climate change initiative

RIVER DISCHARGE

WP5 – Use case : data assimilation into large-scale river routing systems

river discharge cci

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Workshop

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Overview - Scientific context

<u>Obs. <> hydrological models synergy :</u>

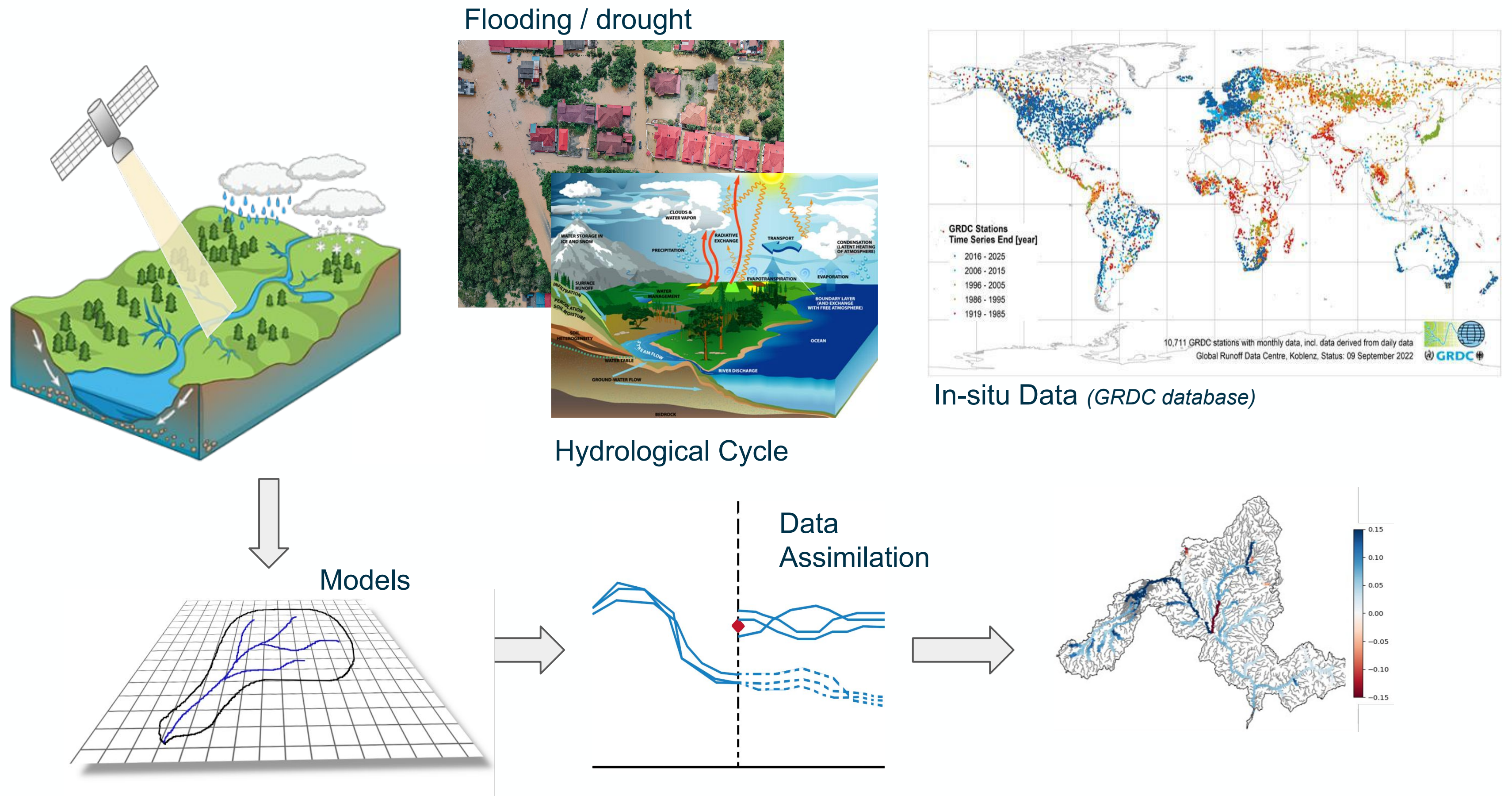
→ : Calibration, DA and so improve models accuracy

- Hist. use of in-situ data into models for seasonal Hydrological Forecasting, Mitigate natural disasters

←: Filling data gaps and expand coverage of “model-based stations” in ungauged river reaches.

<u>In-situ data limitation & advancements in RS :</u>

- Remaining ungauged basins (private data, maintenance costs)
- Several space missions over last decades: Envisat, ERS 1-2, TOPEX, Jason 1-2-3, Sentinel 2 3A-3B, SARAL, MODIS

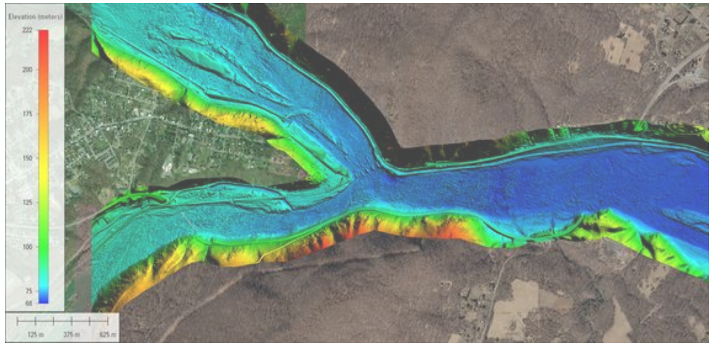


(Pedinotti V., from Hybridation Project presentation, 2023)

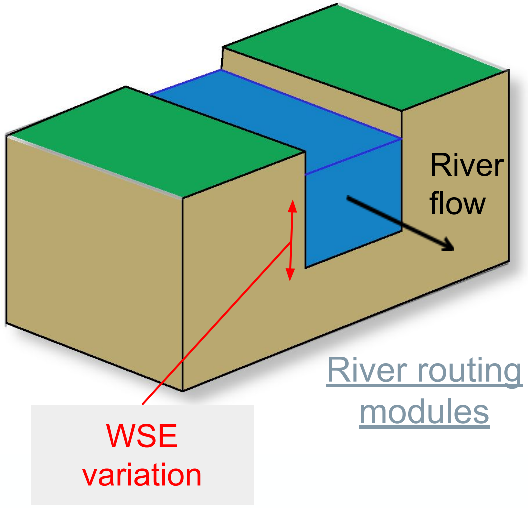
Overview - RS data

WSE Data

- Lower uncertainty
- Valuable for high-resolution hydrodynamic modeling
- Mismatch with the typical outputs of hydrological model
- Lack of detailed bathymetry/topography representation in large-scale models.
  - A single WSE value can correspond to different water volumes depending on bathymetry → affecting model accuracy

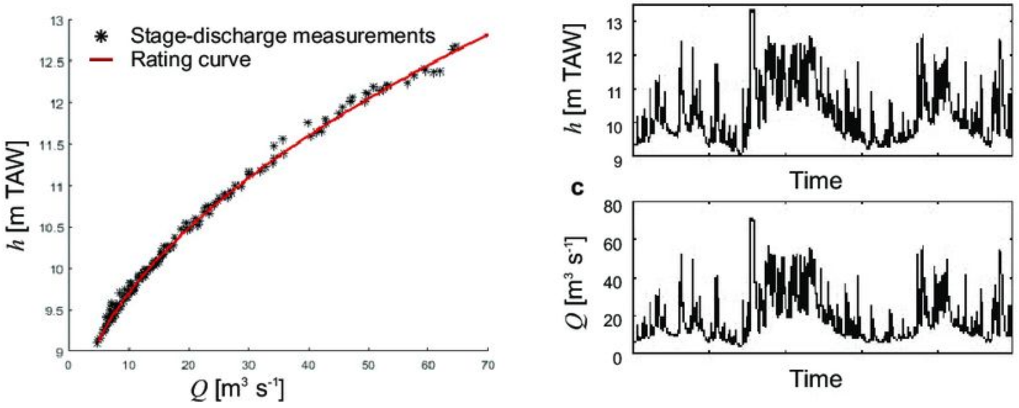


© USGS - Potomac river topography



WSE-Derived Discharge

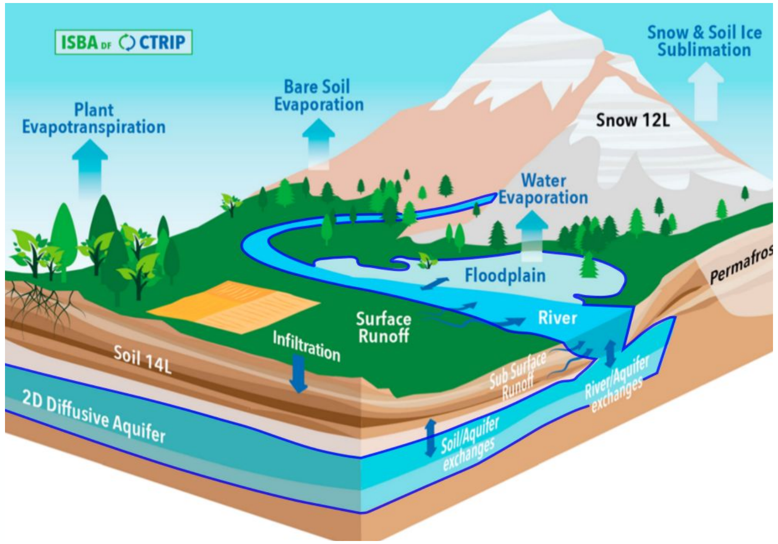
- Closer alignment with hydrological models outputs
- Transformation from WSE to discharge introduces additional uncertainties
  - depending on methods to estimate discharge (hydrological models, empirical rating curves, …)

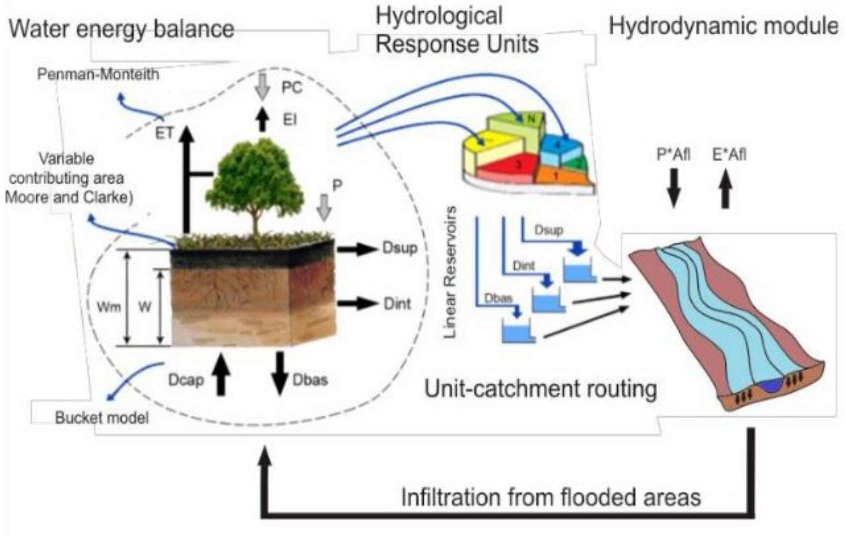


K. Van Eerdenbrugh, 2018

→ THE EUROPEAN SPACE AGENCY

Overview - Models : ISBA-CTRIP vs MGB





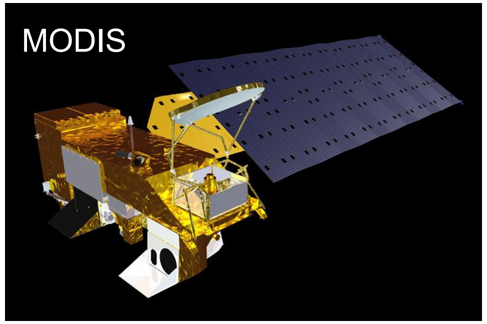
- Global-scale Land Surface - River Routing model
  - ISBA (LSM) : Water & energy fluxes atm <--> land
  - CTRIP (RRM) : river routing + floodplains + aquifers
- Physical-based model, no calibration needed
- Part of Earth-System model (CNRM-ESM)
  - Earth water cycle / Climate studies
  - Water resources monitoring & forecasting

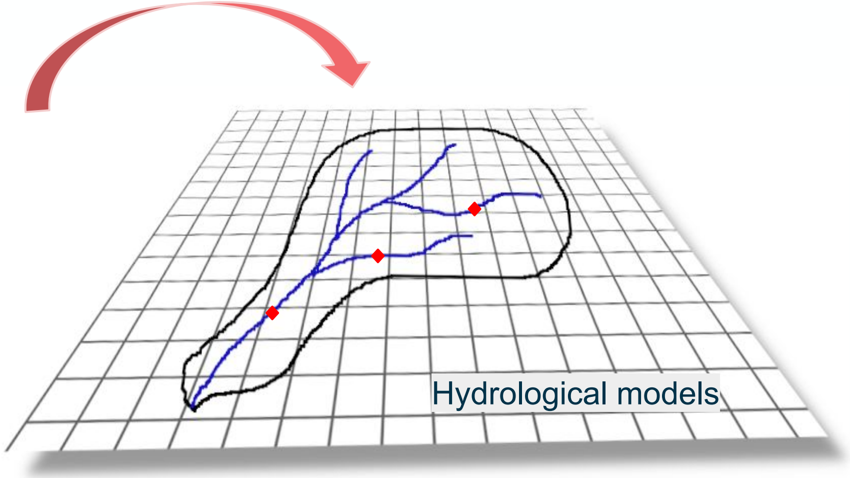
- Regional-basin based hydrological model
  - Production function : hydrologic module
    - Water energy balance | HRUs over a basin
  - Routing function : hydrodynamic module (rivers, floodplains, groundwater)
- Calibrated over basins (Niger, Congo,...)
- Flood forecast application

Overview - RS data

➔ Does assimilating higher uncertain river discharge data perform better than assimilating lower uncertain water elevation data?

➔ Are the spatial coverage and temporal resolution of these products enough for the scale of hydrological processes being studied (depending on each model application)?





Overview - Work Package 5

Objectives:

- Study the potential improvement that could be provided by the assimilation of river discharge products into large scale hydrological models
- Compare how different modeling approaches (regional vs global) compare over long time series

Involved:

CNRS-CNRM, Magellium

Modeling tools :

- **CTRIP** global river routing model (coupled to the ISBA global Land Surface Model) - HyDAS tool
- **MGB** regional hydrological model - HyFAA platform

Inputs (from WP3):

- Satellite **water level** data and associated uncertainties
- CCI river **discharge** products : Q_ality, Q_multispectral, Q_merged

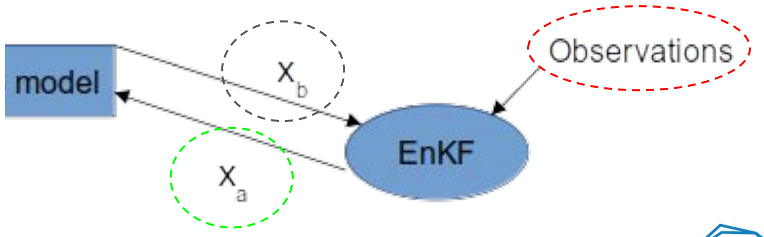
Case study :

- Niger, Congo (MGB,CTRIP) / 18 basins (CTRIP)

HyDAS (CNRS-CNRM) - HyFAA (Magellium)

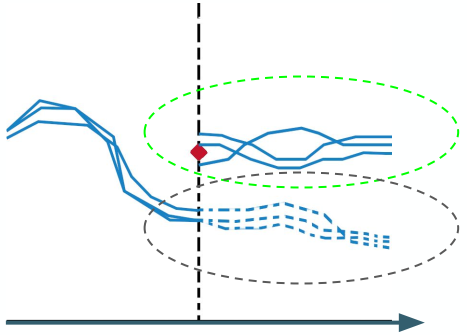
Hydrological **D**ata **A**ssimilation **S**ystem | **Hy**drological **F**orecasting system with **A**ltimetry **A**ssimilation

- Ensemble Kalman Filter (EnKF) → Sequential method : model is updated each time an observation is acquired
- Correct :
  - Model **State** :
    - → CTRIP - River storage
    - → MGB - Compartments storage, soil moisture,...
  - + Model **parameters** in option (riverbed roughness,...)



- Assimilation of either **water level anomaly** or **discharge**
- Ensemble generated by perturbating meteorological forcing using EOFs (allows to conserve the spatio-temporal structure of the forcings)

Xb : background
Xa : analyzed



EnKF gain matrix :

Pf : background covariance error matrix
R : observation error covariance matrix
H : observation operator

$$K = P^f H^T \left[H P^f H^T + R \right]^{-1}$$

→ THE EUROPEAN SPACE AGENCY

HyDAS (CNRS-CNRM) - HyFAA (Magellium)

Hydrological **D**ata **A**ssimilation **S**ystem

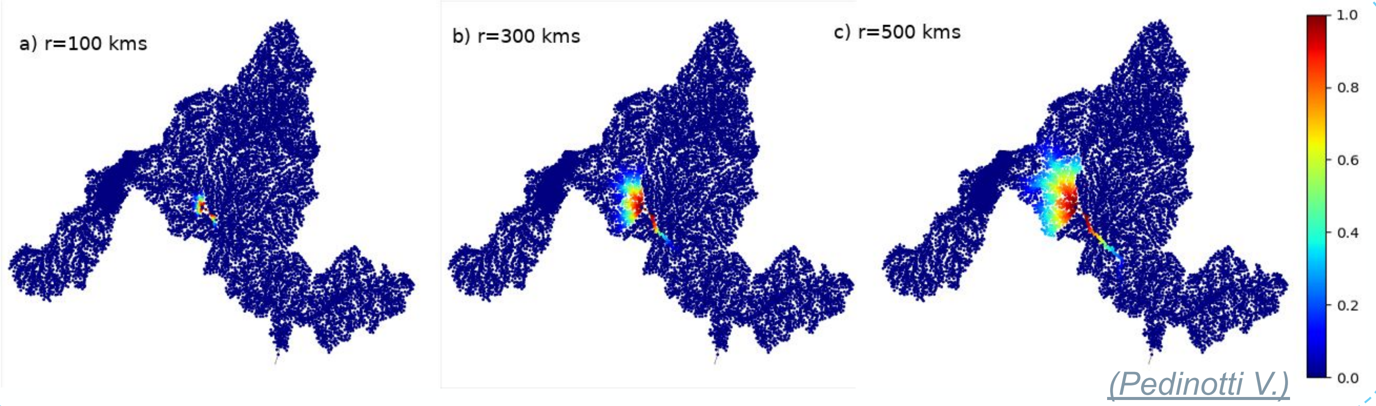
Hydrological **F**orecasting system with **A**ltimetry **A**ssimilation

- Localization algorithm :

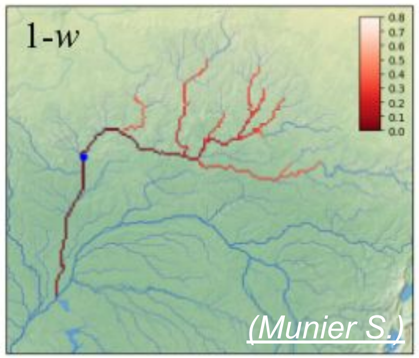
A. based on distance along the river network

B. adaptive method based on covariances between cells :

→ non-linear observation operator based on dynamical relationship between cells/river reaches *(Revel et al., 2018)*



A.



B.

- Kalman Smoother: propagation of error covariance in time
- Within CTRIP's internal code (option to activate) :

  → Potential application over <u>any basin of the world</u>

- Implemented for MGB as externalized (.py) scheme :
  - Communicates with MGB model through a scheduler
  - Used for analysis and <u>forecast</u> of pre-calibrated MGB model state over <u>a chosen basin</u>

Experiment plan : Open-Loop

Forcing ERA 5
2000-2020

Forcing
IMERG/CHIRPS
~2000-2020

CTRIP - HyDAS(n_{ens}=25)

MGB - HyFAA(n_{ens}=100)

In-situ discharge data

<u>Niger basin :</u> ABN (11 stations, ~2010-2017)

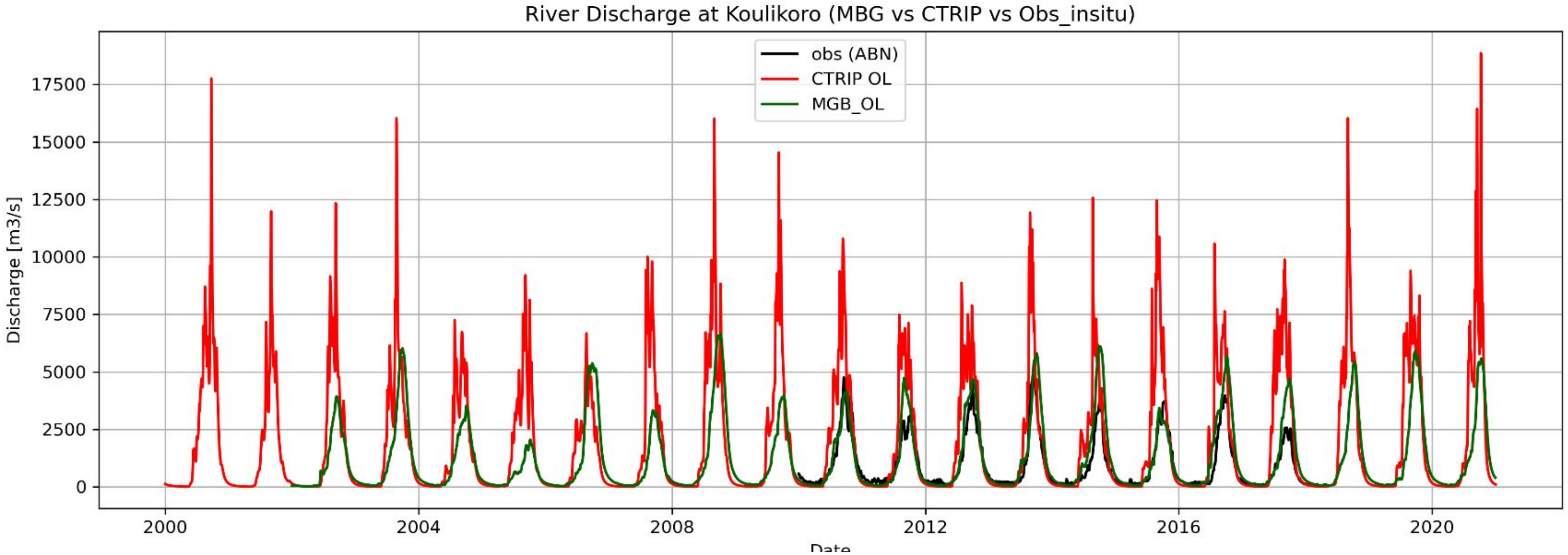
Niger Basin : validation in-situ obs. discharge

In-situ discharge data

Niger basin : ABN
(11 stations,
~2010-2017)

