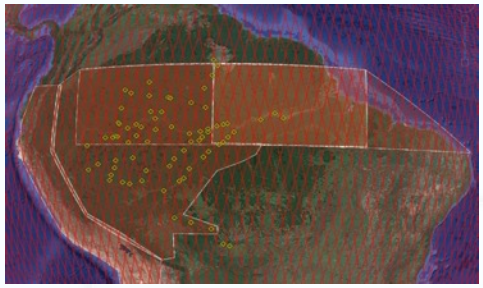

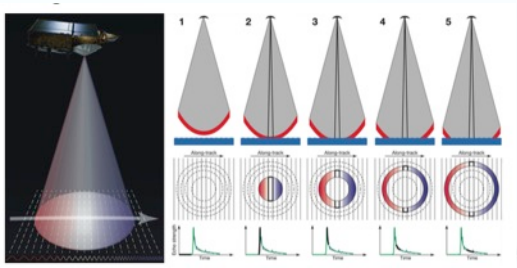

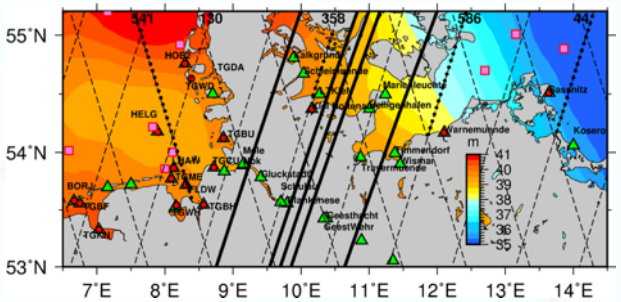

Improving SAR Altimeter processing over the coastal zone and inland waters - the ESA HYDROCOASTAL project.

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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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

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.

