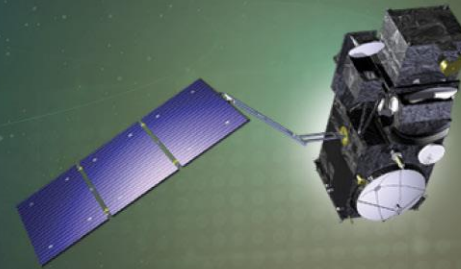




PROGRAMME OF THE  
EUROPEAN UNION



co-funded with



# 7<sup>th</sup> Sentinel-3 Validation Team Meeting 2022

18-20 October 2022 | ESA-ESRIN | Frascati (Rm), Italy

## Evaluating new SAR Altimeter processing algorithms over the coastal zone and inland waters

### David Cotton and the HYDROCOASTAL Project Team

*SatOC, UK*

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## The HYDROCOASTAL Project

- HYDROCOASTAL is funded under the ESA Science for Society Programme Element.
- The aim is to maximise exploitation of SAR and SARin altimeter measurements in the coastal zone and inland waters, by evaluating and implementing new approaches to process SAR and SARin data from CryoSat-2, and SAR altimeter data from Sentinel-3A and Sentinel-3B.
- New SAR and SARin processing algorithms for the coastal zone and inland waters have been developed and tested, and a processing scheme is being implemented to generate global coastal zone and river discharge data sets.
- Case studies will assess these products in terms of their scientific impacts

15 partners:

SatOC (prime), isardSAT, National Oceanography Centre (UK), DTU Space, the University of Bonn, Aresys, Noveltis, DTU Environment, the Technical University of Munich, the University of Cadiz, Along-Track (with AltiHydro Lab), Consiglio Nazionale (ISP, IRPI and IBF), National University of Ireland – Maynooth, and the University of Porto and the Technical University of Delft





## HYDROCOASTAL Overview

### 1. Scientific Review and Requirements Consolidation (Completed 2021)

Review the current state of the art in SAR and SARin altimeter data processing as applied to the coastal zone and to inland waters.

### 2. Implementation and Validation (July 2020 – July 2022)

Implement new SAR, SARin altimeter processing algorithms to generate 2-year test data set.

Evaluate performance of the candidate algorithms.

Selected algorithms used to generate “global” coastal zone and inland water final products

### 3. Impact Assessment (October – December 2022)

The impact of global products assessed through a series of case studies

### 4. Outreach and Road Map (April 2023)

Recommendations for further R&D and implementation in current and future SAR altimeter missions



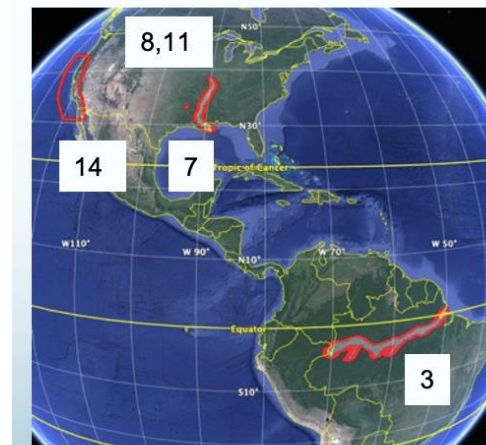
## 1<sup>st</sup> HYDROCOASTAL Test Data Set

- 18 Regions of Interest to cover a wide range of inland water and coastal zone characteristics.
- 2 years data 2018-2019, 3 years for regions with river discharge estimates
- Inputs
  - CryoSat FBR baseline D SAR and SARin mode data.
  - Sentinel 3A and 3B SIRAL L1A data
- Enhanced Wet and Dry Troposphere Corrections (U Porto)
- Documented descriptions of processing schemes and products at [www.satoc.eu/projects/hydrocoastal](http://www.satoc.eu/projects/hydrocoastal)
- Available on request by email to [info@satoc.eu](mailto:info@satoc.eu)



