From level 2 to higher level water height products for hydrological applications - rivers -

P.Thibaut, L.Zawadski, C.Lacrouts, N.Taburet, G.Dibarbourre [(1)]
J.F.Crétaux[(2)] , *F.Boy, N.Picot* [(3)]

1 - Collecte Localisation Satellite
2 - LEGOS
3 - CNES

Context : Copernicus Global Land Monitoring Service

- **A new Copernicus Service "Cryosphere and Water"** has been recently set up by the European Commission and the Joint Research Center delegation
- This service is included in the existing Land Service.

  website : land.copernicus.eu
- The "Cryosphere and Water" service includes **production** and **dissemination** of operational products
- Based on pre-operational existing services
- The objective is **to ensure an European sustained operational core service for fostering emergence of downstream applications**

Cryosphere
Production Facility – FMI - Finland
- Snow Area Extent – **FMI / ENVEO+SYKE**
- Snow Water Equivalent – **FMI / SYKE+ENVEO**
- Lake Ice Extent – **FMI / SYKE**

Water Bodies and Coastal Erosion
Production Facility – VITO - Belgium
- Areas af Water Bodies – **VITO / HYGEOS**
- Coastal Erosion – **VITO / IMCD**

Lake Water
Production Facility – CEMS - UK
- Lake Surface Water Temperature – **PML / UREAD**
- Lake Surface Reflectances – **PML / BC**
- Turbity – **BC / PML**
- Trophic State – **BC / PML**

Water Level
Production Facility – CLS - France
- Lakes Water Level – **CLS / LEGOS**
- Rivers Water Level – **CLS / LEGOS**

Context : Copernicus Global Land Monitoring Service

➔ Focus on the Water Level Service

- **Objectives**:
  - Operational production of Rivers and Lakes water level products
  - Both Near Real Time and Long Time series (reprocessing)
  - High level products (L3, L4): Multi-mission, Cross-calibrated, Merged
  - State-of-the-art service (best algorithms) based on L2 products from Space Agencies

- Built upon the pre-existing CNES THEIA/Hydroweb system (developed and operated by LEGOS and CLS)
  - At T0, it delivers altimetry times series over rives and lakes
  - Designed to integrate any available altimetry mission (2016-2017: Jason-3 and Sentinel-3)
  - Evolutions towards higher level products: combined, multi-mission water levels

1. Improvement of the algorithms

Altimeter data set improvement

- Conventional Altimetry (past and current missions)
  - ✓ Echo characterisation (NN classification)
  - ✓ Improvement of the retrackers
  - ✓ Improvement of the editing & compression methods

    (cf Zawadzki & al poster)
  - ✓ Use of water surface mask (explained later)

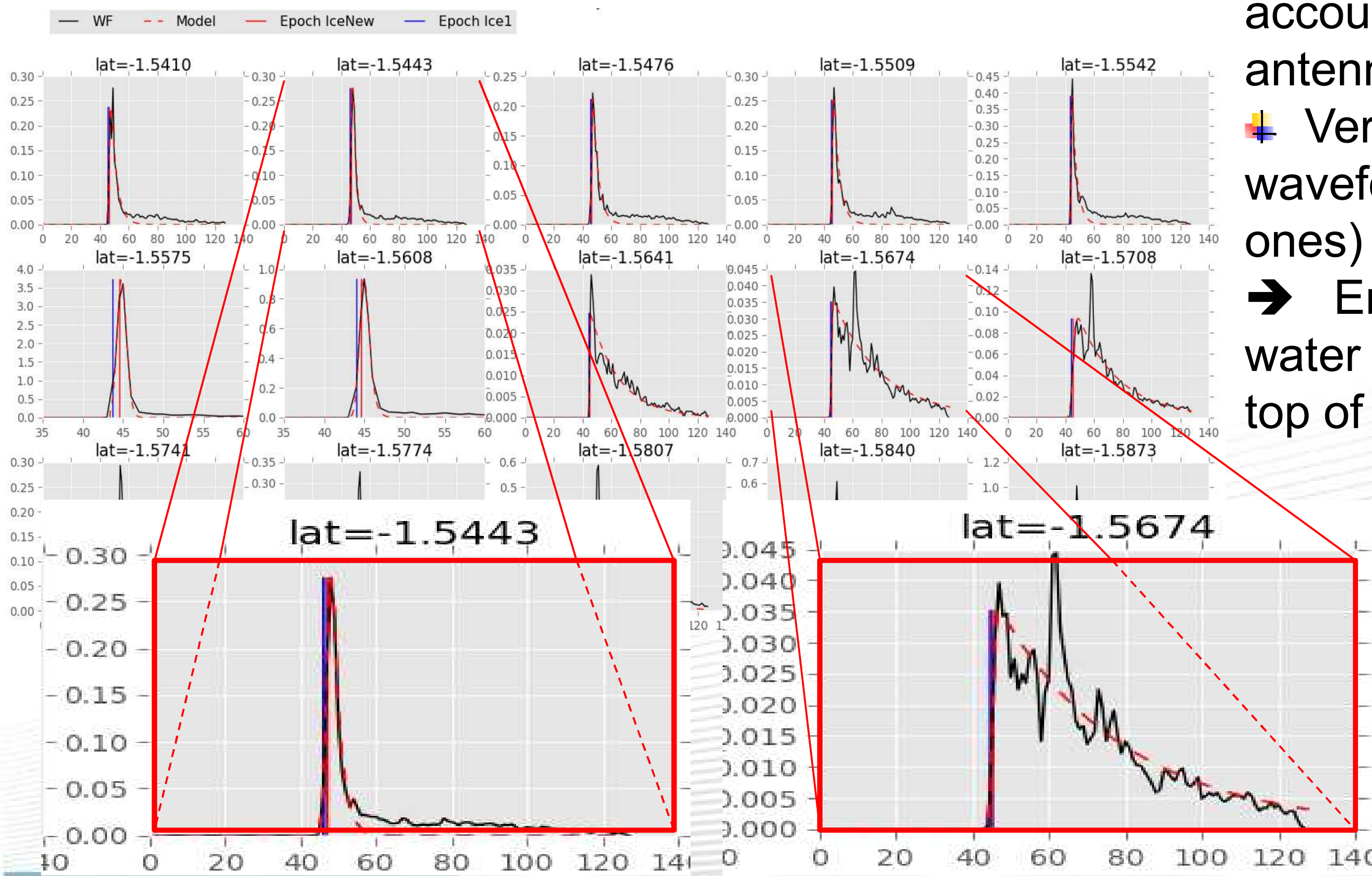
- New Delay Doppler Mode (Sentinel-3)
  - ✓ Same topics +
  - ✓ Dedicated L1 processing

Adaptive retracker based on a physical model

$$S(t) = FFSR(t) \circledast PDF(t) \circledast PTR(t)$$

(see Jackson 1992; Amarouche 2007; Poisson & Quartly submitted in 2016)

Introduction of the mean square slope of the surface (mss)



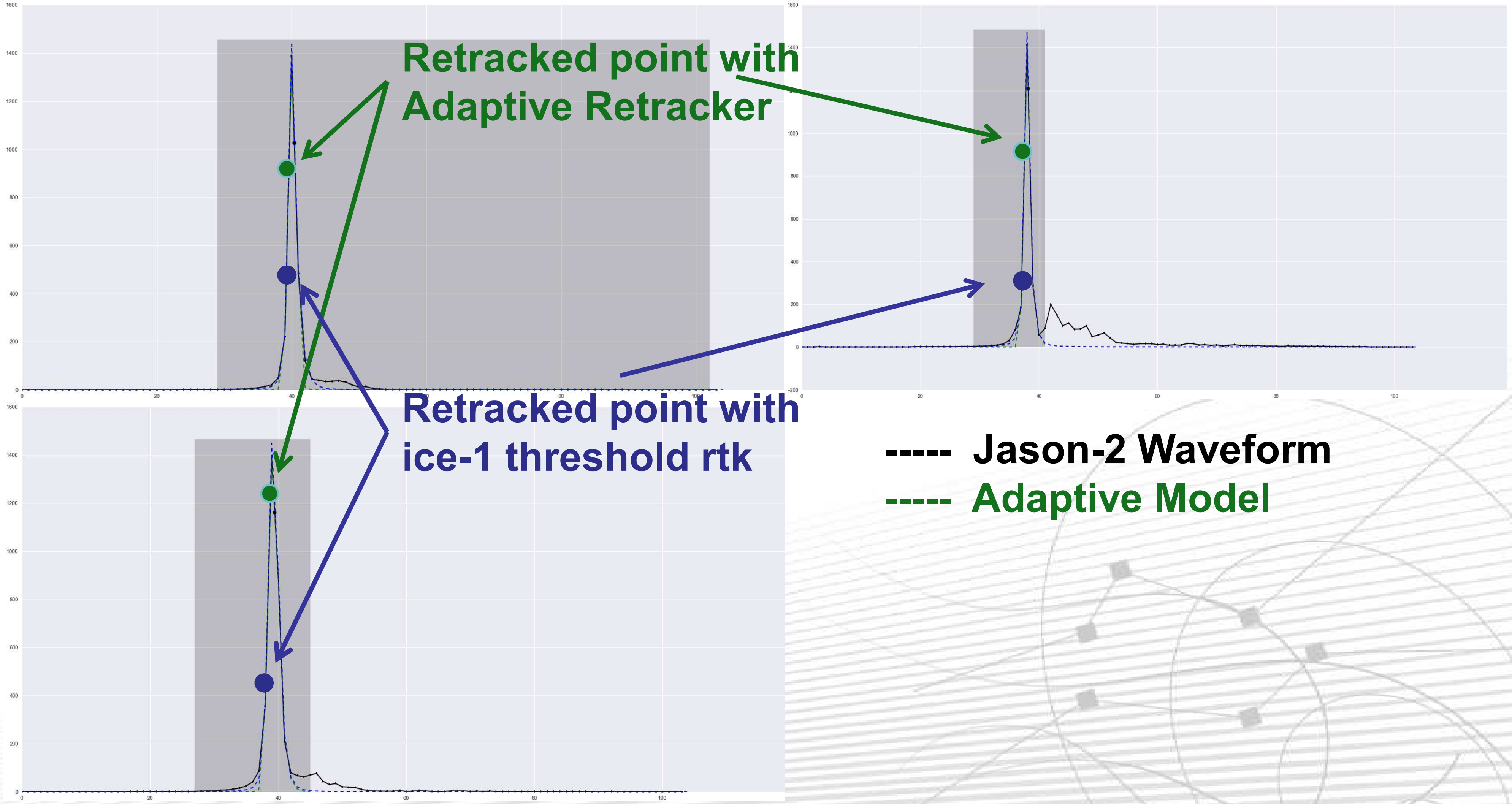
- Based on a physical model accounting for instrumental PTR and antenna gain pattern
- Very good fit with the measured waveform (from Brownian to specular ones)

➔ Enabling to estimate accurate water heights from the outfall to the top of rivers (continuity with ocean)

- ❑ **Same retracker used for the ocean**
- ❑ **Much better performances than a geometrical threshold retracker**

Adaptive retracker based on a physical model

Examples and differences wrt ice-1 retracker



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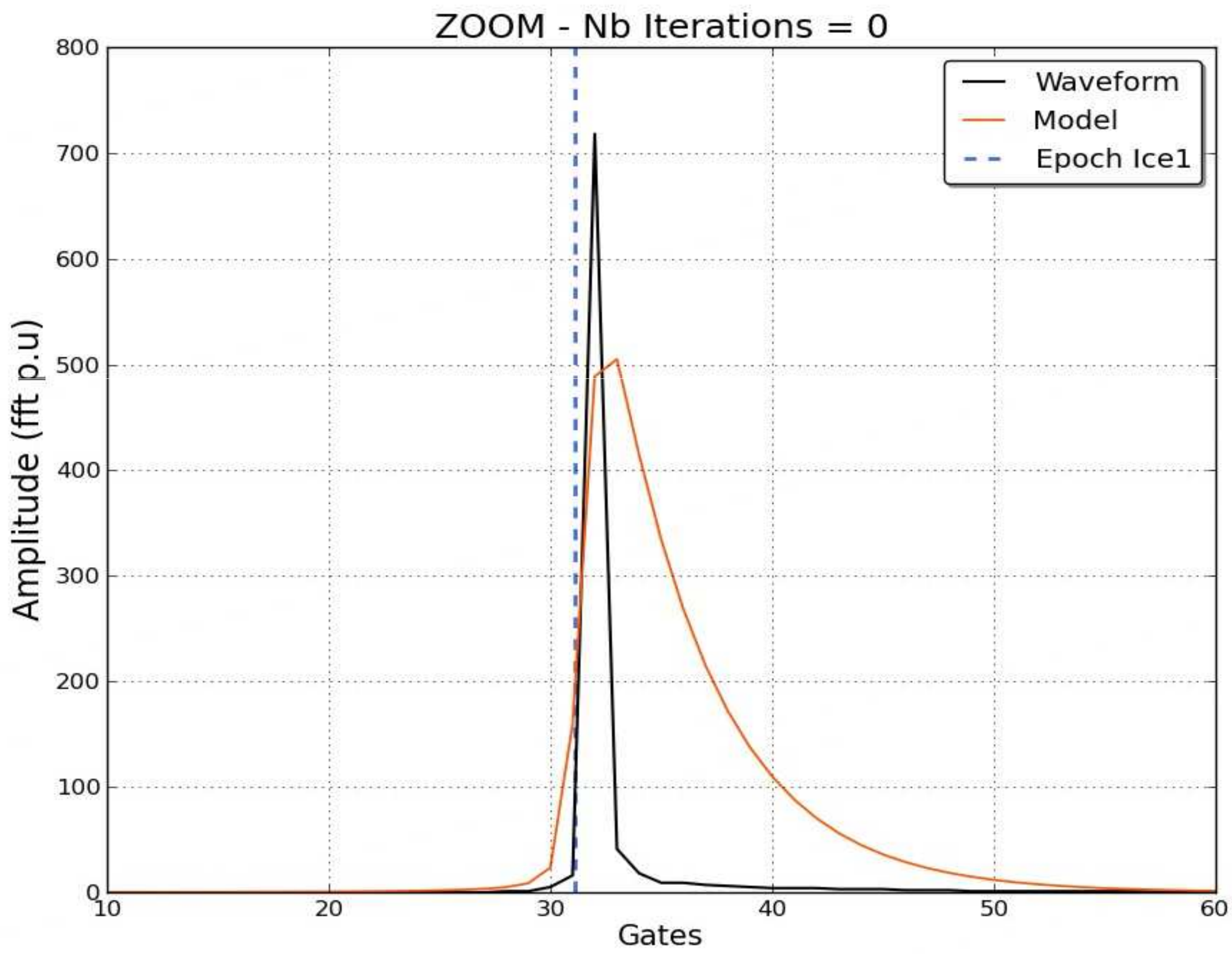
Adaptive retracker based on a physical model



