CryoSat-2 sUCcess over Inland water And Land (CRUCIAL)

ESA/ESRIN Contract 1/6287/11/I-NB

Final meeting, June 6 2017, ESA/ESRIN, Frascati

Open Presentation – Hydrological Modelling

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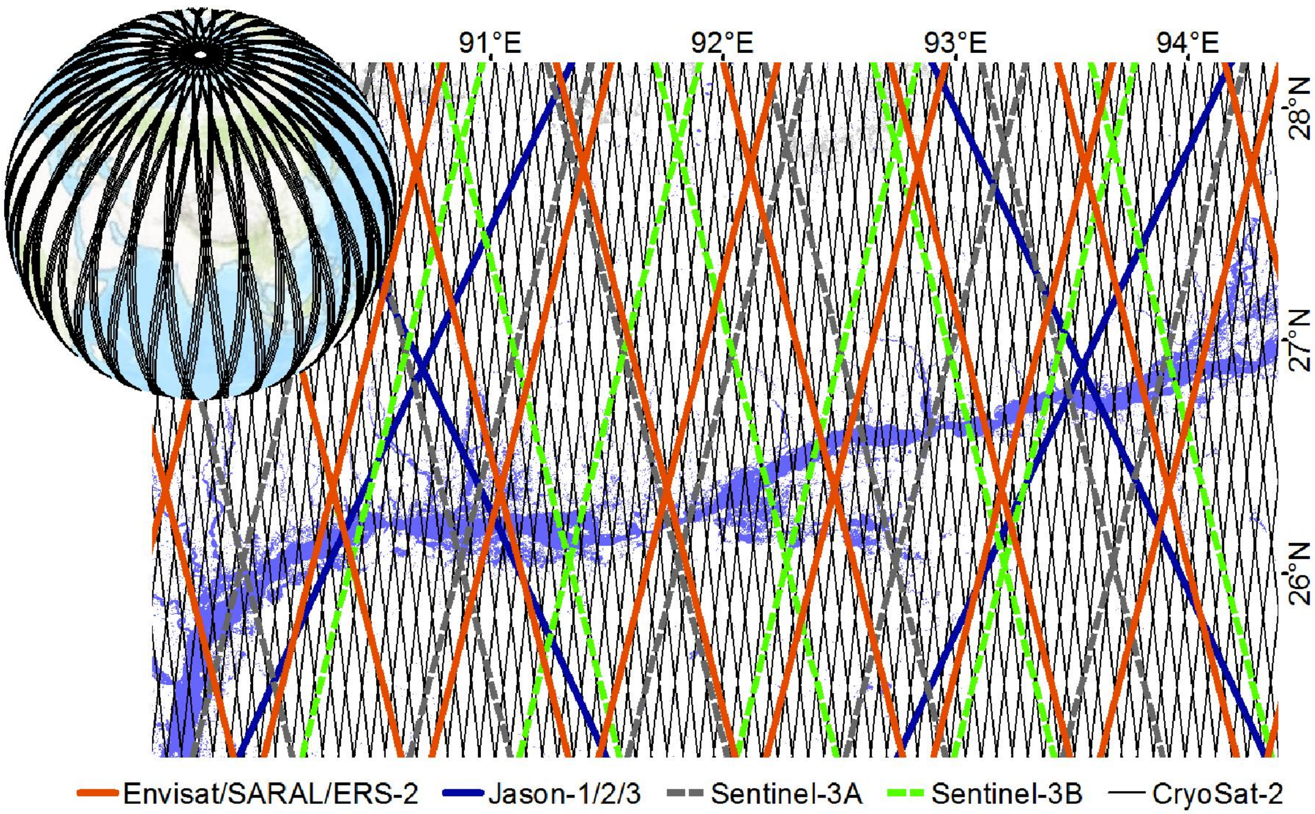
CryoSat-2: drifting ground track pattern



Mission	Repeat cycle	Inter-track distance
Envisat	35 d	80
Jason	10 d	315
Sentinel-3	27 d	104
	…	
CryoSat-2	369 d	7.5

CryoSat-2's drifting ground track pattern, in comparison to the conventional repeat orbit missions
from Jiang et al. (2017)

CryoSat-2: drifting ground track pattern

CryoSat-2's drifting ground track pattern is its **main challenge**

- contionous masking along river needed for data filtering
- no virtual station time series

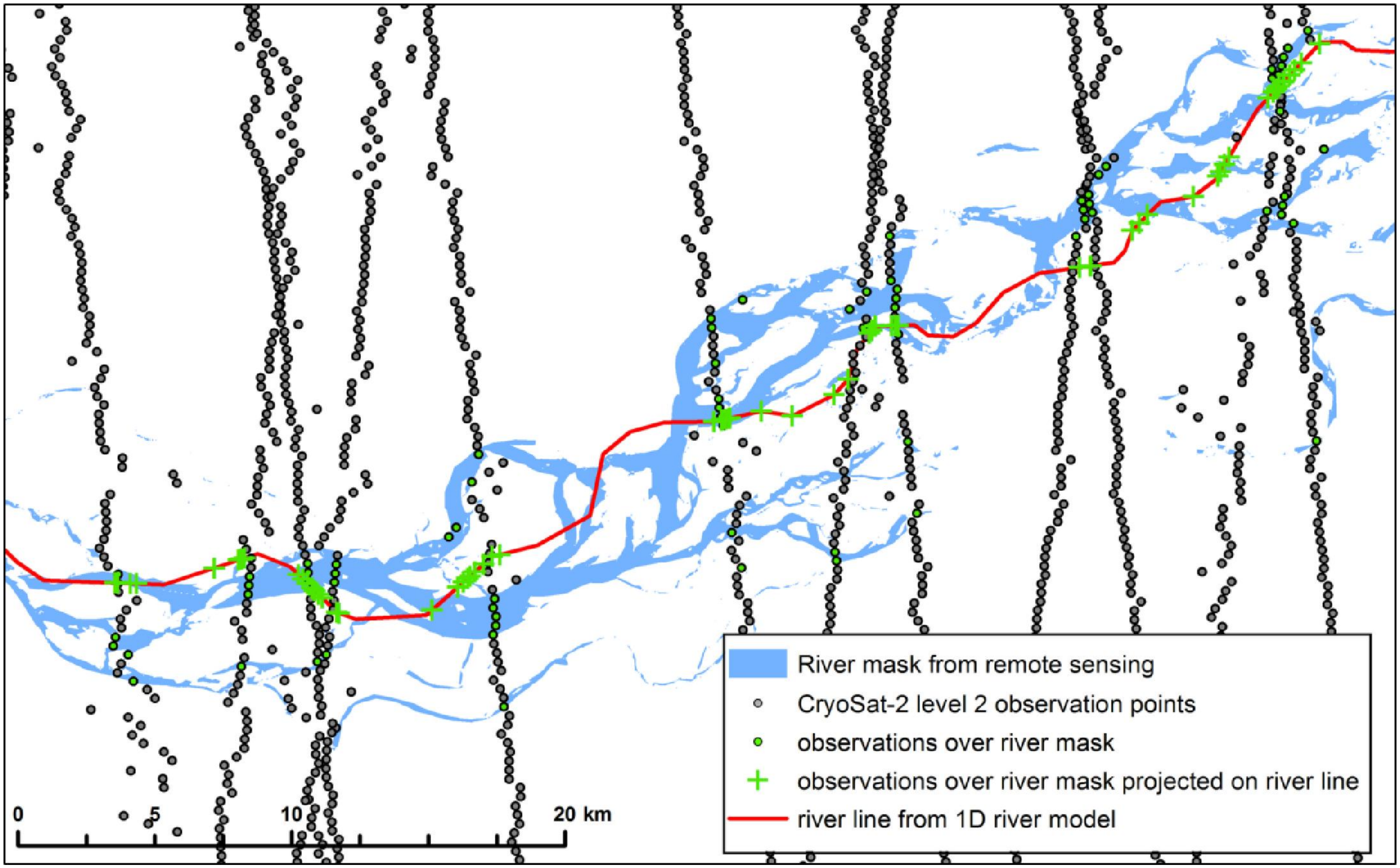
and also **main benefit**

- contionous water level profiles can be derived
- covers more targets (relevant for lakes)

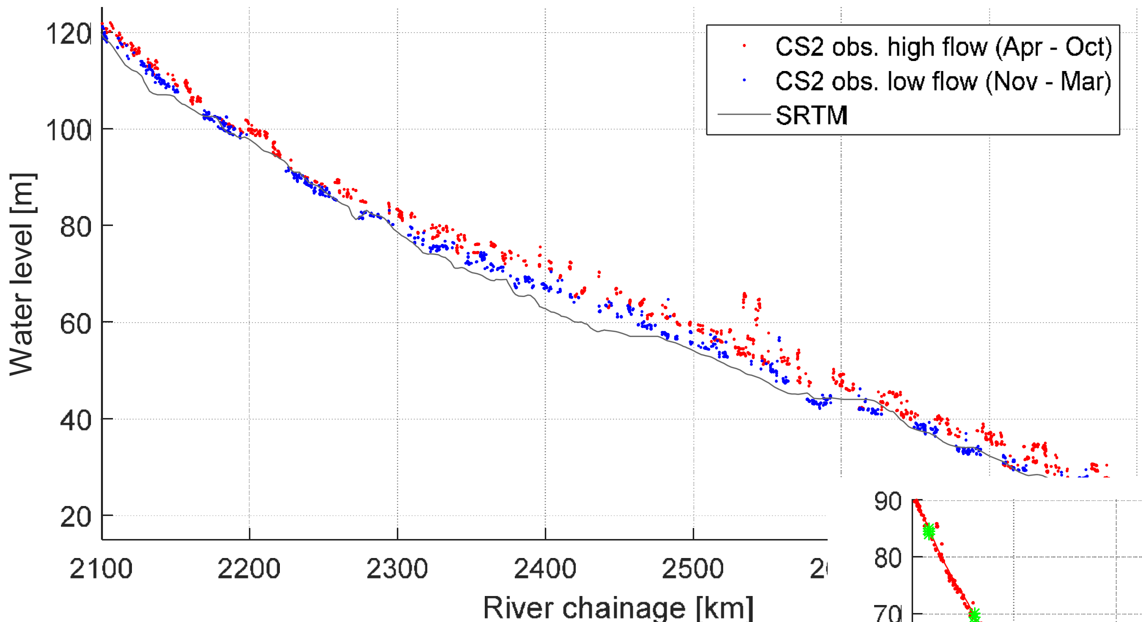
Still, only few inland altimetry studies using CryoSat-2

