# Validation of CryoSat-2 SAR and SARin modes over rivers for the SHAPE project

SHAPE — Sentinel-3 Hydrologic Altimetry Processor prototypE

Corresponding author: nbercher@along-track.com

Nicolas Bercher(1), Pierre Fabry(1), Mònica Roca(2), Bernat Martinez(2), Joana Fernandes(3), Clara Lázaro(3), David Gustafsson(4), Berit Arheimer(4), Américo Ambrózio(5), Marco Restano(6), Jérôme Benveniste(7).

(1) Along-Track - (2) IsardSAT UK - (3) Univ. Porto - (4) SMHI
(5) Deimos/ESRIN - (6) Serco/ESRIN - (7) ESA-ESRIN.

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## Overview of the Project & the SHAPE Processor

### Outline

The SHAPE project is funded by ESA through the Scientific Exploitation of Operational Missions Program Element to prepare for the exploitation of **Sentinel-3** data over the inland water domain (**water heights** and **discharge**).

### Objectives

- Characterise CryoSat-2 SAR data over inland water.
- Assess the performances, in Hydrology, of applying the Sentinel-3 IPF to CryoSat-2 data and emulating repeat-orbit Alti-Hydro Products (AHP).
- Analyse weaknesses of the Sentinel-3 IPF at all levels.
- Assess the benefits of assimilating the SAR/RDSAR derived AHP into hydrological models.
- Design innovative techniques to build and/or to refine the L1B-S and assess their impact onto L1B and AHP.
- Improve SAR/RDSAR retracking over river and lakes.
- Provide improved L2 Corrections (tropospheric, geoid) for Sentinel-3 over land and inland water.
- Specify, prototype, test and validate the Sentinel-3 Innovative SAR Processing Chain for Inland Water.

### The SHAPE Processor

The SHAPE Processor implements all of the steps necessary to derive rivers and lakes water levels and discharge from Delay-Doppler Altimetry and perform their validation against in situ data.

The processor uses FBR CryoSat-2 data as input (and will switch to Sentinel-3A data whenever possible) and various ancillary data (proc. param., water masks, L2 corrections, etc.), to produce surface water levels. When using CryoSat-2 data, a dedicated processing is implemented in order to migrate water level measurements along the river path in order to emulate the Sentinel-3A repeat track pattern. This technique is also used to migrate CryoSat-2 data in this poster to perform their validation.

At a later stage, water level data are assimilated into hydrological models to derive river discharge.

