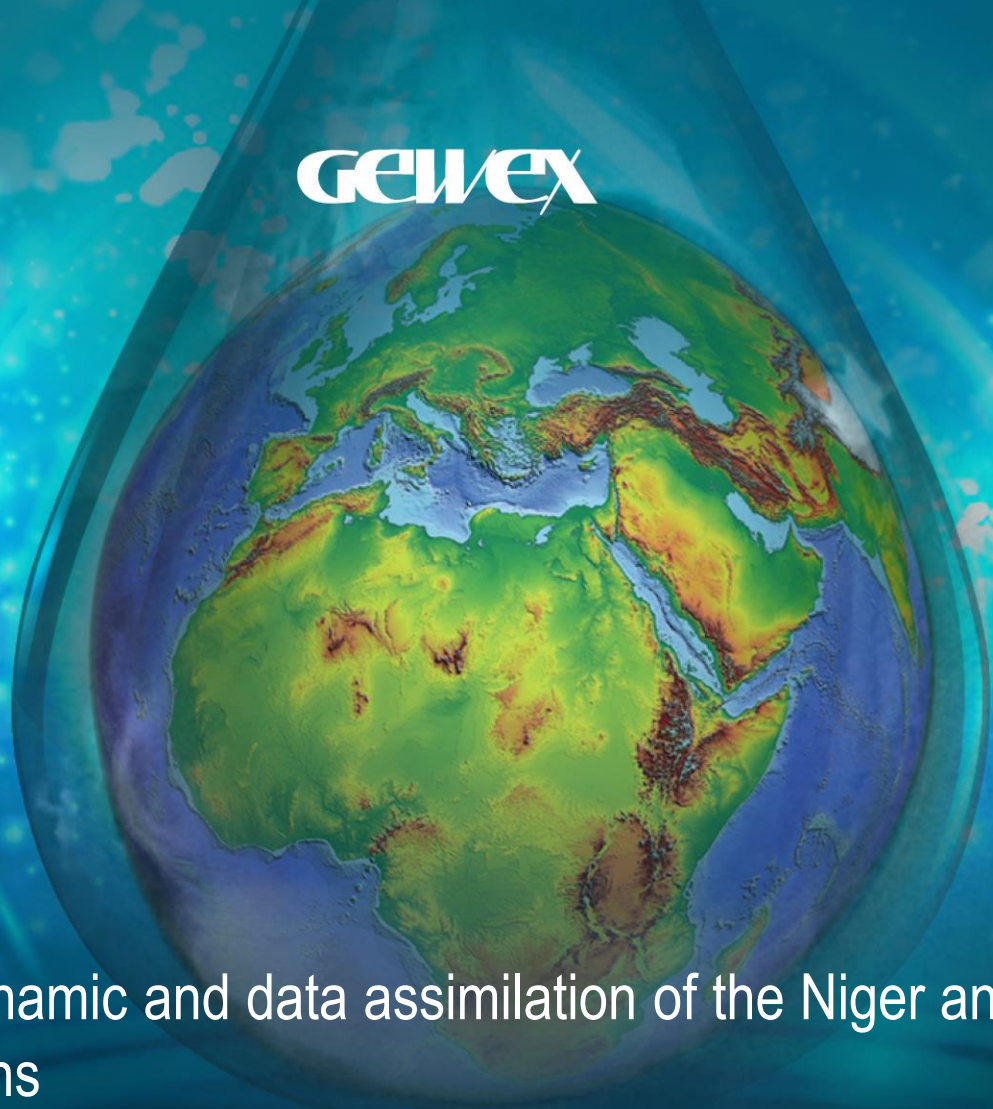
# Coupled hydrological-hydrodynamic and data assimilation of the Niger and Maroni using SWOT river products and other EO missions

K Larnier, C Emery, Pierre-André Garambois, L Gal, A Paris



# Coupled hydrological-hydrodynamic and data assimilation of the Niger and Maroni using SWOT river products and other EO missions

***K. Larnier***[(1)], *C. Emery*[(1)], *P.-A. Garambois*[(2)], *L. Gal*[(3)], *A. Paris*[(3)]

[(1)] *CS GROUP - France, Space Business Unit, France*

[(2)] *INRAE Aix-Marseille, RECOVER Unit, France*

[(3)] *Hydro Matters, France*

Hydrospace 2023, 27 November – 1 December 2023 | FIL Lisbon, Portugal

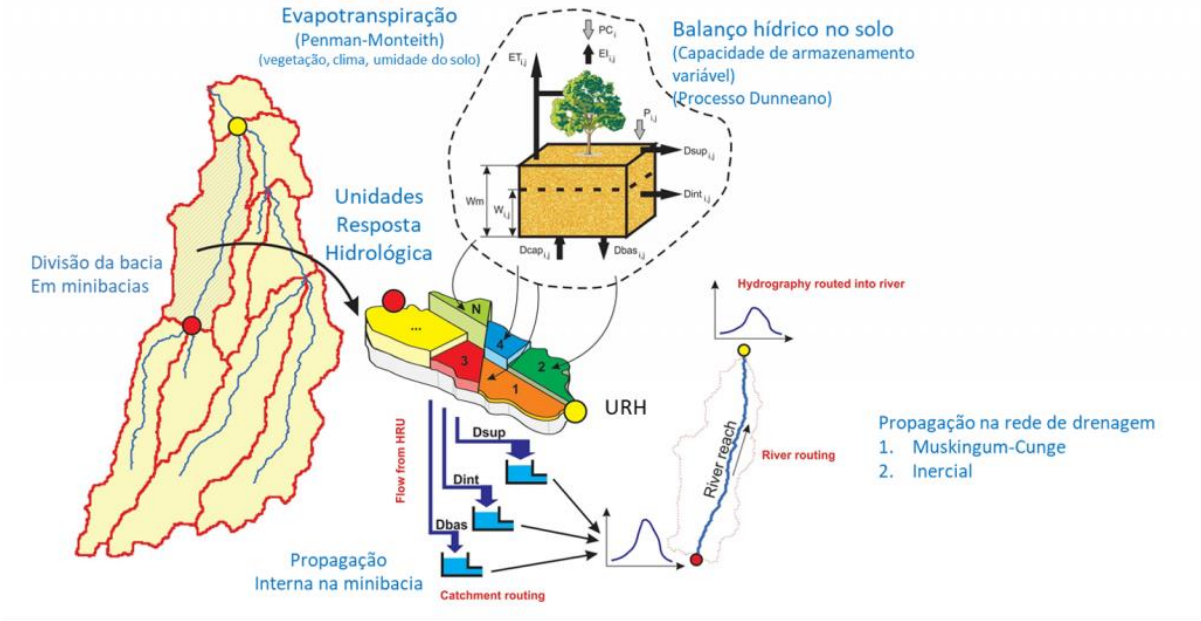
# CONTEXT & OBJECTIVES

- **Context**
  - Steady decrease of in-situ stations over the past 3 decades
  - Real time monitoring using dense in situ data only available in developed countries
  - Strong potential benefits of remote sensing in developing countries such as in Africa
  - Copernicus Sentinels constellation
  - The SWOT mission

- **Objectives**
  - Develop an automatic method to setup coupled hydrology-hydrodynamic models using fusion of EO Open-Data products for basins with sparse in-situ data
  - Analyze the assimilation of conventional altimetry and/or SWOT river L2 products