And CryoSat-2's availability in altimetry databases is limited (not on DAHITI or HydroWeb, very limited on HydroSat, some lakes on AltWater)

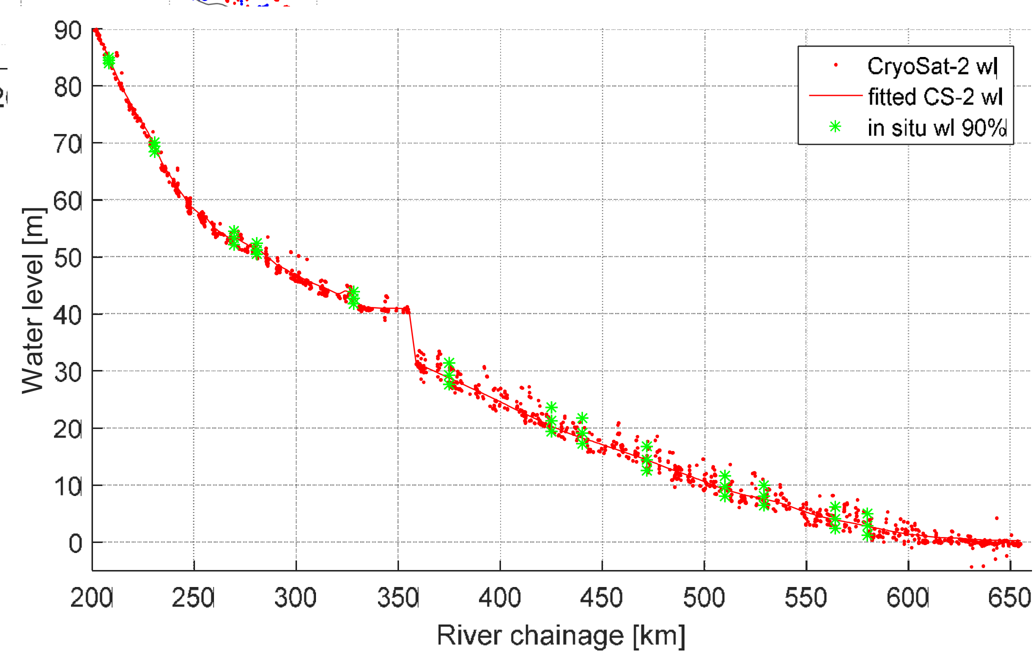
CryoSat-2 level 2 data processing – river mask filtering



CryoSat-2 observations along rivers



Brahmaputra River in the Assam Valley



Po River

In situ validation along Po River and Chinese rivers

Validation of CryoSat-2 observations along the **Po River**

- all observations within 3km of 11 insitu stations
- slope corrected
- bias corrected against sea level data
- common height reference
- River width ~0.2 – 0.5 km

Validation of CryoSat-2 observations along some **Chinese rivers**

- observations within 5km of insitu stations
- per-station bias correction
- LRM mode

	RMSE [m]	**width [km]**
all modes	0.42	~0.2 – 1.0
LRM	2.66	~1.0 – 2.0
SAR	3.21	~0.3 – 1.3
SARIn	0.46	~0.6 – 1.7
	0.30	~1.0 – 1.7

Optical imagery
Sentinel-1A SAR
over the Yangtze River

Use of CryoSat-2 for river model parameterization – 1) cross section calibration

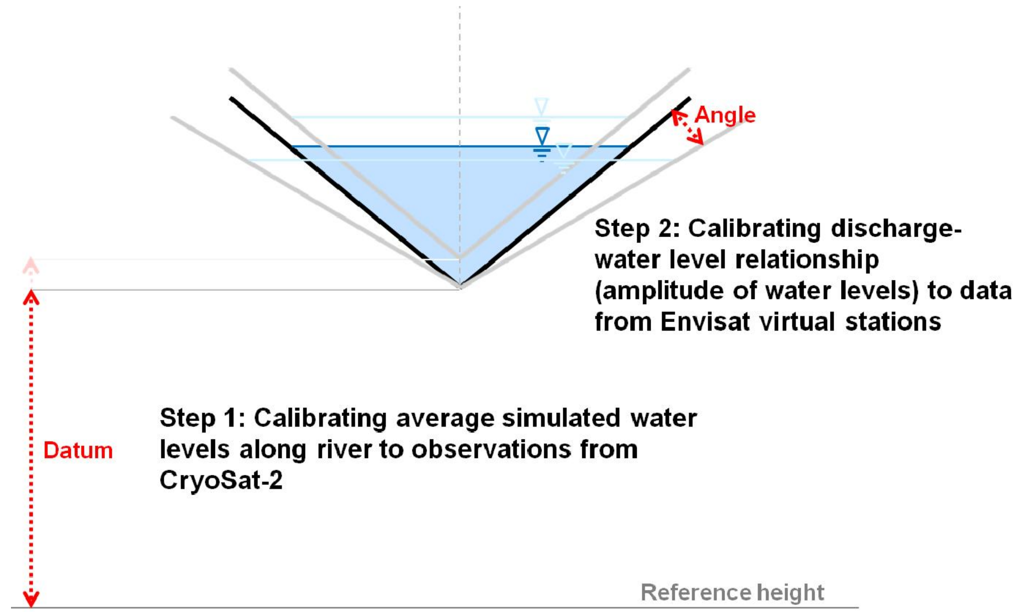
WITHOUT INFORMATION ABOUT RIVER BED GEOMETRY

(after calibration of discharge)

Calibration of synthetic cross sections to make model accurately reproduce water levels

- Step 1: **CryoSat-2 data** to calibrate average simulated **water level profiles** along the river
- Step 2: **Envisat virtual station data** to calibrate **water level-discharge relationships**

(virtual station data is not needed; both steps can also be performed with CryoSat-2 data only)



from Schneider et al. (2017)

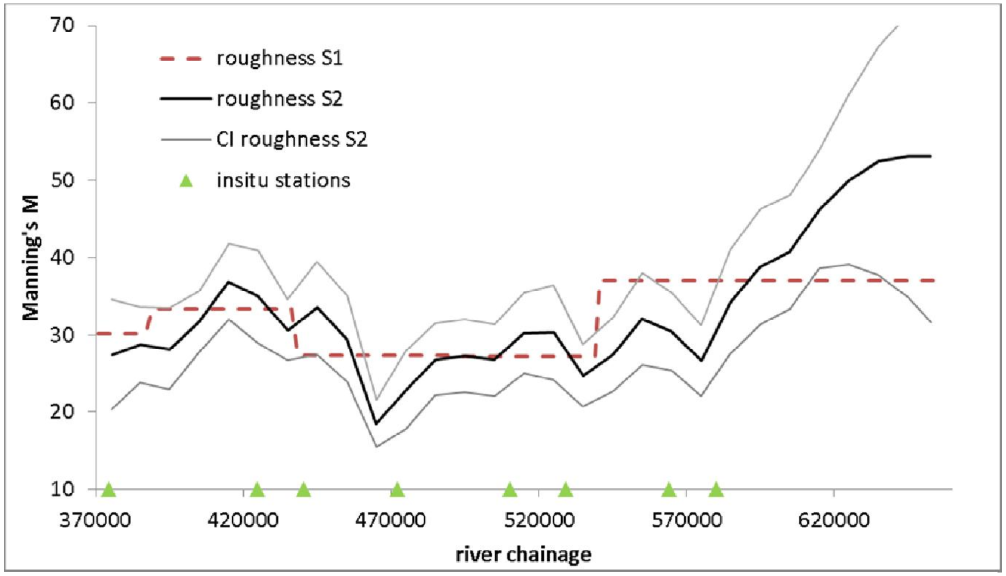
Result:

A **1D hydrodynamic model**, utilizing synthetic cross sections that still is able to **accurately reproduce water levels** across the entire model

(despite the lack of an accurate DEM or bathymetry)

Use of CryoSat-2 for river model parameterization – 2) roughness calibration

WITH INFORMATION ABOUT RIVER BED GEOMETRY



(after calibration of discharge)

Calibration of channel roughness to fit simulated water levels to CryoSat-2 observations

Scenario **S1**:
"best conventional approach", calibrating roughness against data from **8 insitu stations** for five subreaches

Scenario **S2**:

Using CryoSat-2 data to calibrate variable roughness along entire river, exploiting the **finer spatial resolution of CryoSat-2 data**

	S1	S2
RMSE insitu [m]	0.29	0.31
RMSE CryoSat-2 [m]	0.64	0.56

→ Possibility to resolve changes in roughness at **finer spatial resolution** than possible with in situ stations