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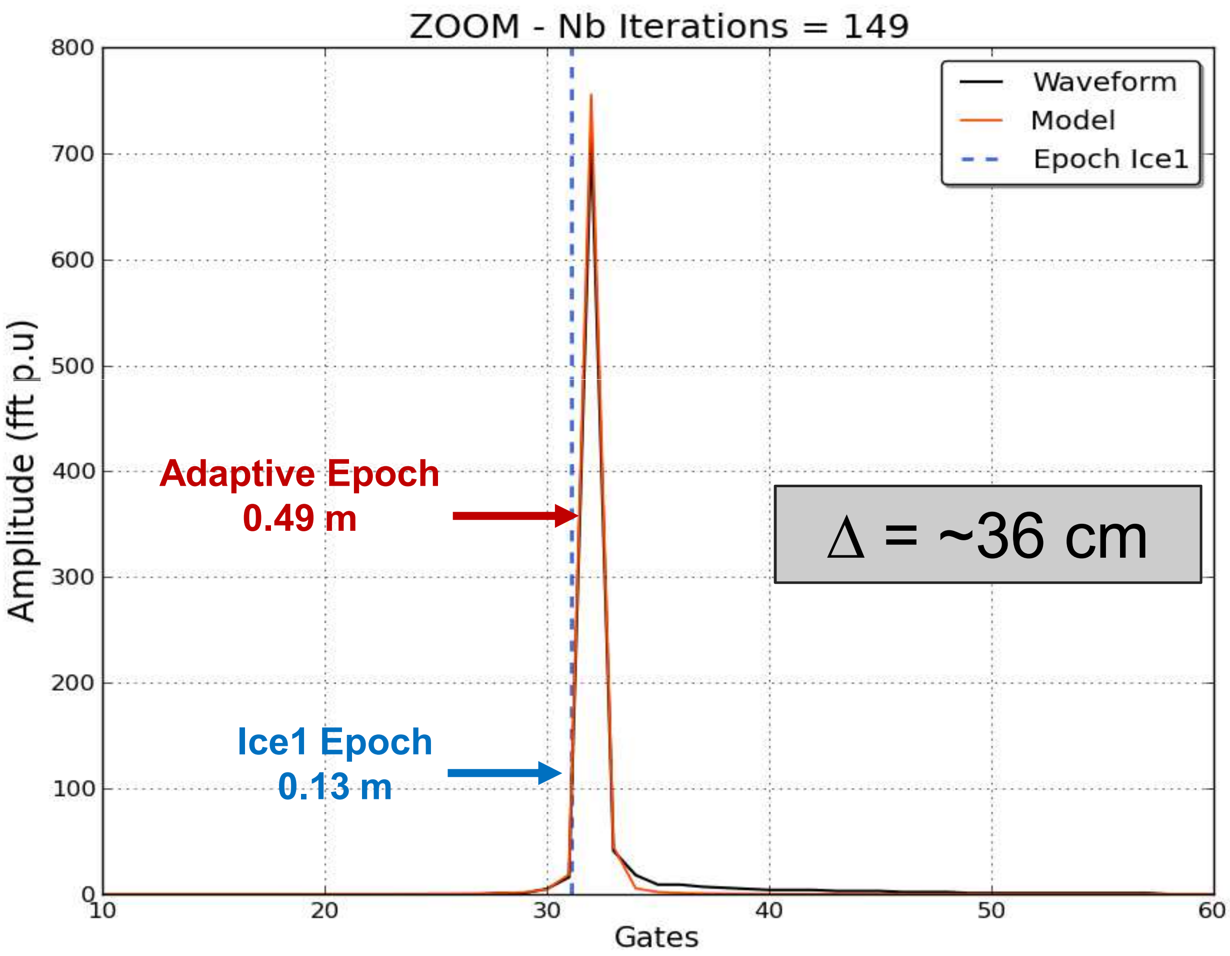

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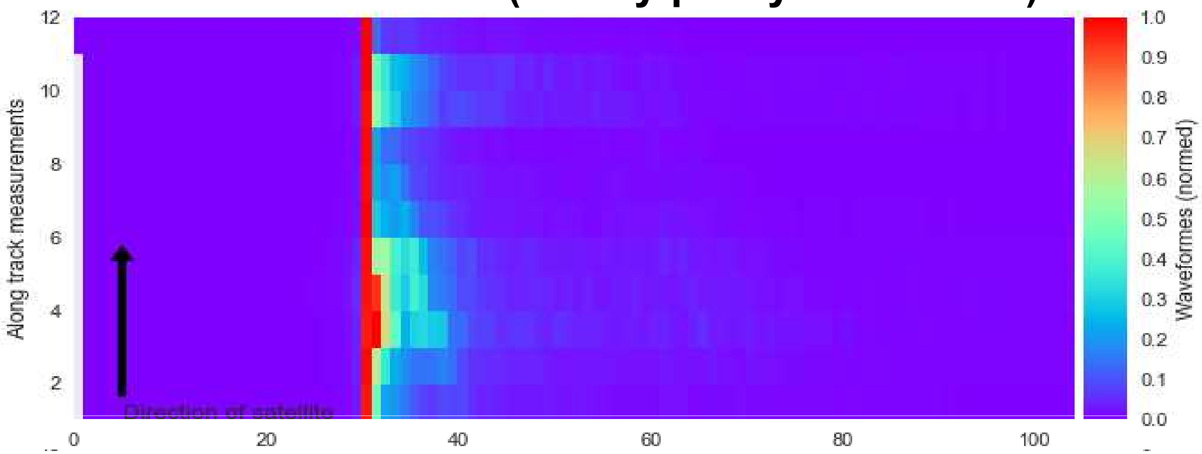
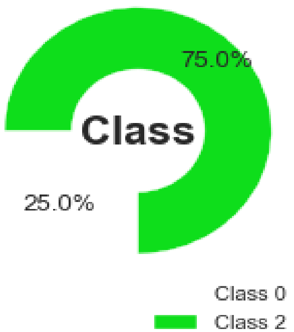
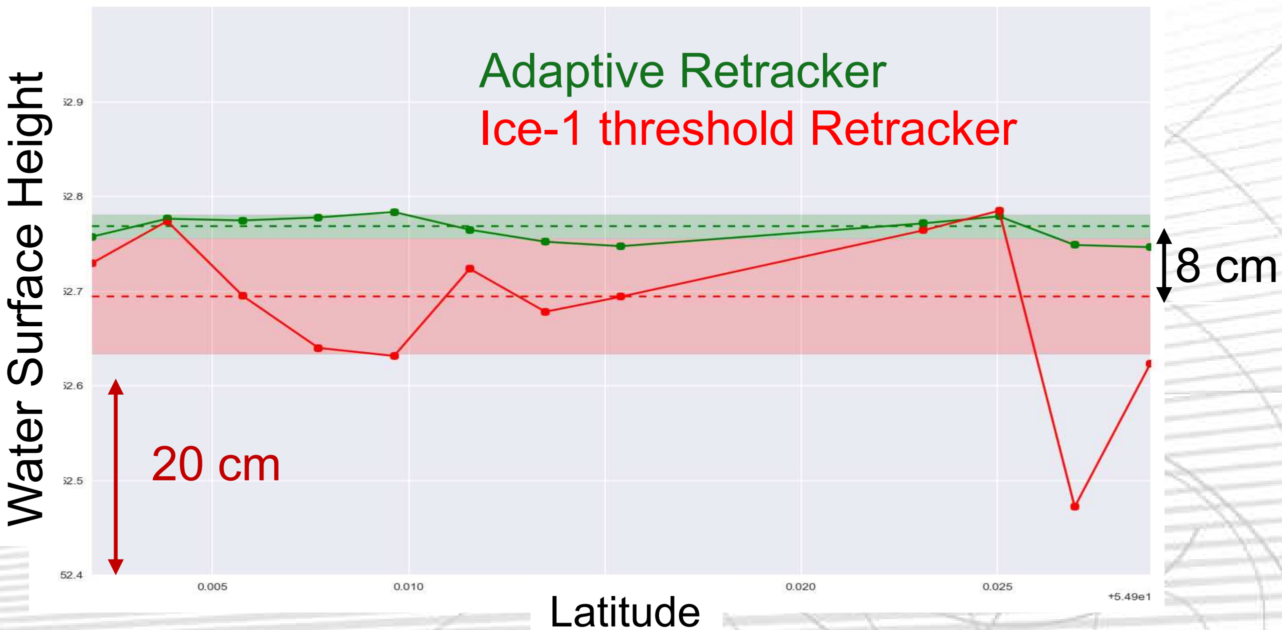
Illustration of the results : Volga river (Jason-3)

Jason-3 waveforms (mostly peaky waveforms)







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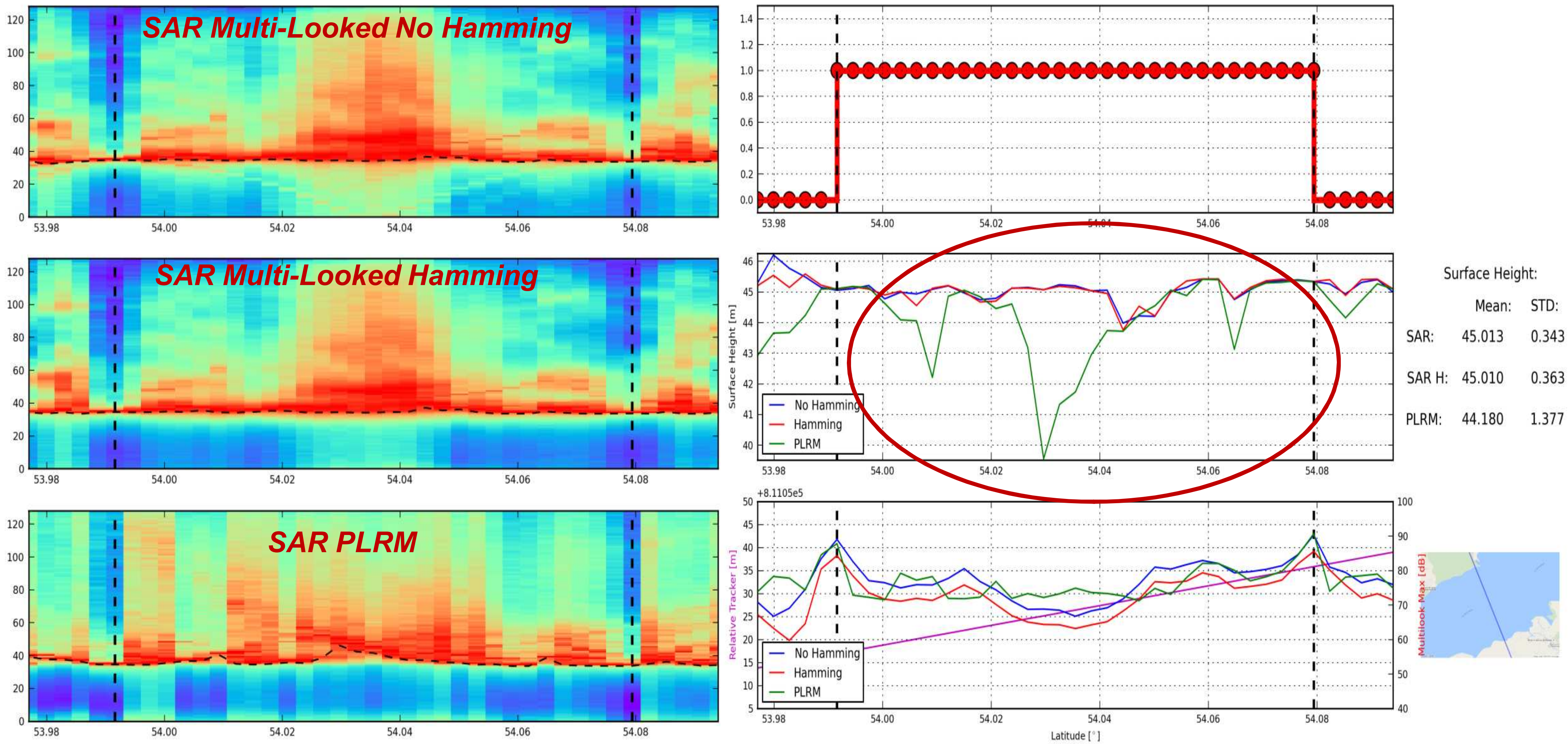
CLS
COLLECTE LOCALISATION SATELLITES

Sentinel-3 (Volga - Passe 167)

Significant improvements will be brought by the Delay Doppler technique (reduced waveform footprint) ➔ an example with CNES S3PP processing (F.Boy)



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2 . Evolutions towards higher level products:

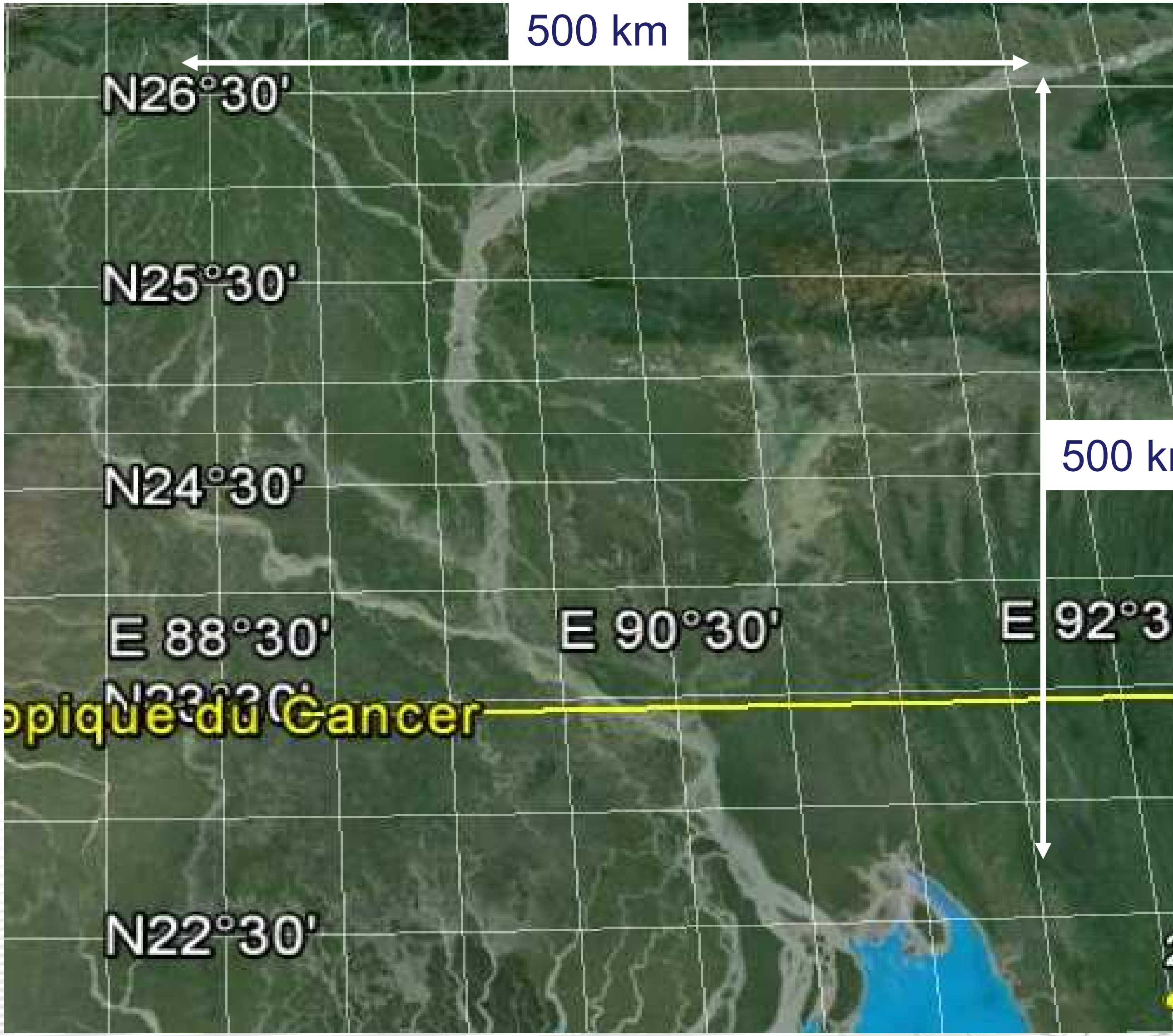
multi-mission water levels

Altimetry observations at a river bassin scale

Brahmaputra (Bangladesh) 250 000 km2

150 M people

In 1998, vast flooding event. 1000 people died
30 M homeless people.
66 % of the country under water.
130 000 animals died.



