Global WSE assimilation to CaMa-Flood

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Motivation & Project Target

SWOT will observe WSE (water surface elevations) globally.
→ Why not using SWOT WSE for global-scale assimilation?

SWOT-constrained global river model simulation shall provide a more accurate estimation of global-scale hydrological cycle.

Our target is to develop **a framework for global SWOT assimilation**.

1) Choose an appropriate model and effective assimilation algorithm.

2) Assess the effectiveness of global SWOT WSE assimilation by a virtual experiment (as an initial trial).

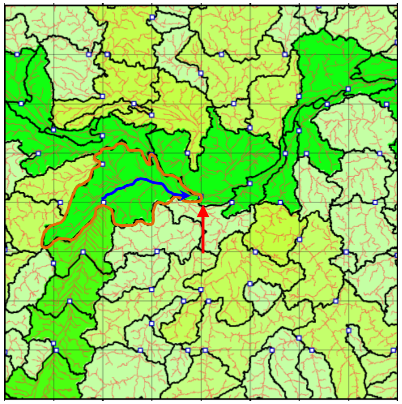
3) Examine the sources of uncertainties in assimilation framework.
   - Improve the framework and/or hydrodynamic model to reduce uncertainties.
   - Test the framework with existing altimetry (preparation before SWOT).

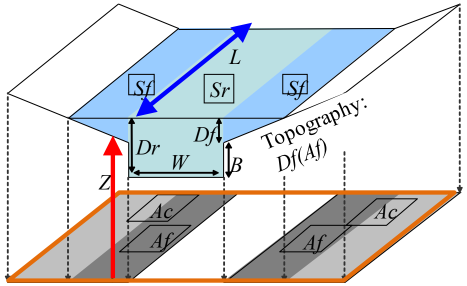
Hydrodynamics Core: CaMa-Flood model

For global SWOT assimilation, the hydrodynamics core model should be
- computationally fast and efficient to execute global ensemble simulations
- better to represent 2-dimentional dynamics of WSE, in order to directly utilize SWOT WSE

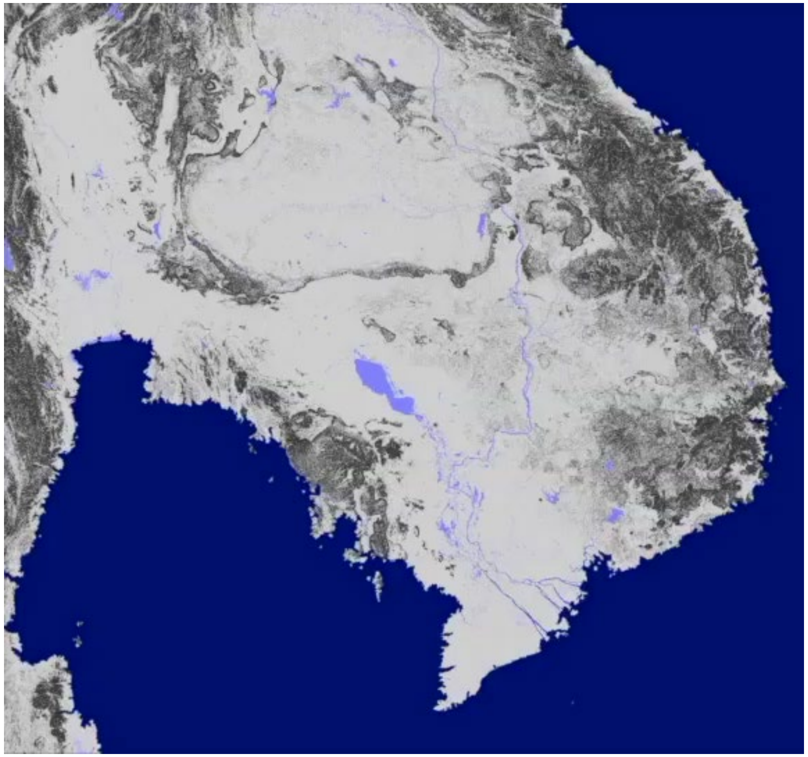
CaMa-Flood global hydrodynamic model was used.

- Global land surface is discretized to unit-catchments.
- Within unit-catchment, **flood stage is diagnosed from storage**, instead of solving 2D floodplain dynamics.





- Flow between unit-catchments (river discharge) is solved by a **shallow water equation**.
- Using runoff forcing from land hydrology model, it calculates river discharge, velocity, water depth, WSE, flooded area.
- Water depth, WSE, and flood area can be downscaled to 90m.



Water depth by CaMa-Flood
[Yamazaki et al., 2011, 2012, 2013, 2014]

Assimilation Scheme: LET Kalman Filter

Computationally efficient assimilation scheme is needed for global applications.

We used **LETKF** (Local Ensemble Transform Kalman Filter) [Hunt et al., 2007].

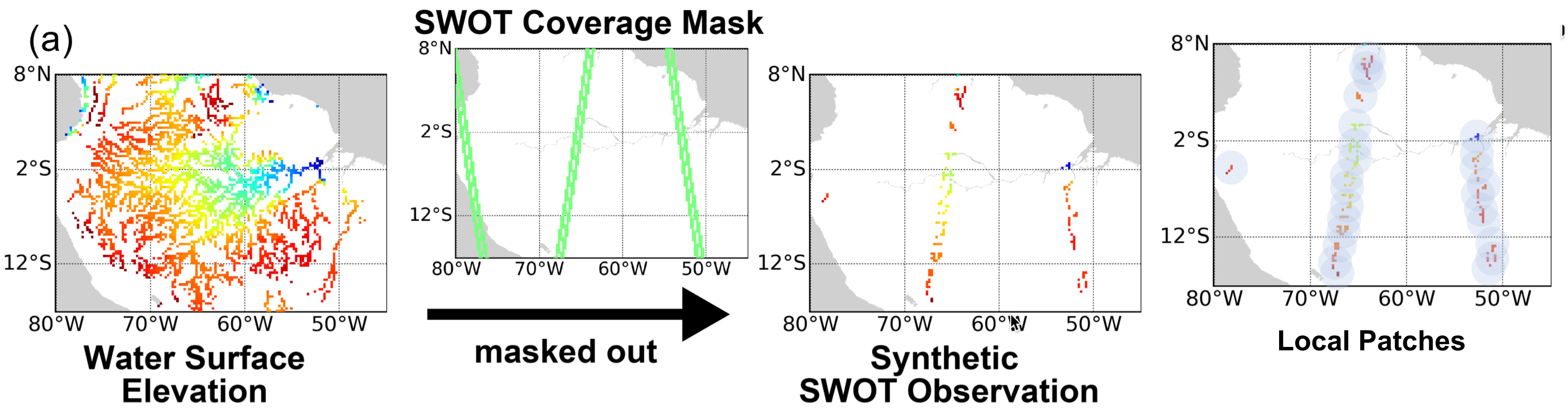
- It assumes covariance between distant points is negligible.
- Kalman Filter is applied to a limited domain near an observation point (**local patch**)
- Computational cost is largely reduced by avoiding global matrix calculation.

CaMa-Flood is set to 0.25deg (~25km) resolution.

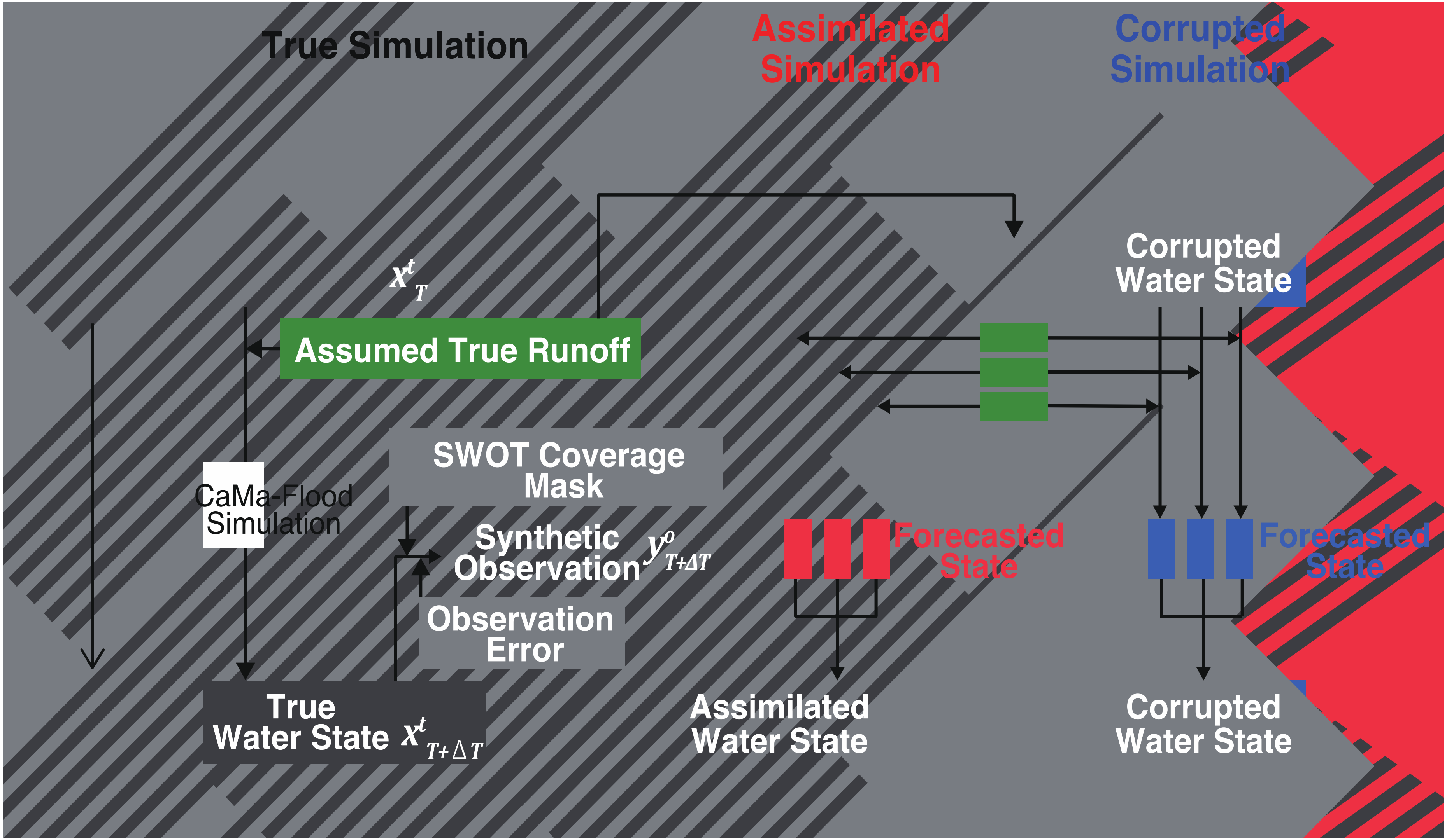
- Synthetic observation for grid with >50m width rivers

Used a local latch with 5 grid radius (~120km).