Use of CryoSat-2 for river model parameterization – 2) roughness calibration

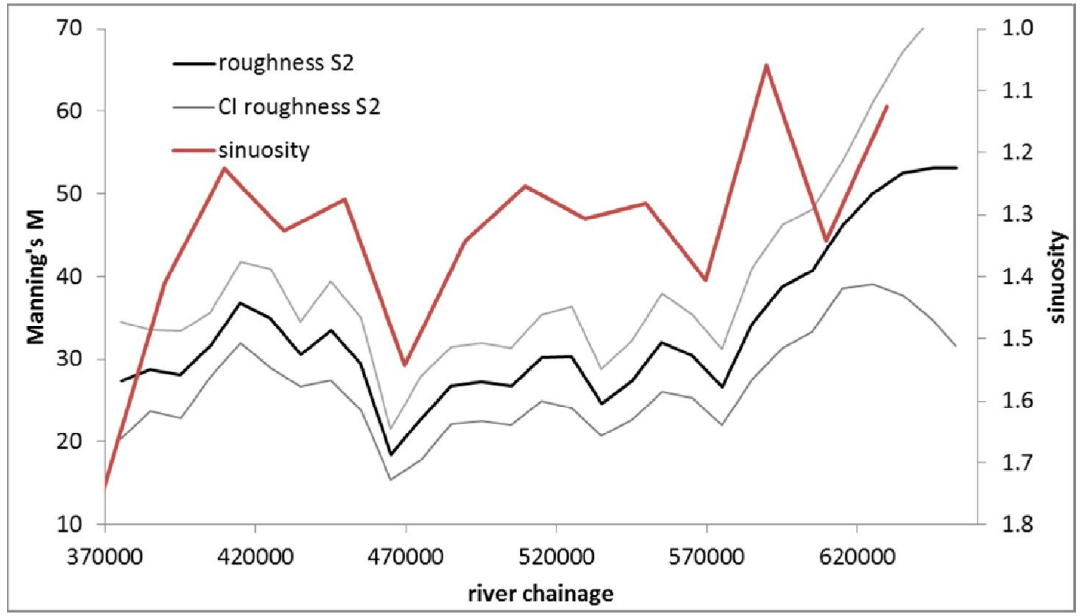
Correlation between calibrated variable roughness and river characteristics?

Channel roughness in 1D hydrodynamic models is a lumped parameter, not only accounting for actual river bed roughness, but also including effects of cross section shapes, curvature, etc.

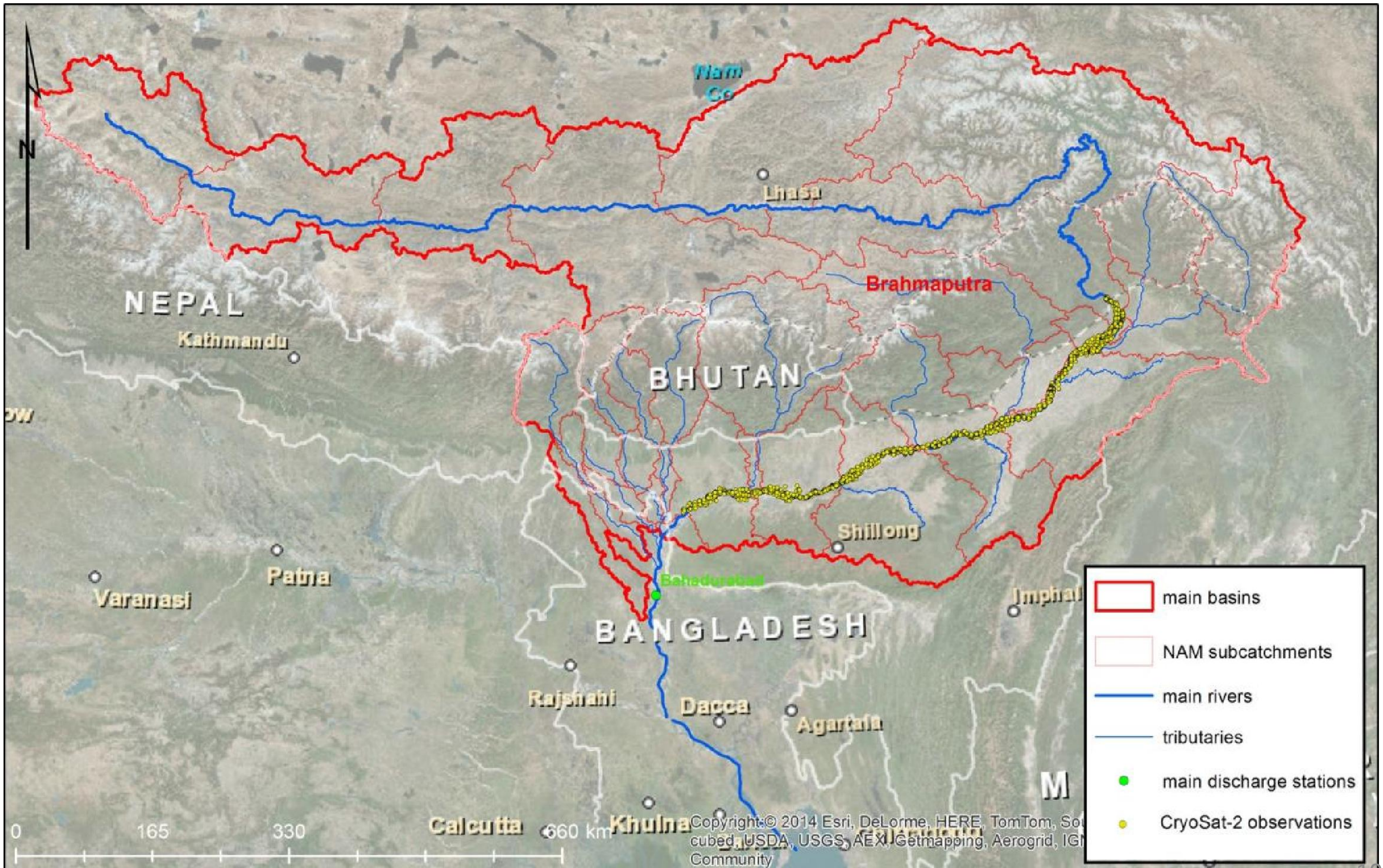
→ Compare variable roughness values with the river's sinuousity

$$S_r = \frac{distance\ along\ river}{euclidian\ distance}$$

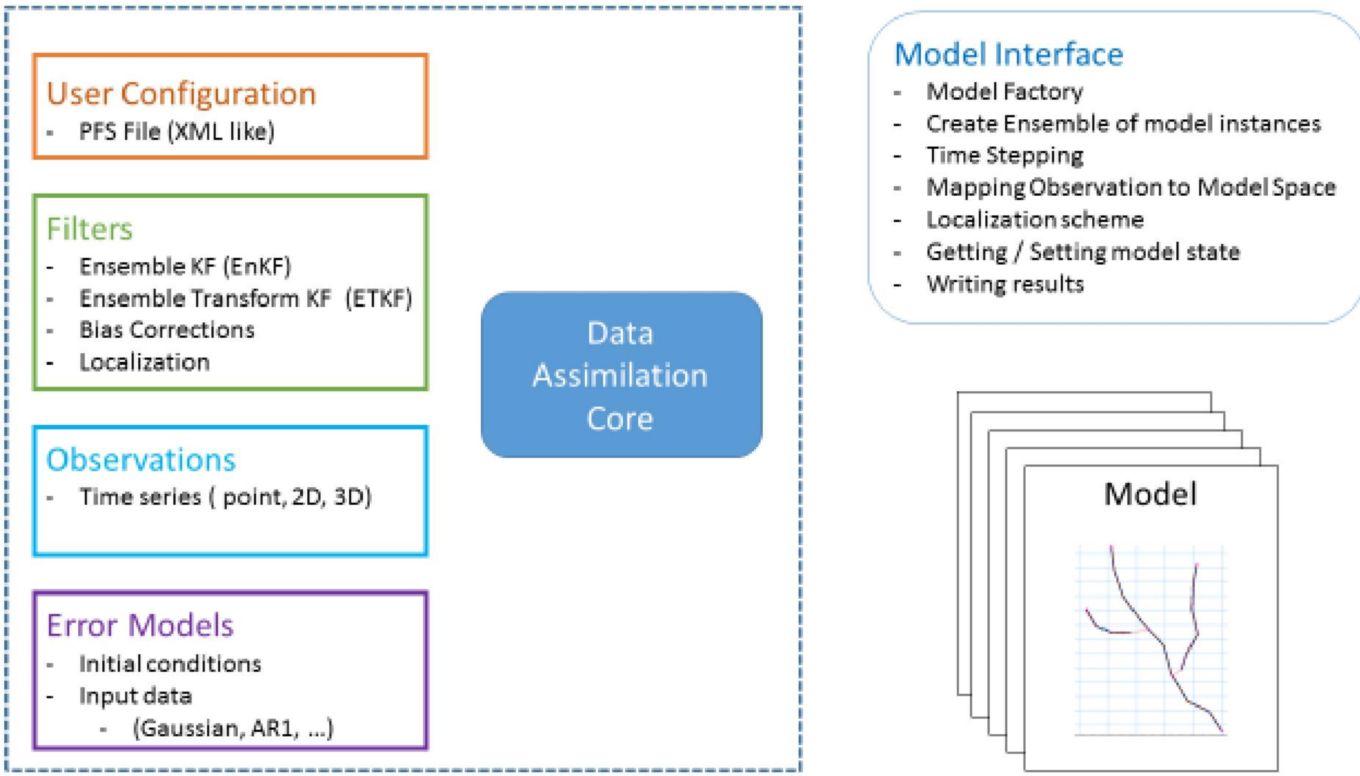
S_r has a minimum of 1 (straight river), meandering rivers have a value of 1.5 – 4



