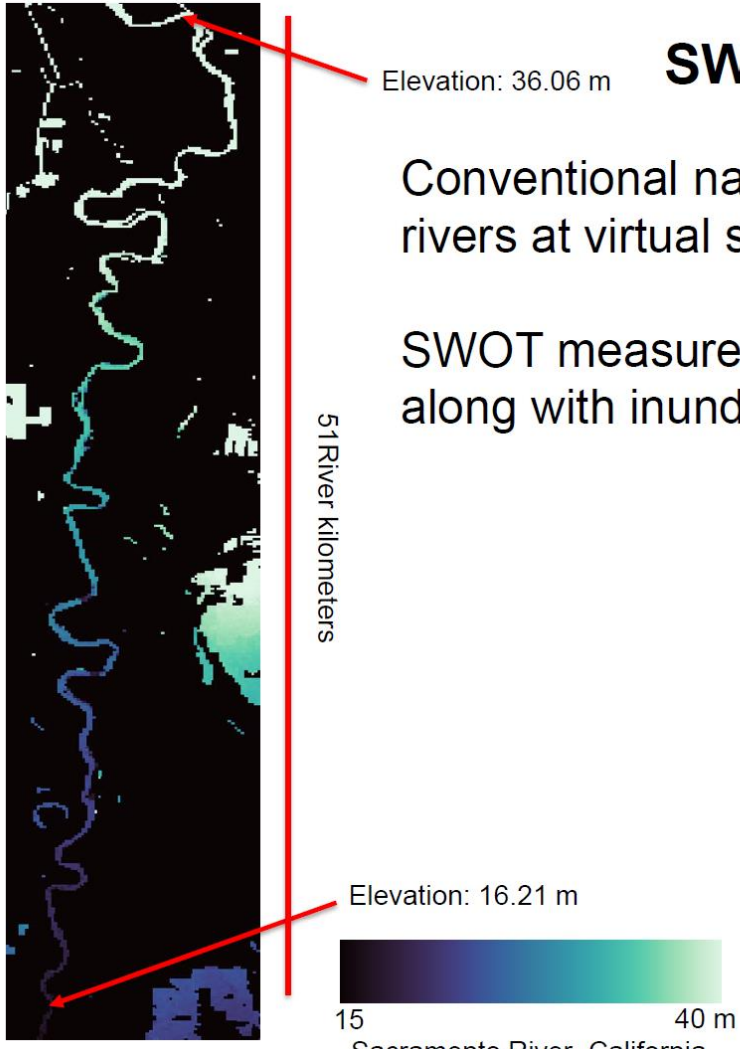
Nœuds et Biefs (Nodes & Reaches)



Logiciel RiverObs fait le passage du Pixel-Cloud aux Nœuds et Biefs :
https://github.com/SWOTAlgorithms/RiverObs

Exemples de données

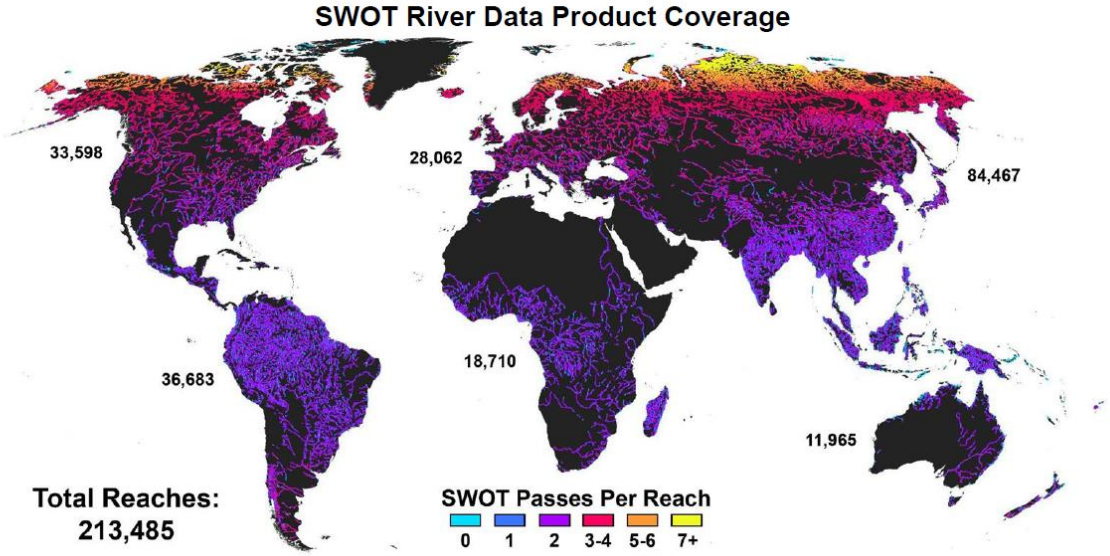
Rivières - Fleuves



SWOT Measurement Capabilities for Rivers

Conventional nadir altimeters measure water surface elevation in rivers at virtual stations.

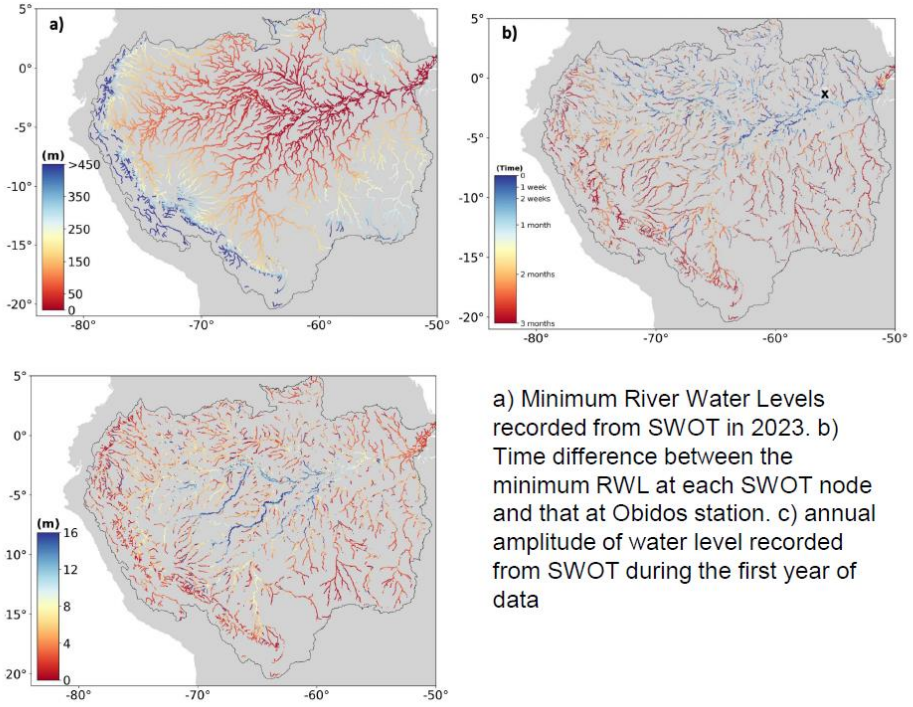
SWOT measures water surface elevation continuously along rivers, along with inundation extent. Slope can also be extracted.



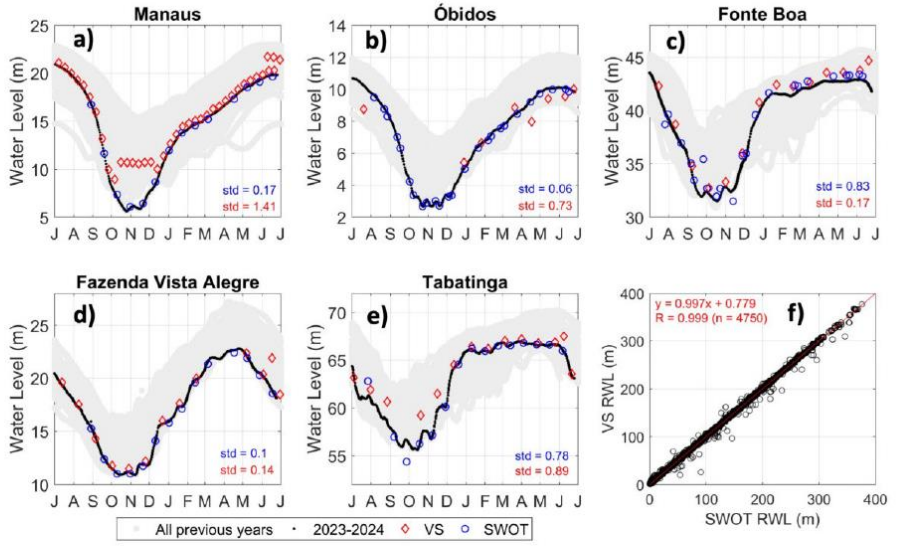
Exemples de données

Rivières - Fleuves

Widespread and Exceptional Reduction in River Water Levels Across the Amazon Basin during the 2023 Extreme Drought Revealed by Satellite Altimetry and SWOT



a) Minimum River Water Levels recorded from SWOT in 2023. b) Time difference between the minimum RWL at each SWOT node and that at Obidos station. c) annual amplitude of water level recorded from SWOT during the first year of data