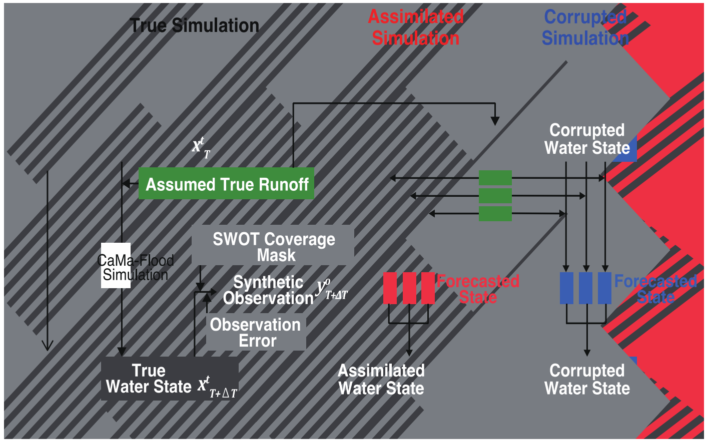
- The status of unit-catchments within the local patches are updated by EnKF at daily time step.



Virtual SWOT synthetic experiment



Detailed Configurations



Experiment 1:
- Minimum degradation on the corrupted model (no bias).
- Assume some uncertainties only in runoff forcing (-25% bias)

	True Model	**Corrupted Model**
Floodplain topo	From SRTM3 + HydroSHEDS	Same as true
Channel width	Hydrogeometry Function	Same as true
Channel depth	Hydrogeometry Function	Same as true
Manning's n	**0.03 + random noise [0.025-0.035]** (spatially distributed, time constant)	0.03 (constant in time and space)
	True Forcing	**Corrupted Forcing**
Runoff input	From LSM MATSIRO (1990-1990)	Degraded by -25% bias to true runoff 20 ensembles by adding 25% Gaussian noise (uncorrelated in space and time)

SWOT synthetic observation

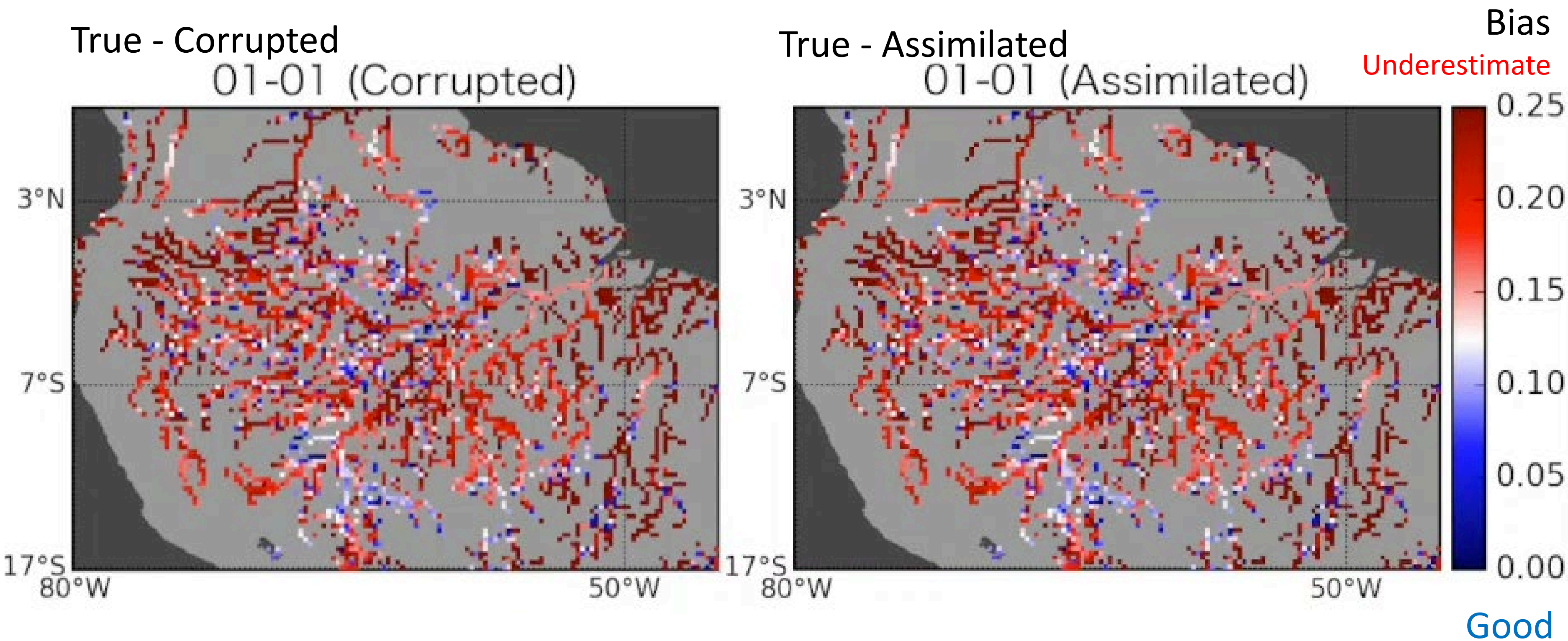
Rivers >50m width, daily time step

(5cm Gaussian noise is added)

Assimilated simulation used "Corrupted model + forcing" and "Synthetic observations".

Results (Amazon)

Bias in River Storage



Corrupted discharge is ~25% underestimated, due to -25% bias in runoff forcing.

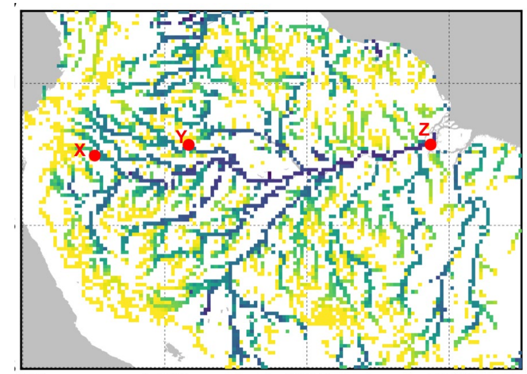
Assimilated discharge showed better agreement to true discharge.

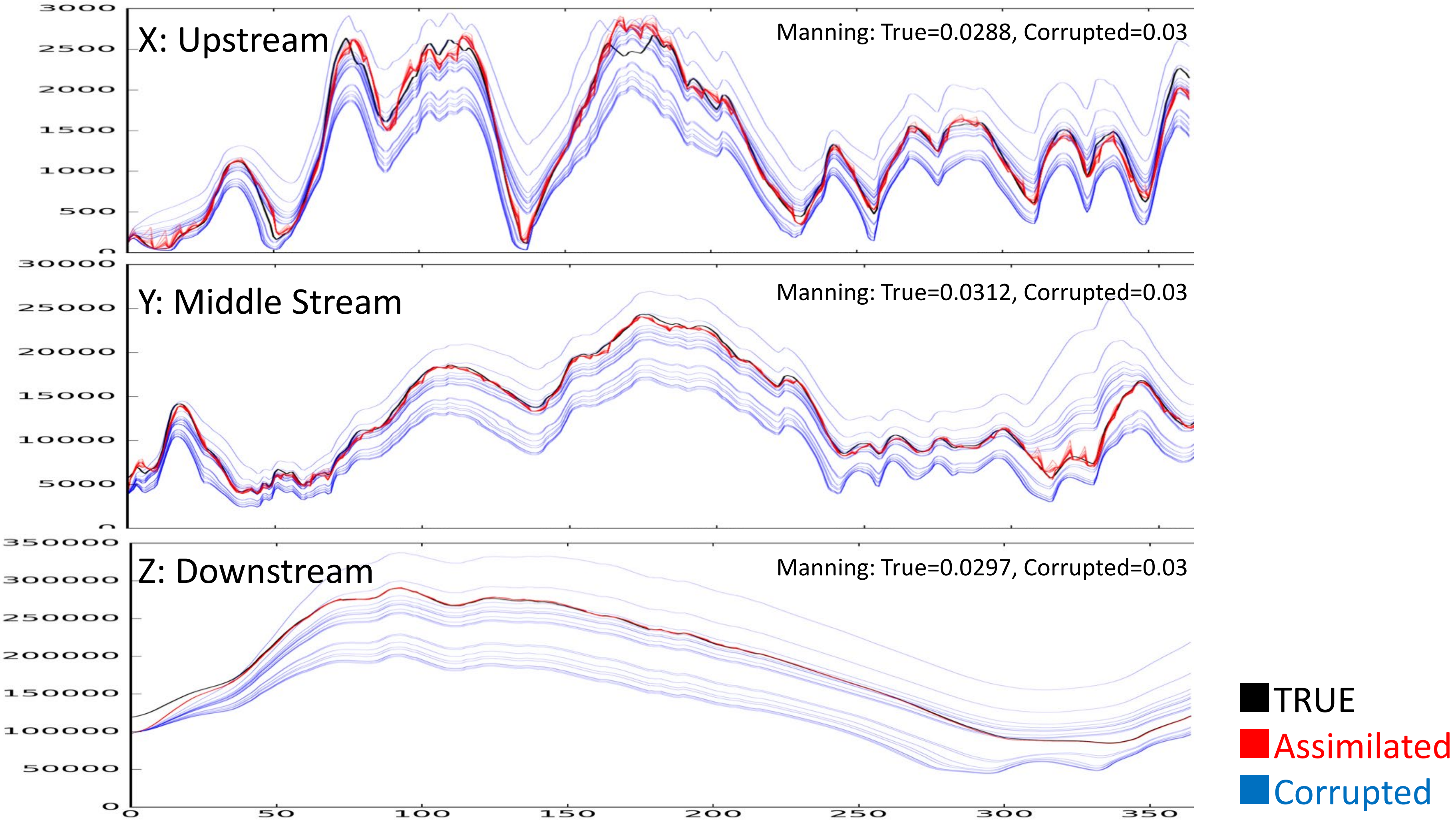
- Error is smaller in downstream, while almost no improvement in uppermost reaches.

