

# Improving SAR Altimeter processing over the coastal zone - the ESA HYDROCOASTAL project

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## Abstract

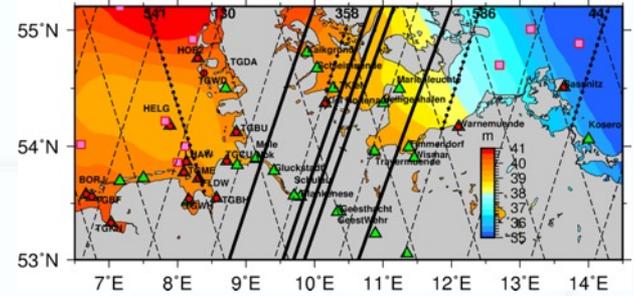
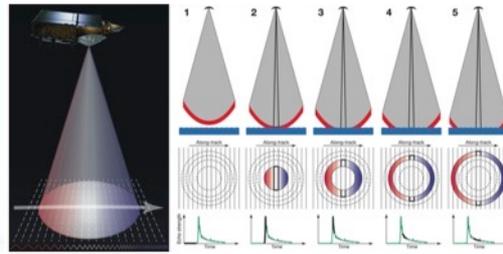
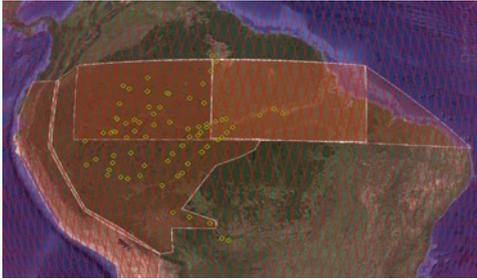
Introduction HYDROCOASTAL is a two year project funded by ESA, with the objective to maximise exploitation of SAR and SARin altimeter measurements in the coastal zone and inland waters, by evaluating and implementing new approaches to process SAR and SARin data from CryoSat-2, and SAR altimeter data from Sentinel-3A and Sentinel-3B. Optical data from Sentinel-2 MSI and Sentinel-3 OLCI instruments will also be used in generating River Discharge products. New SAR and

SARin processing algorithms for the coastal zone and inland waters will be developed and implemented and evaluated through an initial Test Data Set for selected regions. From the results of this evaluation a processing scheme will be implemented to generate global coastal zone and river discharge data sets. A series of case studies will assess these products in terms of their scientific impacts. All the produced data sets will be available on request to external researchers, and full descriptions of the processing algorithms will be provided.

**Objectives** The scientific objectives of HYDROCOASTAL are to enhance our understanding of interactions between the inland water and coastal zone, between the coastal zone and the open ocean, and the small scale processes that govern these interactions. Also the project aims to improve our capability to characterize the variation at different time scales of inland water storage, exchanges with the ocean and the impact on regional sea-level changes.

**The technical objectives** are to develop and evaluate new SAR and SARin altimetry processing techniques in support of the scientific objectives, including stack processing, and filtering, and retracking. Also an improved Wet Troposphere Correction will be developed and evaluated.

**Presentation** The presentation will describe the different SAR altimeter processing algorithms that are being evaluated in the first phase of the project, and present results from the evaluation of the initial test data set focusing on performance at the coast. It will also present the results of a study assessing regional tidal models.



# Improving SAR Altimeter processing over the coastal zone and inland waters - the ESA HYDROCOASTAL project.

D. Cotton, Albert Garcia-Mondejar, Ferran Gibert, Ester Vendrell, Christine Gommenginger, Ole Andersen, Karina Nielsen, Heidi Ranndal, Luciana Fenoglio-Marc, Michele Scagliola, Mathilde Cancet, Marcello Passaro, Denise Dettmerring, Pierre Fabry, Nicholas Bercher, Angelica Tarpanelli, Stefano Vignudelli, Francesco de Biasio, Peter Bauer-Gottwein, Joana Fernandes, Cornelis Slobbe, Marc Naeije, Jesus Gomez-Enri, Peter Thorne, Elena Zakharova, Andy Shaw, Marco Restano, Jérôme Benveniste,

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# Introduction

- The junction between the coastal zone and inland waters is a boundary between
  - Different science domains (hydrology and oceanography),
  - Different satellite measurement regimes.
  - Region of high variability in small spatial and temporal scales.
- HYDROCOASTAL aims to enhance our understanding of
  - interactions at this boundary,
  - the small-scale processes that govern these interactions,
  - to improve characterisation of variation at different time scales of inland water storage,
  - exchanges with the ocean and the impact on regional sea-level changes.