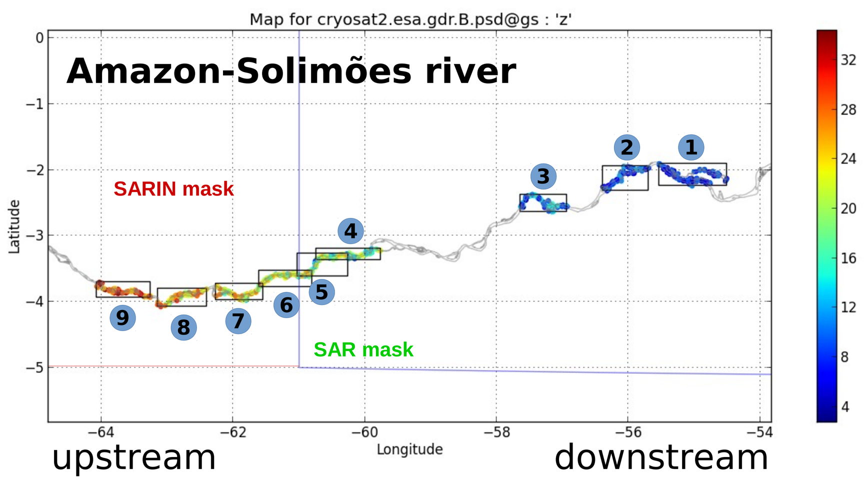
### Project Website

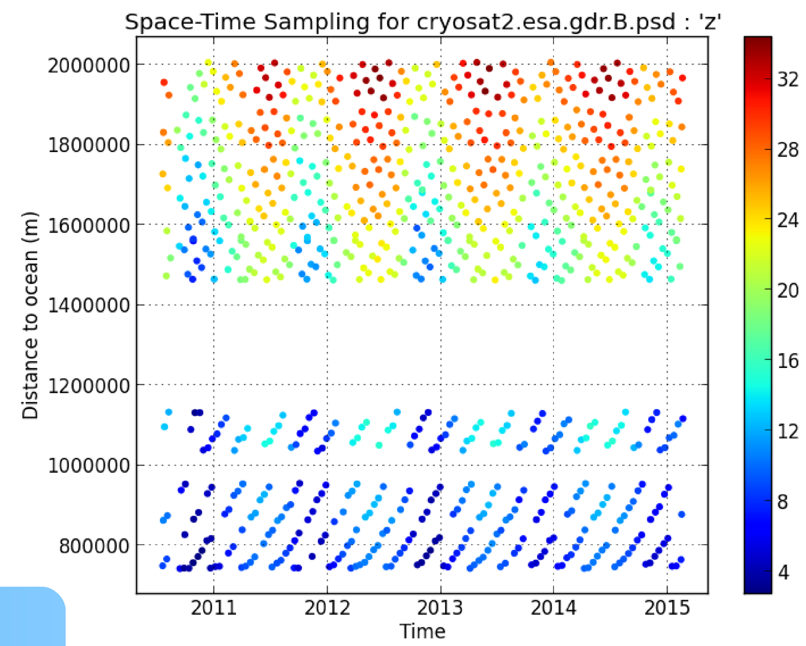
Documents & demo products to be available at **http://projects.along-track.com/shape/**

## Migration of CryoSat-2 measurements at arbitrary locations along river's path

### Map of the Virtual Stations

The CryoSat-2 measurements (dots) are extracted from within SRTM/SWBD water mask polygons (gray lines, which have been edited to isolate the Amazon-Solimões river). Because CryoSat-2 data are spread along the river, we group the them (boxes) using a treshold on curvlinear distances around the arbitrary locations we want to migrate them to.




### Natural CryoSat-2 meas. Sampling

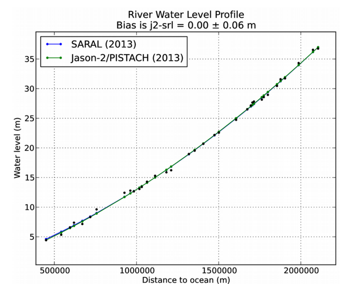
The geo-extraction of CryoSat-2 measurements results in a set of water level measurements **spread in space** (=river path) **and time**.

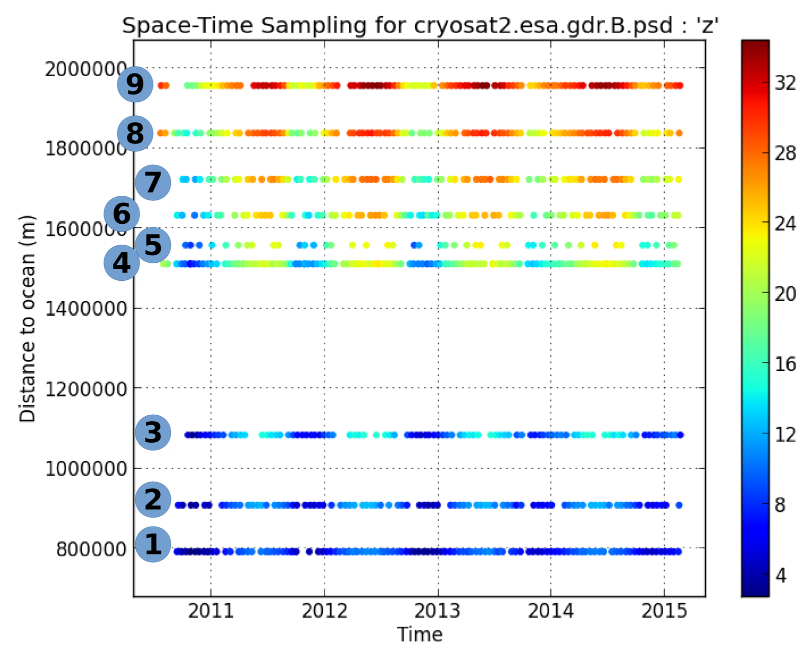
This is illustrated into the facing Hovmöller diagram in which we plotted the data corresponding to the geographical boxes from the above map.

### Migrated CryoSat-2 measurements

The migration of CryoSat-2 measurements is performed using an estimated **longitudinal profile of the river water level height** In the absence of other valuable source of information, this profile is derived from inter-calibrated, contemporary, LRM missions (namely Jason-2 from PISTACH and SARAL from AVISO).