## 1<sup>st</sup> HYDROCOASTAL Test Data Set

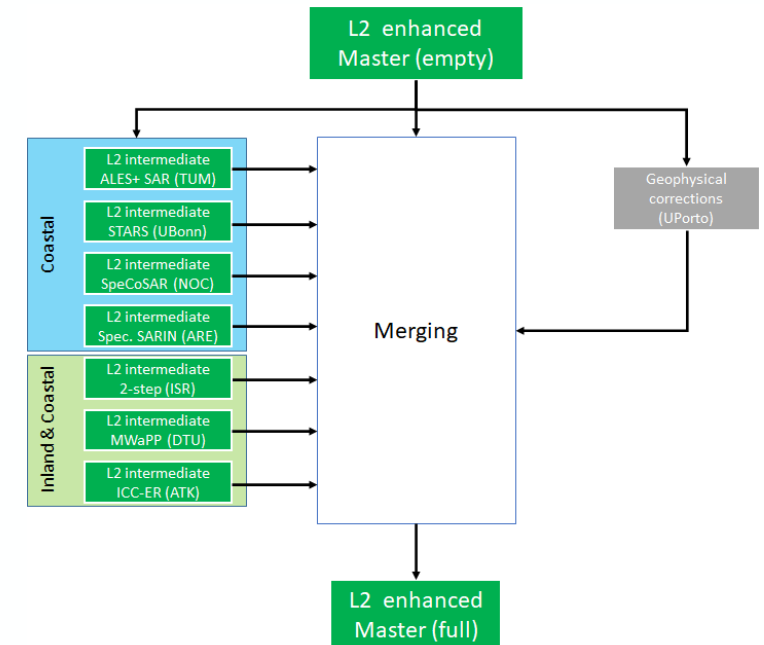
Region	Name	Country	Target Type
TDS1-01	River Rhine	Germany	River
TDS1-02	River Danube	Hungary, Serbia, Romania, Bulgaria	River
TDS1-03	River Amazon – Solimoes	Brazil	River
TDS1-04	River Ob	Russia	River
TDS1-05	River Po	Italy	River
TDS1-06	River Yangtze	China	River, estuary
TDS1-07	River Mississippi	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



## Candidate L2 algorithms

Six candidate L2 processing algorithms have been implemented. Their performance has been evaluated, and the best performing algorithms have been selected to generate global coastal zone and inland water products in the second year of the project.

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



*HYDROCOASTAL L2 product merging. The L2 enhanced Master includes output from all L2 processors. (credit: isardSAT)*

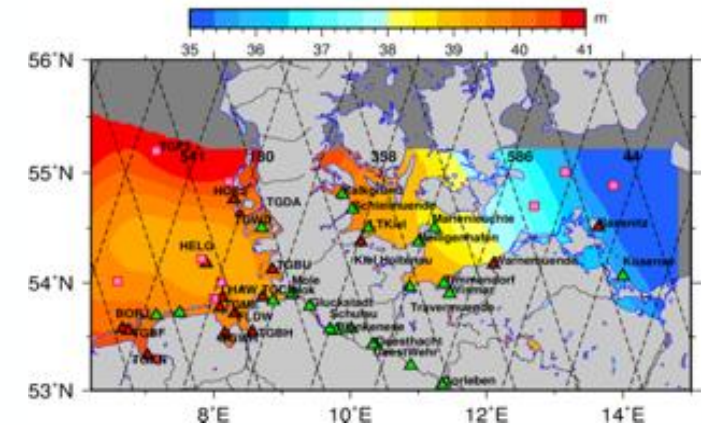
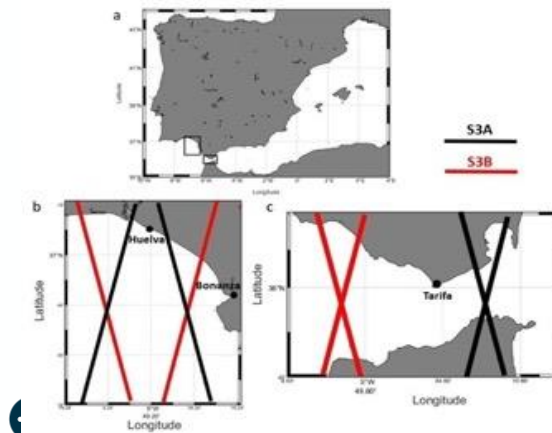