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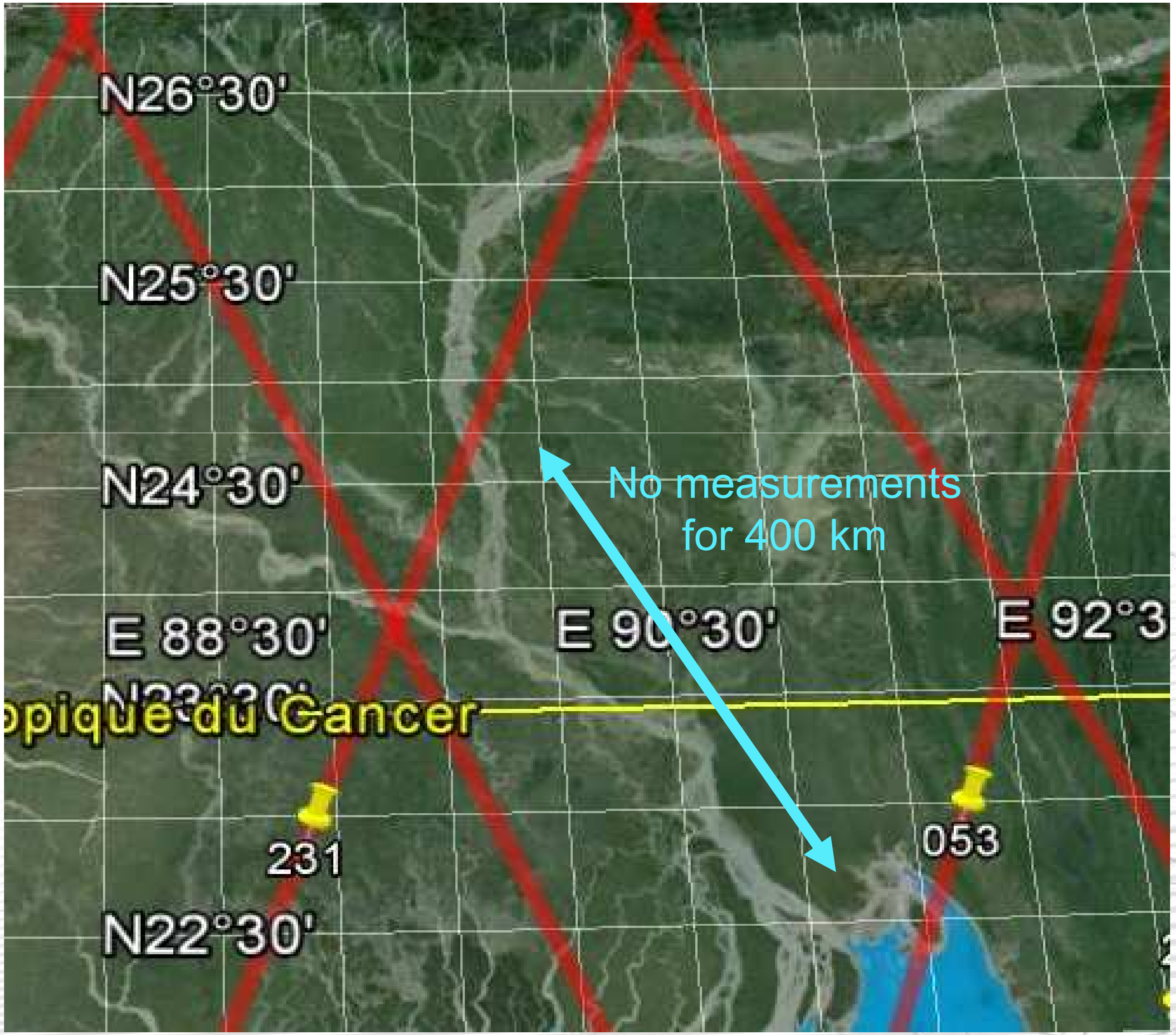
Altimetry sampling over Brahmaputra

Jason-2
(1 cycle/10 days)
6 intersections



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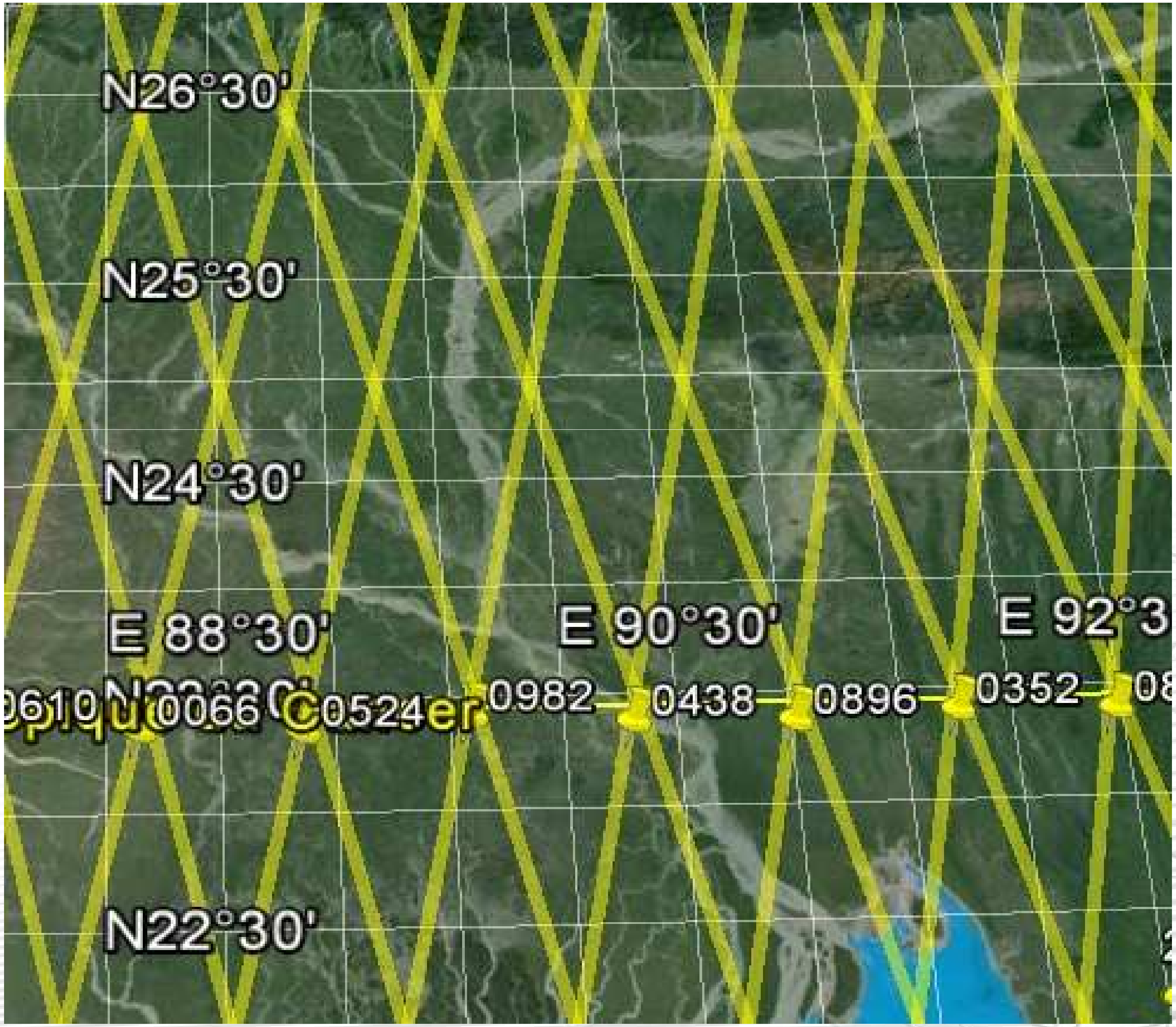
Altimetry sampling over Brahmaputra

Saral
(1 cycle/35 days)
28 intersections



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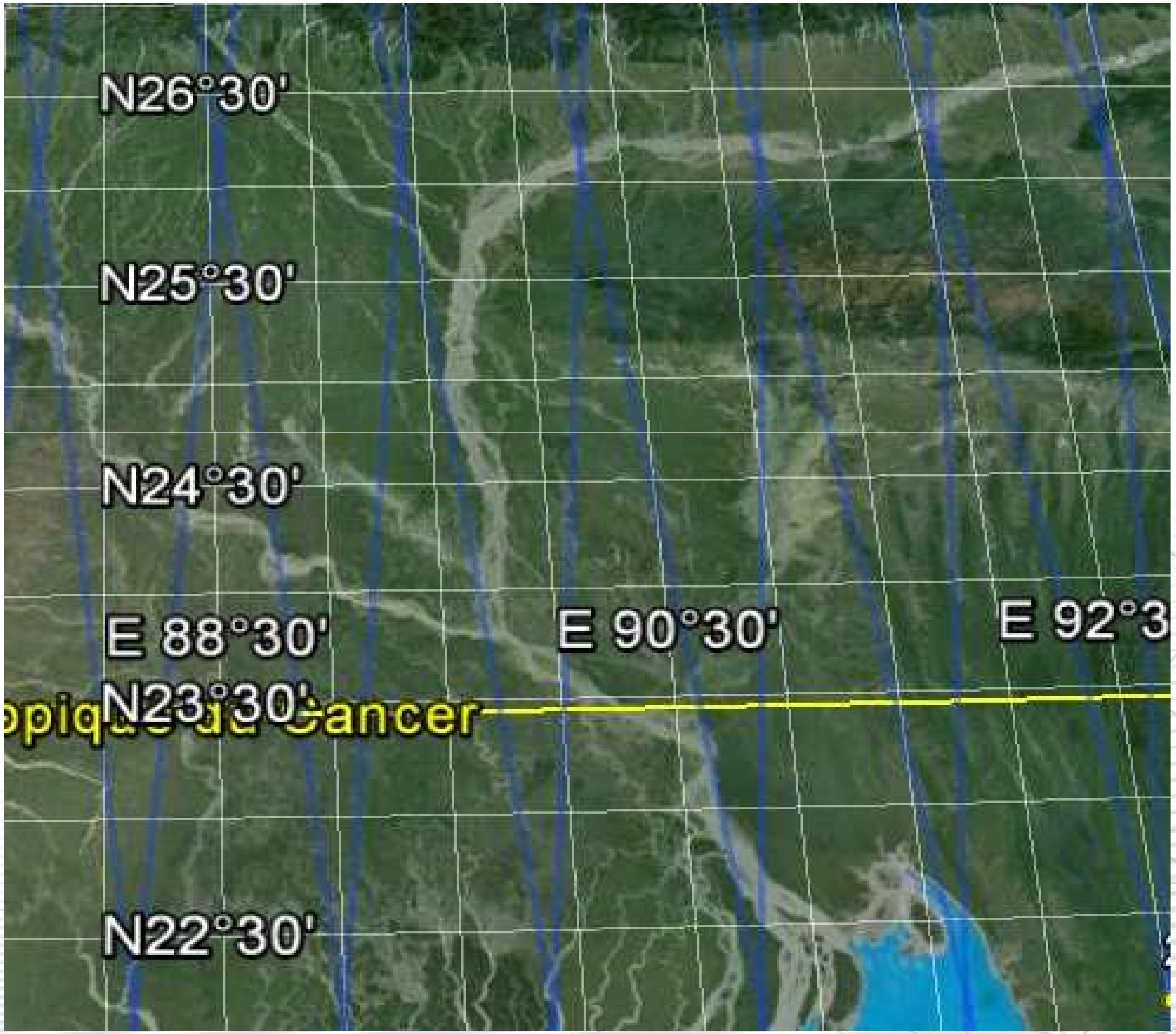
Altimetry sampling over Brahmaputra

<u>**Cryosat-2**</u>
(1 sub-cycle)
24 intersections



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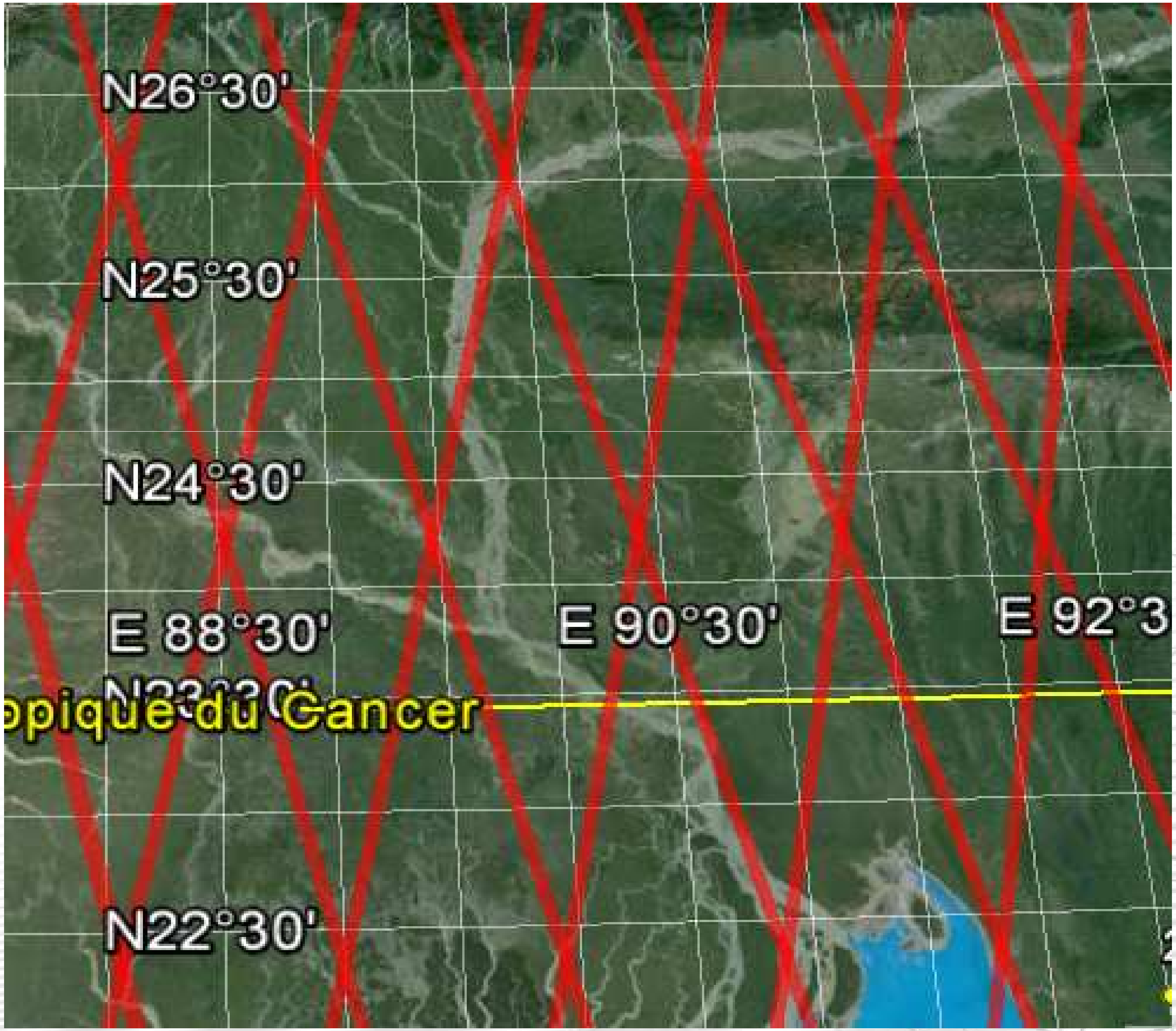
Altimetry sampling over Brahmaputra

Sentinel-3
(1 cycle/27 days)
20 intersections



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Altimetry sampling over Brahmaputra