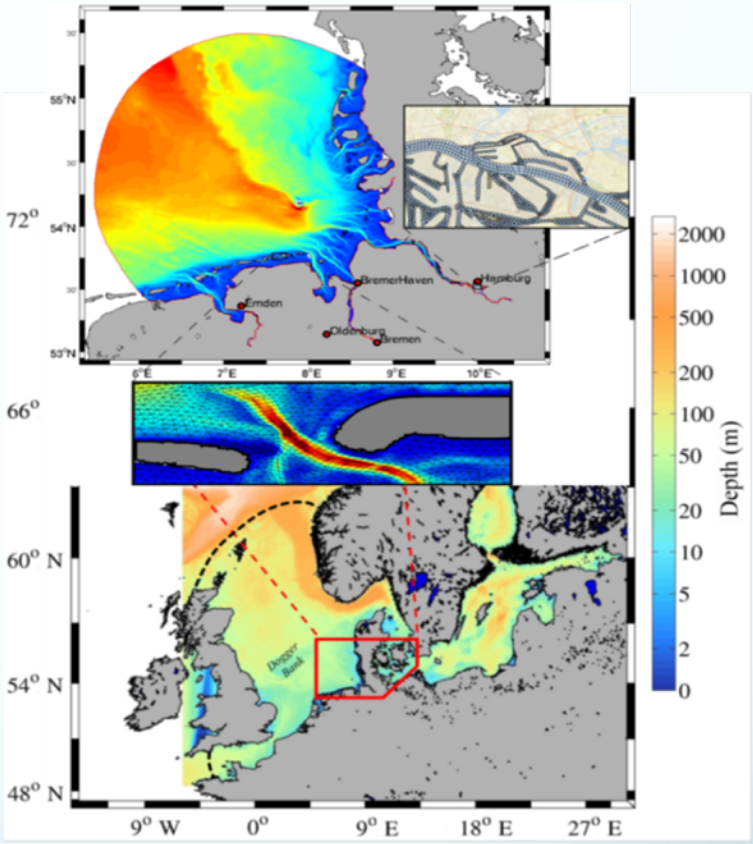


Image courtesy of U Bonn: German Coast of the North Sea and the Elbe Estuary

HYDROCOASTAL Overview

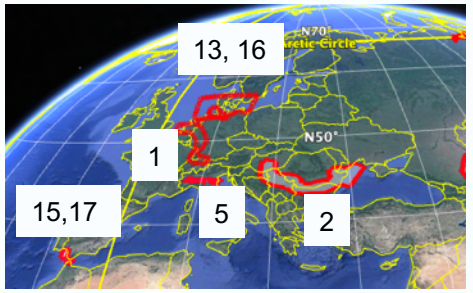
1. **Scientific Review and Requirements Consolidation (Feb-July 2020)**
   - Review the current state of the art in SAR and SARin altimeter data processing as applied to the coastal zone and to inland waters.
   - Output is a Review Paper which is under preparation
2. **Implementation and Validation (July 2020 – August 2021)**
   - 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 (March – December 2021)**
   - The impact of global products assessed through a series of case studies
4. **Outreach and Road Map (March 2022)**
   - Recommendations for further R&D and implementation in current and future SAR altimeter missions

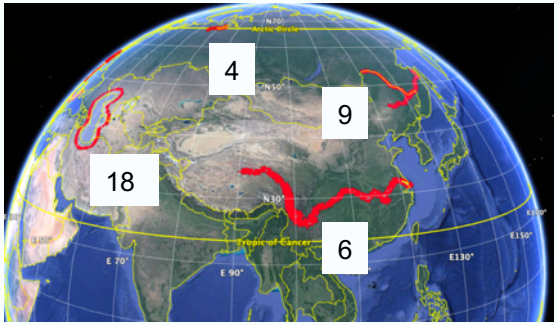
1st HYDROCOASTAL Test Data Set

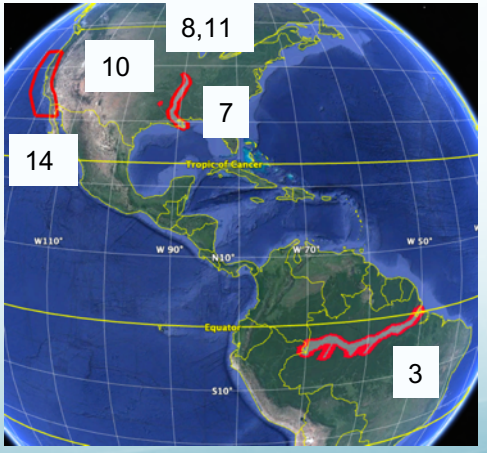
- The First test data set is being produced to evaluate new L2 processing algorithms over the coastal zone and inland waters, and also processing to L3 (river/lake level time series) and L4 (river discharge)
- We have selected 18 Regions of Interest to cover a wide range of inland water and coastal zone characteristics, on all continents (except Antarctica!). Map and table on next page
- 2 years data 2018-2019
- 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***
- Available on request by email to ***info@satoc.eu***

1st HYDROCOASTAL Test Data Set ROIs

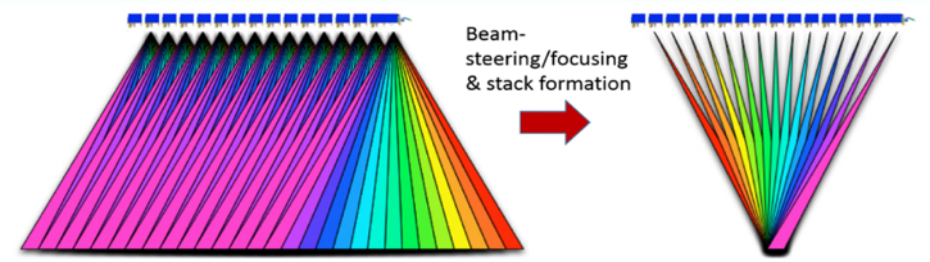
Region	Name	Country	Target Type
TDS1-01	River Rhine	Germany	River
TDS1-02	River Danube	Hungary, Serbia, Romania, Bulgaria	River
TDS1-03	River Amazon – Solimoes	Brazil	River
TDS1-04	River Ob	Russia	River
TDS1-05	River Po	Italy	River
TDS1-06	River Yangtze	China	River, estuary
TDS1-07	River Mississippi	USA	River
TDS1-08	Nonacho Lake	Canada	Lake
TDS1-09	River Amur /Songhua	China, Mongolia, Russia	River, wetland, estuary
TDS1-10	Red River	USA	River
TDS1-11	Reindeer Lake, Woolaston	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





