CTRIP-SWOT HyDAS
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Towards a global scale Hydrological Data Assimilation System

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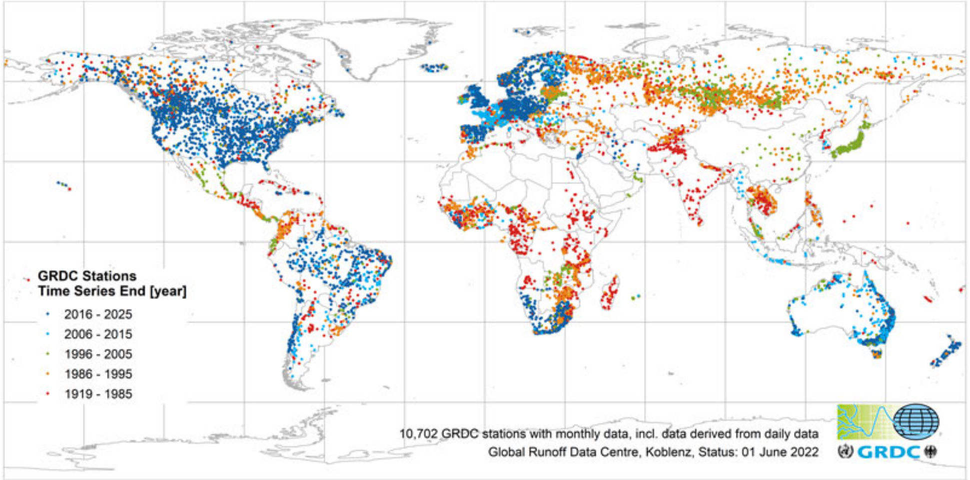
SWOT Science Team – 27-30 June 2022

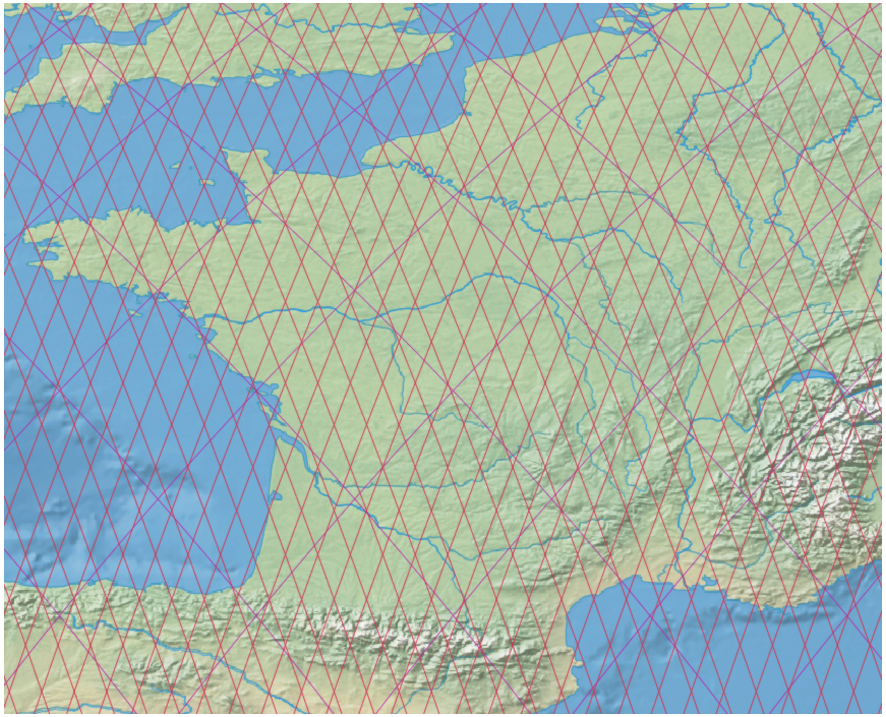
Observing river discharge from space

- Potential of satellite observations to study medium to large rivers dynamics
  - Complement to declining gauging network
- Several types of sensors:
  - Nadir altimetry (eg Envisat, Jason-3)
  - Imagery (eg MODIS, Sentinel-2)
- Mainly water elevation and surface extent
- Use of various algorithms to infer discharge
  - Rating curves
  - Manning equation

Gauge stations from GRDC



Ground tracks of Jason-3 and Sentinel-3

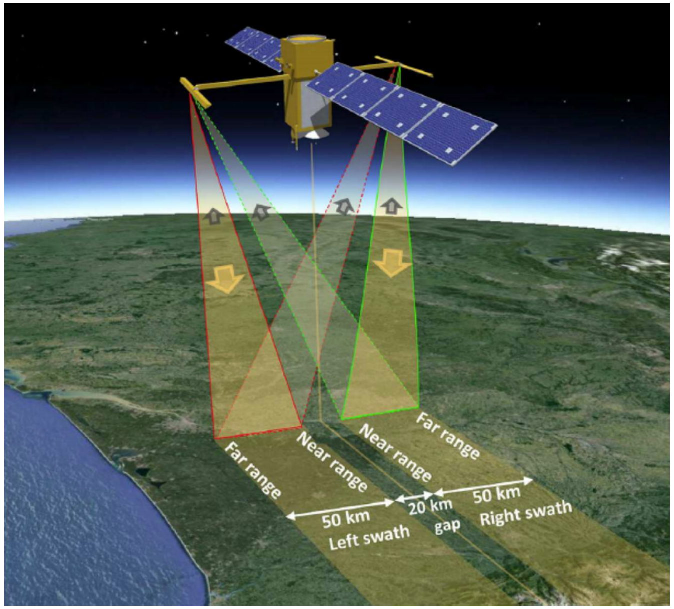


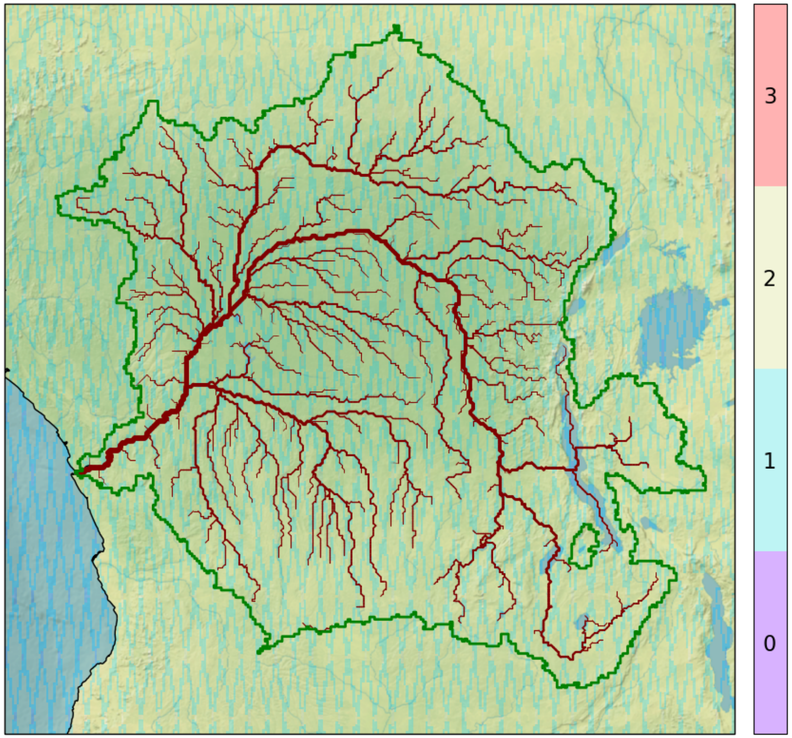
SWOT: Surface Water and Ocean Topography

- CNES-NASA satellite mission (launch nov 2022)
- Interferometric altimetry, 120 km wide swath
- Water surface elevation (and slope) over rivers wider than 100 m, possibly down to 50 m

  uncertainty: ~ 10 cm over 10 km reach
- SWOT-derived river discharge

  uncertainty: up to 40 % (relative RMSE)

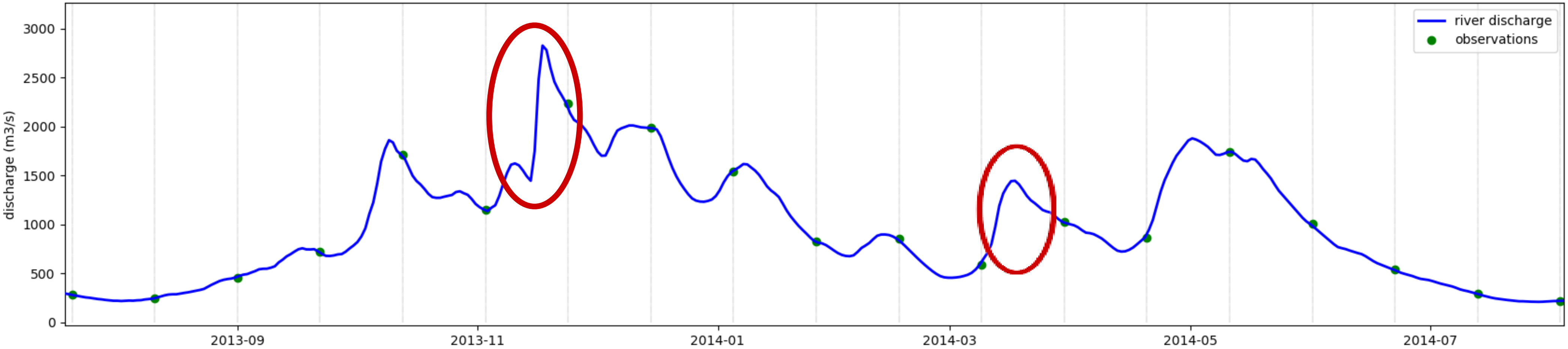


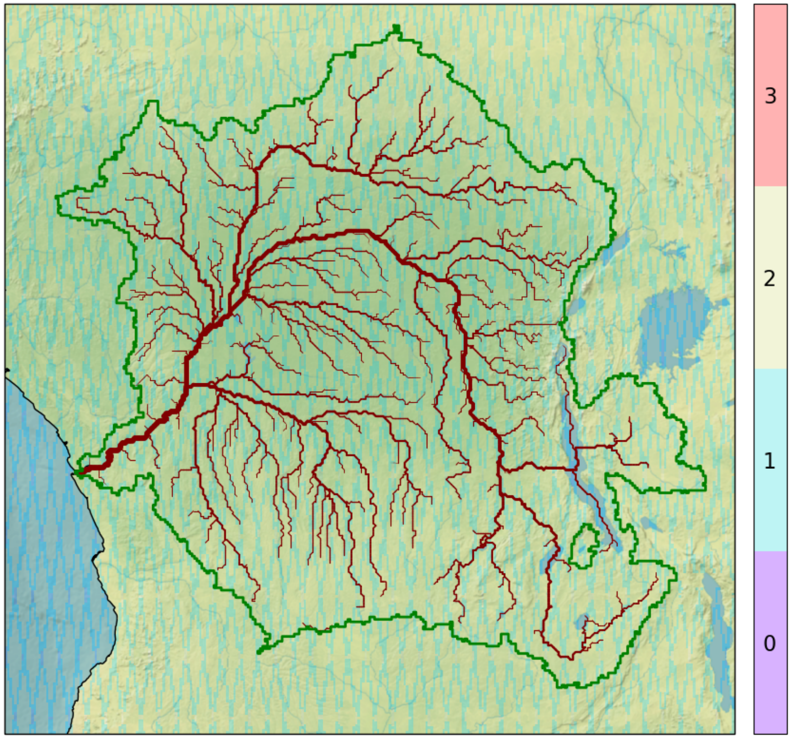


Number of observations within a 21-day cycle

In red: part of the river network observed by SWOT (width > 50 m)

SWOT: Surface Water and Ocean Topography





But time sampling remains critical, especially for small basins or fast dynamics rivers