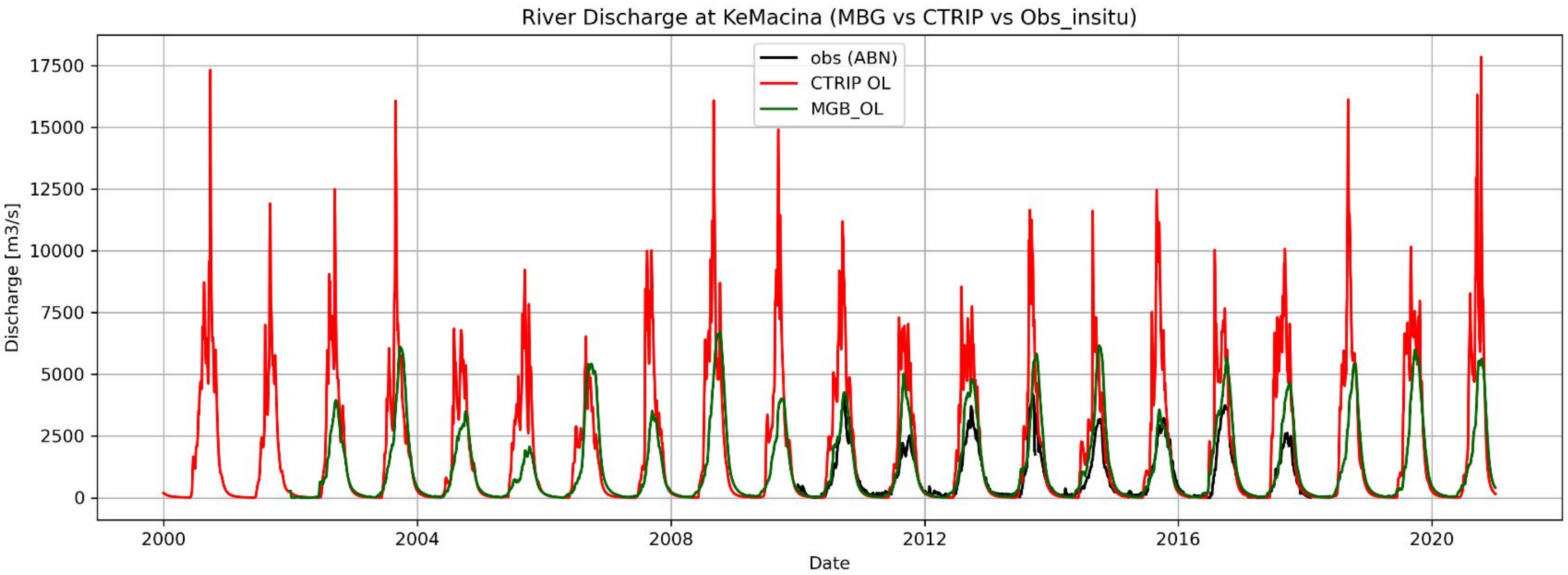
CTRIP vs MGB Open-Loop

Koulikoro station - upstream Delta



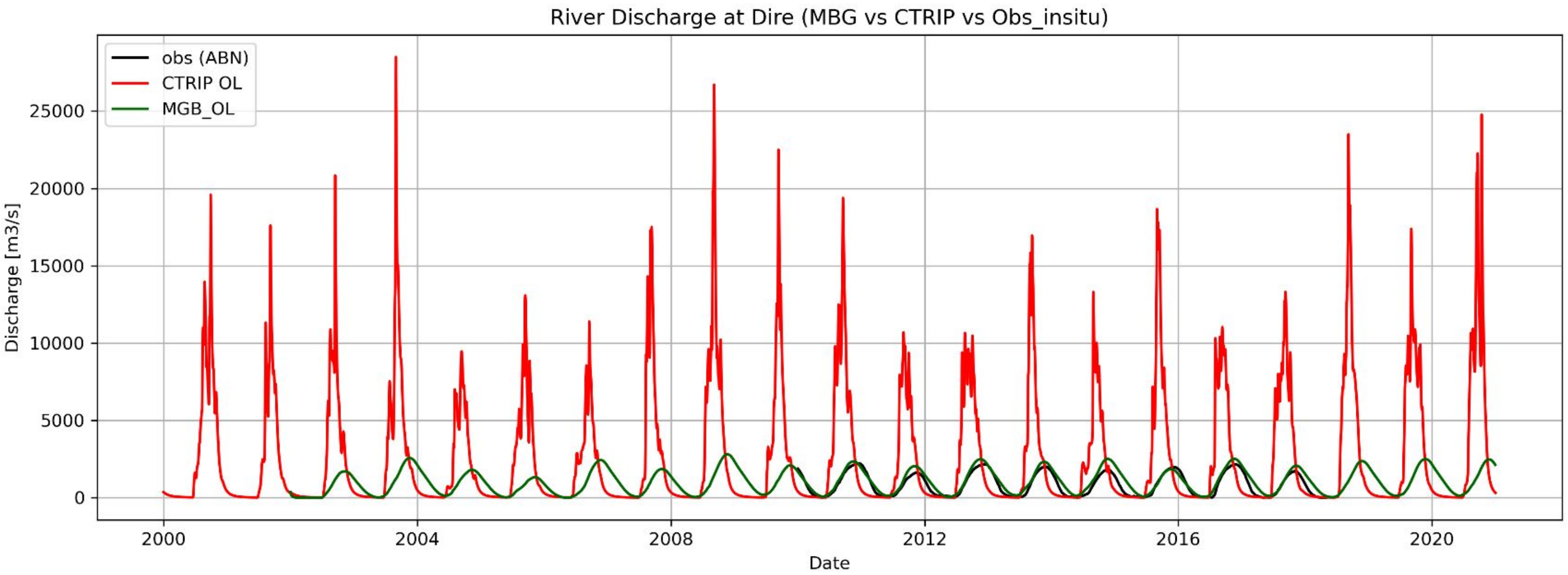
CTRIP vs MGB Open-Loop

Ke-Macina station - within Delta



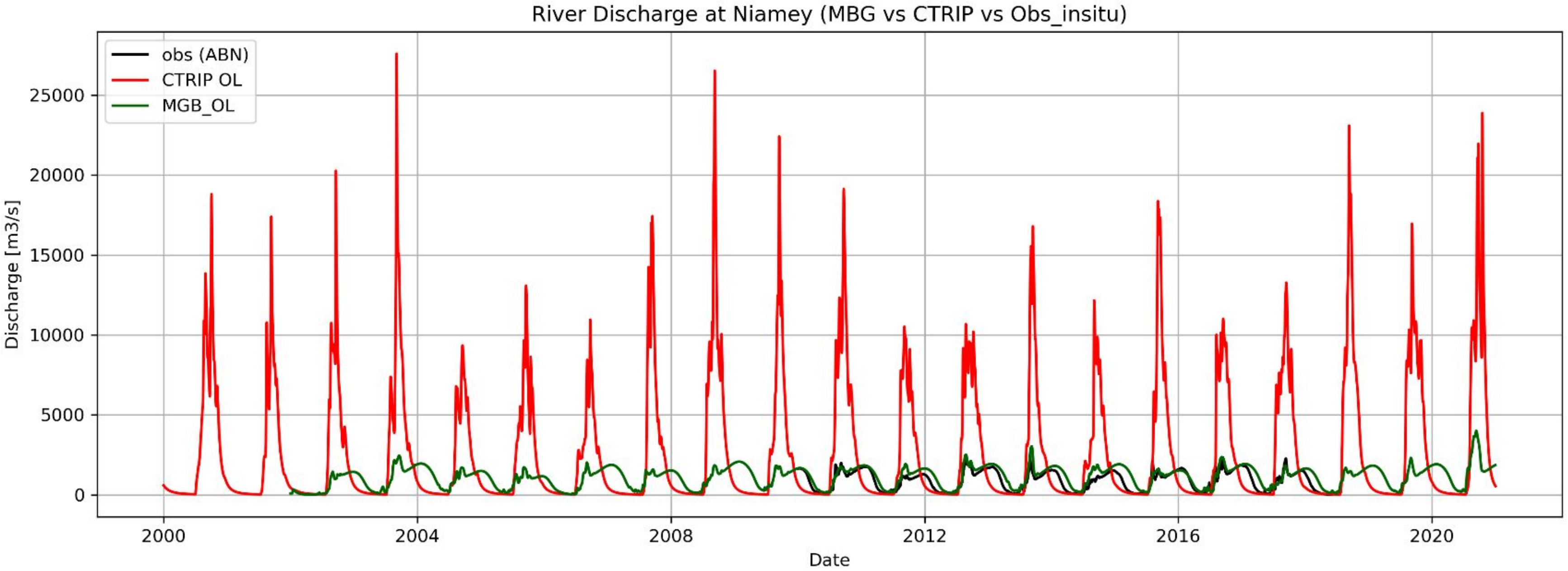
CTRIP vs MGB Open-Loop

Dire station - downstream Delta



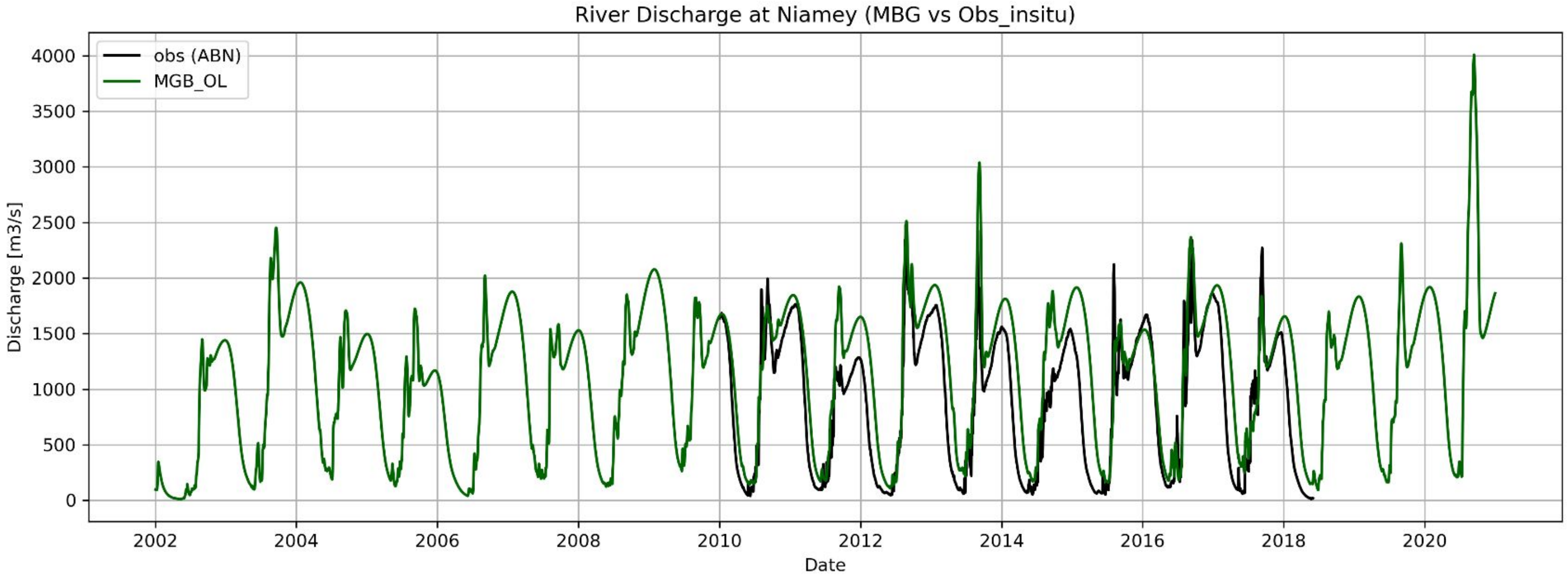
CTRIP vs MGB Open-Loop

Niamey station



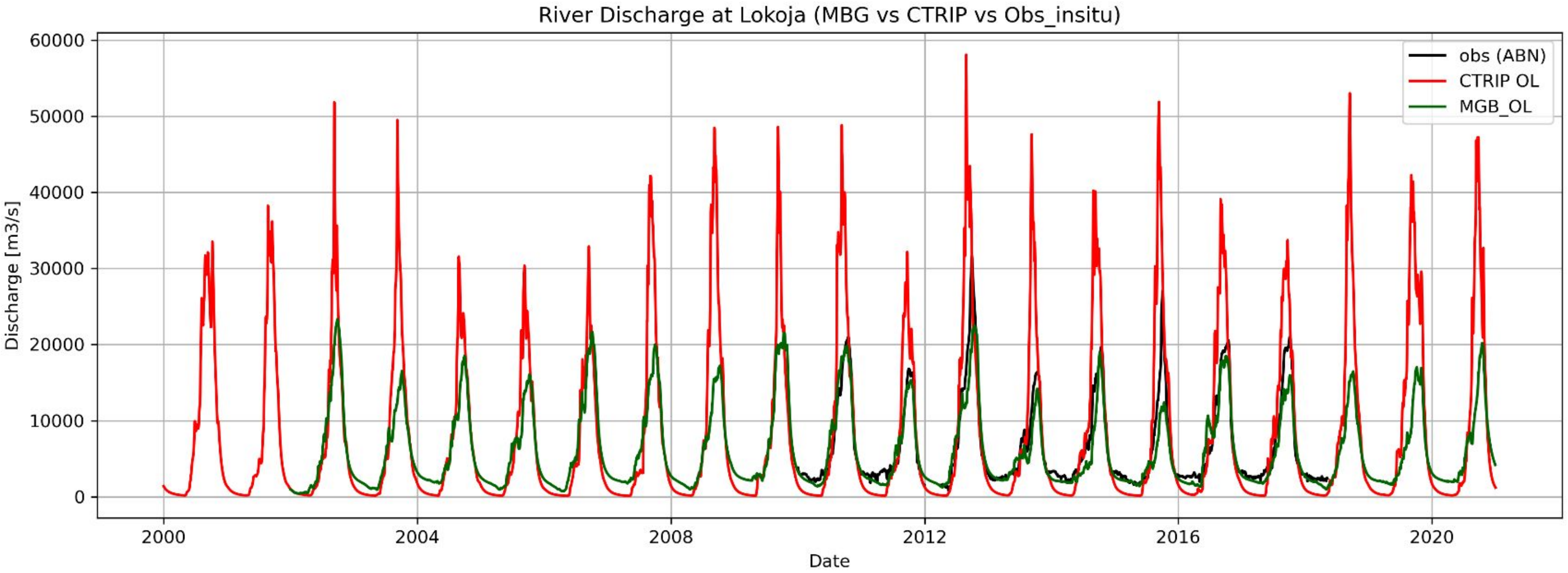
Focus on MGB Open-Loop

Niamey station



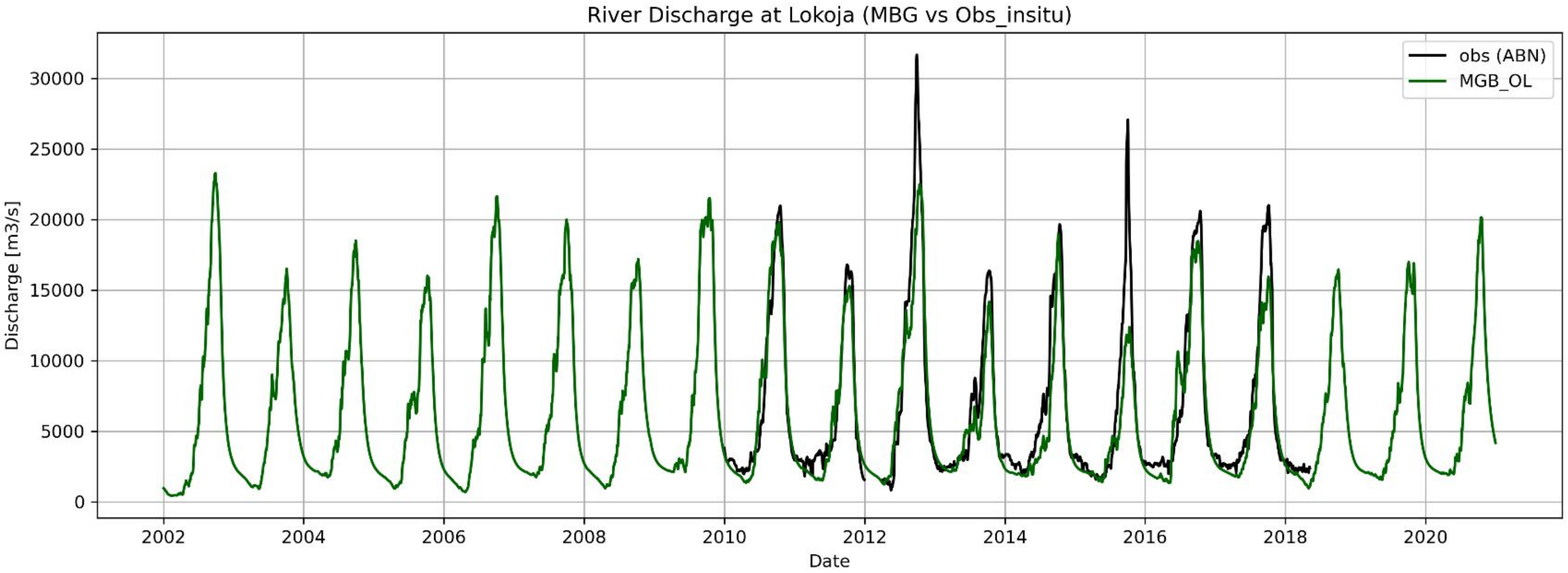
CTRIP vs MGB Open-Loop

Lokoja station - Downstream of confluence with Benoué river



Focus on MGB Open-Loop

Lokoja station - Downstream of confluence with Benoué river



Experiment plan : with assimilation

1 Assimilation of water level anomalies

- CTRIP-HyDAS : Global (18 river basins)
- MGB-HyFAA : Niger, Congo

2 River discharge assimilation

- Relative contribution of each discharge product vs water levels
  - Q from altimetry
  - Q from multispectral
  - Q merged
- Single and cross data assimilation (H/Q or discharge products together)

3 Impacts of assimilation parameters

- Uncertainties (constant, time varying) from WP4.1
- Smoother depth, localization length, inflation...

Experiment plan : with assimilation

Forcing ERA 5
2000-2020

RS Data
(WSE,Qalti,...)

Forcing
IMERG/CHIRPS
~2000-2020

Obs.	Applied constant error		Computed error
WSE	0.2m	0.4m	
Qalti	30%	50%	

CTRIP - HyDAS(n_{ens}=25)

MGB - HyFAA(n_{ens}=100)

Perf. improvement with RS DA

Perf. improvement with RS DA

In-situ discharge data

Niger basin : ABN (11 stations, ~2010-2017)

Actual virtual stations

Niger (~2.1e12 km²)

Congo (~3.7e12 km²)

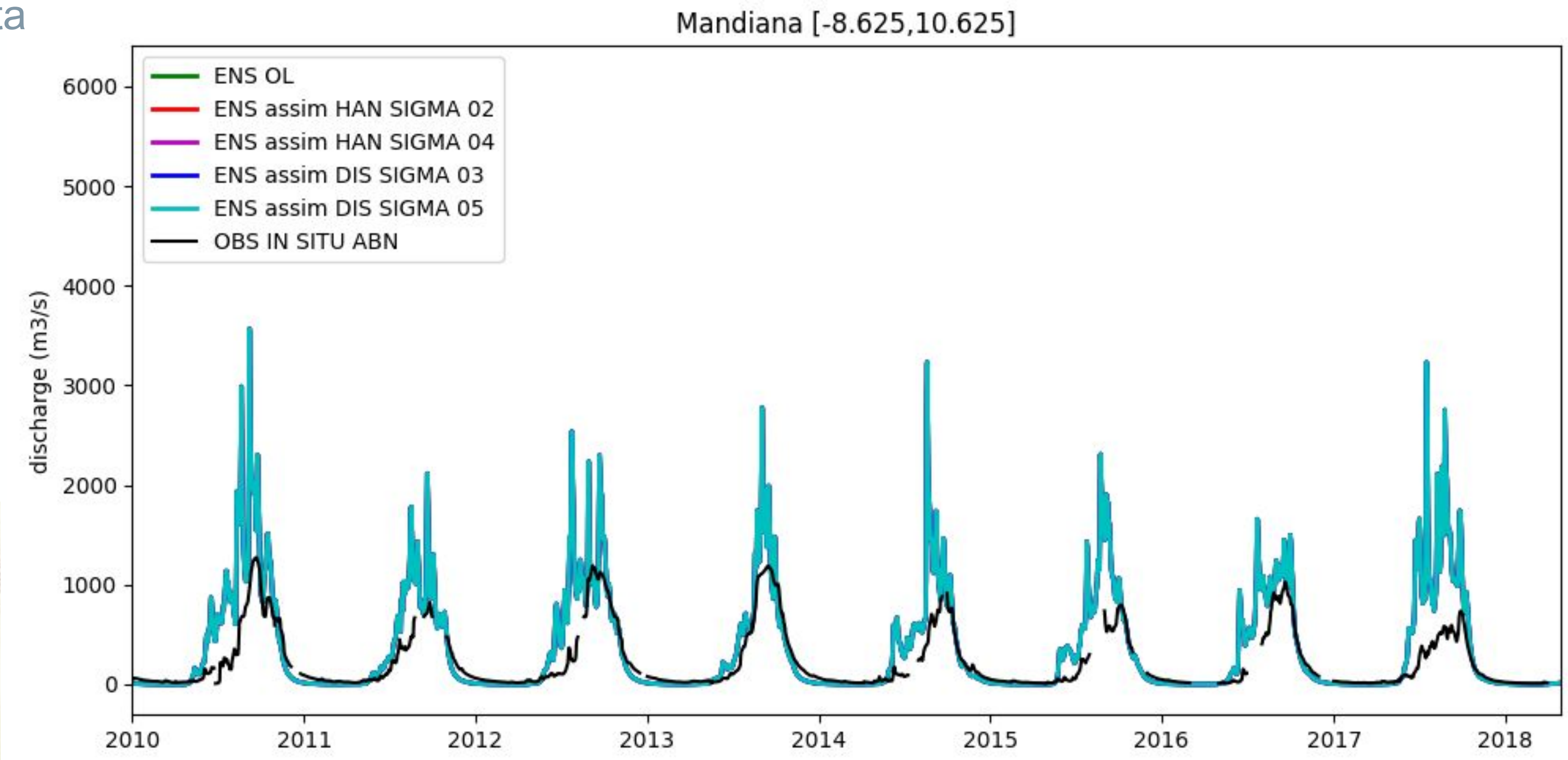
Niger Basin : validation in-situ obs. discharge

In-situ discharge data

Niger basin : ABN (11 stations, ~2010-2017)

