(1)

A generic hydrological forecasting system using existing and future altimetry missions : an OSSE study over the Niger basin

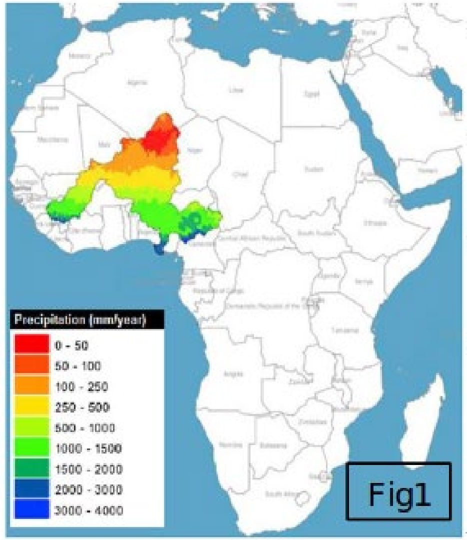
V. Pedinotti [(1)], R. Jugier[(1)], A. Paris[(2)], L. Sourp[(1)], L. Gal[(2)], M. Gosset[(3)], N. Picot[(4)], G. Larnicol[(1)], S. Biancamaria[(5)], D. Blumstein[(4)], B. Tanimoun[(6)] and K. Soungalo[(6)]

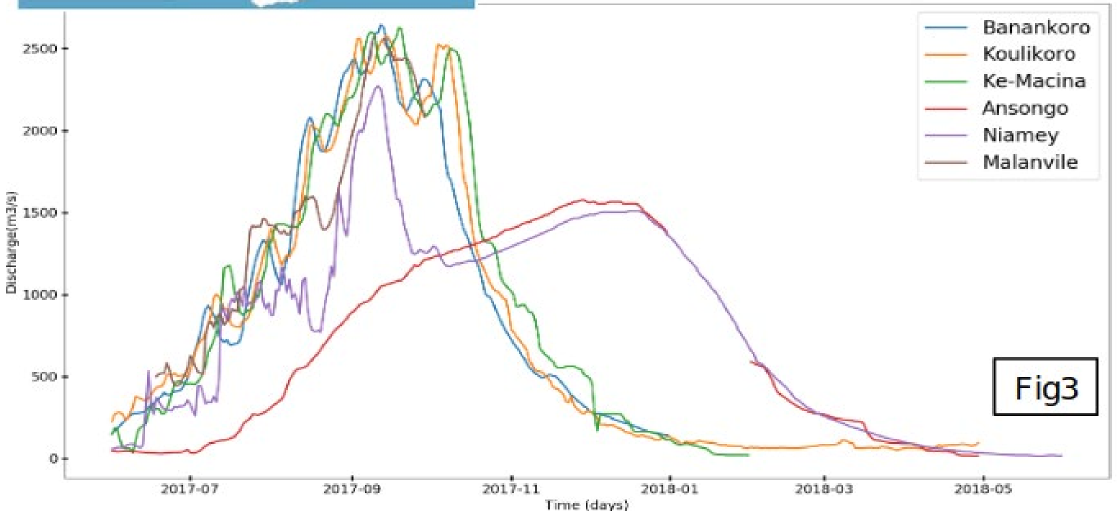
(2) (3) (4) (5) (6)

vanessa.pedinotti@magellium.fr

earthobservation.magellium.com

Flow forecasting in the Niger river basin : a key issue





-Length : 4200km
-Origin: Guinean Fouta-Djalon Plateau
-flows into Atlantic Ocean

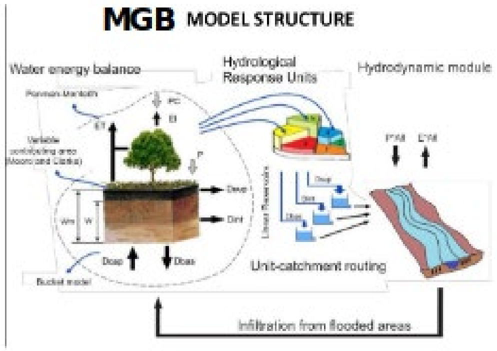
Active basin shared by 9 countries : Benin, Burkina Faso, Cameroon, Ivory Coast, Guinee, Mali, Niger, Nigeria and Chad

Specificities that make simulation difficult :
- Inner delta composed of vast floodplains in Mali
→ great source of evaporation
→ impact on river discharge seasonal outline (see Fig3)
- Flash floods in Niamey area due to small tributaries contribution

Flow modeling in the NRB crucial for :
-monitoring floods and droughts
-water allocation for agriculture
-water management decision making

Requirements for basin scale hydrological forecasting

-large observation datasets : at near to real time
High temporal and spatial resolution



-low computational cost modeling solutions to account for the complexity of the domain

-Real time meteorological forcing (precipitation, temperature, ...)

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High temporal and spatial resolution

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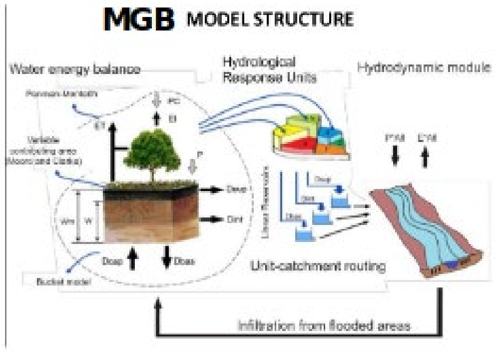

-Real time meteorological forcing (precipitation, temperature, ...)

Need for a monitoring and forecasting system that coordinates the tasks and interactions between the hydrological model and the real time data released on dedicated services

Plan

I - The Hydrological Forecasting system with Altimetry Assimilation (HYFAA)

II - OSSE

1. Methodology
2. Results

III - OSE

1. Preliminary results on Niger and Congo basins

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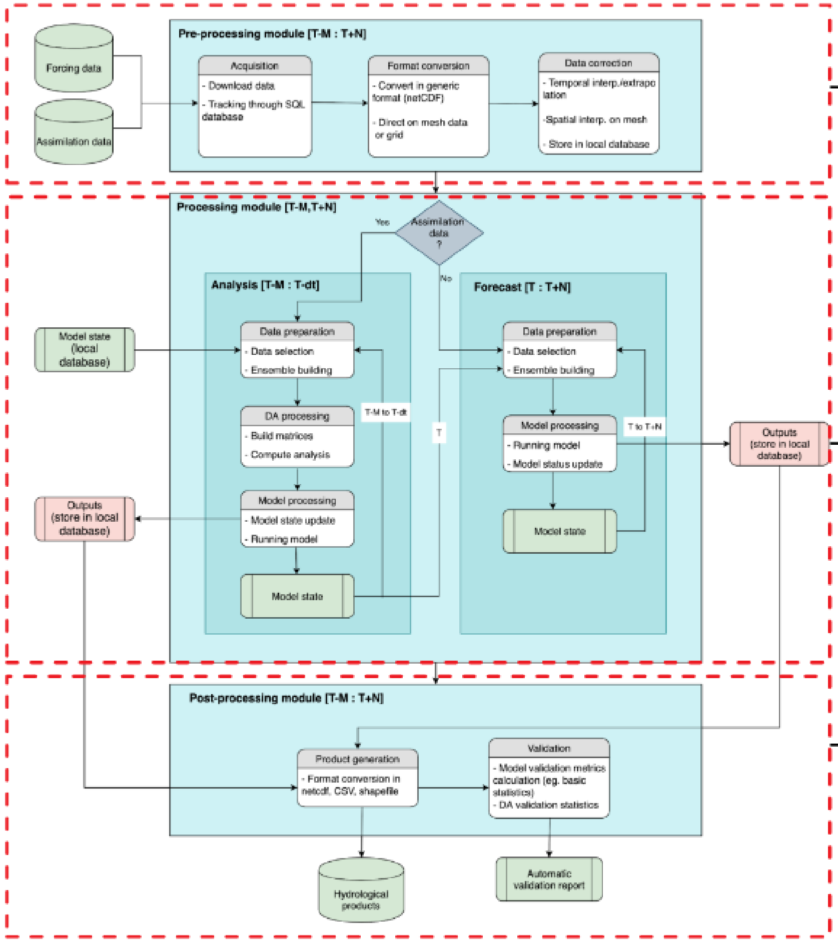
HYFAA : Hydrological Forecasting system with Altimetry Assimilation