Number of observations within a 21-day cycle

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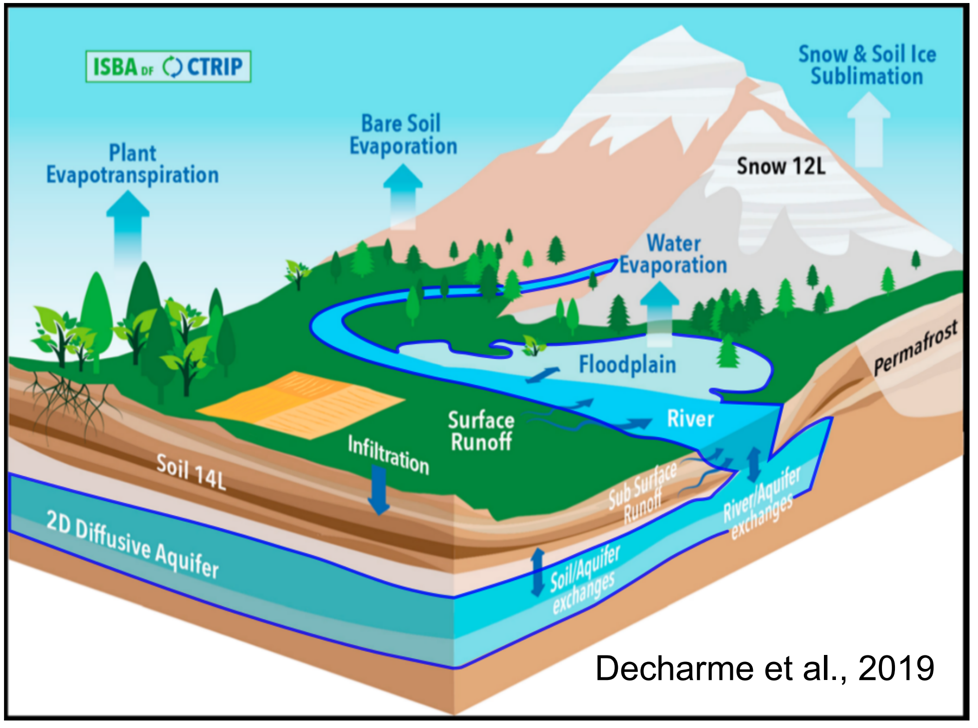
ISBA-CTRIP hydrological system

- **ISBA**: simulates the diurnal cycle of :
  - ➔ water and carbon fluxes
  - ➔ plant growth
  - ➔ vegetation variables

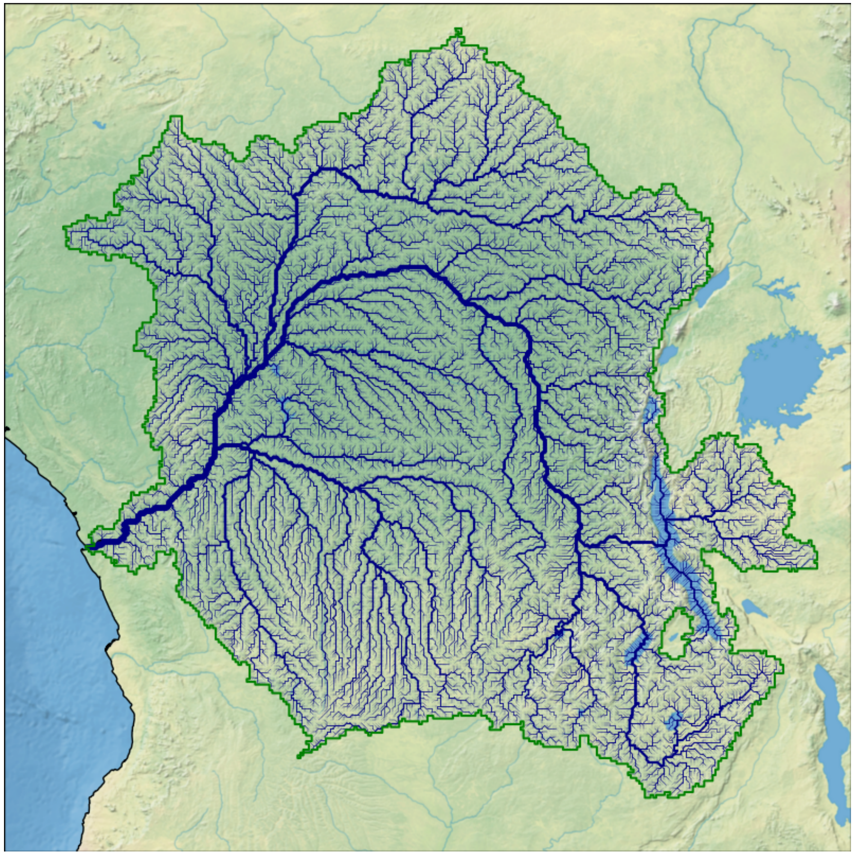
  (Calvet et al., 1998, 2007, Gibelin et al., 2006)

- **CTRIP**: CNRM version of the TRIP based river routing system
  - ➔ 1/12° spatial resolution
  - ➔ flooding by river overflow
  - ➔ aquifers

  (Decharme et al., 2019, Munier and Decharme, 2022)

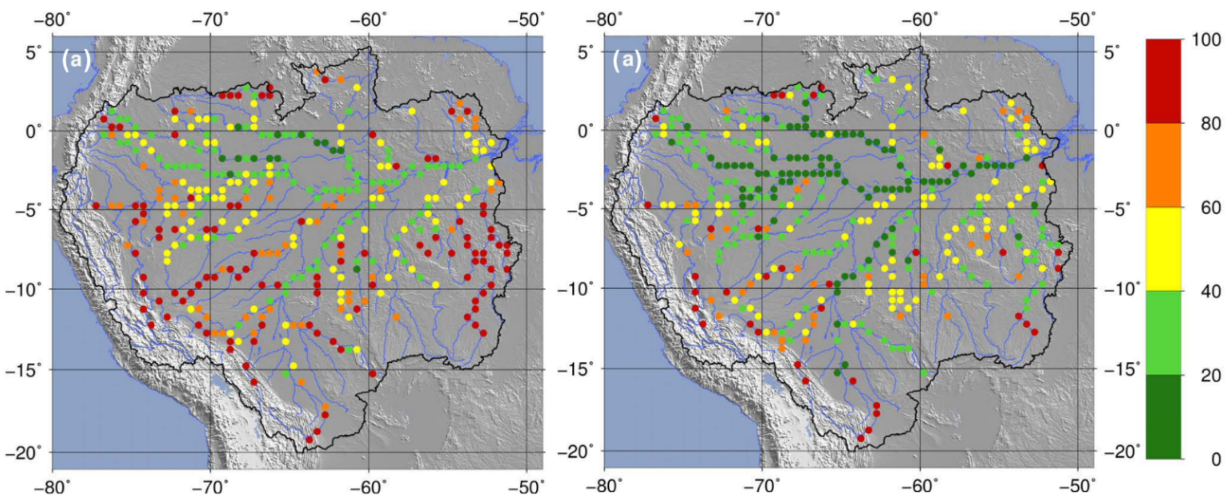


Decharme et al., 2019

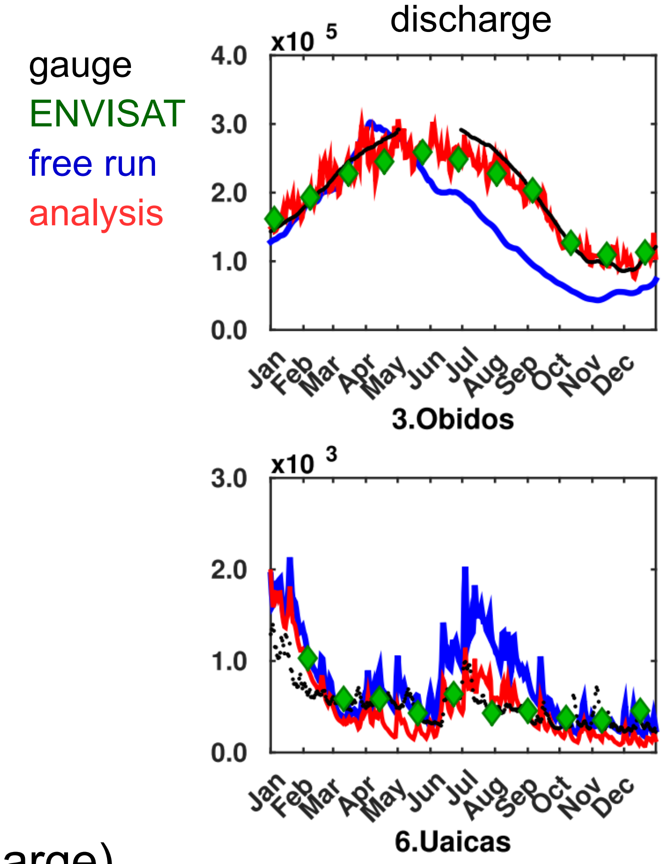


A decade of Data Assimilation within CTRIP

- Previous work by Emery et al. (2018, 2019) over the Amazon basin
  - Assimilation of ENVISAT observations within CTRIP for parameter estimation or state correction (river storage or discharge)



RMSEn of simulated/analyzed discharge with respect to the ENVISAT

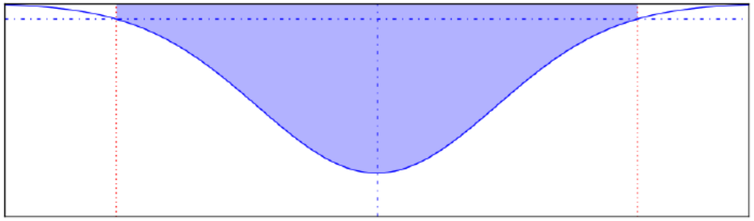


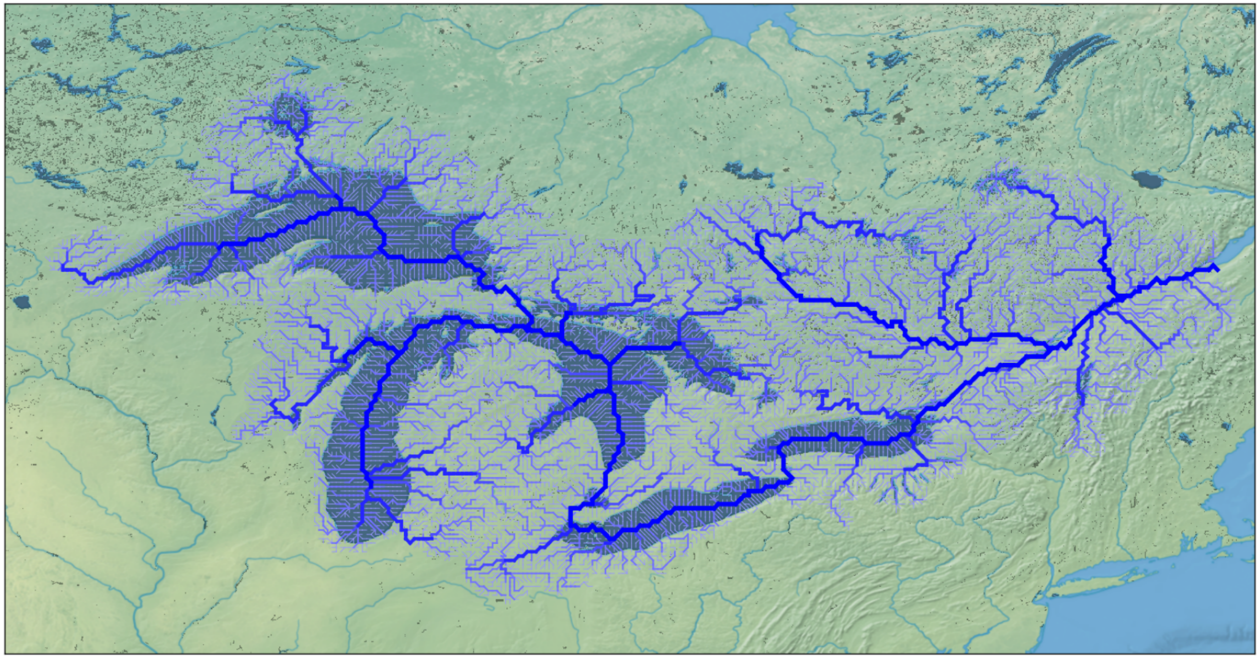
- Recent extensions:
  - Assimilation of SWOT observations (water level or discharge)
  - Assimilation within CTRIP-12D (1/12° ~ 8 km at mid-latitudes)
  - Several improvement in the assimilation algorithm

Model improvements: lakes and reservoirs

- MLake recently developed to represent water balance within natural lakes
  - Global scale extraction of lakes (localization, area) from ECOCLIMAP-II (1 km resolution)
  - Calibration of a Gaussian shape for bathymetry
  - Clipping of lake mask over the CTRIP-12D river network

Thibault Guinaldo PhD (2017-2020)