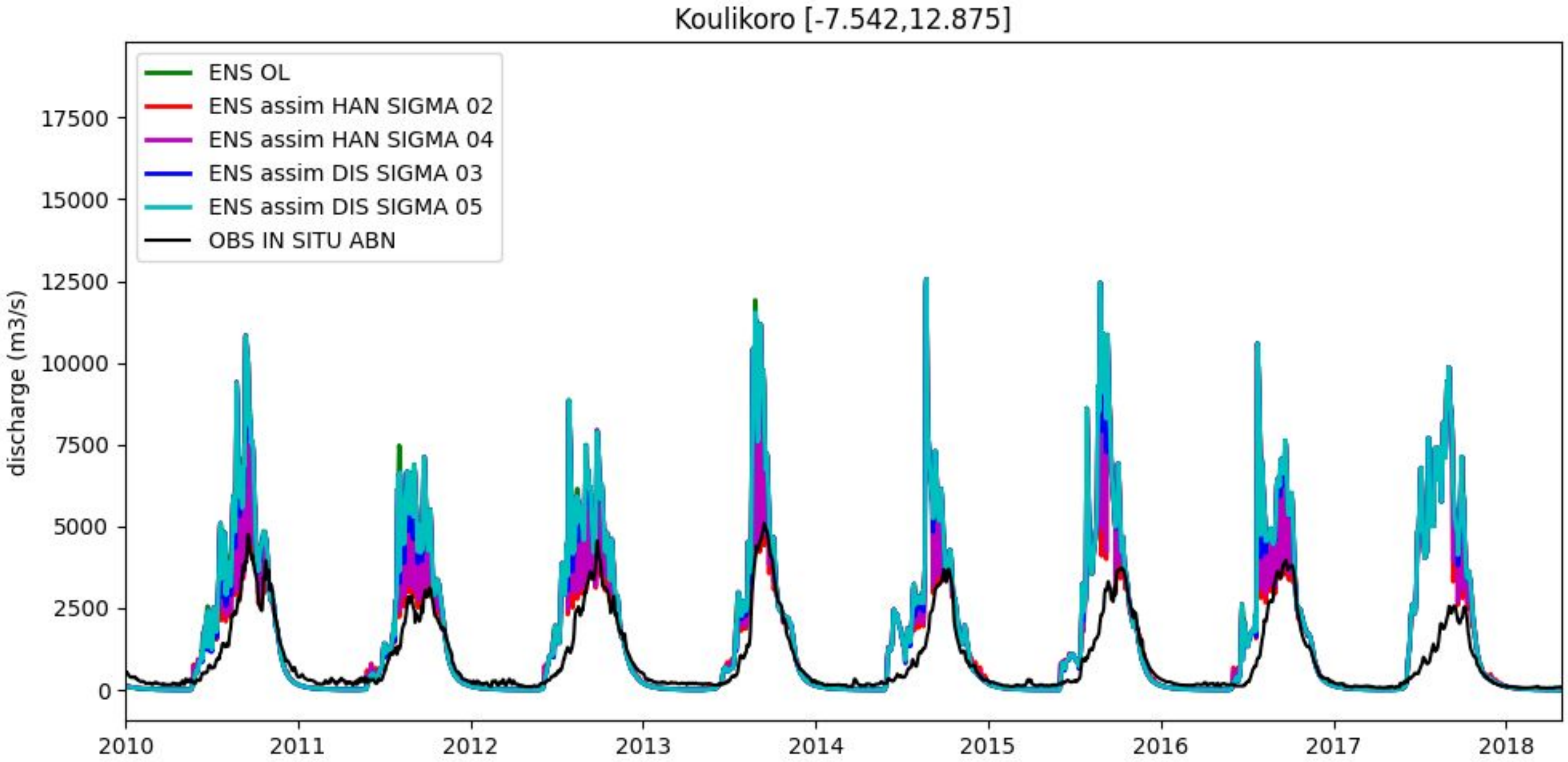
Results - Niger basin : CTRIP-HyDAS

Mandiana station - upstream Delta



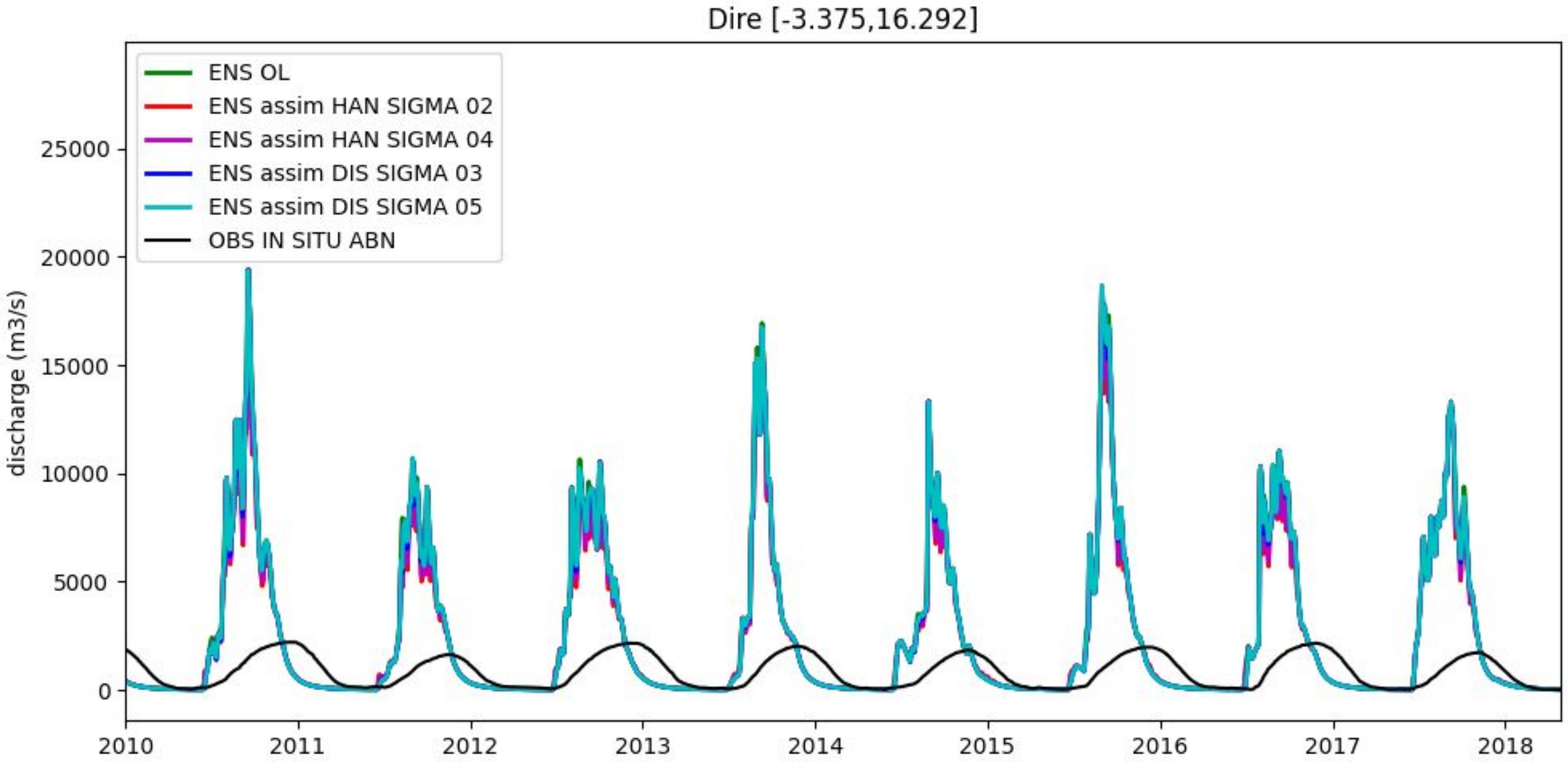
Results - Niger basin : CTRIP-HyDAS

Koulikoro station - upstream Delta



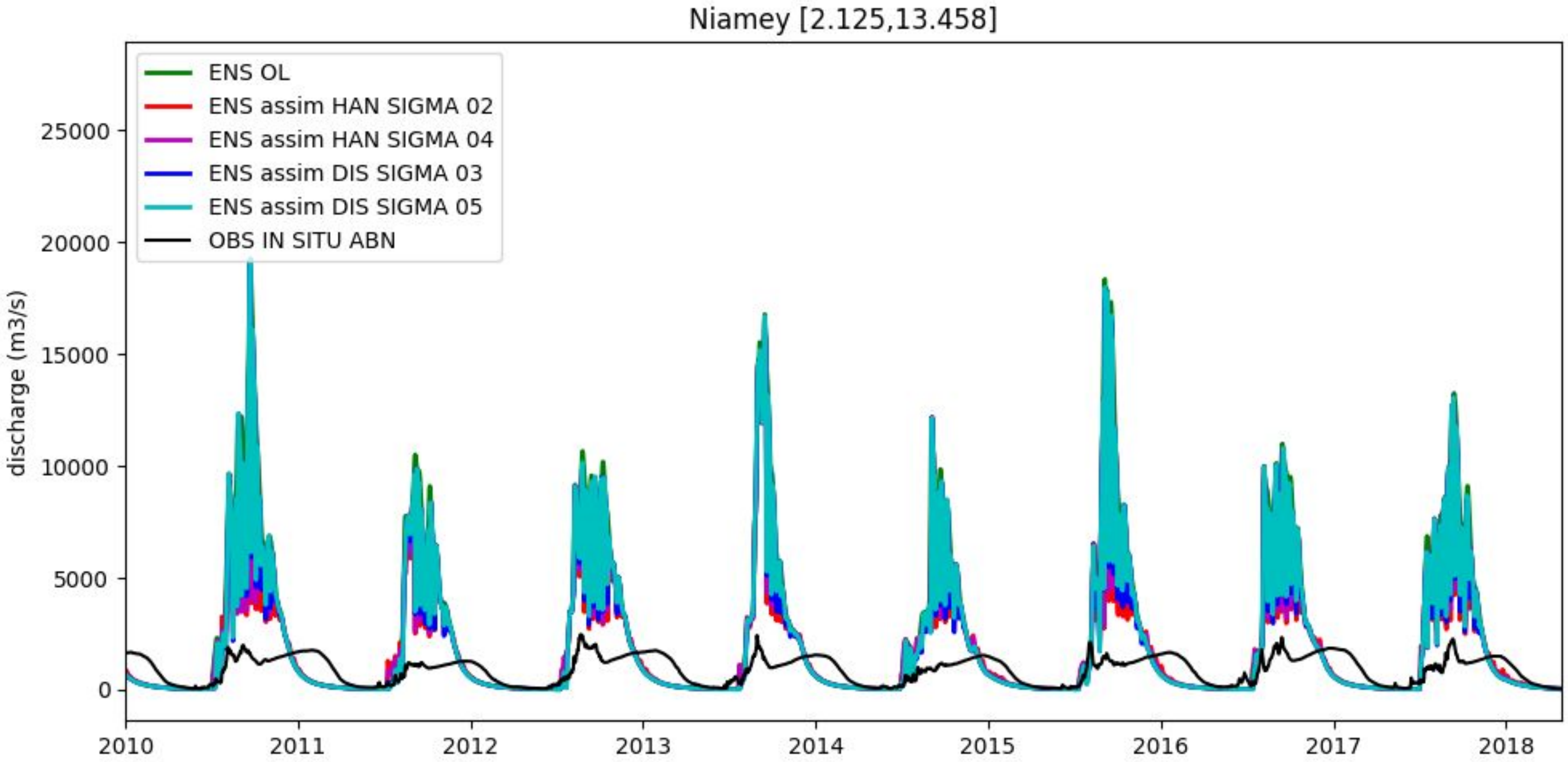
Results - Niger basin : CTRIP-HyDAS

Dire station - downstream Delta



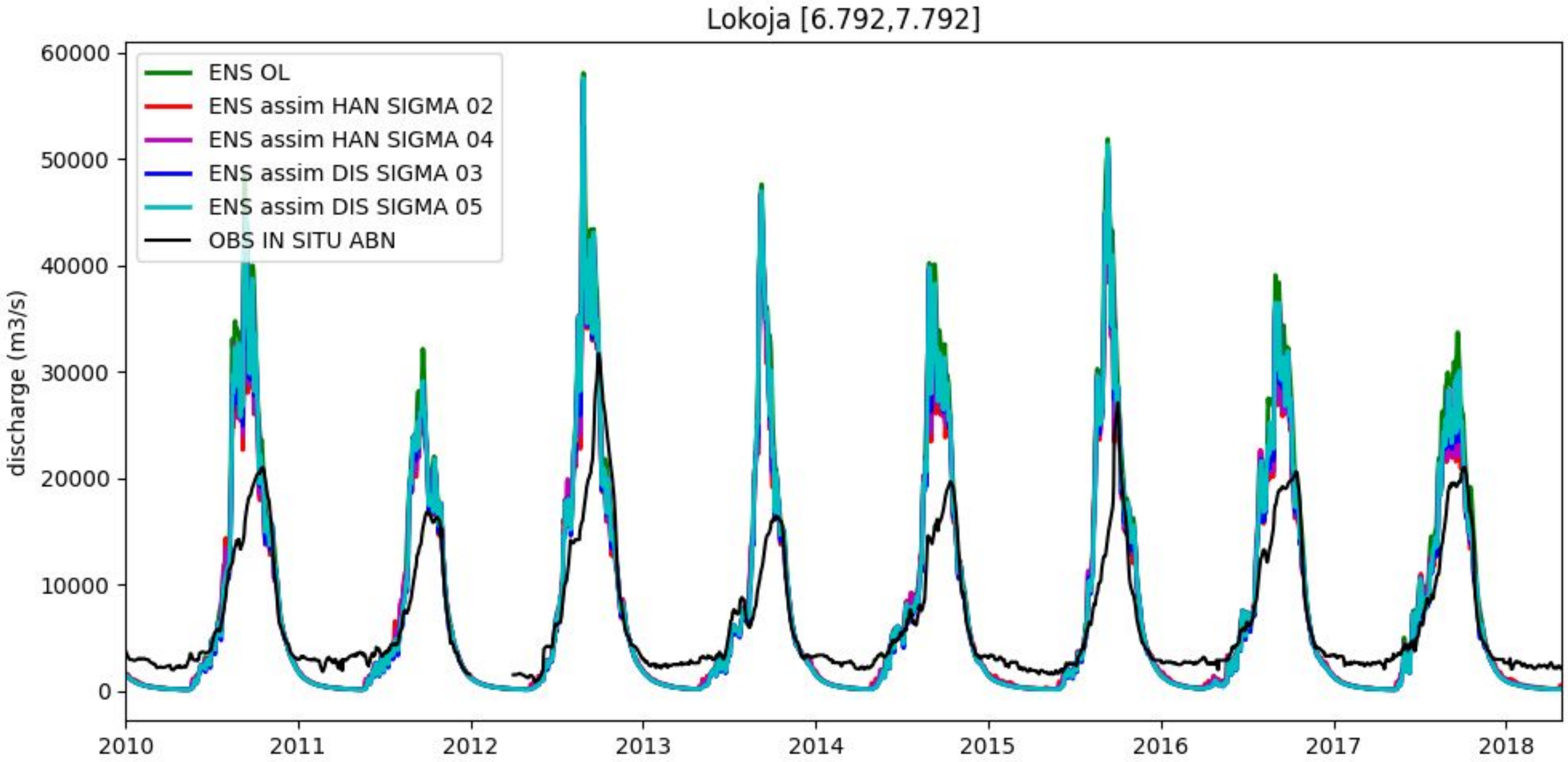
Results - Niger basin : CTRIP-HyDAS

Niamey station



Results - Niger basin : CTRIP-HyDAS

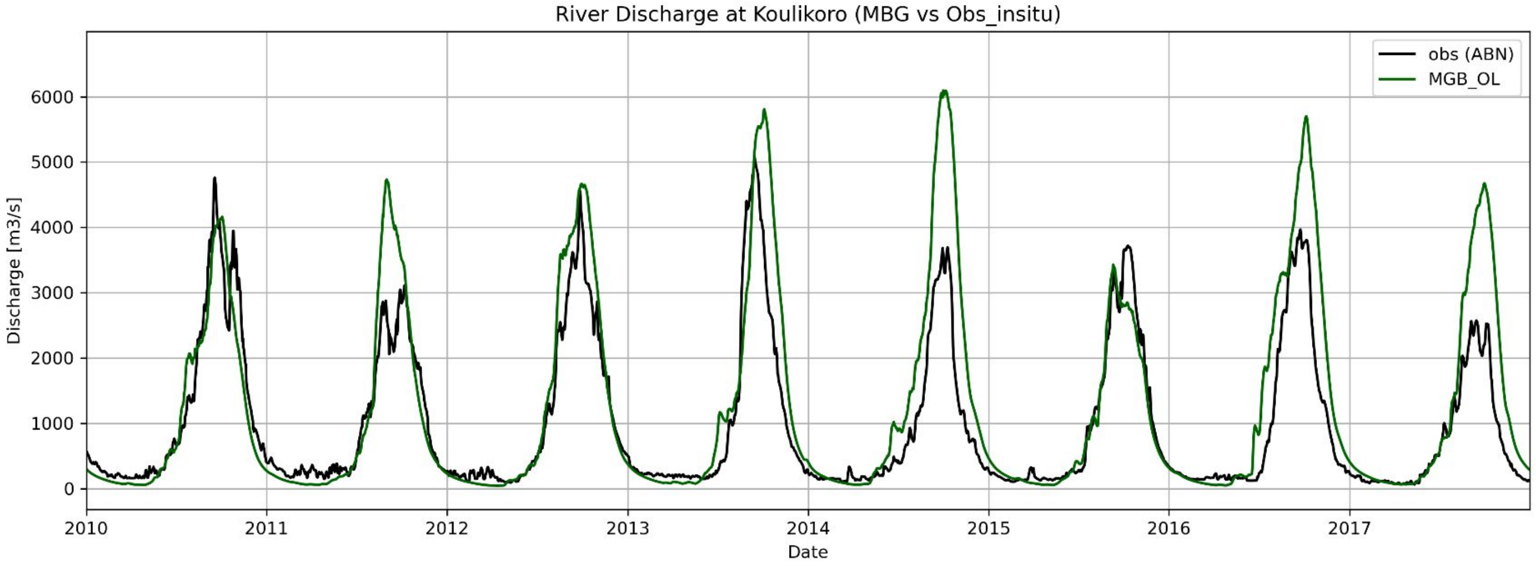
Lokoja station - Downstream of confluence with Benoué river



First results - Niger basin : MGB-HyFAA

Koulikoro station

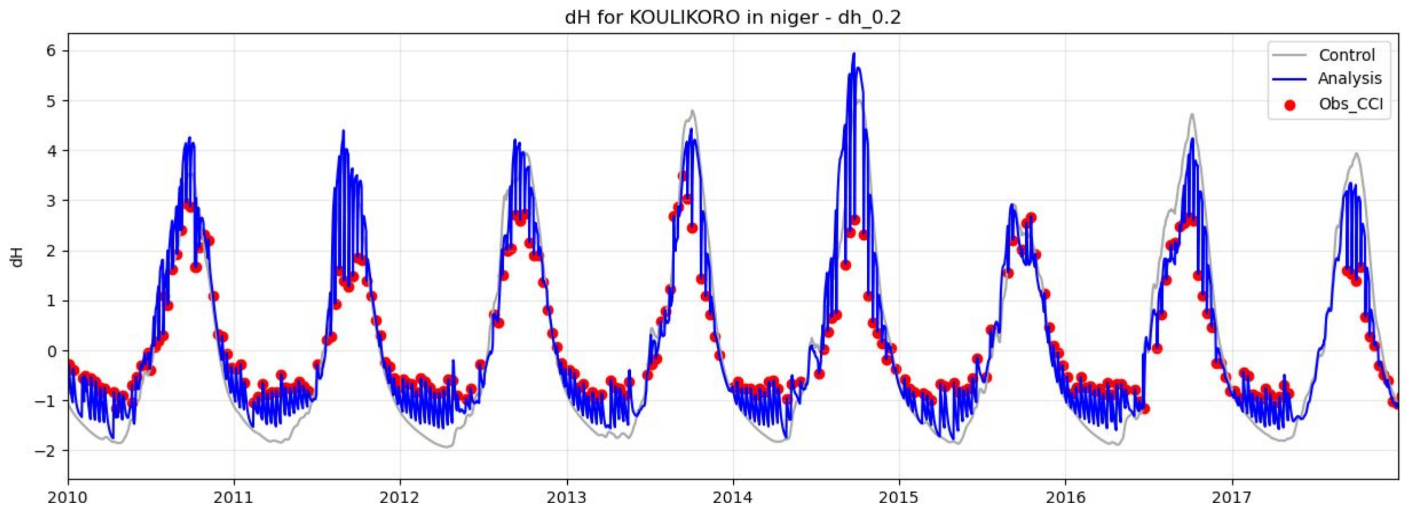
Existing Obs_CCI products :
→ WSE, Qalti

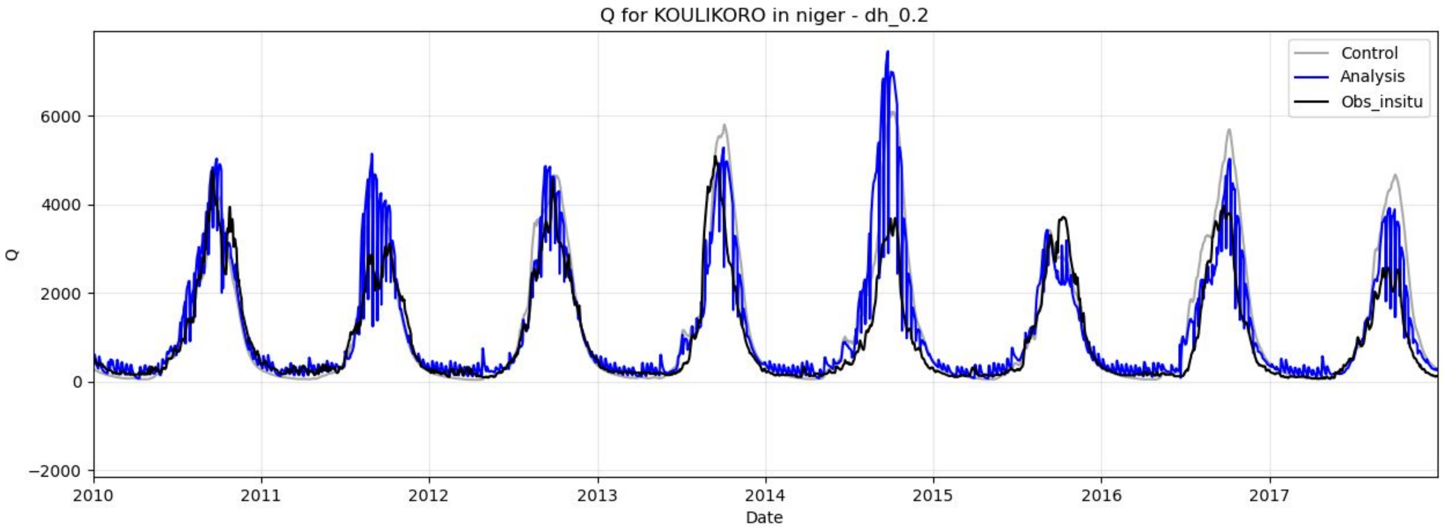


First results - Niger basin : MGB-HyFAA

Koulikoro station

Existing Obs_CCI products :
→ Assimilating WSE (err=0.2m)