Results (Amazon)

Daily River Discharge

Error of assimilated discharge becomes smaller in downstream.



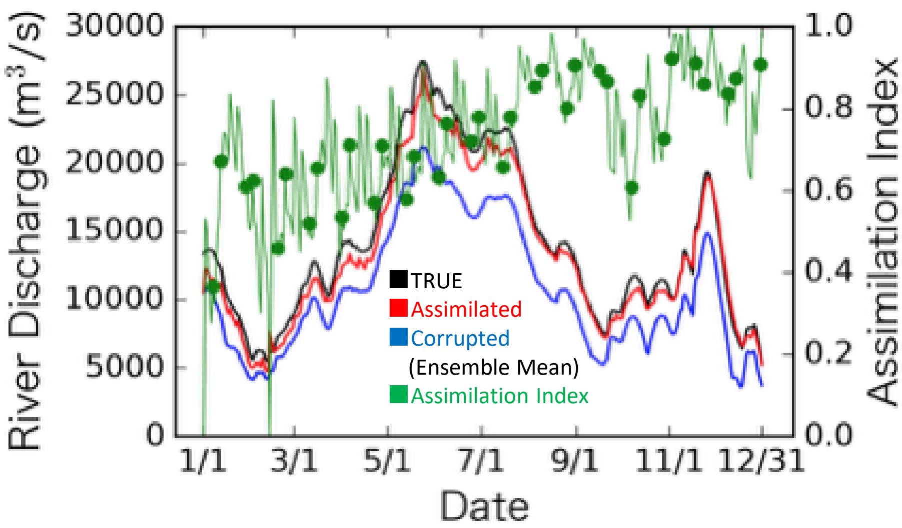


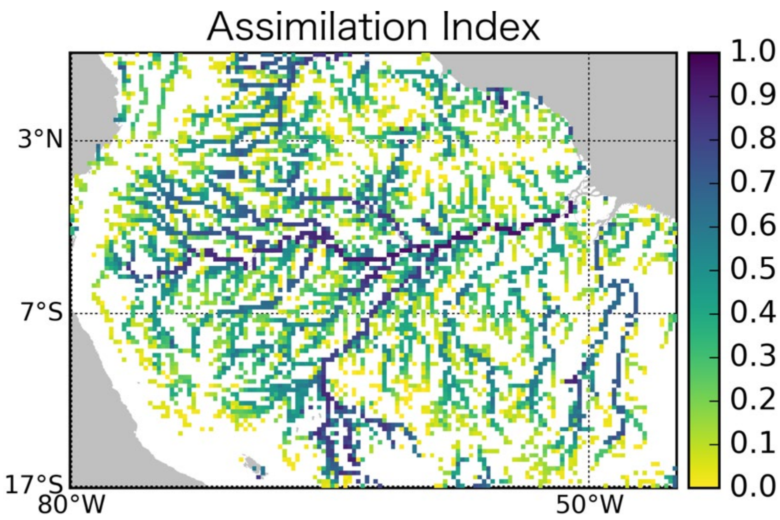
Results (Amazon)

In order to discuss the effectiveness of assimilation at different locations and different time,
We introduce a metrics "**Assimilation Index (AI)**"

$$AI = 1 - \left| \frac{True\ Discharge - Assimilated\ Discharge}{True\ Discharge - Corrupted\ Discharge} \right|$$

AI is **similarity of Assimilated to True**, relatively compared to the difference of "True - Corrupted".
AI=1 when [Assimilation = True], while AI=0 when [Assimilation = Corrupted].





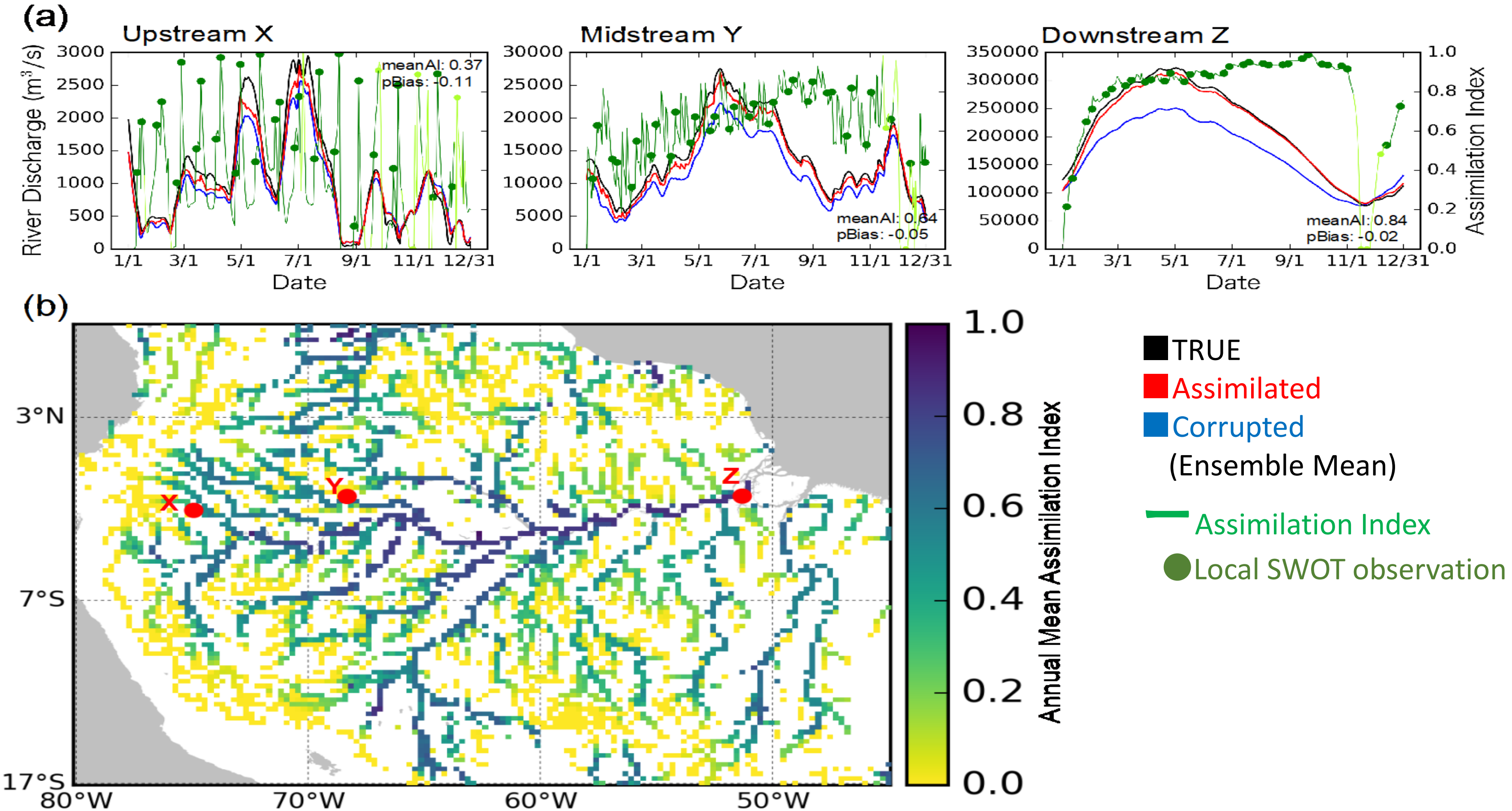
Assimilation Index can be calculated at a daily time scale or as an annual mean.
Comparison between different location is possible because it is "**relative effectiveness of assimilation**"

Results (Amazon)

Why assimilated discharge showed smaller error in downstream?

- WSE assimilation worked both in down- & up-stream. AI increases at days with local SWOT observation.
- However in upstream, AI dropped within a few days after local SWOT observations.
- While in downstream, AI is kept high because of assimilated inflow from upstream regions.