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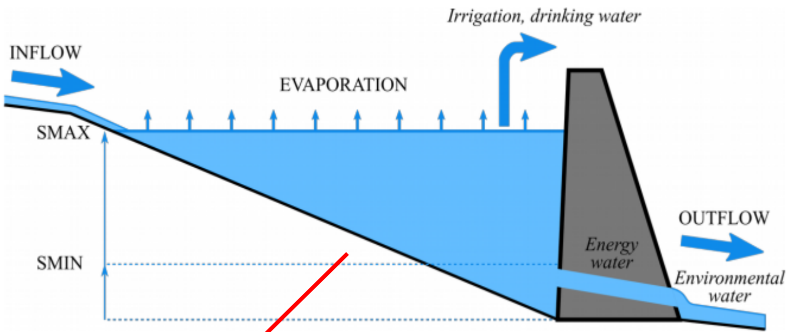
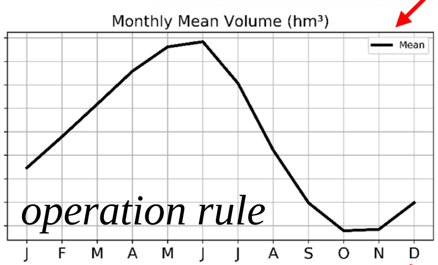
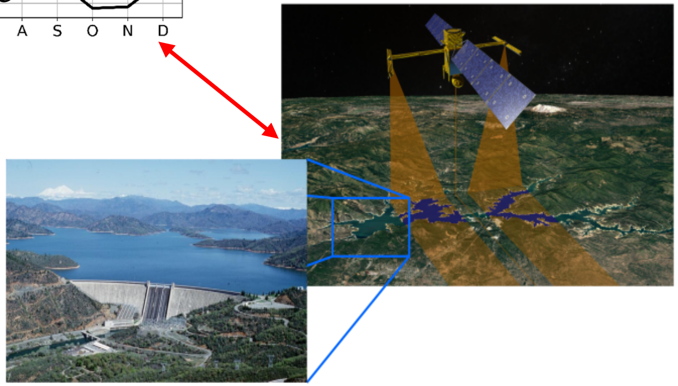


S. Munier, 2019

- DROP (Dam-Reservoir OPeration) model
  - Reservoir management and dam releases
    Hydropower, Irrigation,
    Low-flow sustainability,
    Flood control
  - Assimilation of satellite observations (SWOT)
    Characterization of reservoirs (filling curve)
    Model parameter calibration (operation rules)





CNES PhD: Malak Sadki (2019-2022)

TOSCA project: Towards a better understanding of the global hydrological cycle with SWOT

- PIs: A. Boone, S. Munier, P. Le Moigne, C. Ottlé, D. Yamazaki
- Participants: S. Biancamaria, S. Ricci, J. Polcher, F. Papa, R. Paiva, C. David, C. Garnaud, V. Fortin

- Workpackage dedicated to « rivers »

  SWOT data assimilation into global hydrological model to improve representation of rivers and groundwater dynamics

- Main objectives
  - Better characterize Hydrology Data Assimilation Systems (HyDAS)
  - Validate the whole processing chain

    (obs SWOT > elevation or discharge product > DA analysis)

  Congo Basin as a test case

  - Set up a **global scale hydrological reanalysis**

    Consistency between river networks: SWOT (RiverObs), models

    Feasibility in terms of computing constraints

CNES postdoc: Kaushlendra Verma (2023-2024)

CNRM

METEO FRANCE

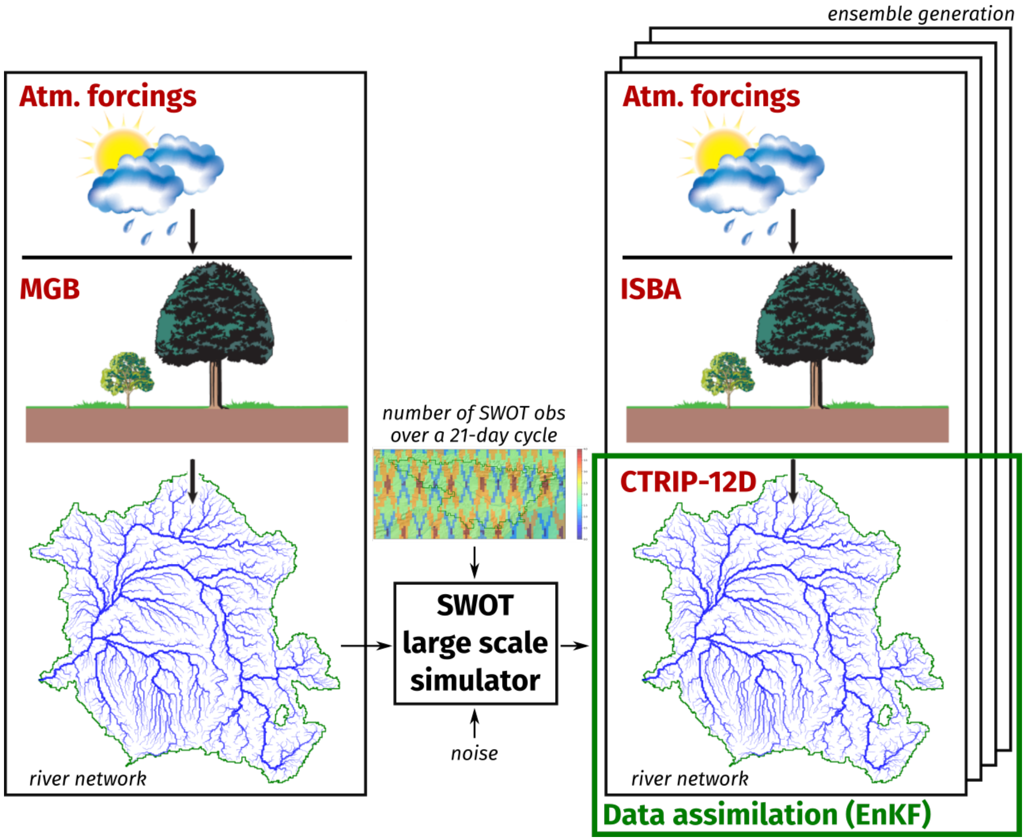
CTRIP-SWOT HyDAS recent work

Assimilation of SWOT discharge versus water level into CTRIP-12D over the Congo Basin

Presented at IAHS congress in Montpellier (30th May 2022)

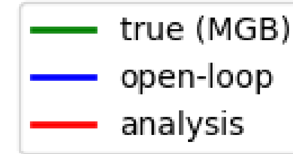
CTRIP-SWOT Data Assimilation Framework

- Simulation of SWOT observation
  - from an independent model (MGB)
  - realistic orbit (time and location)
  - realistic noise added
- Ensemble Kalman Filter
  - perturbed atmospheric forcings to generate the ensemble
  - assimilation of river depth or discharge

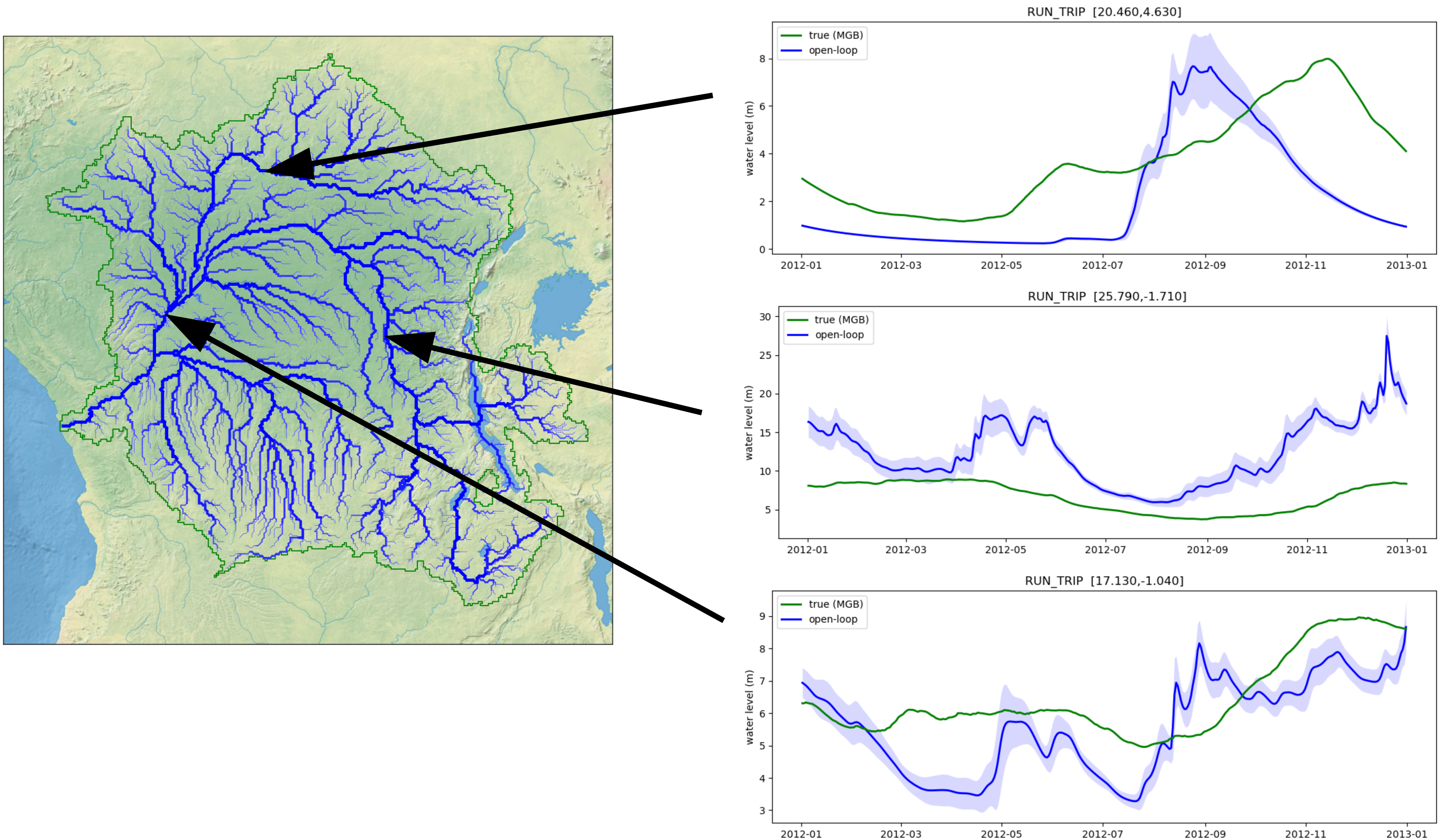


- EnKF improvements
  - physically based localization > *reduces spatial random errors*
  - temporal smoother > *reduces temporal random errors*
  - water level anomalies > *reduces biases (water elevation vs river depth)*

Assimilation of perfect water level (no obs error)

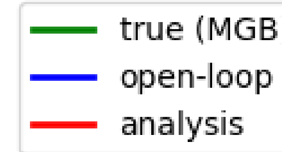


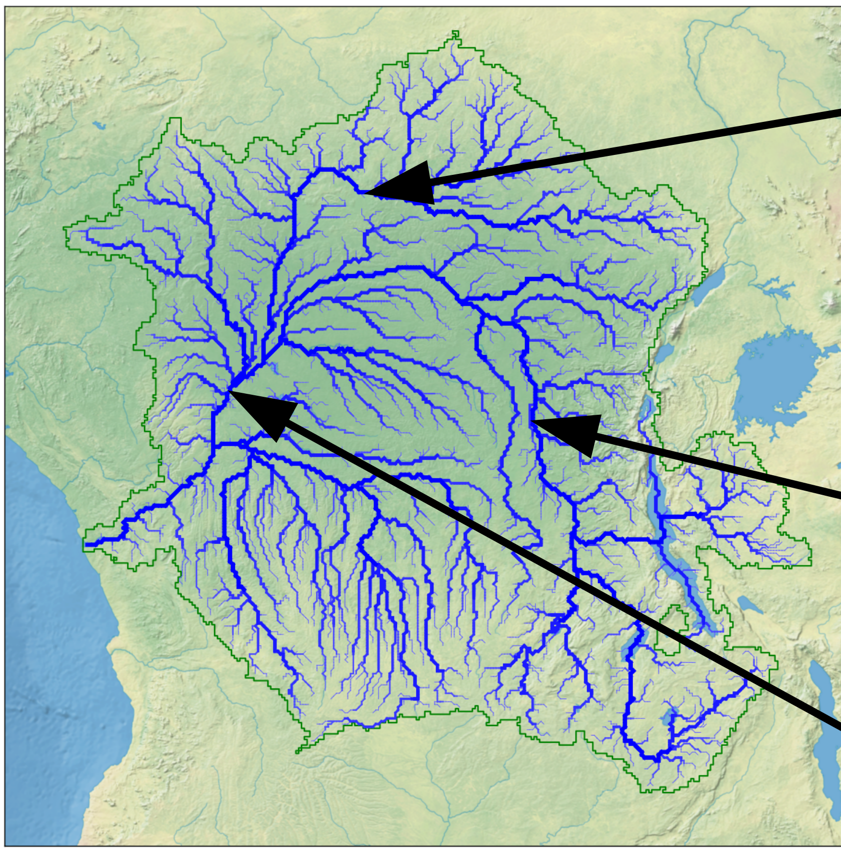
In some places, model outputs can be very far from observations.