Updating hydrodynamic models with CryoSat-2 – Brahmaputra case study



Assimilation of CryoSat-2 data with DHI Data Assimilation framework



in this case:

MIKE HYDRO River (MIKE 11) modelling system

- Sub-catchment rainfall-runoff modelling
- 1D hydrodynamic river modelling

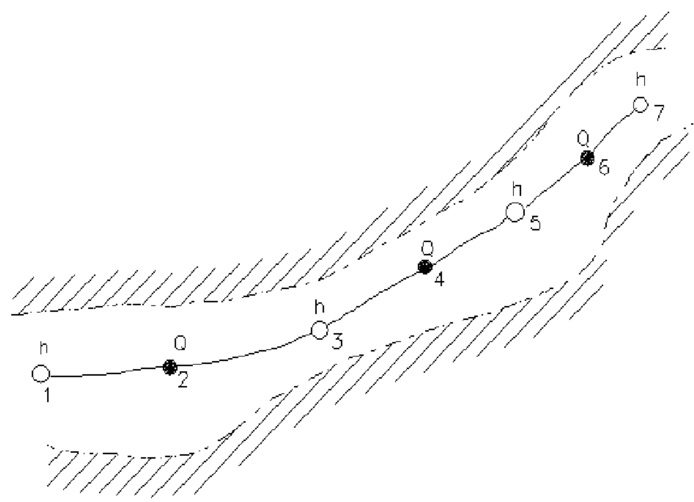
Data assimilation setup

DA algorithm

Ensemble Transform Kalman Filter implemented after Sakov & Oke (2008)

State vector

- Water levels at all grid points of the hydrodynamic model
- Model error via state augmentation



Sketch of the MIKE 11 model computation grid

Data assimilation setup

Model error description

Temporally and spatially correlated perturbation of forcing (runoff from subcatchments)

Observation error

Clustering individual CryoSat-2 data points from one transect into one or more groups, based on their location along the river:

Standard deviations of elevations derived from each cluster group

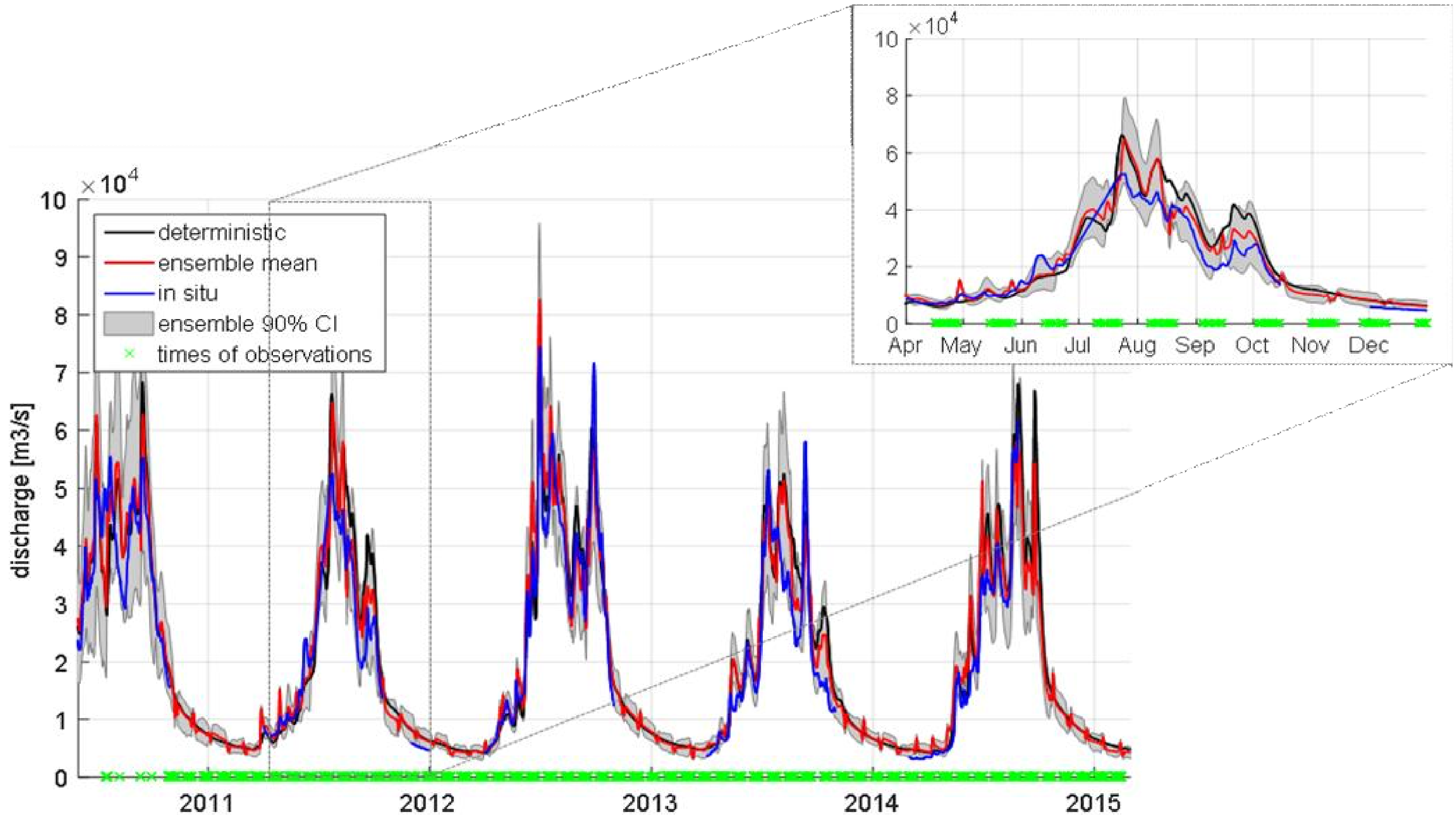
Localization

Distance-based localization needed as otherwise spurious correlations across the river network give unreasonable updates

Virtual observation window

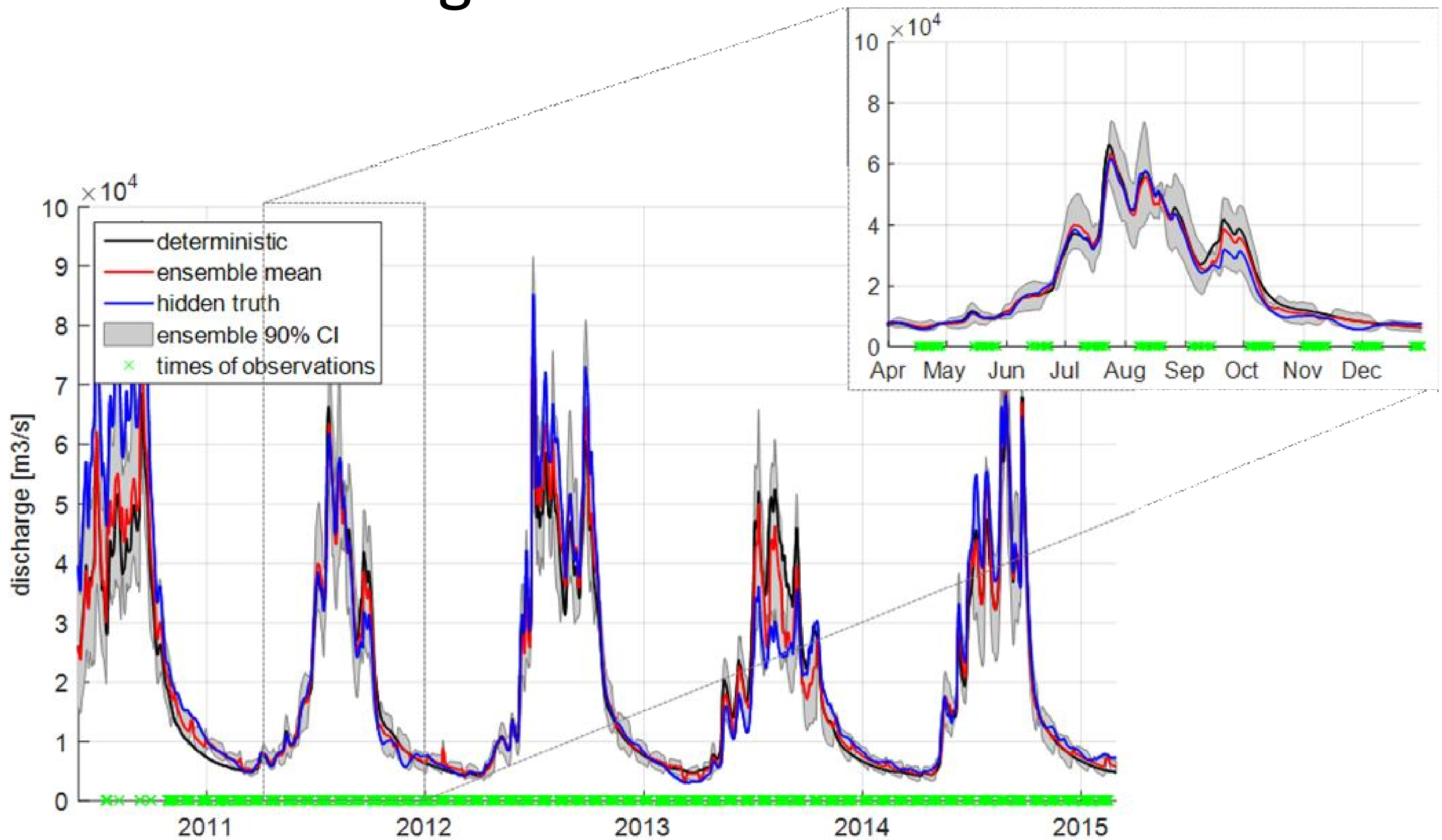
To extend measurement info over several simulation time steps