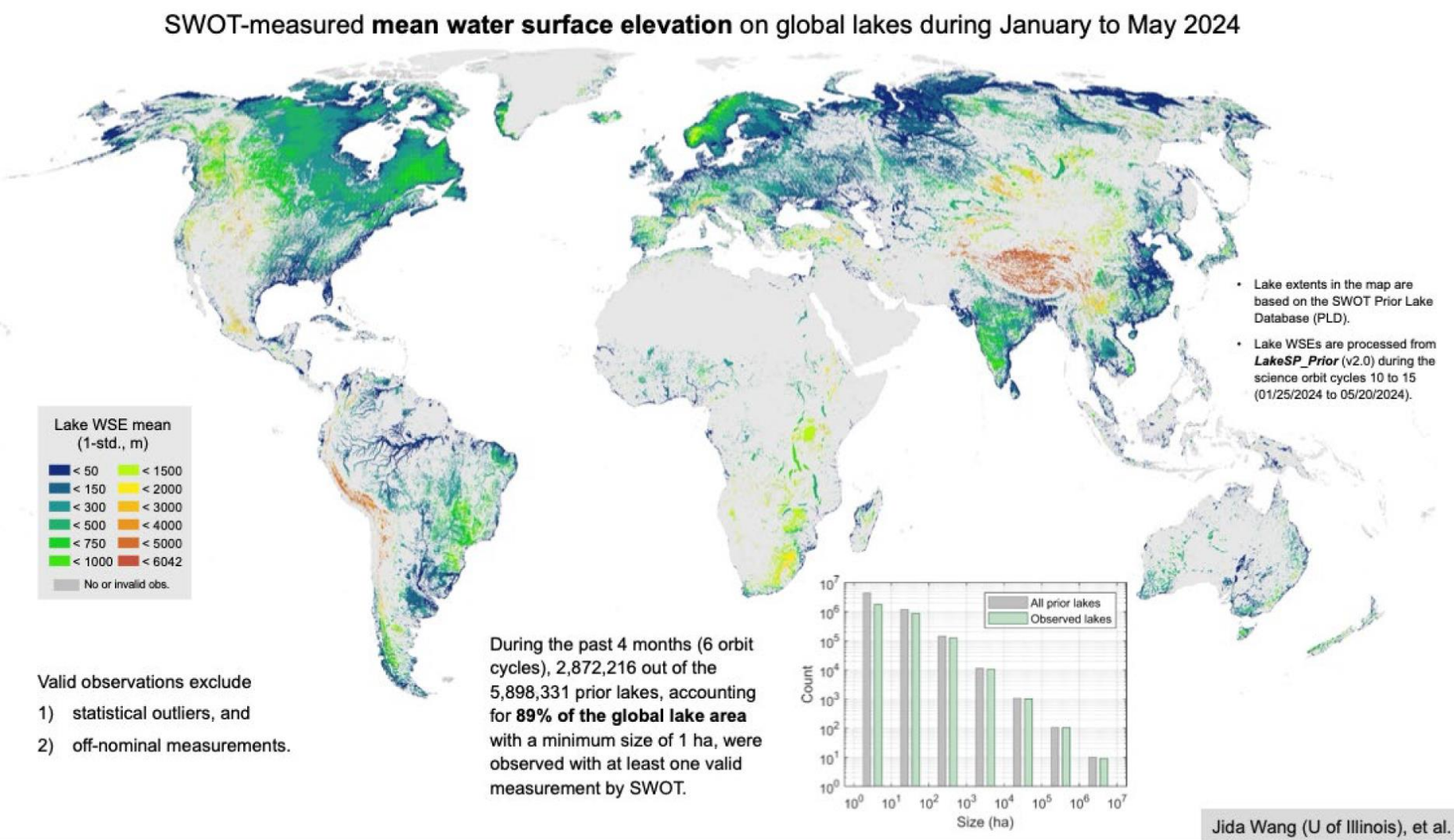


a-e) July to June annual variations (light grey lines) of daily River Water Levels at 276 five gauging stations from 1970 to 2022. The dotted black line is for July 2023 to June 2024, along with River Water Level estimates from nadir altimetry at Virtual stations (red diamond) and from SWOT (blue circle). f) Scatterplot between River Water Level estimates from Virtual Stations and SWOT during the drought period (October and November 2023, 4,750 manuscript submitted to Geophysical Research Letters)

Moreira, Papa et al.,

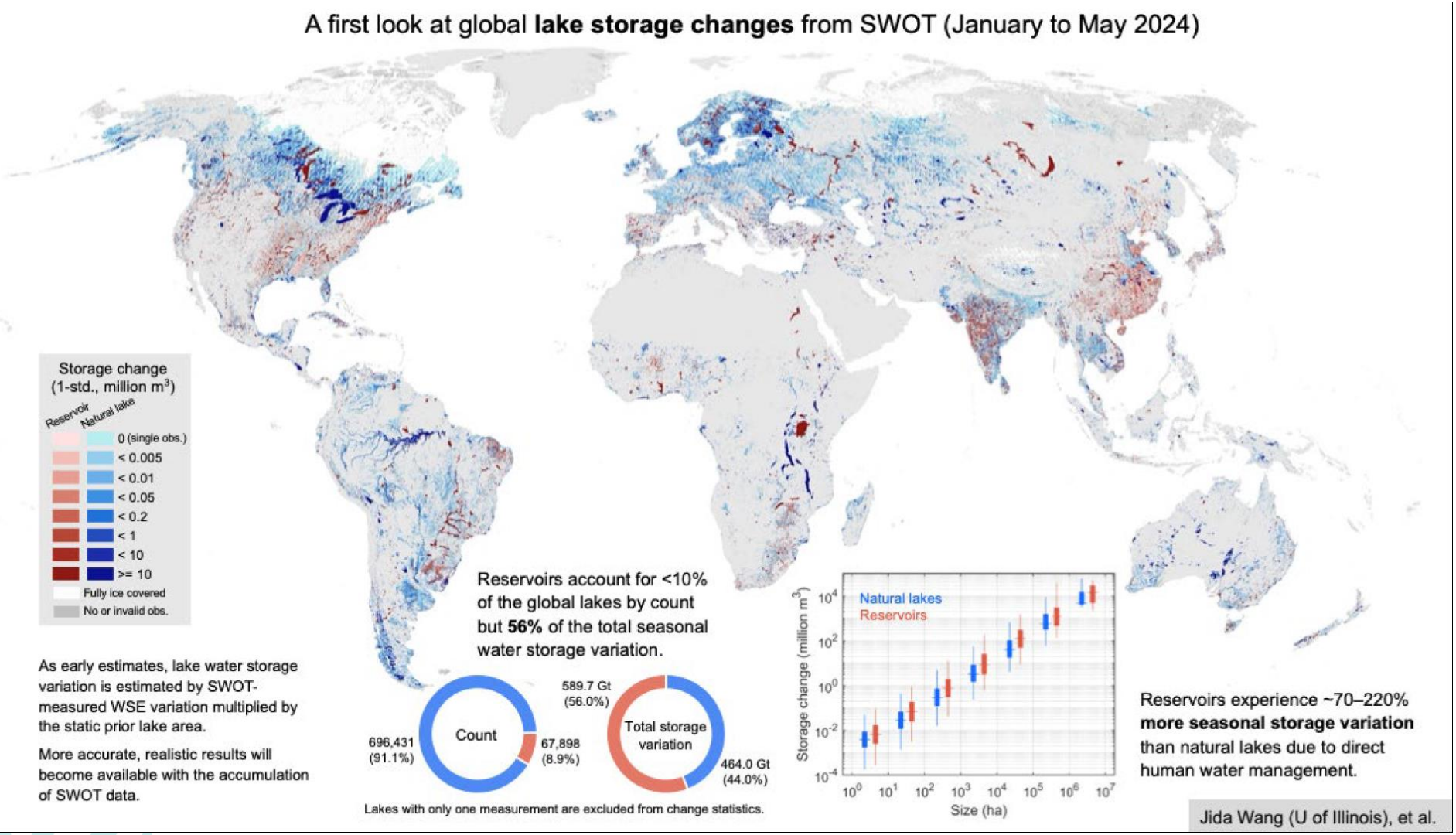
Exemples de données

Lacs et réservoir



Exemples de données

Lacs



Qualité des données HR (continents)

Aux pixel cloud, nœuds, biefs

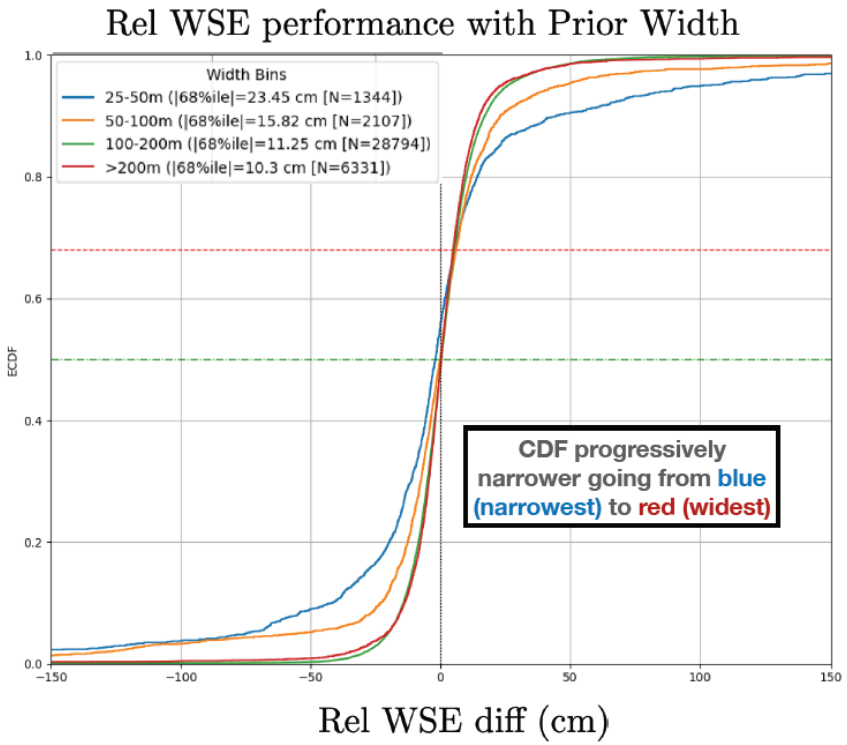
7c: Relationships with prior river width

Node-level data; CNES/Tier 3/Tier 1 combined

This CDF **combines all relative WSE node data from all measurement approaches**, for a total of N=38 576 WSE comparisons.