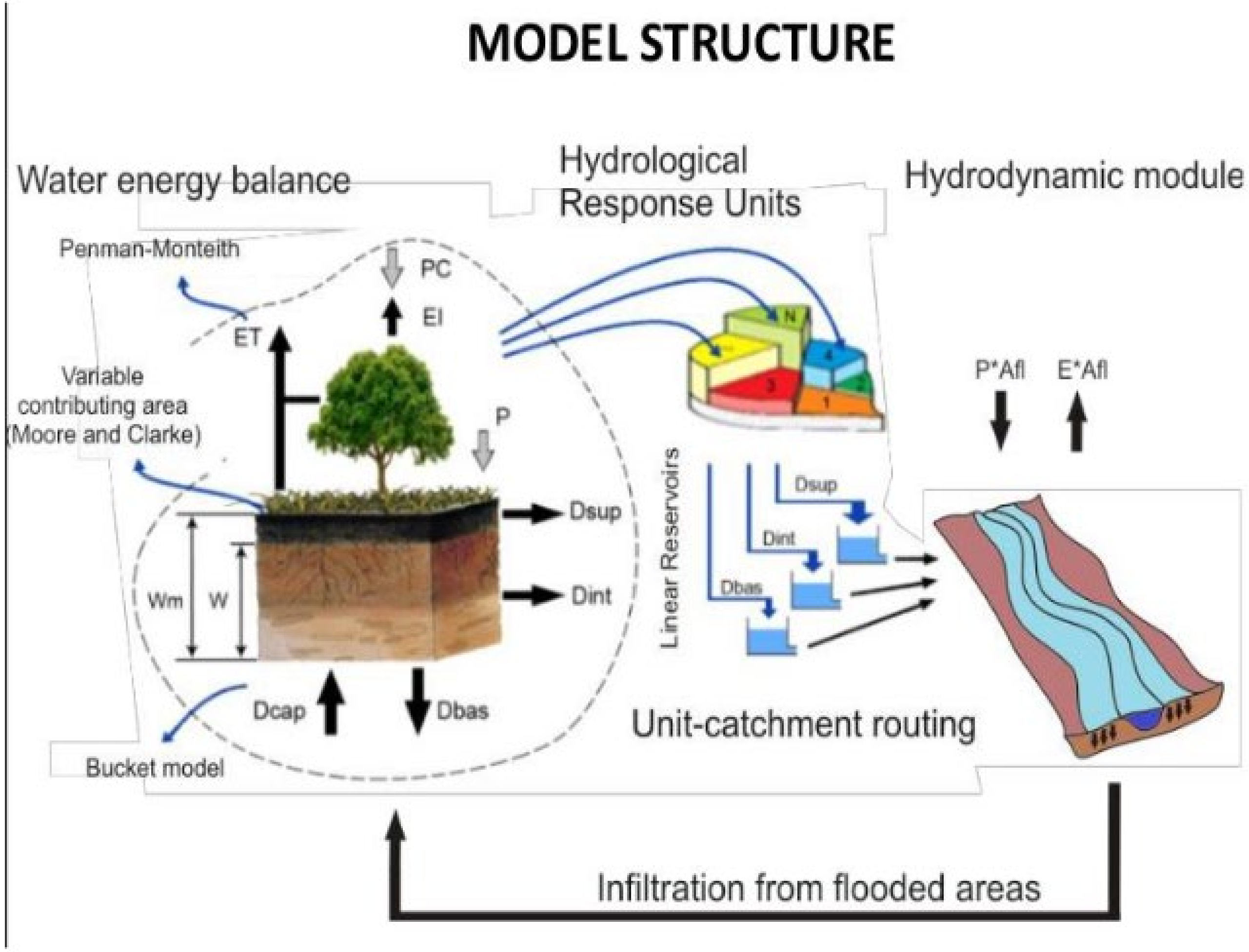


Pre-processing : Update local forcing and assimilation database from external sources, and keep track of changes in data.

Processing :
- launches ensemble hydrological simulations
- manages coupling between the hydrological model and the EnKF filter
- updates model state database
- manages short to lon term hydrological forecasts.

Post-processing : Generate value added products, and a report containing run diagnostics.

The MGB hydrological model : a distributed large-scale model



-vertical hydrologic balance (hydrologic module)

-flood propagation (hydrodynamic module)
- Floodplains
- bifurcations
- 2D flow in inner delta
- Backwater

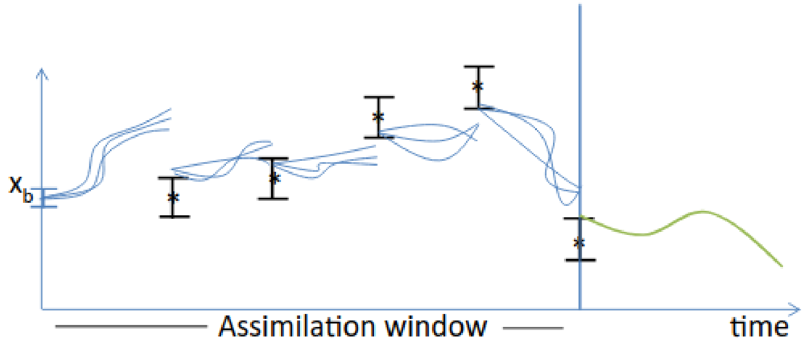
-Two-way coupling
- Infiltration from flooded areas into soil
- Dynamic evapotranspiration (soil & open water)

The model was calibrated over the period 1999-2014 against in-situ discharge observations (Fleischmann et al., 2018)

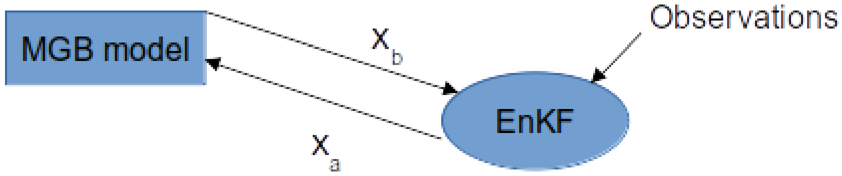
The Ensemble Kalman Filter (EnKF)

- Stochastic method (Evensen, 2003) chosen for its ease of implementation

- Sequential : model is updated each time an observation is acquired.



- Externalized : communicates with MGB model through the scheduler



- Xb : background matrix (ensemble of background vectors)
- Xa : analyzed matrix (ensemble of analyszed vectors)

- EnKF gain matrix : $K = P^f H^T \left[H P^f H^T + R \right]^{-1}$ with Pf as background covariance error matrix, R as observation error covariance matrix, H observation operator.
- Can be easily adapted/plugged in to other modeling systems

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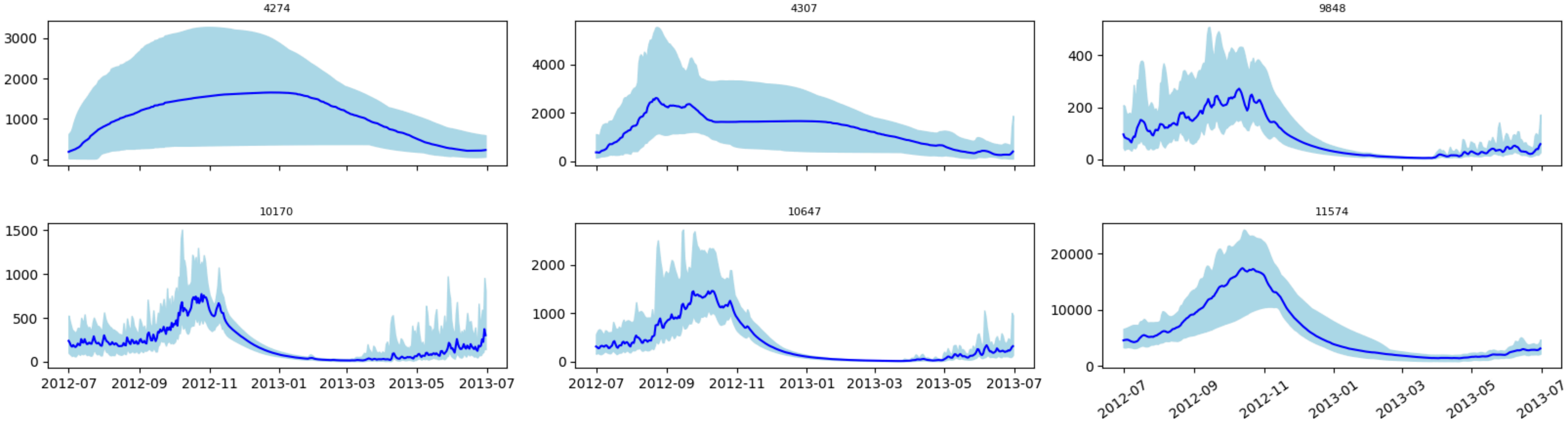
Observing Simulation System Experiment (OSSE)