Results of DA of real CryoSat-2 data, discharge at Bahadurabad station

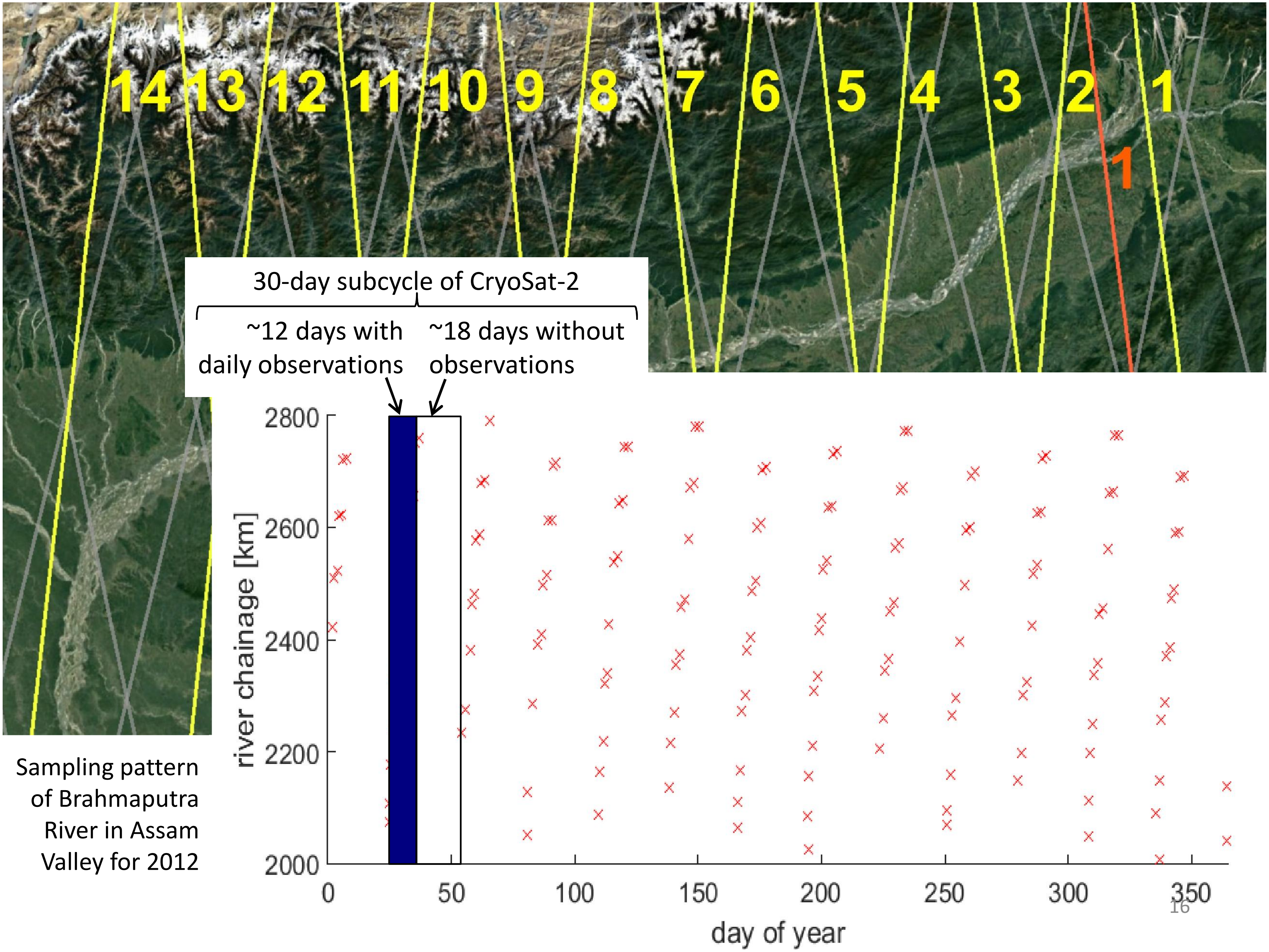


→ Improvement of CRPS of ~10%

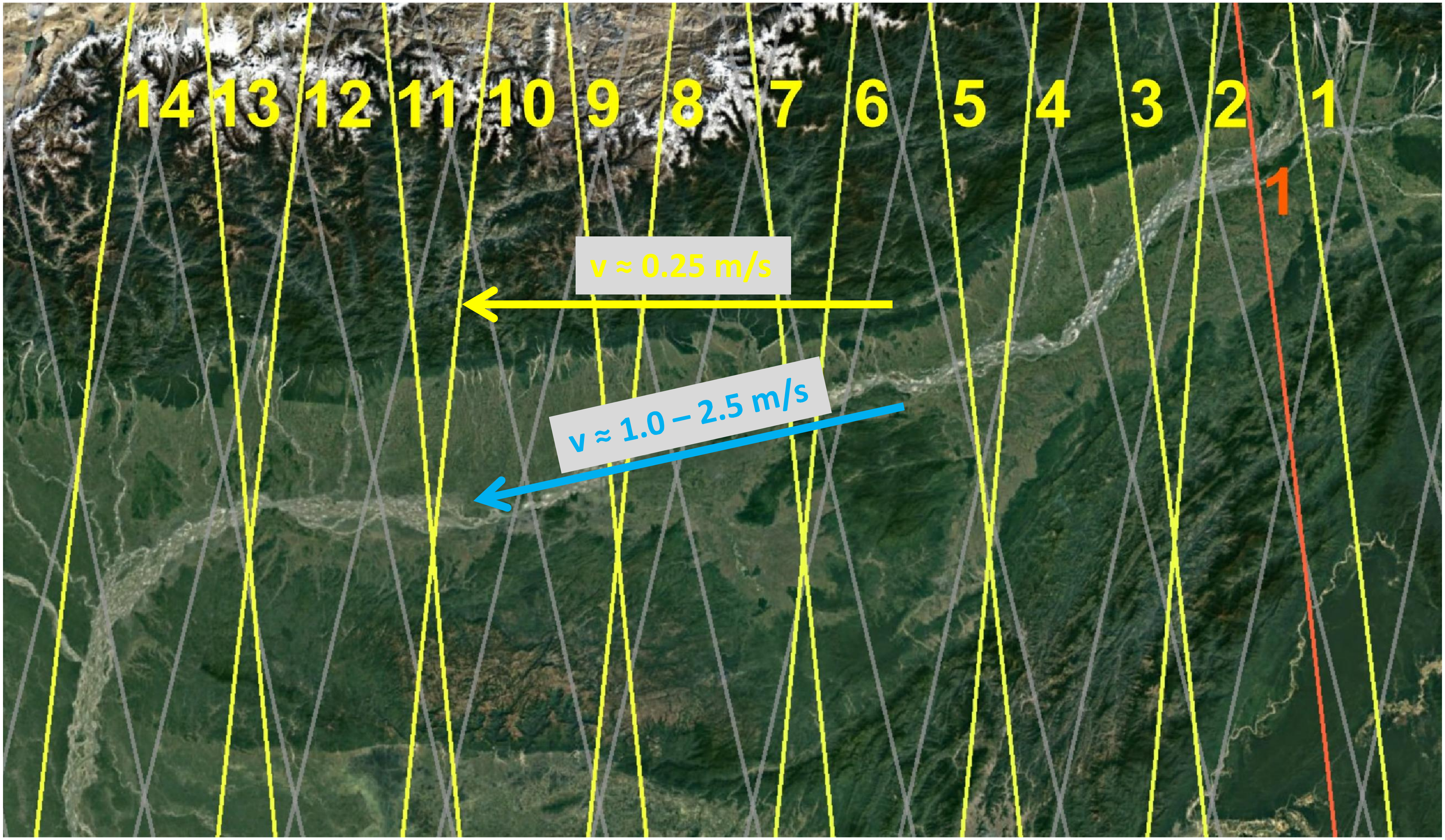
Results of DA of synthetic CryoSat-2 data, discharge at Bahadurabad station