## First Test Data Set Evaluation – Coastal Zone

The isardSAT, DTU, U Bonn and TU Munich processors have been applied to Sentinel 3A, 3B, and Cryosat-2 SAR mode input data over 3 coastal regions, and their performance evaluated through detailed studies and with a set of agreed metrics, as described in the *Product Validation Report*

### Coastal Zone -L2

- German Bight /Baltic Sea (U Bonn)
- California Coast / Harvest (NOC)
- Southern Spain (U Cadiz)
- Land Proximity to Coast / Angle of Approach (SKYMAT)



## Re-tracker Validation Results – Coastal Zone

### Sea Surface Height (SSH):

The altimeter SSH from 4 re-trackers (isardSAT, DTU, U Bonn, TU Munich), was validated by calculating the Sea Level Anomaly and comparing this to measurements from 15 tide gauges in 3 different regions. The standard deviation of differences (STDD) between TG and altimeter data was calculated and averaged from 2-20km from the coast.

The STDD for Sentinel 3A / 3B data ranged from 3.4cm (California), to 17cm in the German Bight / Baltic. The STDD for Cryosat-2 data ranged from 6cm to 50cm. Different re-trackers performed best in different regions, and none was consistently better than the others.

### Significant Wave Height (SWH), 10m ocean surface wind speed (SWH, U10):

Only 2 retrackerers (U Bonn and isardSAT) provided SWH and U10. In validation against data from 30 buoys, the U Bonn data were consistently found to perform better than the isardSAT data, showing higher correlation and lower standard deviations.

***The validation team recommended selection of the U-Bonn re-tracker for coastal processing in the next stage of the HYDROCOASTAL project***



# Re-tracker Validation Results – Coastal Zone – U Bonn

## U Bonn Validation – SLA v Tide Gauges

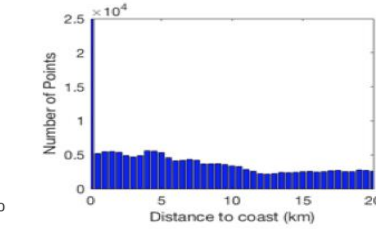
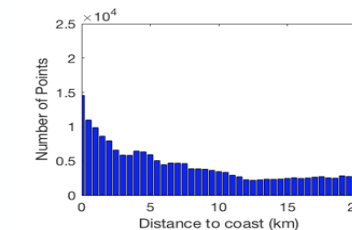
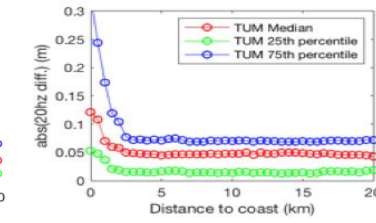
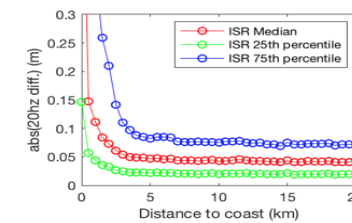
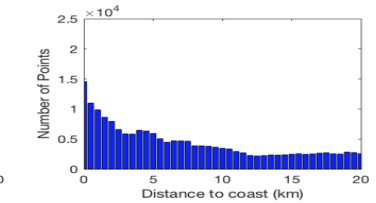
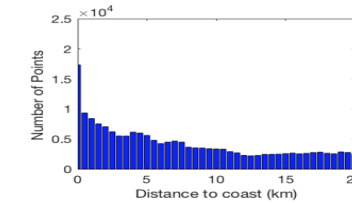
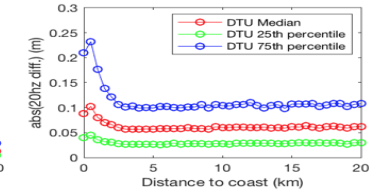
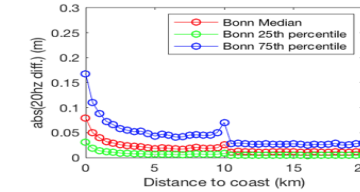
## U Bonn Validation – Noise and no of obs