Aim : validate the method by placing oneself in a framework where the uncertainties are known

- Generate perturbed ensemble of model realizations
  - perurbation applied to precipitation and hydrodynamics parameters (Manning, river width and depth)

- Pick one ensemble member to be the « truth »
- Simulate virtual observations $Q_{obs} = Q_{model} + \varepsilon$ where ε is the observation error



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OSSE - Methodology

Observation systems

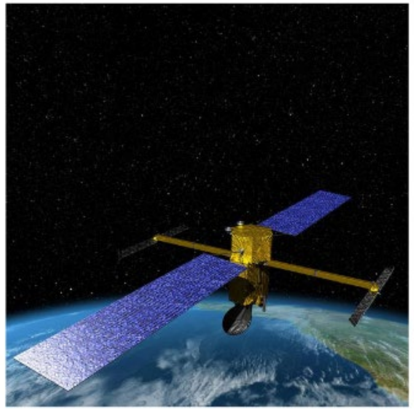
Daily in-situ discharge measurements provided by the Niger Basin Authority

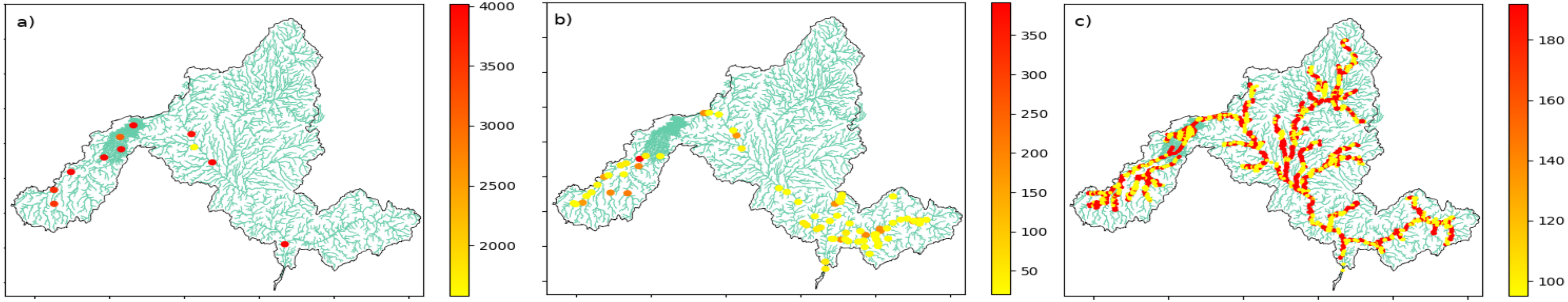
Hydroweb water levels released operationnaly on the Theia Land service

SWOT mission : will deliver high resolution products of water levels and discharge over rivers

Launch planned for end of 2022

SWOT track simulator (Biancamaria et al., 2011)



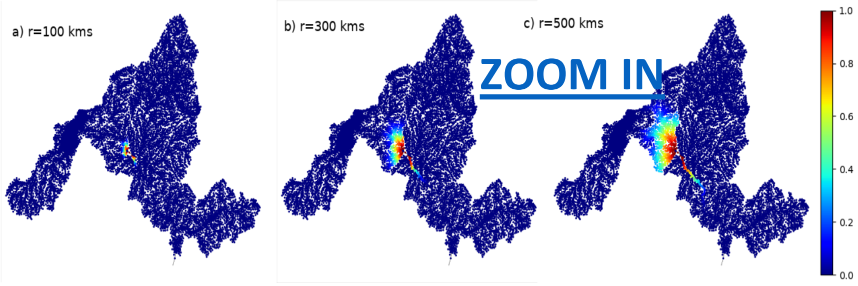


a) In-situ, b) Hydroweb and c) SWOT data coverage for the period July 2012 - December 2017.

OSSE - Methodology

Added EnKF functionalities

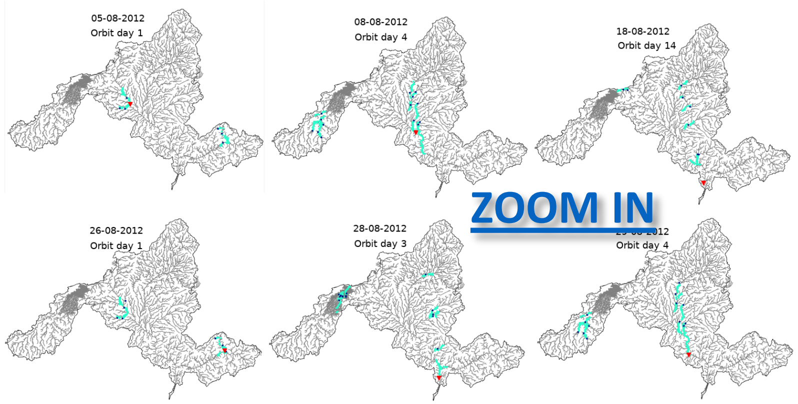
Localization algorithm



Localization matrix in Niamey for r=100kms (a), r=300kms and r=500kms(c).

- Compensate for spurious correlations over long spatial distances

Selection method

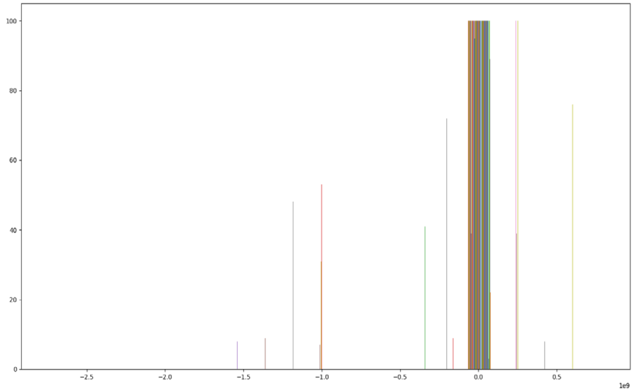


Example maps of data selection applied to SWOT observations. The maximum variance location is represented by a red triangle. SWOT observations for each day of acquisition are in light blue and selected observation are in dark blue.

- Nb of obs >> ensemble size
- leads to inversion pbs

—> obs selection method that only keeps uncorrelated obs

Quality control



Innovation distribution in the case of real Hydroweb data

→ innovation clipping

- Statistical outliers in observation errors leads to divergence issues

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Questions addressed in this study

Considering discharge data assimilation as a way to improve hydrological forecasting :

- What should be the characteristics of a generic system that assimilates these data from different satellite missions and on several basins ? For example, which functionalities work best on a given basin or with a given observation system ?

- What are the assets and limitations of such forecasting systems ?