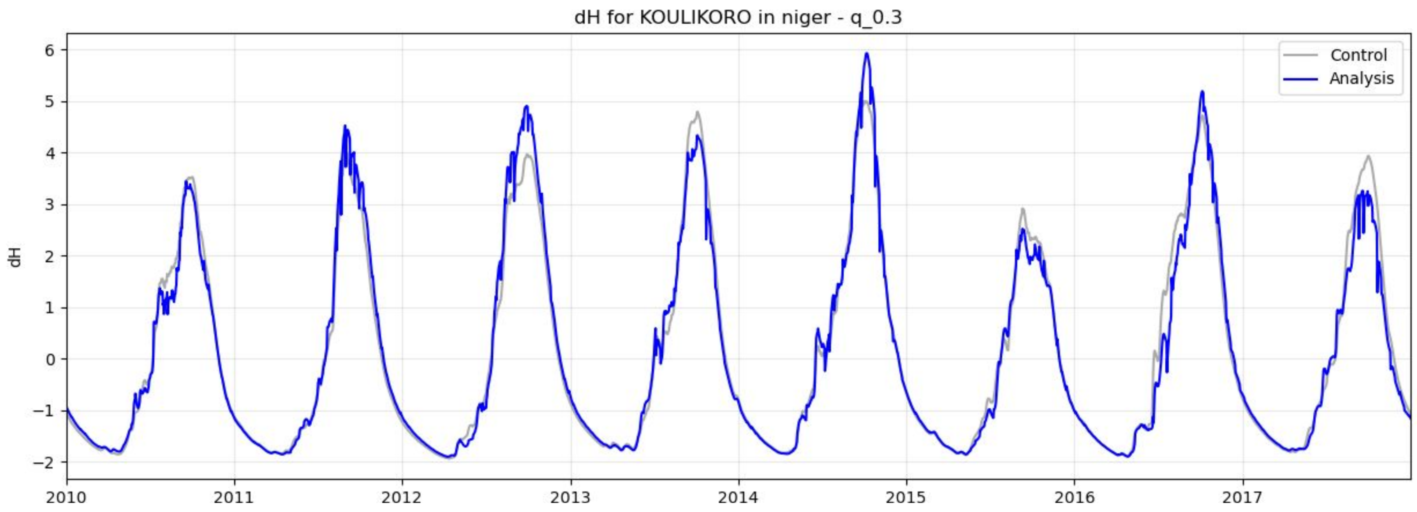


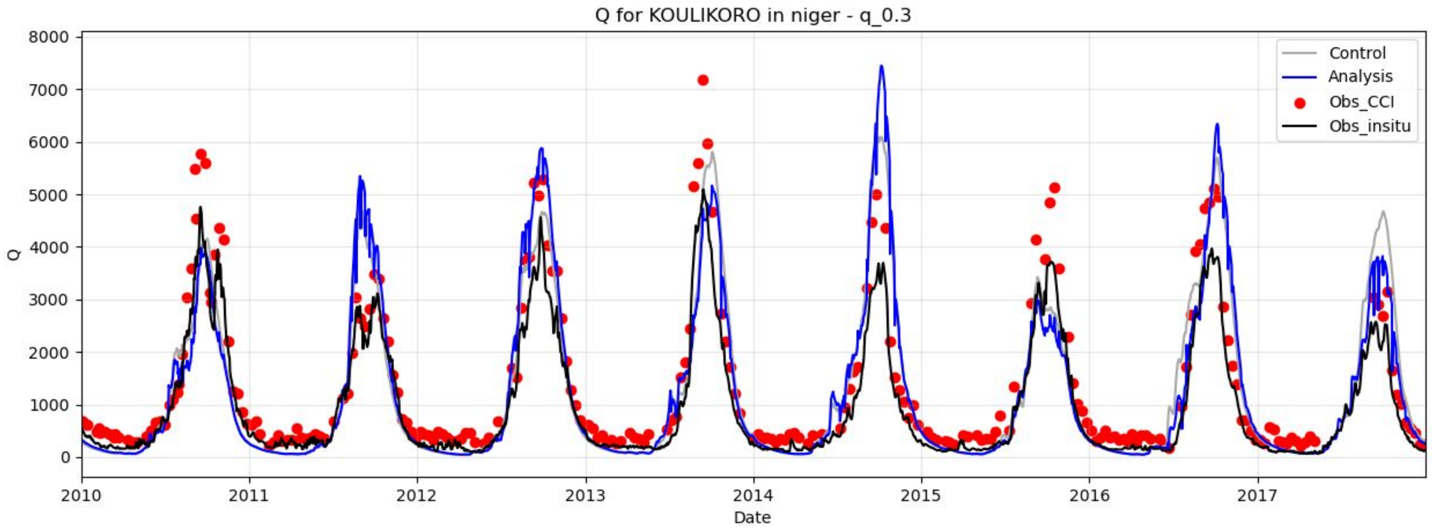


First results - Niger basin : MGB-HyFAA

Koulikoro station

Existing Obs_CCI products :
→ Assimilating Qalti (err%=30%)

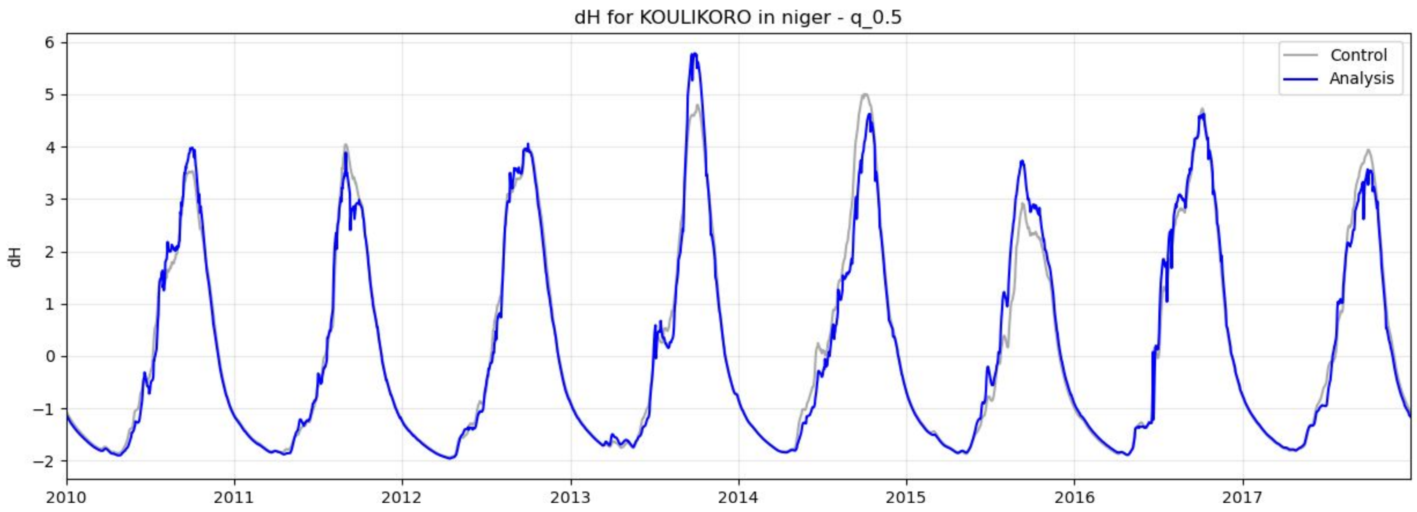


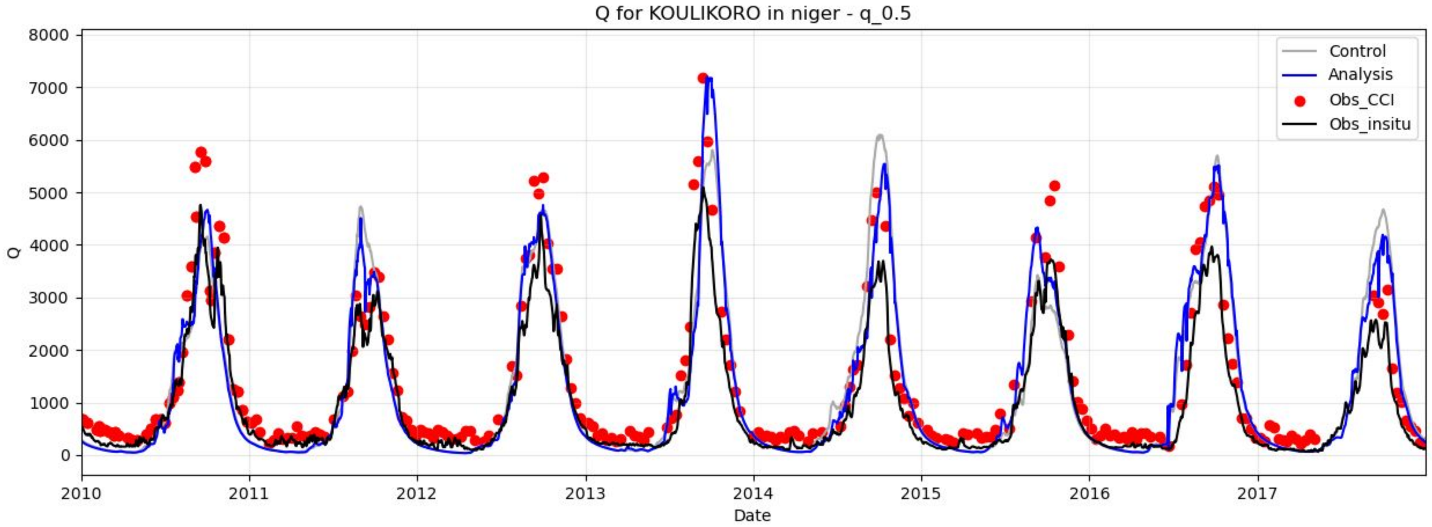


First results - Niger basin : MGB-HyFAA

Koulikoro station

Existing Obs_CCI products :
→ Assimilating Qalti (err%=50%)



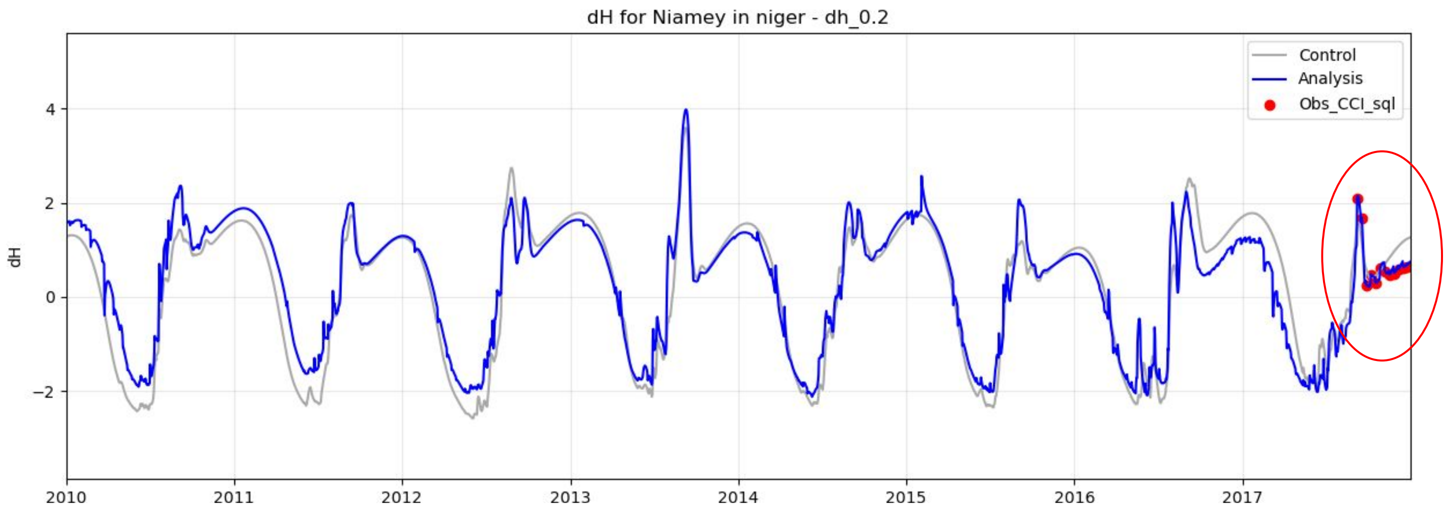


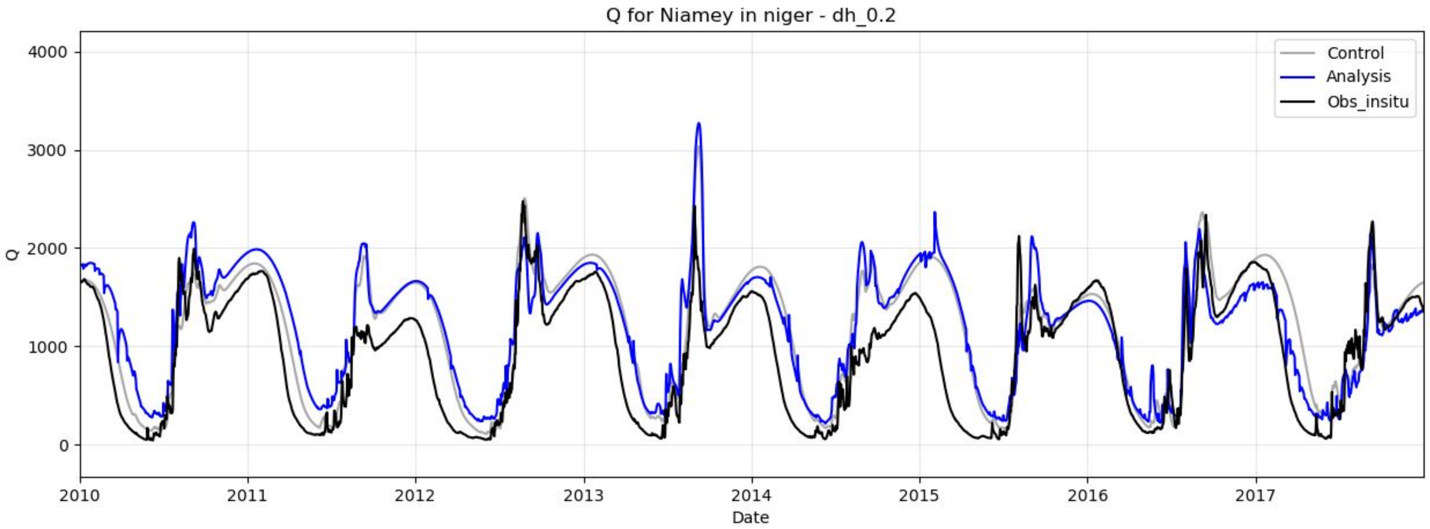
First results - Niger basin : MGB-HyFAA

Niamey station

Existing Obs_CCI products :
→ Assimilating WSE (err=0.2m)

WSE,Qalti > 2018
Can't be compared to ABN in-situ obs.





First results - Niger basin : MGB-HyFAA

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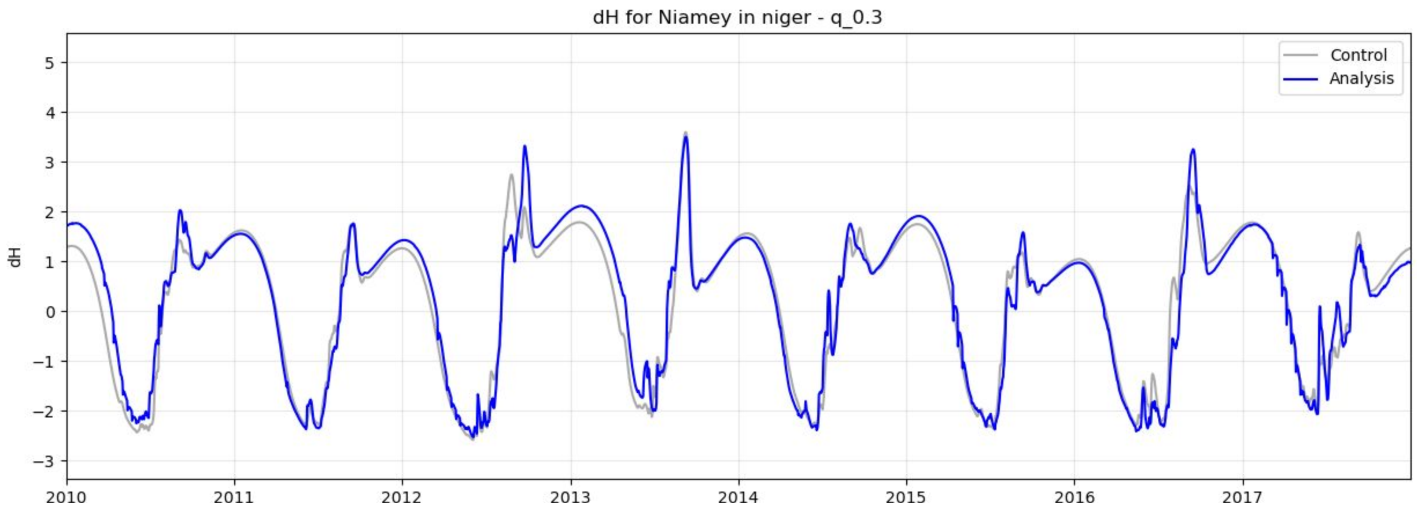
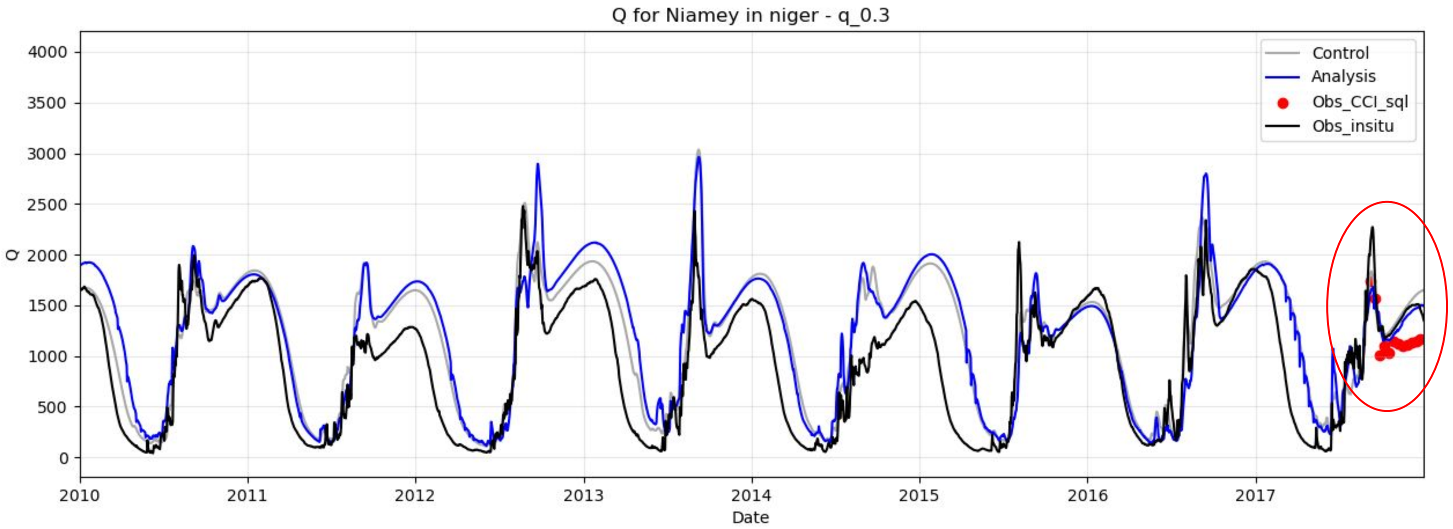


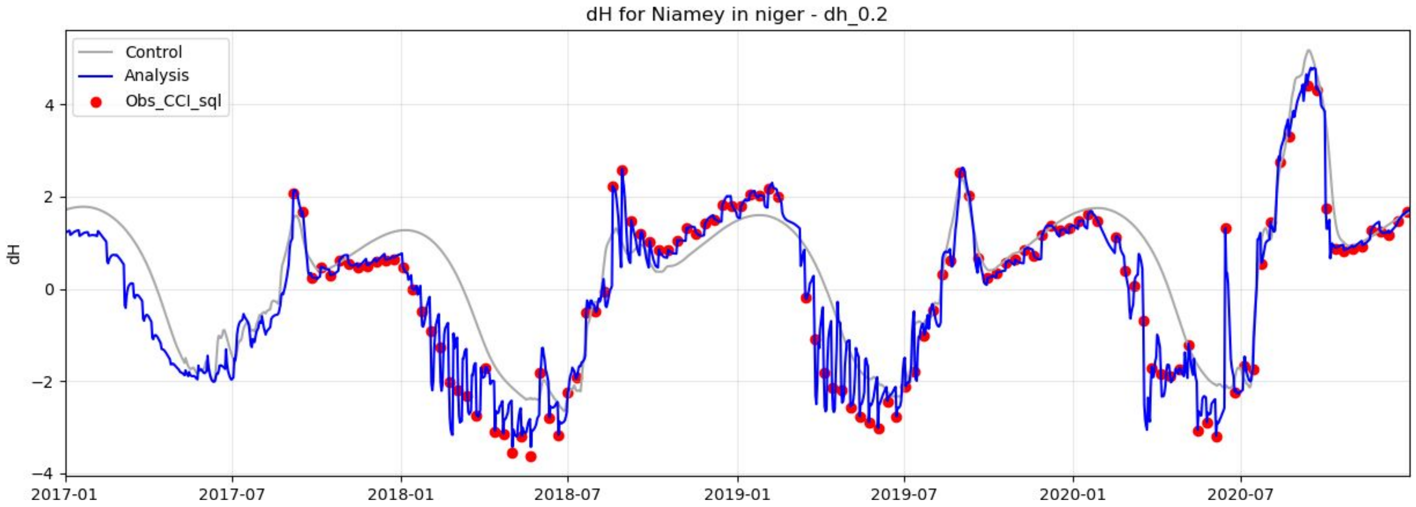


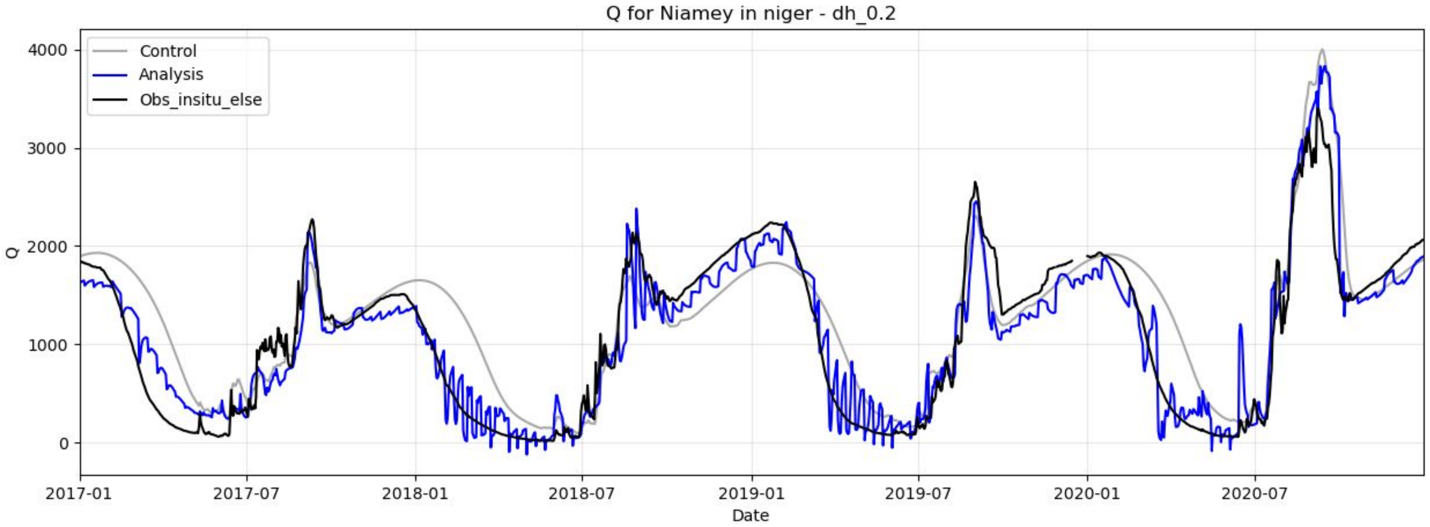
First results - Niger basin : MGB-HyFAA

Niamey station

Existing Obs_CCI products :
→ Assimilating WSE (err=0.2m)