We observe that **node-level performance degrades below 100 m.**

River Width	|68%ile| Node WSE performance
25-50 m	23.5 cm
50-80 m	15.8 cm
100-200 m	11.3 cm
> 200 m	10.3 cm



Accès aux données

7 TB / j -> 5 antennes -> (CNES : 3000 cœurs 18h / j) -> 20 TB / jour

Near Real Time (qq heures à qq jours)

- CNES : DUACS/Aviso+ (LR ie Océans) & Hydroweb.next (HR ie Continents)

- NASA : PO.DAAC, Hydrocron API (https://podaac.jpl.nasa.gov)

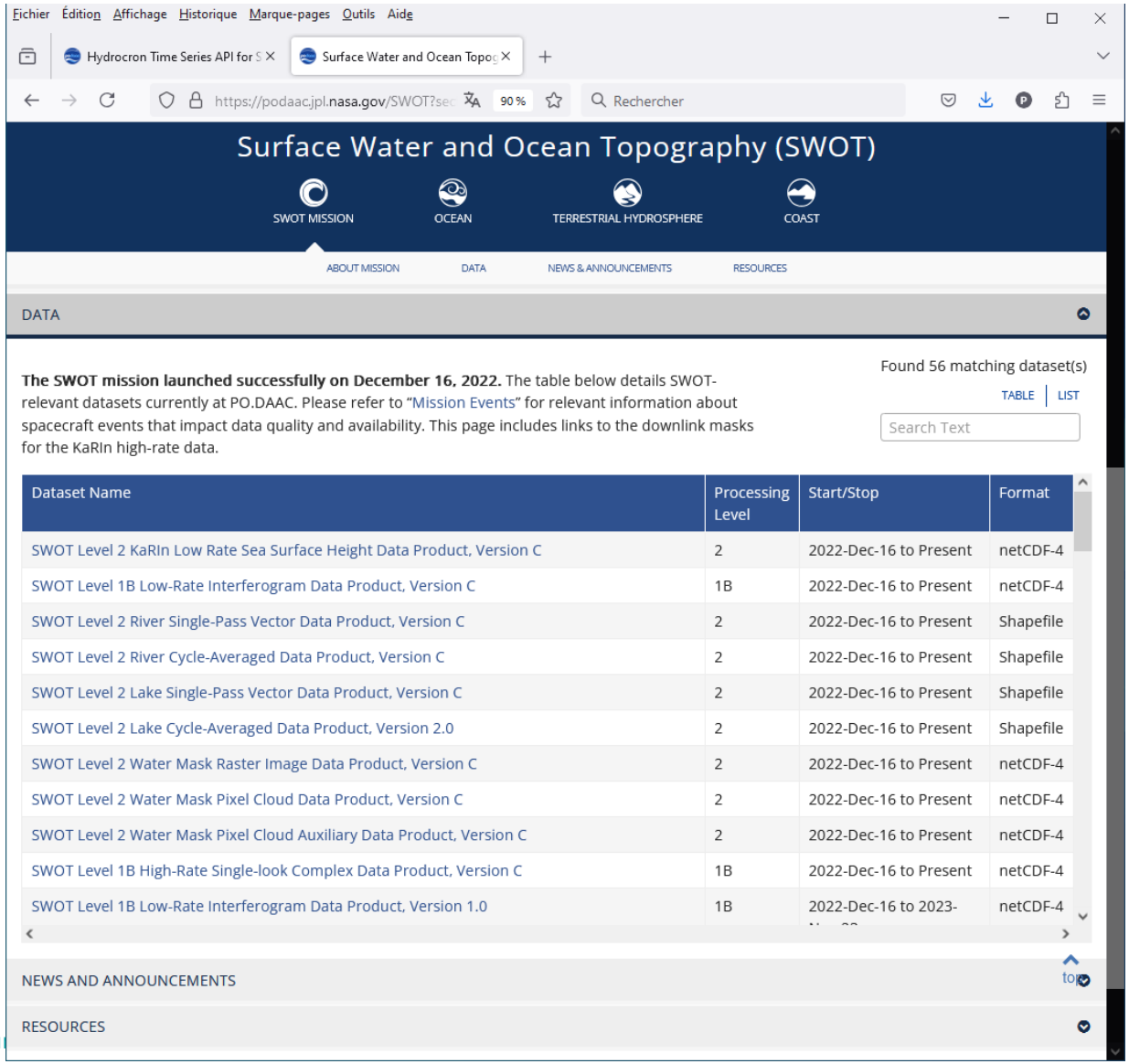
  - individual river reaches and nodes found in the SWOT_L2_HR_RiverSP_2.0 collection (Sword)
  - individual prior lakes found in the SWOT_L2_HR_LakesSP_2.0 collection (PLD)

Accès aux données

NASA, PO.DAAC

Quelques Produits :

- LR interferogram
- LR Sea Surface Height
- HR River single pass
- HR River cycle average
- Lake single pass
- Lake cycle average
- Water mask pixel cloud
- Water mask raster



Accès aux données

CNES Aviso+ (Océans)

Fichier Édition Affichage Historique Marque-pages Outils Aide

Hydrocron Time Series API for S | Surface Water and Ocean Topog | Des données SWOT qui dépasse | SWOT L3 Ocean products

https://www.aviso.altimetry.fr/en/index.php?id=5483

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DATA

- Products guide
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  - Sea surface height products
    - Global
      - SWOT L3 Ocean products
      - SWOT KaRIn Low Rate Ocean products
      - ALTimetry Innovative Coastal Approach Product (ALTICAP)
      - Simulated SWOT products
      - SSALTO/DUACS Experimental products
      - Experimental Multimission Gridded L4 sea level heights and velocities with SWOT
      - SSALTO/DUACS Experimental products including CFOSat for wave-current interactions studies
      - Gridded sea level heights and derived variables - Multiscale Interpolation
      - Gridded sea level heights and derived variables - Multiscale Interpolation combining altimetry and drifters
      - Gridded velocities - altimetry and SST
      - Gridded Mean and Climatology
      - SSHA
      - Along-track Sea Level Anomalies (L2P)
      - GDR, IGDR and OGDR
      - Experimental Sentinel-6 products

BROWSING MENU

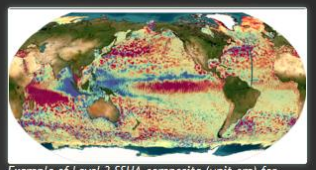
AVISO+ > DATA > PRODUCTS > SEA SURFACE HEIGHT PRODUCTS > GLOBAL > SWOT L3 OCEAN PRODUCTS

SWOT LEVEL 3 OCEAN PRODUCTS

Type of dataset: SWOT Sea Surface Height Data Products (SWOT_L3_LR_SSH)

Digital Object Identifiers (DOIs):

- SWOT_L3_LR_SSH_Basic: 10.24400/527896/A01-2023.017 - more metadata
- SWOT_L3_LR_SSH_Expert: 10.24400/527896/A01-2023.018 - more metadata
- SWOT_L3_LR_SSH_Unsmoothed: 10.24400/527896/A01-2024.003 - more metadata



Example of Level-3 SSHA composite (unit cm) for January 2024 (ascending passes). Credits CNES,CLS.

Condition of access: SWOT_L3_LR_SSH is distributed by AVISO under standard AVISO+ license agreement.

Contents: The SWOT_L3_LR_SSH product provides ocean topography measurements obtained from the SWOT KaRIn and Nadir altimeter instruments, merged into a single variable. The dataset includes measurements from KaRIn swaths on both sides of the image, while the measurements from the Nadir altimeter are located in the central columns. In the areas between the Nadir track and the two KaRIn swaths, as well as on the outer edges of each swath (restricted to cross-track distances ranging from 10 to 60 km), default values are expected.

Use: SWOT_L3_LR_SSH is a cross-calibrated product from multiple missions that contains only the ocean topography content necessary for thematic research (e.g., oceanography, geodesy) and related applications. This product is designed to be simple and ready-to-use, and can be combined with other altimetry missions. The SWOT_L3_LR_SSH product is a research-orientated extension of the L2_LR_SSH product, distributed by the SWOT project (NASA/JPL and CNES). SWOT_L3_LR_SSH is managed by the SWOT Science Team project DESMOS.

Description: The SWOT_L3_LR_SSH product is organized in 3 subproducts:

- Basic L3_LR_SSH (or lightweight), which includes only SSHA (Sea Surface Height Anomaly) and mean dynamic topography.
- Expert L3_LR_SSH (or extended), which includes the backscatter coefficient (sigma0), the mean sea surface (MSS) and geostrophic currents (absolute and anomalies) in addition to SSHA and mean dynamic topography (MDT). It also integrates a quality flag, corrections and external models as separate layers.
- Unsmoothed L3_LR_SSH: which includes the MSS, MDT and geostrophic currents (absolute and anomalies) in addition to the SSHA and MDT on the 250 m KaRIn native grid. Like the Expert subproduct, it also integrates a quality flag, corrections and external models as separate layers.

Geographic coverage: global.