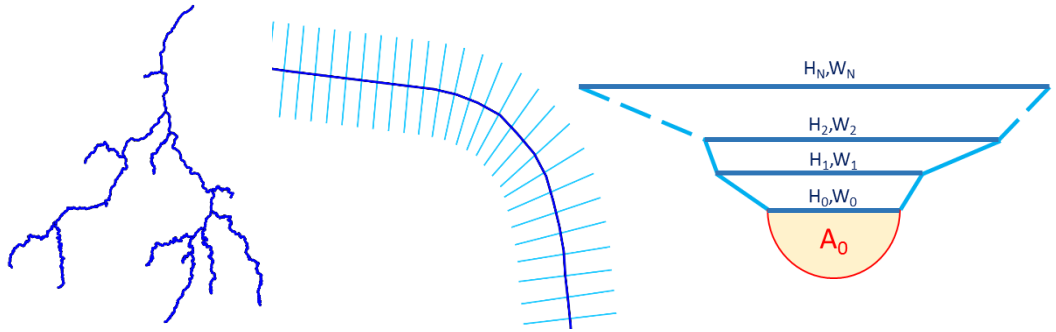
# METHODS

- **What do we need to setup a coupled hydrological-hydrodynamic model ?**



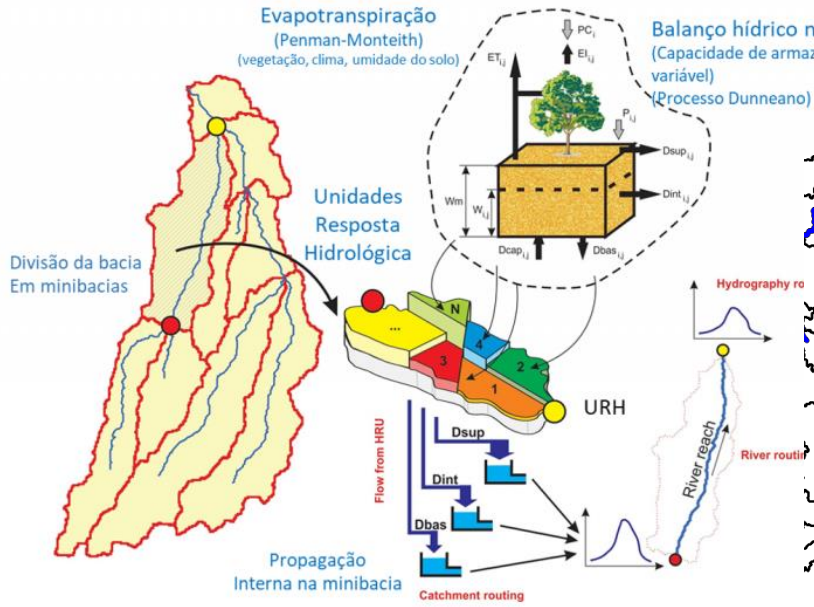

MGB-IPH LSM [Collischonn et al, 2011]

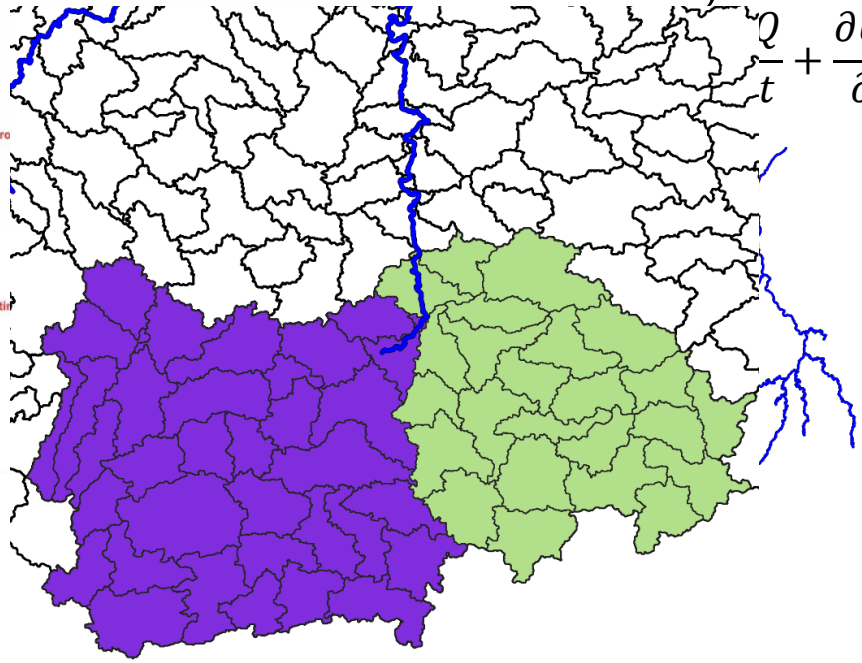
$$\begin{cases} \dfrac{\partial A}{\partial t} + \dfrac{\partial Q}{\partial x} = q_L \\ \dfrac{\partial Q}{\partial t} + \dfrac{\partial UA}{\partial x} + g\left(\dfrac{\partial Z}{\partial x} - Sf\right) = v_L q_L \end{cases}$$




DassFlow-1D [Larnier et al, 2020]
Part of the DassHydro project

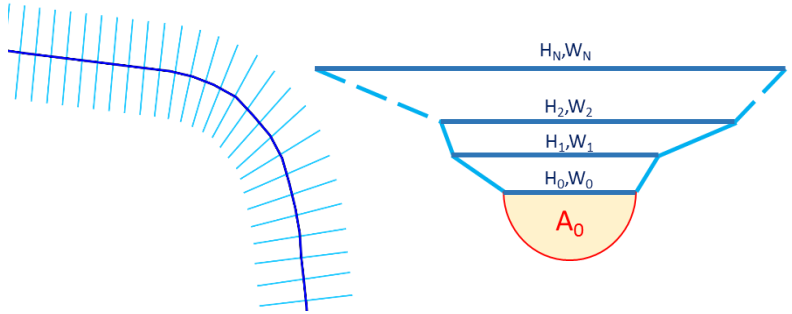
- **What do we need to setup a coupled hydrological-hydrodynamic model ?**



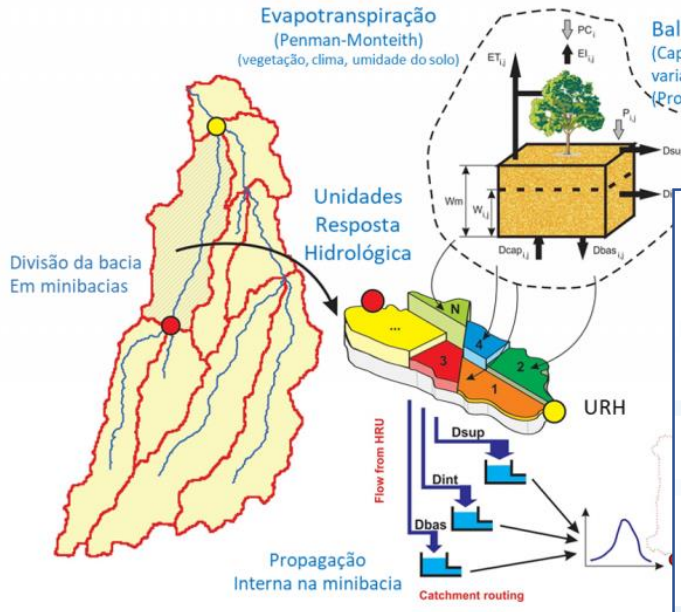
$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_L$$

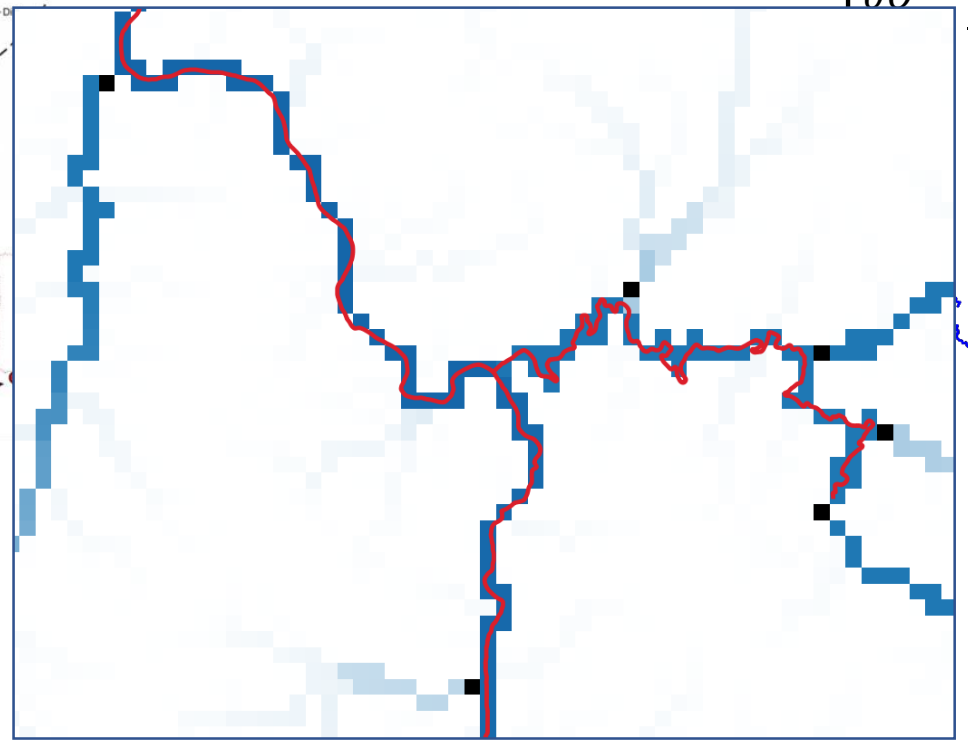
$$\frac{\partial Q}{\partial t} + \frac{\partial UA}{\partial x} + g\left(\frac{\partial Z}{\partial x} - Sf\right) = v_L q_L$$



