

# Improving SAR Altimeter processing over inland water - the ESA



P. D. Cotton<sup>1</sup>, A Garcia-Mondejar<sup>2</sup>, C. Gommenginger<sup>3</sup>, O Andersen<sup>4</sup>, L. Fenoglio-Marc<sup>5</sup>, M. Scagliola<sup>6</sup>, M. Cancel<sup>7</sup>, M. Passaro<sup>8</sup>, P. Fabry<sup>9</sup>, N Bercher<sup>10</sup>, A Tarpanelli<sup>11</sup>, S Vignudelli<sup>12</sup>, F de Biasio<sup>13</sup>, P Bauer-Gottwein<sup>14</sup>, M.J. Fernandes<sup>15</sup>, C. Lázaro<sup>15</sup>, T. Vieira<sup>15</sup>, C. Slobbe<sup>16</sup>, J Gomez-Enri<sup>17</sup>, E Zakharova<sup>18</sup>, A. Shaw<sup>19</sup>, M. Restano<sup>20</sup>, A. Ambrózio<sup>21</sup>, J. Benveniste<sup>22</sup>

(1) SatOC, (2) isardSAT, (3) National Oceanography Centre, (4) DTU Space, (5) University of Bonn, (6) Aresys, (7) Noveltis, (8) TU Munich, (9) Along-Track, (10) AltiHydroLab, (11) CNR-IRPI, (12) CNR-IBF, (13) CNR-ISP, (14) DTU-Environment, (15) University of Porto, (16) TU Delft, (17) U Cadiz, (18) NUIM, (19) SKYMAT, (20) SERCO/ESA, (21) DEIMOS/ESA, (22) ESA-ESRIN



## The HYDROCOASTAL Project

HYDROCOASTAL is funded by the ESA Science for Society Programme, and is planned to run from Feb 2020 – April 2023, in 4 phases:

- Scientific Review & Requirements Consolidation** (Feb-July 2020)
  - State of the art review of SAR and SARin altimeter data processing for coastal zone and inland waters.
- Implementation and Validation** (July 2020 – May 2022)
  - Implement new SAR, SARin altimeter processing algorithms to generate a test data set
  - Evaluate performance of the candidate algorithms
  - Generate “global” coastal zone and river discharge data sets
- Impact Assessment** (June 2022 – December 2022)
  - Assessments of the global output products through a series of case studies
- Outreach and Road Map** (ends April 2023)

## Context

The junction between the coastal zone and inland waters is a boundary between

- Different science domains (hydrology, oceanography).
- Different satellite measurement regimes.
- Regions of high variability in small scales.

HYDROCOASTAL aims to enhance understanding of:

- interactions at this boundary,
- the small-scale processes that govern these interactions,
- exchanges with the ocean and the impact on regional sea-level changes.