OSSE - Methodology

Study configuration

General configuration

Model

- Simulation TAPEER 2012-2017
- Climate forcing (except rain) [climatologies] air T°c, wind, humidity, atm pression, solar radiation, vegetation data, albedo, LAI, tree height, superficial resistance
- Calibration : against obs
  - Model parameters (soil, flow, hydrodynamic propagation) and forcing (vegetation)
  - Geometry: (floodplains)
- Evaluation/validation : against obs In situ data from Niger Basin Authority (discharge)

EnKF

Ensemble size : 100
Observed variable : discharge

Experiments

EnKF varying configuration

- Background vector :
  - all state variables (soil moisture, baseflow, subsurface and surface water, canopy interception, runoff, chanel water depth, river water storage, flooded are, flow interconnections)
  - parameters : river width, river depth, Manning coefficient
- Functionalities
  - localization
  - observations selection
  - observations quality control

OSSEs

- Simulated observations
  simplified framework where all uncertainties are known
- 3 observing systems : in-situ, Hydroweb, SWOT
- Reference simulation : 28th member of the ensemble

OSEs

- Real observations
- Hydroweb
- Extension to the Congo river basin

OSSE - Methodology

General overview

Exp1			
Exp2			
Exp3			
Exp4			
Exp5			
Exp6			
Exp7			
Exp8			
Exp9			
Exp10			

10 experiments

General overview

	Observing system		
Exp1	In situ		
Exp2			
Exp3	Hydroweb		
Exp4			
Exp5			
Exp6	SWOT		
Exp7			
Exp8	SWOT river		
Exp9	SWOT		
Exp10			

10 experiments
3 observing systems

OSSE - Methodology

General overview

	Observing system	Control vector	Filter
Exp1	In situ	sv	
Exp2		sv+par	
Exp3	Hydroweb	sv	
Exp4		sv+par	
Exp5		sv	
Exp6	SWOT	sv+par	
Exp7		sv+par	
Exp8	SWOT river	sv+par	
Exp9	SWOT	sv+par	
Exp10		sv+par	

10 experiments
3 observing systems
Control vector : state variables (sv), parameters (par)

OSSE - Methodology

General overview

	Observing system	Control vector	Filter
Exp1	In situ	sv	EnKF
Exp2		sv+par	EnKF
Exp3	Hydroweb	sv	EnKF
Exp4		sv+par	EnKF
Exp5		sv	LEnKF
Exp6	SWOT	sv+par	EnKF
Exp7		sv+par	EnKF
Exp8	SWOT river	sv+par	EnKF
Exp9	SWOT	sv+par	OS+EnKF
Exp10		sv+par	OS+LEnKF

10 experiments
3 observing systems
Control vector : state variables (sv), parameters (par)
Filter : EnKF
    Localized EnKF (LenKF)
    Observations' selection (OS)

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OSSE - Methodology

General overview

	Observing system	Control vector	Filter
Exp1	In situ	sv	EnKF
Exp2		sv+par	EnKF
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Exp6	SWOT	sv+par	EnKF
Exp7		sv+par	EnKF
Exp8	SWOT river	sv+par	EnKF
Exp9	SWOT	sv+par	OS+EnKF
Exp10		sv+par	OS+LEnKF

10 experiments
3 observing systems
Control vector : state variables (sv), parameters (par)
Filter : EnKF
Localized EnKF (LenKF)
Observations' selection (OS)

$$NRMSE = [\sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y})^2}{n}}]/\sigma$$

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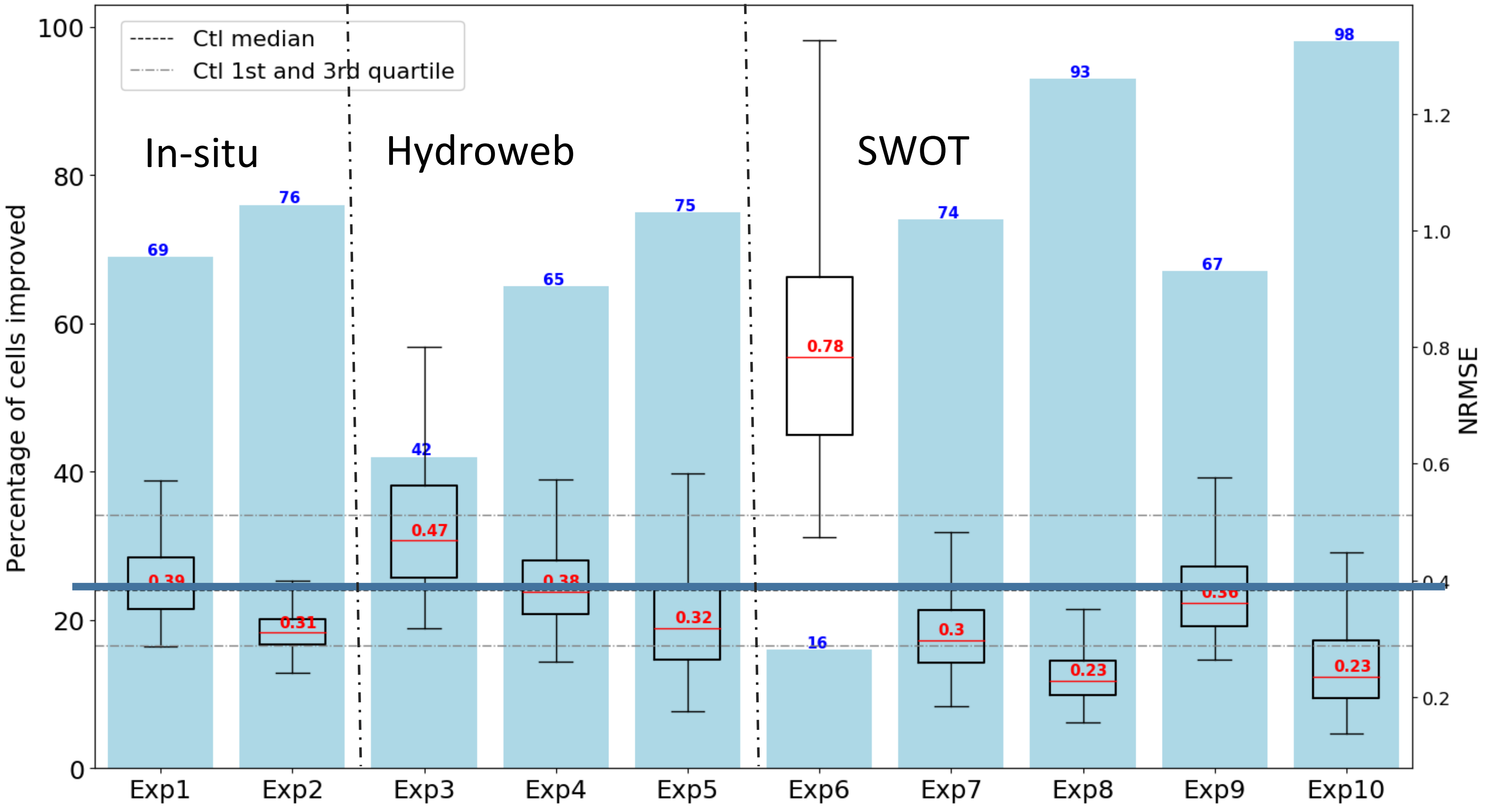
Plan