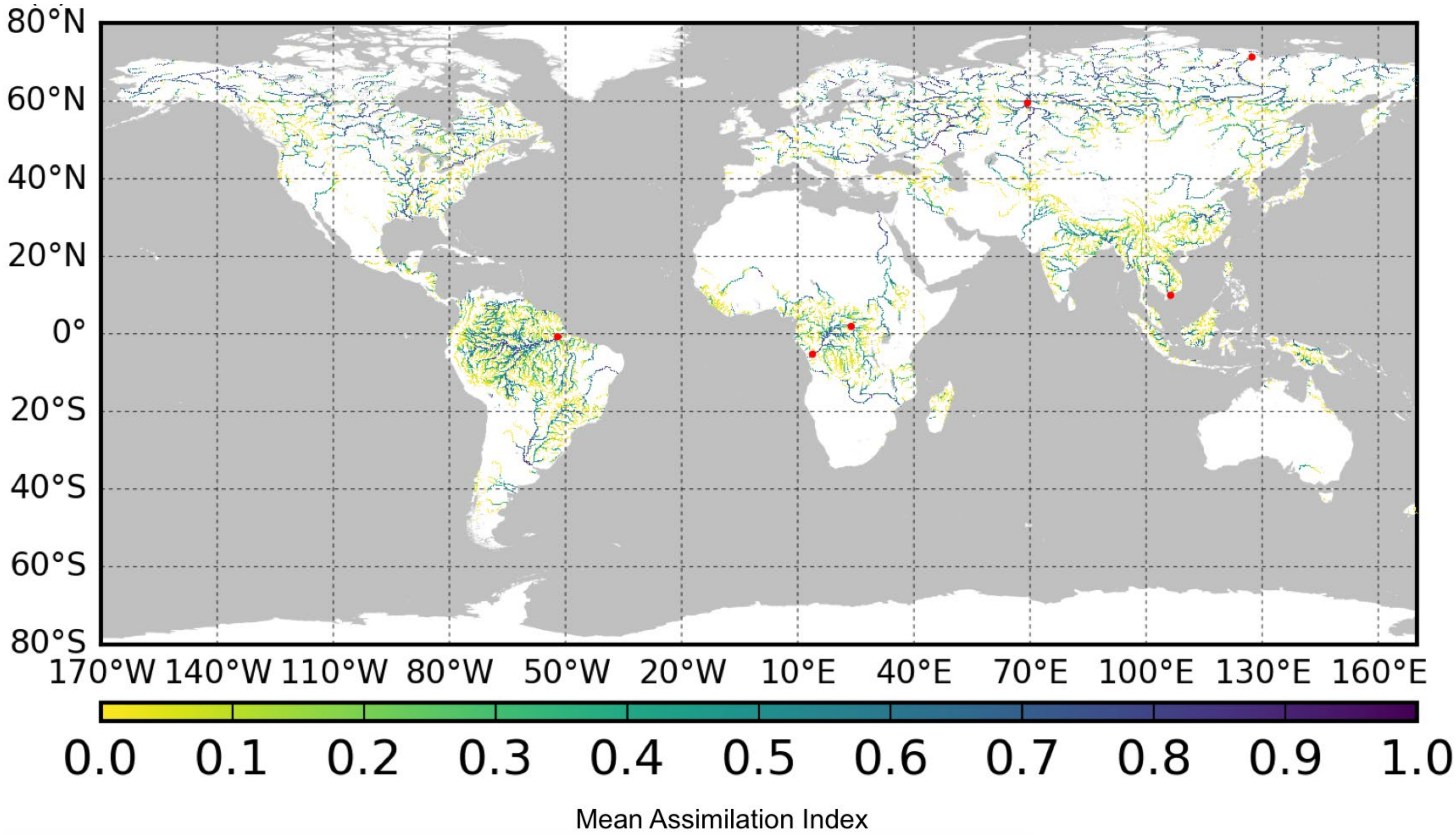
→ Larger rivers are expected to have more benefit from SWOT observation.



Results (Global)

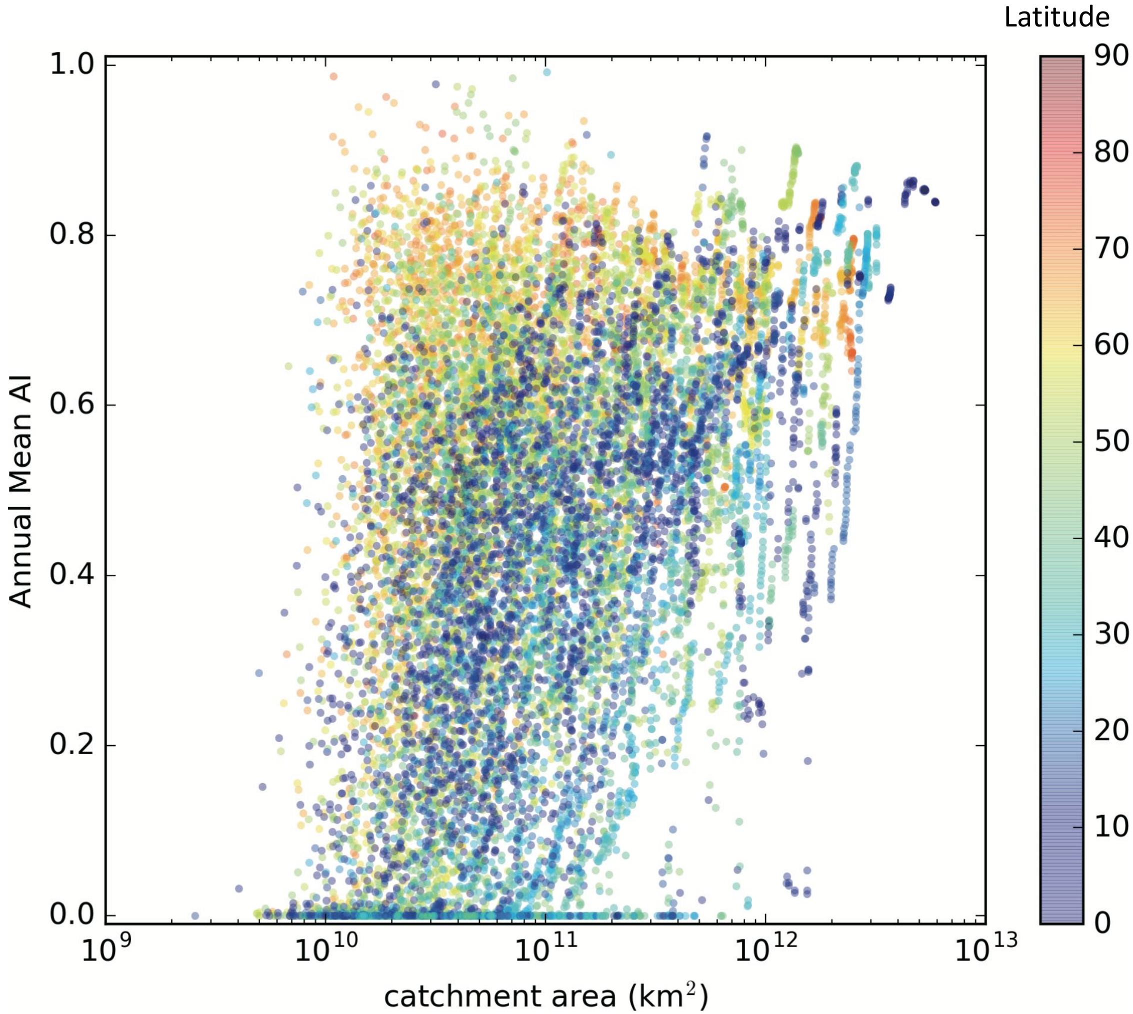
Larger rivers are expected to have more benefit from SWOT observation.

Rivers in high latitude tends to have larger improvement, because of frequent observations.



Results (Global)

Where we can expect high-accuracy river discharge estimation?



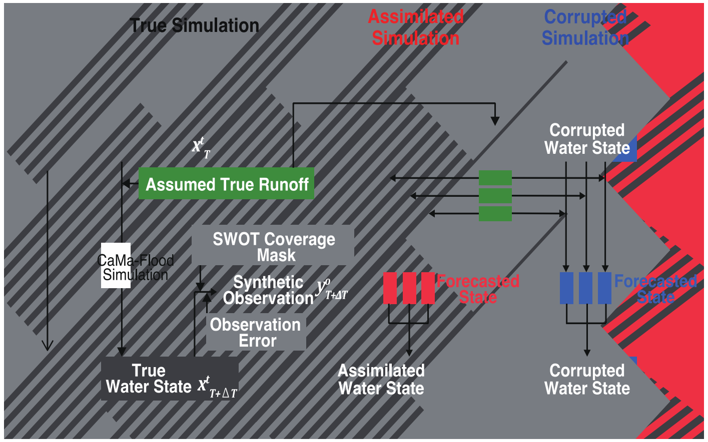
We can say, in general:
- Larger river is better
- Downstream is better
- Higher latitude is better

No clear relation found yet

We might consider:
- Observation numbers
- Geometry of river networks
- Direction of river networks
- Existence of floodplains
- ....

More realistic case

The above analysis assumed no model bias.
What happened if the corrupted model contains bias?