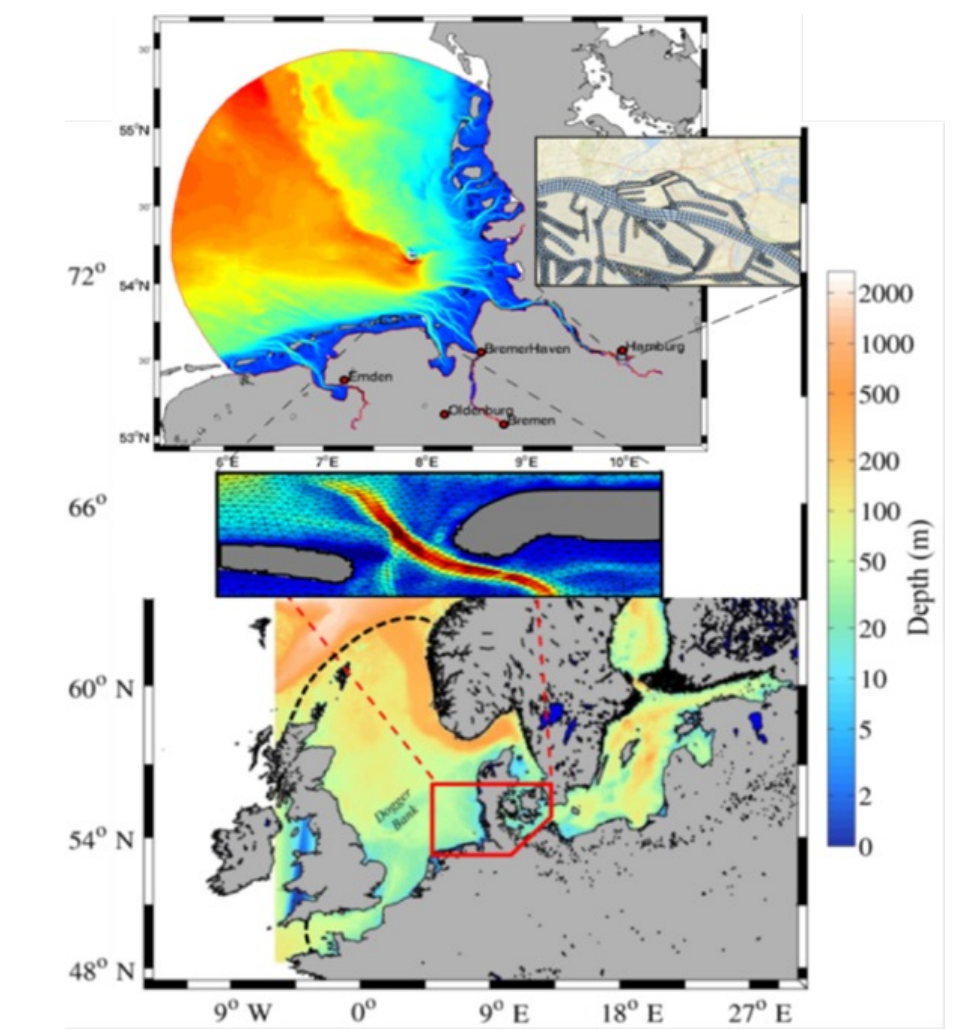


Image courtesy of U Bonn: German Coast of the North Sea and the Elbe Estuary

## HYDROCOASTAL SAR Altimeter Test Data Set

The first test data set was produced to evaluate new L2 processing algorithms over the coastal zone and inland waters, and also processing to L3 (river/lake level time series) and L4 (river discharge)

We have selected 18 Regions of Interest to cover a wide range of inland water and coastal zone characteristics, on all continents (except Antarctica). The data set includes 2 years data: 2018-2019

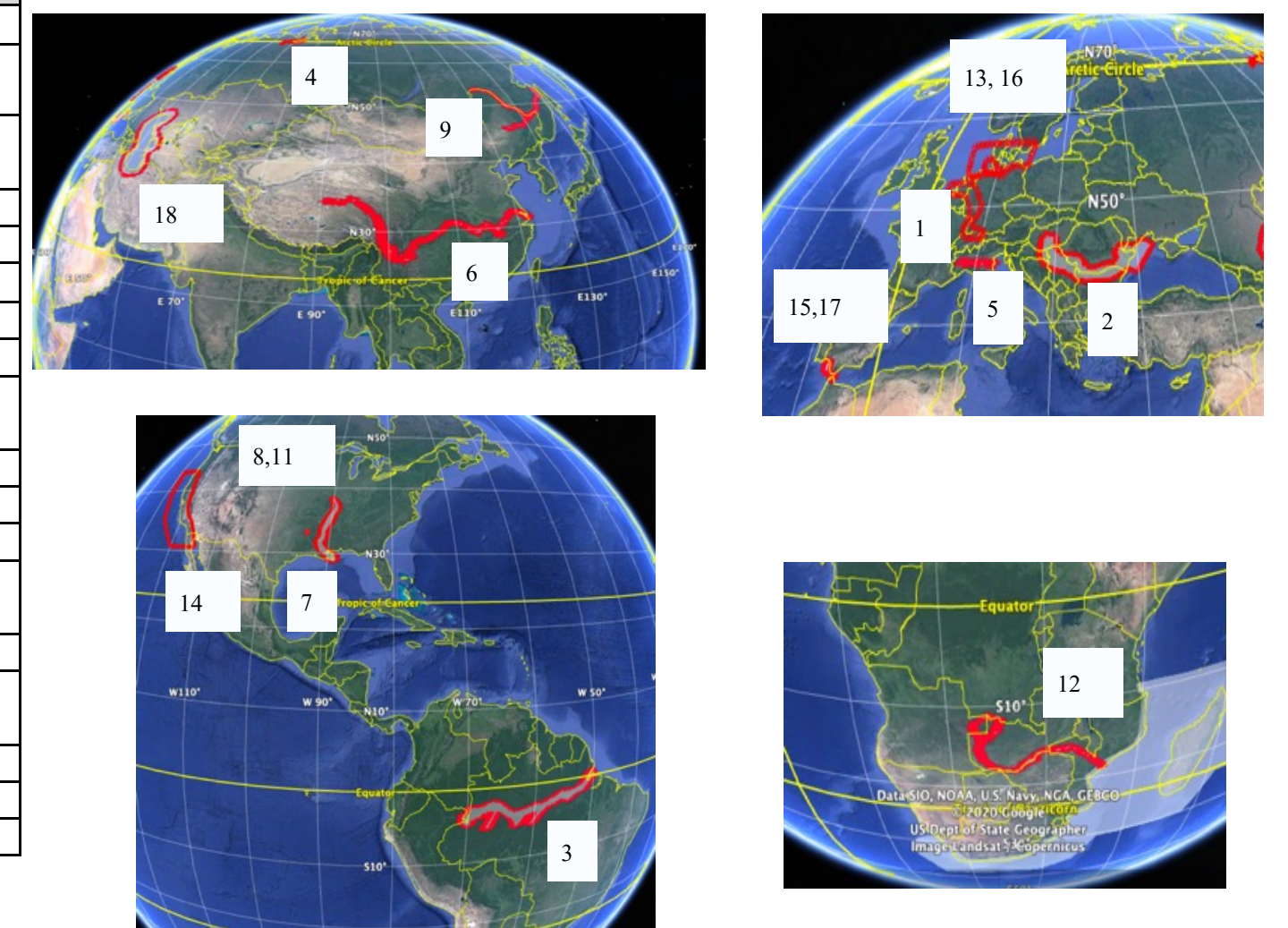
Input data products are CryoSat FBR baseline D SAR and SARin mode data, and Sentinel 3A and 3B SIRAL L1A data

