FFSAR - COASTAL

Fully Focused SAR Altimetry and innovative river level gauges for Coastal Monitoring

Final Report

Deliverable D4.4

Fully Focused SAR Altimetry and innovative river level gauges for Coastal Monitoring

ESA Contract 4000136960/21/I-DT-Ir

Project Reference FFSARCOASTAL_ESA_ D4.4
Issue:1.1

This page has been intentionally left blank

Change Record

Date	Issue	Section	Page	Comment
01/09/2023	1.0	all	all	1st version
19/09/2023	1.1	various	various	Updatse following ESA review

Control Document

Process	Name	Date
Written by:	David Cotton	19/09/2023
Checked by	David Cotton	
Approved by:	David Cotton	

Subject	Fully Focused SAR Altimetry and Innovative River Level Gauges for Coastal Monitoring	Project	FFSARCOASTAL

Author	Organisation	Internal references
David Cotton	SatOC	FFSARCOASTAL_ESA _D4.4

	Signature	Date
For FFSARCOASTAL team	David Cotton	19/09/23
For ESA	Date: 2023.10.05 13:26:53 '+02'00 Digitally signed by Jérôme Benveniste	

Table of Contents

1 Introduction 5
1.1 The FFSAR Coastal Project 5
1.2 Scope of this Document 5
1.3 Applicable Documents 5
1.4 Reference Documents 5
1.5 Overview of this Document 5
2 Summary of Main Activities 6
2.1 Introduction 6
2.2 User Engagement and Application Road Map (WP1000) 8
2.3 Fully Focused SAR Processing and Water Level Analysis (WP2000) 8
2.4 Installation and operation of micro-stations and drone campaign (WP3000) 16
2.5 Issues Impacting the Project 18
2.6 Project Deliverables 19
3 Highlights of Results 20
3.1 User Engagement and Application Road Map 20
3.2 Fully Focused SAR Processing and Water Level Analysis 20
3.3 Installation and operation of micro-gauges and drone campaign 21
4 Project Outreach 21
5 Project Recommendations 21

1 Introduction

1.1 The FFSAR Coastal Project

The project has applied the Fully Focused (FF) SAR altimetry processor to Sentinel-3 data and evaluated its potential to make a significant new contribution to coastal and estuarine monitoring systems, when coupled with innovative water level gauges for validation.
The team has investigated the potential benefits to applications that can take advantage of the very high along-track resolution in water level and backscatter that can be provided through Fully Focused SAR processing. The FFSAR processing has been applied to Sentinel-3 tracks in the two study regions: The Severn Estuary in the UK and the Rhône River in France. User agencies and groups from the two regions have been consulted to identify gaps and priorities for monitoring requirements.
Innovative in-situ water level gauges have been used to validate the satellite data. Time series have been provided by autonomous gauges placed at fixed locations, and gauges mounted on drones were used to provide water level profiles between the fixed locations and satellite tracks.

1.2 Scope of this Document

This Final Report provides a summary of main activities, issues impacting the project, highlights of results, and lists the main outputs and recommendations.

1.3 Applicable Documents

AD-01: Fully Focused Sar Altimetry and Innovative River Level Gauges For Coastal Monitoring (FFSAR-Coastal) - ESA Contract No. 4000136960/21/I-DT-Ir

1.4 Reference Documents

RD-01 FFSAR-Coastal Proposal. V1.1 29/07/21, SatOC and FFSAR-Coastal team.
RD-02 FFSAR-Coastal Application Road Map V1.1, D1.1, 17/08/23
RD-03 FFSAR-Coastal Data Set of Processed Altimeter Data, D2.1, 14/08/23
RD-04 FFSAR-Coastal Product Validation and Evaluation Report V2.1, D2.2 22/08/23
RD-05 FFSAR-Coastal In situ data campaign Report V1.0, D3.1, 15/06/23
RD-06 FFSAR-Coastal In situ data set Format V1.2, D3.2 15/06/23
RD-07 FFSAR-Coastal Communications Package V2.0, D4.5 29/08/23

1.5 Overview of this Document

This deliverable is organised into the following sections:

Section 2: Summary of Main Activities
Section 3: Highlights of Results
Section 4: Project Recommendations.

2 Summary of Main Activities

2.1 Introduction

The FFSAR-Coastal project was funded by the European Space Agency under the EO Science for Society Open Call. It was submitted under the Grand Science Challenges theme. The project was kicked-off on 11th March 2022, and the Final Review meeting was held on 21st June 2023. The project timescale was extended from 12 months to 15 months, primarily to allow a minimum of 9 months of in-situ data to be collected from the specially installed vorteX.io micro-gauges.