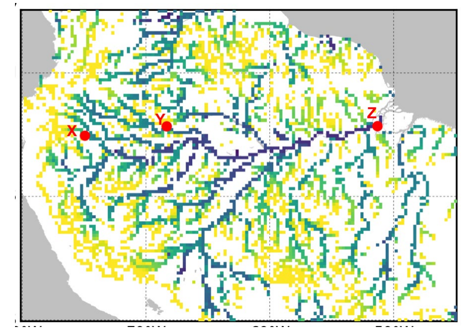


Experiment 2:
- Larger roughness for corrupted model (bias, higher WSE).
- Assume some uncertainties only in runoff forcing (-25% bias)

	True Model	**Corrupted Model**
Floodplain topo	From SRTM3 + HydroSHEDS	Same as true
Channel width	Hydrogeometry Function	Same as true
Channel depth	Hydrogeometry Function	Same as true
Manning's n	**0.03** (constant in time and space)	**0.035** (constant in time and space)

	True Forcing	**Corrupted Forcing**
Runoff input	From LSM MATSIRO (1990-1990)	Degraded by -25% bias to true runoff 20 ensembles by adding 25% Gaussian noise (uncorrelated in space and time)

Biased model experiment

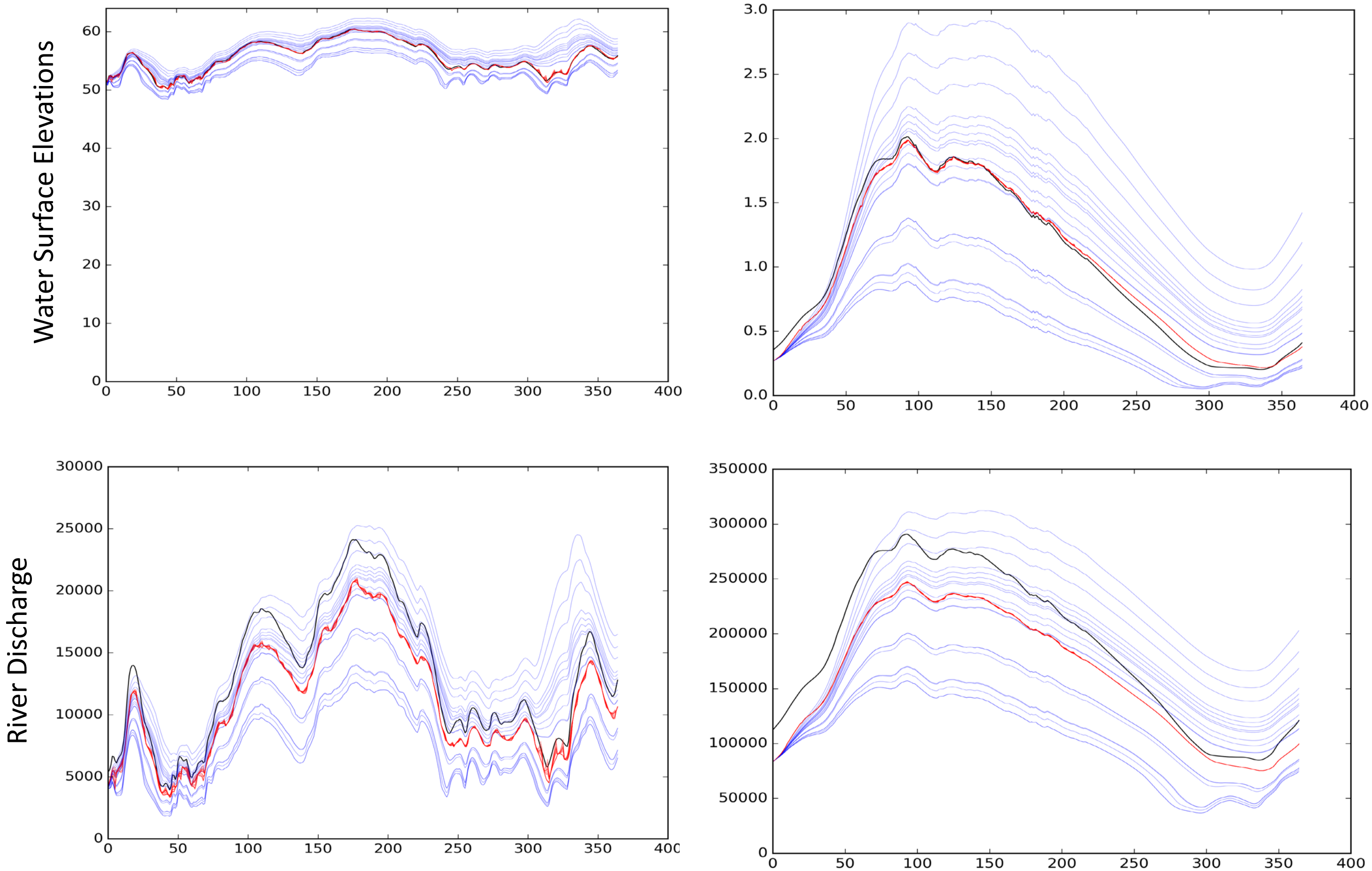


Water surface elevations are assimilated very well,
but river discharge was largely underestimated.

When roughness is larger, **discharge is smaller for a given water depth.**

→ [1] **Need to handle model bias**, and/or [2] **Improve the model to reduce bias**.

Amazon Midstream Amazon Downstream

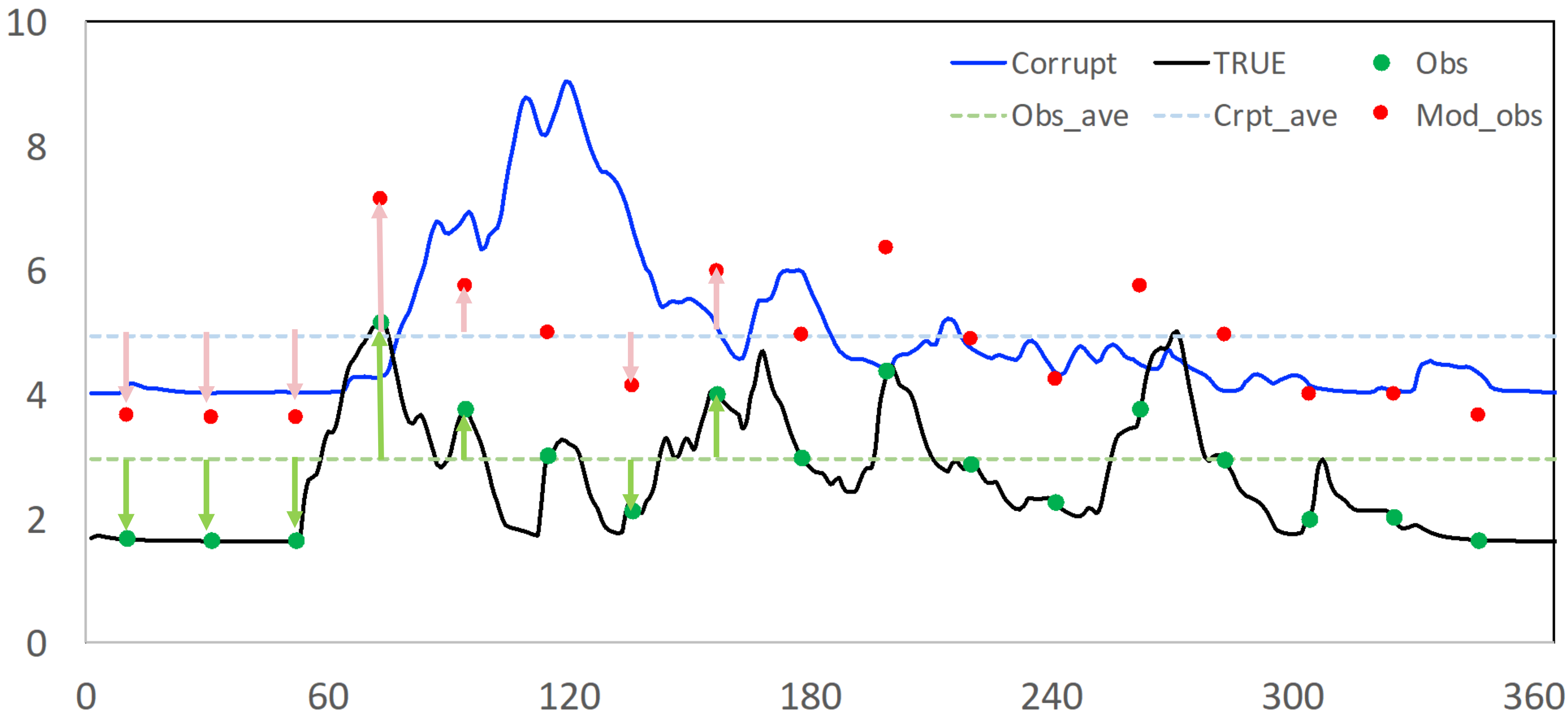


True: Manning n=0.03
Corrupt: n=0.035

TRUE
Assimilated
Corrupted

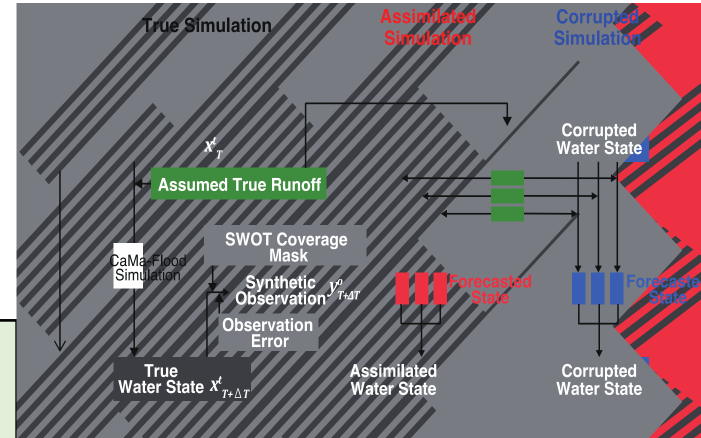
[1] Handling model bias

Assimilating **anomaly of WSE**, instead of absolute WSE values.



Anomaly Assimilation

Can we handle model bias by **”anomaly assimilation”**?