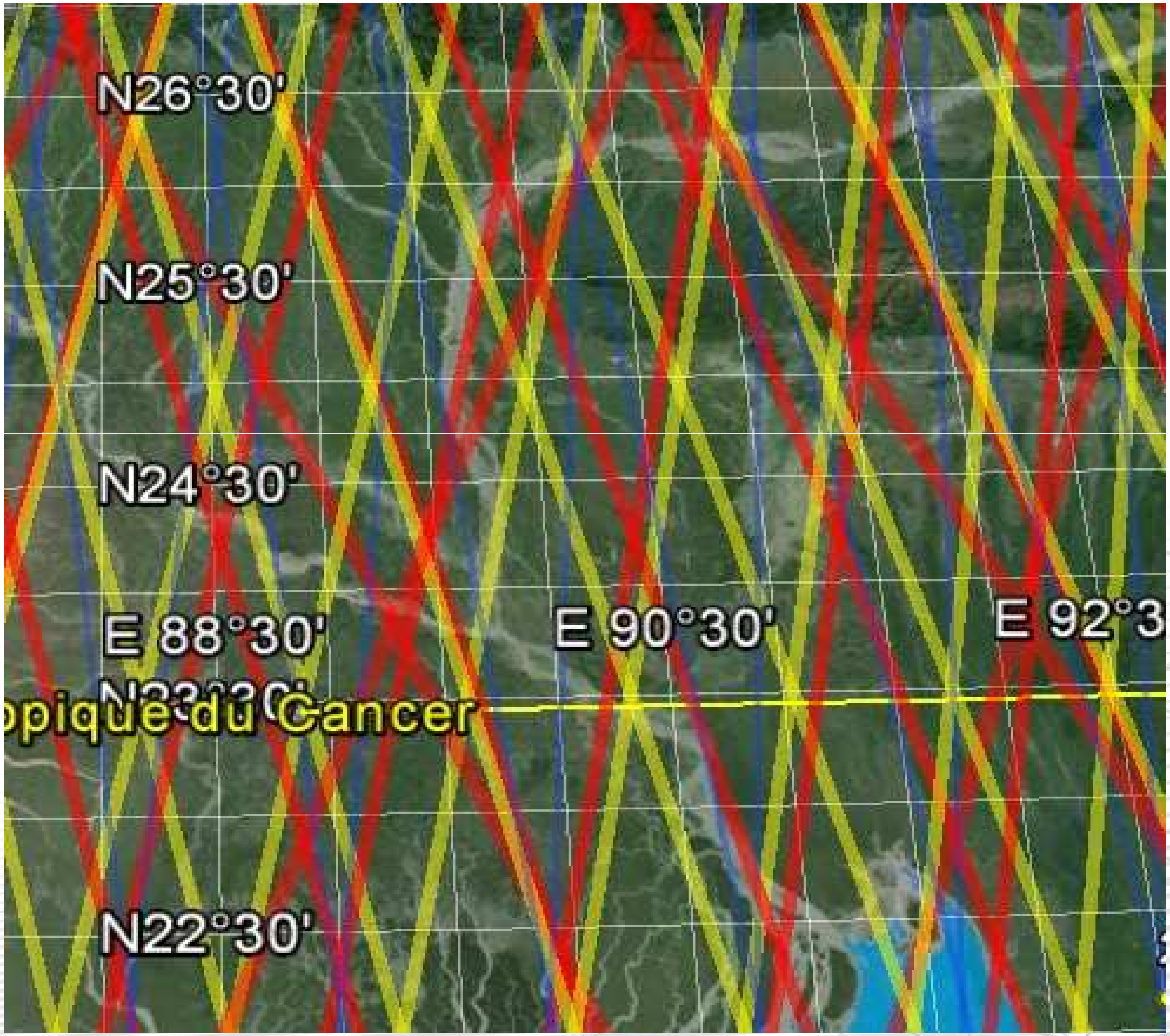
Jason-2
(1 cycle/10 days)
6 intersections

Saral
(1 cycle/35 days)
28 intersections

Cryosat-2
(1 sub-cycle)
24 intersections

Sentinel-3
(1 cycle/27 days)
20 intersections

Total
(over 35 days)
 # 80 intersections
 # 100 measures



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Altimeter measurement densification along the rivers : main steps

The basic idea is to take benefit of the altimeter constellation measurements to provide high level water level products merging all data set (**similar to what has been done in oceanography with DUACS system**). (already presented in the ESA Living Planet Symp in Prague, 2016,Thibaut & al)

To achieve that aim, **we first have to densify the altimeter measurements** over each segment of a river (using an optimal interpolation at each position along the river)

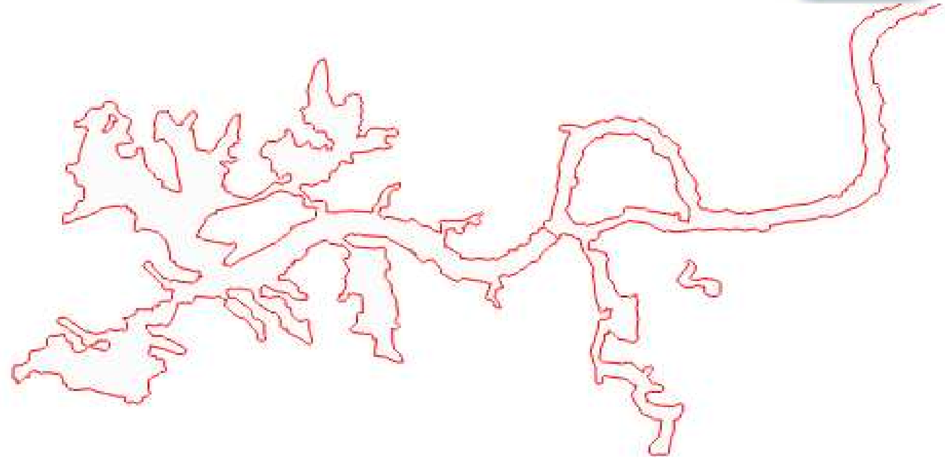
- Need to compute a curvilinear abscissa at each point of the river wrt a reference point (at the outfall for example)
- Use of a water/land mask (static or dynamic) and skeletonization of the mask
- Segmentation of the river bassin in arms between nodes and leaves
- Creation of a oriented graph to connect arms and nodes
- Interpolation of the altimeter measurements on each arm (computation of the Hovmöller diagrams) mono or multi missions (need to intercalibrate the missions)
- Take care of the continuity between the different arms (at nodes)

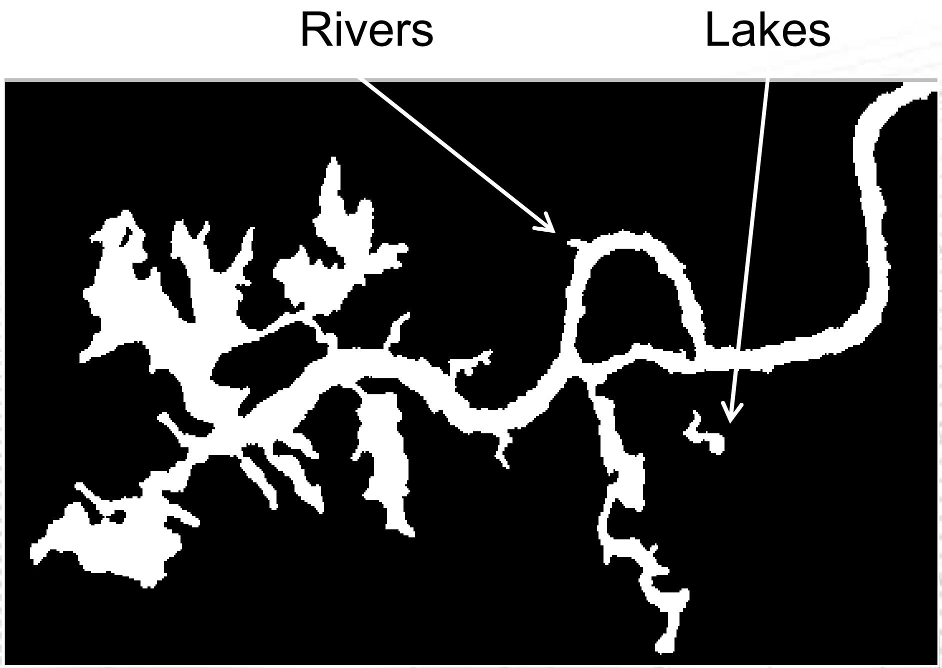
Use of a Water Mask

(SRTM Water Body in this case but any other could be used)

SRTM Water Body Dataset (NASA) :

- Water surface contours in shapefile format (vectors)
- Tiles of 1°x1°
- Resolution 30m x 30m
- River width > 183m and lenght > 600m





- Computation of a land/water mask (raster file) + extension for flood event monitoring
- Management of the central islands and multi bed river

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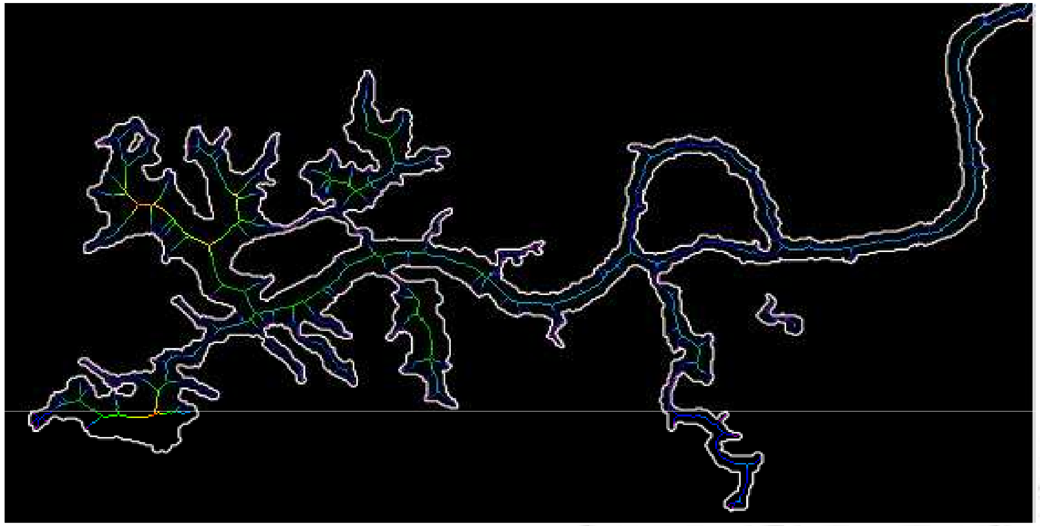
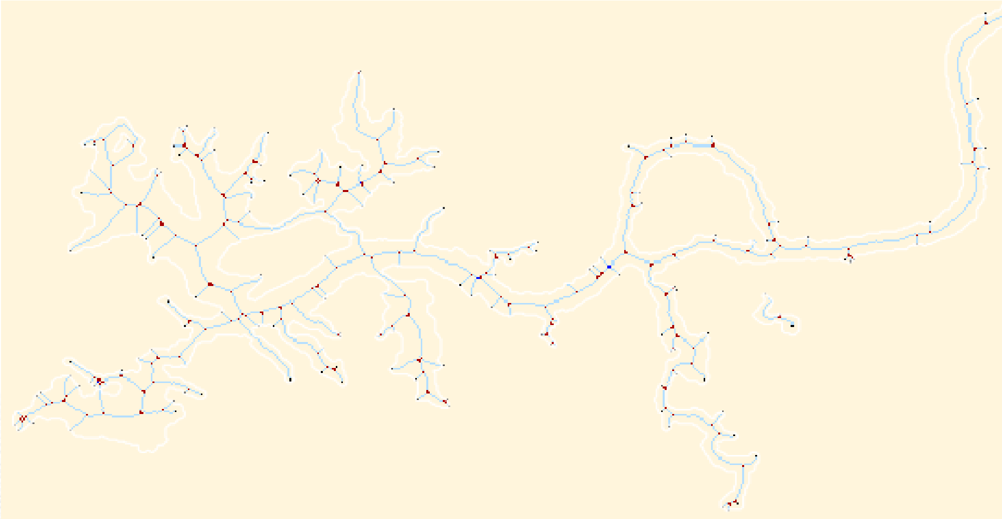
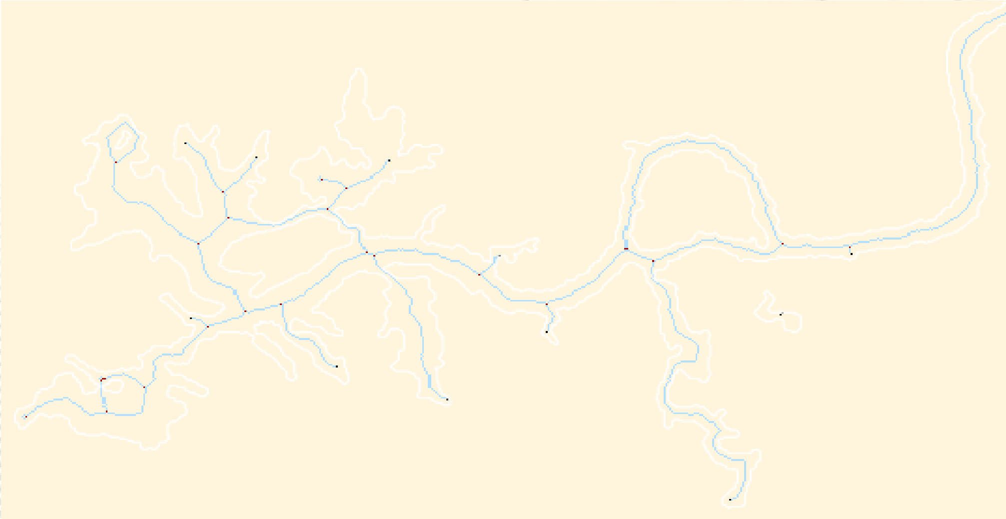
Use of a Water Mask
(SRTM Water Body in this case but any other could be used)

Skeletonization of the mask

- Automatic determination of the central line of the river
- Computation of the curvilinear abscissa along the river (15 m res) and witdh at each point
- Reduction of artefacts induced by skeletonization







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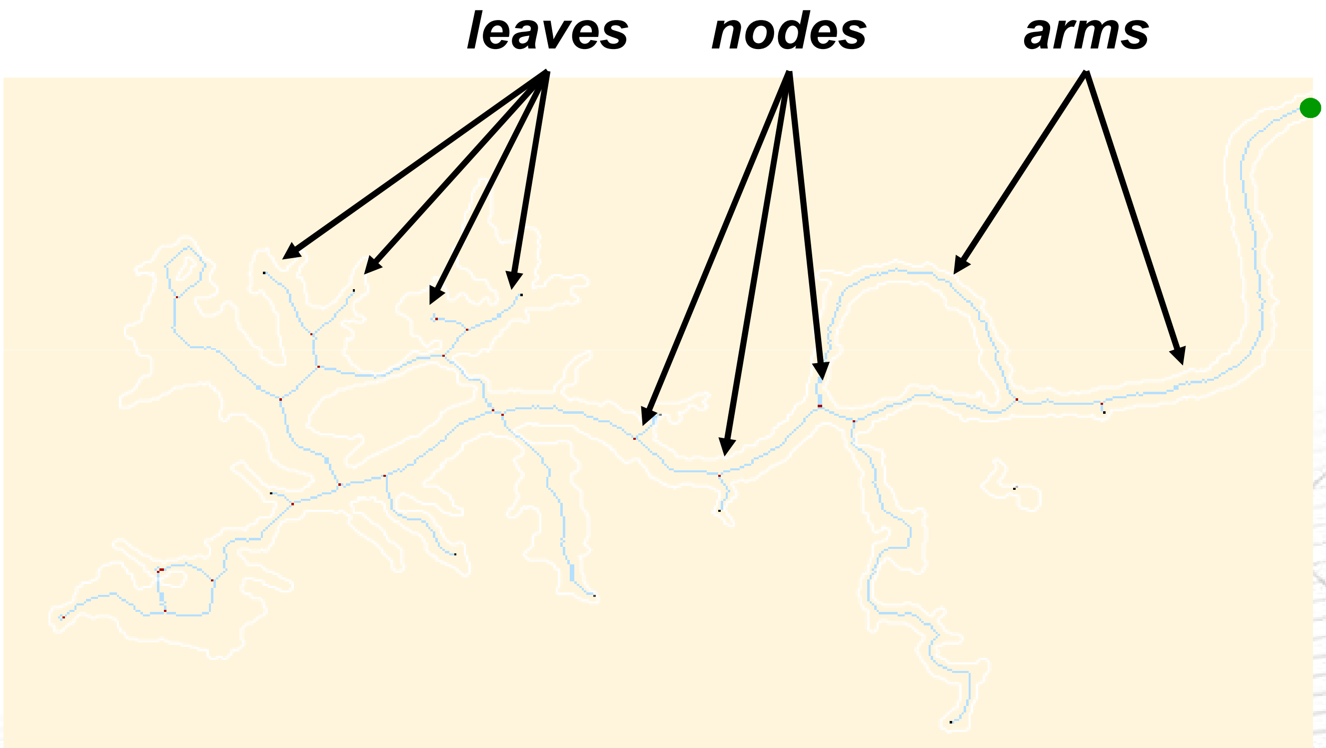
Creation of an oriented graph to connect arms and nodes over a river basin