Also enhanced Wet and Dry Troposphere Corrections have been produced by U Porto, and coastal tidal models assessed by Noveltis.

Documented descriptions of processing schemes and products available at [www.satoc.eu/projects/hydrocoastal](http://www.satoc.eu/projects/hydrocoastal)

### First Test Data Set Regions of Interest

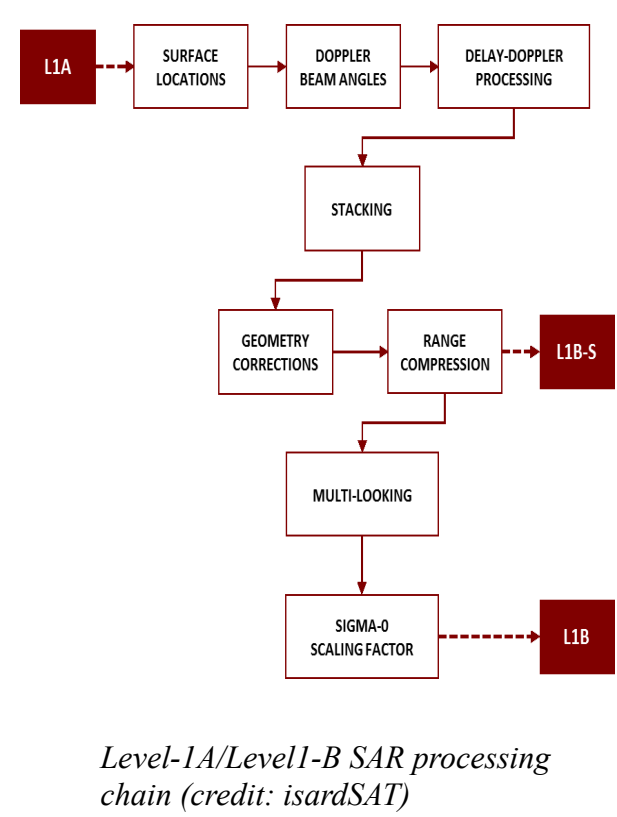
Region	Name	Country	Target Type
TDS1-01	River Rhine	Germany	River
TDS1-02	River Danube	Hungary, Serbia, Romania, Bulgaria	River
TDS1-03	River Amazon – Solimões	Brazil	River
TDS1-04	River Ob	Russia	River
TDS1-05	River Po	Italy	River
TDS1-06	River Yangtze	China	River, estuary
TDS1-07	River Mississippi	USA	River
TDS1-08	Nonacho Lake	Canada	Lake
TDS1-09	River Amur/Songhua	China, Mongolia, Russia	River, wetland, estuary
TDS1-10	Ionian / Aegean	Greece	Coastal / SARin
TDS1-11	Reindeer Lake,	Canada	Lake
TDS1-12	Zambezi River	Zambia, Mozambique	River
TDS1-13	German Bight, Baltic Coast	Germany	Coastal
TDS1-14	California Coast	USA	Coastal
TDS1-15	Huelva and Bonanza	Spain	Coastal, Estuary
TDS1-16	Elbe Estuary	Germany	Estuary
TDS1-17	Tarifa	Spain	Coastal
TDS1-18	Caspian Sea	Russia	Inland Sea