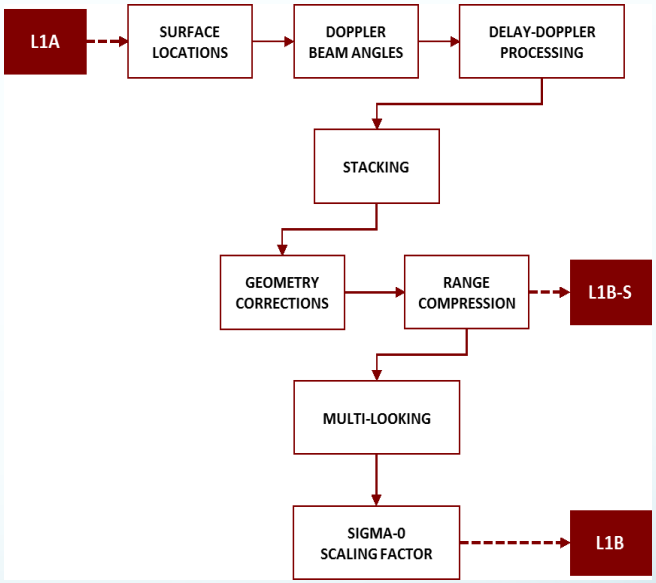


Processing to L1B (isardSAT)



Conceptual representation of beam-steering processing and stack formation for a given surface (credit: ESA)

- isardSAT will generate Level 1B-S and Level 1B products, from input Cryosat-2 SAR and SARin FBR data, and Sentinel SIRAL 3A and 3B SAR L1A data.
  - L1B-S contains fully SAR-processed and calibrated SAR complex echoes arranged in stacks after slant range correction and before multi-looking.
  - L1B is the final science product and contains geo-located and fully calibrated multi-looked SAR power echoes
- Delay Doppler processing steps:
  - Surface locations, Final burst datation and Window delay computation
  - Beam angles computation
  - Azimuth processing (Delay-Doppler processing + Stacking)
  - Geometry corrections
  - Range compression
  - Multi-looking
  - Scaling factor computation (sigma0 extraction)
  - *For SARin the interferometric processing will be implemented in the multi-looking step.*