Other in-situ data source [2017-2020]





First results - Niger basin : MGB-HyFAA

Niamey station

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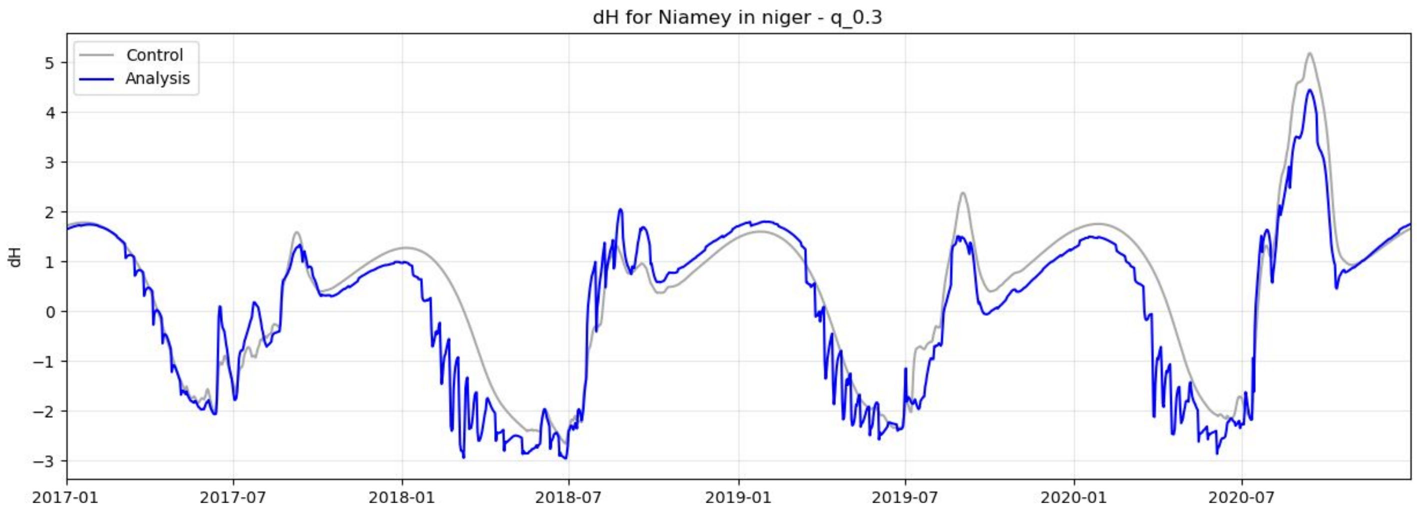
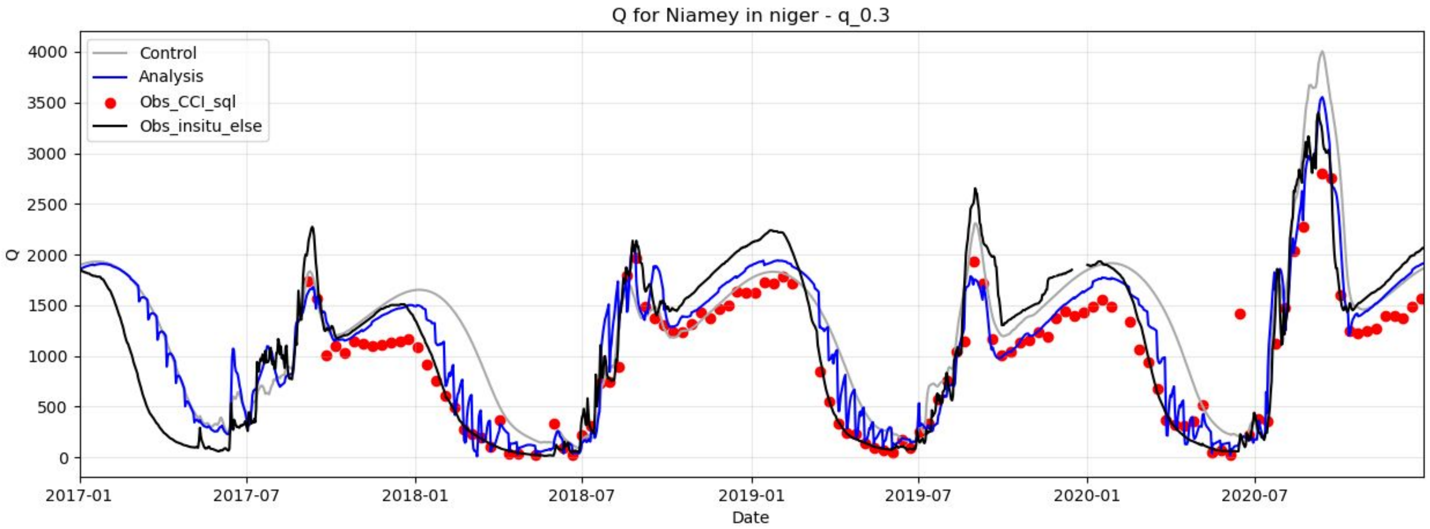


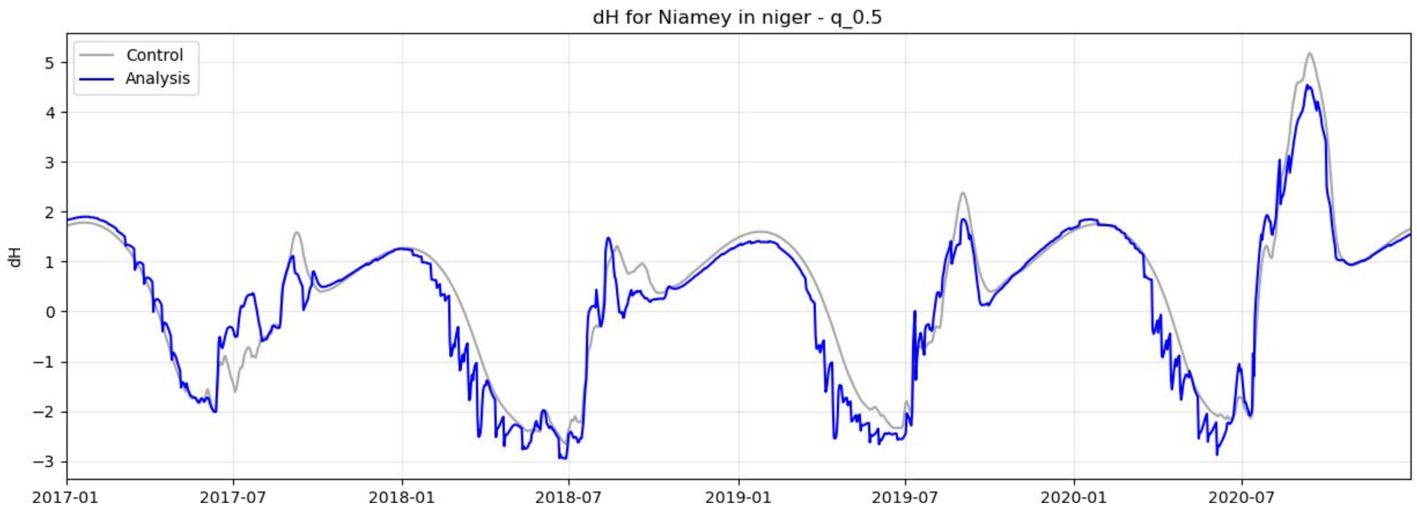


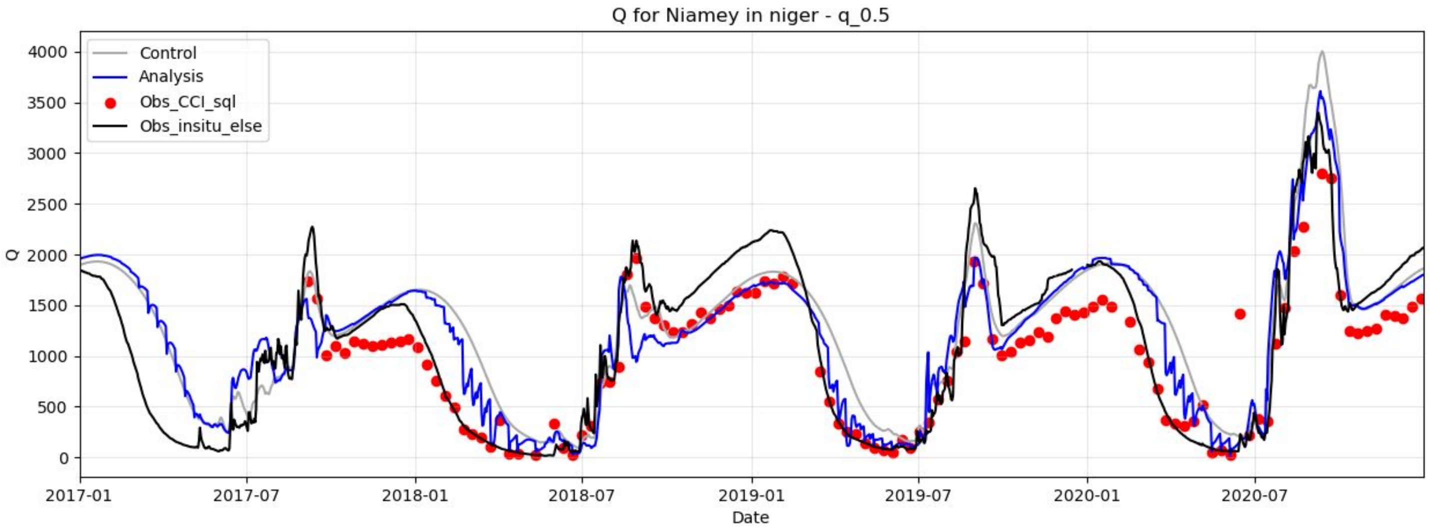
First results - Niger basin : MGB-HyFAA

Niamey station

Existing Obs_CCI products :
→ Assimilating Qalti (err%=50%)

Other in-situ data source [2017-2020]

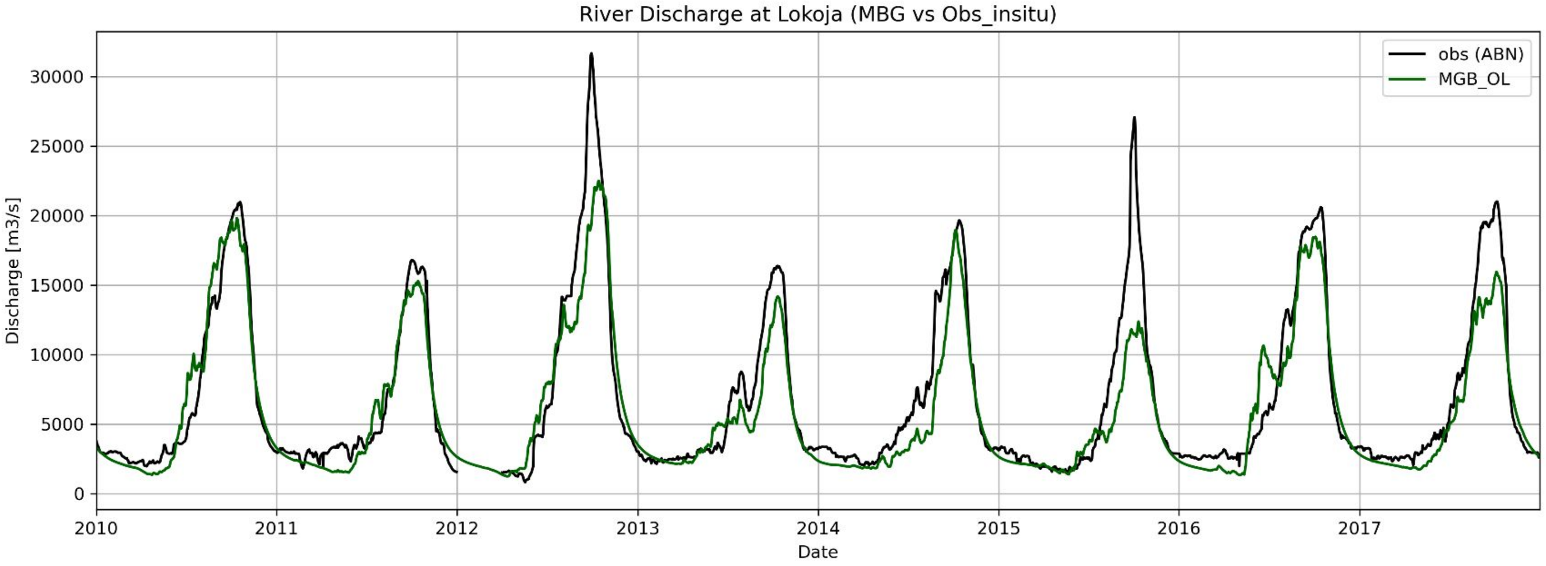




First results - Niger basin : MGB-HyFAA

Lokoja station

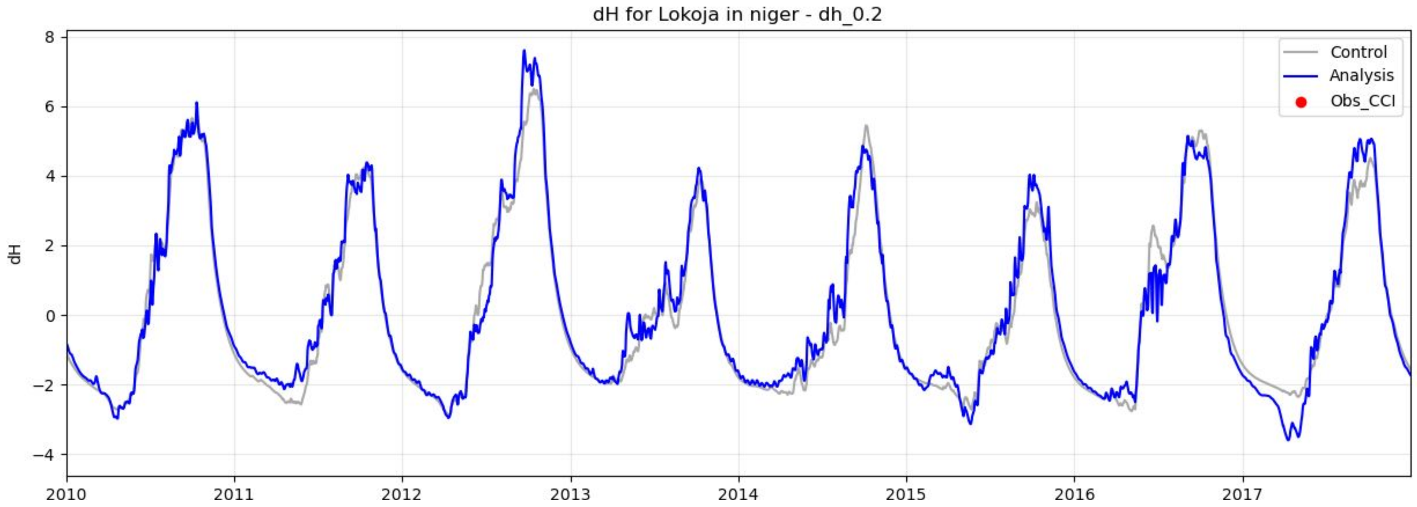
Existing Obs_CCI products :
→ WSE, Qalti

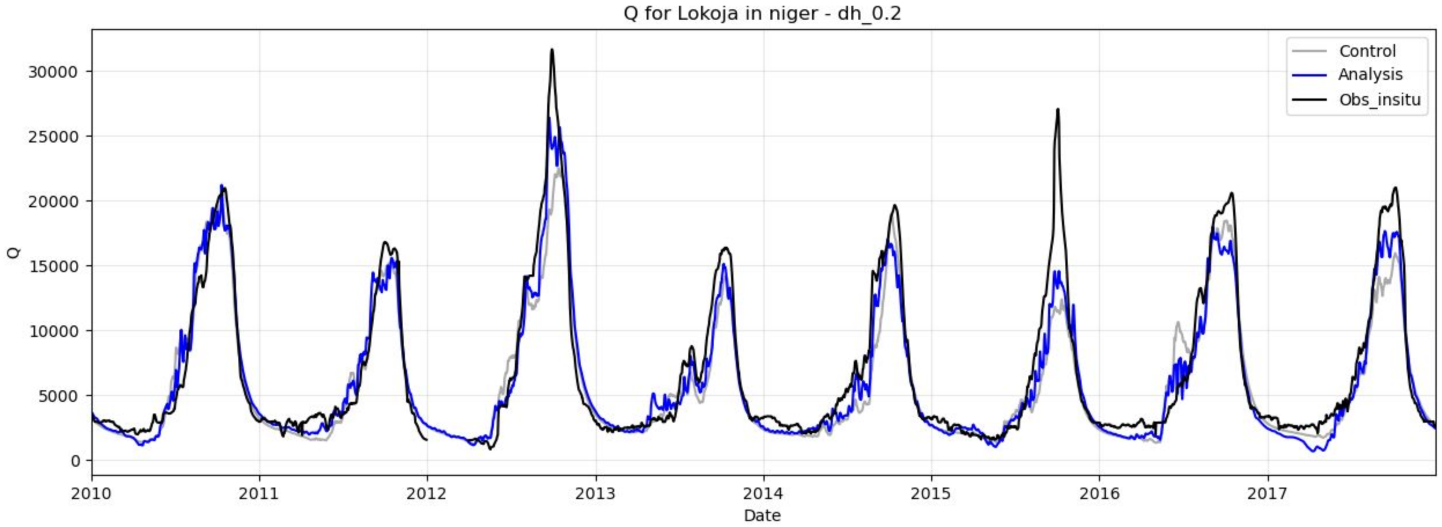


First results - Niger basin : MGB-HyFAA

Lokoja station

Obs_CCI products :
→ WSE at Lokoja = nan





First results - Niger basin : MGB-HyFAA

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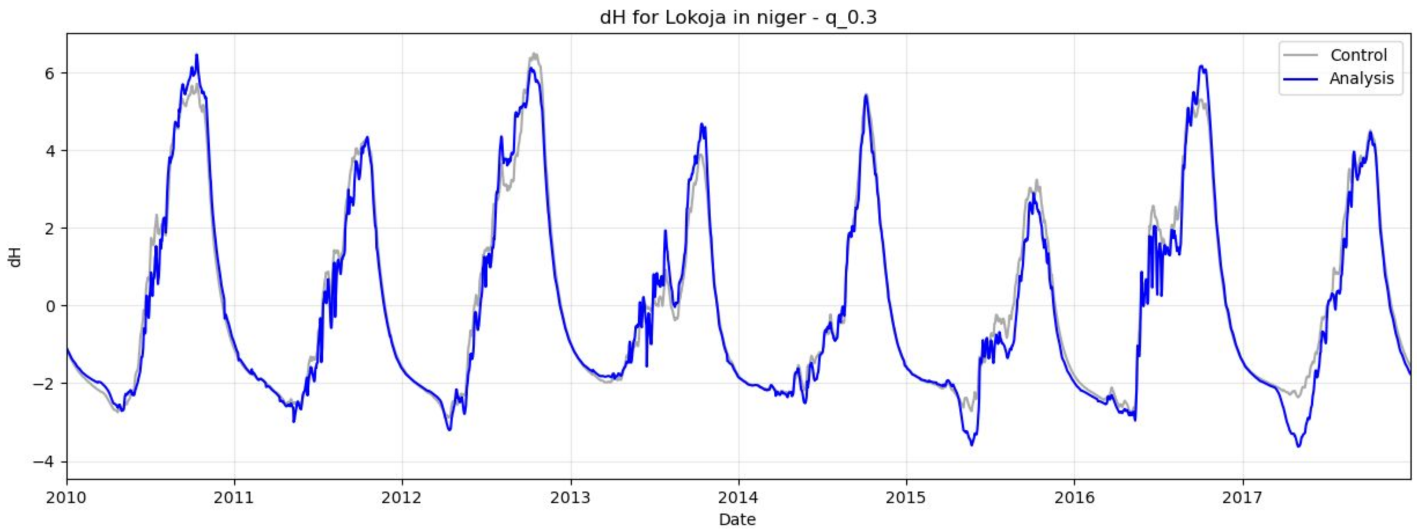