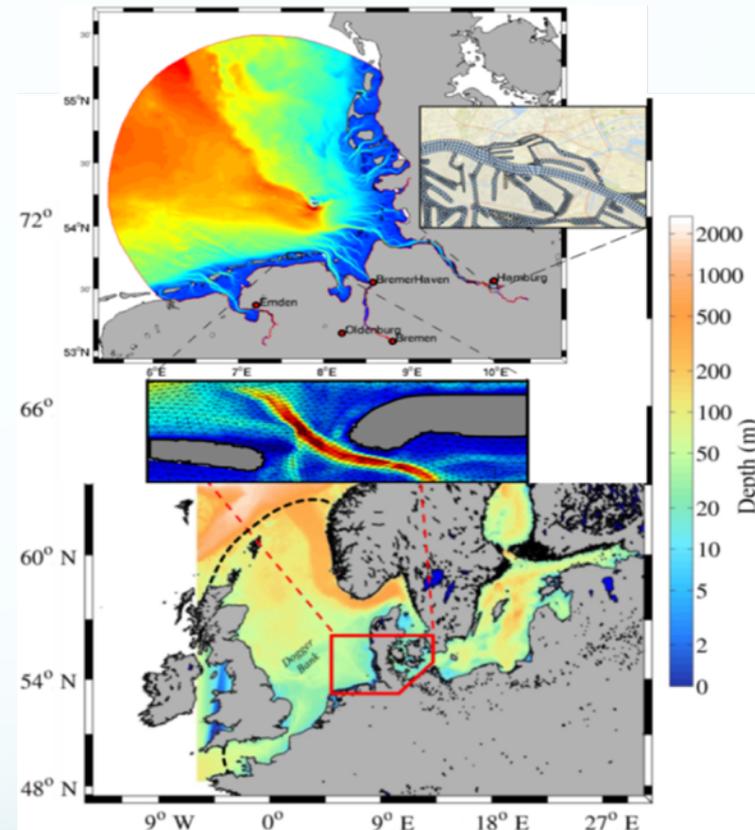


Image courtesy of U Bonn: German Coast of the North Sea and the Elbe Estuary

# The HYDROCOASTAL Project

- HYDROCOASTAL is funded under the ESA Science for Society Programme Element.
- 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 will be developed and tested, and a processing scheme will be implemented to generate global coastal zone and river discharge data sets.
- Case studies will assess these products in terms of their scientific impacts
- 14 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)

- Review the current state of the art in SAR and SARin altimeter data processing as applied to the coastal zone and to inland waters.
- Output is a Review Paper which is under preparation

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

- Implement new SAR, SARin altimeter processing algorithms to generate 2-year test data set
- Evaluate performance of the candidate algorithms against models, in situ data, and other satellite data sets
- Selected algorithms used to generate “global” coastal zone and river discharge data sets