OSSE - Results

General results



Median of control ensemble

Boxplots of discharge NRMSE over the basin

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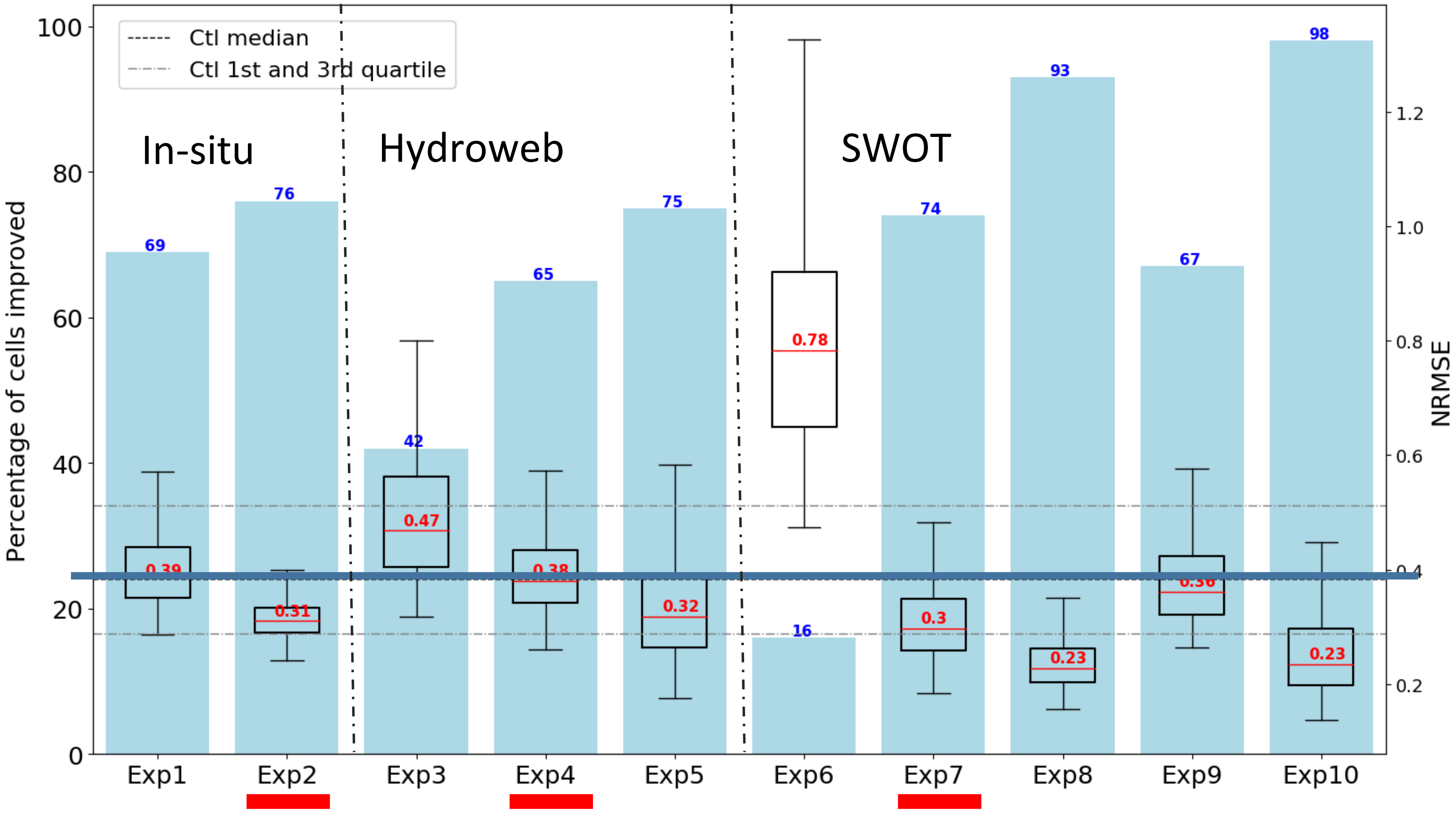
OSSE - Results

General results

Parameters' correction consistantly improves the performance of DA



Median of control ensemble

Boxplots of discharge NRMSE over the basin

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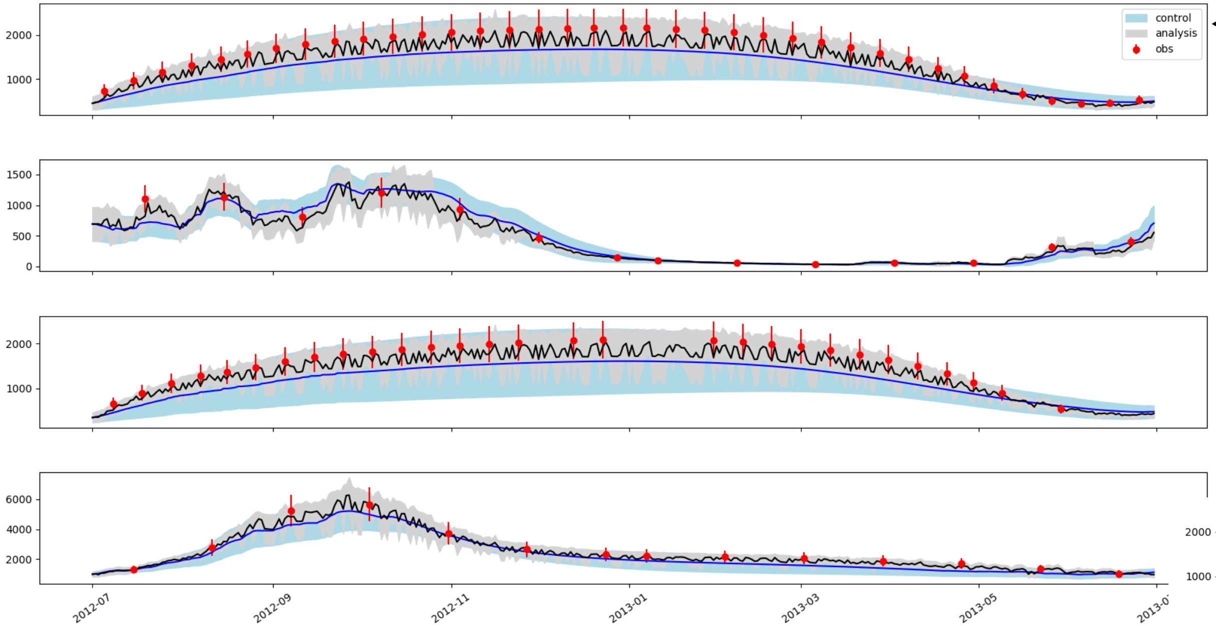
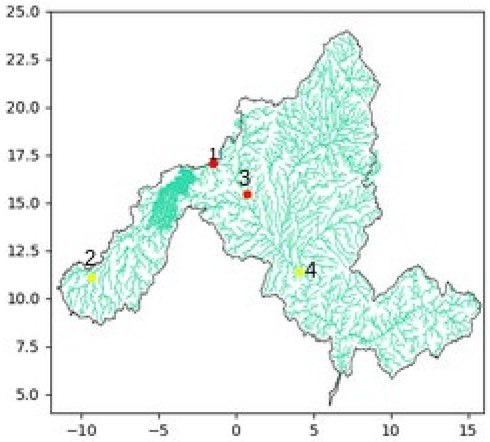
OSSE - Results

Without parameters correction



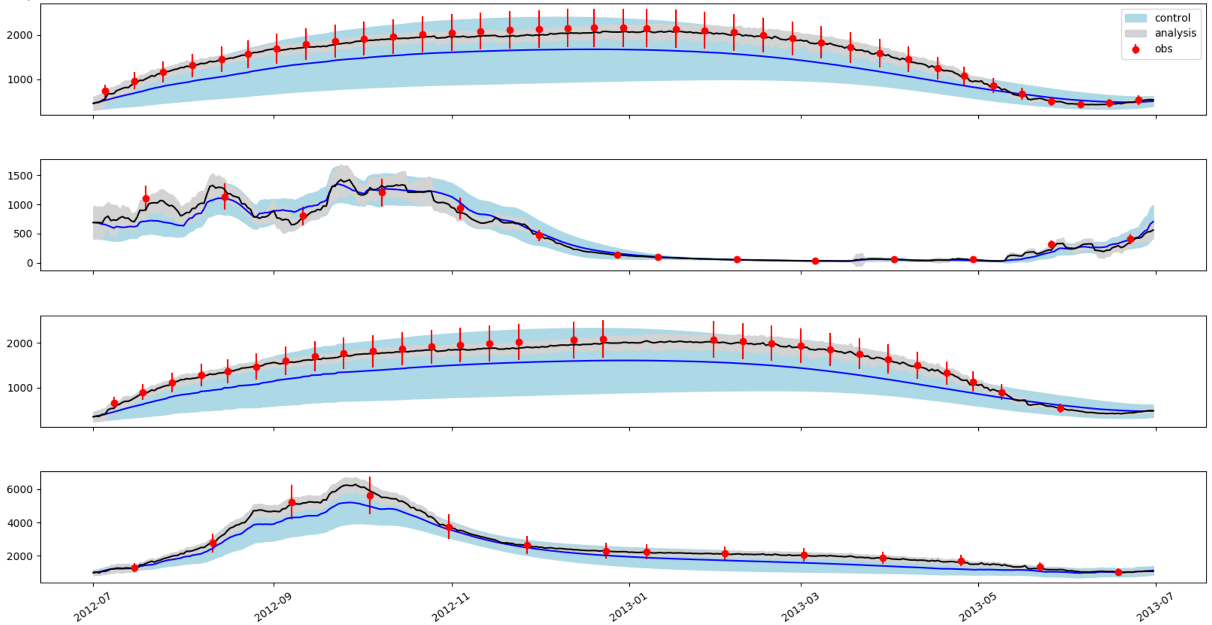
← Correction of state variables only



Correction of state variables + parameters (Manning, river width and depth)