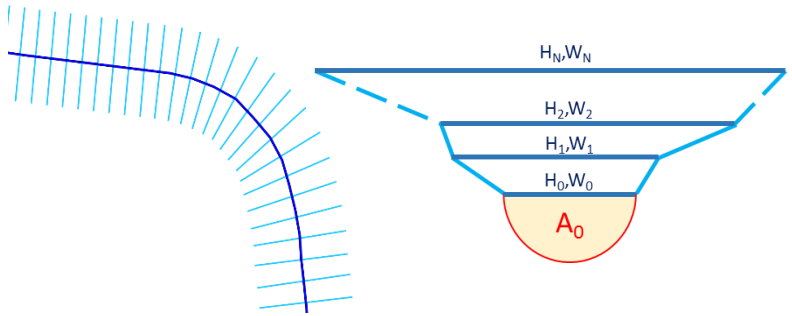
# METHODS

- **What do we need to setup a coupled hydrological-hydrodynamic model ?**



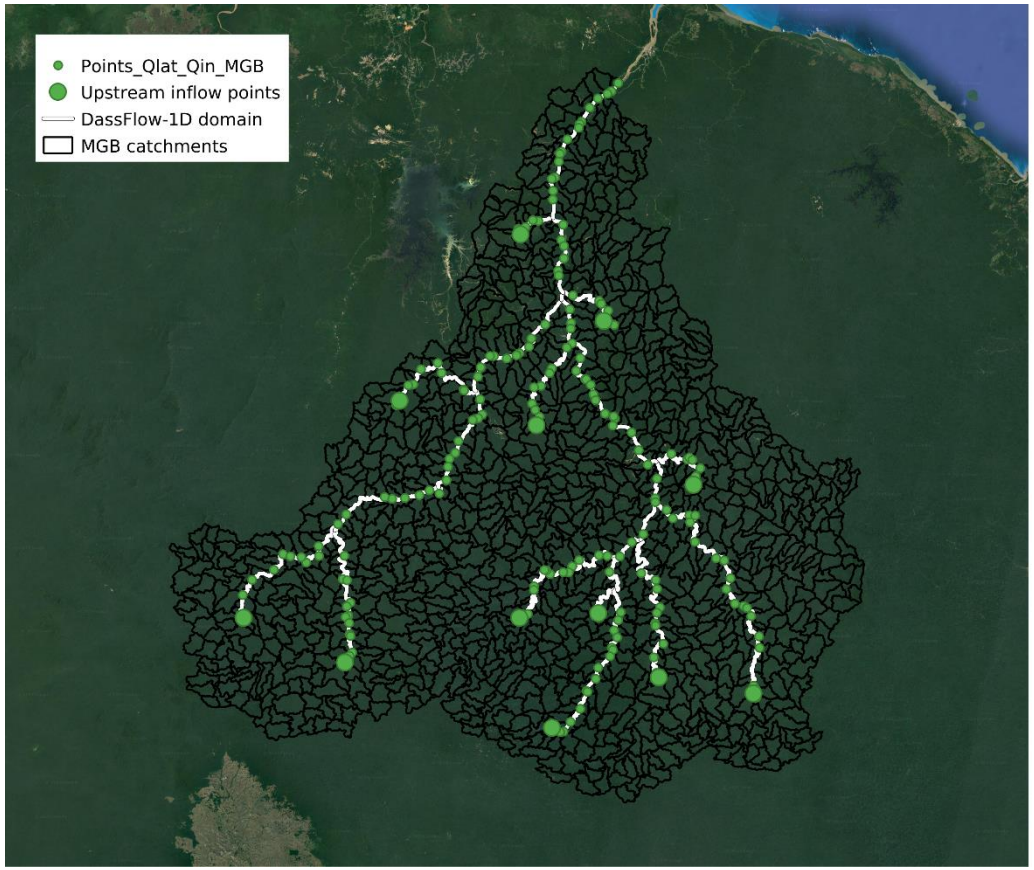
$$\begin{cases} \dfrac{\partial A}{\partial t} + \dfrac{\partial Q}{\partial x} = q_L \\ \dfrac{\partial Q}{\partial t} + \dfrac{\partial UA}{\partial x} + g\left(\dfrac{\partial Z}{\partial x} - Sf\right) = v_L q_L \end{cases}$$




Also available for distributed models (see poster #37)

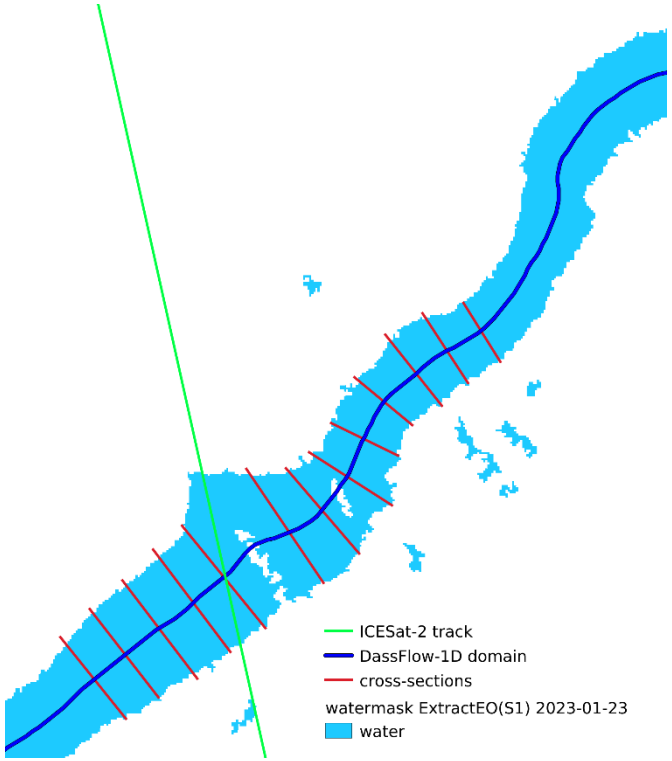
# METHODS

- **Automatic setup of the connectivity table for coupling**



# METHODS

- **Estimation of the effective cross-sections**




**Preprocessing ICESat-2**

Pekel occurrence raster → Extraction polygon

1. Polygonize (occurence > 50%)
2. Expert manual correction: smoothing, filling, cleaning
3. Merging

**Processing ICESat-2**

ATL13 → Timeseries virtual stations (VS): Z(xs,t)

1. Filtering with occurrence watermask from preprocessing
2. Projection onto centerline
3. Associate to closest VS
4. Outlier detection
5. Time-aggregation
6. Space-aggregation

**Processing EO watermasks**

EO watermask (WM) → Timeseries virtual stations (VS): W(xs,t)

1. Draw cross-sections at VS with Z data
2. Draw buffer around sections
3. Extract water pixels from WM within buffer
4. Get water area within buffer
5. Estimate W as ratio between water area and buffer thickness