Longitudinal profile of mean river height:



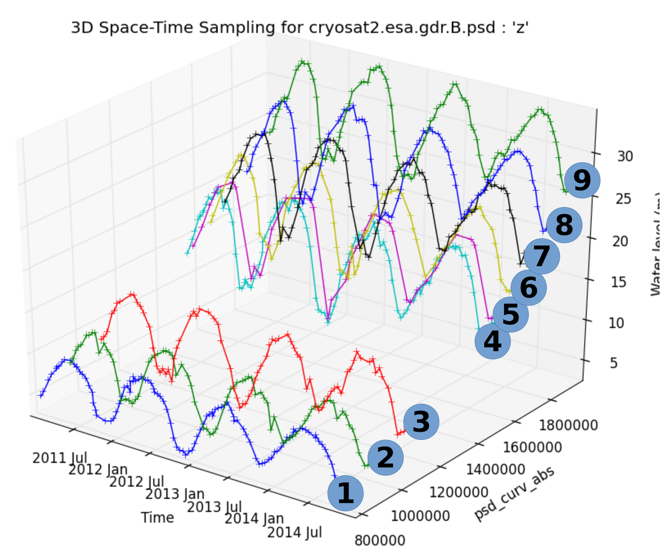




**Figure:** 3D plot of the CryoSat-2 time series at gauging station locations (for the sake of validation) after measurements have been migrated. SAR and SARIN data are mixed together.

## Alti-Hydro Processing & Validation Method

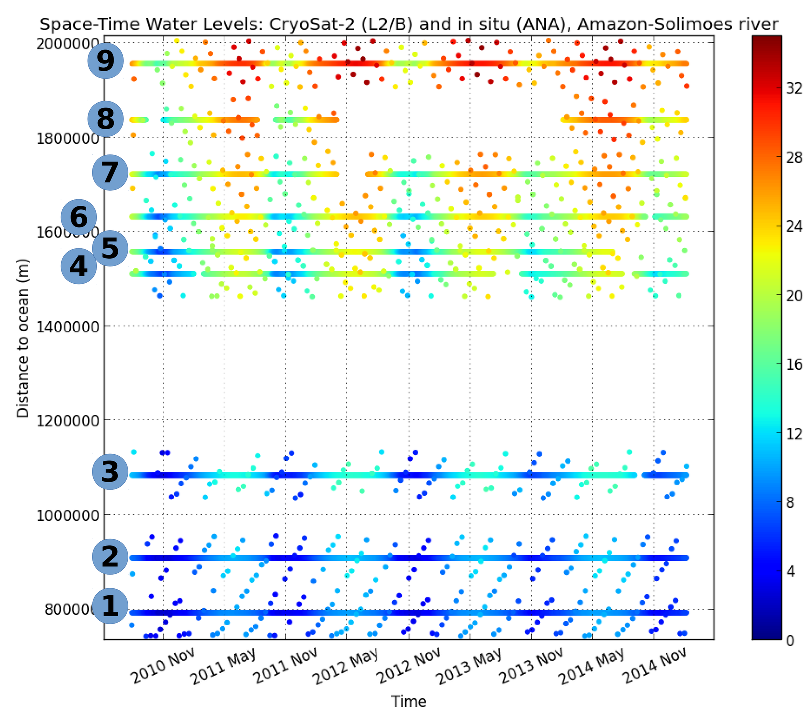
In this study, Alti-Hydro processing and the validation methods are entangled together due to the space-time nature of the CryoSat-2 data (spread along the river path) and the need for Altimetry water level time series derived from fixed locations.

### Alti-Hydro Processing

Generally speaking, this step consist in transforming level 2 measurements to time series or river water level (RWLTS) and is usually done onto time series from a single river crossing (or Virtual Station).

Then, a set of temporal filters are applied to the RWLTS in order to remove inconsistent measurements.

In the specific case of CryoSat-2, this step is done after the measurements migration, onto CryoSat-2 data in the shape of time series at arbitrary location.




### Validation Method

**Colocation:** For the sake of validation, we implemented the migration of CryoSat-2 measurements at the exact locations of in situ gauging stations.

**Codatation:** For each virtual station, both in situ and CryoSat-2 data are restricted to their overlapping time interval(s), taking care of missing data in both time series.

The figure above illustrates the result of all of these steps.

## Validation Results for CryoSat-2 ESA/L2/B products

The validation process has been **implemented for gauging stations along the Amazon river, located inside the CryoSat-2 SAR** (2012-2015) and **SARIN** (2010-2012) masks.