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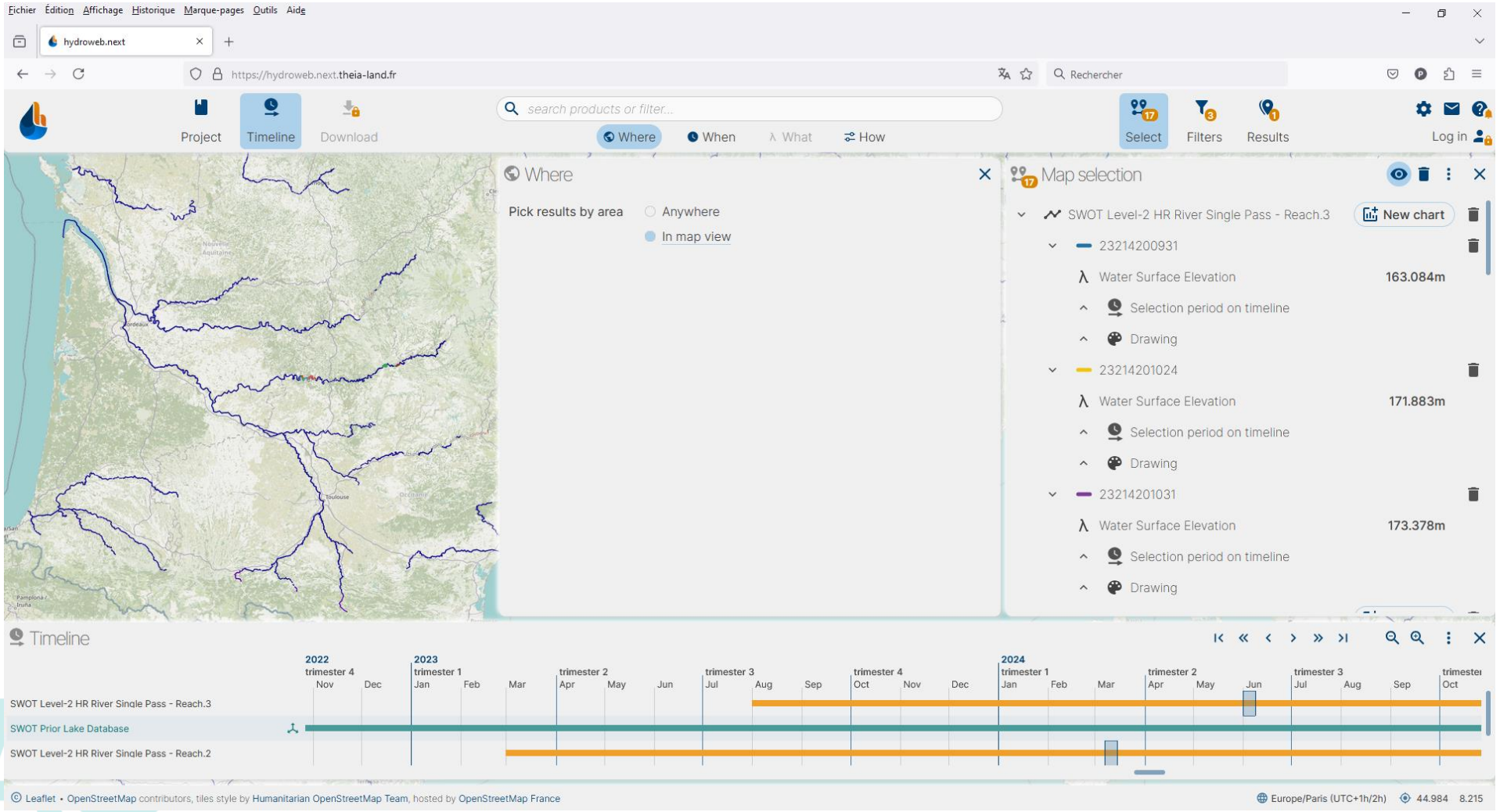
Accès aux données

Hydroweb Next (Rivières : Sword & Lacs : PLD = Prior Lake Database)

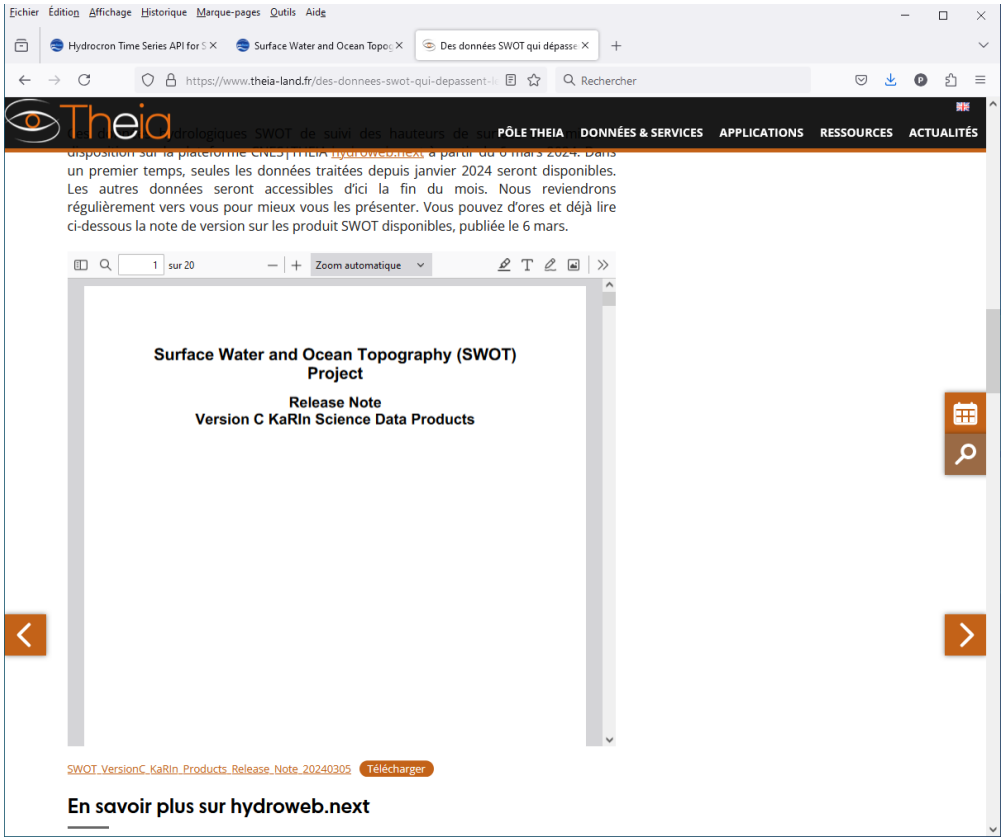
https://hydroweb.next.theia-land.fr/



Accès aux données

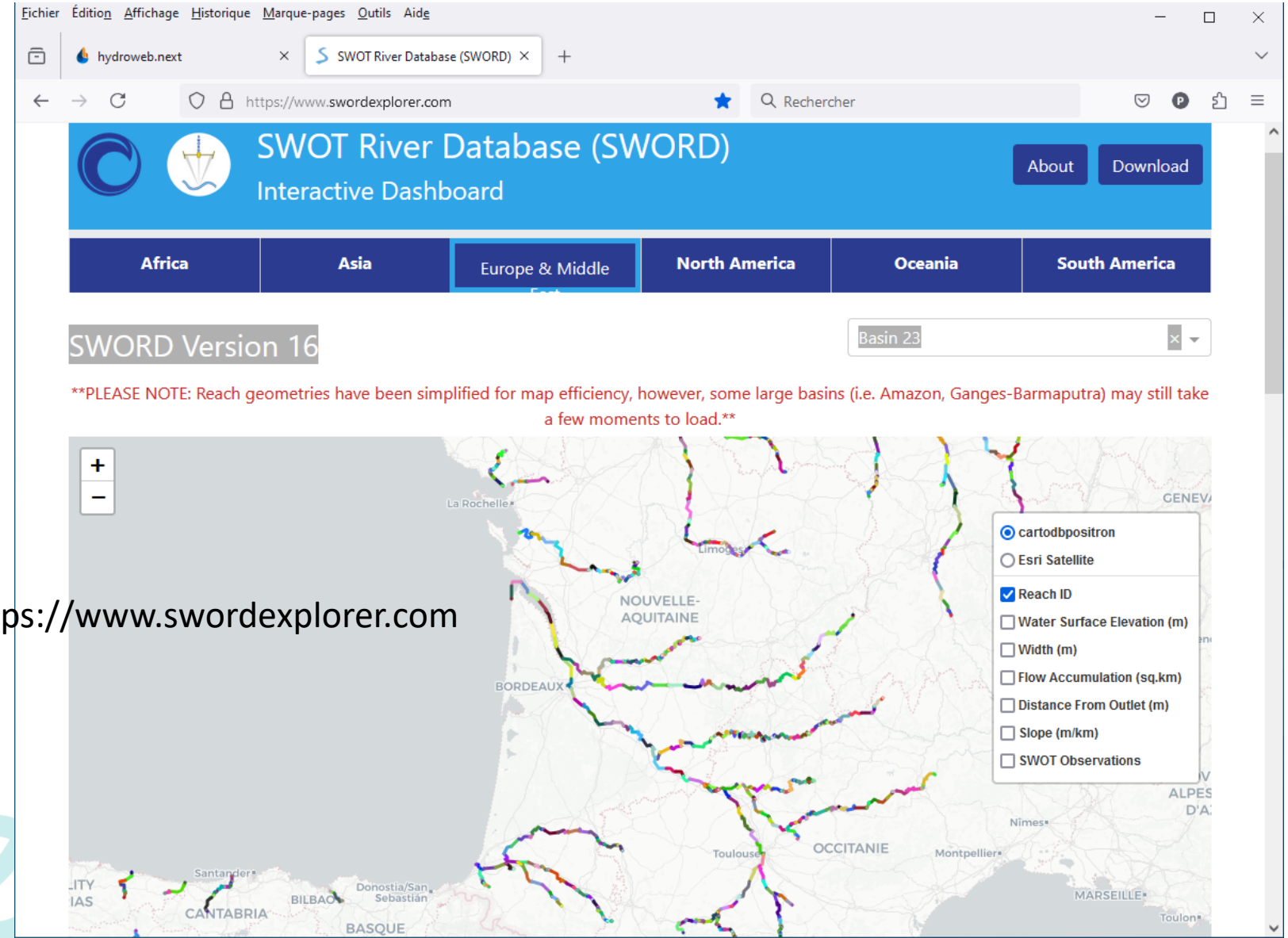
Document de référence sur les données (6 Mars 2024, version C)

- https://www.theia-land.fr/wp-content/uploads/2024/03/SWOT_VersionC_KaRIn_Products_Release_Note_20240305.pdf



Accès aux données

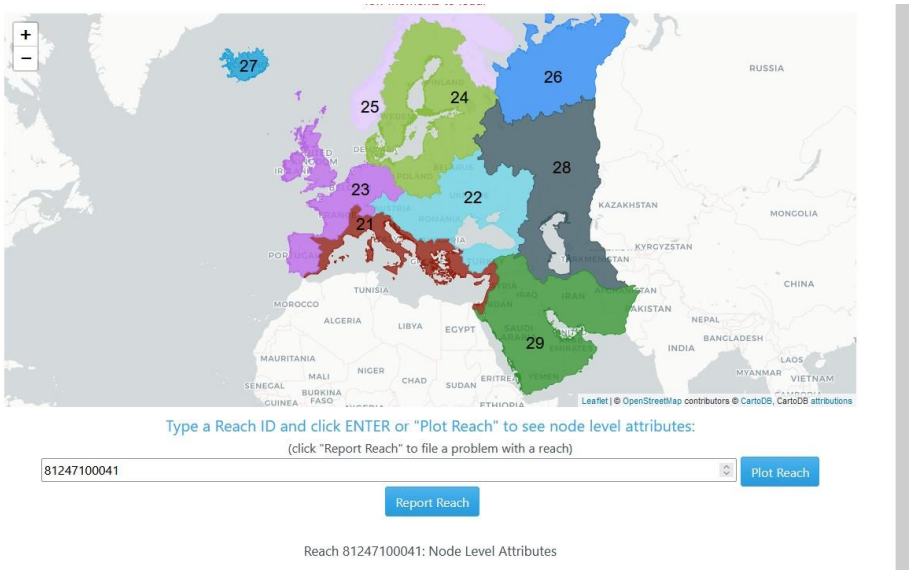
Base statique SWORD (Rivers). V16, bientôt v17 (Novembre 2024 ?)