↓

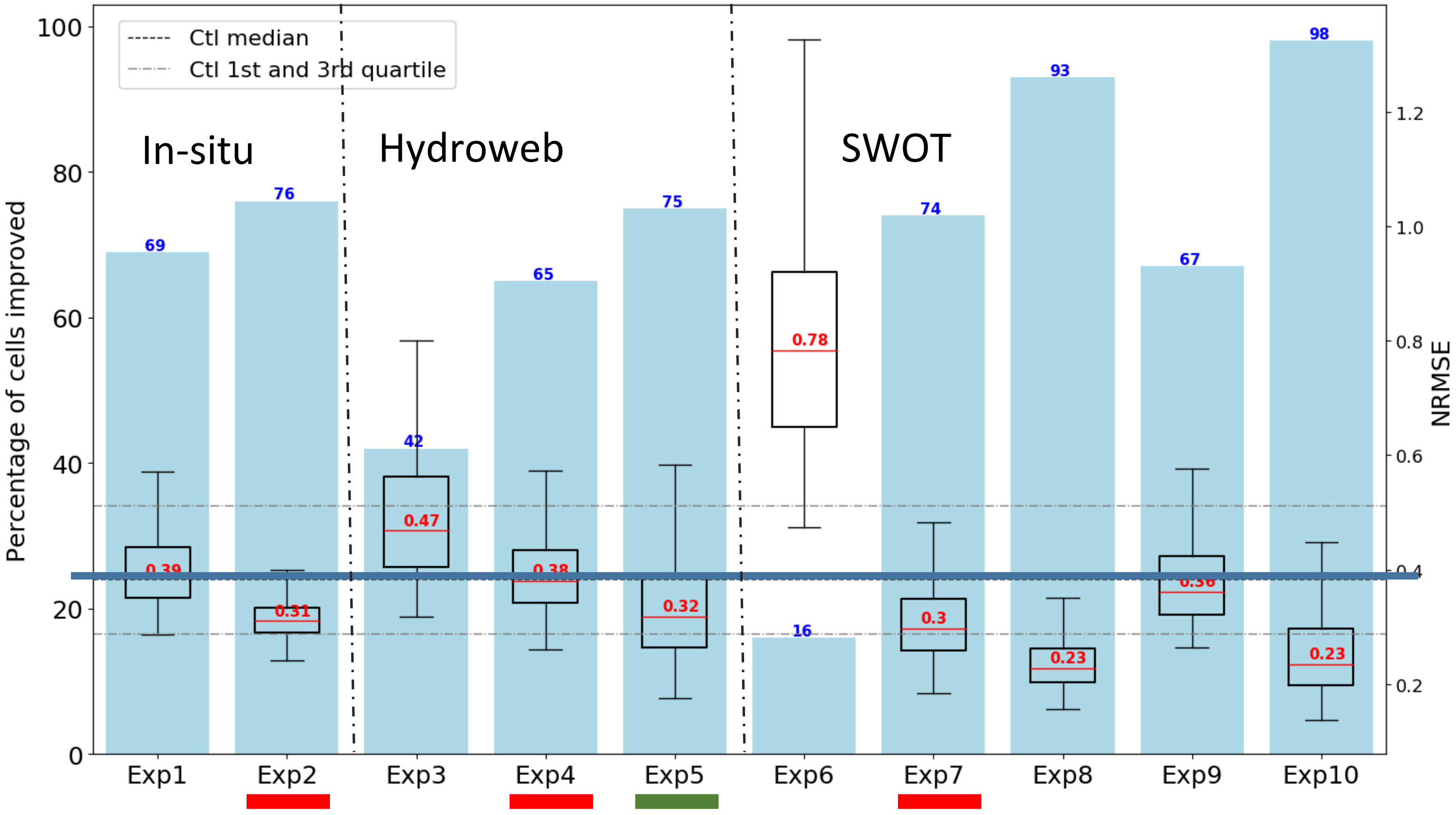
With parameters correction



→ Correction of parameters stabilizes the signal between two observation dates and reduces model uncertainties

Control/Analyzed (blue/black) discharge and their range of uncertainty, observations (red)

General results



Median of control ensemble

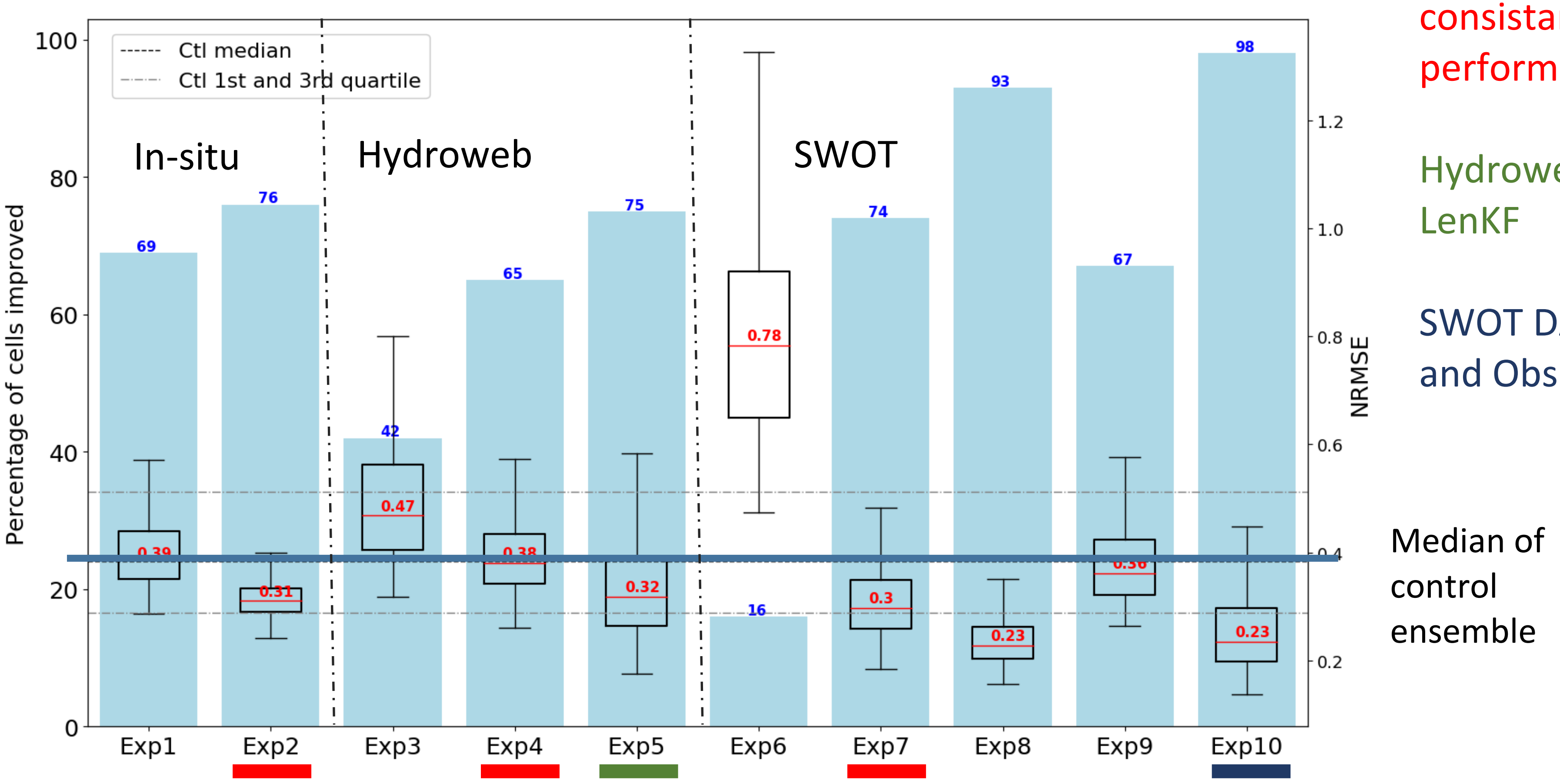
Boxplots of discharge NRMSE over the basin