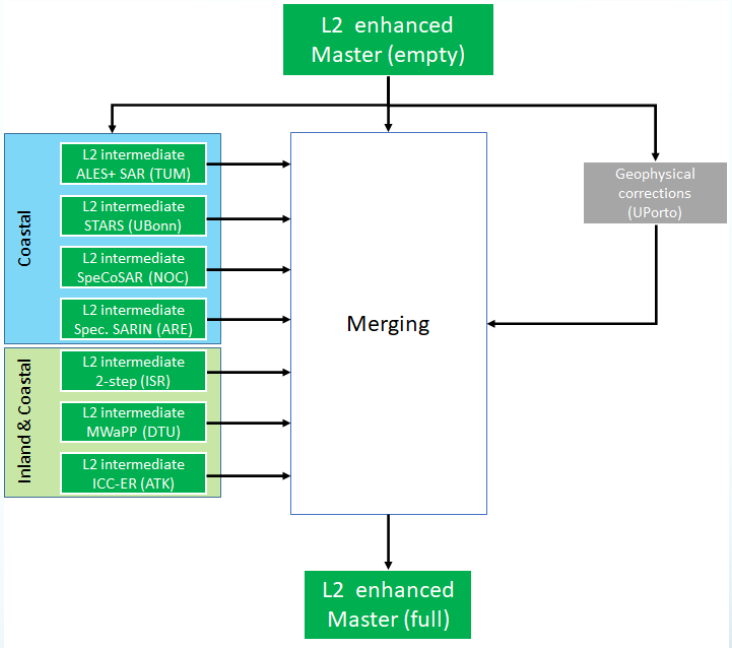


Level-1A/Level1-B SAR processing chain (credit: isardSAT)

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)

L3, and L4 processing – Inland Waters

L3 – Water Level Time Series

- L3 products are provided by Alti HydroLab (AHL) and DTU
- The overall intension is to provide global inland water products based on CryoSat-2 and Sentinel-3A and 3B.
  - L3 Sentinel-3A/B virtual station product (AHL) provided at 1° X 1° tiles NetCDF
  - L3 Lake product based on Sentinel-3A/B and CryoSat-2 (DTU) 1° X 1° tiles NetCDF.
  - L3 River virtual station product based on Sentinel-3A/B (DTU) 1° X 1° tiles NetCDF
- AHL and DTU will use different approaches but follow a common structure
  - Mask out data over inland water bodies using raster and vector water masks
  - Outlier filtering to clean L2 data
  - Time series generation
  - Validity check
  - Generation of output files

L3, and L4 processing – Inland Waters

L4 – River Discharge

- L4 products are provided by NUIM and CNR-IRPI
- L4 will not be provided globally but at a number selected rivers which will be made available to users during/after the project.
- Both altimetry and near infrared (NIR) imagery is applied to derive discharge
- Some of the proposed algorithms and approaches include:
  - The rating curve approaches where in situ discharge is related water level
  - Bjerklie equation
  - The physical Manning method
  - Discharge based on reflectance ratio from NIR images

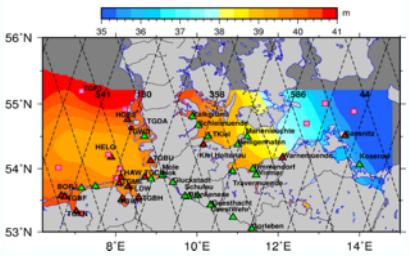
First Test Data Set Evaluation

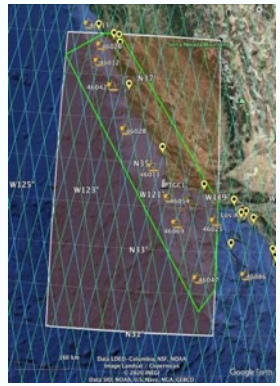
The performance of the different processors will be evaluated through detailed studies and with a set of agreed metrics, as described in the *Product Validation Plan*:

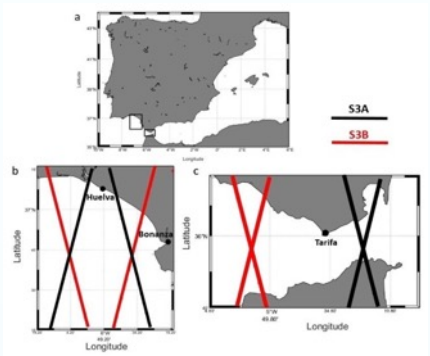
- **Coastal Zone -L2**
  - German Bight /Baltic Sea (U Bonn)
  - California Coast / Harvest (NOC)
  - Southern Spain (U Cadiz)
  - Land Proximity to Coast / Angle of Approach (SKYMAT)