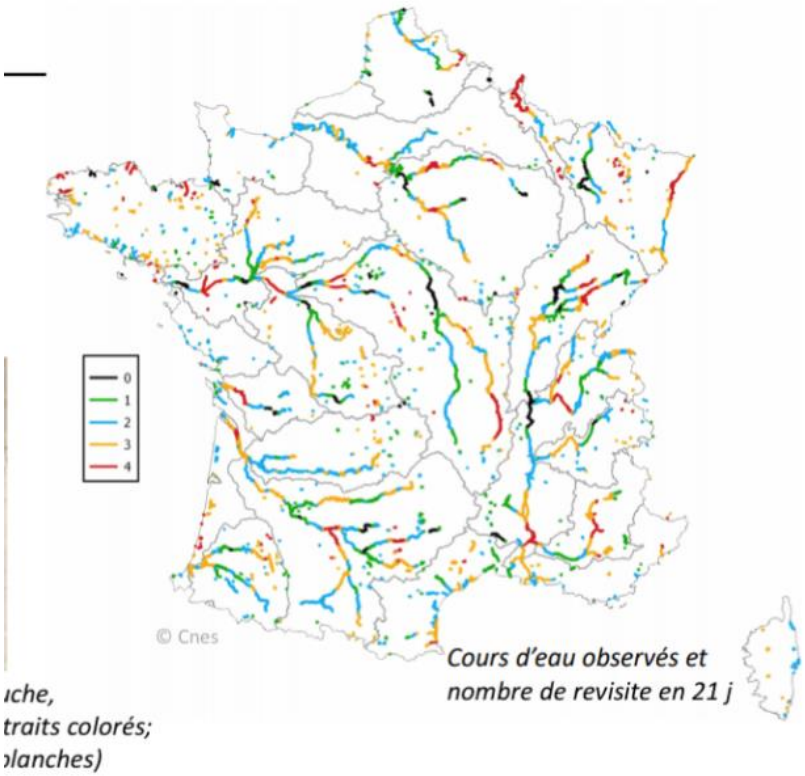


https://www.swordexplorer.com

Fleuves couverts en France

https://www.swordexplorer.com/





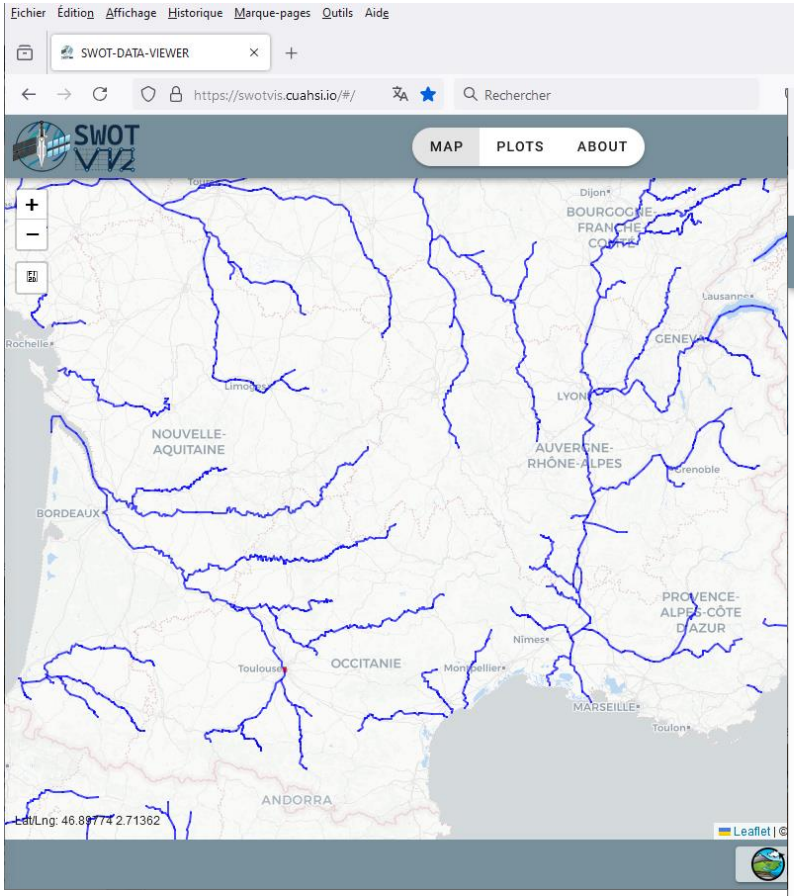
SWORD database

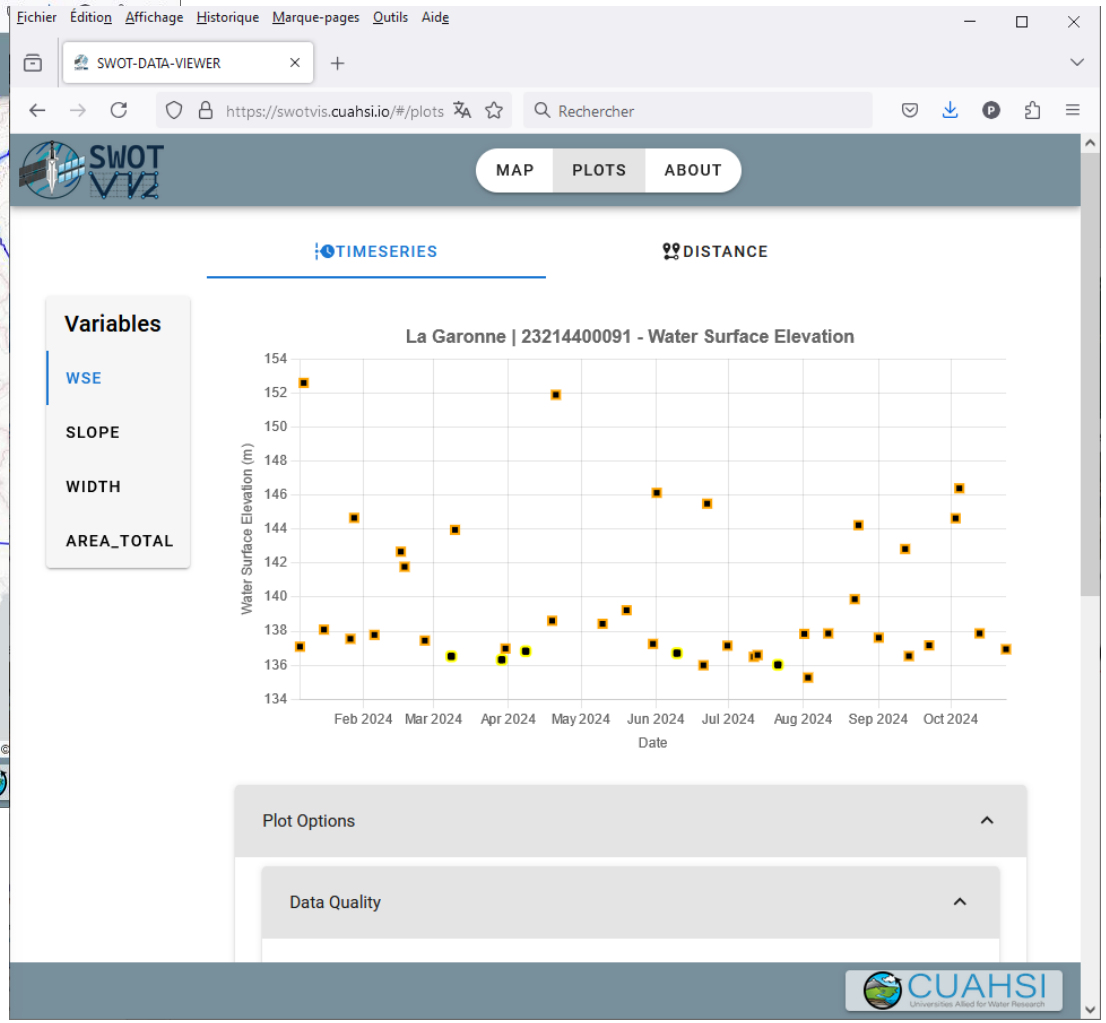
Datasets

Dataset	Attribute Contribution
Global River Widths from Landsat (GRWL) (*Allen and Pavelsky, 2018*)	Provides river centerline locations at 30 m resolution and associated width, water body type, and number of channels attributes.
MERIT Hydro (*Yamazaki et al., 2019*)	Provides river surface elevation and flow accumulation at 3 arc-second resolution.
HydroBASINS (*Lehner and Grill, 2013*)	Provides Pfafstetter basin codes.
Global Reservoir and Dam Database (GRanD) (*Lehner et al., 2011*)	Provides global locations for large dams.
Global River Obstruction Database (GROD) (*under development, UNC*)	Provides global locations of all river obstructions along the GRWL river network.
Global Delta Maps (*Tessler et al., 2015*)	Provides the spatial extent of 48 of the world's largest deltas.