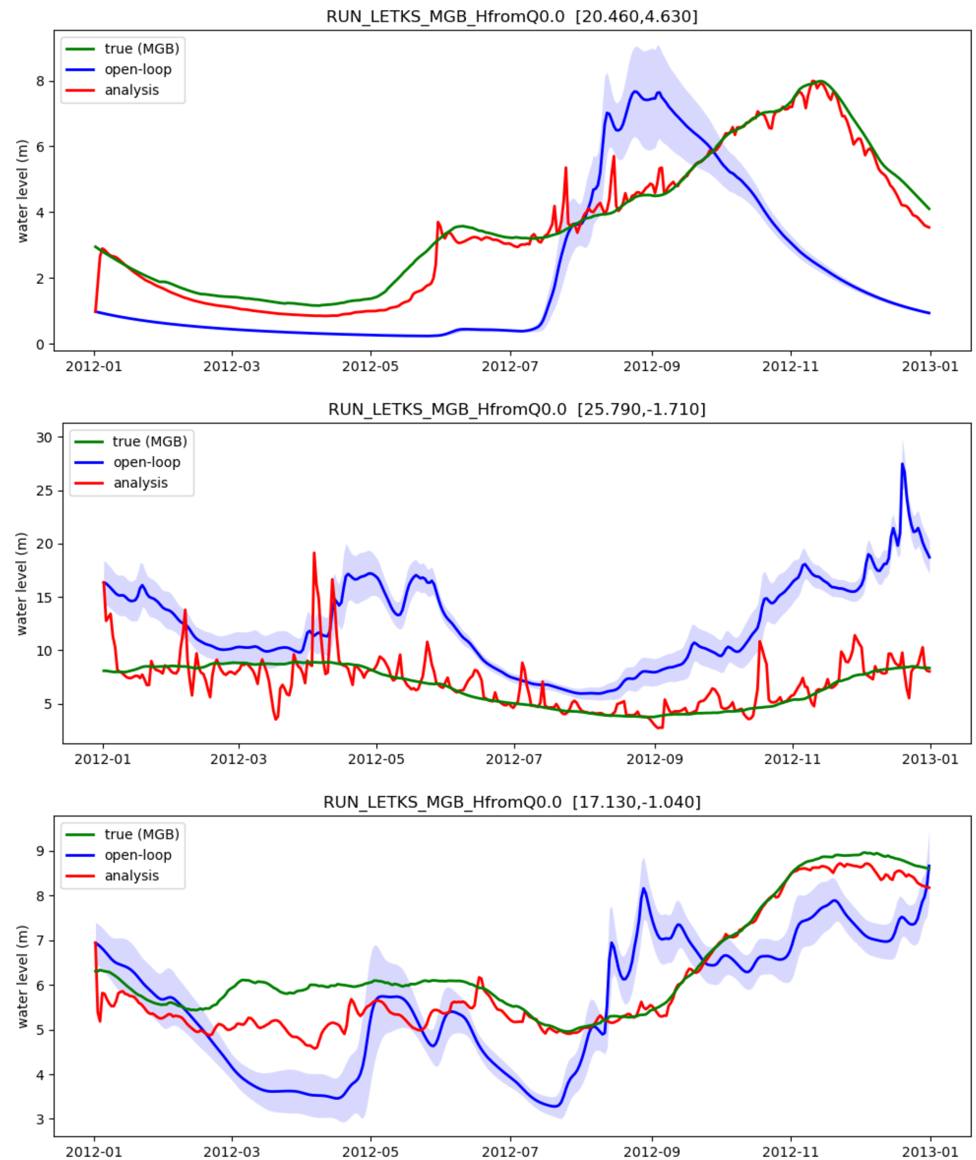


Assimilation of perfect water level (no obs error)

In some places, model outputs can be very far from observations.
But the DA is able to correct the model state quite efficiently.

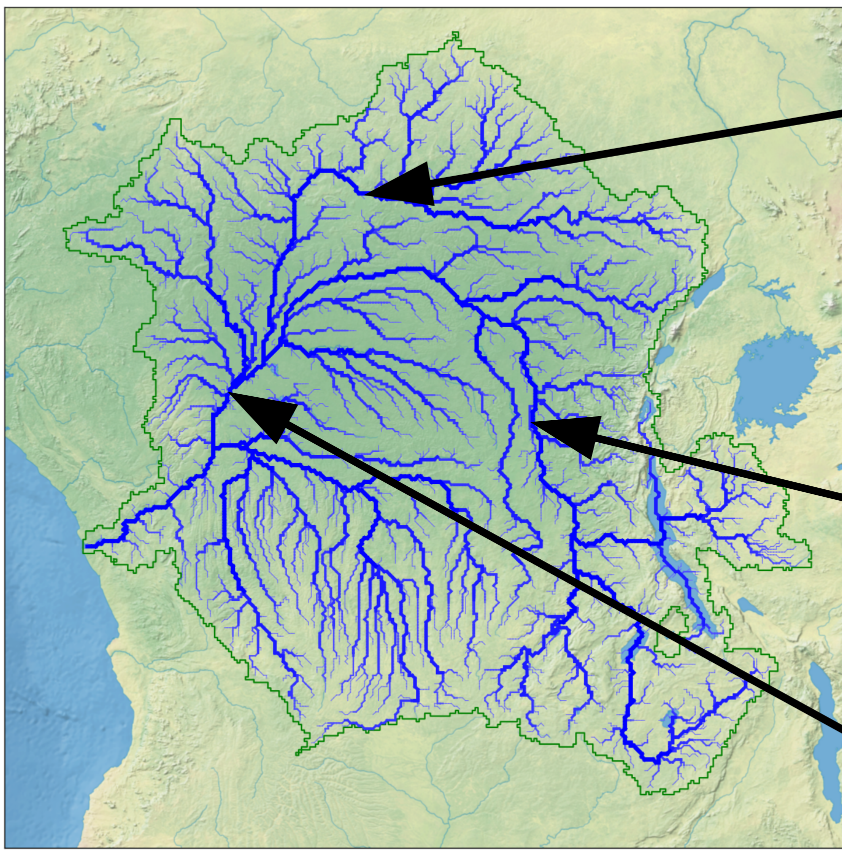


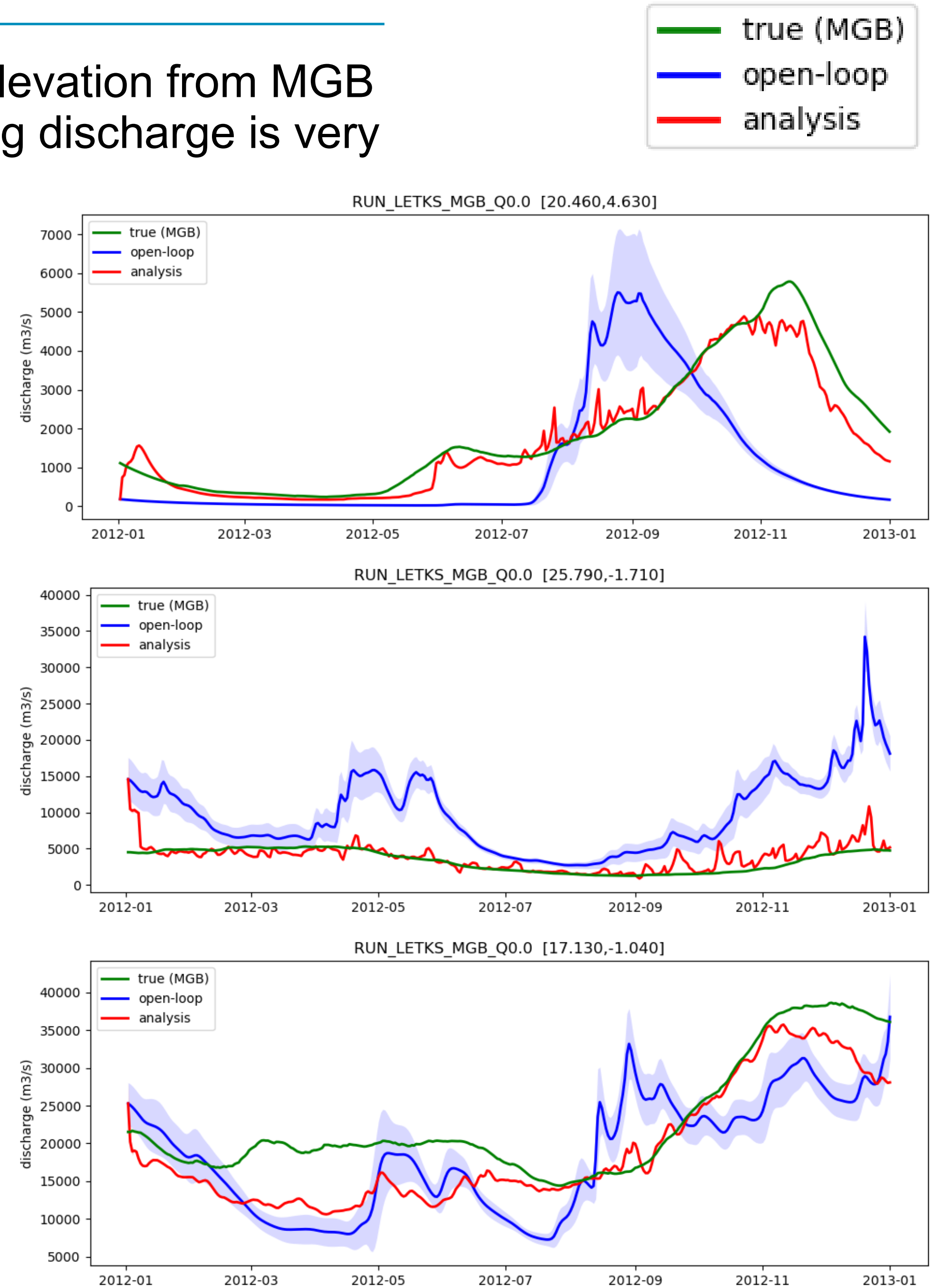




Assimilation of perfect discharge (no obs error)

If the H-Q relationship is perfect (MGB water elevation from MGB discharge and CTRIP rating curve), assimilating discharge is very similar to assimilating water elevation.