1



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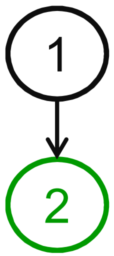

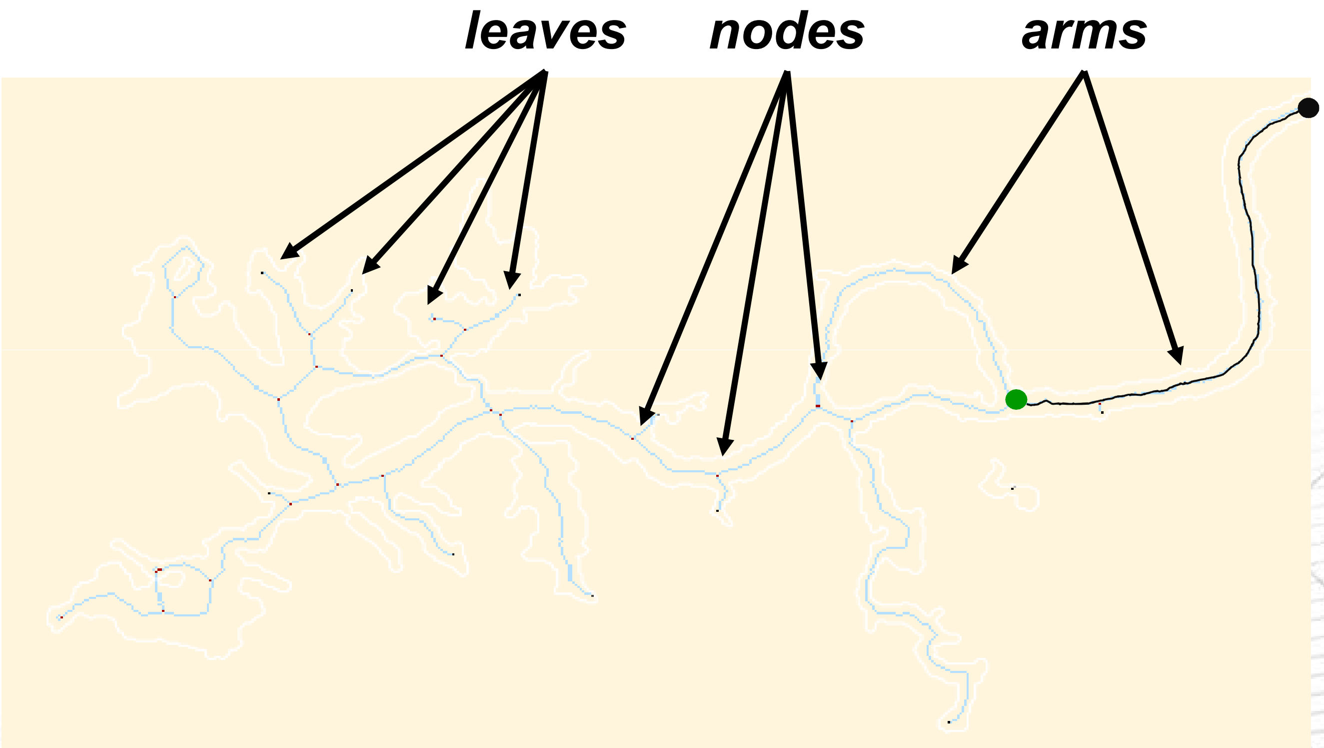

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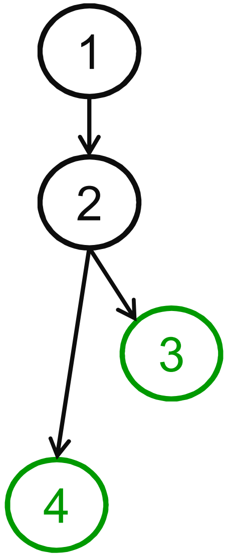

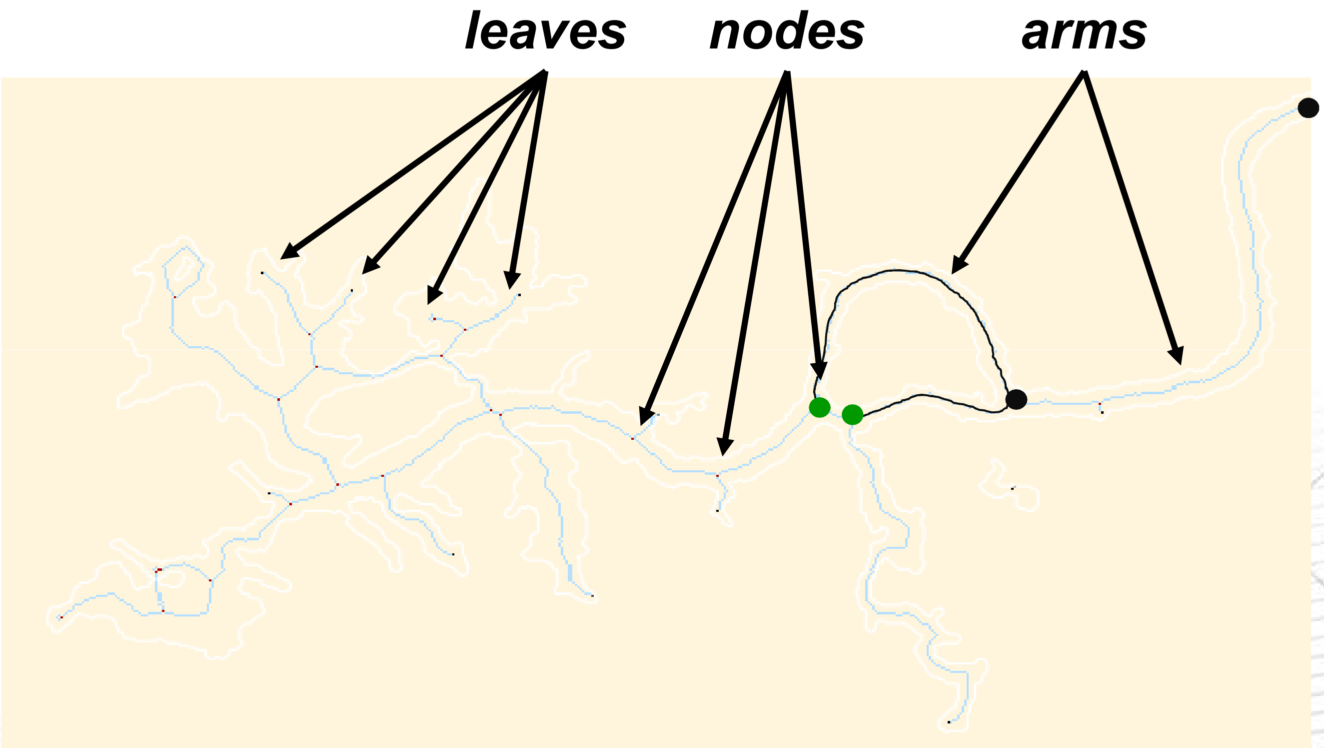

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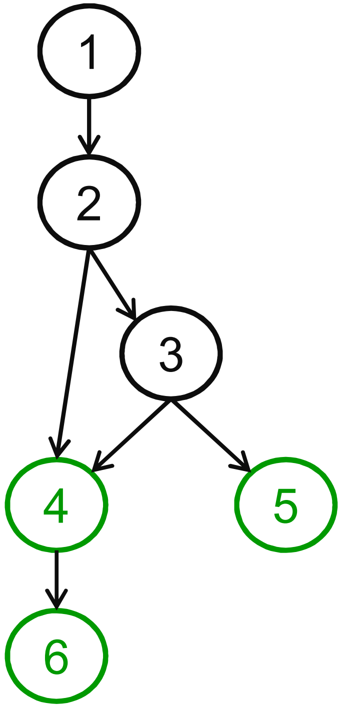

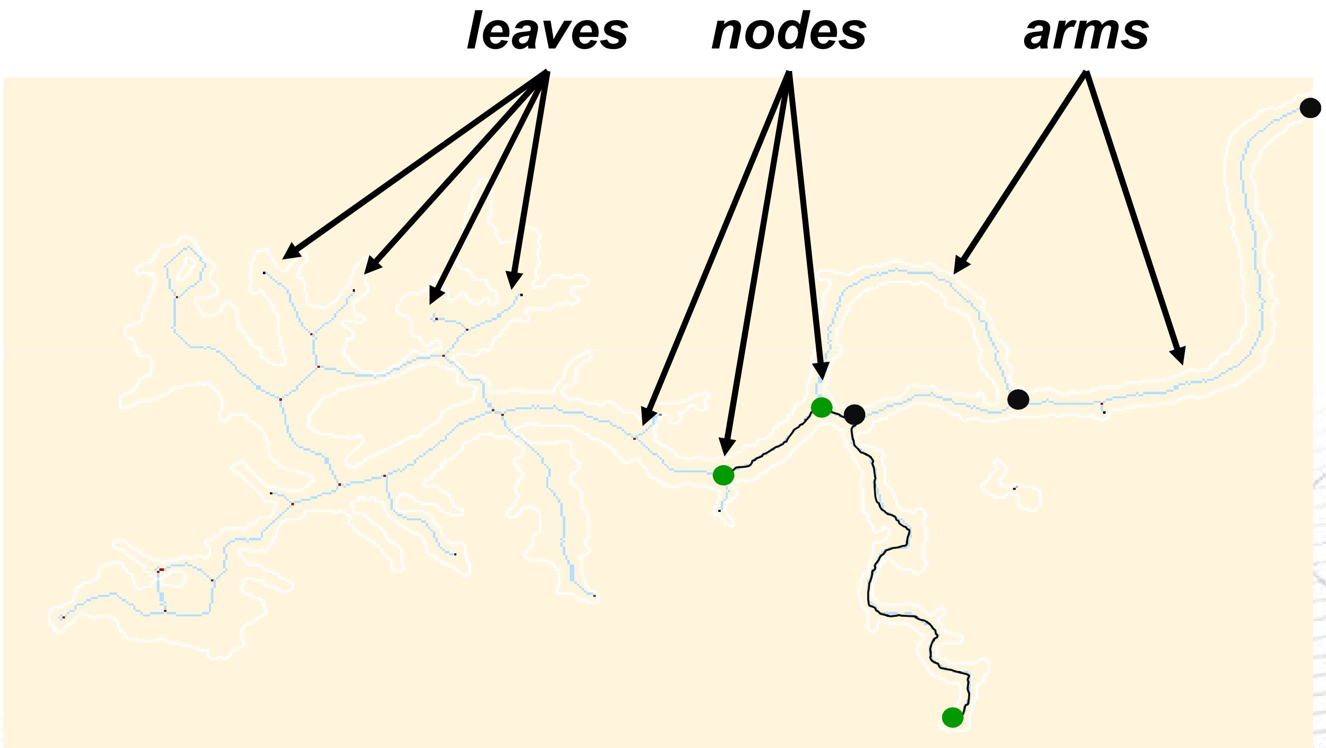

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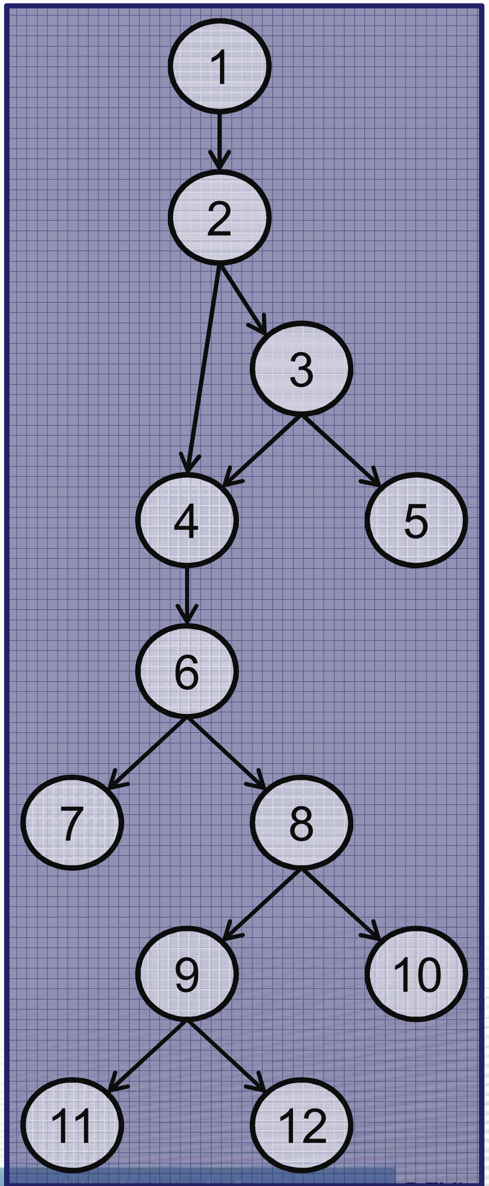
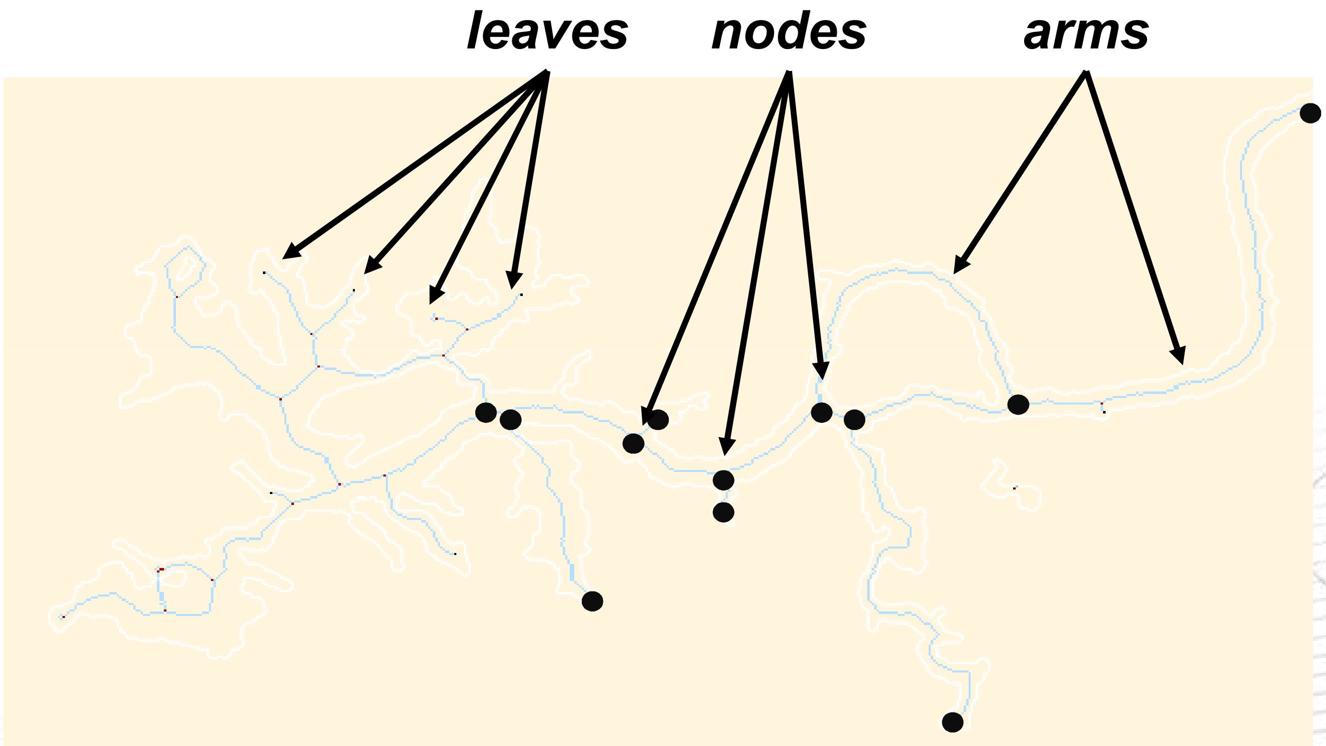
Creation of an oriented graph to connect arms and nodes over a river basin