Accès aux données

SWOT DATA VIEWER: https://swotvis.cuahsi.io





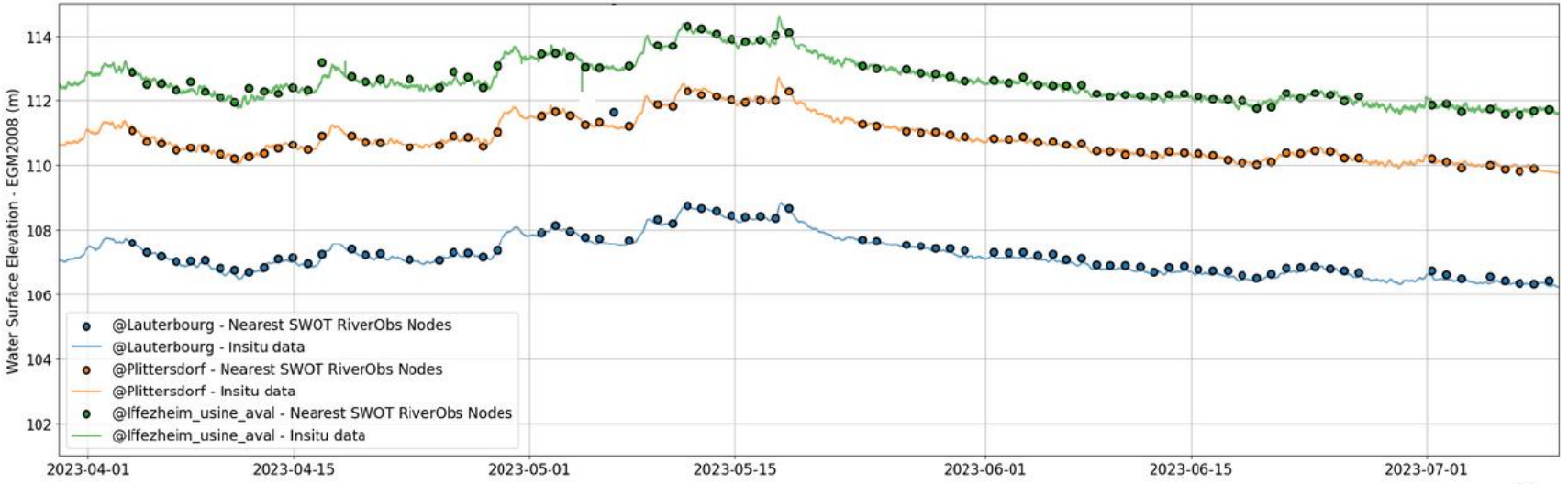
Applications

Sur le Rhin (Ledauphin, Yésou et al)

At station scale : comparison insitu data vs nearest node

Example of the stations located on the reach between Iffezheim and Lauterbourg (last reach)

Station	WSE Error Sigma0 (m)
Iffezheim usine aval	0.09
Plittersdorf	0.09
Lauterbourg	0.11

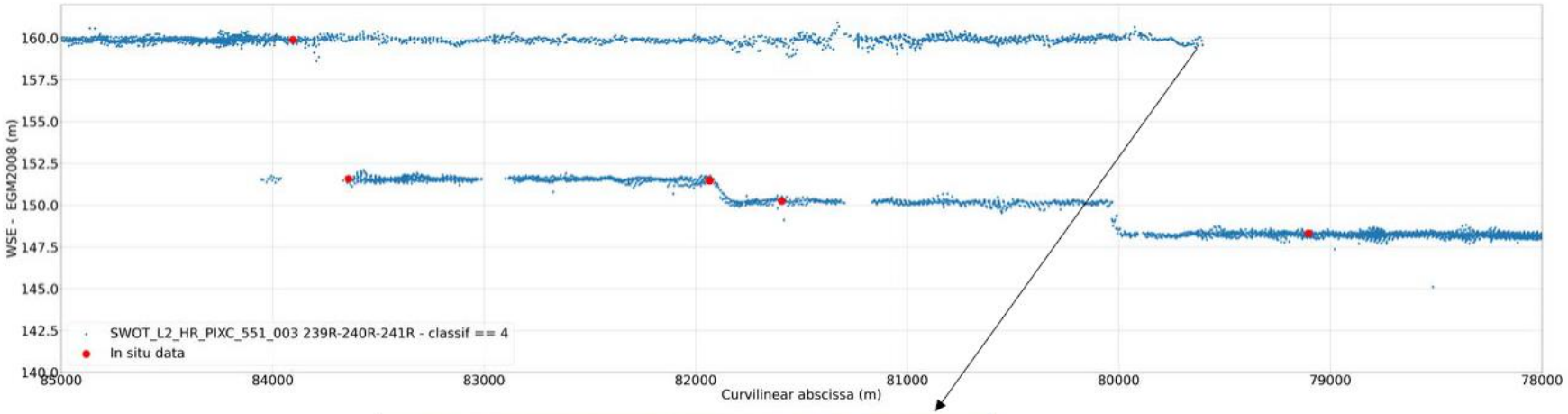


Applications

Sur le Rhin (Ledauphin, Yésou et al)

Utilisation du Pixel cloud pour contourner des problèmes de Sword v14

Gerstheim Dam (GCA)



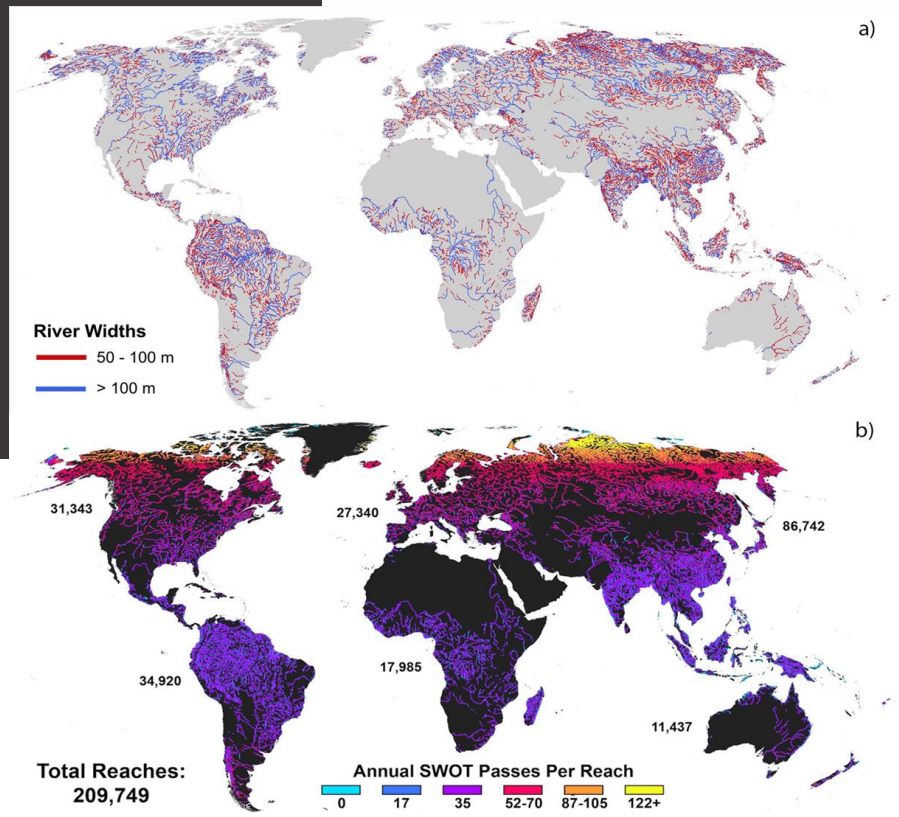
- ~12 meter dam
- In line with EDF dam's description

Calcul des débits ?

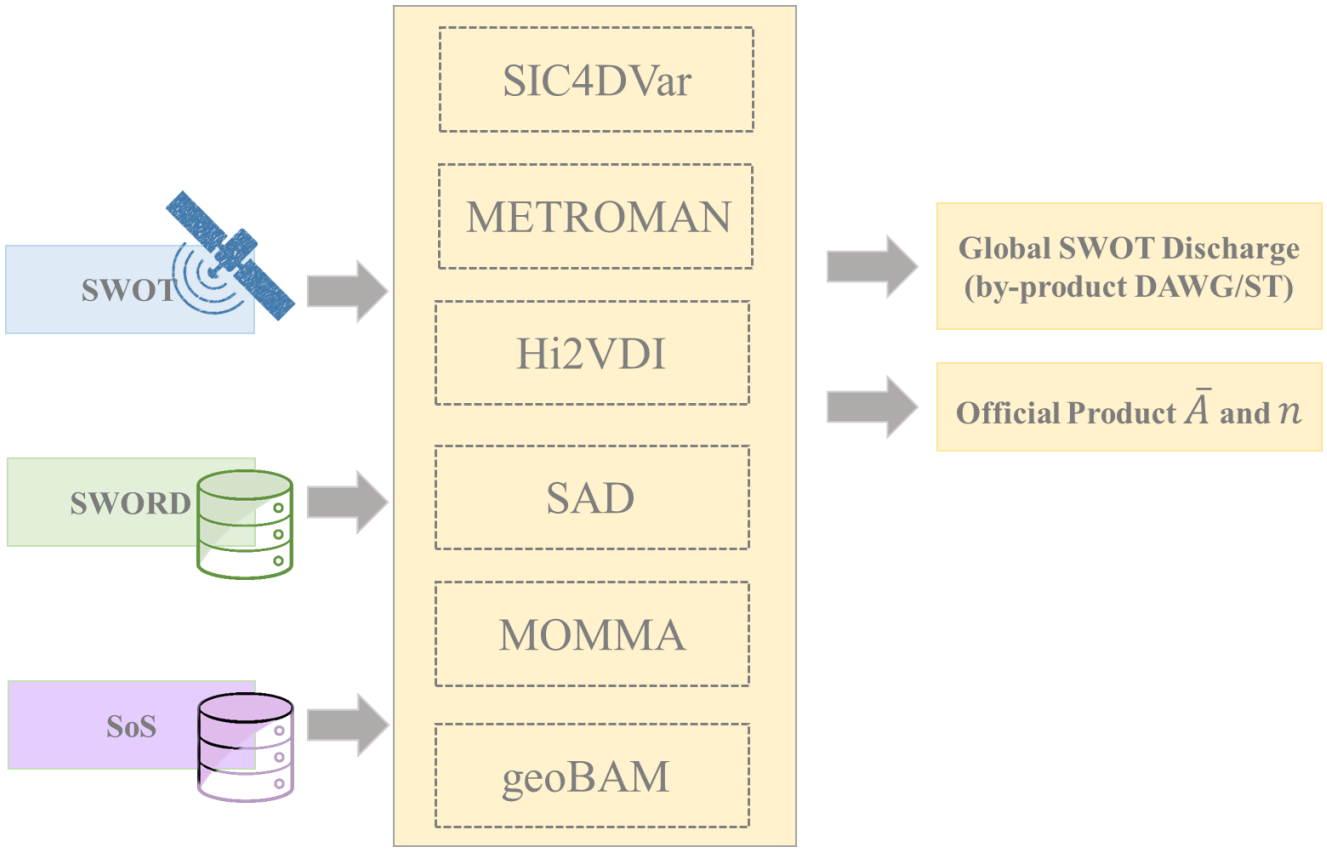
"Official" Discharge Product :