Experiment 3:

- Corrupted channel bathymetry 2m deeper than trues.

- Assume no bias in runoff for easy discussion (only ~25% noise)

	True Model	**Corrupted Model**
Floodplain topo	From SRTM3 + HydroSHEDS	Same as true
Channel width	Hydrogeometry Function	Same as true
Channel depth	Hydrogeometry Function	**TRUE bathymetry + 2m (deeper)**
Manning’s n	**0.03 + random noise [0.025-0.035]** (constant in time and space)	**0.03** (constant in time and space)

	True Forcing	**Corrupted Forcing**
Runoff input	From LSM MATSIRO (1990-1990)	No bias assumed 20 ensembles by adding 25% Gaussian noise (uncorrelated in space and time)

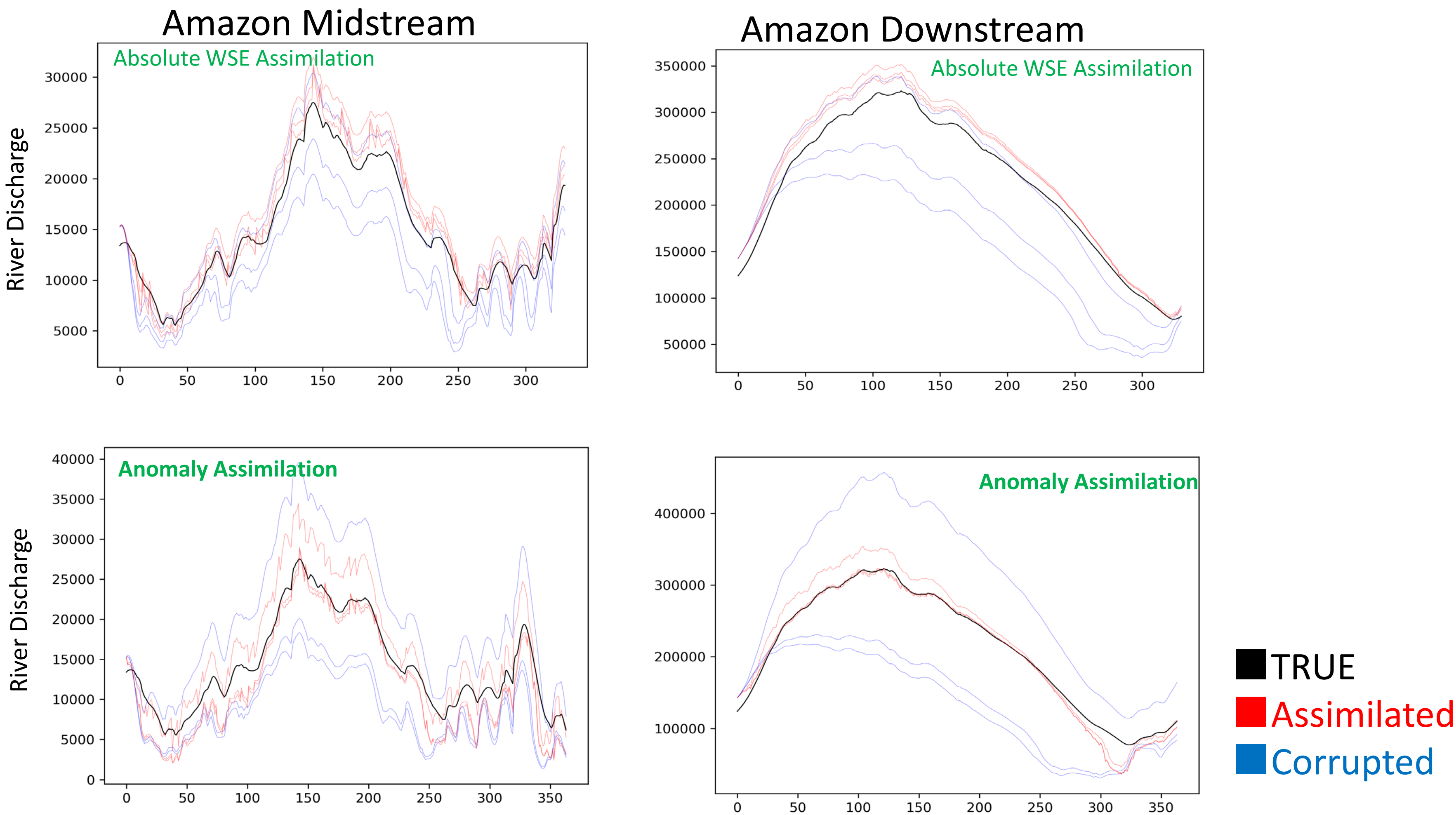
Anomaly Assimilation: (Preliminary results)

Because the corrupted bathymetry is 2m deeper,

Corrupted model shows larger discharge than true model for the same WSE.

→ Direct assimilation of absolute WSE caused discharge overestimation.

→Bias can be removed by applying Anomaly WSE assimilation.



[2] Reducing model bias

In order to fully utilize SWOT observations, we need a better hydrodynamic model.
The **model should replicate "WSE – Discharge" relationship** of the actual world.

- Realistic hydrodynamics (i.e. physics).
- Better DEM (SRTM is still crude, no good DEM above 60N)
- Better Hydrography (HydroSHEDS is good, but it has many errors)
- Better channel cross-section (width + depth)
- Reasonable runoff forcing
- Global Manning's n distribution

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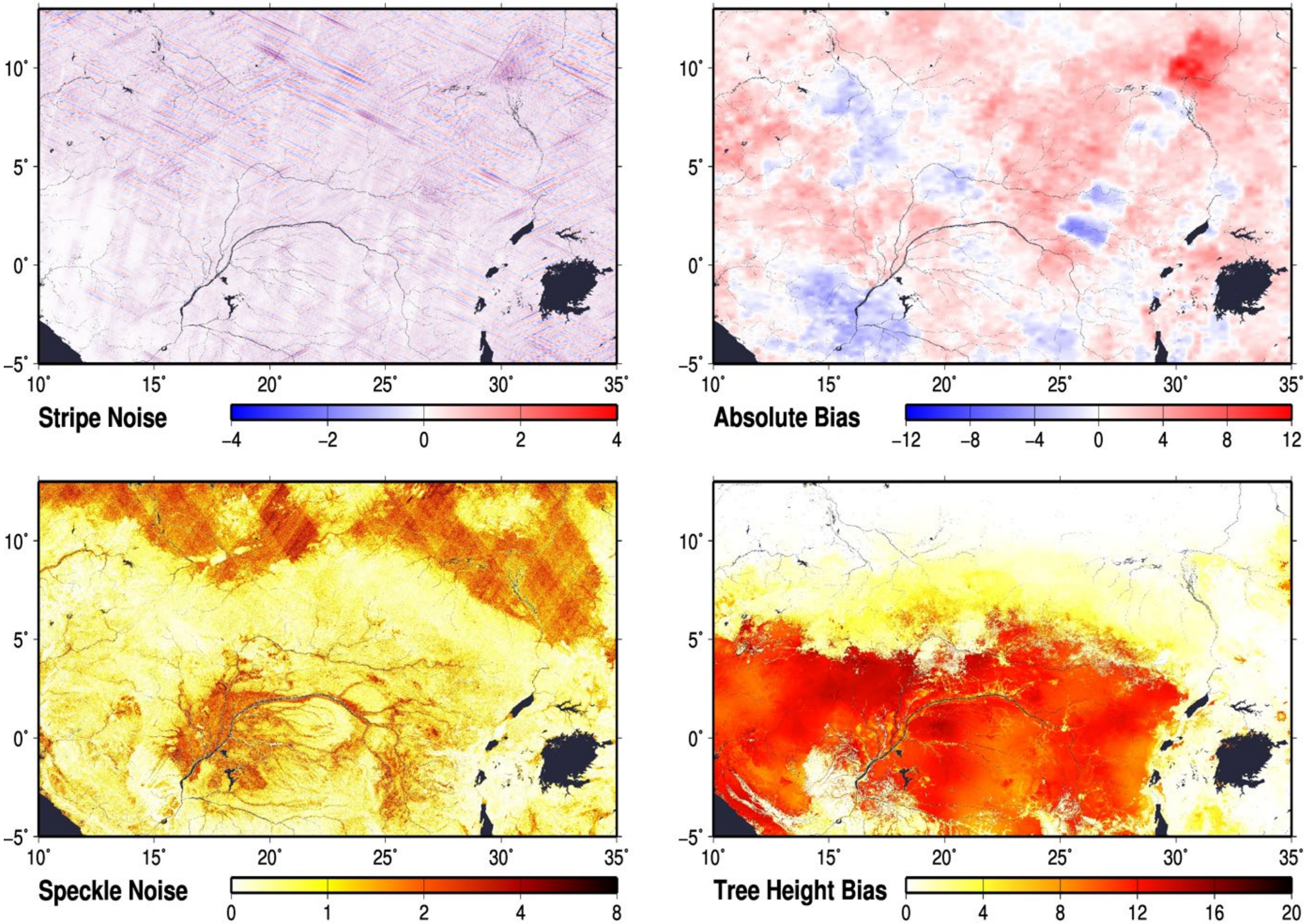
A high-accuracy global DEM just released.

Baseline DEMs: SRTM3, AW3D-30m, Viewfinder DEM, ASTER GDEM

Supplement: ICESat land elevation, Landsat forest density, satellite tree height

Filters: 2D Fourier Filter, Adaptive smoothing filter, etc.