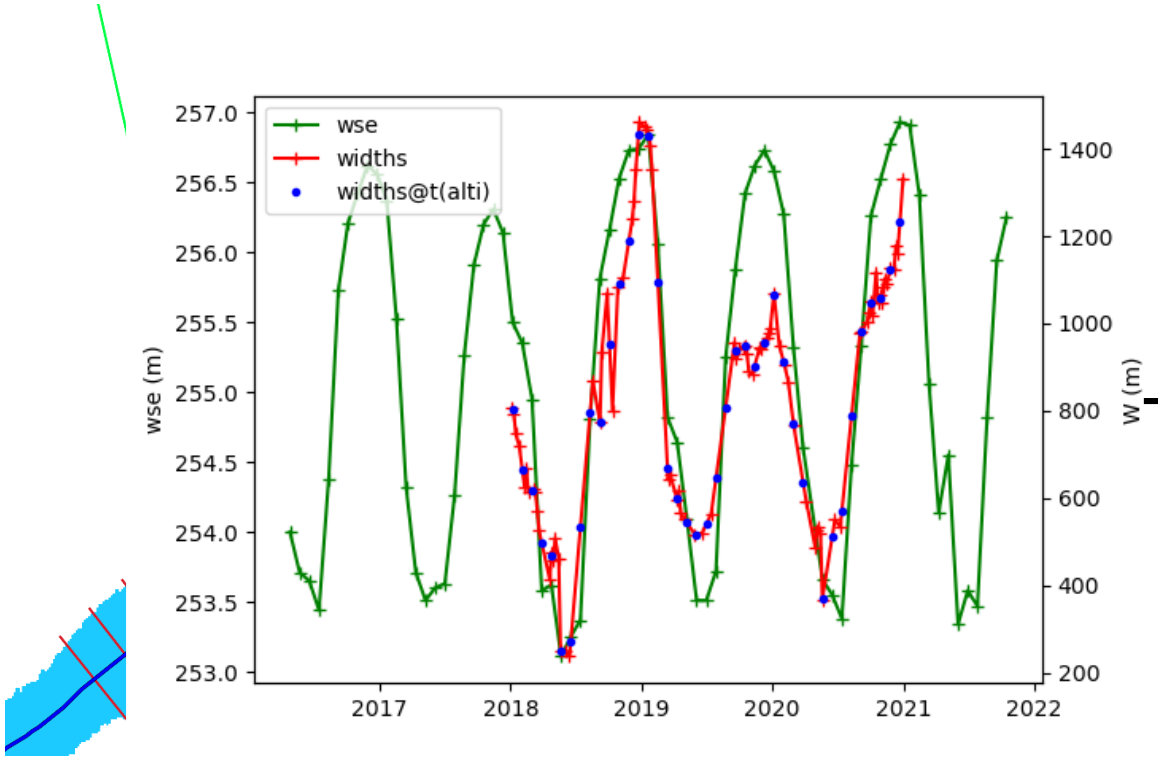
**1D model setup**

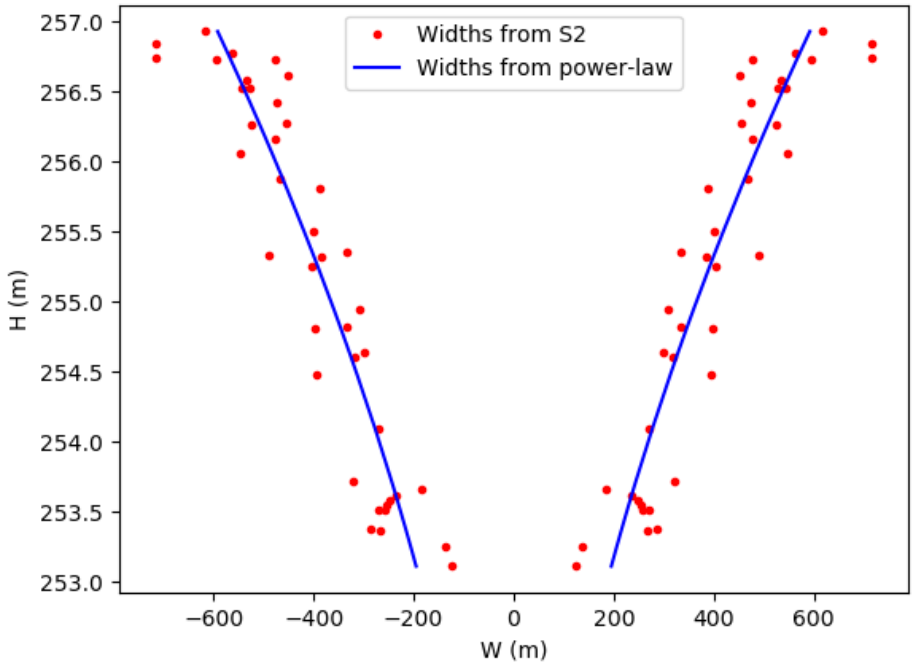
Z(xs,t) + W(xs,t) → 1D geometry + First guess (K,b)

1. Interpolate W(xs, *) and Z(xs,t) timeline,
2. Fit power law between Z(xs,*) and W(xs,*)
3. Set prior b(xs)
4. Set prior K(xs)

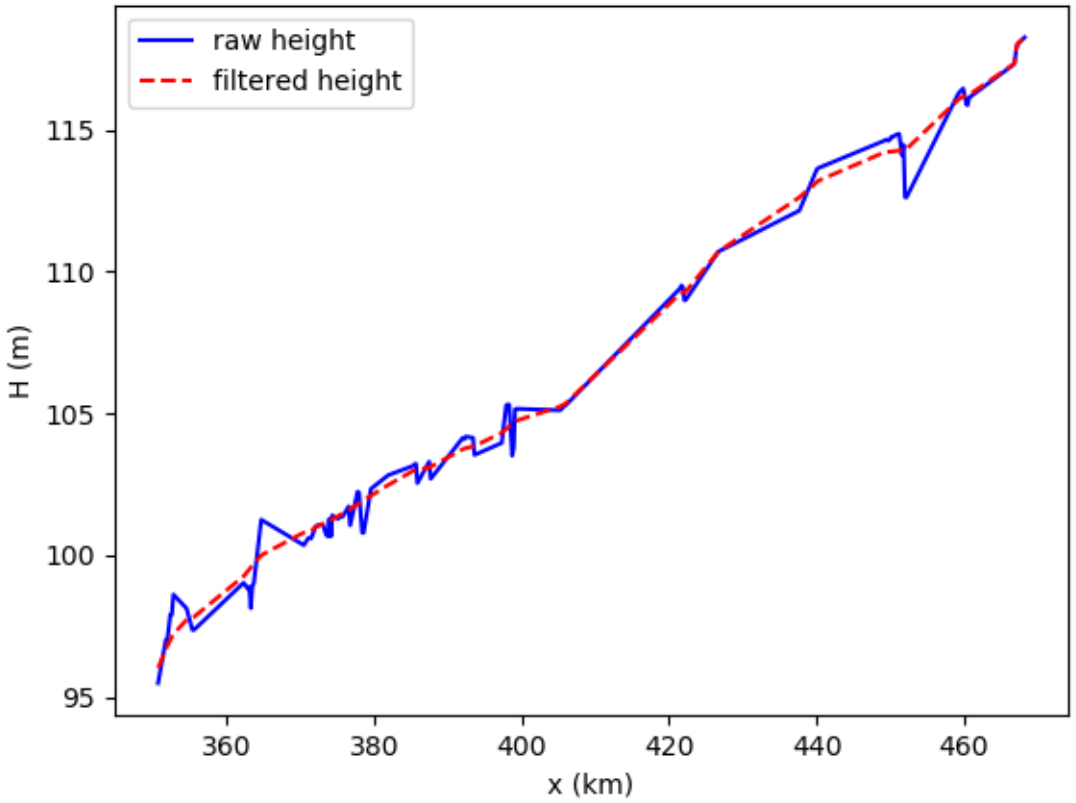
# METHODS

- **Estimation of the effective cross-sections**



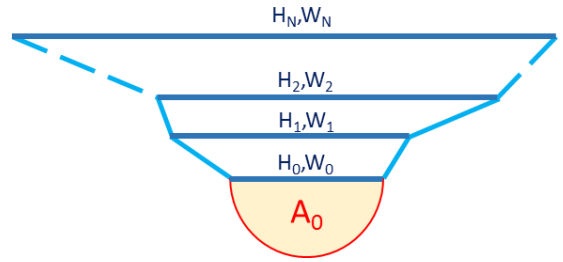



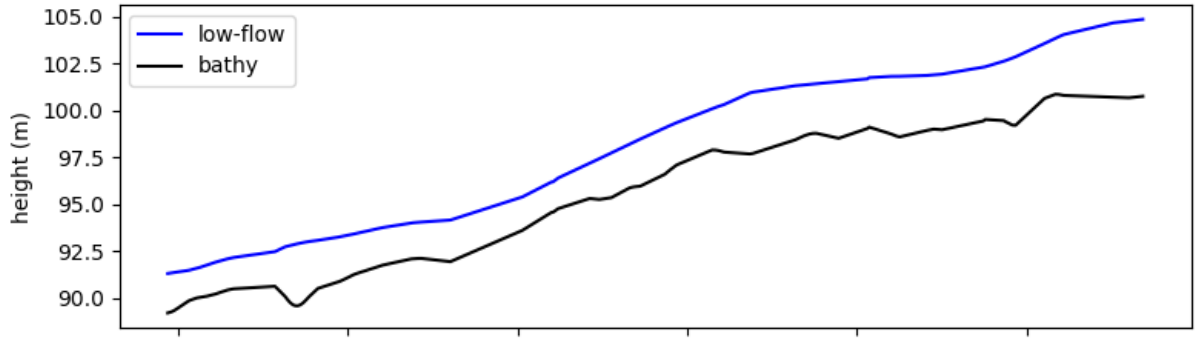
- **Estimation of the riverbed elevation**




« Hydraulic » filtering
(see poster #61)

$$Q = K(A_0 + \Delta A)^{5/3} W^{-2/3} S^{1/2}$$



# METHODS

- **Data assimilation framework**
  - 4D-VAR, embedded in DassFlow-1D software.
  - The inverse problem to solve is:

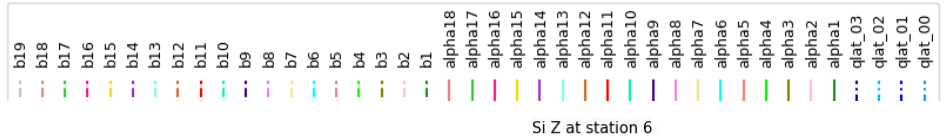
$$\min\big(j(c)\big) \text{ with } j(c) = \|Z(c) - Z_{obs}\|_R$$