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

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

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

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

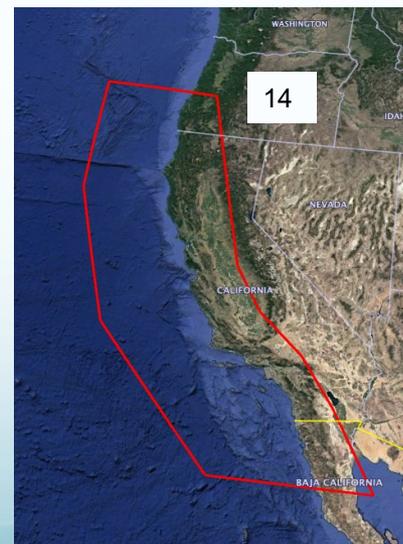
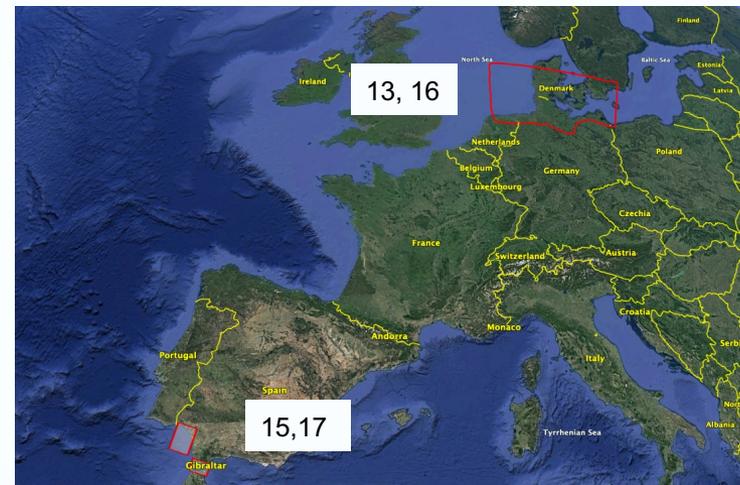
# 1<sup>st</sup> HYDROCOASTAL Test Data Set

- The First test data set has been 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). Map and table on next page
- 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

## Coastal ROIs

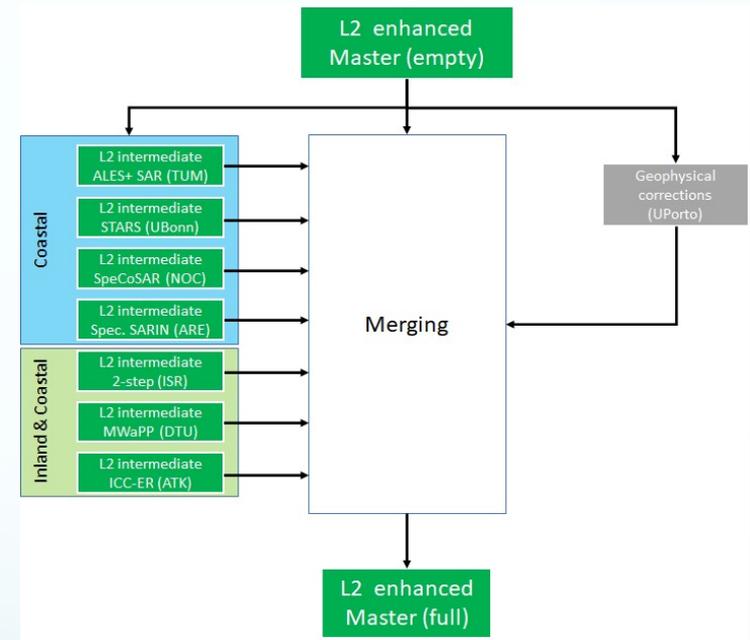
| Region         | Name                              | Country                            | Target Type             |
|----------------|-----------------------------------|------------------------------------|-------------------------|
| TDS1-01        | River Rhine                       | Germany                            | 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 |
| <b>TDS1-10</b> | <b>Ionian / Aegean</b>            | <b>Greece</b>                      | <b>Coastal /SARin</b>   |
| TDS1-11        | Reindeer Lake,                    | Canada                             | Lake                    |
| TDS1-12        | Zambezi River                     | Zambia, Mozambique                 | River                   |
| <b>TDS1-13</b> | <b>German Bight, Baltic Coast</b> | <b>Germany</b>                     | <b>Coastal</b>          |
| <b>TDS1-14</b> | <b>California Coast</b>           | <b>USA</b>                         | <b>Coastal</b>          |
| <b>TDS1-15</b> | <b>Huelva and Bonanza</b>         | <b>Spain</b>                       | <b>Coastal, Estuary</b> |
| <b>TDS1-16</b> | <b>Elbe Estuary</b>               | <b>Germany</b>                     | <b>Estuary</b>          |
| <b>TDS1-17</b> | <b>Tarifa</b>                     | <b>Spain</b>                       | <b>Coastal</b>          |
| <b>TDS1-18</b> | <b>Caspian Sea</b>                | <b>Russia</b>                      | <b>Inland Sea</b>       |