U Bonn

DTU

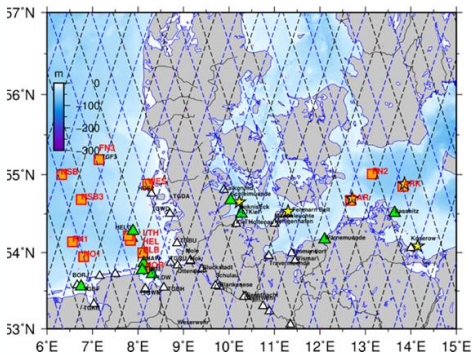
ISR

TUM



SLA S3A SSB own				
Order	Name	Mean of Correlation	Mean of STDD	STD of STDD
1	BONN	0.89	0.12	0.07
2	DTU	0.86	0.15	0.08
3	TUM	0.85	0.15	0.11
4	ESA	0.81	0.15	0.11
5	ISR	0.78	0.16	0.11

SLA S3B SSB own				
Order	Name	Mean of Correlation	Mean of STDD	STD of STDD
1	DTU	0.86	0.13	0.10
2	BONN	0.83	0.13	0.08
3	TUM	0.76	0.16	0.18
4	ESA	0.75	0.17	0.19
5	ISR	0.73	0.17	0.17

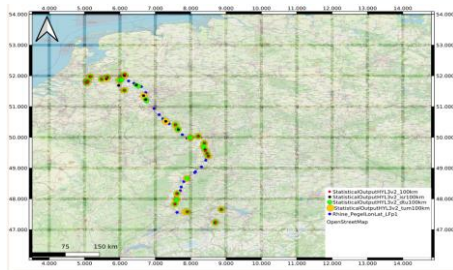


## First Test Data Set Evaluation – Inland Water

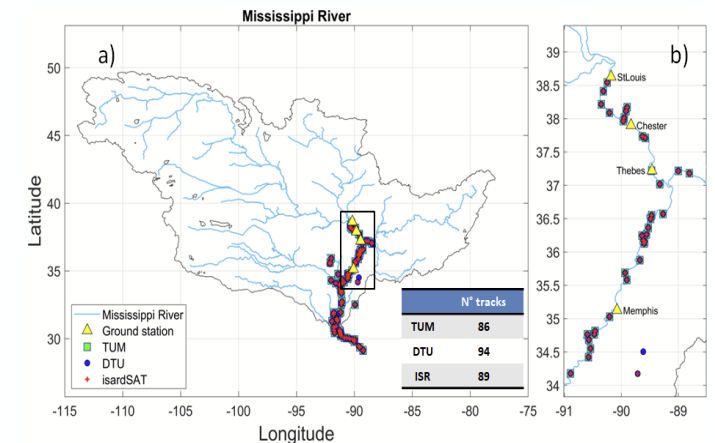
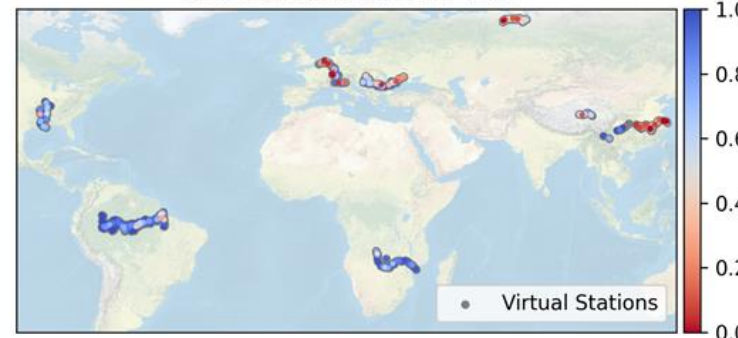
The isardSAT, DTU and TU Munich processors have been applied to Sentinel 3A, 3B, and Cryosat-2 SAR mode input data over inland water regions, and their performance evaluated through detailed studies and with a set of agreed metrics, as described in the *Product Validation Report*