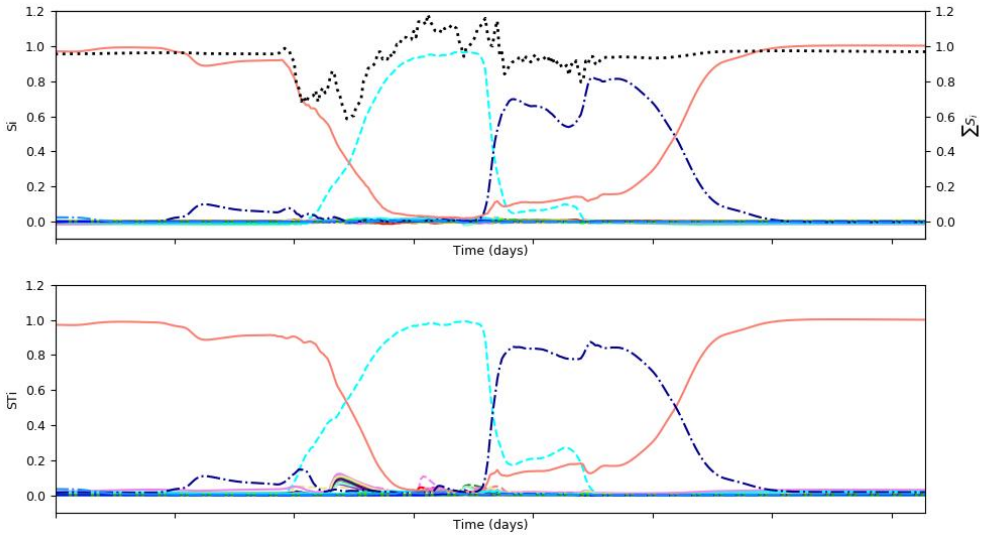
$$c = (Q_{in}(t), \{Q_{trib}^k(t)\}_k, b(x), \alpha(x), \beta(x))$$

  - Preconditioning using change of variable and covariance matrix

$$k = B^{1/2}\big(c - c^{(0)}\big) \text{ with } B = diag(\{B_X\}_X),\ B_X = \sigma_X^2 \exp\left(-\frac{|x_i - x_j|}{L_X}\right)$$

  - Sensitivity analysis (ANOVA) to get:
    - estimation of correlations length ($L\_X$)
    - Multi-steps optimization



# EXPERIMENTS

| Case | Setup dataset | Assimilation dataset |
|---|---|---|
| Maroni | ICESat-2 x ExtractEO (S1) | ICESat-2 + S3 |
| Maroni | ICESat-2 x ExtractEO (S1) | ICESat-2 + S3 + in-situ (2/5) |
| Maroni | ICESat-2 x ExtractEO (S1) | SWOT (nodes) |
| Maroni | SWOT (nodes) | SWOT (nodes) |
| Middle Niger | S3 + J2 x NDWI (S2) | S3 + J2 |
| Middle Niger | ICESat-2 x NDWI (S2) | ICESat-2 + S3 + J2 |
| Middle Niger | ICESat-2 x NDWI (S2) | SWOT (nodes) |
| Middle Niger | SWOT (nodes) | SWOT (nodes) |

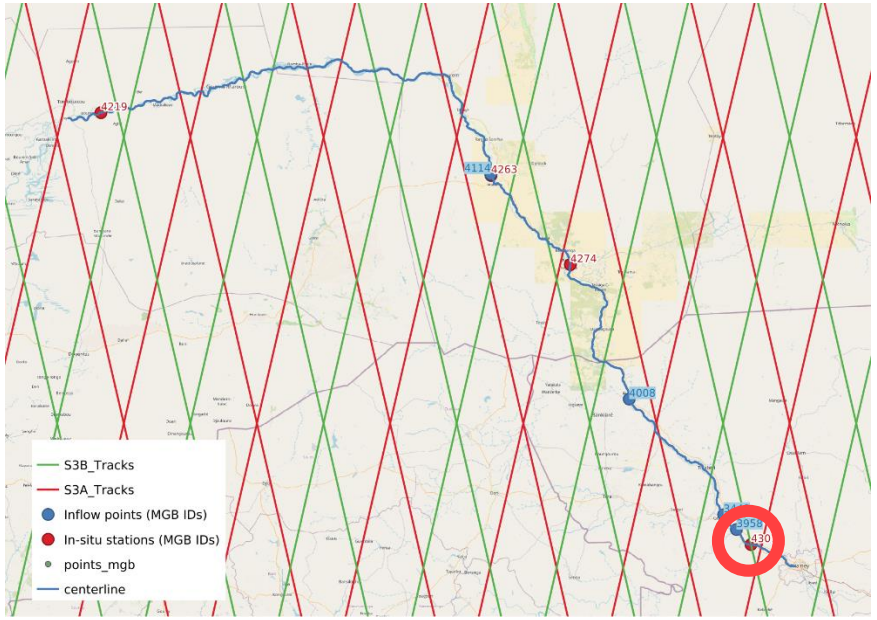
# EXPERIMENTS

| Case | Setup dataset | Assimilation dataset |
|---|---|---|
| Maroni | ICESat-2 x ExtractEO (S1) | ICESat-2 + S3 |
| Maroni | ICESat-2 x ExtractEO (S1) | ICESat-2 + S3 + in-situ (2/5) |
| Maroni | ICESat-2 x ExtractEO (S1) | SWOT (nodes, 1day orbit) |
| Maroni | SWOT (nodes, 1day orbit) | SWOT (nodes, 1day orbit) |
| Middle Niger | (S3 + J2) x NDWI (S2) | S3 + J2 |
| Middle Niger | ICESat-2 x NDWI (S2) | ICESat-2 + S3 + J2 |
| Middle Niger | ICESat-2 x NDWI (S2) | SWOT (nodes, 1day orbit) |
| Middle Niger | SWOT (nodes, 1day orbit) | SWOT (nodes, 1day orbit) |

# RESULTS

- **Experiment #5**

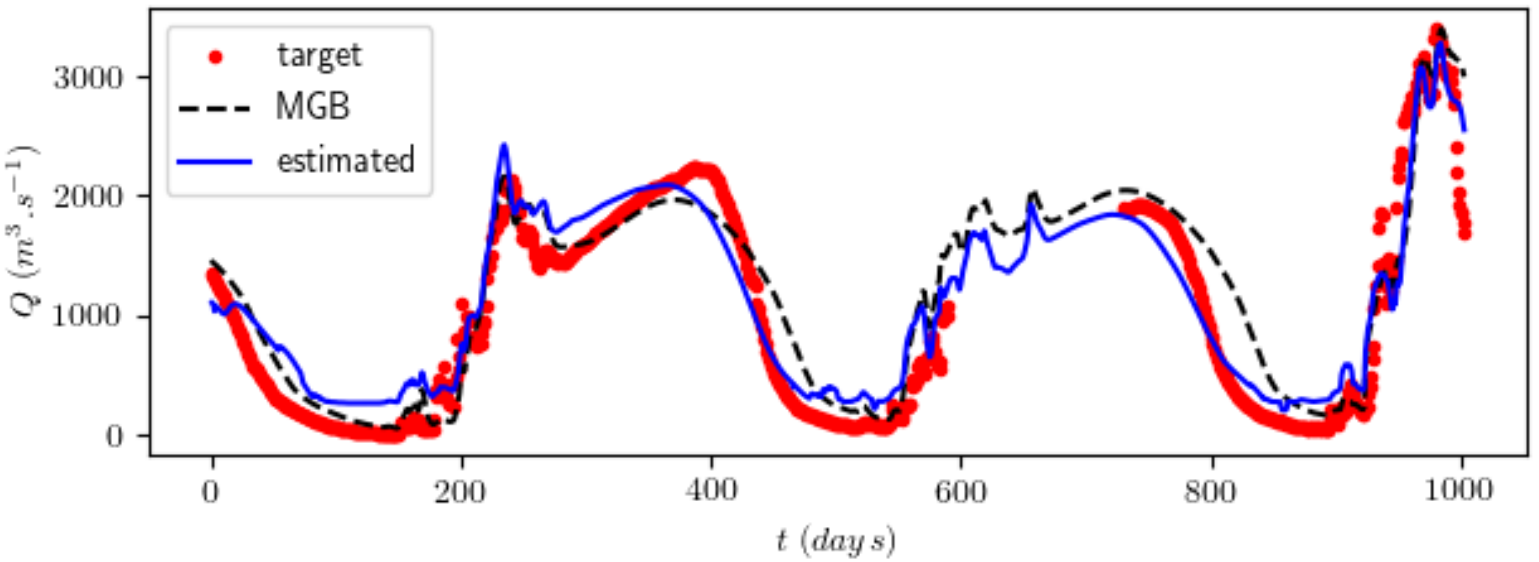
| | | |
|---|---|---|
| Middle Niger | (S3 + J2) x ExtractEO (S2) | S3 + J2 |