# Candidate L2 algorithms

Seven candidate L2 processing algorithms will be implemented. Their performance will be evaluated, and based on this, algorithms will be 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**
7. **SCOOP-SAR – Specialised COastal Operator for SAR waveforms – coastal: NOC**



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

# Adding Vertical Motion of Wave Particles to SAR Altimeter Processing

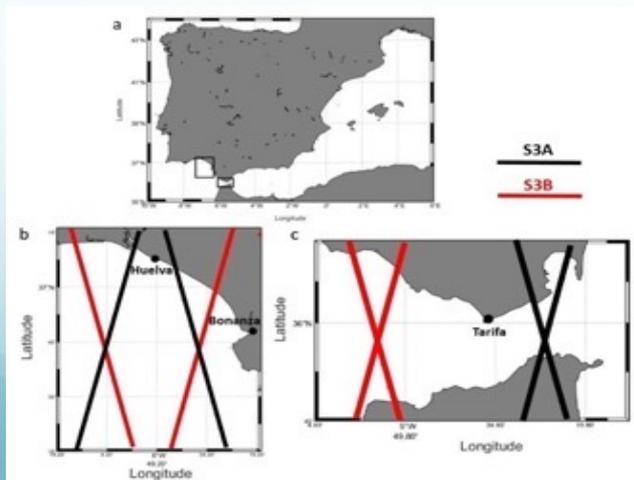
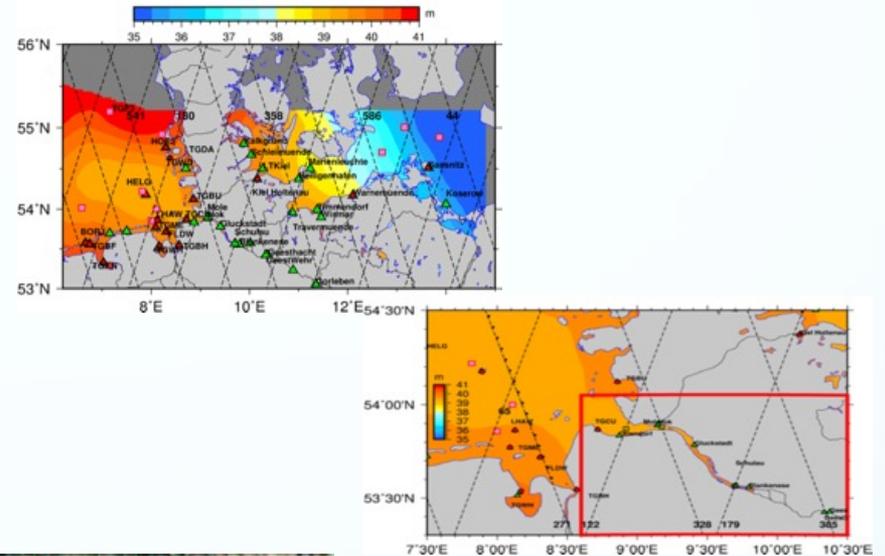
- The precision of SAR altimeter measurements has been shown to be dependent on significant wave height and wave period.
- It is postulated that this dependency is due to vertical motion of wave particles, that is currently not included in SAR Altimeter data processing
- U Bonn are carrying out an additional activity to include the effect of vertical motion of wave particles in SAR altimeter processing and to assess the impact of this on accuracy and precision.

# First Test Data Set Evaluation

The performance of the different processors will be evaluated through detailed studies and with a set of agreed metrics, as described in the *Product Validation Plan*:

- **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)



# Wet and Dry Troposphere

## Enhanced Dry and Wet Tropospheric Corrections (DTC and WTC)

**Objective** → To generate and validate enhanced DTC and WTC for CryoSat-2 and Sentinel-3A/B in the coastal zone and inland water domains.