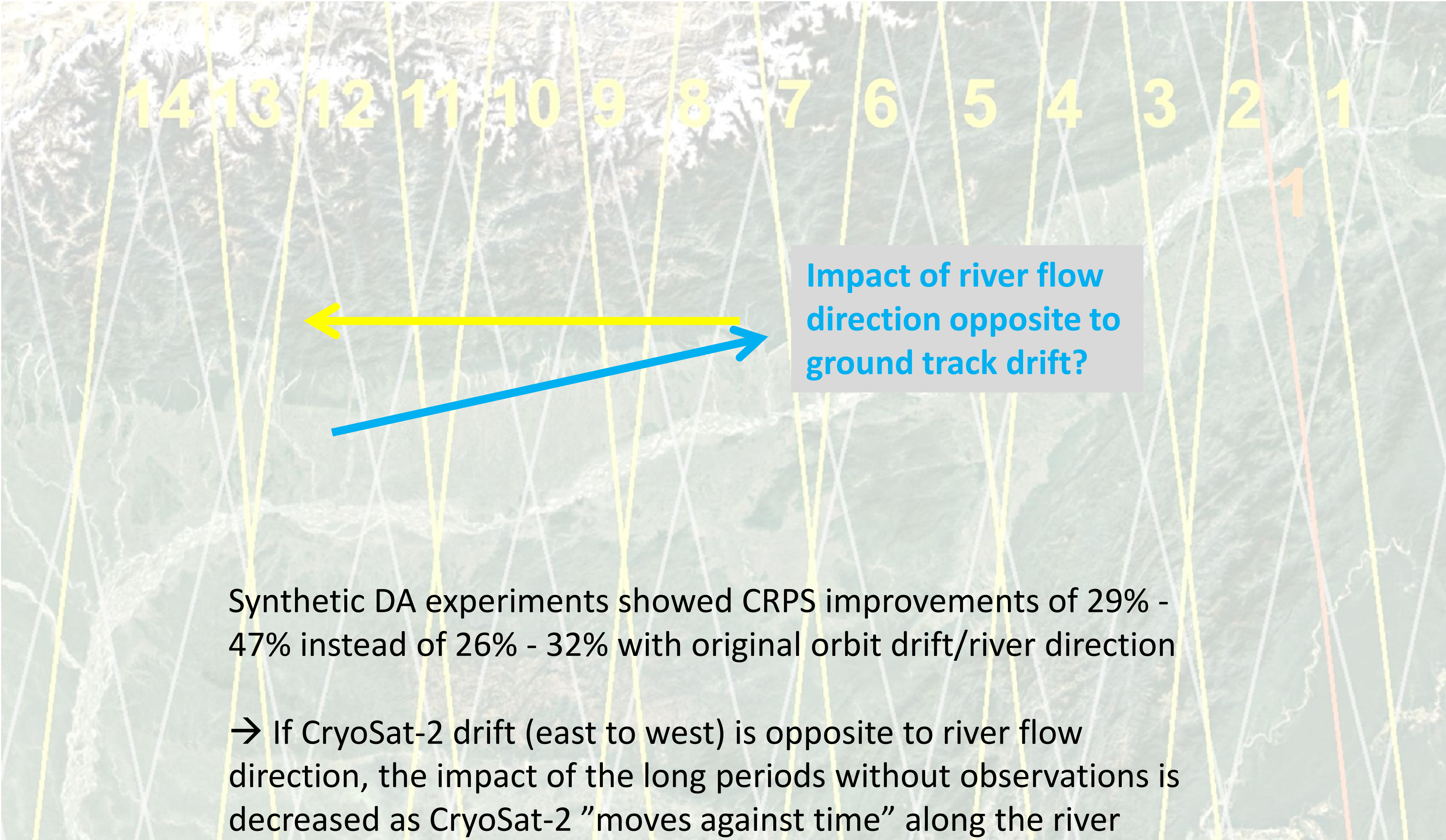
→ Improvement of CRPS of ~26% - 32%



Sampling pattern of Brahmaputra River in Assam Valley for 2012



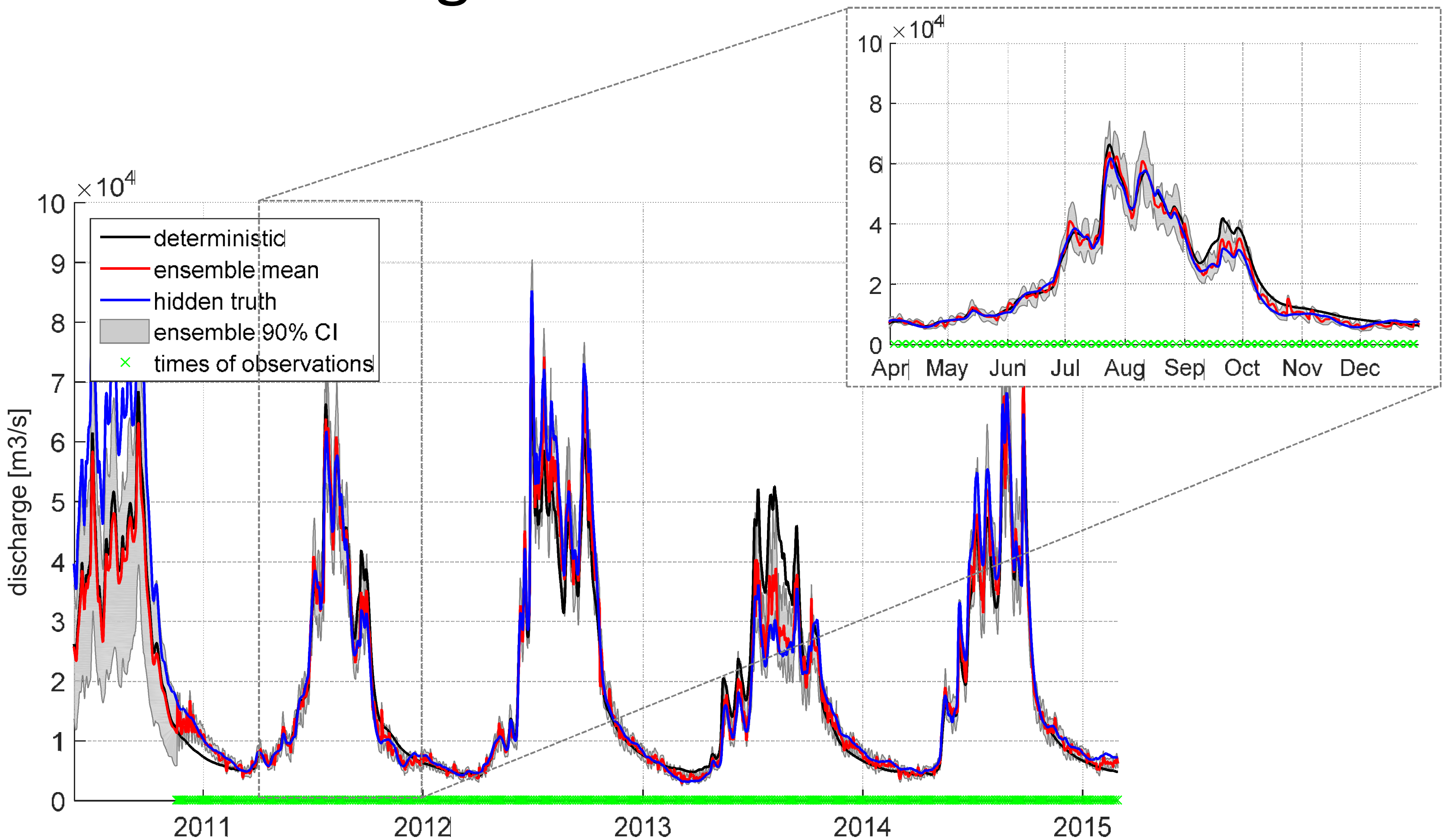
Sampling pattern of Brahmaputra River in Assam Valley for 2012



Synthetic DA experiments showed CRPS improvements of 29% - 47% instead of 26% - 32% with original orbit drift/river direction

→ If CryoSat-2 drift (east to west) is opposite to river flow direction, the impact of the long periods without observations is decreased as CryoSat-2 ”moves against time” along the river

Results of DA of synthetic Sentinel-3 data, discharge at Bahadurabad station



→ Improvement of CRPS of ~28% - 34%, i.e. slightly better than with CryoSat-2 (despite the number of river crosssings in this period: 754 with Sentinel-3A, 973 with CryoSat-2), likely due to more homogenous temporal sampling pattern

Conclusions – DA framework

Developed approach to process CryoSat-2 data over rivers and make it usable in hydrodynamic models with cross section calibration, relying mainly on publically available remote sensing data.

Approach does not rely on virtual station data

Data assimilation framework developed for hydrologic-hydrodynamic models

- Flexible framework that allows assimilation of different altimetry products and in-situ data
- Facilitates comprehensive testing of different data assimilation algorithms, error descriptions, localisation methodologies, etc.

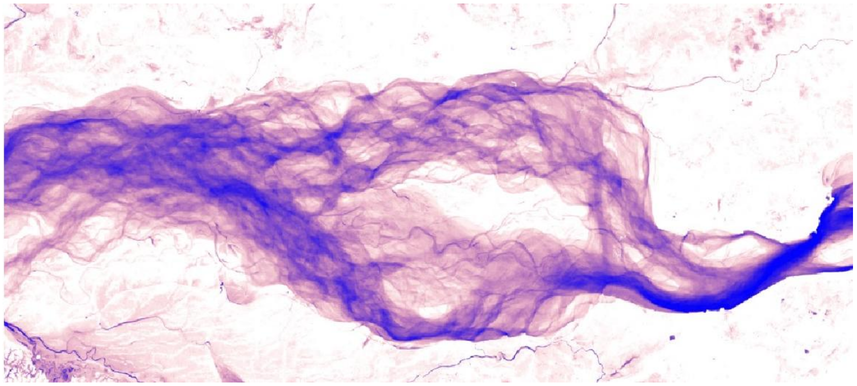
Synthetic DA experiments gave insight into impact of spatio-temporal sampling pattern

Conclusions – general

- First **DA system** developed and tested that handles data with **arbitrary spatio-temporal distribution** such as CryoSat-2
- **Think beyond time series at virtual stations!**
  Even though upcoming missions such as Sentinel-3, Jason-CS remain on repeat orbits. If one thinks beyond virtual station time series, multi-mission data can be used, and data from any source (UAV, …) can be intergrated
- **Continous water level profiles** that can be derived from **CryoSat-2** data are its main novelty for river applications
  Those allow to derive **additional information** for unmonitored rivers (calibration of cross sections), and **even for densly monitored rivers** (calibration of roughness)

Open ends

- Use of multi-mission altimetry dataset with developed DA system
- Integration of different remote sensing data into DA (e.g. soil moisture)
- Use of high spatial resolution (and temporal where necessary) river masks, potentially based on SAR imagery (Sentinel-1)



Water occurence 1984 – 2015 from Global Surface Water Explorer
https://global-surface-water.appspot.com/

- **Move beyond virtual station concept** for inland water altimetry
This also means to include CryoSat-2 in level-2 altimetry databases. Possible solution: Allow users to derive all observations over a river mask, instead of only giving access to pre-created time series.