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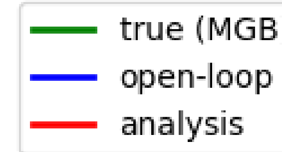
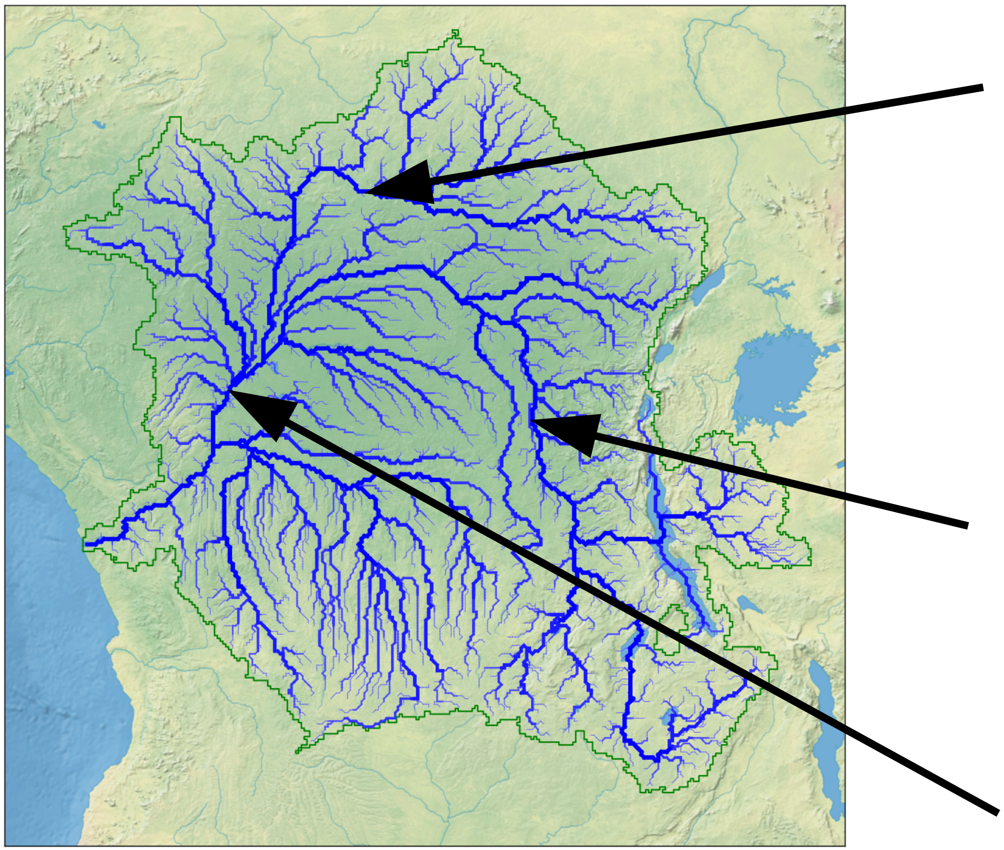
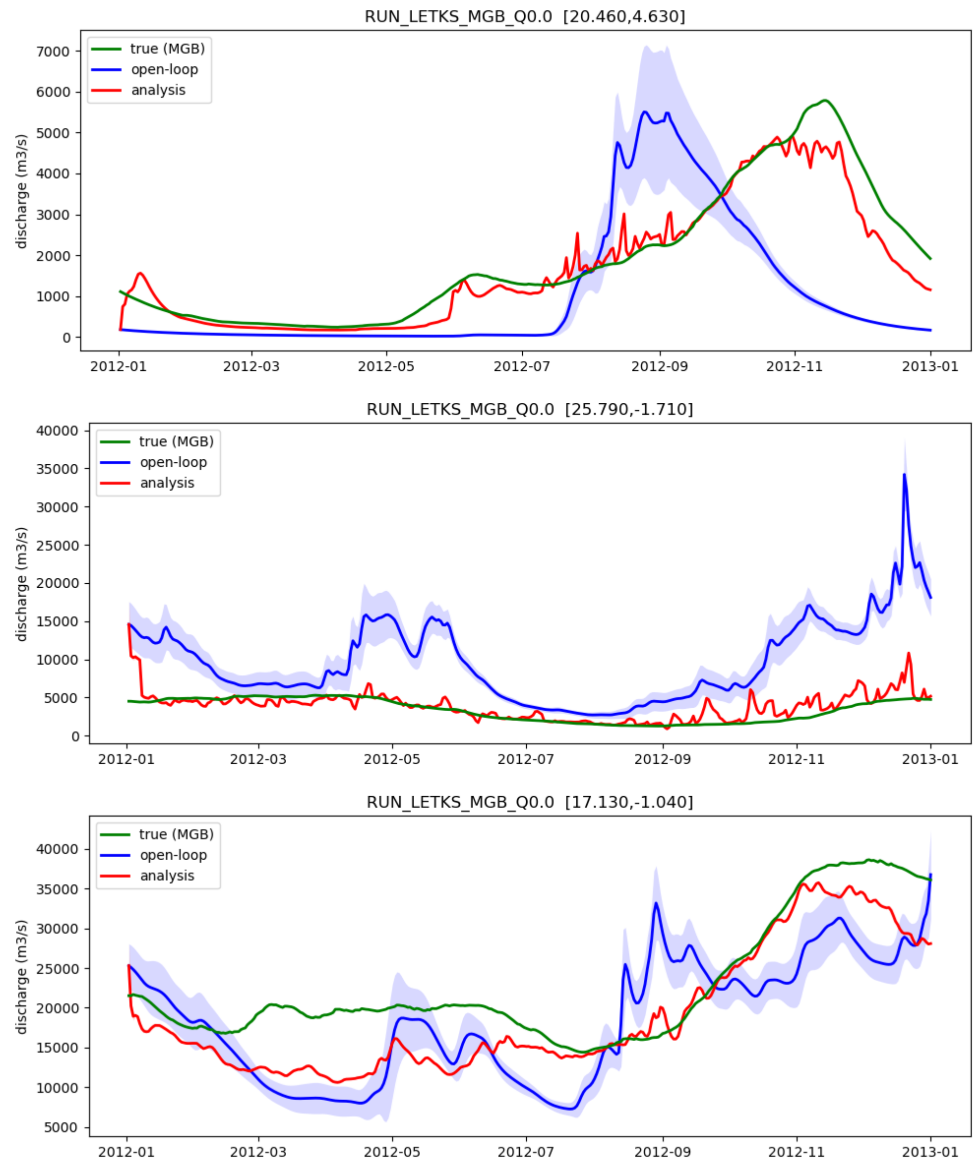


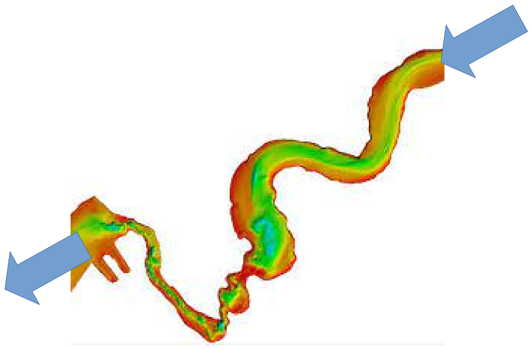




What if the CTRIP rating curve is wrong?

The stage-discharge relationship

Water elevation highly depends on the local river geomorphology
River discharge is more or less conservative (from one reach to the next)



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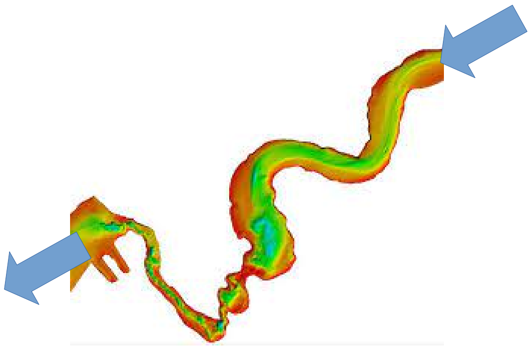
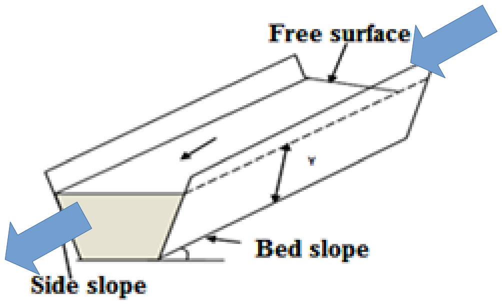


Large scale river routing models mainly rely on the mass conservation law, while their representation of water elevation is more conceptual.



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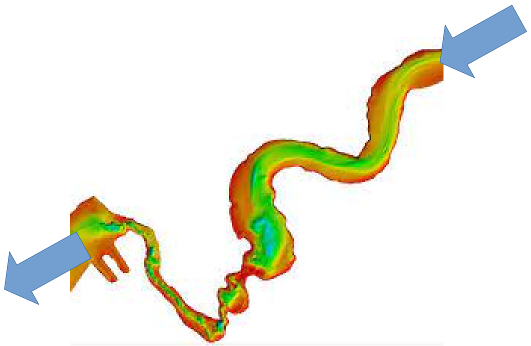
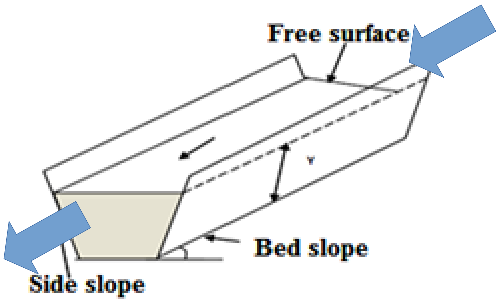
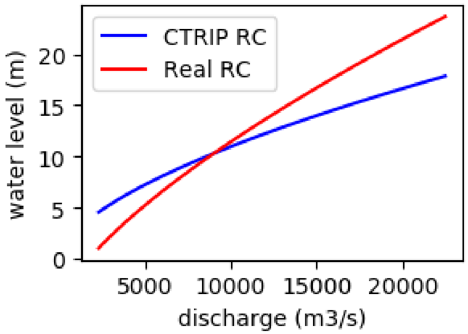
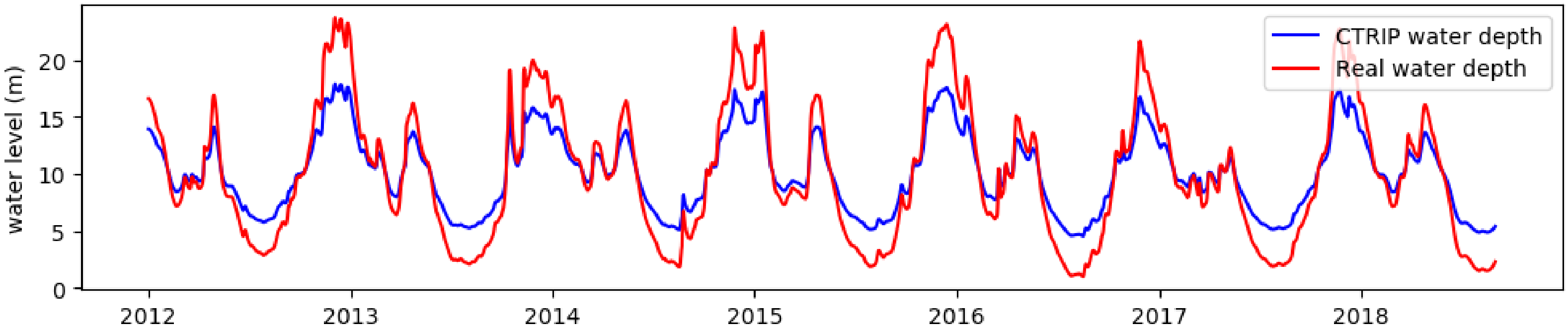




The relationship between water elevation and river discharge in CTRIP may by very different from what SWOT will observe.





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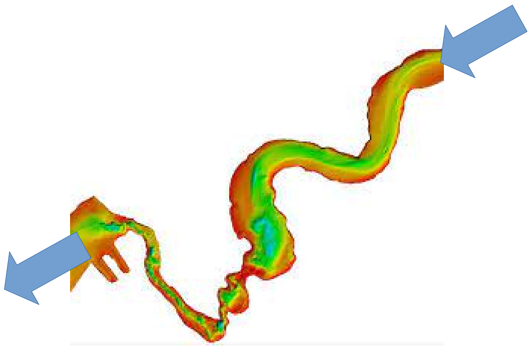
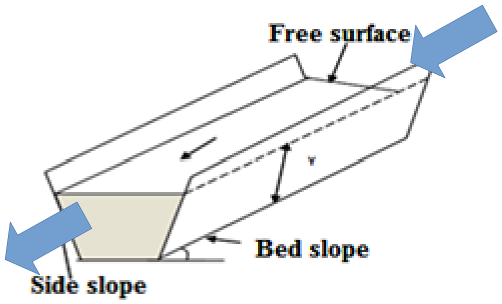