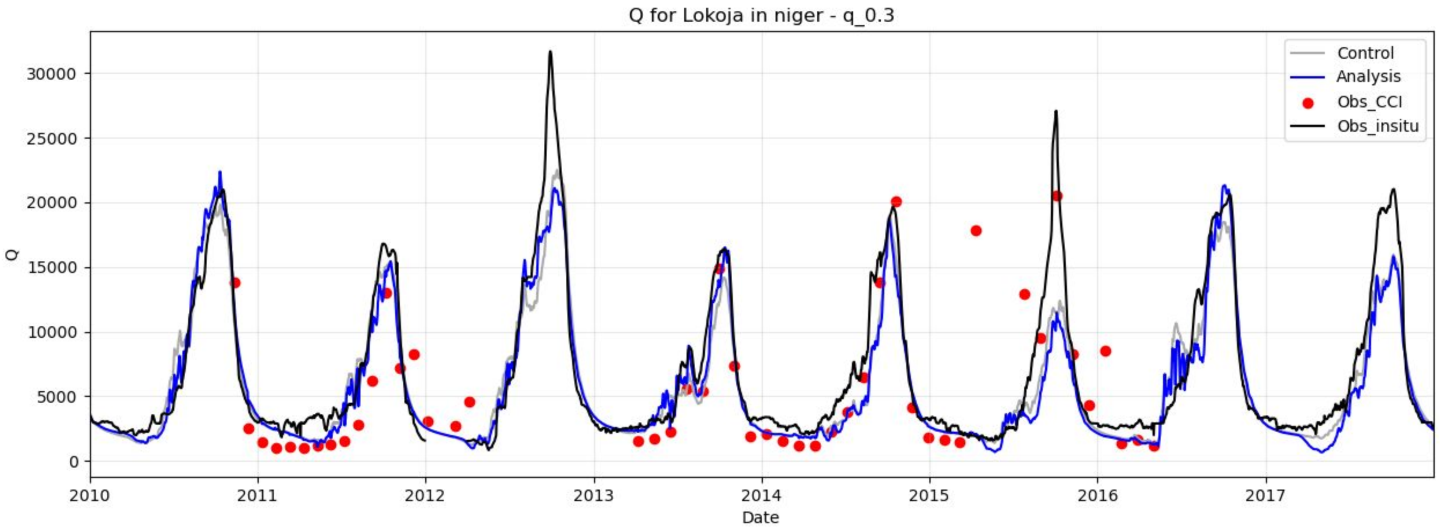

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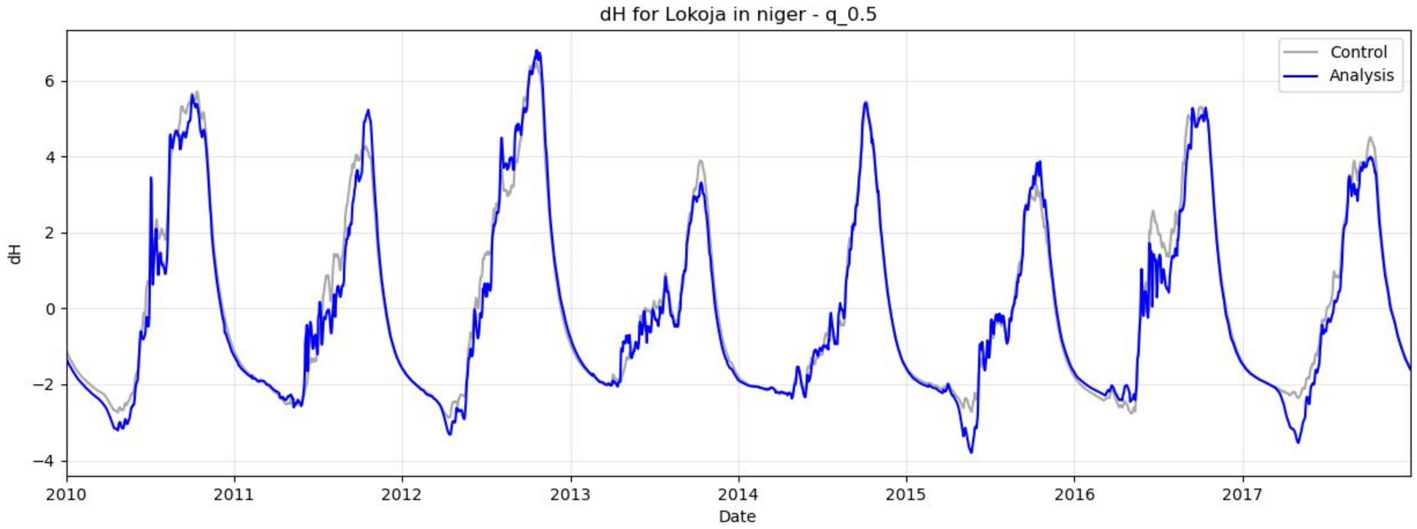
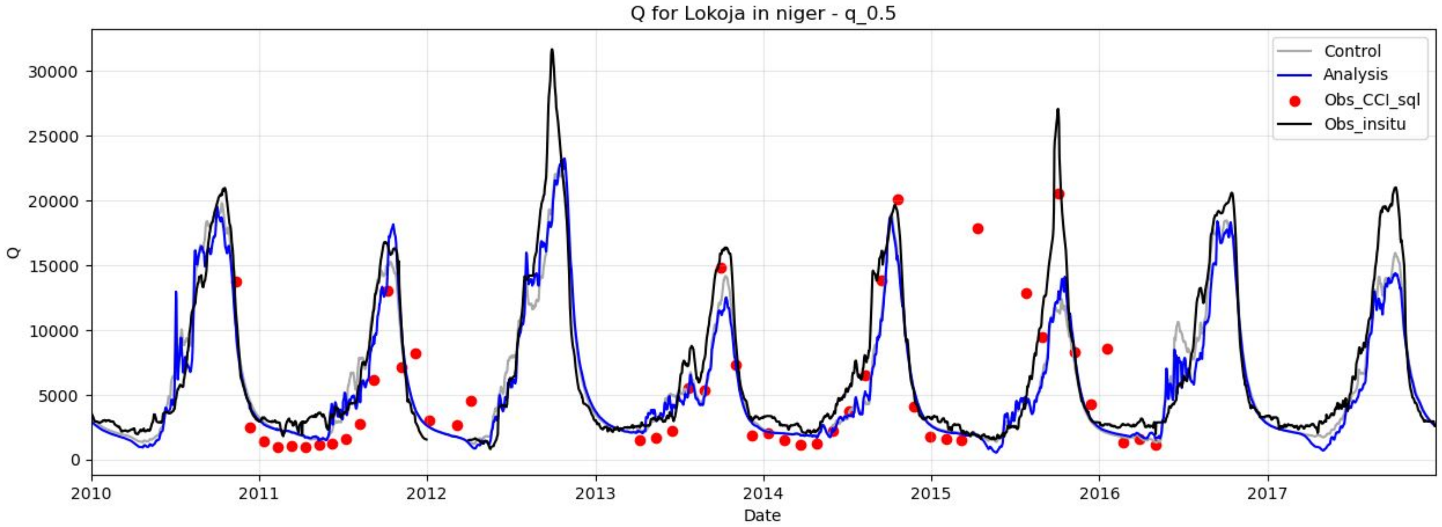




Perspectives

- Sparse Virtual Stations: Few virtual stations within each river basin
  - Limited impact at the basin scale
  - Relevance of Assimilating additional observations

- Validation Approaches:
  - Daily vs. monthly metrics.
  - Independent observations

        In-situ data :

            Niger: **ABN** with ~40 gauge stations / daily data 2010-2017, …

            Congo: **GRDC**, …

- Assimilation Methods to Test:
  - Dual state-parameter correction
  - Inflow correction

- Project SEED-FD: Offers cross-validation perspectives for specific basins (LISFLOOD model)