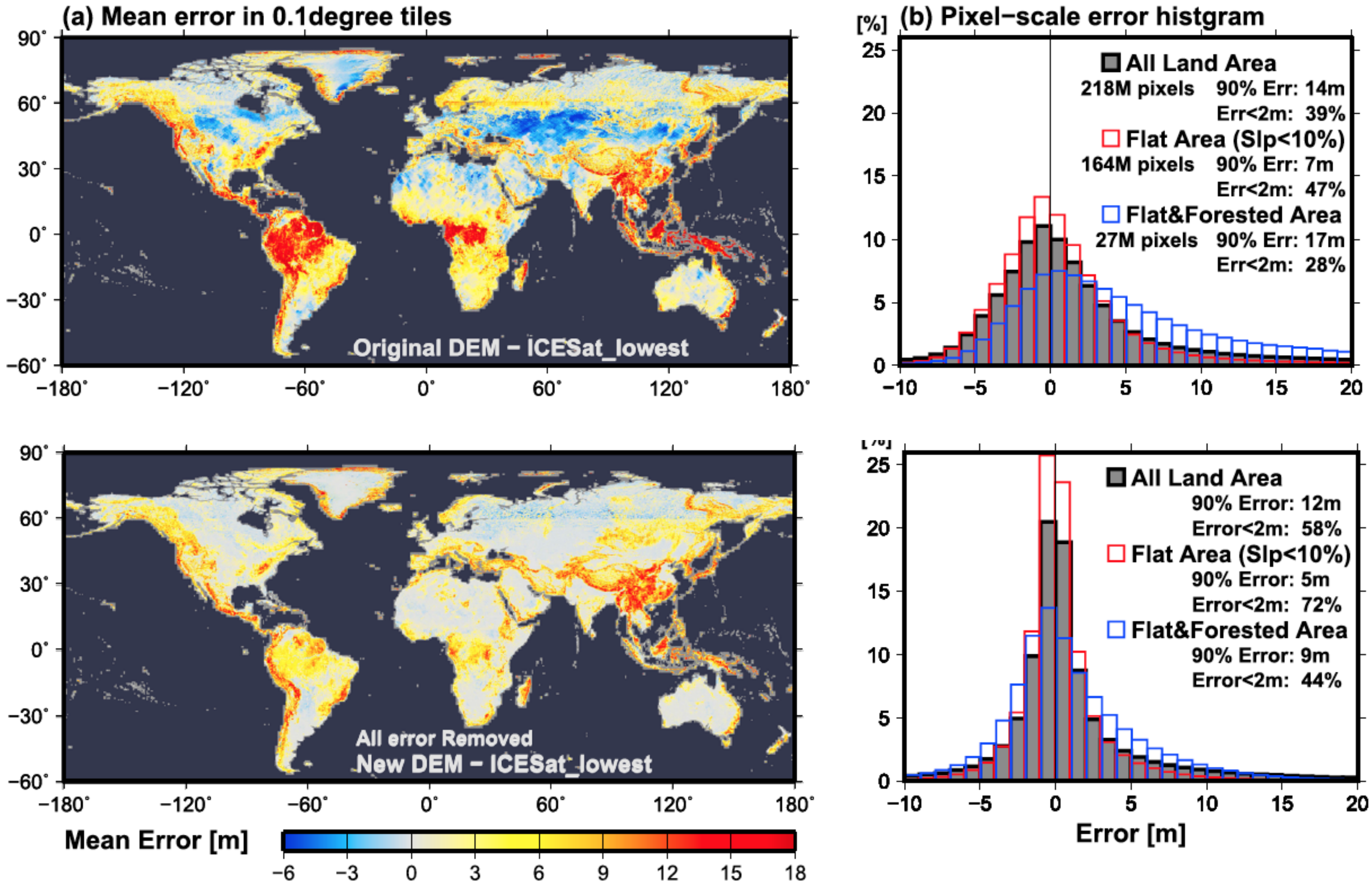


Multi-Error-Removal

- Stripe Noise
- Absolute Bias
- Tree Height Bias
- Speckle Noise

A high-accuracy global DEM just released.

MERIT DEM (Multi-Error-Removed Improved-Terrain DEM)



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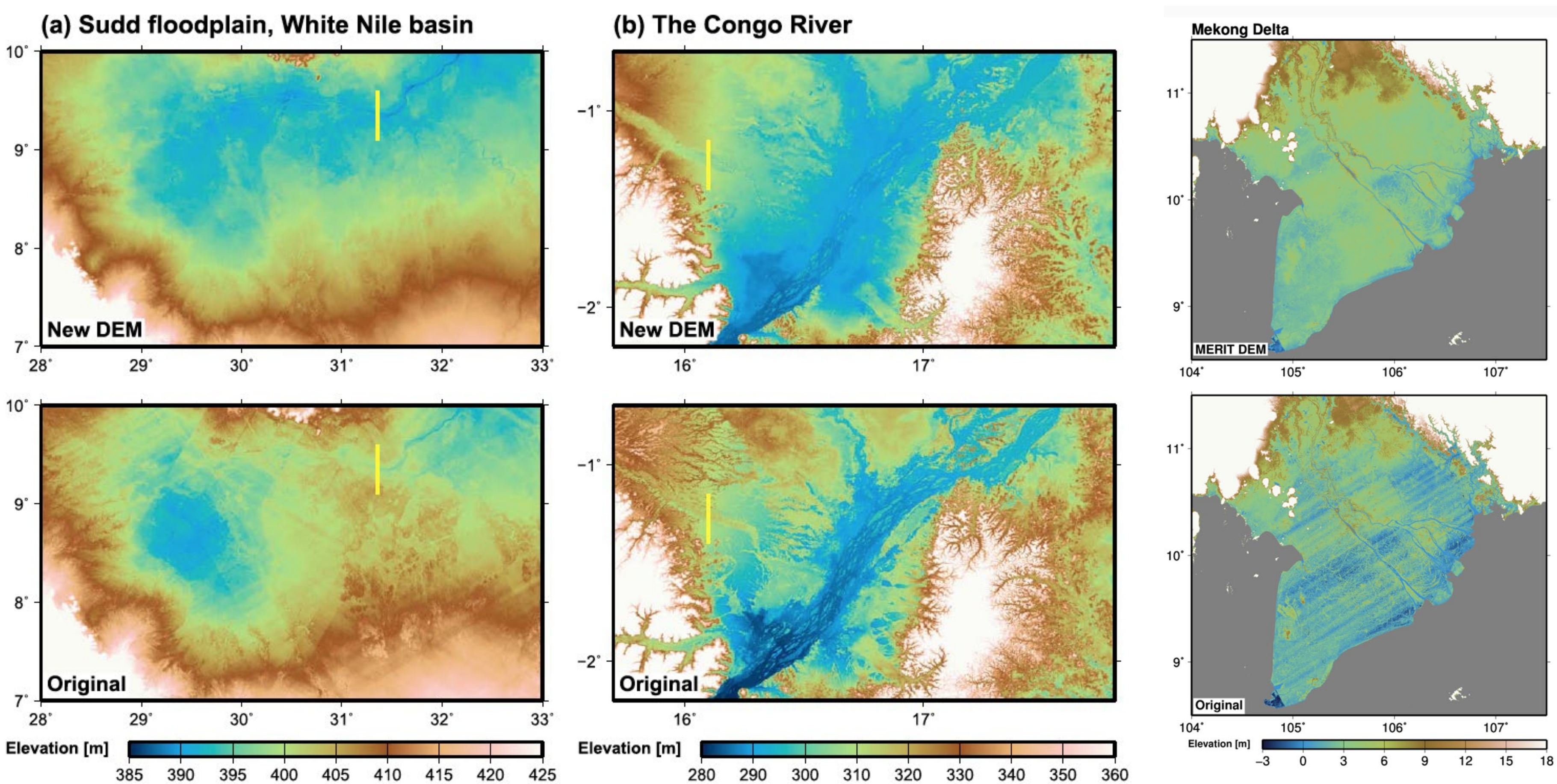


Available online: http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_DEM/

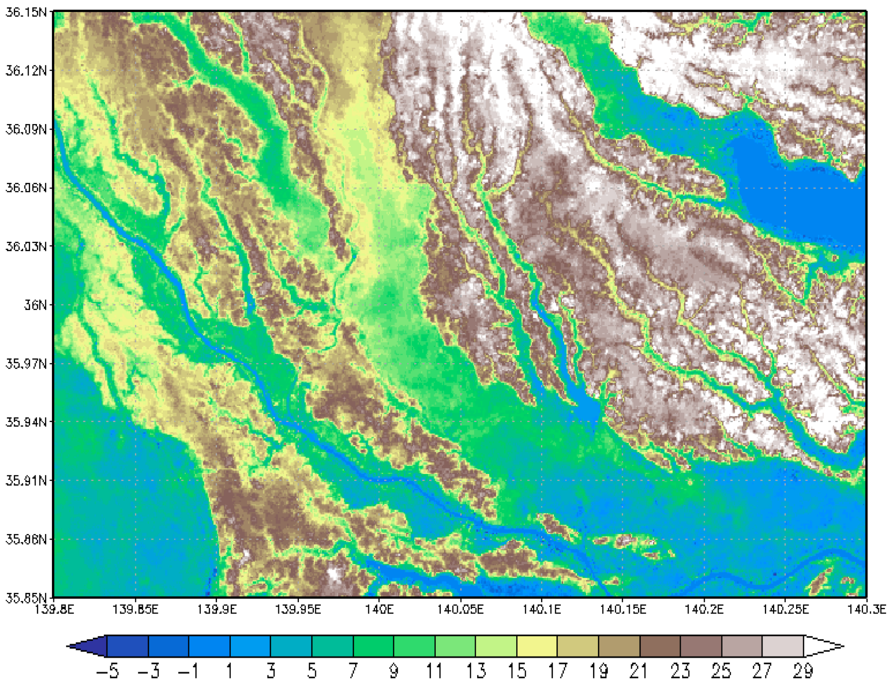
Yamazaki et al., 2017, GRL, doi: 10.1002/2017GL072874