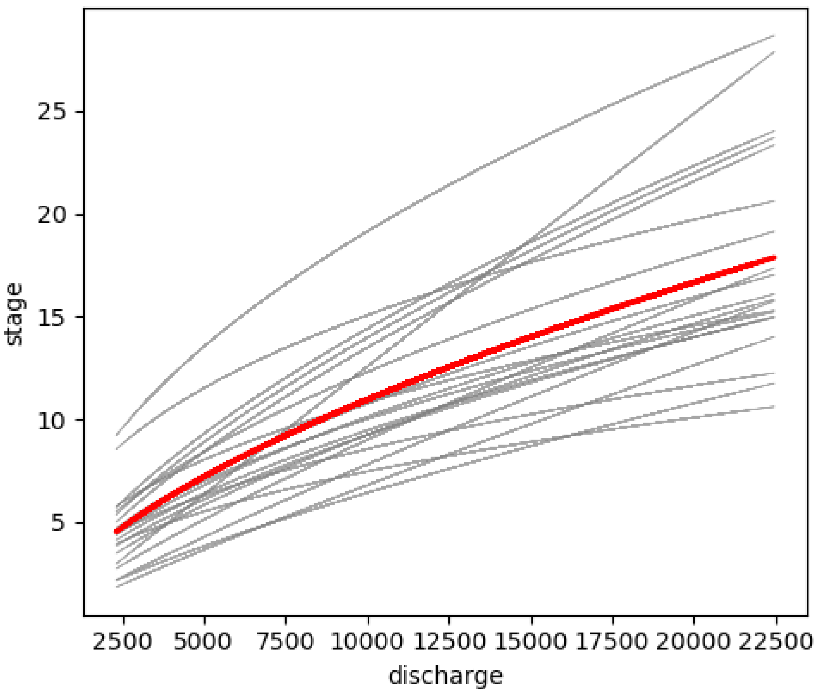


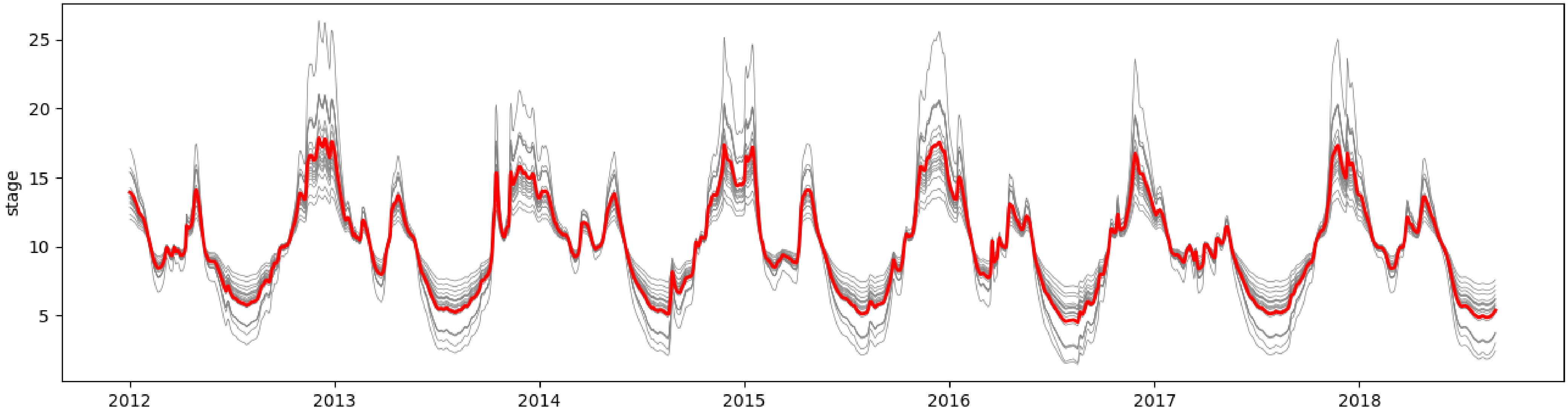
The relationship between water elevation and river discharge in CTRIP may by very different from what SWOT will observe.

Does the assimilation of “highly” uncertain river discharge performs better than the assimilation of the more “conceptual” water elevation?

Experimental setup

- Derivation of CTRIP rating curves
- Random perturbation of rating curves
- Computation of “true” water elevation from MGB discharge
- Remove mean difference





Experimental setup

- Derivation of CTRIP rating curves
- Random perturbation of rating curves
- Computation of “true” water elevation from MGB discharge
- Remove mean difference
- Add noise:
  - 10 cm for water level
  - 10%, 20% or 40% for discharge
- Evaluation using Assimilation Index (AI)