2.1.1 Project Overview

The project has applied the CLS/ESA/CNES SMAP Fully Focussed (FF) SAR altimetry processor (https://github.com/cls-obsnadir-dev/SMAP-FFSAR) on Sentinel-3 data and evaluated its potential to make a significant new contribution to coastal and estuarine monitoring systems, when coupled with innovative water level gauges for validation.

Two different environments were considered (see Figure 2.1):

- The Severn Estuary and river: A highly dynamic mixed tidal estuary environment, the confluence between a river and its estuary experiencing large tidal range and strong tidal currents.
- The lower Rhône Delta and Camargue: A low lying, flat river delta and wetland environment, susceptible to inundation and water level rise.

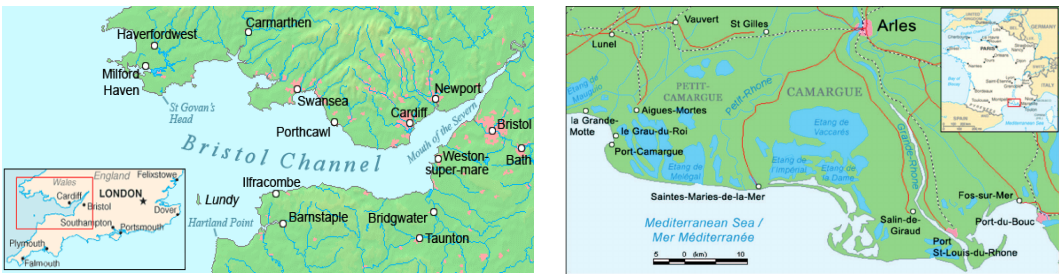

Figure 2.1 The two regions of interest investigated in the FFSAR-Coastal Project. Left: The Bristol Channel / Severn Estuary in the UK. Right: The Rhône delta in Southern France

The project investigated the potential applicability and benefits offered by FF SAR altimeter data in these two different environments. Analysis focused on the benefits offered by the very high along-track resolution in water level and backscatter that can be provided through Fully Focussed SAR processing. User agencies and groups from the two regions were consulted to identify gaps and priorities for monitoring requirements.

Innovative in-situ water level gauges were used to validate the satellite data. Time series were provided by autonomous gauges placed at fixed locations, gauges

mounted on drones were used to provide water level profiles between the fixed locations and satellite tracks.

2.1.2 Scientific and Technical Objectives

The main objective was to demonstrate and evaluate the application of Fully Focussed (FF) SAR Altimetry as a contribution to coastal and estuarine monitoring systems when coupled with innovative water level gauges for validation.

Specific scientific / technical objectives were:

- Apply a fully focused (FF) SAR processor on Sentinel 3A and Sentinel 3B data for 2 selected areas.
- Installation and operation of innovative water level micro-gauges.
- Validation of FF SAR products against in-situ data, and evaluation of the performance of these FF SAR products in terms of accuracy, precision, and resolution.
- Objective assessment of the potential contribution of FF SAR products and innovative water level micro-gauges in a coastal monitoring system.

These objectives were addressed under three technical work packages:

WP1000 User Engagement and Application Road Map
WP2000 Fully Focused SAR Processing and Water Level Analysis
WP3000 Installation and operation of micro-gauges and drone campaign

Figure 2.2 gives a diagrammatic representation of the links and timing of the work-packages.