### Inland Water

- Rhine and Elbe (U Bonn)
- Time Series against DAHITI global data base – 1031 virtual stations in 8 river basins (DGFI / TUM)
- Amur, Yangste and Zambezi (DTU)
- Ob and Rhine (NUIM)
- Po and Mississippi (CNR-IRPI)



Correlation: DAHITI vs. DTU



## Re-tracker Validation Results – Inland Water

For inland water, the altimeter water level from 3 re-trackers (isardSAT, DTU, TU Munich), as applied to Sentinel 3A and 3B input data, was validated in comparisons against river gauge data, and against other satellite derived measurements. This 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.

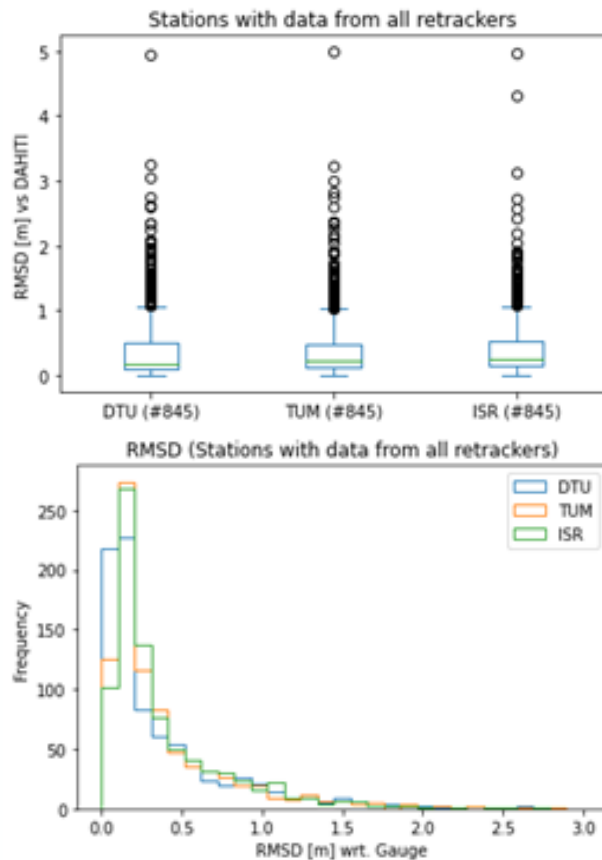
An ideal approach could be to categorise different types of river / lake environment and apply different re-trackers that were optimised to these environments.

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



# Re-tracker Validation Results – Inland Water – DAHITI Analysis

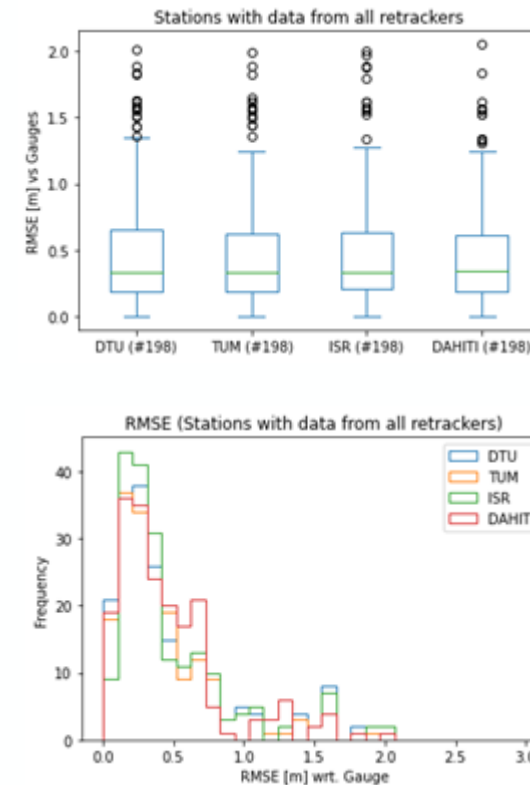
Validation against DAHITI Virtual Stations  
with common data (845 stations)