$$AI = 1 - \left| 1 - \frac{Q_{DA} - Q_{OL}}{Q_{true} - Q_{OL}} \right|$$

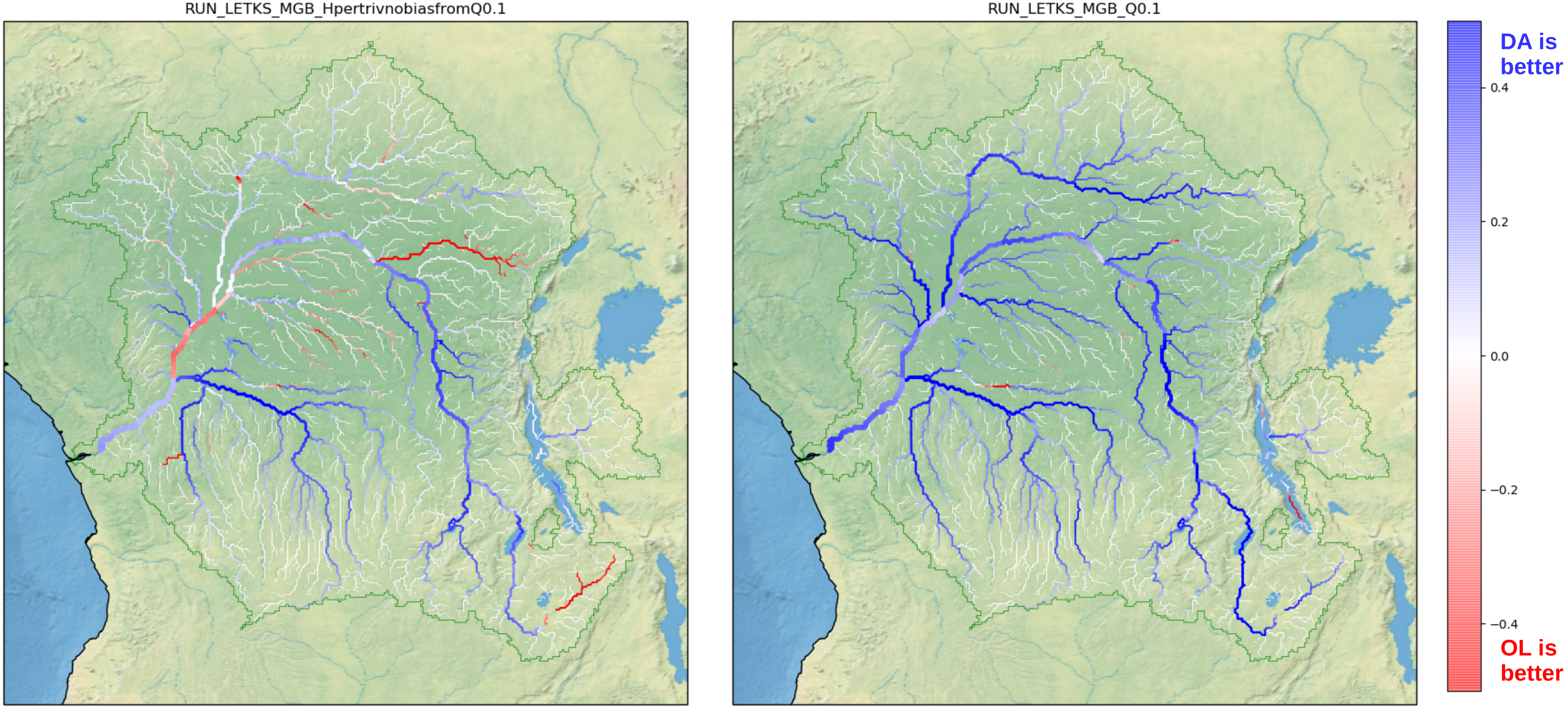
Q_{OL} Discharge from open-loop

Q_{DA} Discharge from data assimilation

Data assimilation results: AI

Water level assim, uncertainty 10 cm

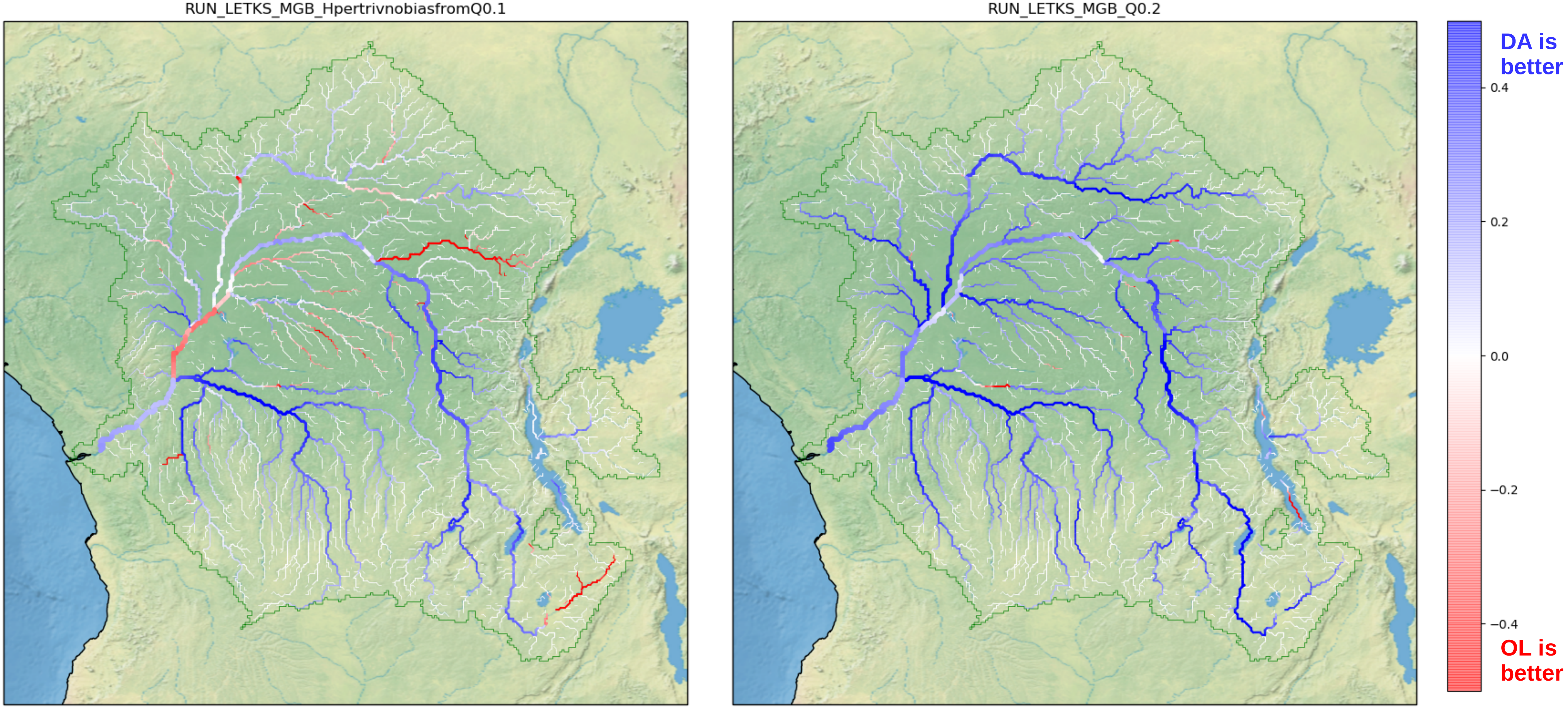
Discharge assim, uncertainty 10 %



Data assimilation results: AI

Water level assim, uncertainty 10 cm

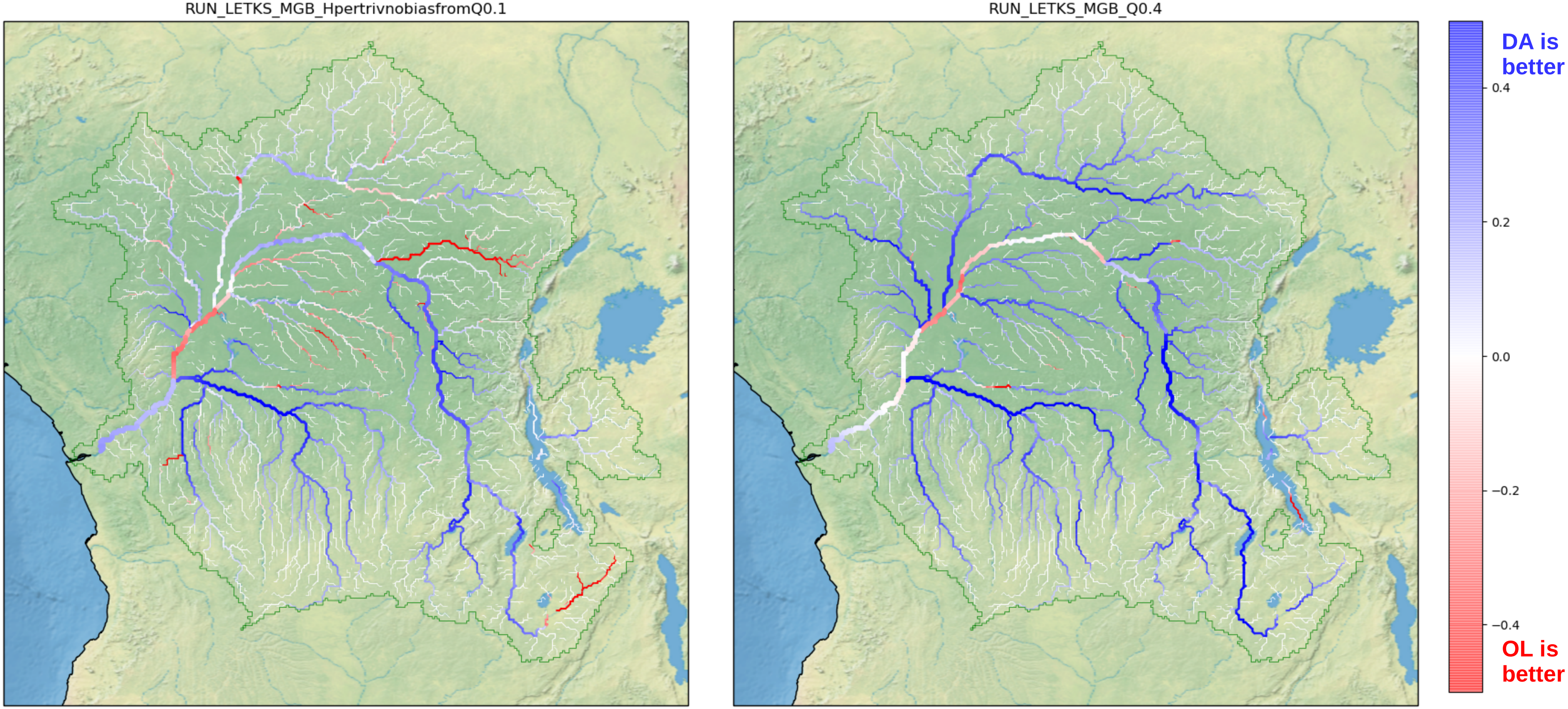
Discharge assim, uncertainty 20 %



Data assimilation results: AI

Water level assim, uncertainty 10 cm

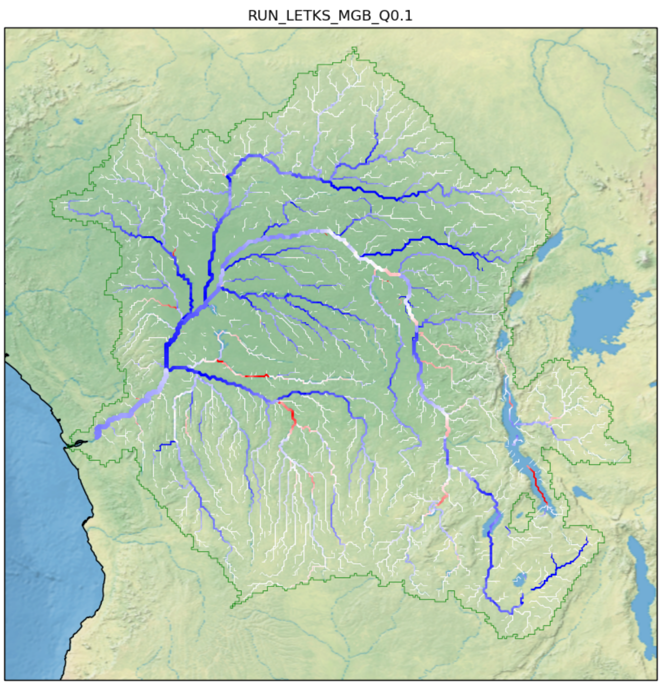
Discharge assim, uncertainty 40 %



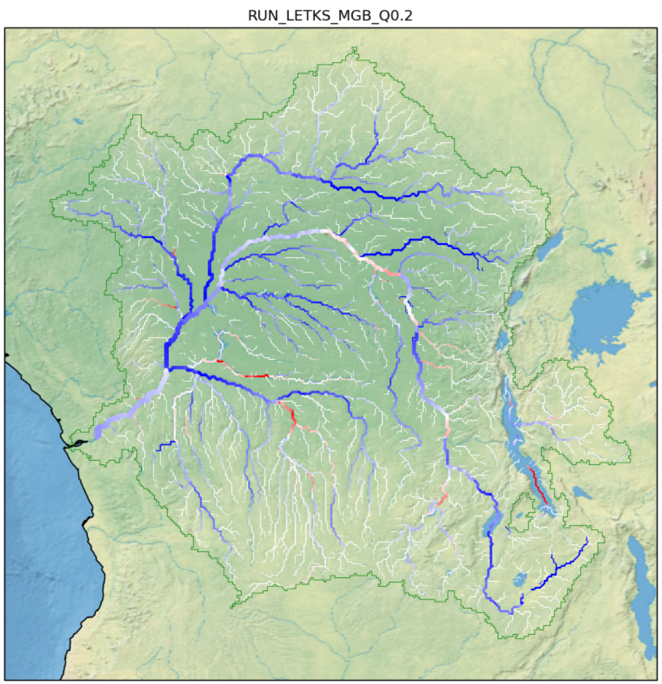
Water elevation vs discharge

Normalized Information Content (NIC) $$NIC = \frac{AI_{DIS} - AI_{WSE}}{1 - AI_{WSE}}$$

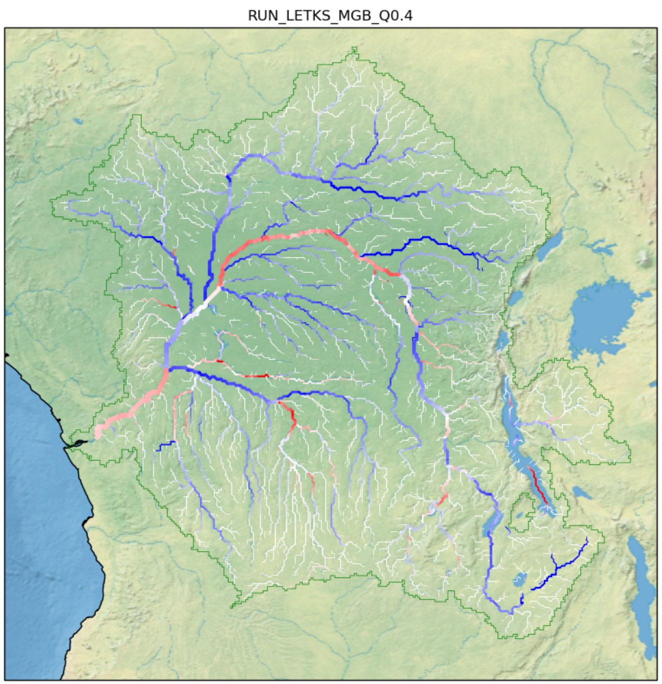
Discharge assim uncertainty 10 %

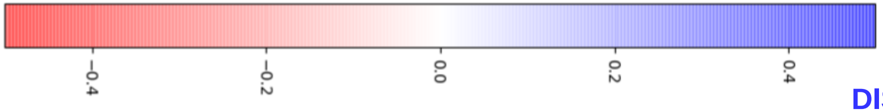


Discharge assim uncertainty 20 %



Discharge assim uncertainty 40 %





WSE is better

DIS is better

Conclusions

- A data assimilation framework has been developed within the CTRIP model
- It is able to assimilate either water elevation or discharge
- Assimilating water elevation may require a good approximation of the stage-discharge relationship
- The assimilation of water elevation with a 10 cm uncertainty may be more or less equivalent to the assimilation of discharge with a 40 % uncertainty

Future work

- The localization threshold and the smoother depth may impact the results
  - Comprehensive sensitivity analysis has to be conducted
- More realistic stage-discharge relationship
  - High resolution simulation with more complex river geometry and processes (eg with the LISFLOOD model)

Supplementary slides

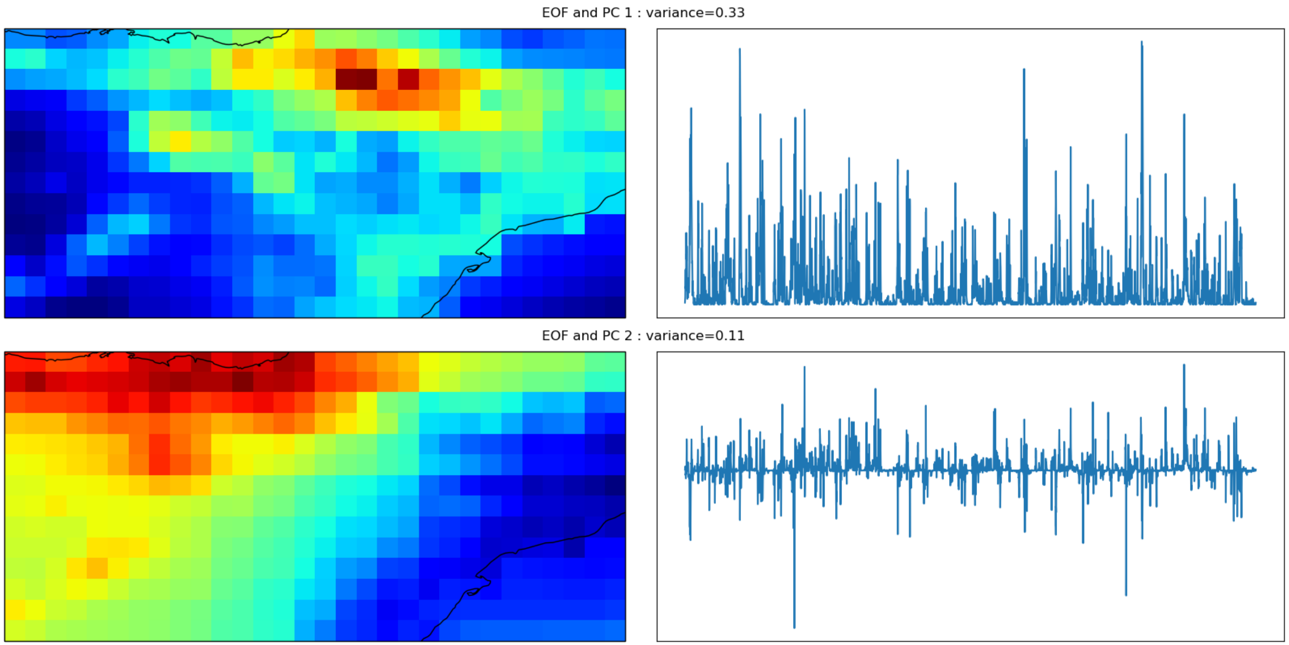
Ensemble generation

- From reference meteorological dataset (Earth2Observe)
- Perturbation of precipitation field
- Based on Empirical Orthogonal Functions (EOFs)
- Multiplicative error following a normal distribution with variance = 0.2

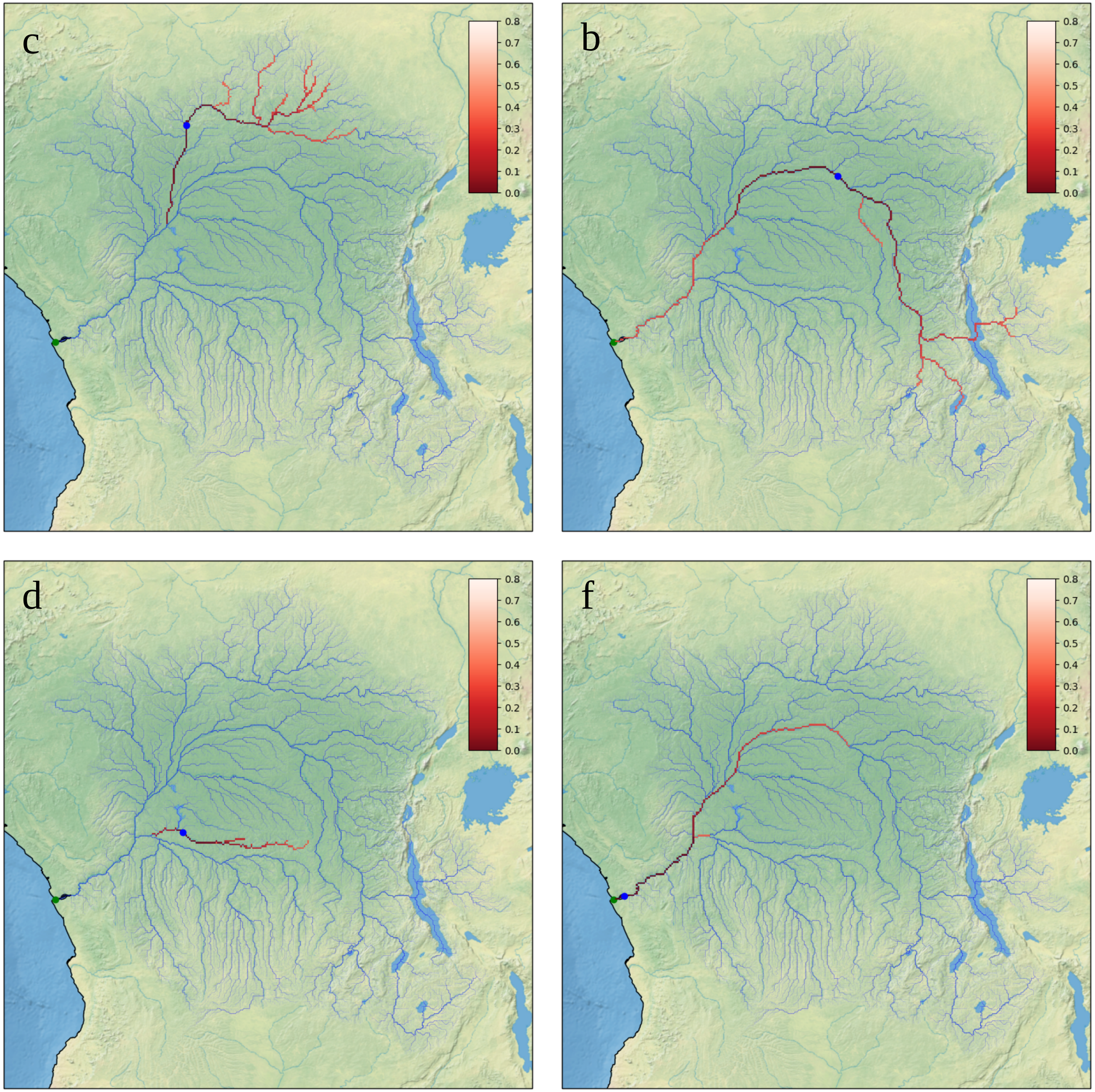
  => *allows to conserve the spatio-temporal structure of the forcings*