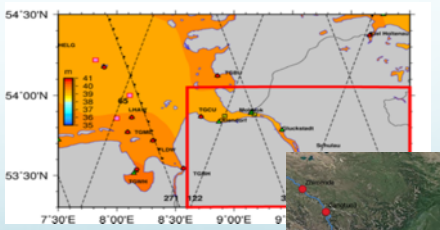
- **Inland Water – L2**
  - Rhine and Elbe (U Bonn)
  - Water Level Time Series (DGFI/TUM)
  - Influence of ground-track and water fraction (ATK)
  - Amazon Basin (AHL)
  - Amur, Yangtze, and Zambezi (DTU)

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









Wet and Dry Troposphere

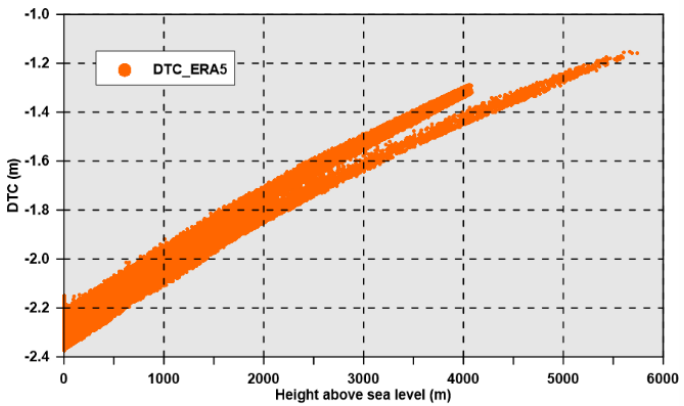
Enhanced Dry and Wet Tropospheric Corrections (DTC and WTC)

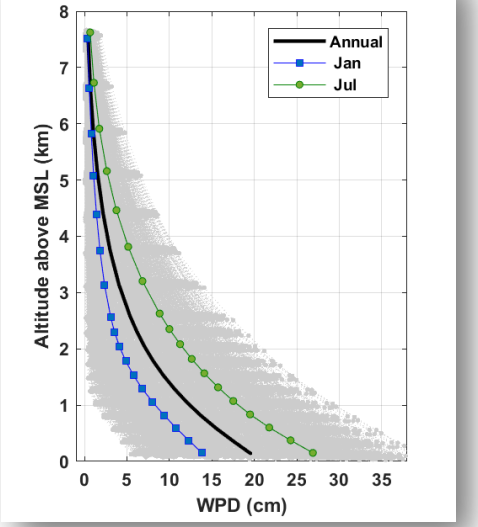
Objective → To generate and validate enhanced DTC and WTC for CryoSat-2 and Sentinel-3A/B in the coastal zone and inland water domains.

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.

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





WTC profiles from ERA5, for the year 2010, for the location ϕ=25°, λ=-75°.

Algorithms

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

Assessment of tidal models in coastal regions

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.**

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

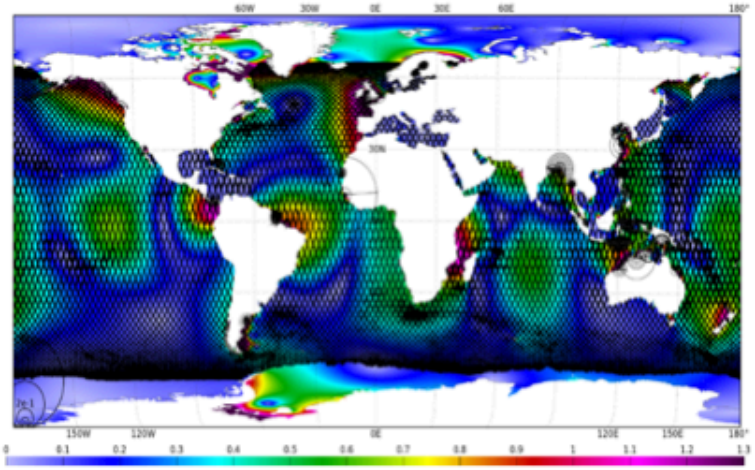
➔ **Assess the models regionally to provide recommendations.**