Median RMSD

- DTU  $0.17\text{m} \pm 0.04$
- TUM  $0.20\text{m} \pm 0.03$
- ISR  $0.22\text{m} \pm 0.03$

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



Median RMSD

- DTU  $0.33\text{m} \pm 0.04$
- TUM  $0.34\text{m} \pm 0.04$
- ISR  $0.33\text{m} \pm 0.03$

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 (SAR and SARin)
- 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”.

The final specifications of the global data set, including spatial and temporal coverage are being finalised

This product will be made freely available.

We expect this product to be available in Autumn 2022

*Please contact us if you would be interested in accessing this data set, and would like to recommend regions to be covered*

## Impact Assessment

A series of **impact assessment studies** will be carried out, to test and demonstrate the potential impact and benefits of the global dataset.

### Processing Case Studies

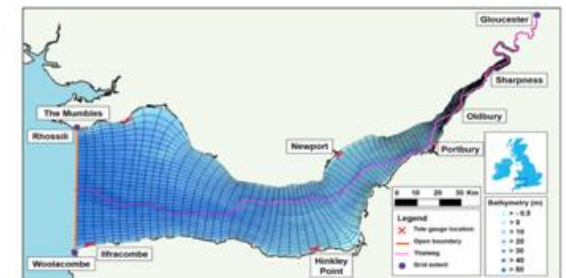
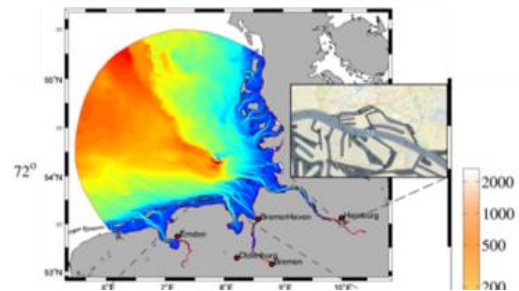
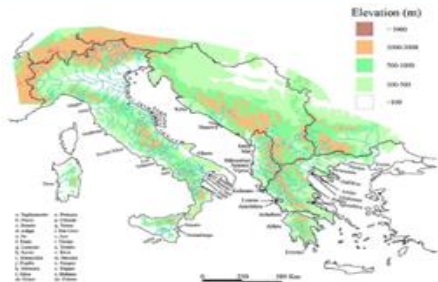
- Fully Focused SAR (Aresys, isardSAT)
- Attitude Errors (Aresys)
- Along and Across track slope (Aresys)
- Open Loop Tracking Study (NOVELTIS)
- Phase Unwrapping / Across Track Slope (DTU Space)

### Coastal / Inland

- Severn Estuary (NOC)
- Baltic, German Bight, Elbe Estuary (U Bonn)
- Venice Lagoon (CNR)
- Thailand Coast (TU Delft)
- Ebro River and Delta (isardSAT)
- Wadden Sea (TU Delft)

### Inland

- Operational Hydrological Forecasting (DTU Env)
- Lake Size, riverbank configuration (NUIM)
- Discharge Validation (CNR)
- Global Water Level Climatology (AHL, ATK)



*Groups from outside the project team are welcome to engage with the project and carry out their own case studies. Please contact us with your suggestions!*



## HYDROCOASTAL Outcomes

The outcomes of the HYDROCOASTAL will include:

**State of the art review** of SAR Radar Altimetry and current challenges.

**Initial SAR / SARin satellite altimeter L2, L3 and L4 Test data set** over 18 Regions of Interest.

Full descriptions of **processing algorithms** and **output products**.

**Global Output products:**

A Global L2 coastal and inland water SAR altimeter data set.

Time series (L3) and river discharge (L4) data sets for medium to large rivers

A **Scientific Road Map** including recommendations for further developments, implementations and research for SAR altimetry

<https://www.satoc.eu/projects/hydrocoastal>