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

SWOT Discharge Algorithms



Calculs des Débits des Fleuves

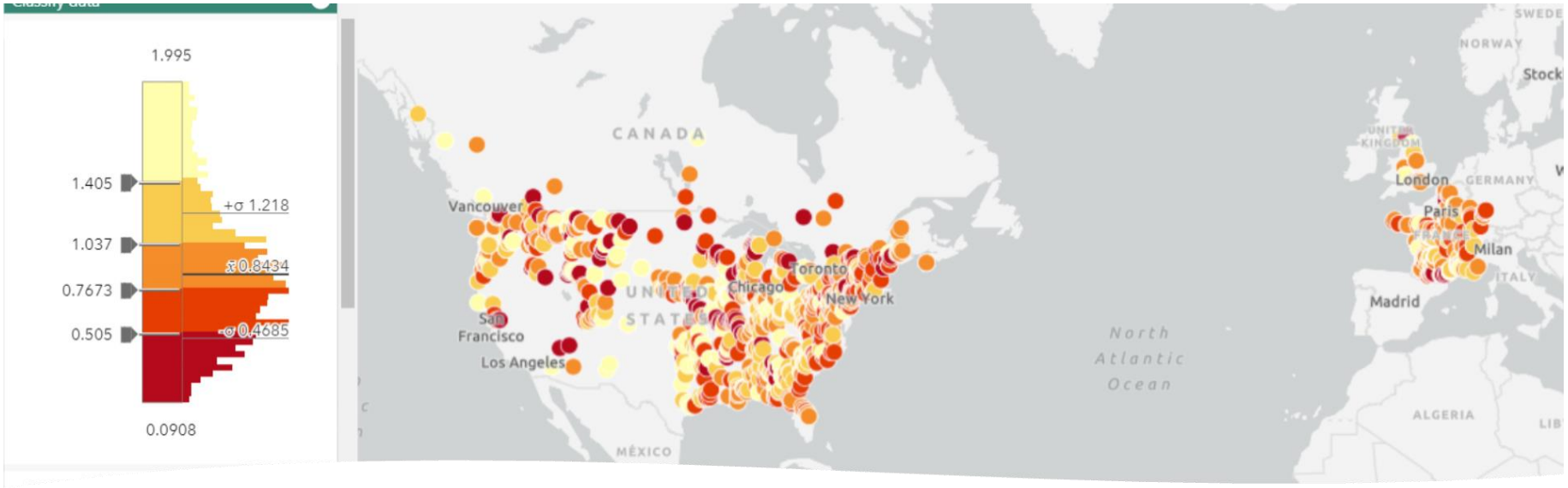


DAWG (Discharge Algorithm Working Group)

SWOT Discharge
ALGORITHMS

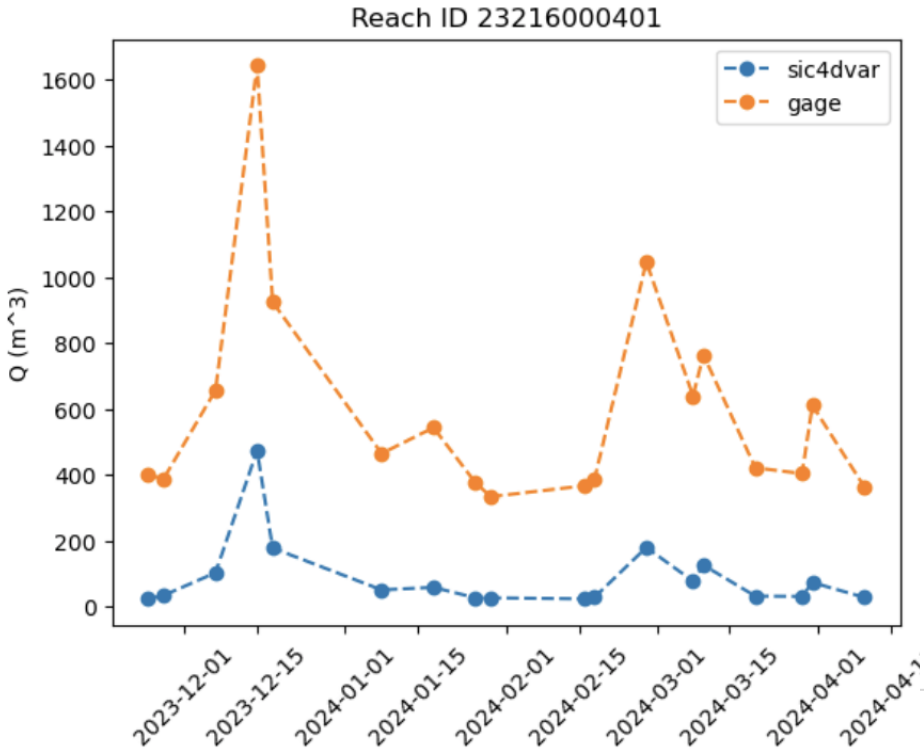
Algorithm	Theoretical basis	SWOT data	Method
geoBAM	Hydraulic geometry + Manning's eq.	Water surface width (W), slope (S), cross-sectional area anomaly (dA)	Bayes
MetroMan	Manning's eq. w/o Q	Water surface height (H), W, S, dA	Bayes
Hi2VDI	1D Saint-Venant + Manning's eq.	H, W, S, δA	Assimilation Machine 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

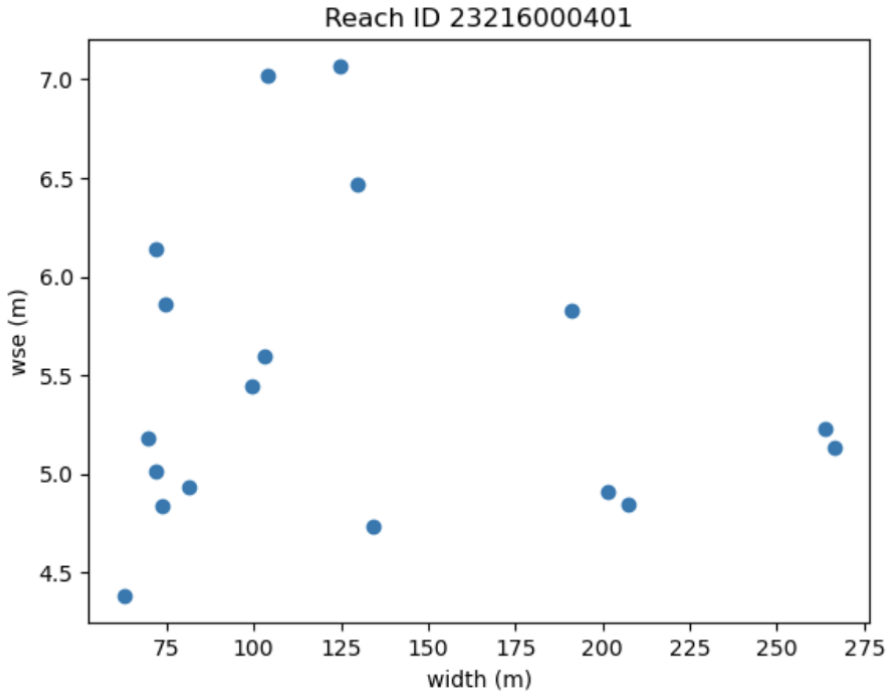
Premières comparaisons des Q(t)



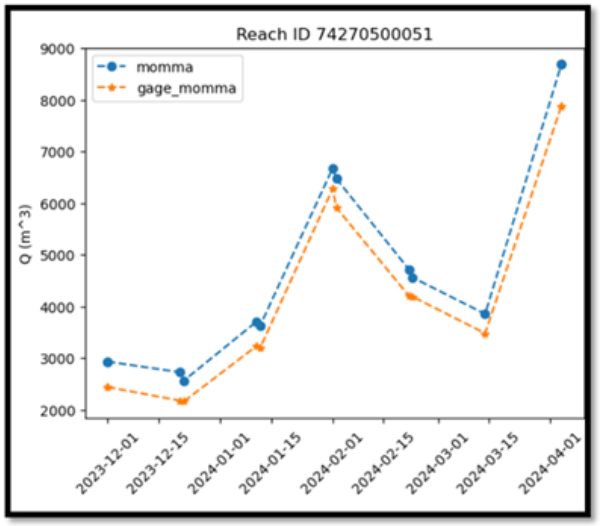
La chaine opérationnelle (Confluence) fonctionne
La base SoS est disponible (NASA & CNES)
Comparaisons par rapport à des centaines de stations in-situ
Variabilité des Q(t) à comprendre et améliorer
Problème important dû aux largeurs pas toujours très fiables
Gros travail en cours et à venir …

Illustration de difficultés pour Q(t)