- Opportunities with SWOT products

- Long-Term: Implement operational reanalysis

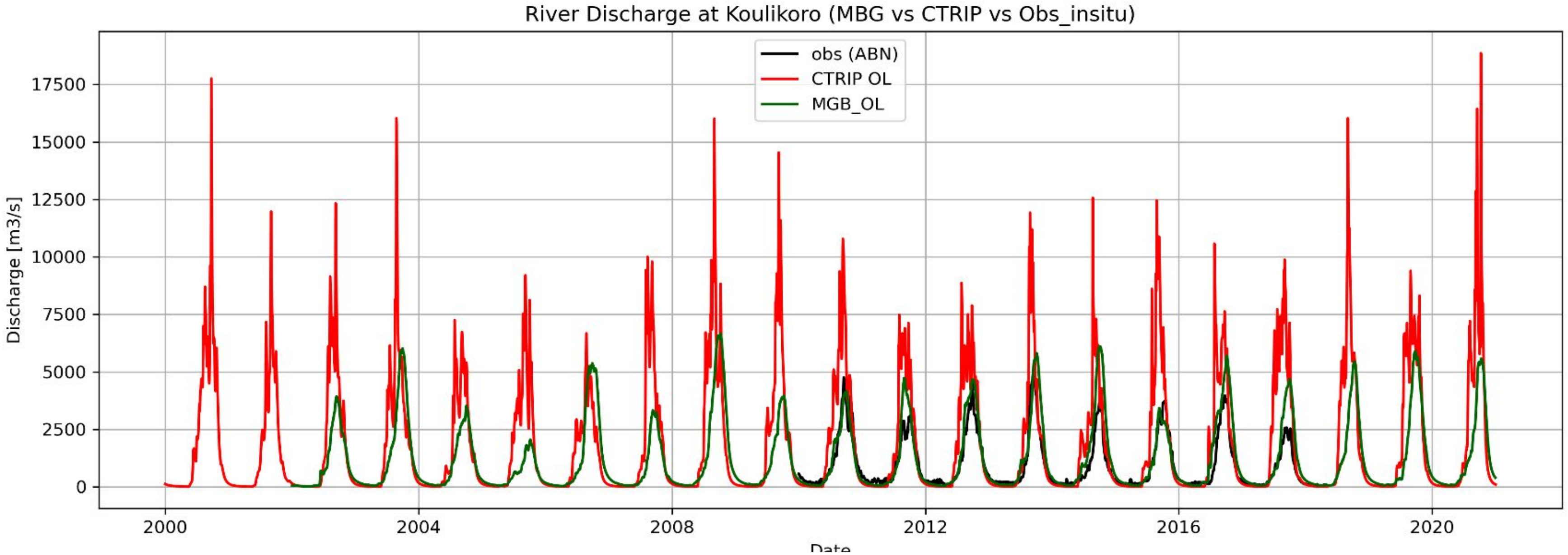
river
discharge
cci

climate.esa.int/projects/river-discharge

Appendix

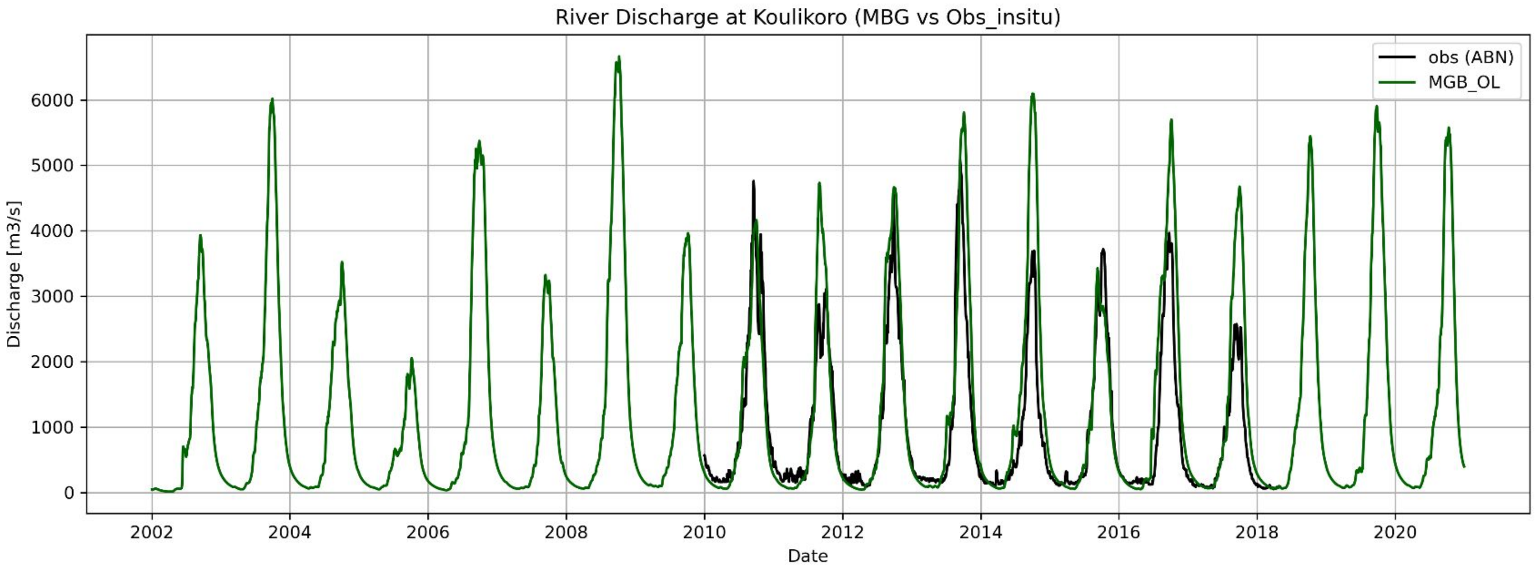
Reference Run - CTRIP vs MGB

Koulikoro station - upstream Delta



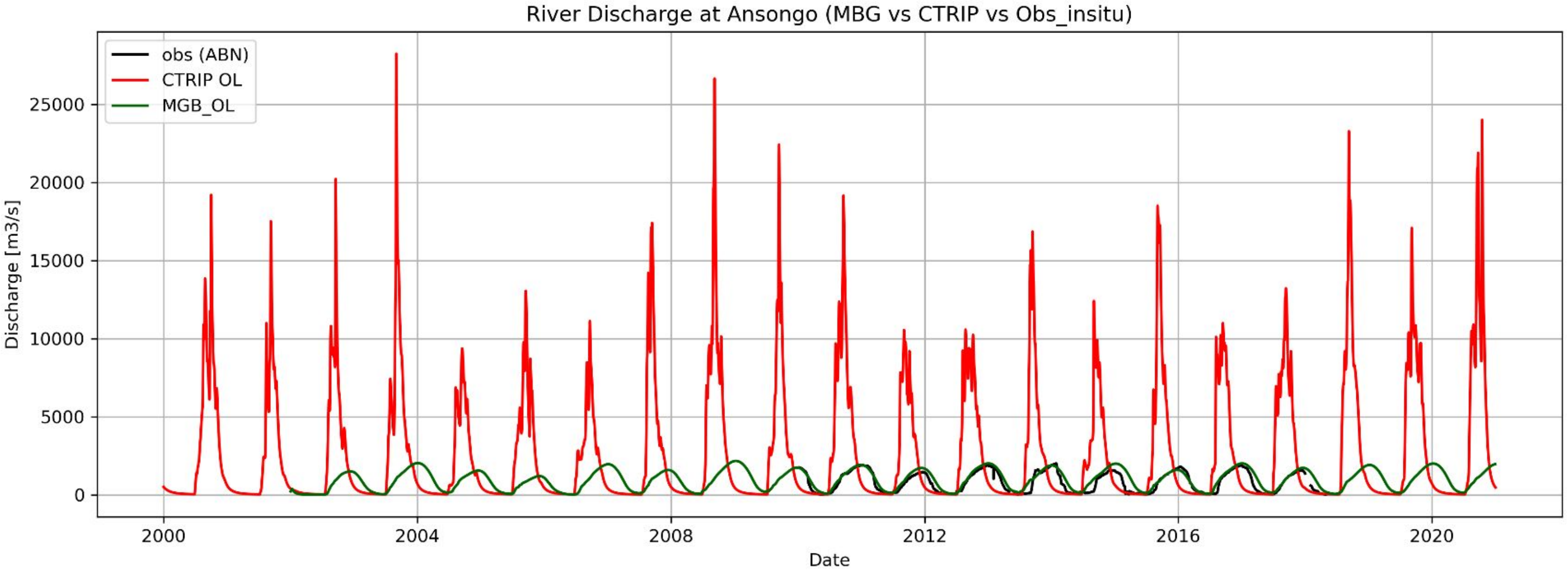
Reference Run - CTRIP vs MGB

Koulikoro station - upstream Delta



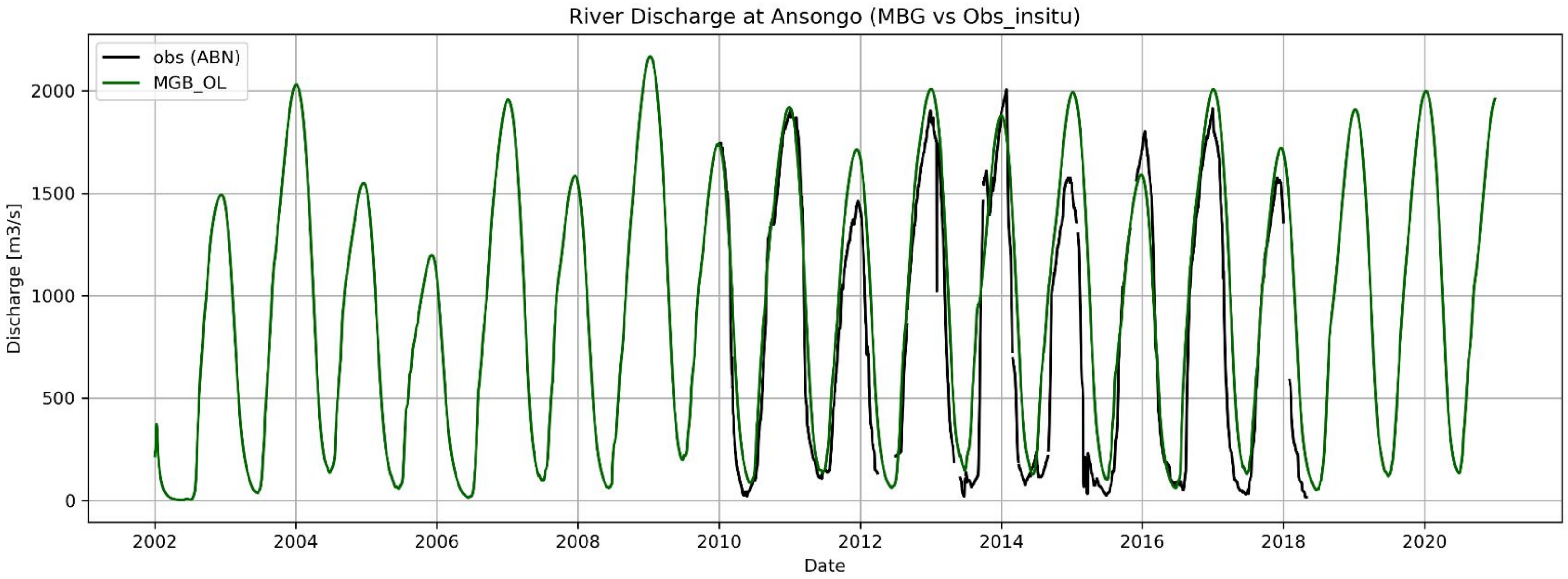
Reference Run - CTRIP vs MGB

Ansongo station



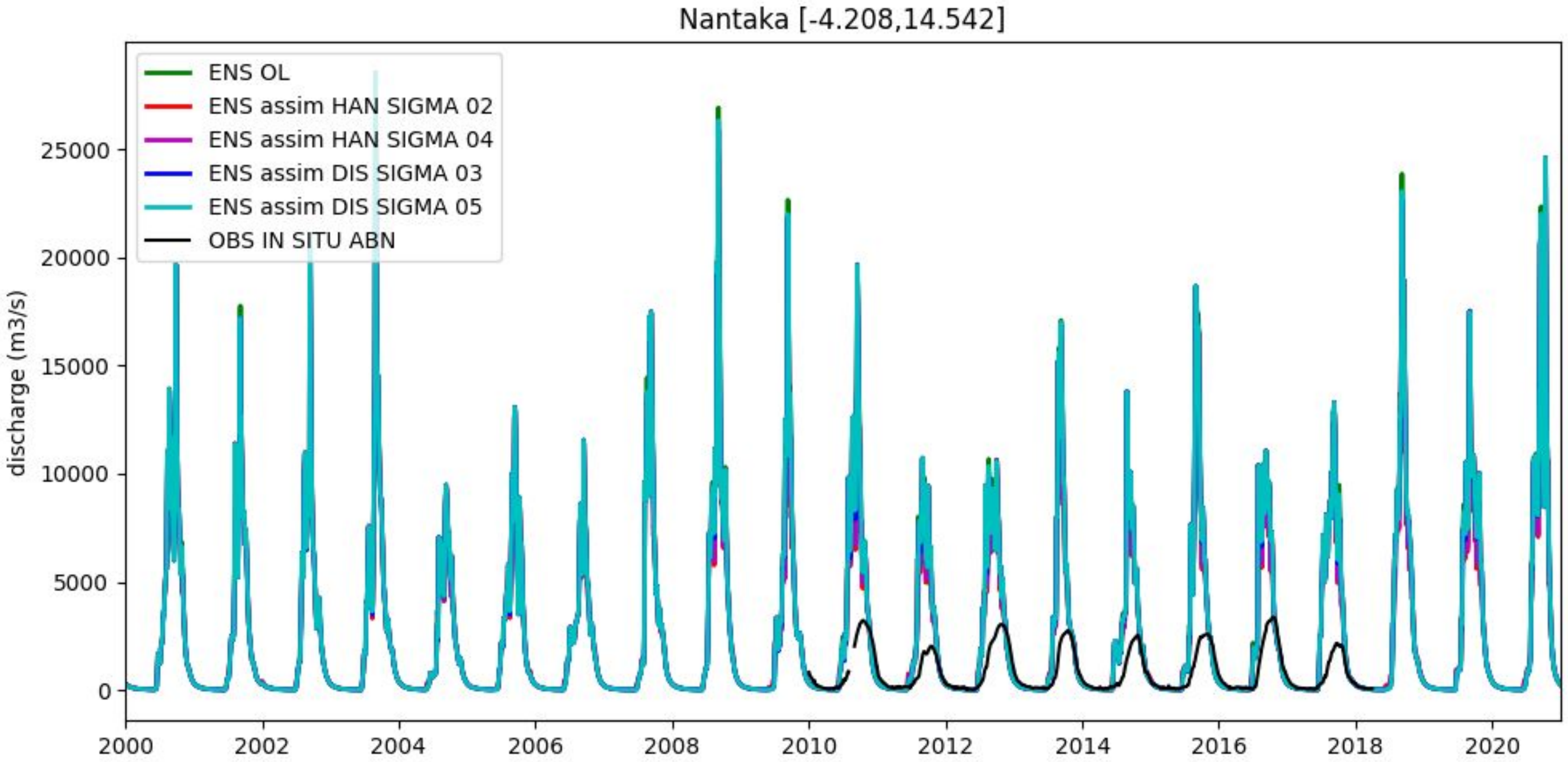
Reference Run - CTRIP vs MGB

Ansongo station



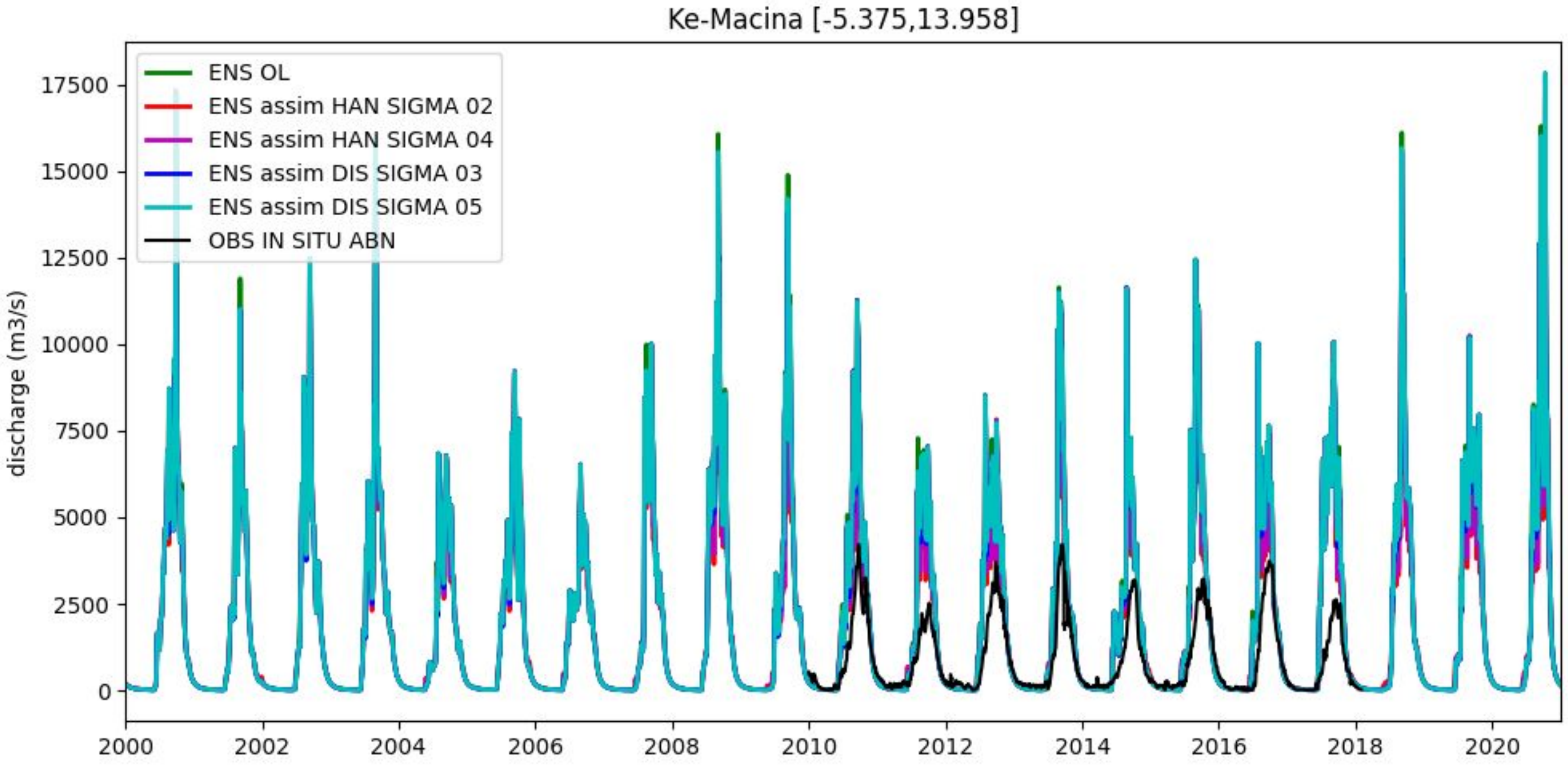
Results - Niger basin : CTRIP-HyDAS

Nantaka station - within Delta



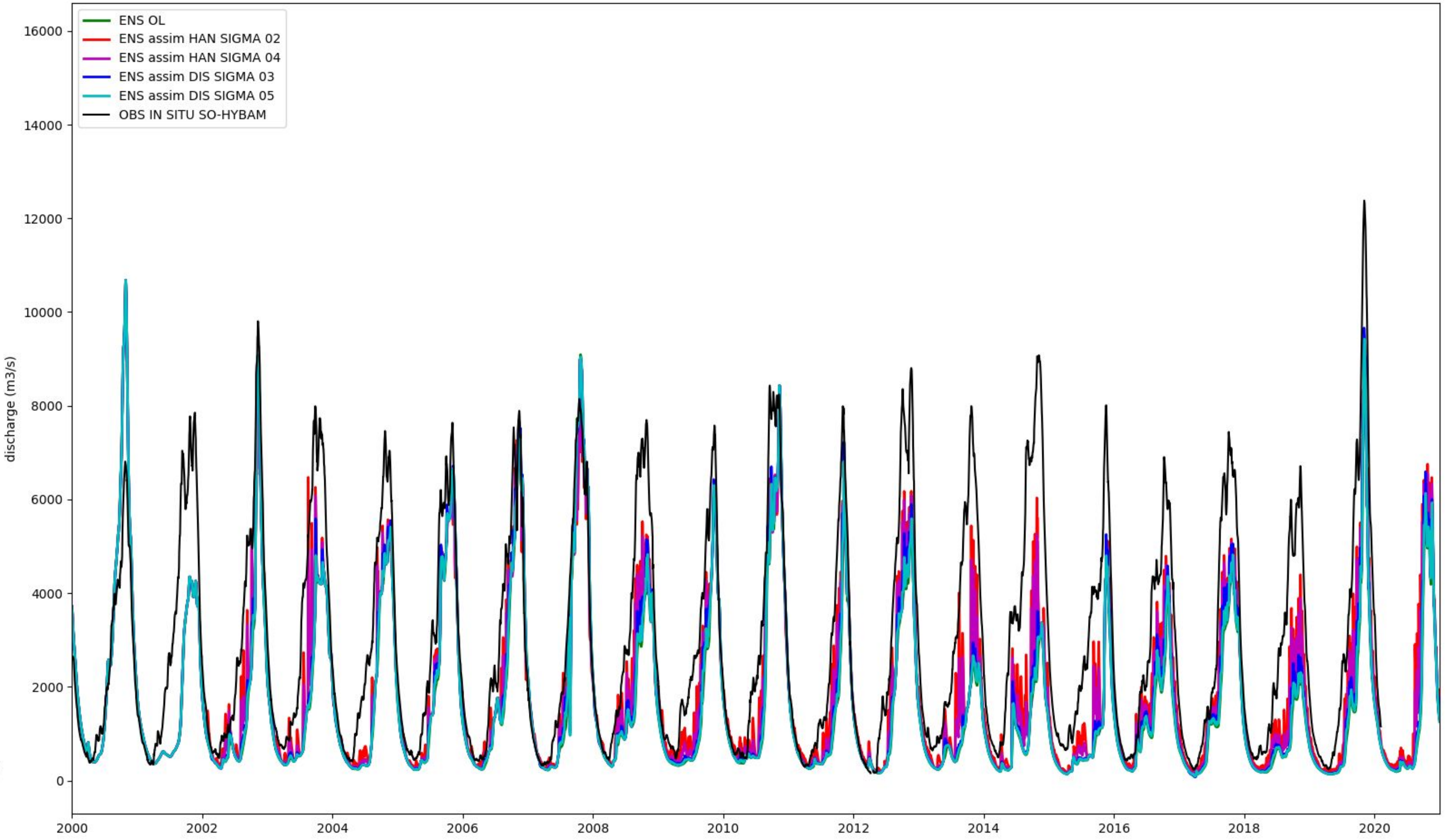
Results - Niger basin : CTRIP-HyDAS

Ke-Macina station - within Delta



Results - Congo basin : CTRIP-HyDAS

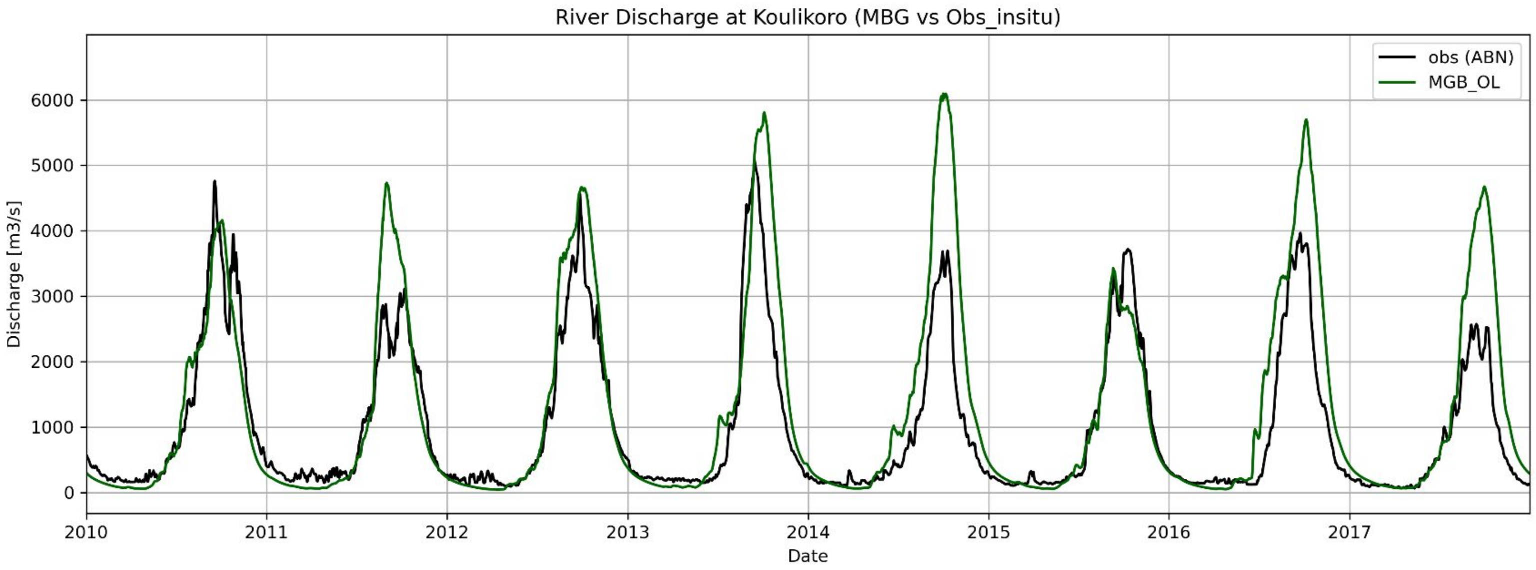
Oubangui station



First results - Niger basin : MGB-HyFAA

Koulikoro station

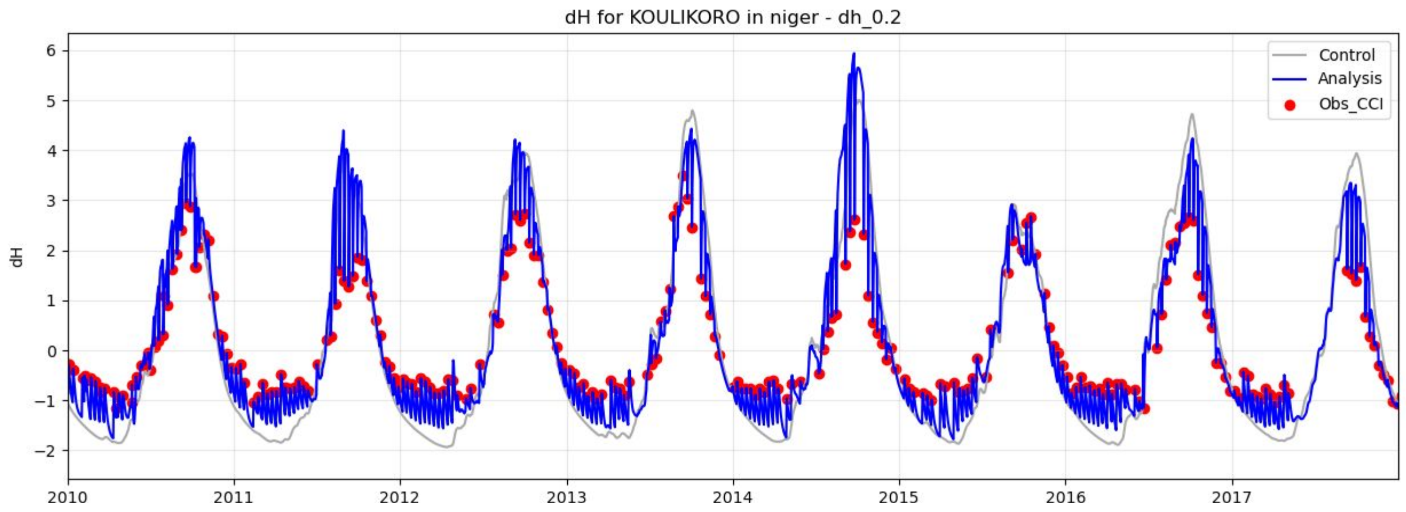
Existing Obs_CCI products :
→ WSE, Qalti

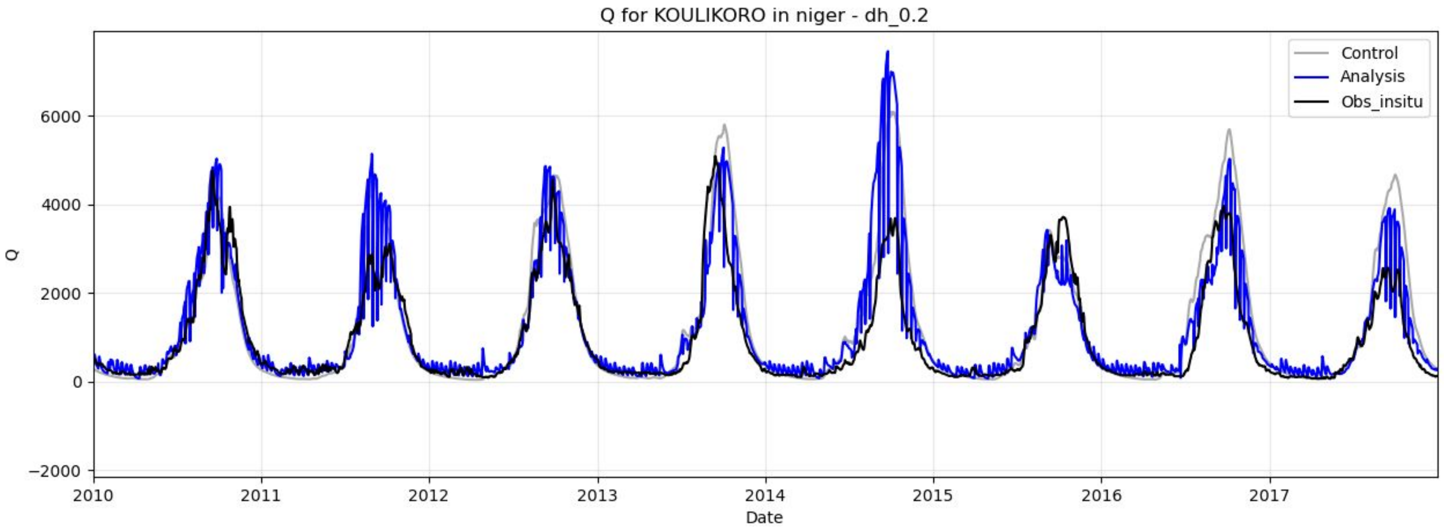


First results - Niger basin : MGB-HyFAA

Koulikoro station

Existing Obs_CCI products :
→ Assimilating WSE (err=0.2m)

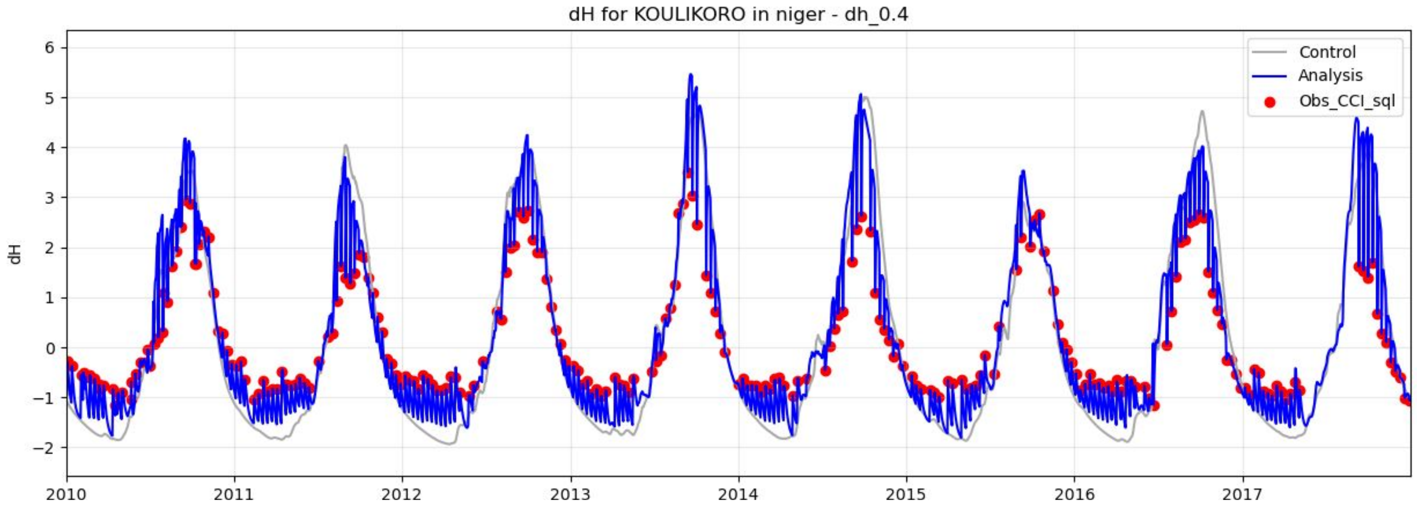


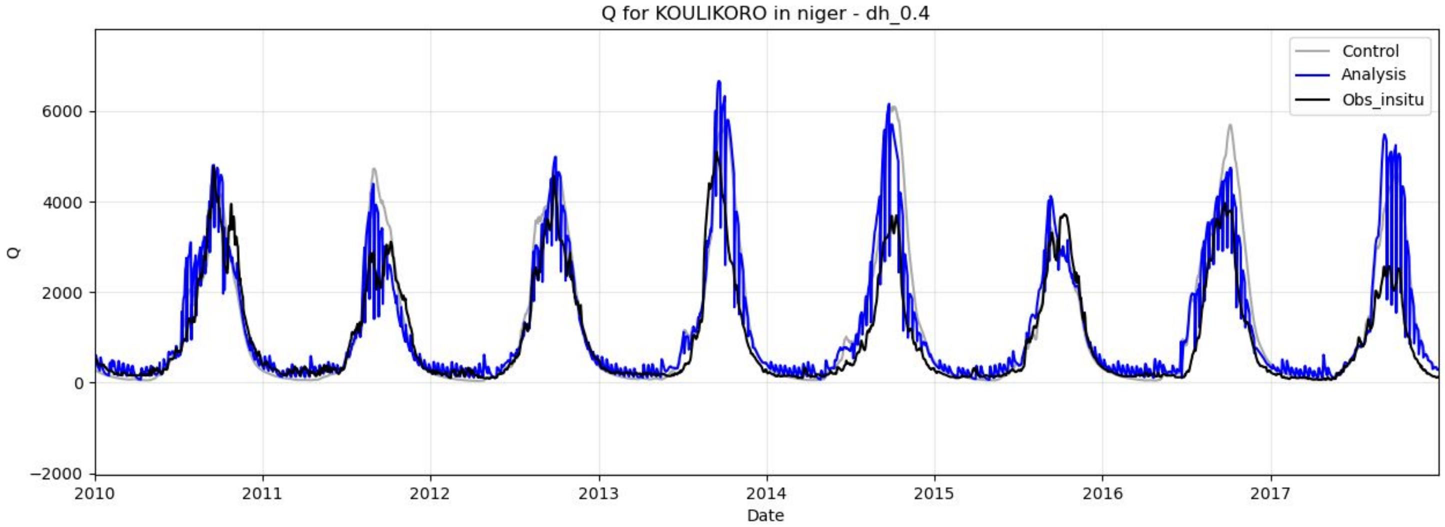


First results - Niger basin : MGB-HyFAA

Koulikoro station

Existing Obs_CCI products :
→ Assimilating WSE (err=0.4m)

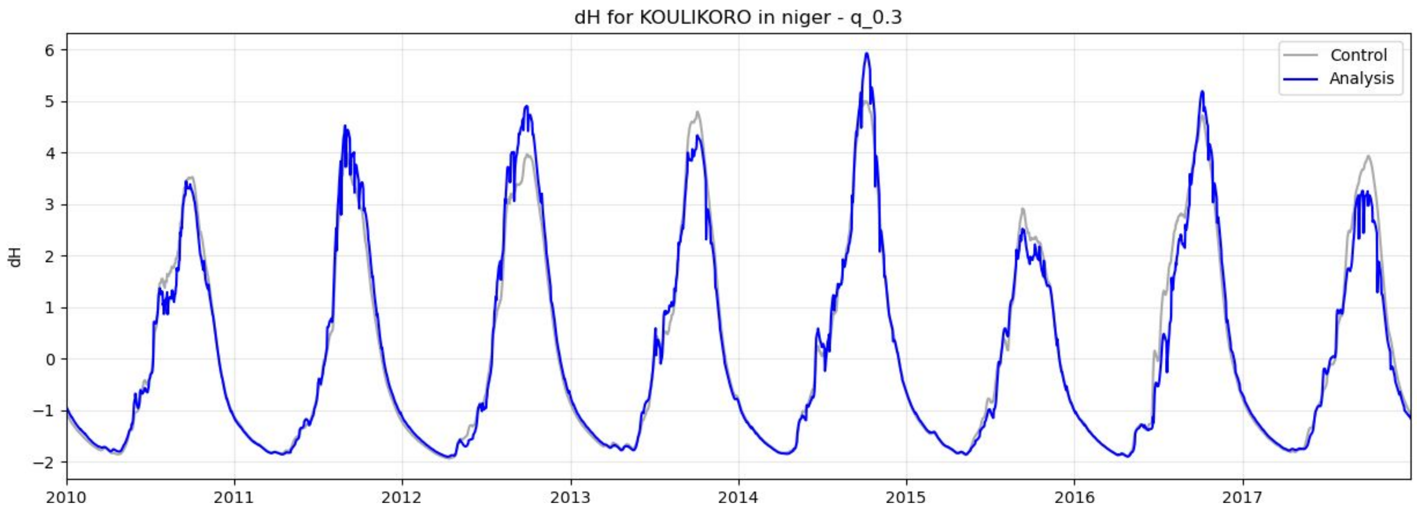


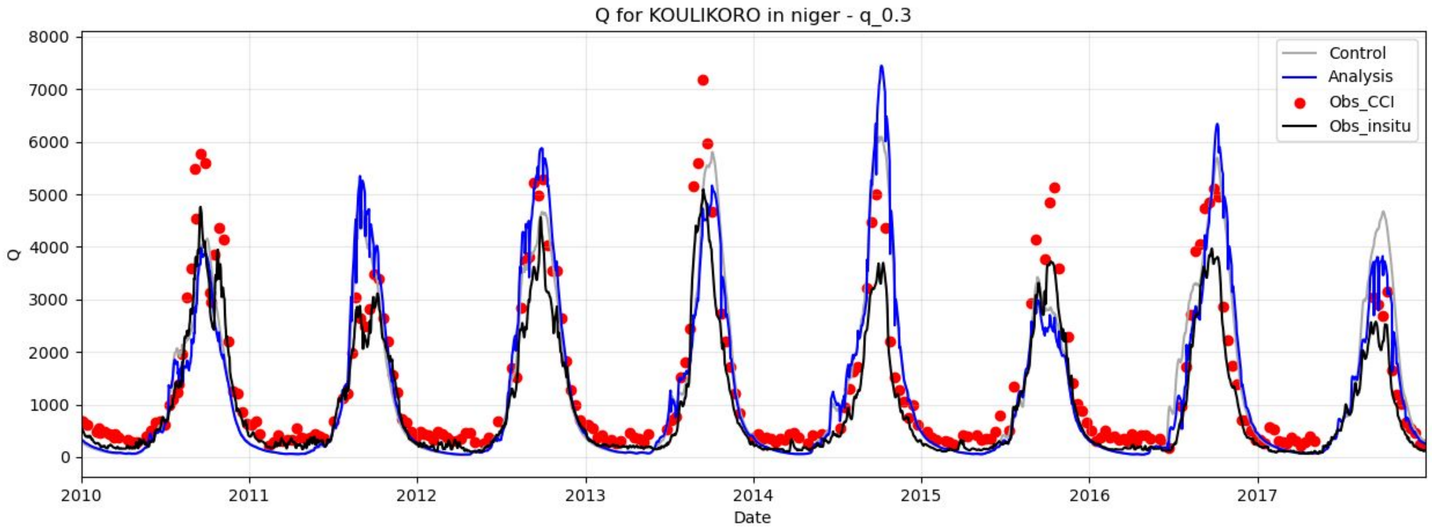


First results - Niger basin : MGB-HyFAA

Koulikoro station

Existing Obs_CCI products :
→ Assimilating Qalti (err%=30%)