EOF 1

EOF 2

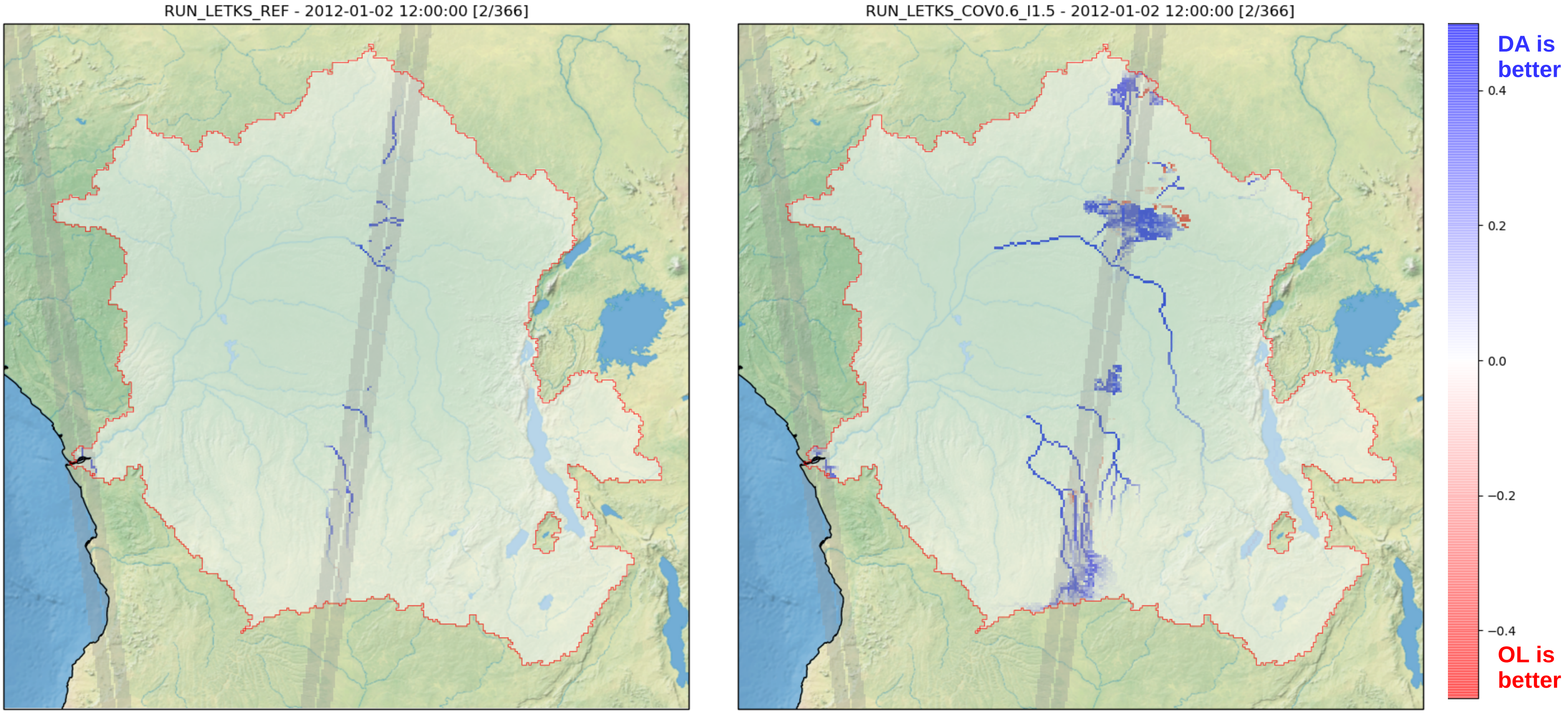


Localization: semi-variogram



Data assimilation results

- Impact of localization: Assimilation Index $$AI = 1 - \left| 1 - \frac{Q_{DA} - Q_{OL}}{Q_{true} - Q_{OL}} \right|$$



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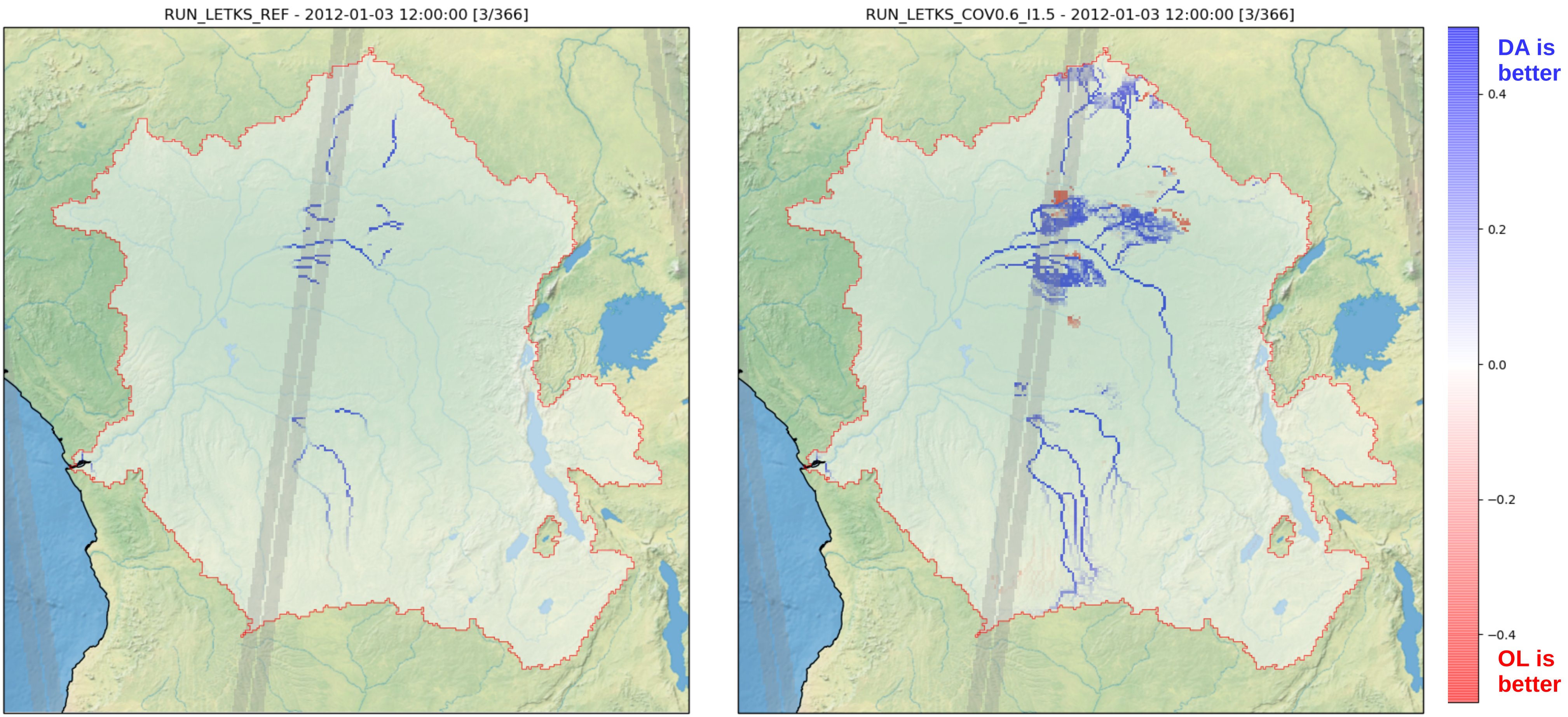

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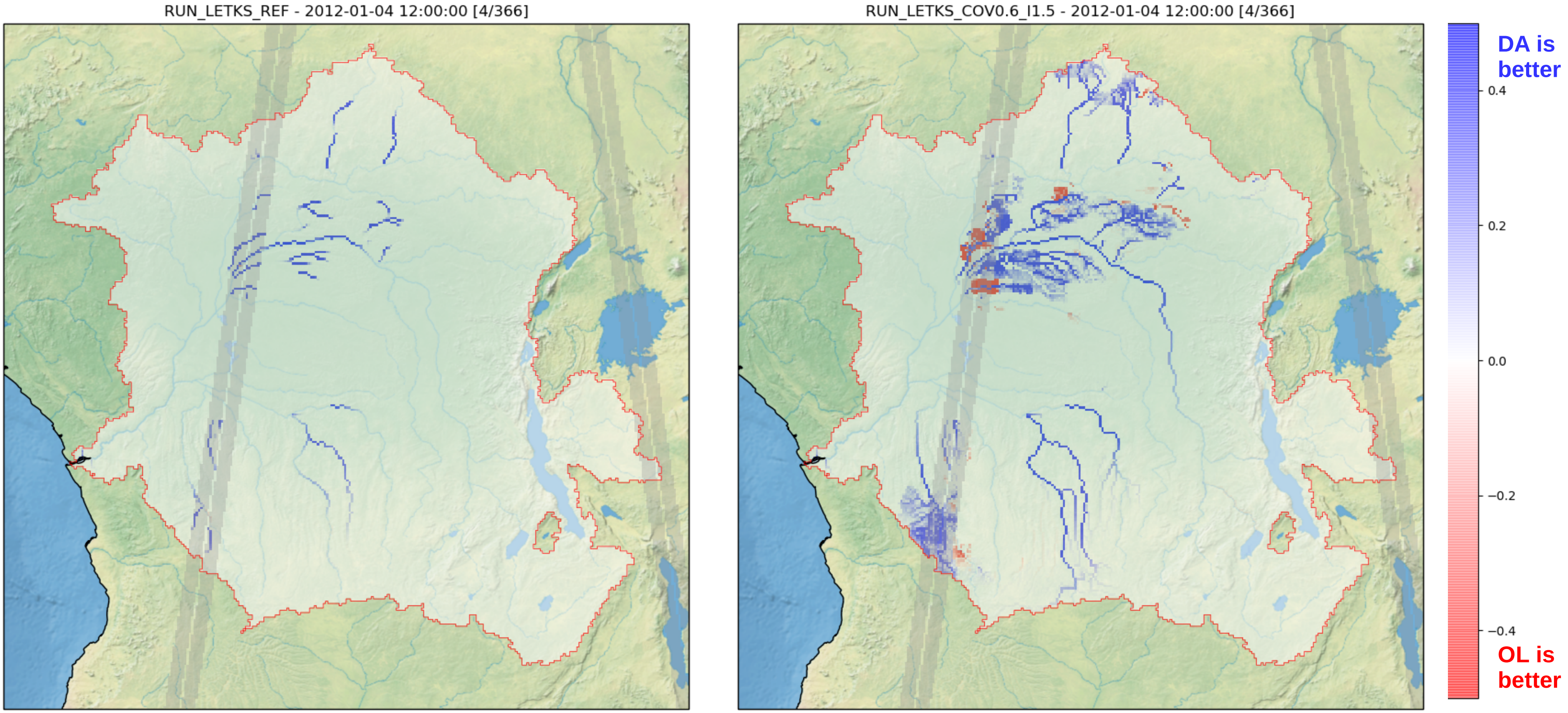

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