**Overall Mean results are** (mean(error)±STD(error)):

**SAR: 1.19±0.50 m** (best: 0.42±0.23 m ; RMS=0.48 m)

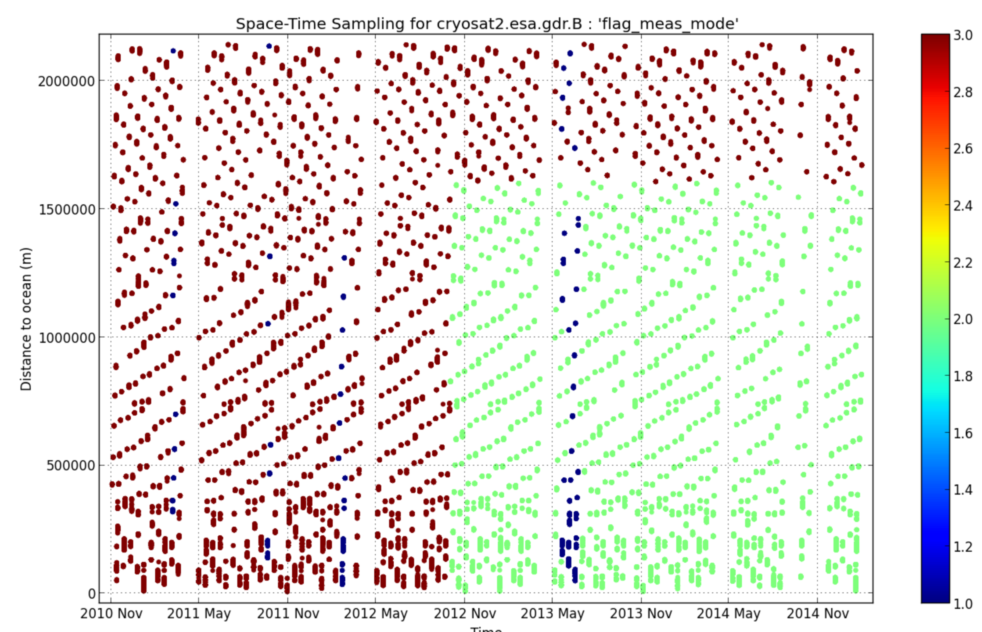
**SARIN: 1.50±0.52 m** (best: 0.77±0.36 m ; RMS=0.86 m)

SAR & SARIN mode **results are better than those of LRM altimetry**(*) despite the CryoSat-2 measurements have been migrated along the river path!

**SARM data are slightly more precise (STD) and are more accurate (Mean) than SARIN data**. This might be explained by errors coming from the computation of {lon, lat, surf_height} tuple which **depends on the accuracy of the platform attitude & the SARIN interferometric angles**. Also, we note that SARM precision values are strictly increasing w.r.t. to distance to ocean.

*(*Overall error STD for PISTACH/Jason-2 data for a similar area was 0.64 m.)*

| Period | | Gauging Station | Virtual Station dist. (km) | Mode | Nb meas. | RMS (m) | Mean (m) | STD (m) | MAD (m) | Teff (days) |
|---|---|---|---|---|---|---|---|---|---|---|
| 2012 – 2015 / 2010 – 2012 | 1 | Santarem | 793 | SAR | 61 | 0.48 | 0.42 | 0.23 | 0.17 | 13.9 |
| | | | | SARIN | 56 | 0.86 | 0.77 | 0.36 | 0.24 | 13.9 |
| | 2 | Obidos | 909 | SAR | 45 | 1.19 | 1.09 | 0.49 | 0.18 | 17.7 |
| | | | | SARIN | 41 | 1.41 | 1.31 | 0.52 | 0.22 | 19 |
| | 3 | Parintins | 1084 | SAR | 48 | 1.04 | 0.91 | 0.50 | 0.19 | 17.7 |
| | | | | SARIN | 38 | 1.24 | 1.15 | 0.46 | 0.20 | 20.5 |
| | 4 | Jatuarana | 1512 | SAR | 53 | 1.49 | 1.38 | 0.57 | 0.24 | 15.8 |
| | | | | SARIN | 57 | 1.71 | 1.59 | 0.63 | 0.24 | 13.7 |
| | 5 | Manaus | 1558 | SAR | 34 | 2.06 | 1.98 | 0.57 | 0.18 | 17.9 |
| | | | | SARIN | 49 | 2.27 | 2.20 | 0.55 | 0.25 | 24.6 |
| | 6 | Manacapuru | 1633 | SAR | 13 | 1.51 | 1.37 | 0.63 | 0.11 | 63.2 |
| | | | | SARIN | 89 | 2.07 | 1.97 | 0.61 | 0.18 | 18 |
| 2010 – 2015 | 7 | Anama | 1723 | SARIN | 84 | 2.23 | 2.19 | 0.44 | 0.25 | 19.6 |
| | 8 | Codajas | 1838 | SARIN | 50 | 2.09 | 2.06 | 0.34 | 0.14 | 32.5 |
| | 9 | Itapeua | 1957 | SARIN | 103 | 2.44 | 2.42 | 0.36 | 0.21 | 15.9 |




Map of the CryoSat-2 measurement modes as a Hovmöller diagram: **LRM=blue**, **SAR=green**, **SARIN=red**. Note: Despite the masks are theoretically pure SAR and/or SARIN masks, a few LRM measurements existed during year 2013.