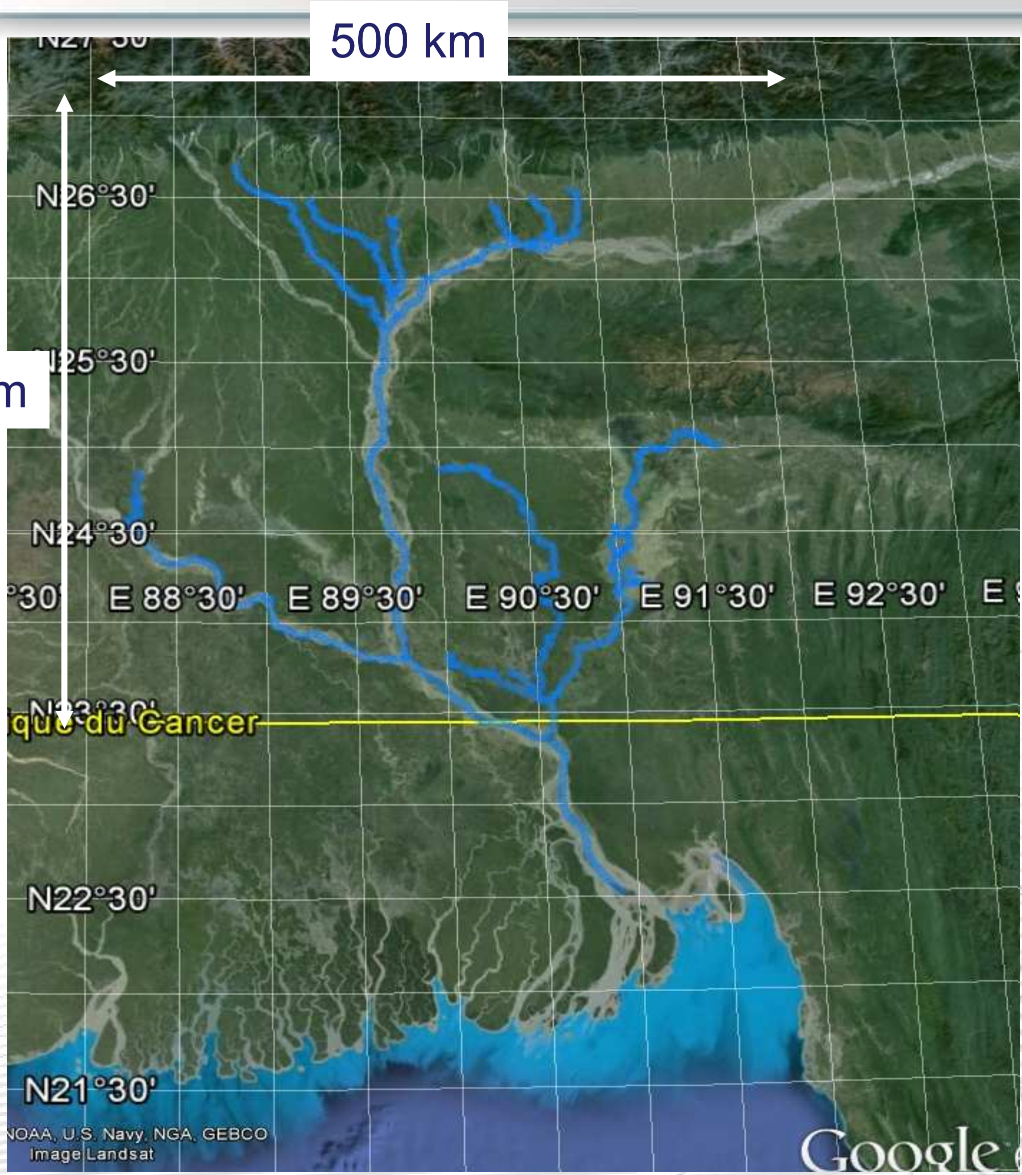




- ❑ Automatic processing that feeds a hydrological data base at CLS

Altimetry observations over one river basin

Brahmaputra River



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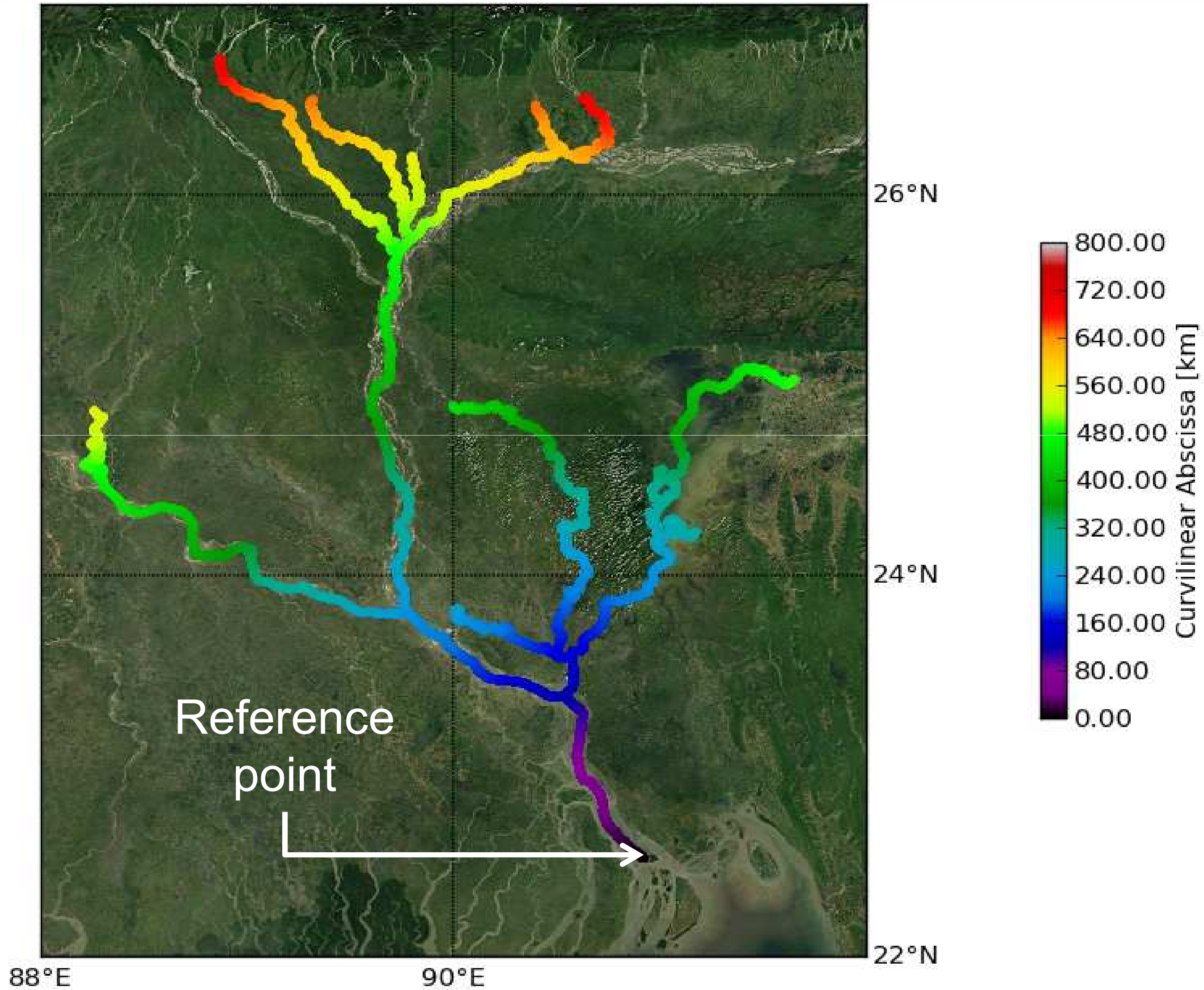
Curvilinear Abscissa

Brahmaputra River



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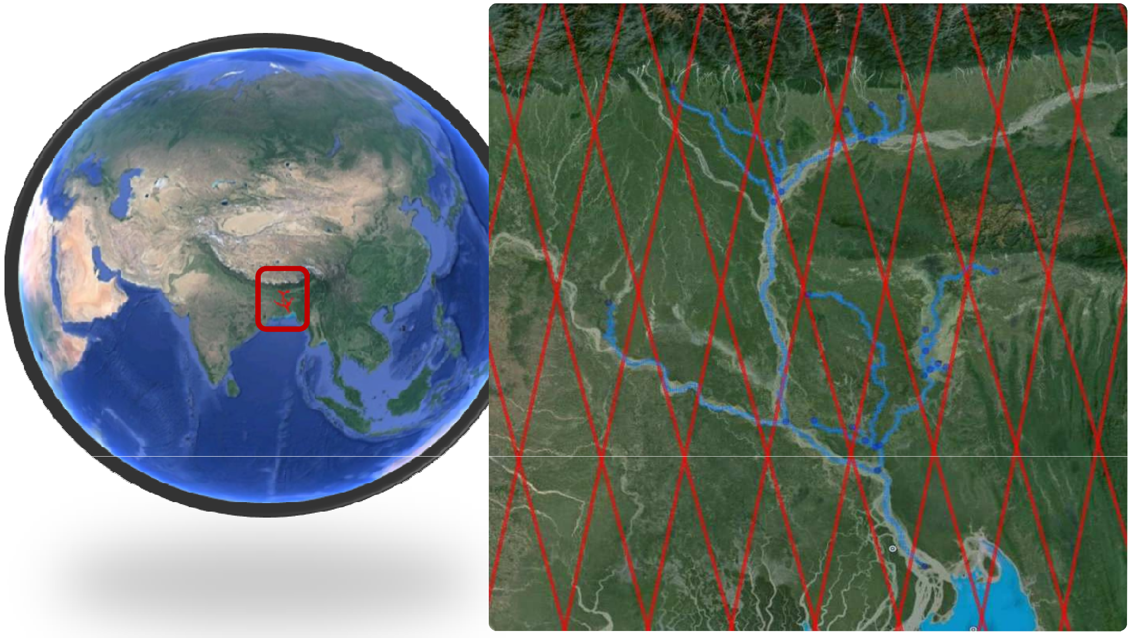
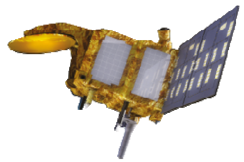
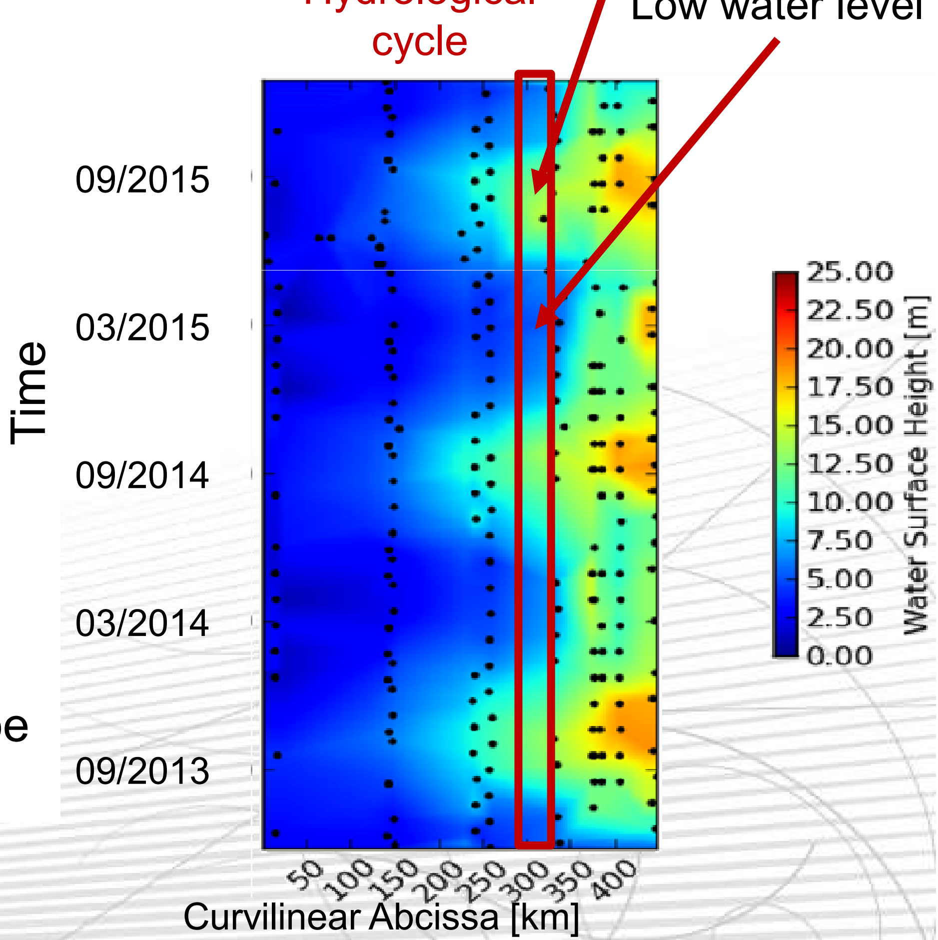
Hovmöller Saral Brahmapoutra