## Processing to L1B\*

isardSAT have generated Level 1B-S and Level 1B products as input to processing to L2.

- L1B-S: fully SAR-processed and calibrated SAR complex echoes arranged in stacks after slant range correction and before multi-looking.
- L1B : Geo-located and fully calibrated multi-looked SAR power echoes



Level-1A/Level-1-B SAR processing chain (credit: isardSAT)

## Candidate L2\*Algorithms

Six candidate L2 processing algorithms are implemented. Their performance is being evaluated, and based on this, algorithms will be selected to generate global coastal zone and inland water products.

- Two Step Analytical Processor – coastal and inland: isardSAT**
- Specialised SARin – coastal: Aresys**
- MWaPP – Multiple Waveform Persistent Peak – inland: DTU Space**
- ICC-ER (Isolate, Cleanse, Classify - Empirical Retracker) – inland: ATK**
- Statistical Re-tracker STARS type – coastal: U Bonn**
- ALES+ for SAR – coastal and inland: TU Munich**

## Inland Water L3\*, L4\* Products

The L2 inland water data are being further processed to generate L3 and L4 data products:

- L3 Water Level Time Series**
  - L3 products provided by AltiHydroLab.fr (AHL) and DTU Space
  - Include river level virtual station products and lake products
  - Products are on a river basin basis
- L4 River Discharge**
  - L4 products are provided by NUIM and CNR-IRPI, initially for the Rhine, Ob, Po, and Mississippi.
  - Both altimetry and near infrared (NIR) imagery is applied to derive discharge

## Validation Results

Validation was carried out across 11 river basins, in North and South America, Europe, Asia and Africa.

When comparing time series data against river gauge data, median root mean square errors across all stations and re-trackers were 33-34cm. The DTU re-tracker was found to be the best performing (lowest rmse) when looking across all data sets, although there were some locations with complex geomorphology, or during ice melt, where the DTU retracker did not provide good results.

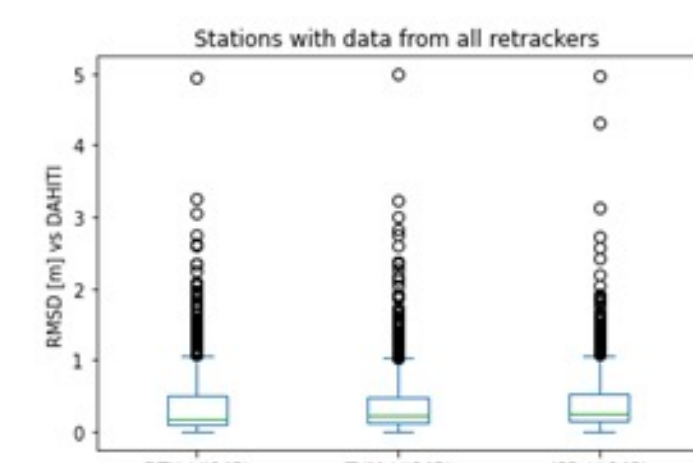
An ideal approach could be to categorise different types of river / lake environment and apply different re-trackers that were optimised to these environments.