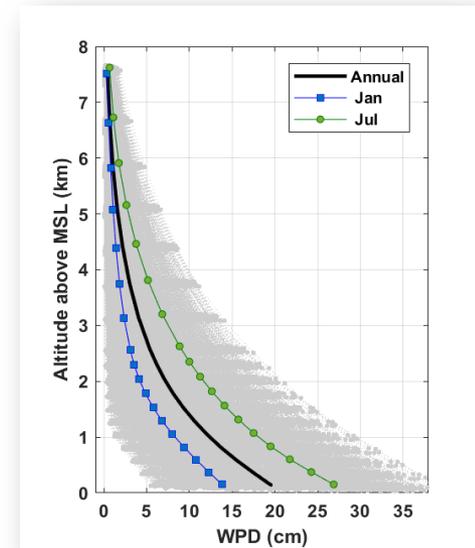
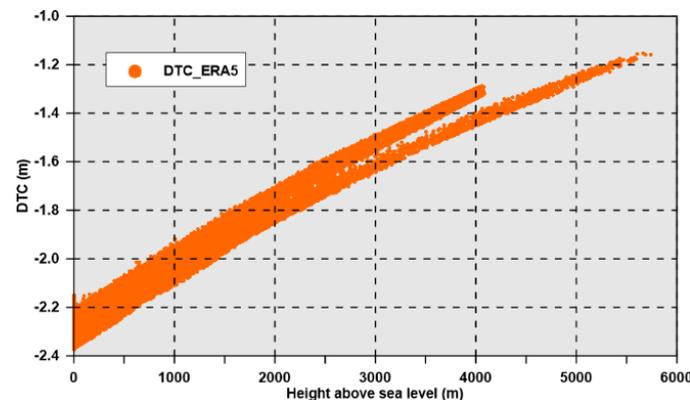
### Main points

- Use state-of-the-art computation techniques, numerical weather models and observations.
- Correction of errors present in current altimeter products (wrong data rate and reference surface, invalid MWR-derived WTC).
- Enhanced handling of the DTC/WTC variation with altitude.
- Data rate: 20 Hz.

### Algorithms

- DTC → Formulae and procedure from Davis et al. (1985) and Fernandes et al. (2014).
- WTC → GPD+ with enhanced features.

DTC (in) function of surface height for one S3 cycle.



WTC profiles from ERA5, for the year 2010, for the location  $\phi=25^\circ$ ,  $\lambda=-75^\circ$ .

## 1 – Context

To retrieve satellite altimetry SSH at the centimetre level, the ocean tide signals must be accurately removed from the altimeter measurements.

→ Reference global ocean tide models are used (GOT4.10, FES2014b).

However, other tide solutions (global or regional) may be more accurate for coastal altimetry, depending on the region.

→ Regionally assess the models to provide recommendations.

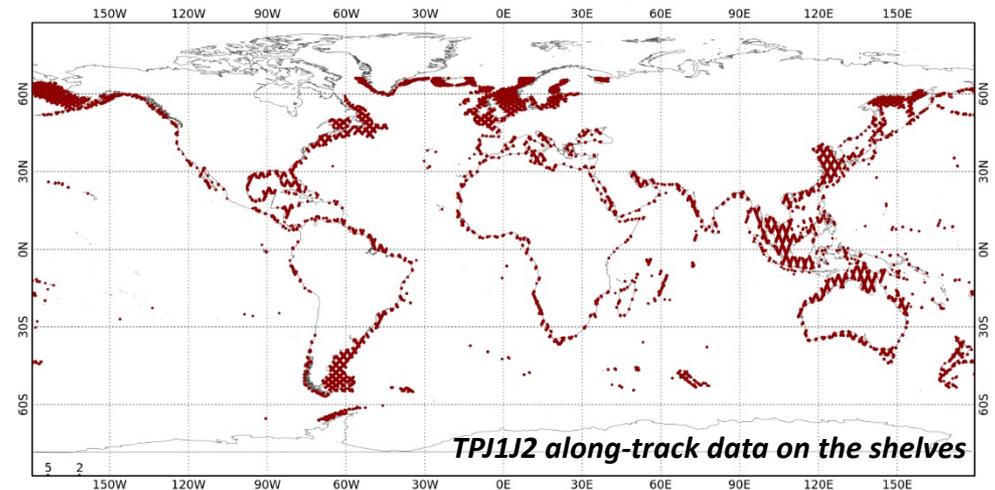
## 2 – Assessed models

→ **Global models:** FES2004, GOT4.10, FES2014b, DTU16, EOT20, TPXO7.2, TPXO8, TPXO9v4.