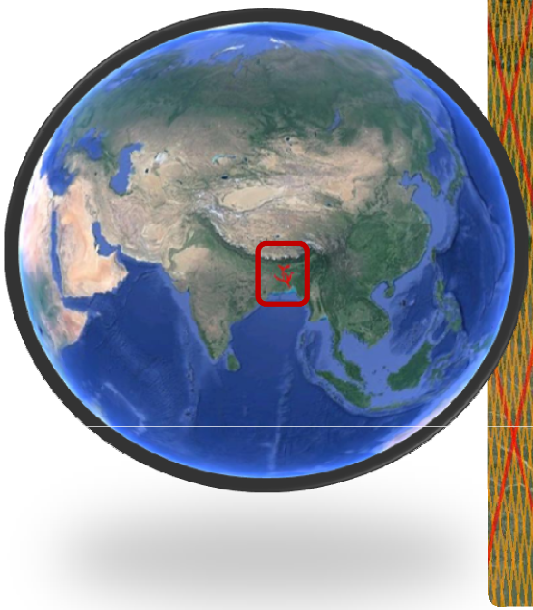


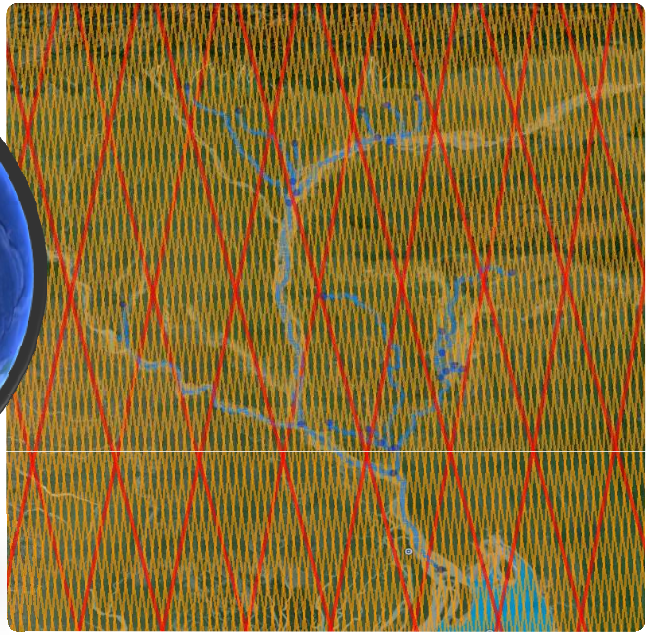


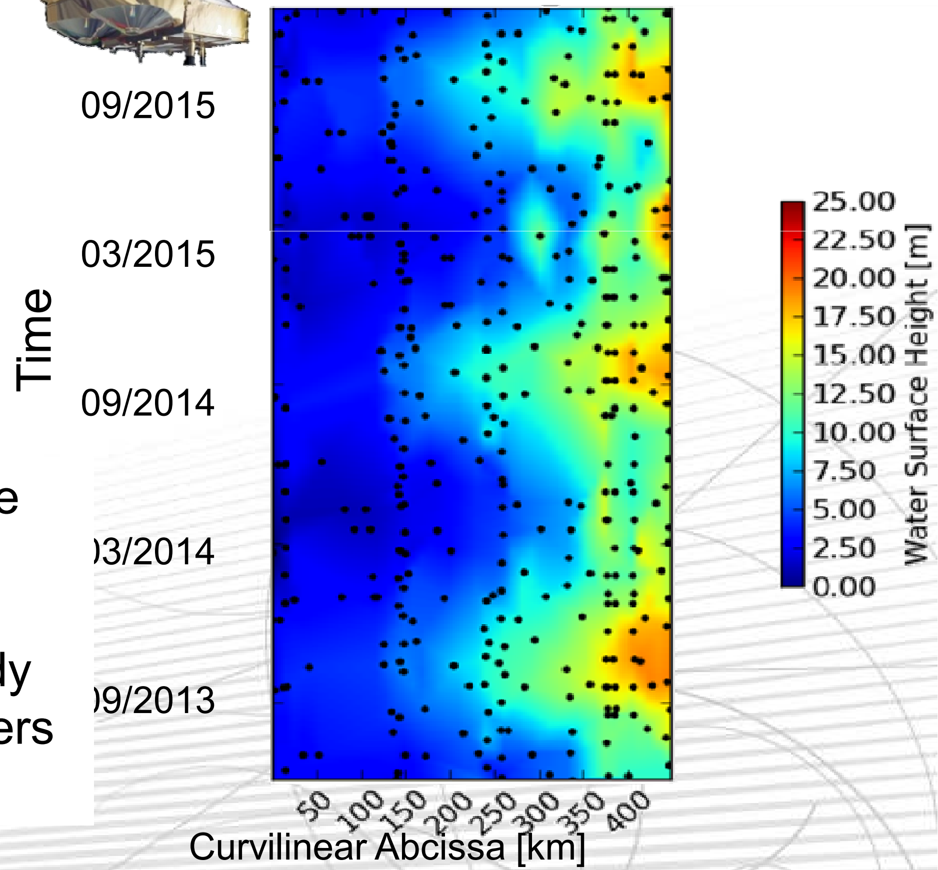


- ❑ Hovmöller diagram : each dot represents an altimeter measurement (see Bercher, PhD Thesis, 2008; Tourian, OSTST 2014, Thibaut &al, Hydrospace meeting 2015)
- ❑ A more or less sophisticated interpolation method (time/space) (using hydrological models or not) can be applied on each segment

Hovmöller Saral + CS-2 Brahmapoutra



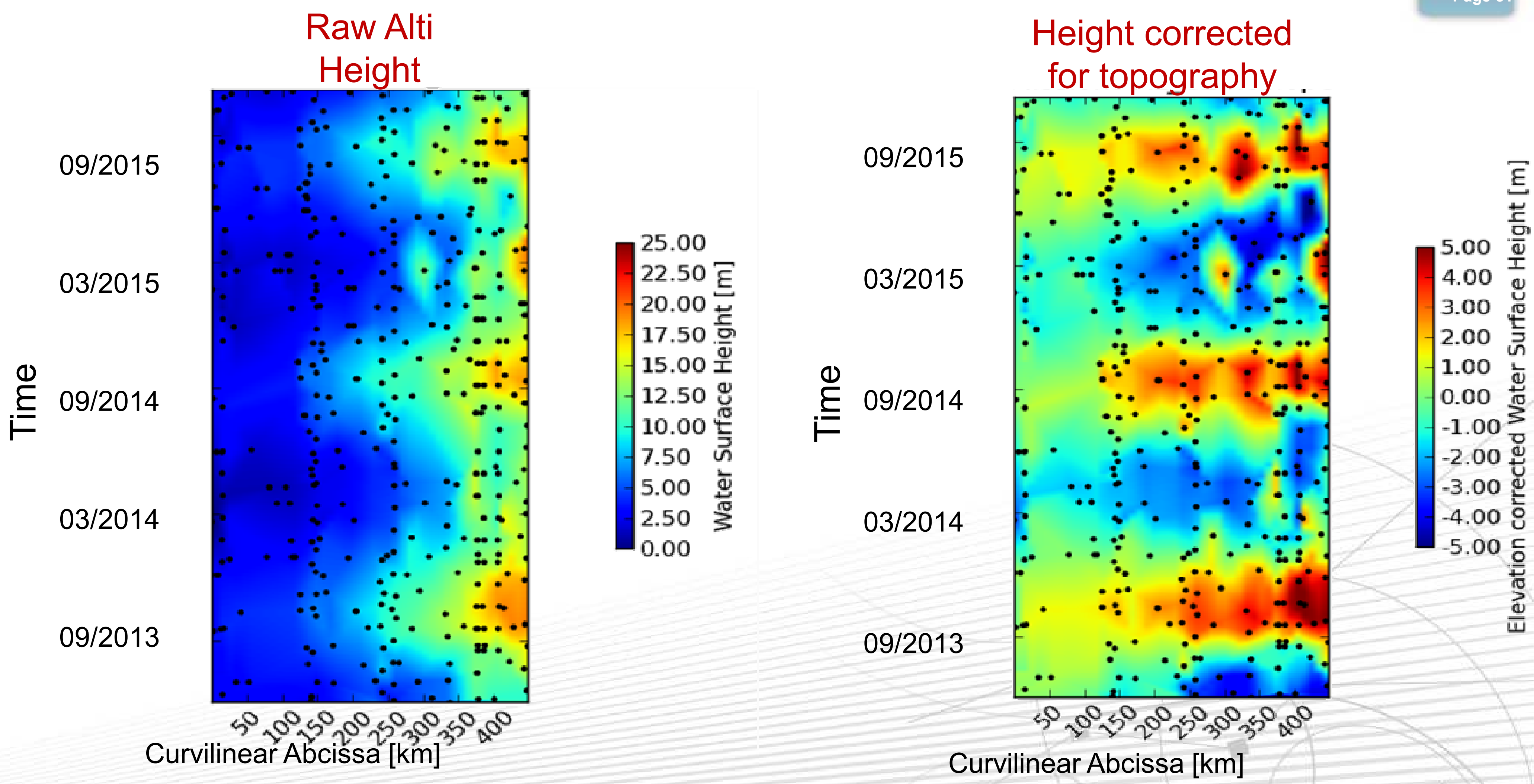




- ❑ The Hovmöller diagram can be derived using one or several mission measurements
- ❑ Jason-2, Jason-3, Sentinel-3 can be added
- ❑ HY-2 quality has to be checked even if we already know that its tracker is not optimal, over inland waters

➔ Potentially 6 missions

Multi-missions Hovmöller diagrams (raw and corrected for topography)



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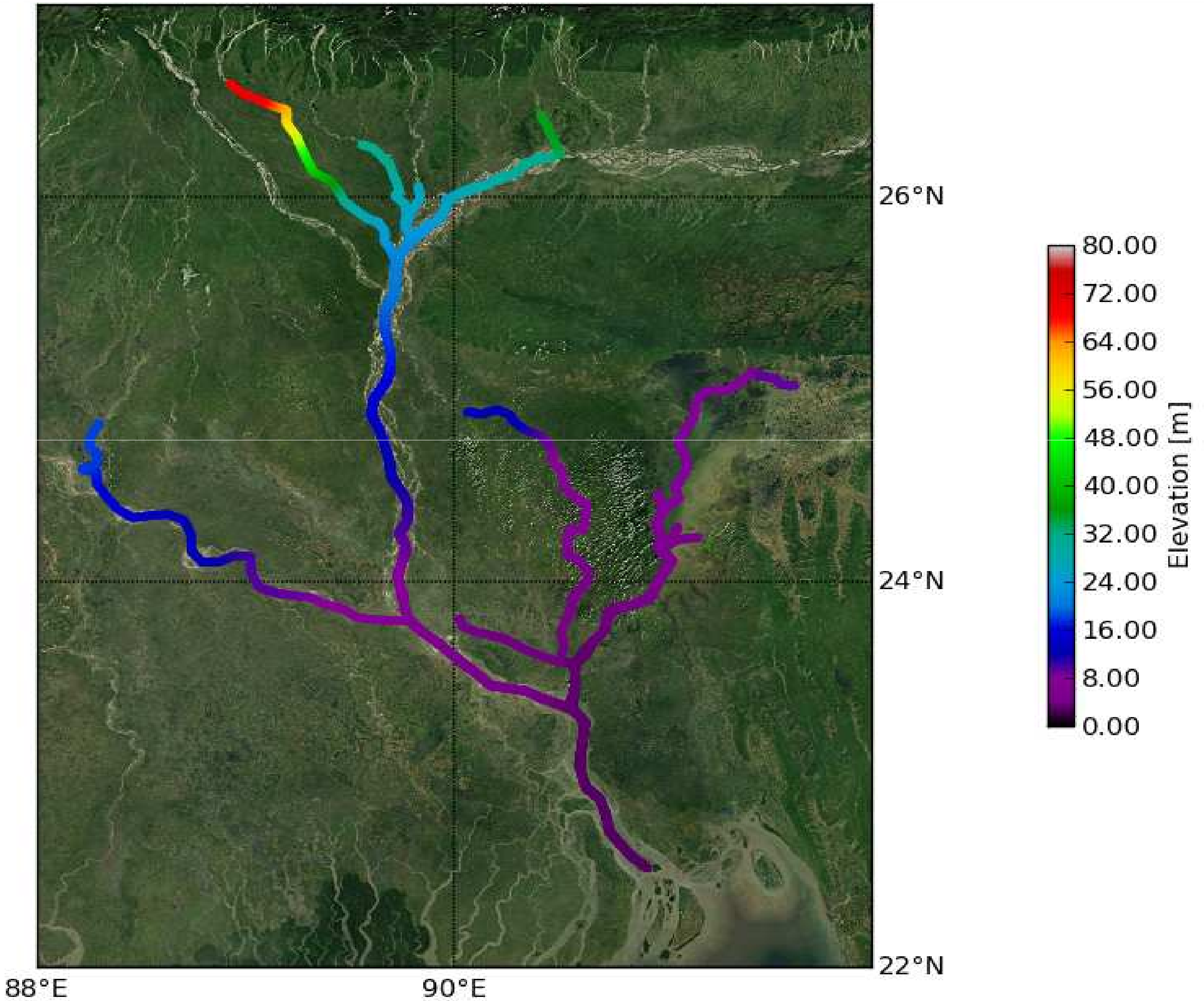
Map of elevations (from altimetry)

Brahmaputra River



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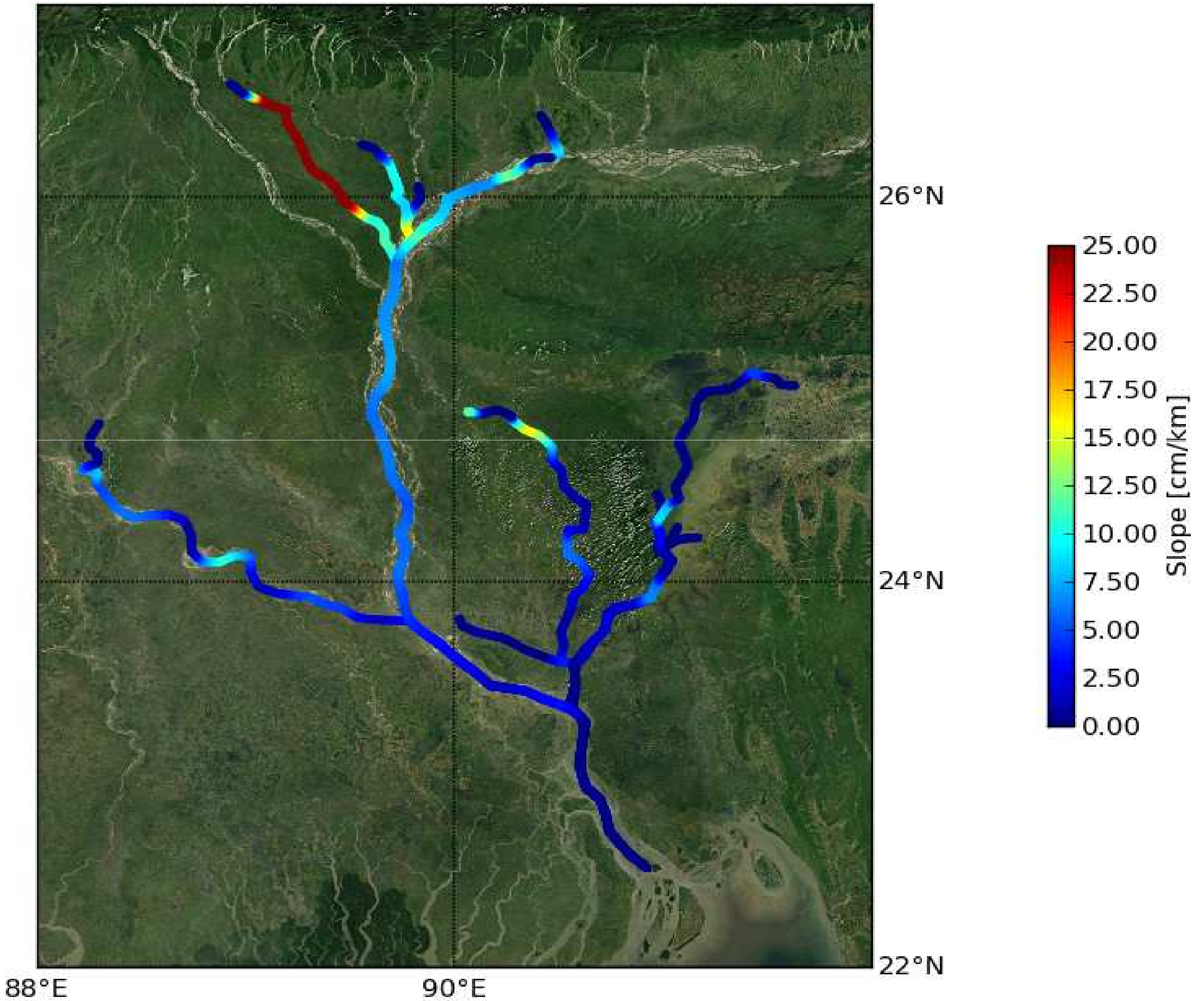
Map of slopes (from 0 to 25 cm/km)
(derived from altimetry measurements)