01-01-2018 - 09-30-2020

19 VS

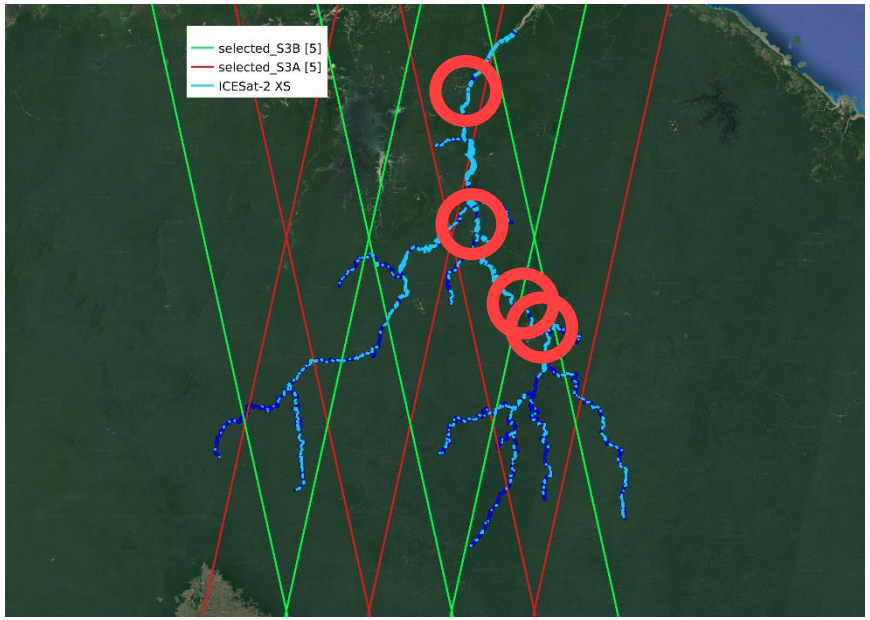
Niamey, nrmse=0.33



# RESULTS

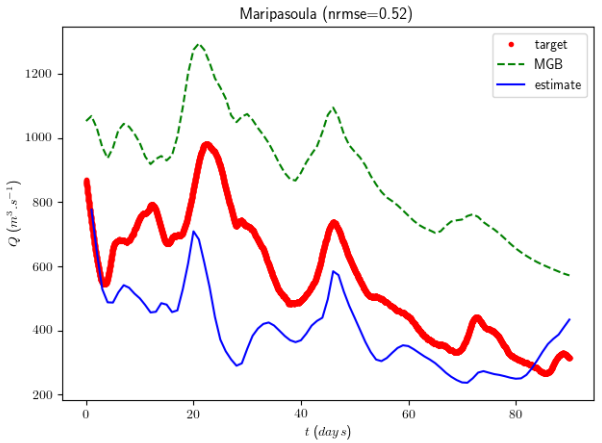
- **Experiment #1**

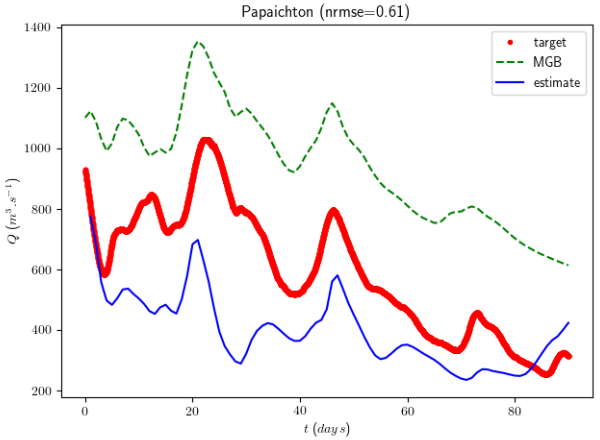
| Maroni | ICESat-2 x ExtractEO (S1) | ICESat-2 + S3 |
|---|---|---|

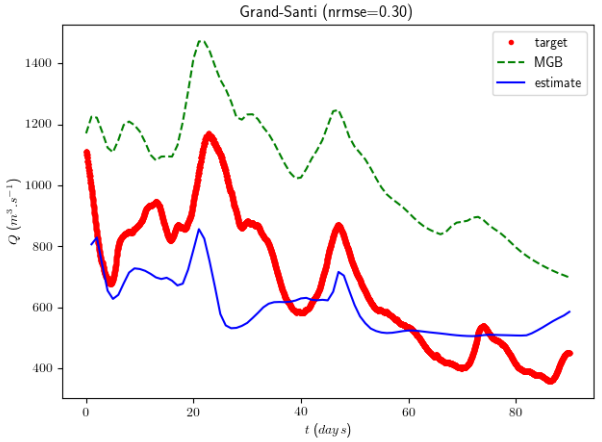


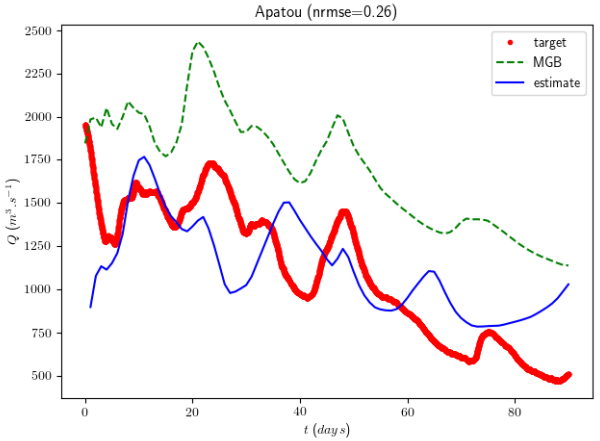

01-01-2019 - 03-31-2019

219 ICESat-2 VS
19 S3A/B VS



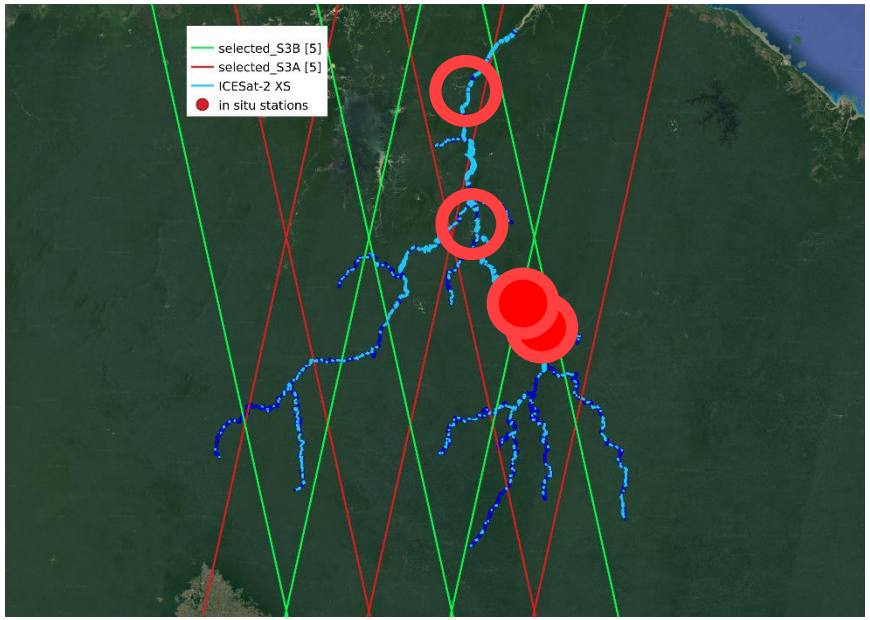



# RESULTS

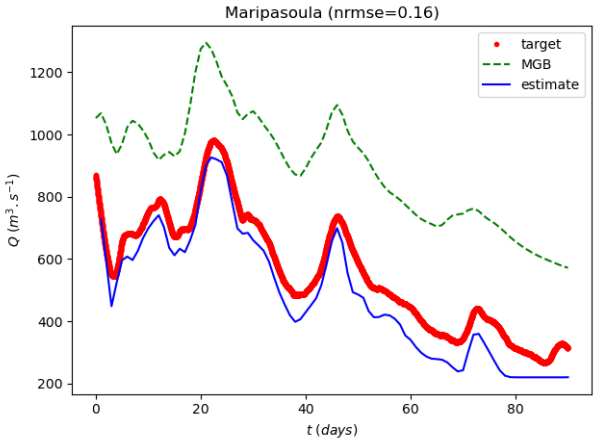
- **Experiment #2**

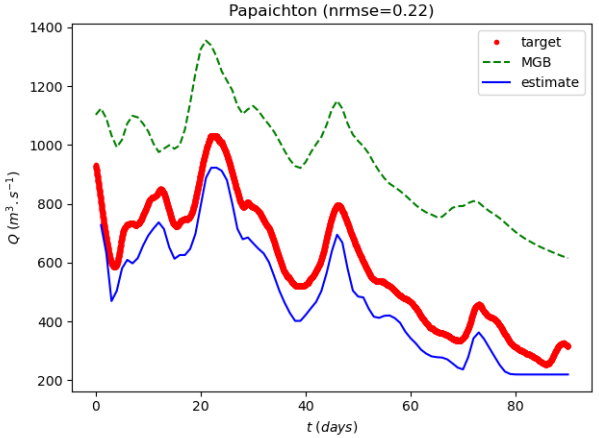
| Maroni | ICESat-2 x ExtractEO (S1) | ICESat-2 + S3 + in-situ (2/5) |
|---|---|---|