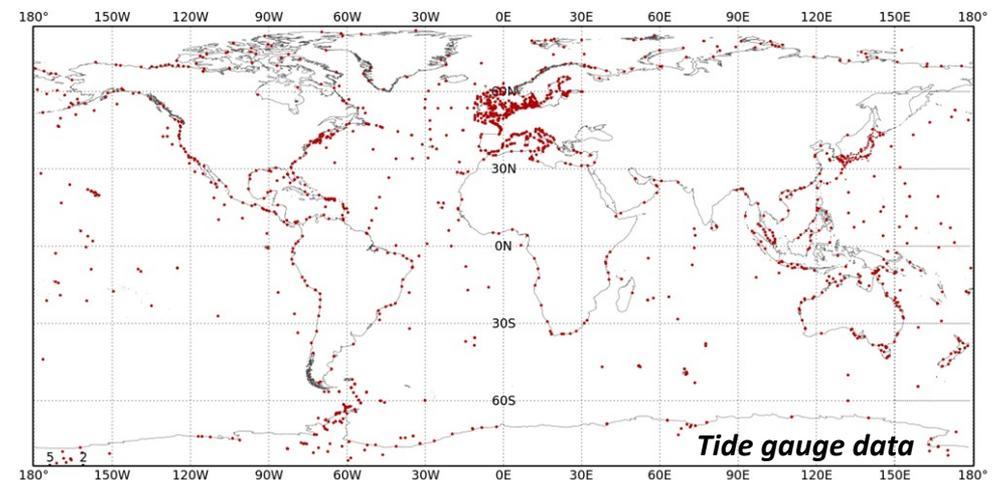
→ **Regional models:** CNES/NOVELTIS RegAT regional solutions, CATS2008.

## 3 – Validation datasets

Tidal harmonic constituents derived from **altimetry** along-track data and crossover points (TP/J1/J2, CryoSat-2 in the Arctic)



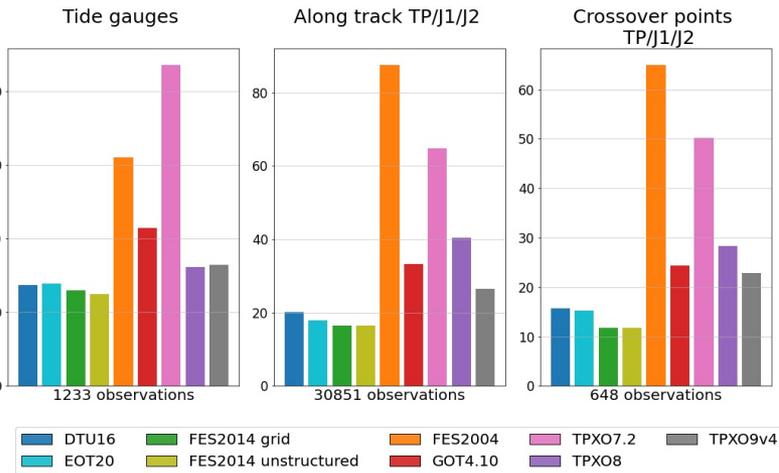
Tidal harmonic constituents derived from **tide gauge** time series



## 4 – Global mean vector differences

Vector difference calculated for each tidal component, between each model and each validation dataset, reduced to the continental shelves. The RSS scores provide overall statistics on the models performance.