**The validation team recommended selection of the DTU re-tracker for inland water processing in the next stage of the HYDROCOASTAL project**

## DGFI Analysis – DAHITI data base

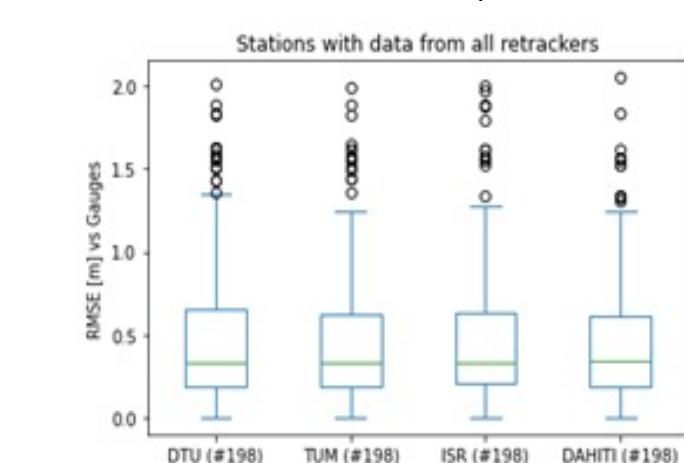
DGFI / TUM compared water level times series from the different retracker to virtual station and in situ data from DAHITI

Validation against DAHITI virtual stations with common data (845 stations)



Median RMSE  
• DTU 0.17m ±0.04  
• TUM 0.20m ±0.03  
• ISR 0.22m ±0.03

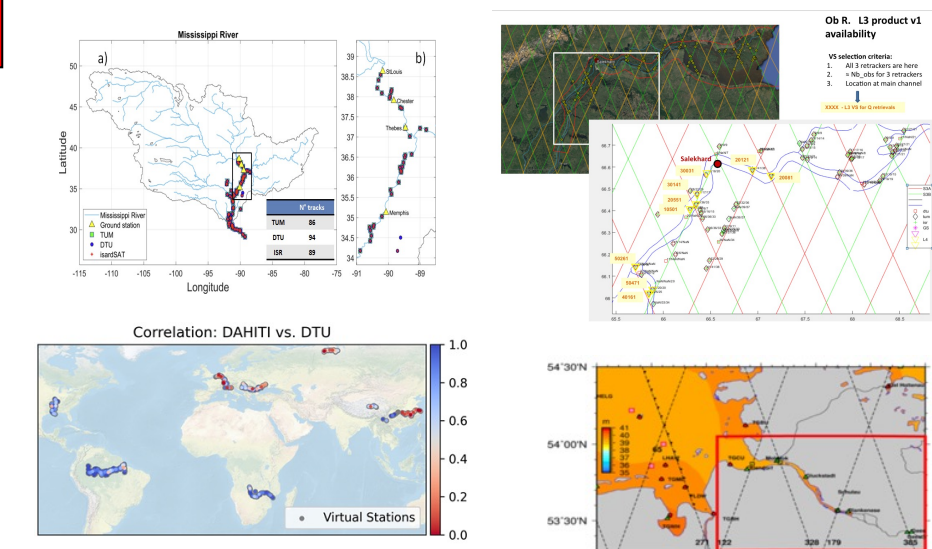
Validation against DAHITI in situ gauges with common data (198 stations)



Median RMSE  
• DTU 0.33m ±0.04  
• TUM 0.34m ±0.03  
• ISR 0.33m ±0.03

## 1st Data Set Inland Water Validation

The performance of the isardSAT, DTU and TU Munich processors over inland water regions has been evaluated through detailed studies and with a set of agreed metrics, as described in the *Product Validation Report*



**Inland Water – L2**  
Rhine and Elbe (U Bonn)  
Water Level Time Series from DAHITI data base – 1031 virtual stations in 8 river basins (DGFI/TUM)  
Amur, Yangtze, and Zambezi (DTU)

**Inland Water – L3, L4**  
Rivers Ob and Rhine (NUIM, U Bonn)  
Rivers Po and Mississippi (CNR-IRPI)

## HYDROCOASTAL Final Product

From the evaluation of the first test data set, algorithms will be selected to generate a “global” coastal and river data set.

The global data set will comprise:

- Global L2 data sets for coastal zone and inland water
- Global L3 data sets (time series) for selected “large to medium” rivers
- Global L4 data sets (river discharge) for selected “large to medium” rivers
- Experimental data set for “small rivers and tributaries”

This “global” product will be made freely available.