“A high accuracy map of global terrain elevations”

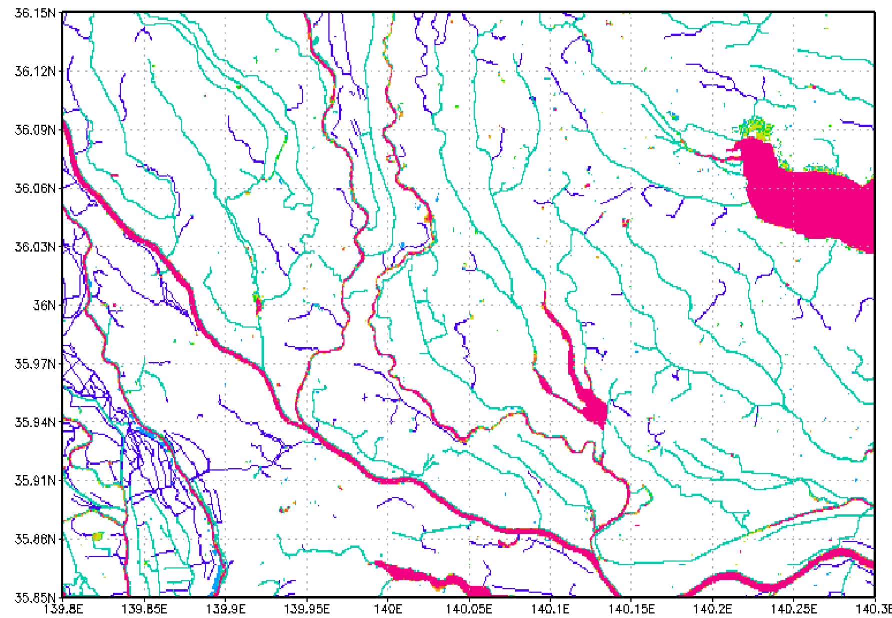
A better global hydrogarphy (incl >60N)

Re-construct ”HydroSHEDS” from a scratch

using the new DEM and recently-developed water body datasets.



The new MERIT DEM



Integrated Water Body Map

- Satellite (GSWO, G3WBM, etc)
- OpenStreetMap River
- OpenStreetMap Streams

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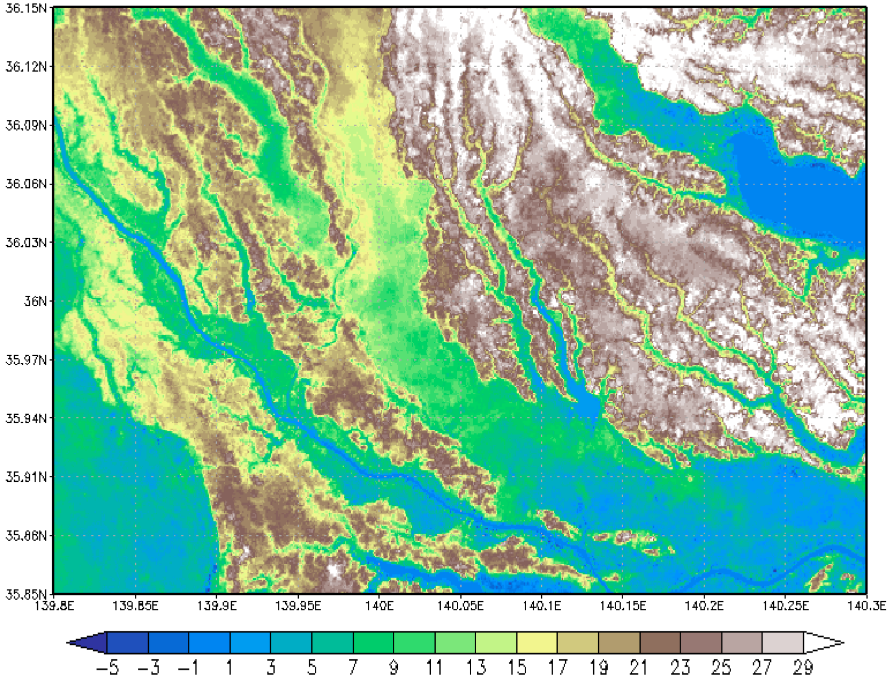
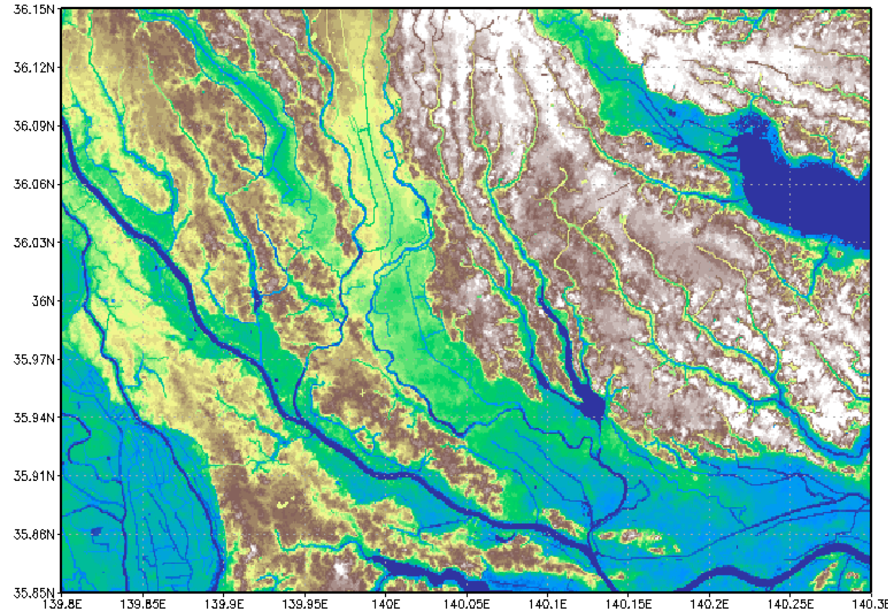


The new MERIT DEM



Enhanced DEM with water body data

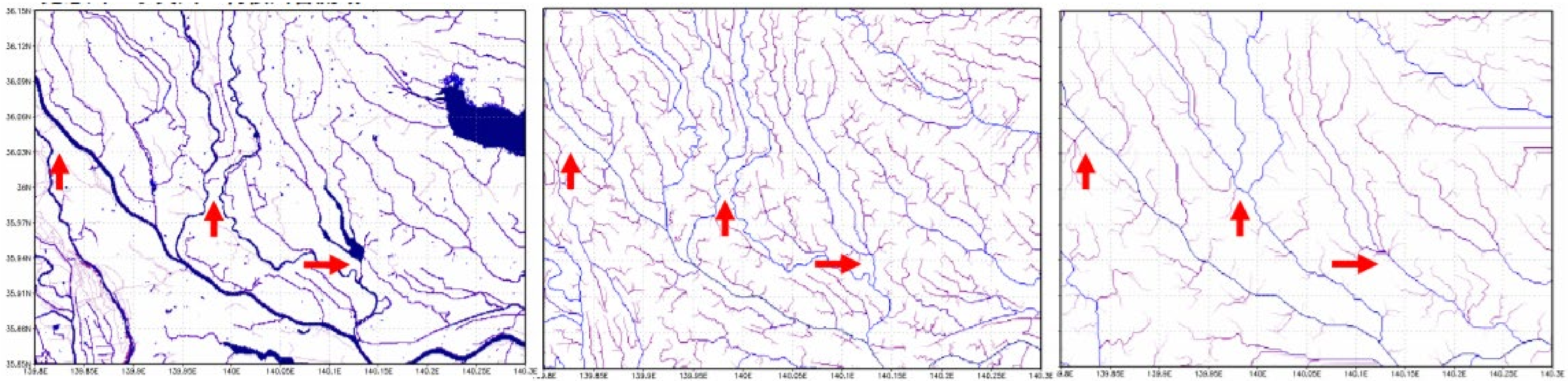
Applied a brand-new Fortran90 codes to generate hydrography (almost) automatically.

A better global hydrogarphy (incl >60N)

Re-construct "HydroSHEDS" from a scratch.

using the new DEM and recently-developed water body datasets.

Kinu, Kokai, Tone Rivers confluence in Japan



Water Body Data New Hydrography HydroSHEDS

Expected Timeline:

- Development will be completed in 2017 Summer.
- Preliminary version available within SWOT community in 2017 Fall/Winter.
- Official release to public in 2018 Spring.

Summary

Developed a framework for **global SWOT WSE assimilation** to hydrodynamic model.

- Preliminary results suggest SWOT shall improve discharge estimate globally especially for larger rivers, and rivers in high latitudes.
  → **Good implication for global hydrology studies.**
- Need to address model bias.
  Realistic "WSE-Discharge" relationship should be represented to fully utilize SWOT observations.

We **need to handle model bias**:

- **Anomaly SWE assimilation** seems to work well. More studies needed.
- **Improvement of global hydrodynamic models** are essential to fully utilize SWOT.
  →Some progress on global DEM, hydrography, river width
  →Global channel bathymetry is probably most important challenge.

Some other important tasks:

- Assimilation of river discharge, SWE slope, inundated area.
- Consistency with river vector products (shared ancillary data between ADT & models?)
- Assess forecast skill for large river flooding (could be an interest of application WG)
- Assimilating of other altimetry before SWOT launch to test the framework feasibility.
- Do we need global 30m DEM & Hydrography?