**RSS score (mm) - Global - shelf**



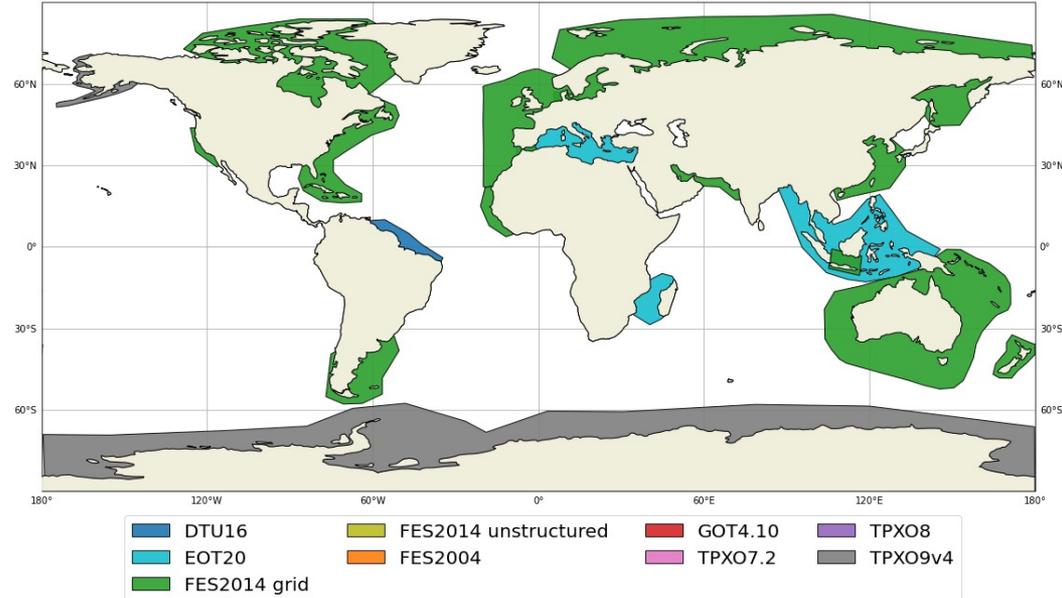
→ Globally, FES2014b performs best.

**Warning:** Some of these global models are not compatible with the HF DAC correction provided in the altimetry products (missing S1 tidal component)

## 5 – Regional mean vector differences

The analysis of the global and regional models in a regional approach, considering 20 shelf regions, provides more contrasted results.

**Most relevant global tidal models depending on the regions**



→ Where available, the recent regional models provide the most accurate results

→ The global models perform differently depending on the regions

# HYDROCOASTAL Global 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 (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, will be agreed between ESA and the project team at the mid-term review.
- 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

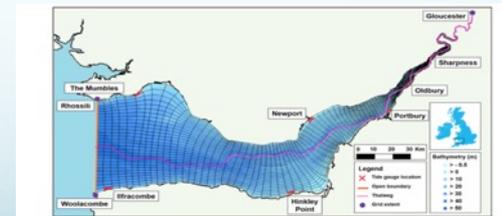
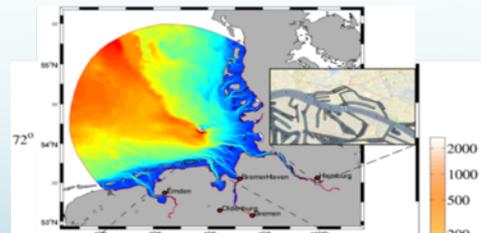
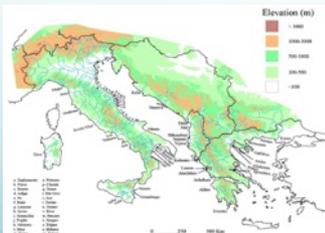
In the final year of the project a series of impact assessment studies will be carried out, to test and demonstrate the potential impact and benefits of the global dataset.

## 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

- Bristol Channel / Severn Estuary (NOC)
- Baltic, German Bight, Elbe Estuary (U Bonn)
- Venice Lagoon (CNR)
- Thailand Coast (TU Delft - with Deltares)
- Ebro River and Delta (isardSAT)



*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 / Participation Invitation

The outcomes of the HYDROCOASTAL will include:

- **Review Paper** on state of the art 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

**Thank You – Please get in touch if you are interested!**

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