Parameters' correction consistantly improves the performance of DA

Hydroweb DA works best with LenKF

OSSE - Results

General results



Boxplots of discharge NRMSE over the basin

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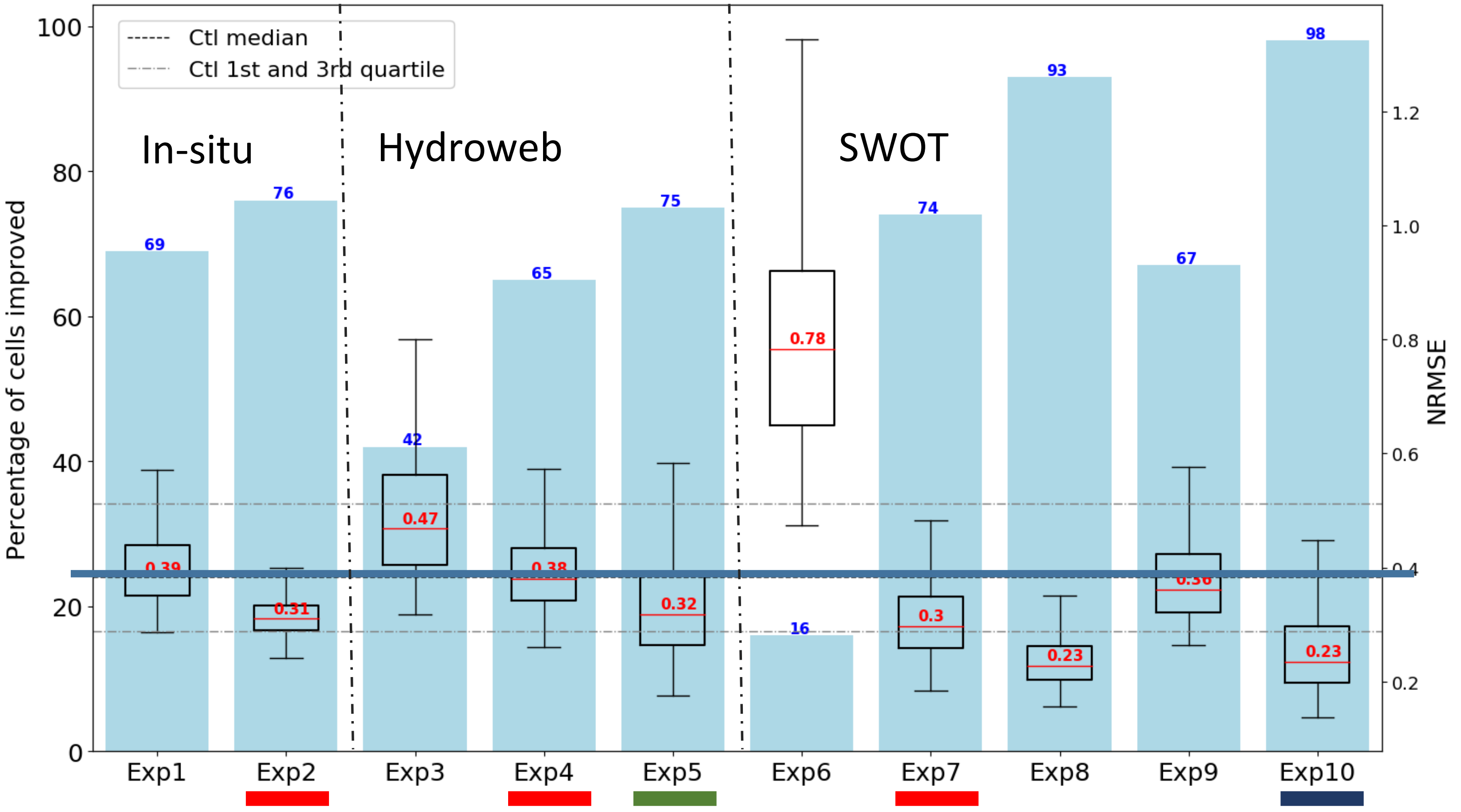
General results



Boxplots of discharge NRMSE over the basin

Median of control ensemble

Parameters' correction consistantly improves the performance of DA

Hydroweb DA works best with LenKF

SWOT DA works best with LenKF and Obs selection

Best NRMSE : Exp 8 & 10 (both SWOT)
Best percentage of cells improved : Exp10 (SWOT)

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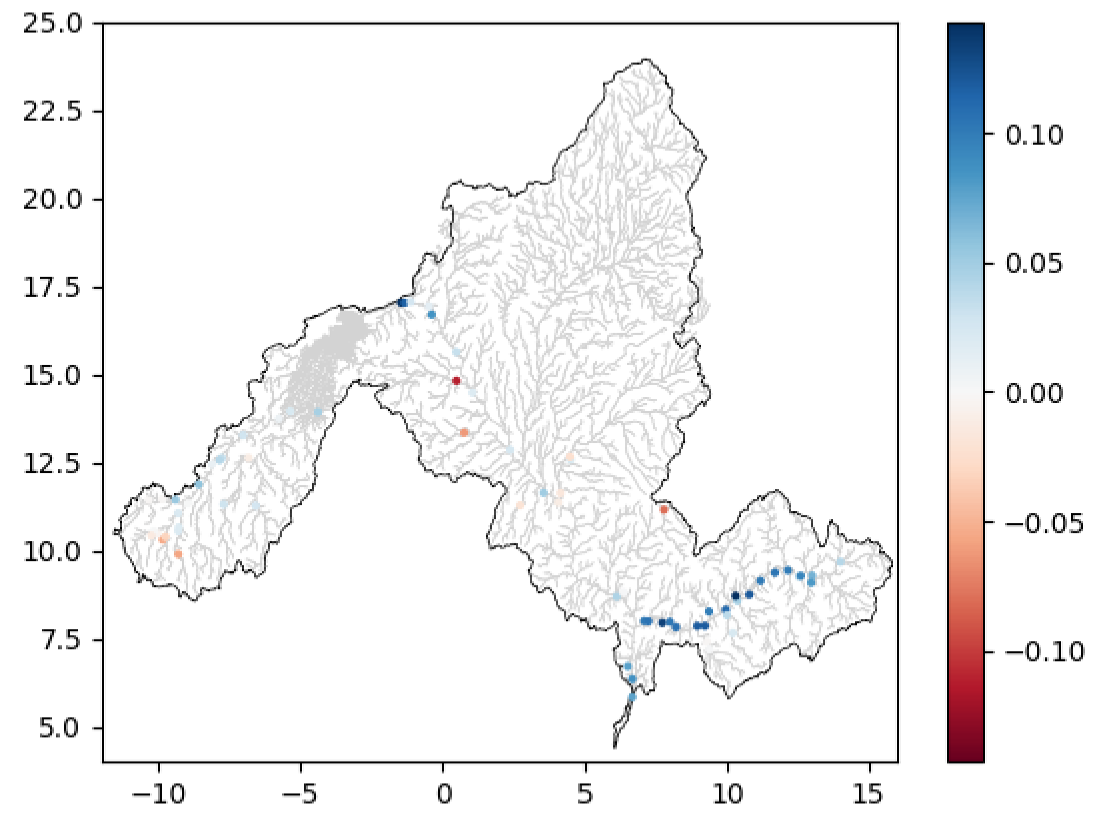
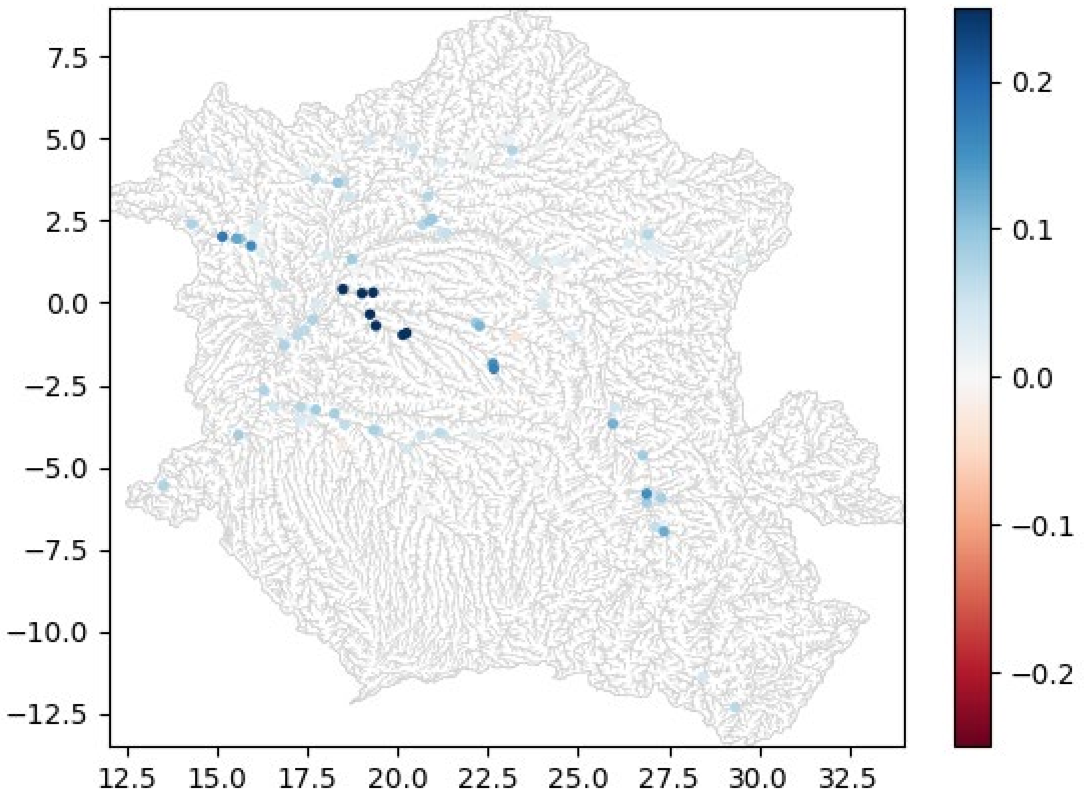
OSE - Preliminary results