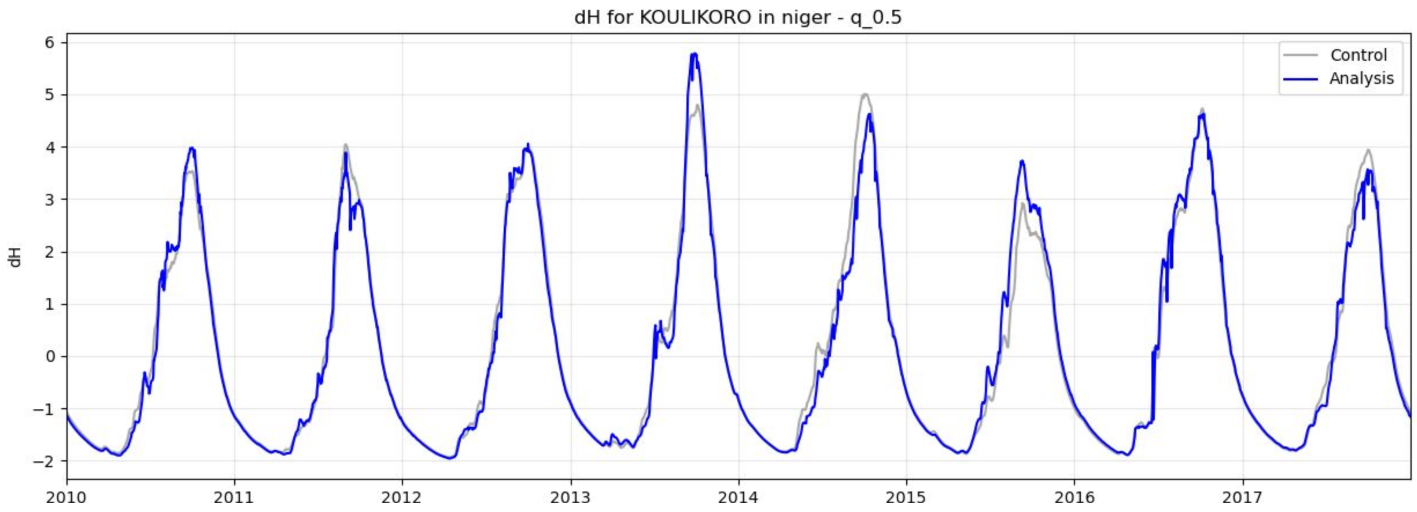


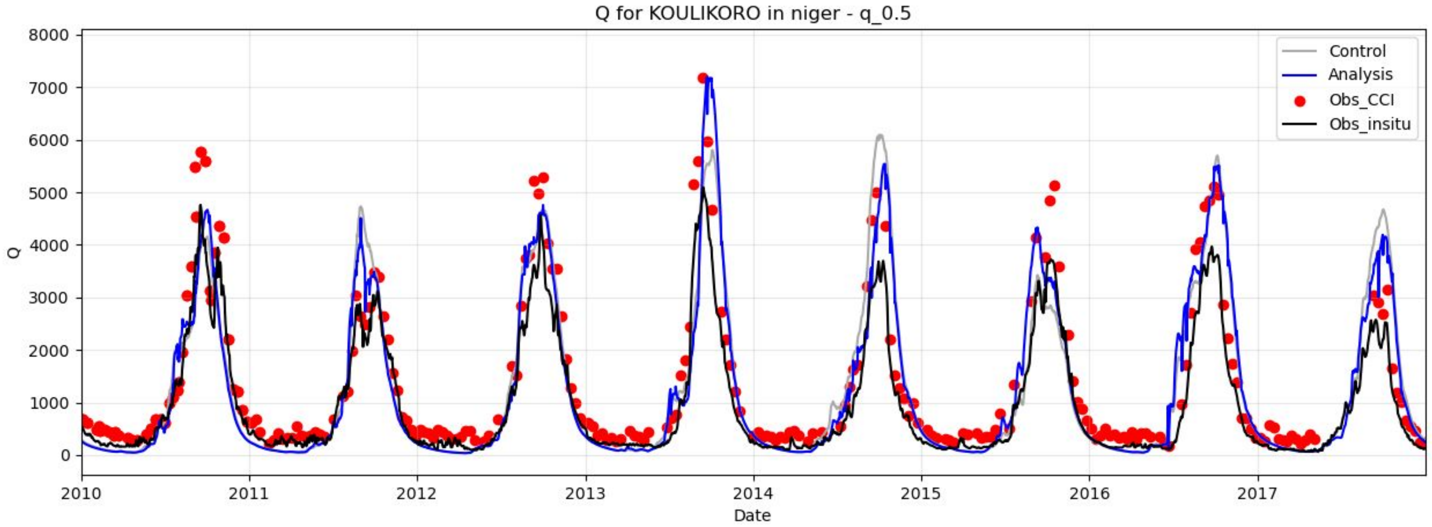


First results - Niger basin : MGB-HyFAA

Koulikoro station

Existing Obs_CCI products :
→ Assimilating Qalti (err%=50%)



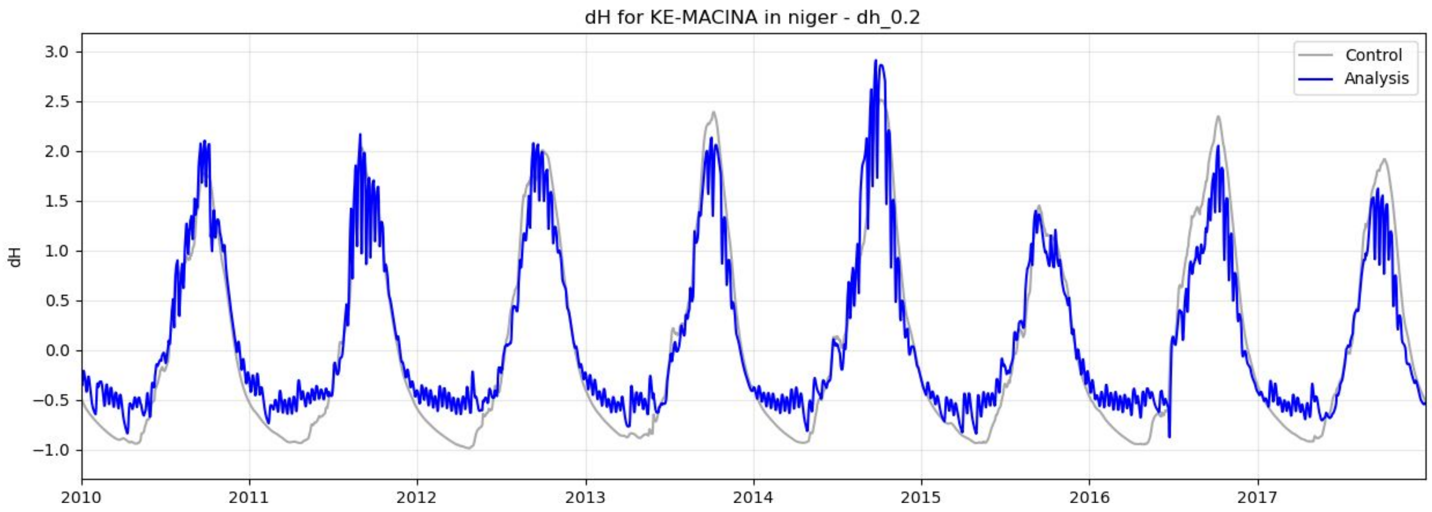


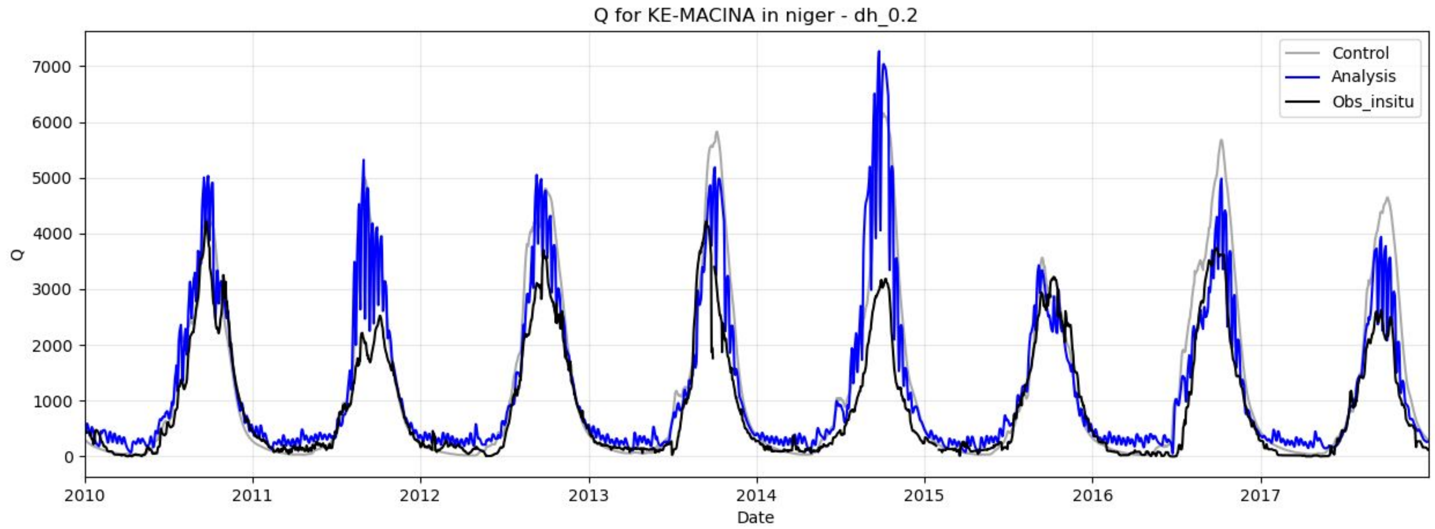
First results - Niger basin : MGB-HyFAA

Ke-Macina station

No CCI_obs product

Assimilating WSE in upstream/downstream stations (err=0.2m)



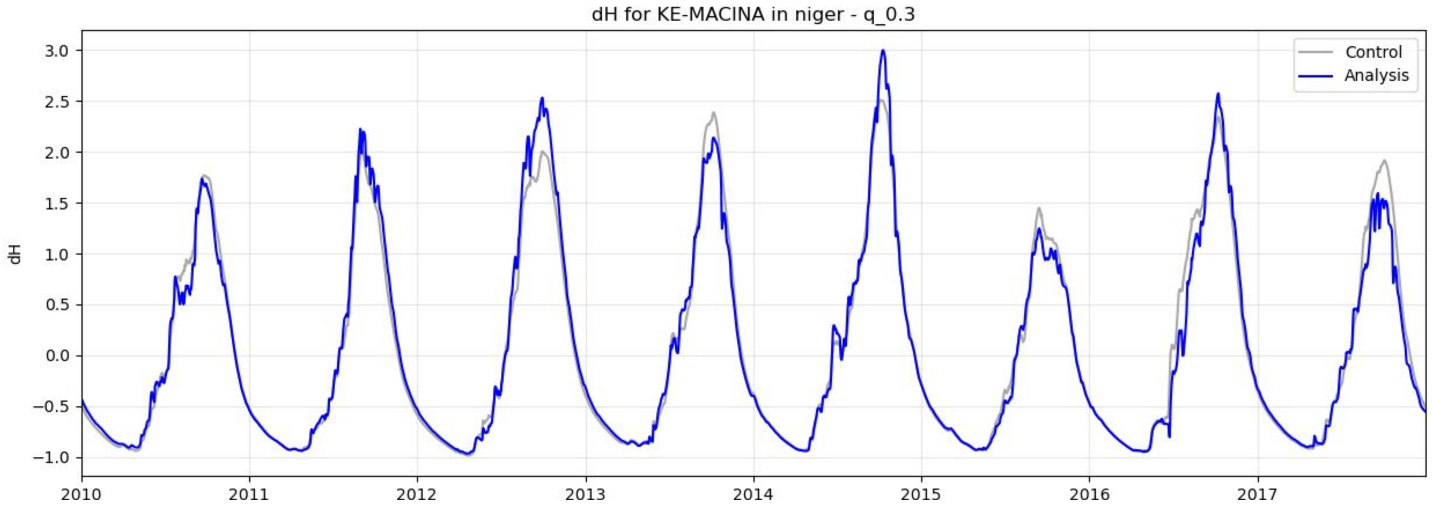


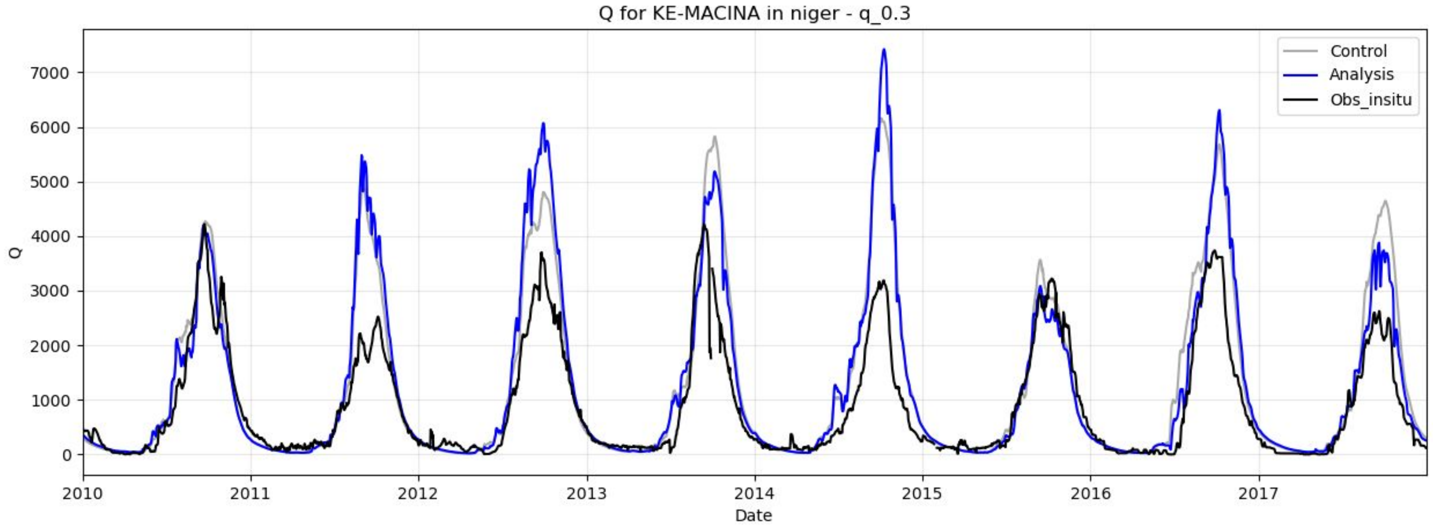
First results - Niger basin : MGB-HyFAA

Ke-Macina station

No CCI_obs product

Assimilating Qalti CCI_obs (err%=30%)

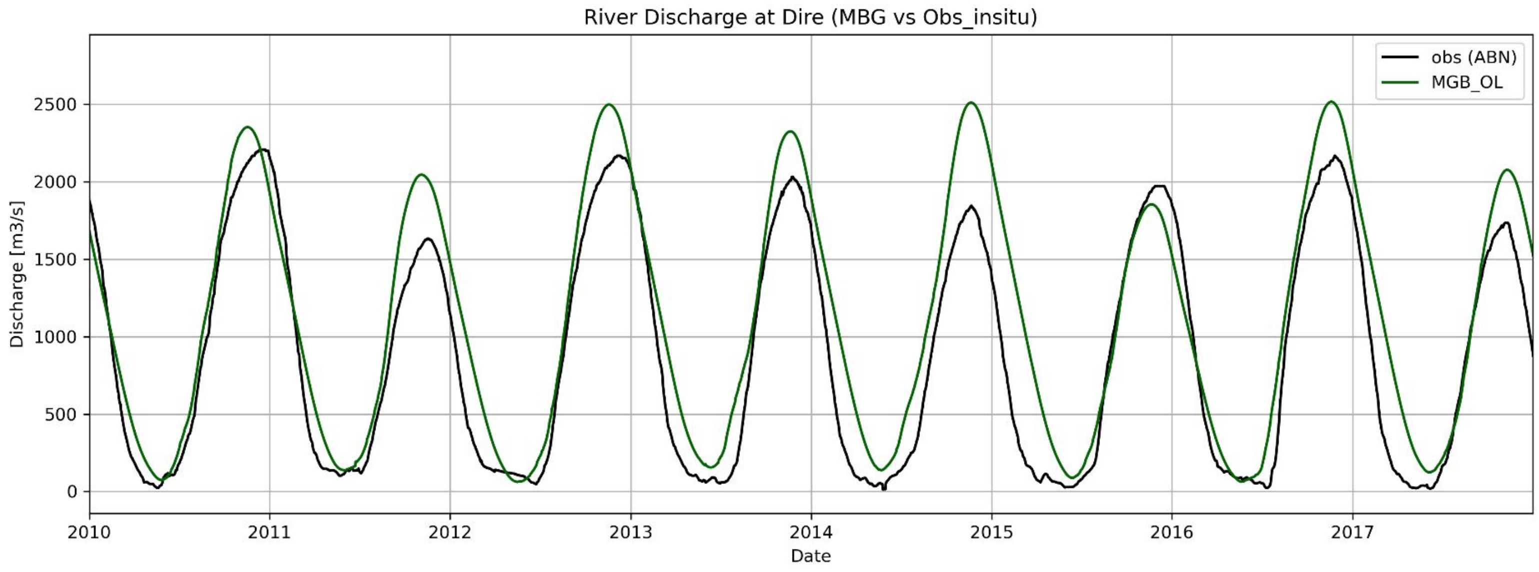




First results - Niger basin : MGB-HyFAA

Dire station

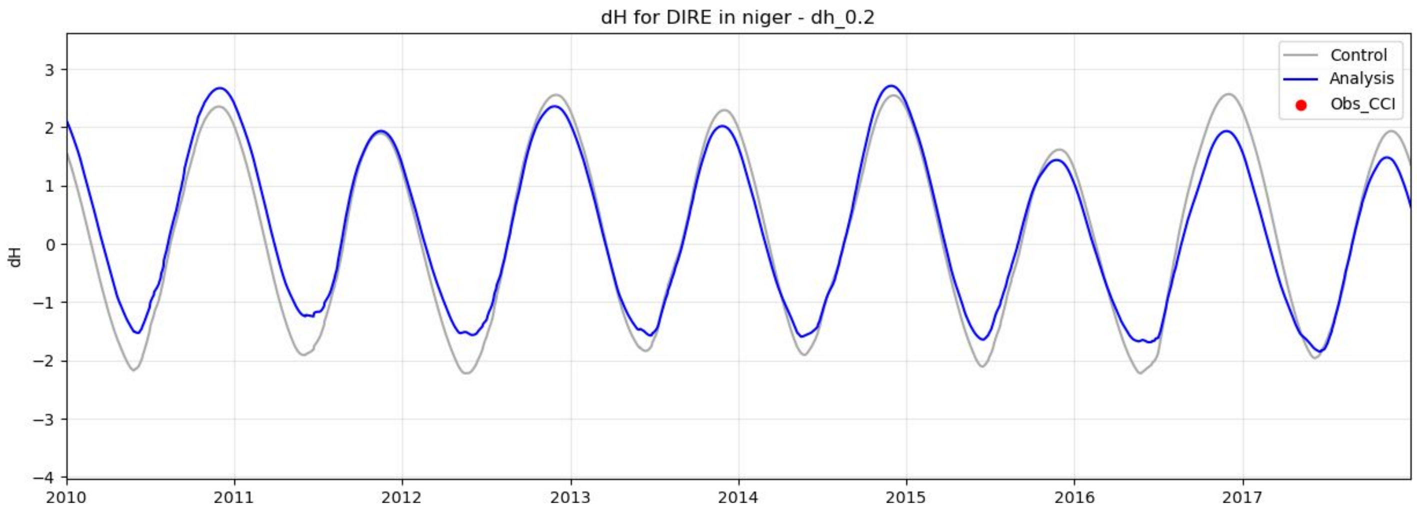
No Obs_CCI product

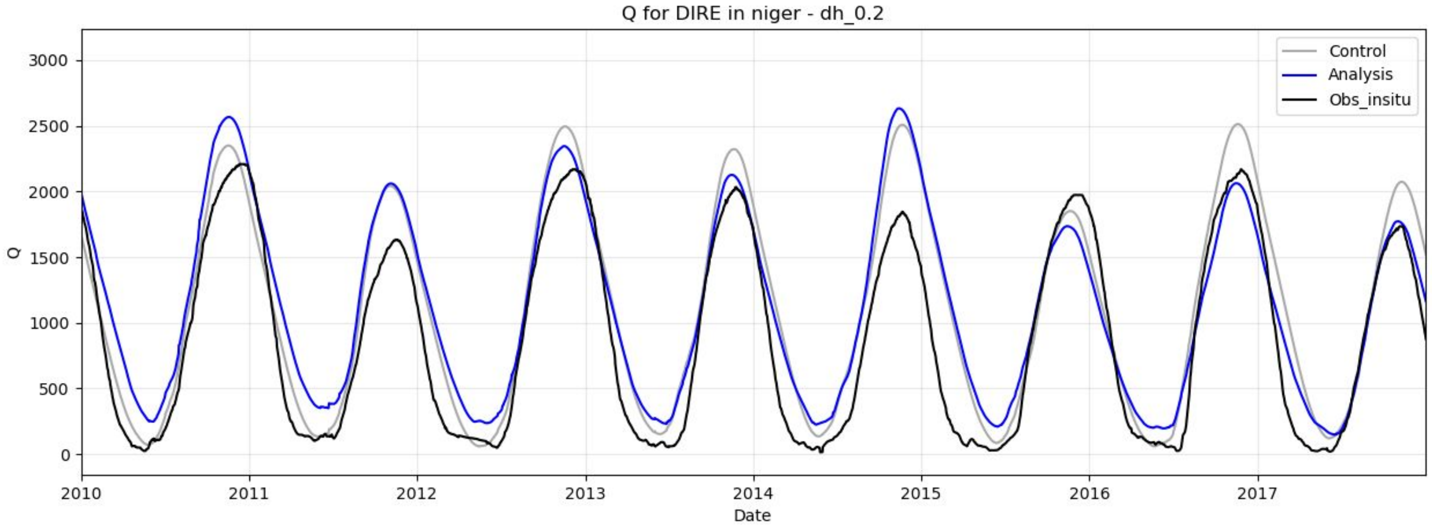


First results - Niger basin : MGB-HyFAA

Dire station

No Obs_CCI product
→ Assimilating WSE in upstream/downstream stations (err=0.2m)





First results - Niger basin : MGB-HyFAA

Dire station

No Obs_CCI product
→ Assimilating Qalti in upstream/downstream stations (err%=30%)