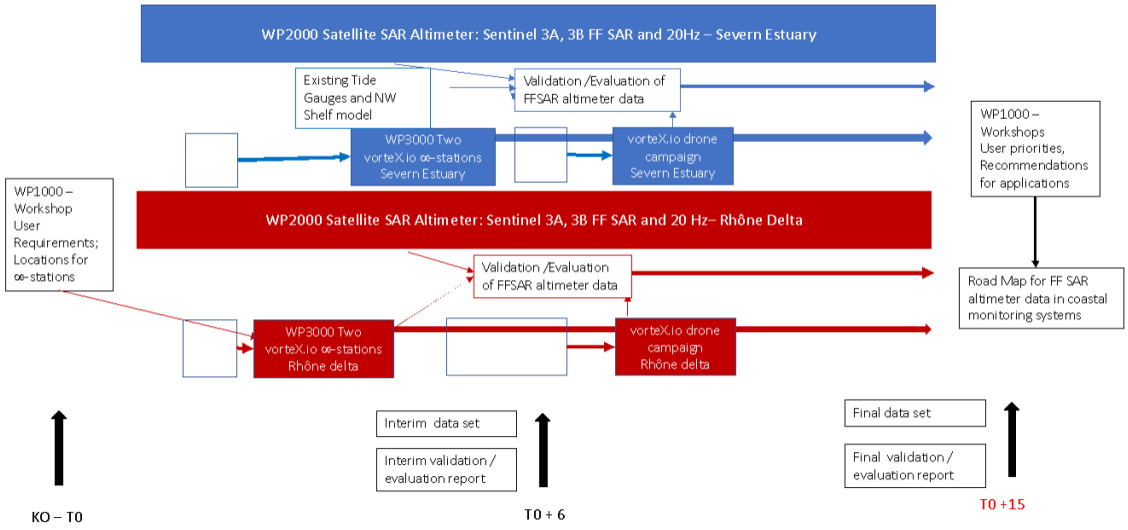

Figure 2.2 Overview of the FFSAR-Coastal work programme and links between the work packages. The timing of the project runs from left to right. Note that NW shelf model data were not used in the evaluation / validation of FFSAR altimeter data, but ICESAT-2 data were used instead.

The activities of the three technical work packages are described in more detail in sub-sections below.

2.2 User Engagement and Application Road Map (WP1000)

This activity was led by NOC, with support from the Channel Coast Observatory as a coordinating body for the UK user community, from vorteX.io to provide a link to French users, and from SatOC to edit the compilation of the Application Roadmap (RD-02).

The aim was to consult with local partnerships and forums, environment agencies, regional authorities and other stakeholders in the Severn Estuary and Rhône Delta to identify key issues and data requirements that are currently not satisfied.
Follow up and final workshops presented the project findings to the user communities and invited recommendations for further implementation.

Table 2.1 lists the meetings held with users.

	Dates	Details	Participants
Initial Workshop	17/05/22	Online	16 UK, 2 France
Follow Up	11/01/23 & 18/01/23	Online	19 UK, 3 France
Final Workshop	13/06/23 15/06/23	Hybrid (UK): in person at NOC Southampton Online France	11 UK, 1 France

Table 2.1 FFSAR Coastal User Workshops.

Reports were written after each workshop and were circulated to the users who attended to ensure that all key points had been captured.

In general, there was an interest in the additional capabilities that FFSAR processing of SAR altimeter data could offer, in terms of higher along-track resolution and the possibility to measure water levels where it was previously not possible from satellites. However, satellite data are often not widely used, because of the limited sampling available in time and space at the coast.

Section 2 of the Application Road Map (RD-02) summarises the key user requirements and gaps in data provision that were identified by users.

2.3 Fully Focused SAR Processing and Water Level Analysis (WP2000)

This activity was carried out by DTU Space, who were responsible for the implementation of the CLS/ESA/CNES SMAP (Standalone Multi-mission Altimetry Processor) Fully Focused SAR processor, the assessment of different processing options, validation against in-situ data, and the evaluation of the final FFSAR processed water level product.

2.4.1 Fully Focused SAR Altimeter Processing

RD-03 provides a full description of the Fully Focused SAR processing that was implemented, and the data sets that were produced. The FFSAR processed data sets are available through the resources page on the UK Coastal Monitoring website at: https://www.coastalmonitoring.org/ccoresources/FFSAR-Coastal/.

DTU Space implemented the SMAP (Standalone Multi-mission Altimetry Processor) that was developed by CLS in collaboration with ESA and CNES, and which is available at https://github.com/cls-obsnadir-dev/SMAP-FFSAR. The SMAP processor is implemented in python 3 and, for this project, used Sentinel-3 L1A netCDF4 products as input.