2 – Assessed models

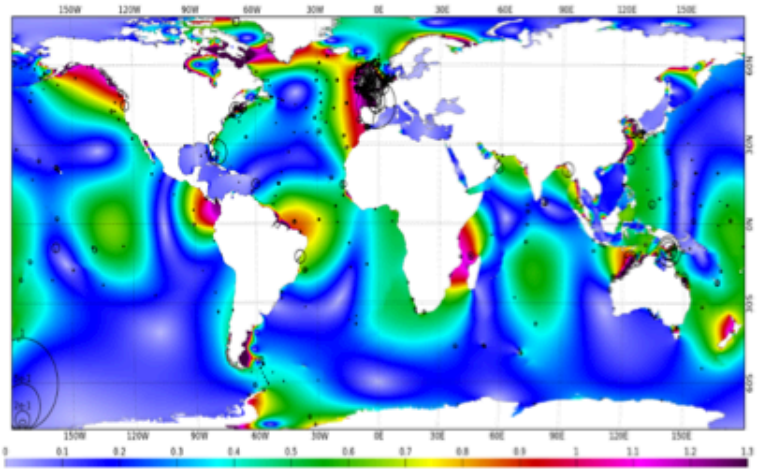
➔ **Global models:** FES2004, GOT4.8, GOT4.10, DTU10, DTU16, EOT11a, OSU12, TPXO8, FES2012, FES2014, TPXO9.

➔ **Regional models:** NOVELTIS regional solutions, TUM regional solutions,…

3 – Validation datasets



Tidal harmonic constituents extracted from along-track **altimetry** data (TP/J1/J2)



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

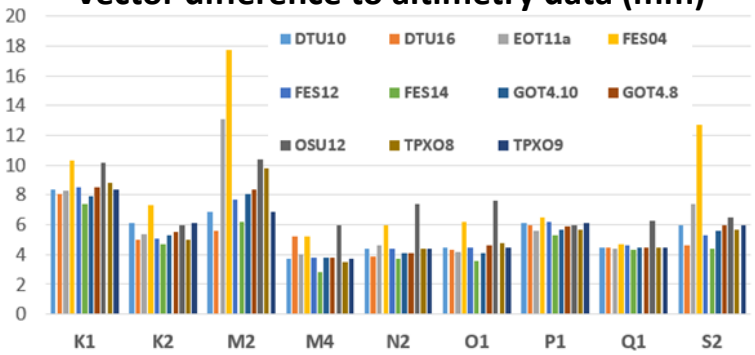
Assessment of tidal models in coastal regions

4 – Global mean vector differences

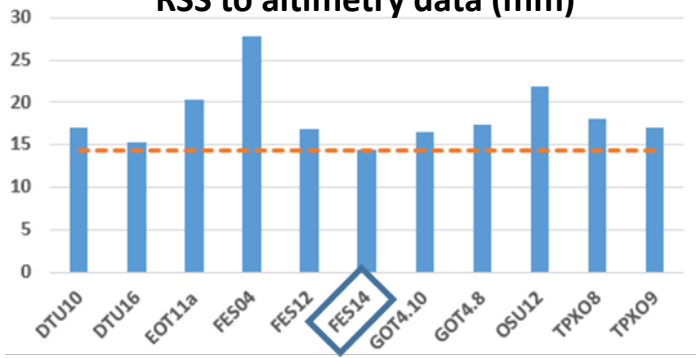
Vector difference calculated for each tidal component, between each model and the two validation datasets. The RSS provides an overall statistics on the models' performance.