Niger



Congo



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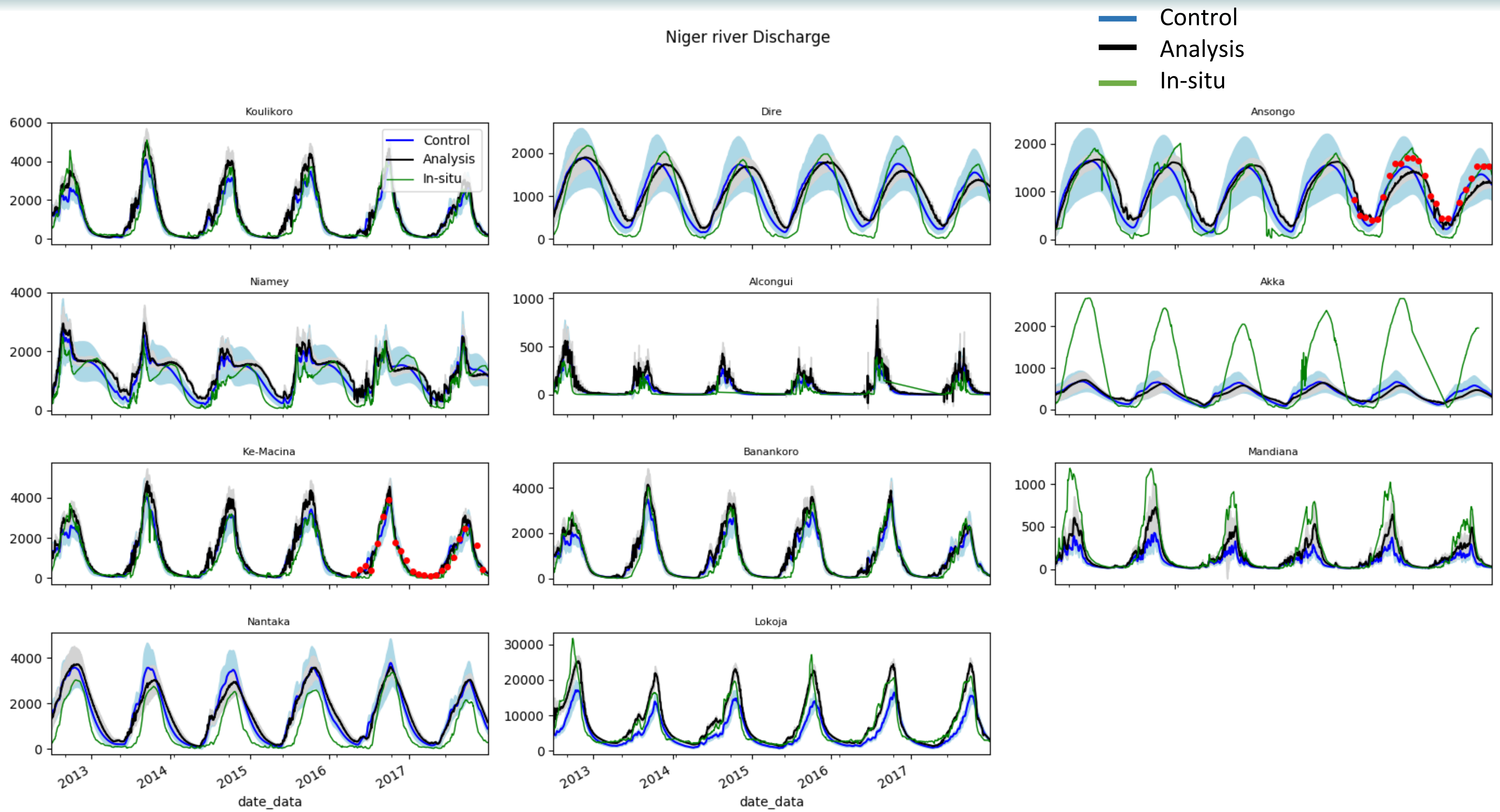
OSE - Preliminary results



Conclusions

- Data assimilation helps to improve discharge estimation over the Niger river basin
- The correction of parameters improves the performance of DA by introducing longer term corrections (could be forcing biases)
- The DA system's functionalities can be adapted to the characteristics of the observing systems
- The assimilation of real observations needs to be improved, in particular the management of outliers can be an issue
- SWOT data could contribute to improve large scale hydrological forecasting

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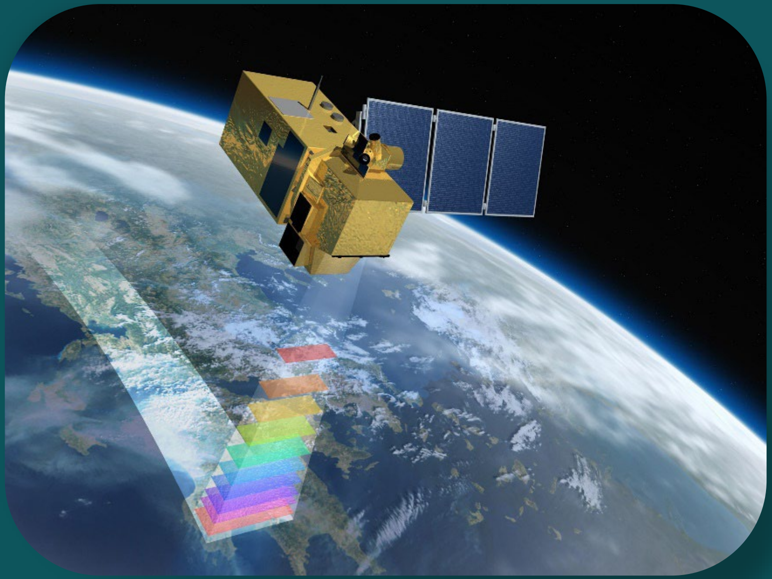

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vanessa.pedinotti@magellium.fr