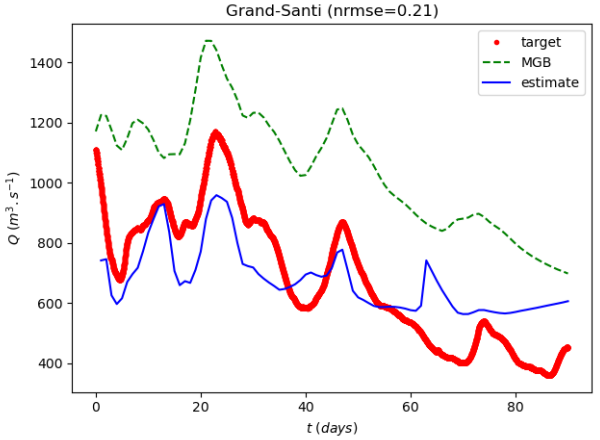


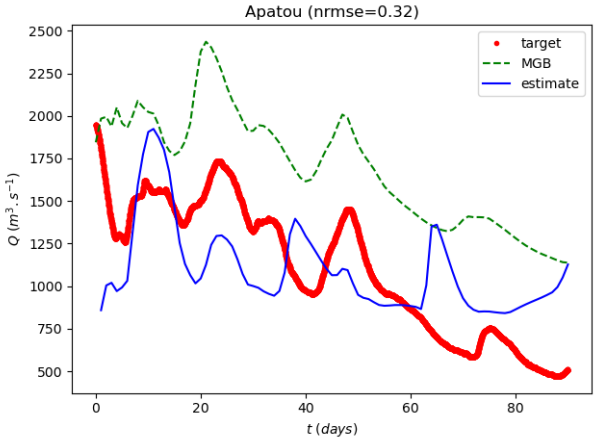

01-01-2019 - 03-31-2019

219 ICESat-2 VS
19 S3A/B VS



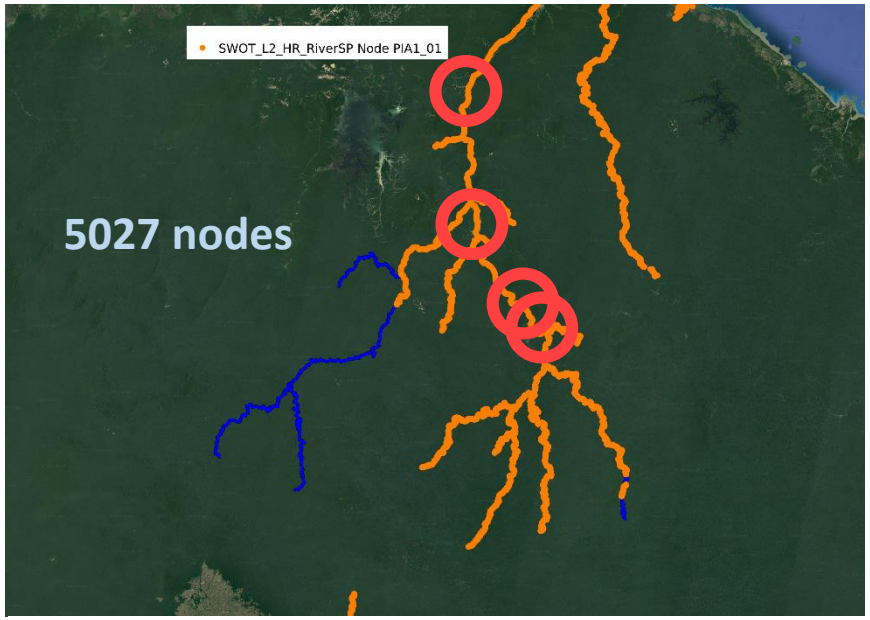



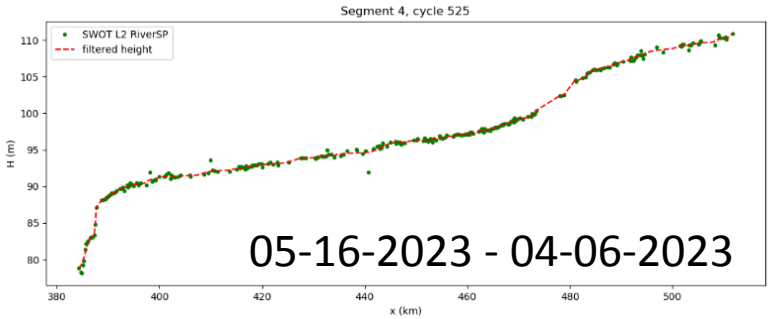



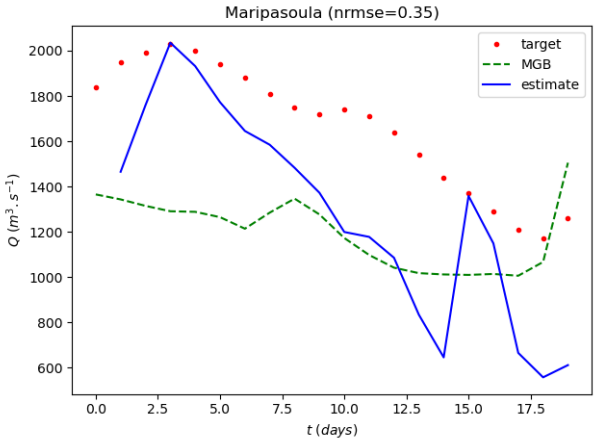
# RESULTS

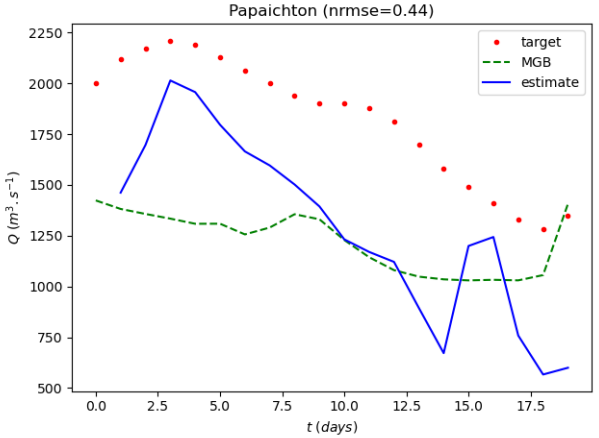
- **Experiment #3**

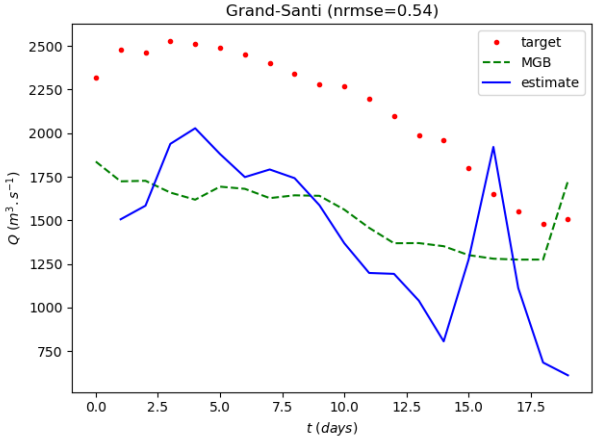
| Maroni | ICESat-2 x ExtractEO (S1) | SWOT (nodes, 1day orbit) |
|---|---|---|

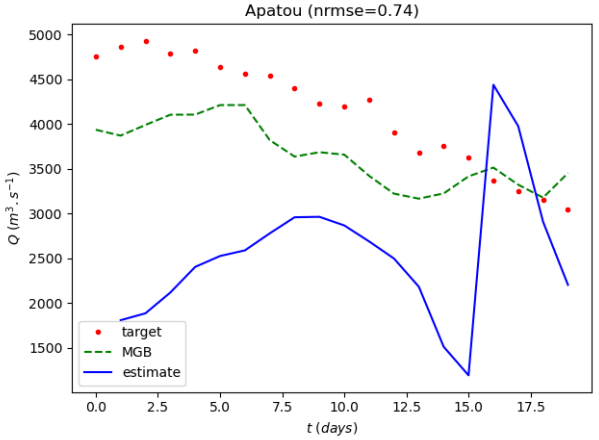


# CONCLUSION & PERSPECTIVES

- **Conclusion**
  - Automatic setup of coupled hydrological-hydrodynamic model on a river network
  - 4DVar data assimilation to estimate:
    - Multiple inflow discharge time series
    - Roughness parameters
    - Riverbed elevation
    - On a full  river network
  - SWOT ready, results are promising !
- **Perspectives**
  - Longer time series (whole time series of MGB simulation)
  - Fusion of historical altimetry missions
  - 2D patches for anabranching areas
  - More basins !