➔ **Globally, FES2014 performs best.**

Vector difference to altimetry data (mm)



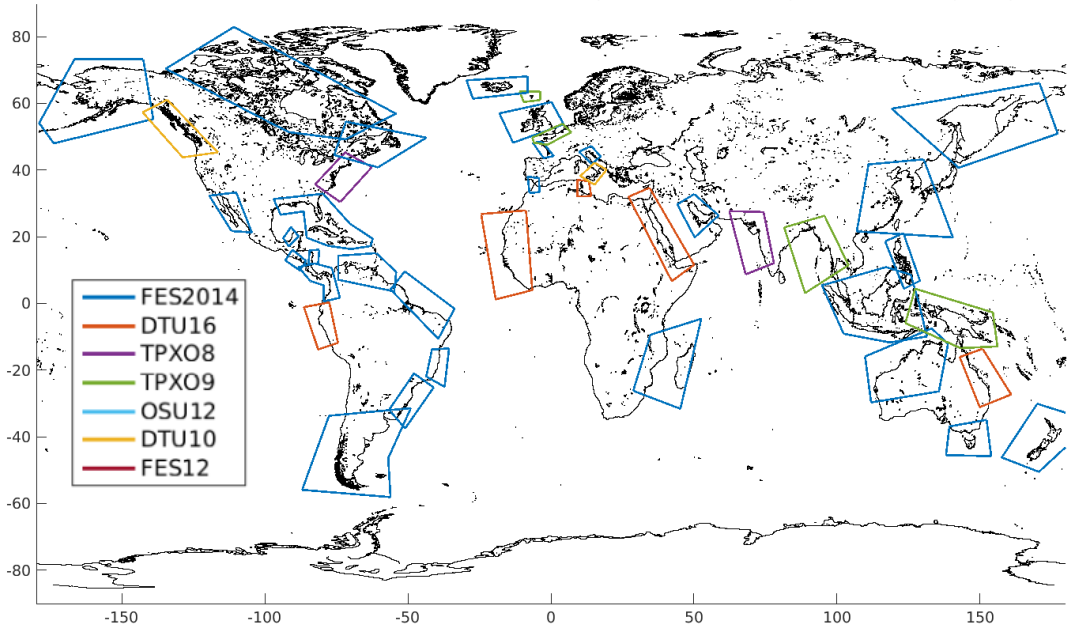
RSS to altimetry data (mm)



5 – Regional mean vector differences

The computation of the vector difference on a regional approach, considering about 40 coastal/shelf regions, provides more contrasted results.

Most relevant tidal models according to altimetry and tide gauges



[Preliminary results to be completed with regional models and additional tide gauge observations in some regions of interest.]