It is worth noting that **systematic bias errors for both modes are partly imputable to the lack of high accuracy spirit leveling** in the Amazon basin gauging stations data. However they've been compensated for, thanks to leveling data from Kosuth et al. (2006).

Teff is the mean sampling period of the time series obtained at each gauging station.

***Errata:*** *This poster corrects the values presented during LPS2016 (talk on similar work) which where highly wrong due to a series of bugs in the implementation of the validation tools.*

## Conclusions

### Conclusion

- A technique has been implemented to **migrate CryoSat-2 measurements along the Amazon river**, at gauging station locations (cf. [Bercher.2012b] at http://chronos.along-track.com/, 2012-09-23).
- A **validation method has been defined & implemented for geodetic orbit data** (while for repeat orbit, another method has been introduced (Bercher, 2008 PhD) and implemented (Bercher et al., 2010,. 2012)).
- **SAR and SARIN data are of better precision than LRM** over the same area: **STD around 50 cm** against 64 cm for LRM.
- Considering the validation results, **the migration technique seems to have a limited impact** on precision & accuracy.
- CryoSat-2 data have been migrated onto **SMHI Amazon-Hype hydrologic model outlets and will be assimilated to derive discharge data** (cf. Gustafsson2016b
- 2016 Project's poster, available from the SHAPE web site).

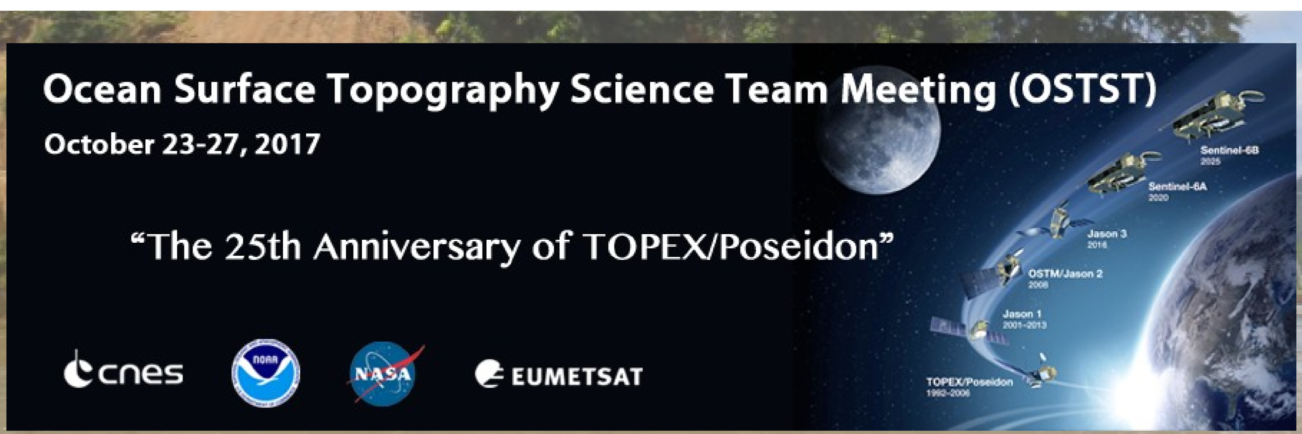
### What's to come?

- In this poster, the validation methodology is illustrated for ESA data, but CryoSat-2 data reprocessed for the project are already available from partner **isardSAT** and will be used really soon.
- L2 atmospheric corrections from **University of Porto** will be produced and integrated into SHAPE L2 altimetry products.

## Acknowledgments

**The SHAPE project is founded by ESA**

**Altimetry data:** CryoSat-2 data are L2/Baseline B from ESA ; Jason-2 data are PISTACH/Hydro from CLS ; SARAL data are IGDR from AVISO. **Ancillary data:** In situ data from ANA (Brazil) ; in situ gauge stations leveling from Kosuth et al. (2006) ; Water mask are SWBD ShapeFiles from SRTM ; River path and longitudinal profiles are Along-Track products ; Geoid heights are computed from GOCE grids from GRGS & GFZ.

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