# RECOMMENDATIONS

- Using coupled hydrological-hydrodynamic model on a entire river network one can propagate some sparse measurements in space-time.
- With SWOT we will have fine scale snapshots of the all the major rivers in the world
- Then with spare measurements we will have an efficient system for analyses related to water management and even extremes (flood, droughts)
  - Either sparse in time but with frequent revisit
  - Or sparse in time but with good spatial resolution

- We also need more accurate series of (W, H) to better detect the overbanks and thus better simulate the change in flow regime during high flow conditions

  $\Rightarrow$ Improvement of the watermasks

  $\Rightarrow$ More measurements of both W (watermasks) and H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Thank you for your attention
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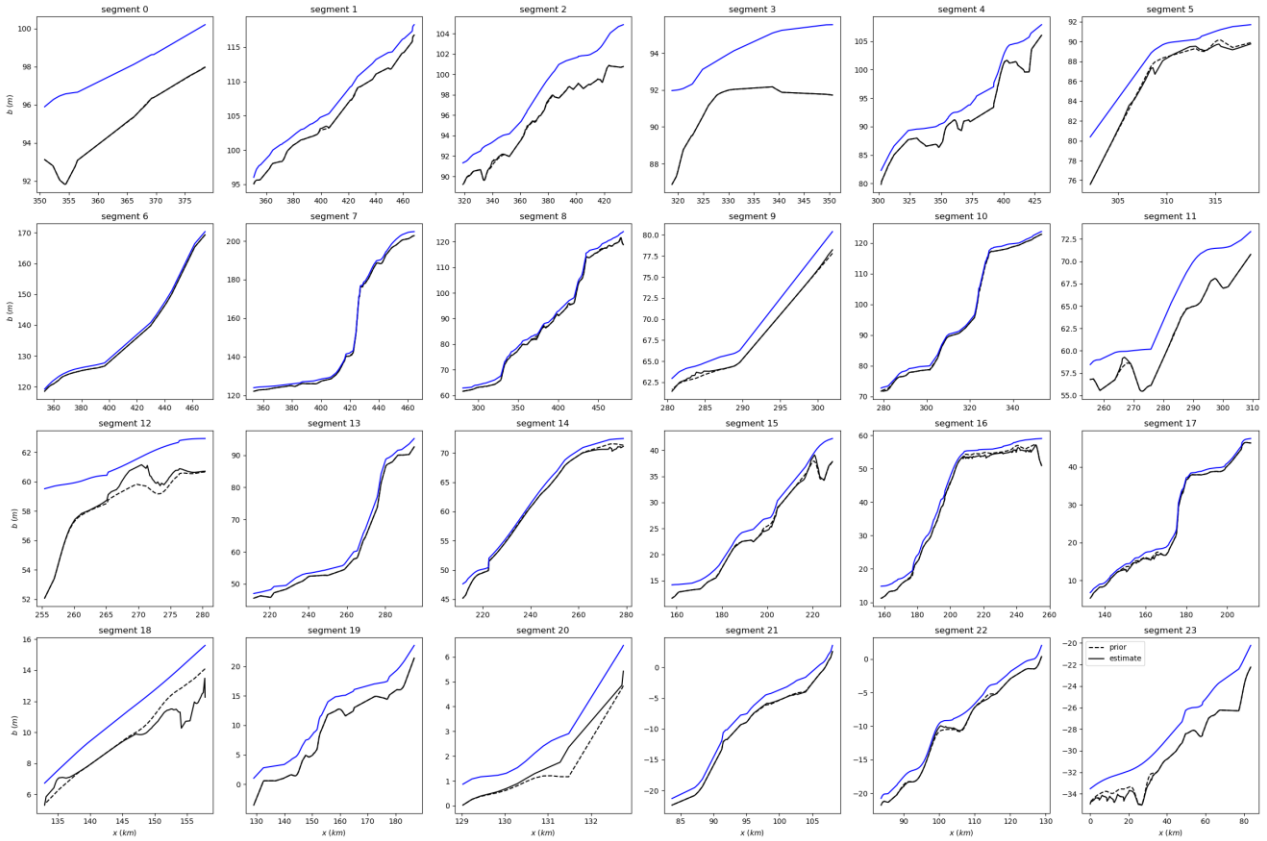
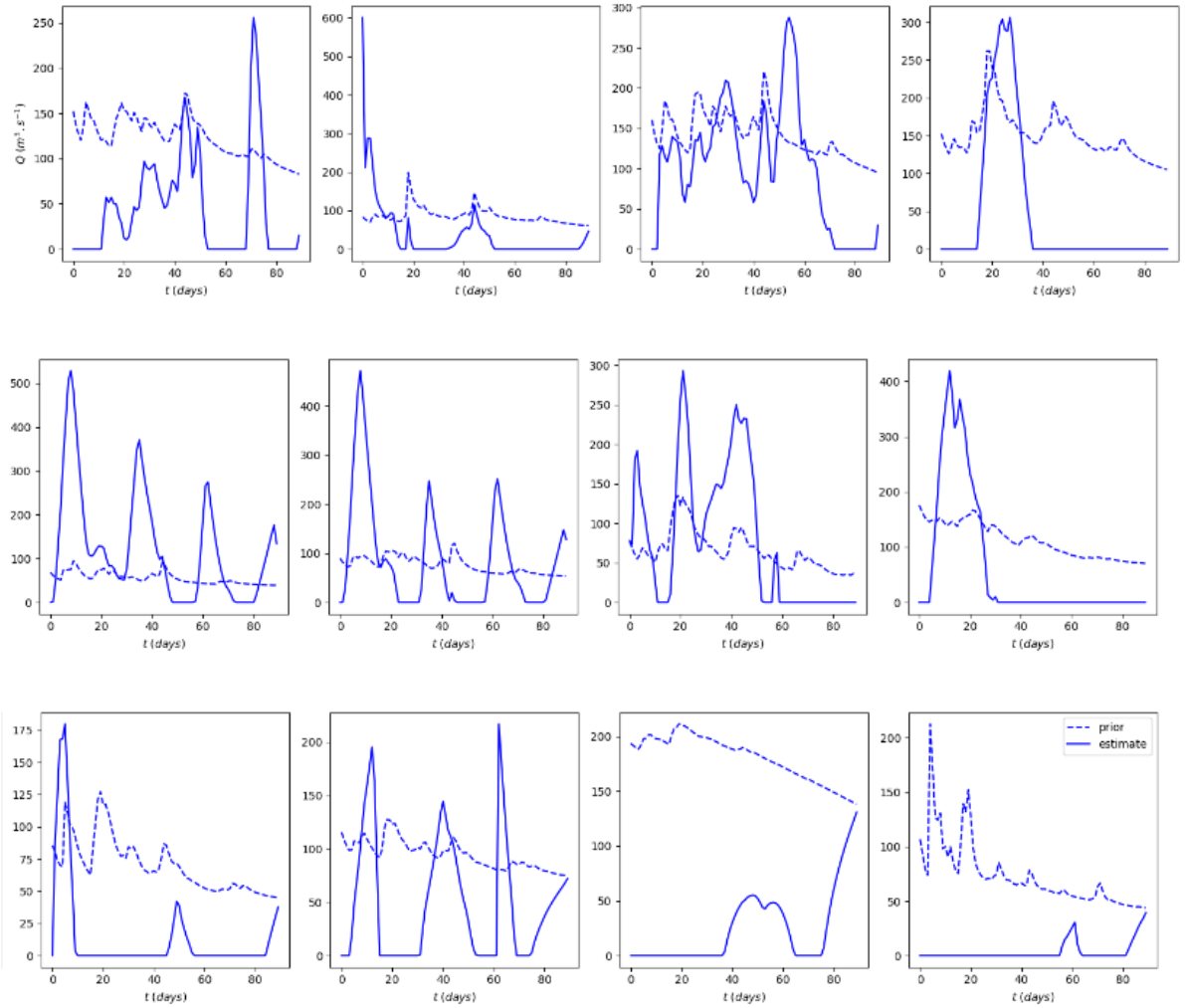

segment 0
segment 1
segment 2
segment 3
segment 4
segment 5
segment 6
segment 7
segment 8
segment 9
segment 10
segment 11
segment 12
segment 13
segment 14
segment 15
segment 16
segment 17
segment 18
segment 19
segment 20
segment 21
segment 22
segment 23
b (m)
x (km)
prior
estimate


Q (m³ · s⁻¹)
t (days)
prior
estimate