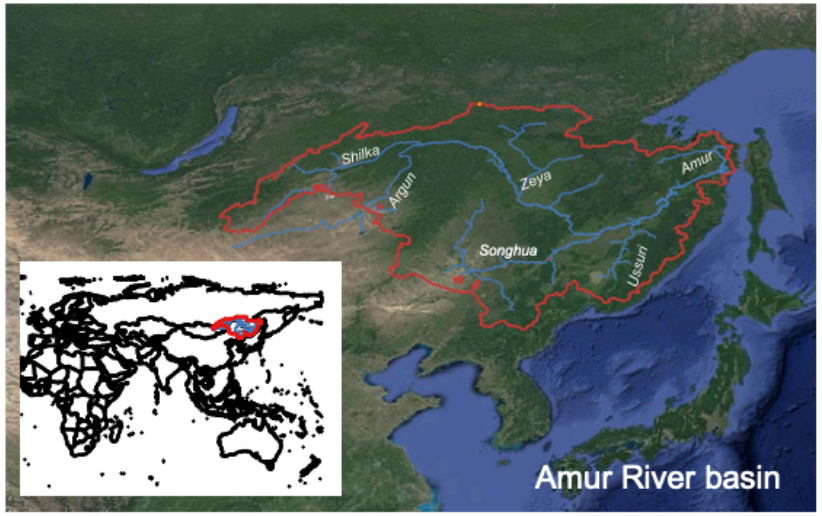
Amur Catchment Study

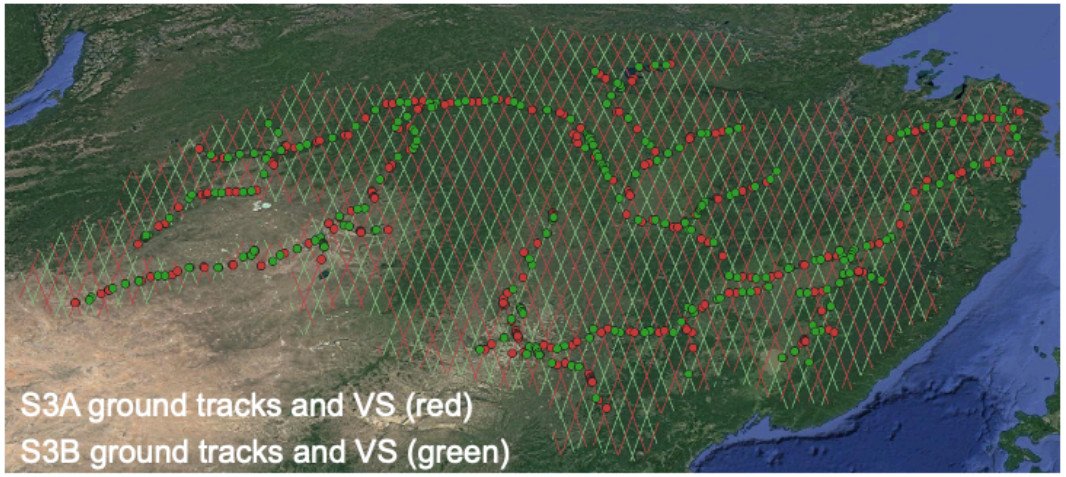
Catchment Modelling – Amur case study

Objectives

1. Build a hydrologic-hydraulic model of the Amur River Basin
2. Process and evaluate satellite radar altimetry data from Sentinel-3 (and CryoSat-2) available in the basin
3. Inform the modeling system with water surface elevation data based on satellite radar altimetry
   a. Inform the hydrologic (rainfall-runoff) model with altimetry-derived discharge
   b. Inform the hydraulic model with water surface elevation observations from radar altimetry (cross section geometry and roughness)
4. Predict discharge, water level (and flood inundation) in the rivers and wetlands using the model

Demonstration on 1 large basin - a blueprint for global-scale application





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 August 2021

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

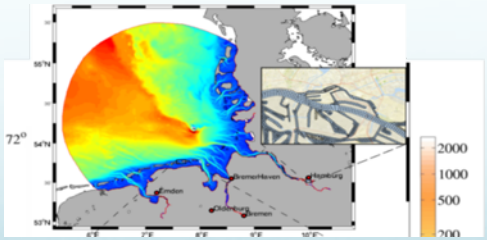
- Fully Focused SAR (Aresys, isardSAT)
- Attitude Errors (Aresys)
- Along and Across track slope (Aresys)
- Open Loop Tracking Study (NOVELTIS)
- Phase Unwrapping / Across Track Slope (DTU Space)

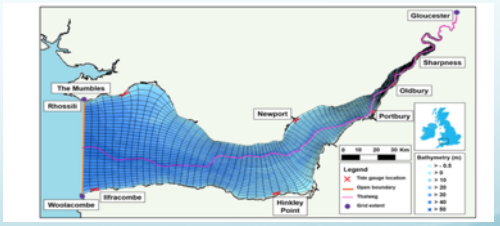
Coastal / Inland

- 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)

Inland

- Operational Hydrological Forecasting (DTU Env)
- Lake Size, river bank configuration (NUIM)
- Discharge Validation (CNR)
- Global Water Level Climatology (ATK)
- Wadden Sea study (TU Delft, Deltares





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