Acknowledgements

DHI

National Space Institute
Technical University of Denmark

LOTUS (EU FP7 grant no. 313238)

Hydrology group of the Research Institute for Geo-Hydrological protection (CNR IRPI)

China Scholarship Council

Refernces

Jiang, L., Schneider, R., Andersen, O.B., Bauer-Gottwein, P., 2017. CryoSat-2 Altimetry Applications over Rivers and Lakes. Water 9, 211. doi:10.3390/w9030211

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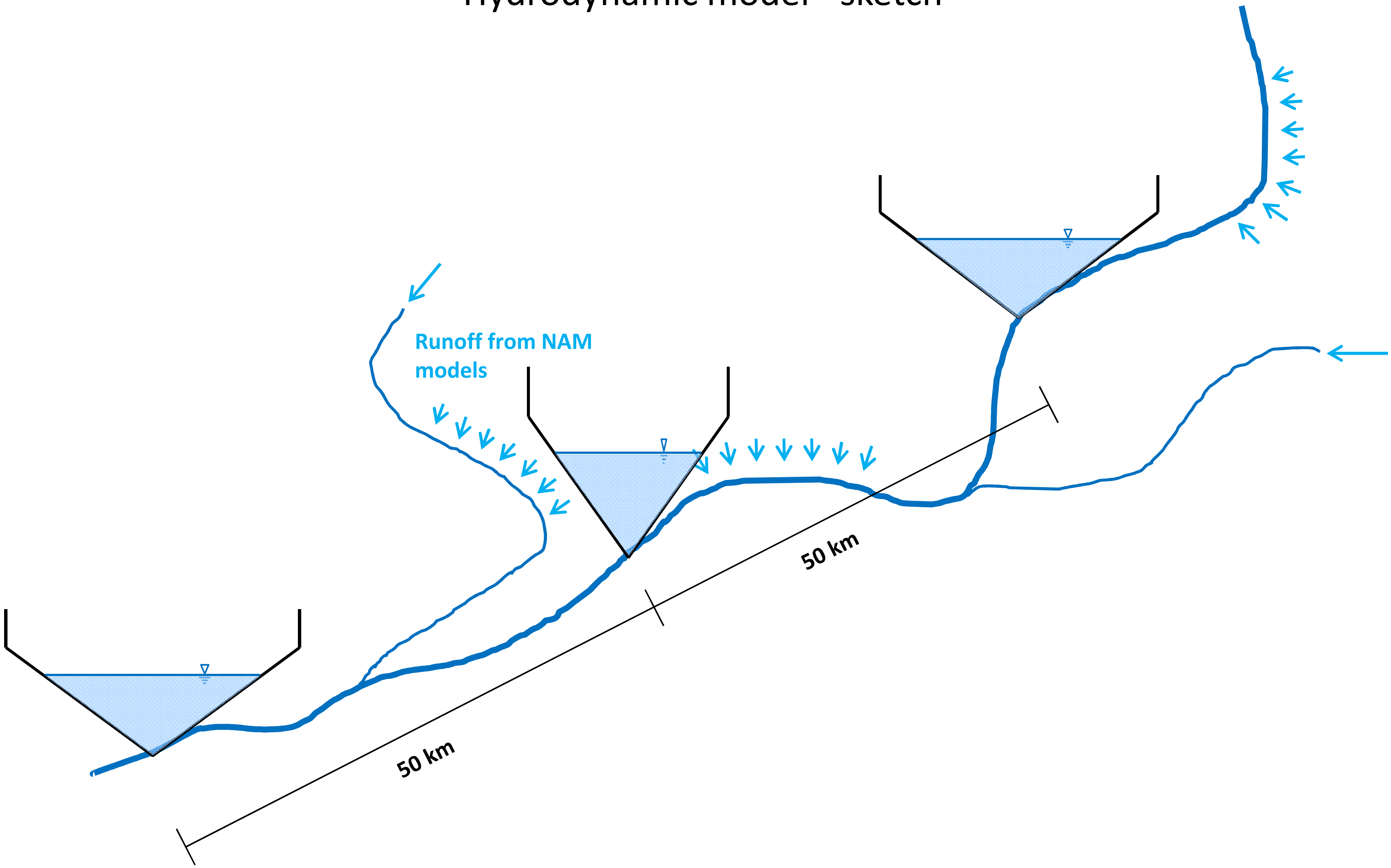
Inland altimetry databases

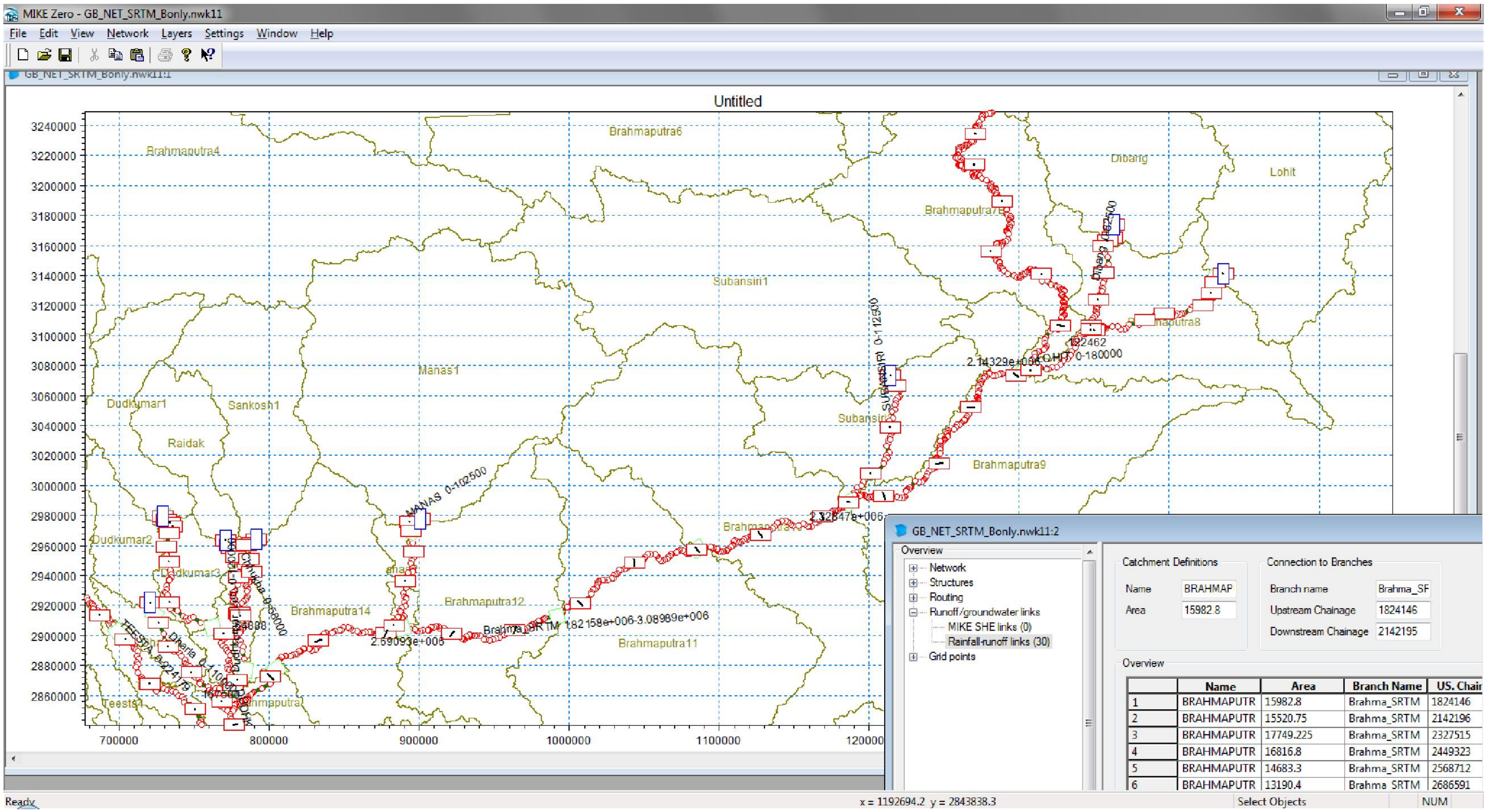
- DAHITI (DGFI TUM):
  http://dahiti.dgfi.tum.de/en/
- HydroWeb (GOHS/LEGOS):
  http://www.legos.obs-mip.fr/soa/hydrologie/hydroweb/
- HydroSat (GIS University of Stuttgart):
  http://hydrosat.gis.uni-stuttgart.de/php/index.php
- AltWater (DTU Space):
  http://altwater.dtu.space/