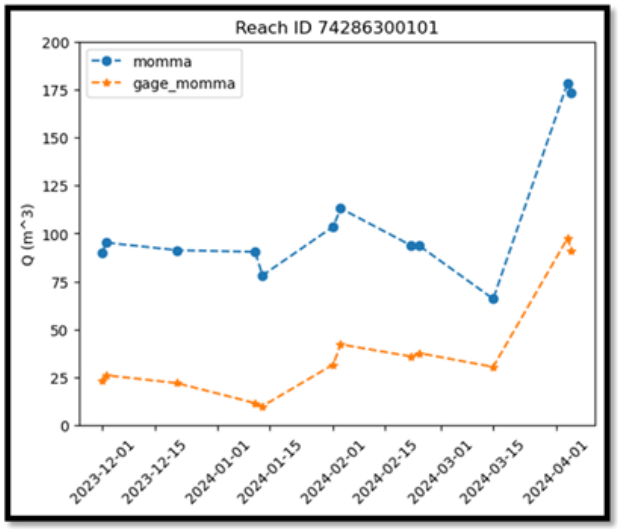




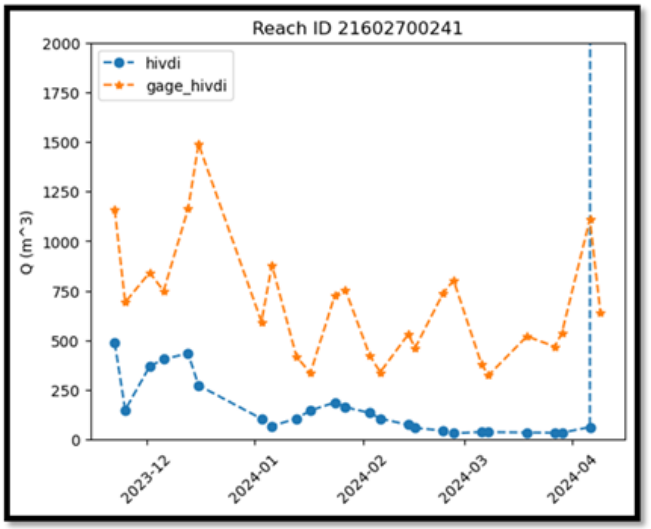
Q(t) : Good, Bad & Ugly



Good

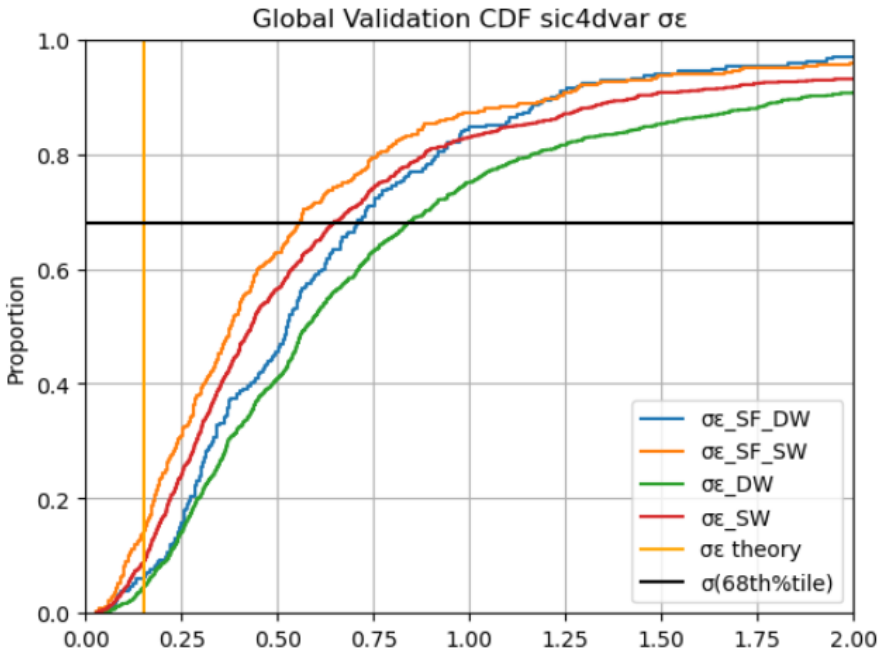


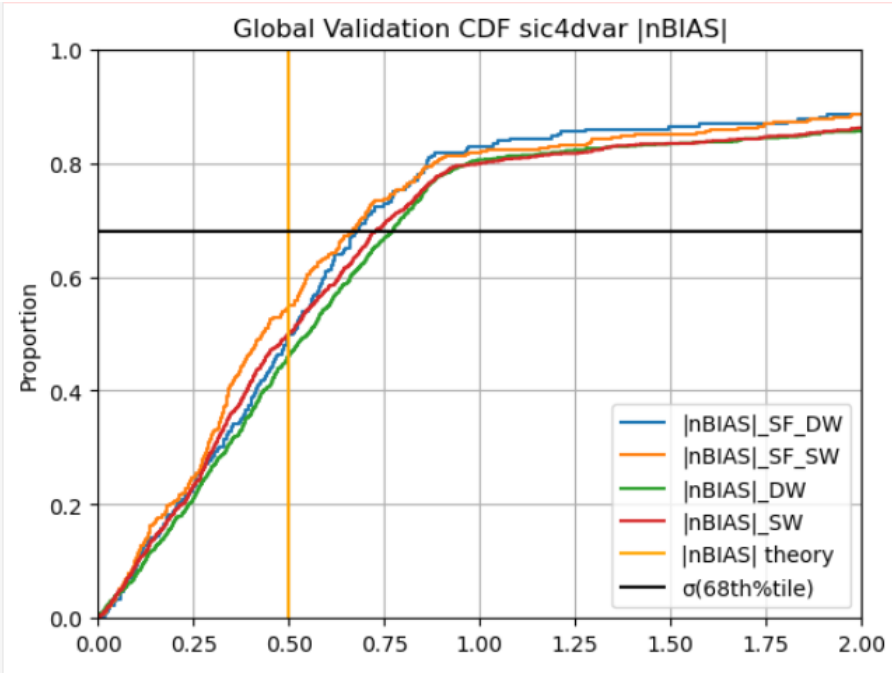
Bad (bias)



Ugly (bias & dynamics)

Illustration de difficultés pour Q(t)






```
SF_DW n= 151
SF_SW n= 437
DW n= 644
SW n= 960
```

Perspectives et Suites

30 ans de travail en perspective …

- Q(t) sur 10% des biefs en Novembre 2024 sur Sword v16. Produit global en 2025 sur Sword v17
- Séminaire DAWG à Montpellier les 11-14 Février 2025
- Produit débit opérationnel en 2025 (Confluence USA avec 6 algorithmes + le consensus + calculs sur AWS & CNES)
- Centre d'Expertise Hydrologie Multi-Mission (CNES), sur sites spécifiques (Maroni, Garonne, Ohio), puis France, puis …
- Durée de vie initiale prévue de 3 ans (2026 ?), ou plus si tvb … (et réentrée contrôlée)

Perspectives et Suites

Futures missions sur les rails …

- Sentinel 3 NG-TOPO : 2 altimètres à large fauchée et lancé après 2030, prolongera les avancées initiées par SWOT (ESA Copernicus)
- Smash : 10 petits satellites embarquant un altimètre (bande Ka) optimisé pour le suivi des eaux continentales. Avec des acquisitions journalières : Priorité P0 (ou «majeure») (info du 10 Oct 2024). Financement avec partenaire privé (BWI – Hemeria Group ?), BPI France 2030 ?
- SWOT-LAND OCEANIC AQUATIC CONTINUUM (LOAC) ?

Perspectives et Suites

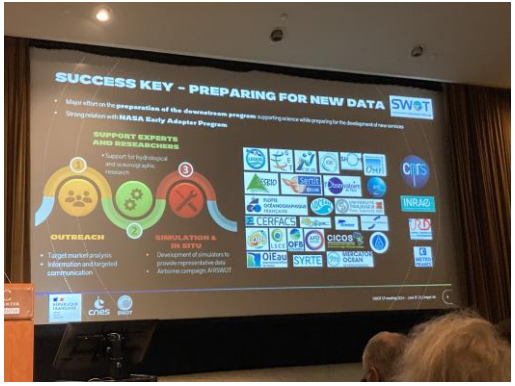
Science participative …

- LOCSS Area App on Google Play
- Lake Observations by Citizen Scientists and Satellites (LOCSS)
- Contribuer à aider à comprendre la capacité de SWOT à distinguer l'eau de la terre
- pour collecter des données sur les emplacements des limites eau/terre et les envoyer et les comparer à SWOT
- Android app

Conclusions

- Première mission satellitaire dédiée majoritairement à l'hydrologie continentale
- Grand succès, supérieur aux attentes en altimétrie, en détection des objets divers (océans, icebergs, côtier, lacs, rivières, zones humides, glace, dune, vents de surface, vitesse et direction, etc)
- Y compris avec neige ou glace. Y compris sous végétation (angle d'incidence 0.6-3.9°)
- Difficultés à résoudre sur les masques en eau (largeur des rivières, surfaces les lacs) : en cours d'amélioration. Mais très bon pour voir les humidités de surface (cf. Sentinel 1)
- Les traitements HR sont bien plus complexes que LR, et nouveaux … fort potentiel d'amélioration pour SWOT et les missions suivantes (FP DEM, Geoid, X-cal, etc.)

Conclusions



- Travaux sur l'amélioration des traitements des données
- Favoriser la recherche en hydrologie et océanographie
- Favoriser les applications aval
  (gestion des fleuves transfrontaliers, inondations, gestion de l'eau, navigation, épidémies, pèche, biodiversité, etc)
- Intégration en cours dans les chaines opérationnelles (Copernicus Marine Service, etc)
- Intégrations dans des Systèmes d'Informations Hydrologiques
- Evolutions futures de Sword et PLD ? (ex: objets plus petits)

Merci. Questions et Remarques ?

Science Team SWOT, Septembre 2023, Toulouse

Toute la matière de cette présentation vient de cette communauté