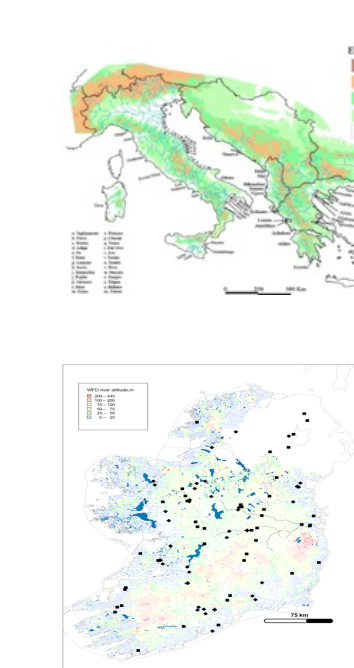
## Final Product Coverage

The final coverage of the output data set is to be finalised. The table opposite includes all areas required by the project impact assessment studies.

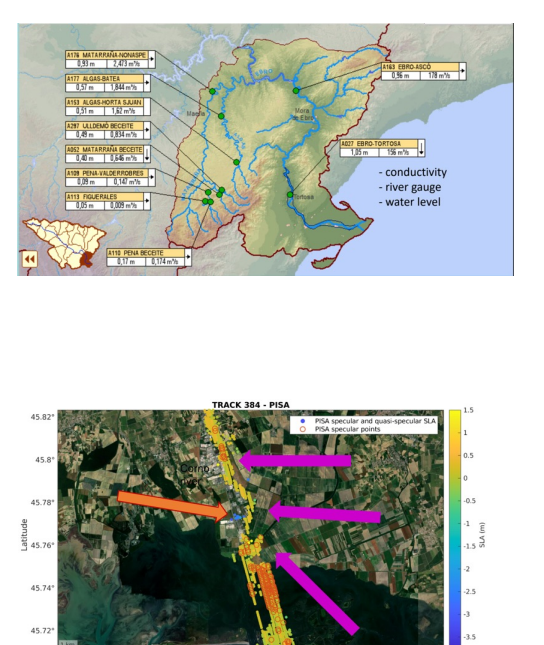
If external users would like to propose other areas for their own study, then please contact the project manager: [d.cotton@satoc.eu](mailto:d.cotton@satoc.eu)

Target name	Country	Target type
Venice Lagoon	Italy	Coastal
Po	Italy	River
Ireland lakes	Ireland	Lakes
Yakutian alasses	Russia	Lakes
Kolyma R	Russia	River
Nadym R	Russia	River
Songhua/Amur	China/Russia	River/Estuary
Mackenzie	Canada	River
Amour	Russian part	River
Ebro Basin	Spain	River/Lakes/Coastal
Southern Baltic Sea	Germany	Coastal
German Bight	Germany	Coastal
Wadden Sea	Germany	Coastal/Estuary
River Rhine	Germany	River
Amazon basin	Brazil	River
British Channel / Severn Estuary	UK	Coastal
Gulf of Thailand / Andaman Sea	Thailand	Coastal
Alps	Italy/Switzerland	River/Lakes

## Coastal / Inland Water Studies



Impact assessment studies of inland water cover a range of aspects, from basin scale water level climatologies (AHL), to catchment modelling to more localised studies for the Ebro, Po and Rhine



## HYDROCOASTAL Outcomes

The outcomes of HYDROCOASTAL will include:

- State of the Art Review** on SAR Radar Altimetry.
- First SAR / SARin satellite altimeter L2, L3 and L4 Test data set** over 18 Regions of Interest.
- Descriptions of **processing algorithms and products**.
- Global Output Products:**
  - Global L2 coastal & inland water SAR altimeter data set.
  - Time series (L3) and river discharge (L4) data sets for medium to large rivers
- Scientific Road Map** for further developments, implementations and research for SAR altimetry

### \* Data Levels

Summary of data levels for HYDROCOASTAL products

- Level 0 – raw telemetered data
- Level 1B – L0 data corrected for instrumental and geometric effects. Includes range, scaling factors and multi-looked waveforms
- Level 2 – “Re-tracked” data. Includes geolocated, geophysical parameters
- Level 3 – River level time series data at points
- Level 4 – River Discharge time series

Interested? Please contact us to access the data and discuss possible applications and case studies  
[www.satoc.eu/projects/hydrocoastal](http://www.satoc.eu/projects/hydrocoastal) - <https://eo4society.esa.int/projects/hydrocoastal>