Brahmaputra River



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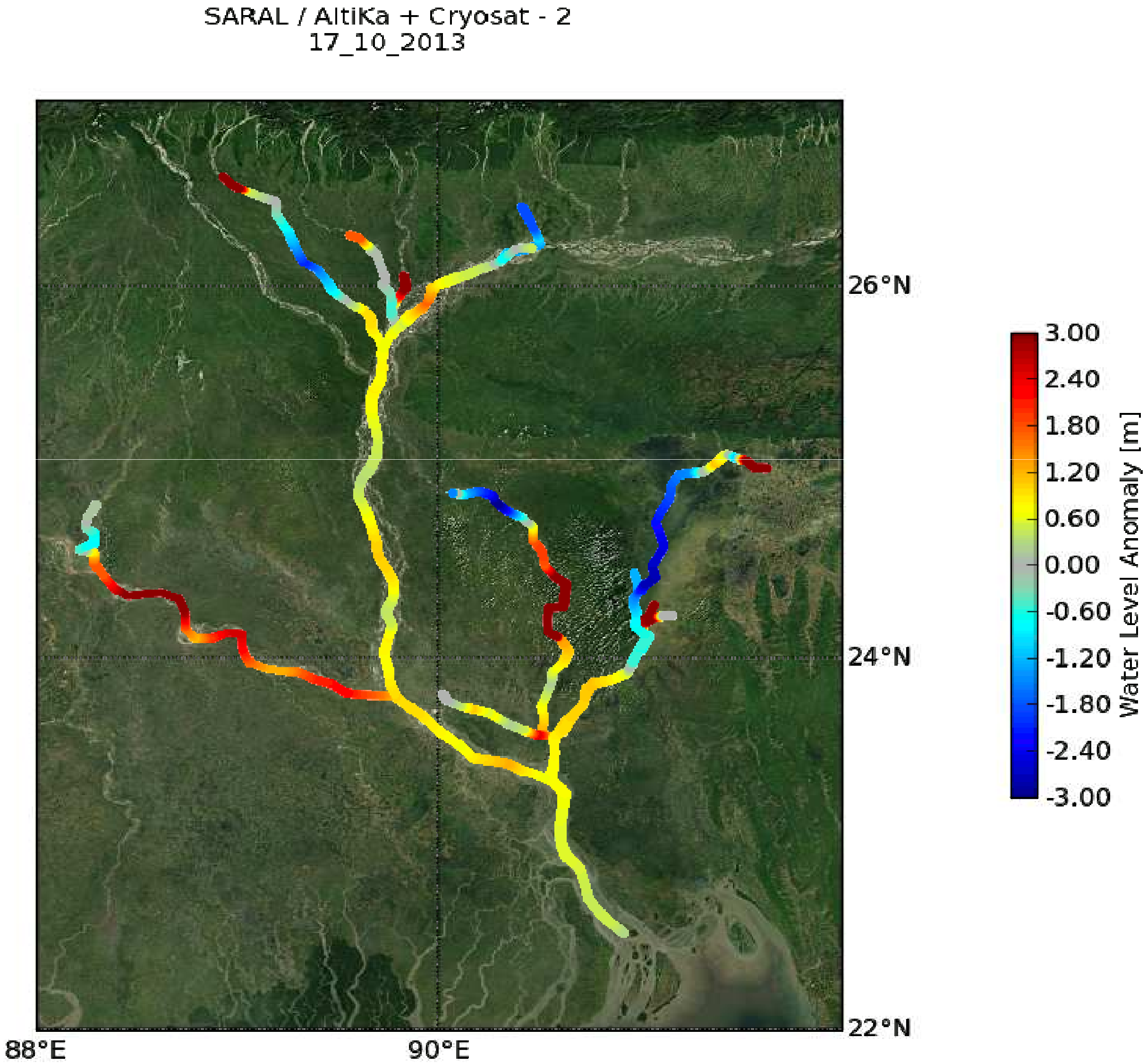
Evolution of the altimetry water level, topography removed (from Oct 2013 to Oct 2014)

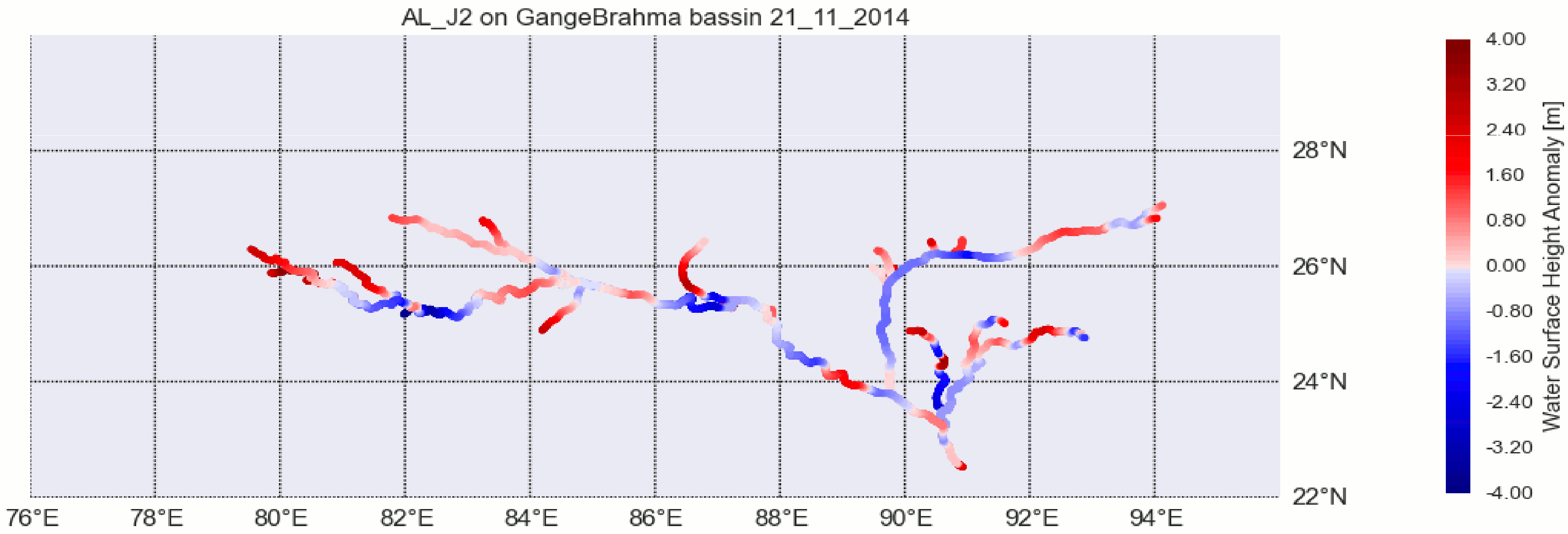
Brahmaputra River

Saral
+
Cryosat-2

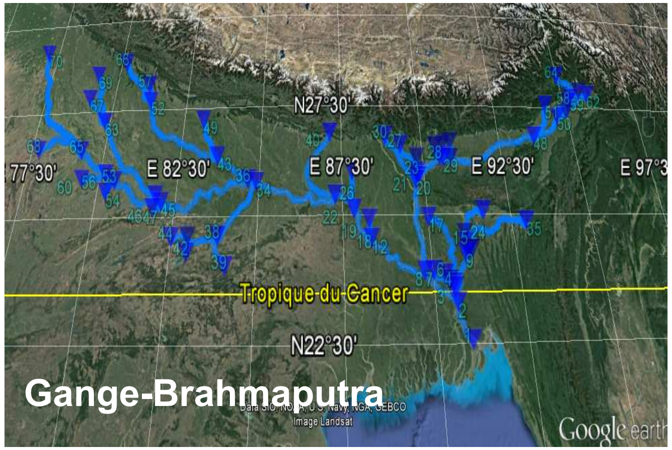


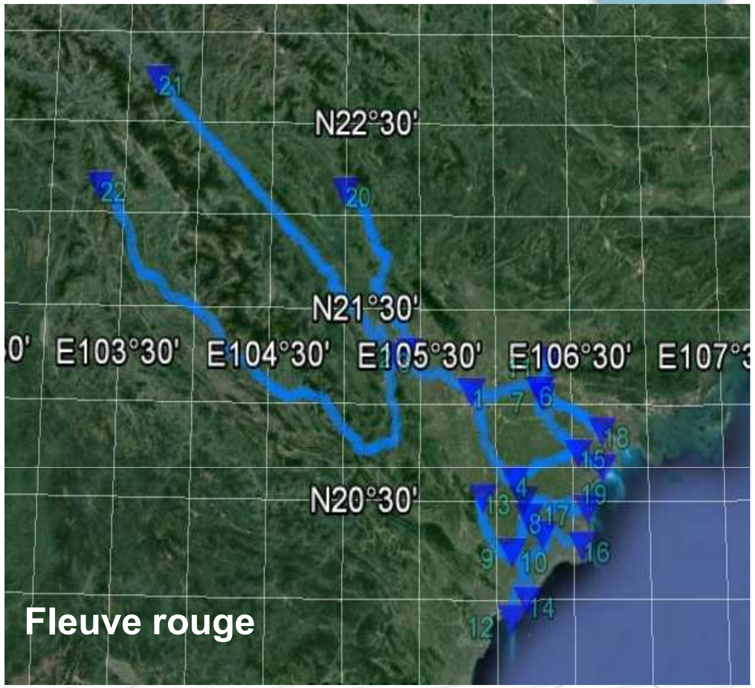
Evolution of the anomalies wrt mean hydrological cycle

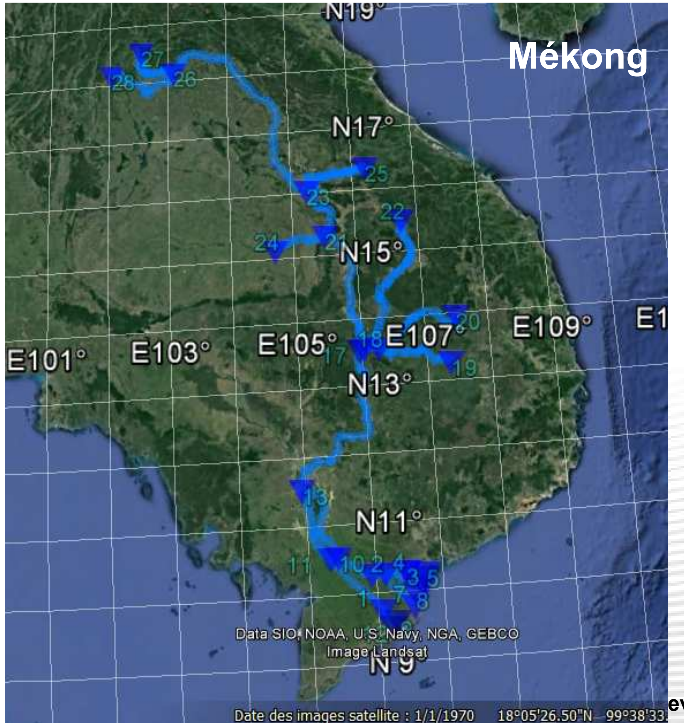
- Terrain elevation has been removed
- Hydrological cycle has been removed (using SVD filtering)

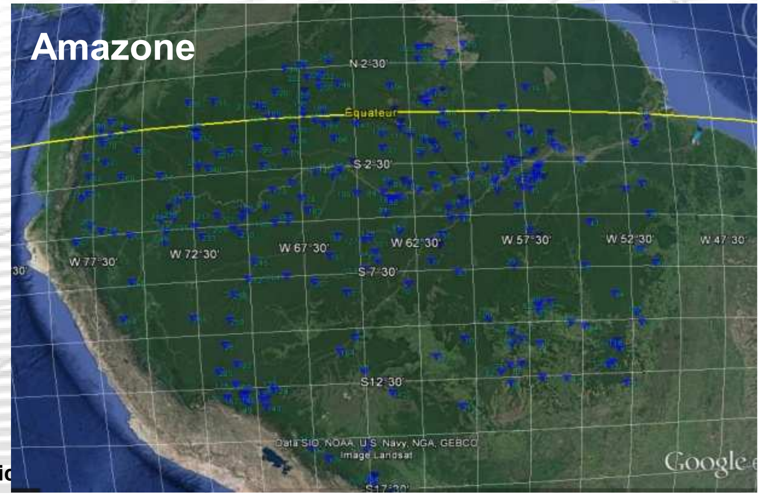


Other river basins



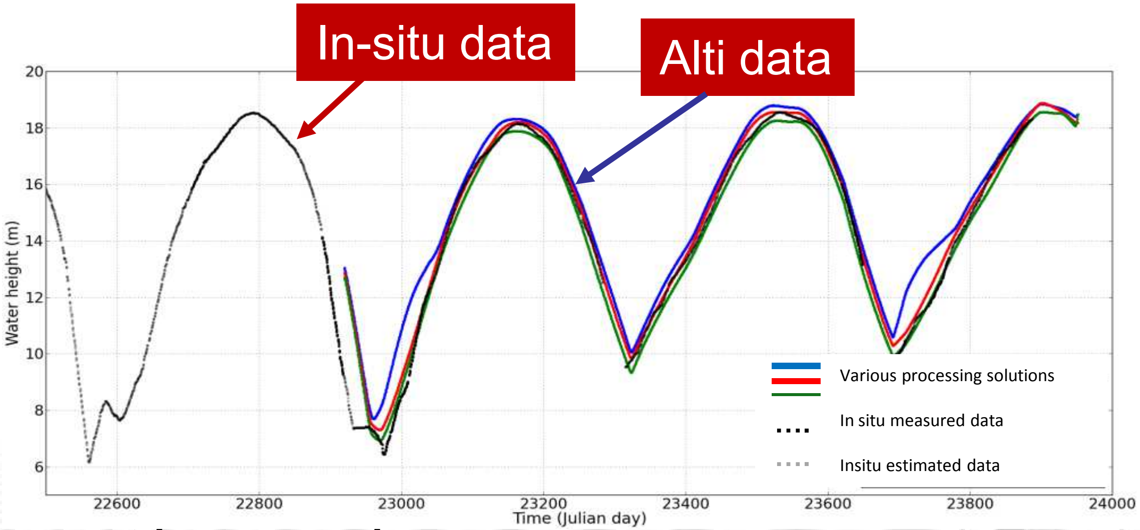






On-going work

- Integration of the new missions (S3 and J3) and HY-2 (?)
- Many points have still to be improved in particular heights close to the leaves of the river and arms which are not visited often; continuity between arms, …
- Validation wrt to in-situ measurements (at VS or between VS)



- Definition … n of the benefit of such products

Conclusions and Perspectives

- **LRM data set can be improved** considering
  - a physical solution for the retracker (we recommend the use of a physical numerical Adaptive Retracker)
  - reinforced editing strategies
- **SAR altimeter brings significant improvements on the water level precision (with dedicated L1/L2 processing)**
- **Products merging all altimeter measurements should/must (?) be considered**
- **Need to validate (wrt in situ) and need to assimilate multi mission products into models in order**
  - to analyze their quality
  - to improve the hydrological models and related forecasting

All these improvements or evolutions should be introduced in the future in the products delivered by the Copernicus Land Service

THAT YOU !!