Additional slides

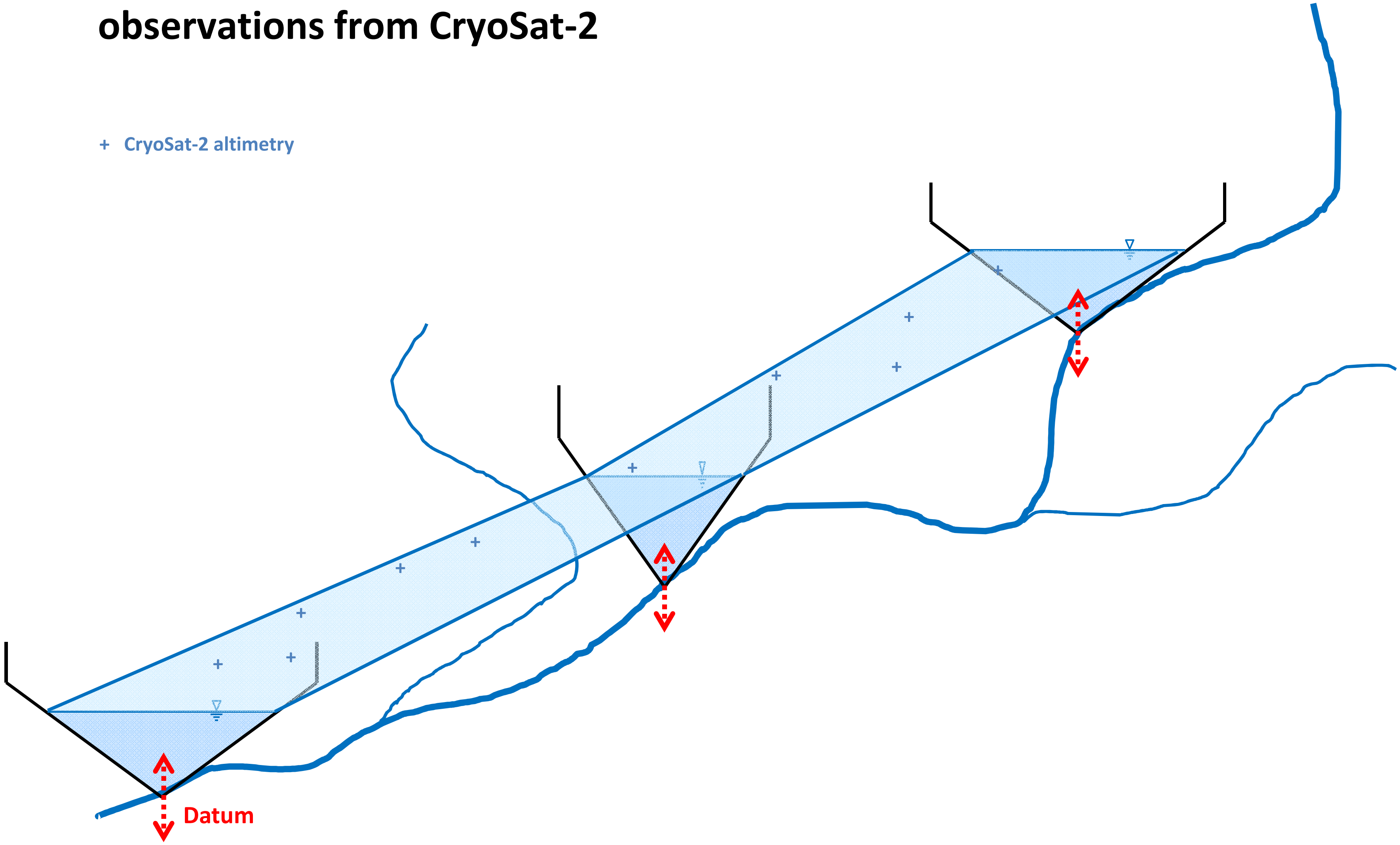
Hydrodynamic model - sketch



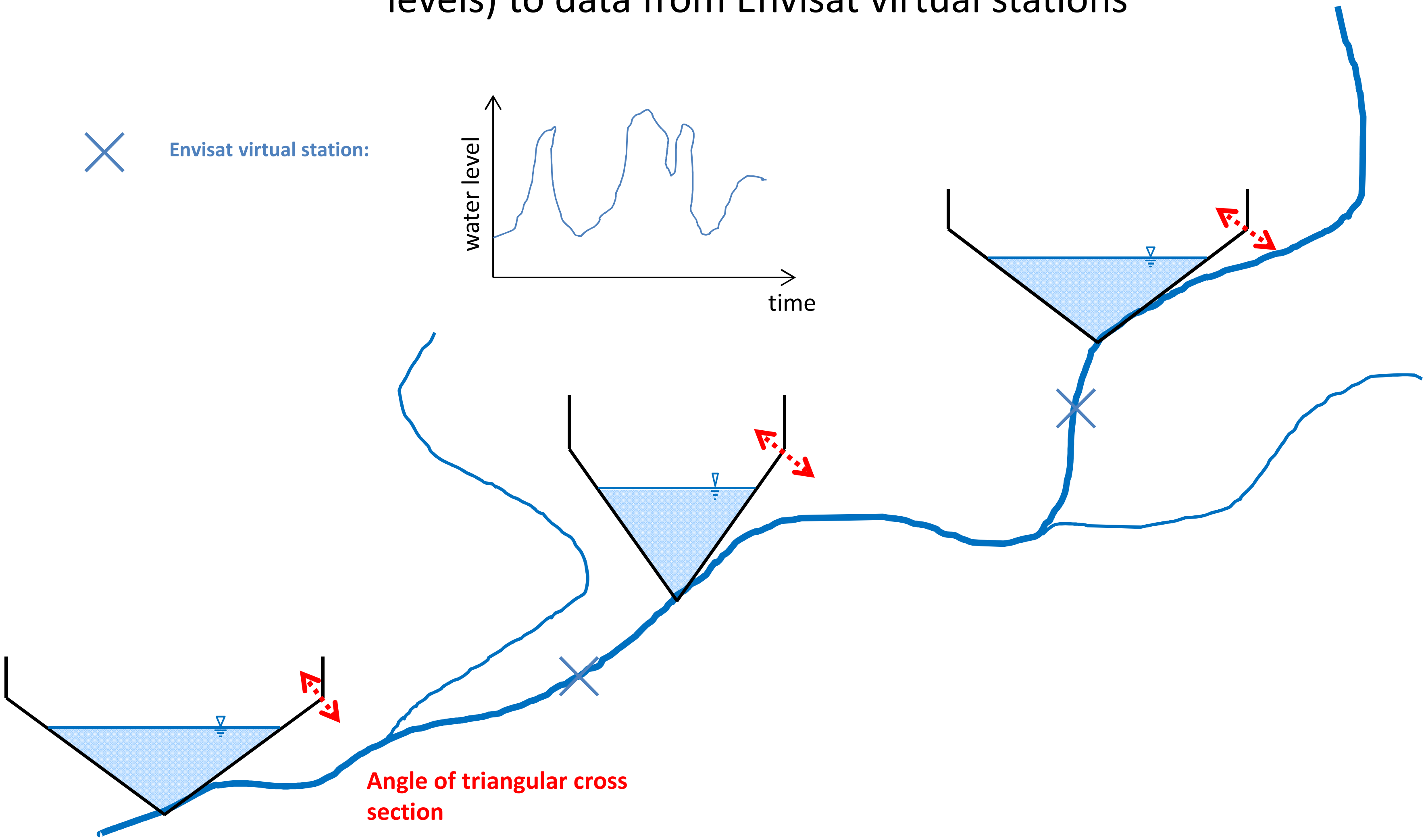
Hydrodynamic model – MIKE 11 user interface



Step 2: Calibrating average simulated water levels along river to observations from CryoSat-2



Step 3: Calibrating discharge-water level relationship (amplitude of water levels) to data from Envisat virtual stations



Some thoughts on evaluation of operational hydrologic forecasting

We always have two forecasts ”for free”:

- Climatology, i.e. (mean of) observations from past years
- Persistence, i.e. ”tomorrow = today”

→ A meaningful hydrologic model should beat these forecasts!

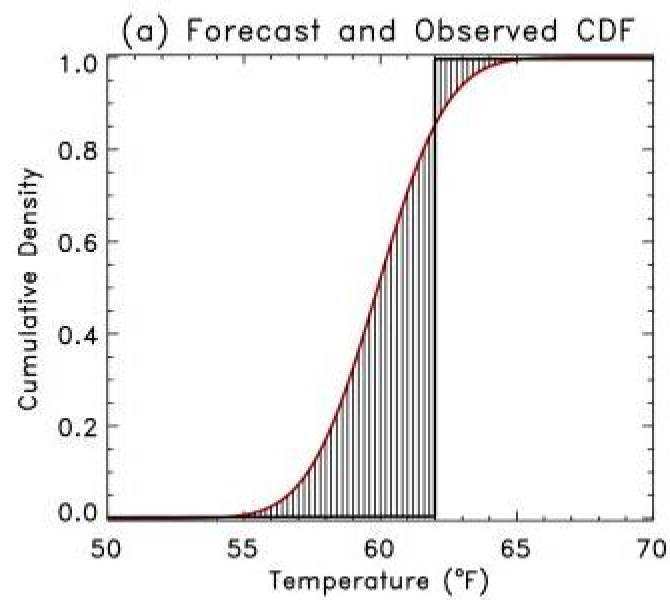
Indicator?: **Continuous Rank Probability Score (CRPS)**

$$CRPS = \frac{1}{k} * \sum_{i=1}^{k} \int_{x=-\infty}^{x=\infty} \left(F_i^f(x) - F_i^0(x)\right)^2 dx$$

where k forecast cases (timesteps)

$F_i^f(x)$ forecast probability cdf of k

$F_i^0(x)$ observation at timestep k



- combines reliability and sharpness
- for deterministic forecast: CRPS = MAE

CRPS for Bahadurabad on the Brahmaputra