The processor was applied to selected Sentinel-3A and S Sentinel-3B tracks for the two selected study areas the Severn Estuary in the UK, and the Rhone Delta in Southern France (Figure 2.3)

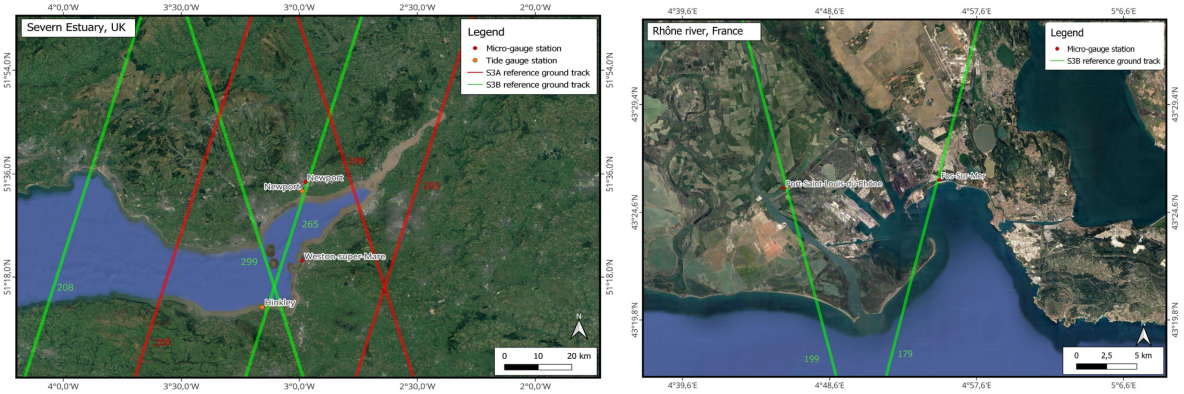

Figure 2.3 A map showing the Severn Estuary (left) and Rhône delta (right) along with the S3A and S3B reference ground tracks that FFSAR altimetry processing was applied to in the project. The locations of the micro-gauge stations installed by vorteX-io are shown as red dots, and the two tide gauge stations in the Severn Estuary as orange dots. [Imagery © TerraMetrics 2023, Map data © 2023 Google]

Data processed for the Severn Estuary initially included data from all six reference ground tracks illustrated in Figure 2.3. Later, more detailed analysis, focussed on data from track S3B-265. The final data set only includes data from track S3B-265. For the Rhône River data from two tracks were processed: S3B-179 and S3B-199 from S3B. 179 is a descending track, and 199 is ascending. Table 2.2 lists the input data that were processed for the two regions.

Region	Relative Orbit Number	Sentinel-3B period (cycles)
Severn	265	Dec 2018 (cycle 19) -April 2023 (cycle 78)
Rhône	179	March 2019 (cycle 23) – April 2023 (cycle 78)
Rhône	199	Dec 2018 (cycle 19) – May 2023 (cycle 79)

Table 2.2 Downloaded and FFSAR processed SAR altimeter data (RON = Relative Orbit Number)

Different processing options are available on the SMAP processor, firstly at the L1b level, and then secondly in terms of the re-tracker that is applied to the waveform generated. Table 2.3 lists the L1b processing parameters that were selected on the SMAP processor. Outputs from three re-trackers available on SMAP were analysed: OCOG (Offset Centre of Gravity), PTR (Point Target Response), and MultiPTR (Multiple Target Response). In addition, the DTU in-house Multiple Waveform Persistent Peak (MWaPP) re-tracker was implemented and evaluated.

Parameter	Value Severn Estuary	Value Rhône River
Illumination time	2.3 s	2.3 s
Hamming range	Yes	Yes
Hamming azimuth	Yes	Yes
Zero padding	2	2
Posting rate	1000 Hz	1000 Hz
Range extension factor	1	1

Table 2.3 L1b processing parameters used in the application of the SMAP for the two study areas.

2.4.2 Validation of Fully Focused SAR Data

The methodology and results of the validation of the FFSAR data sets is fully described in FFSAR-Coastal Product Validation and Evaluation Reports (RD-04).

The FFSAR processed data sets, with different L1b processor and re-tracker options, were validated against available in-situ data and also against ICESAT-2 data. The use of ICESAT-2 data had not been initially planned, but these data were found to be a very reliable and useful reference. Validation against ICESAT-2 took precedence against the initially planned use of operational hydrodynamic model data.

Posting rates and illumination times

Different posting rates (500Hz – 1500 Hz) and illumination times (1s and 2.3s) were applied to the FFSAR processing and validated against data from the Rhône Fos Sur Mer and Port St Louis (only illumination time of 2.3s used) vorteX.io micro-gauges. In general, the results of median bias, root mean square error (rmse) and correlation were similar for all options. The best correlation and the lowest RMSE were obtained when using a posting rate of 700, and the highest number of matching heights estimate and micro-gauge reference data was obtained using a posting rate of 1100Hz. This was taken to validate the selected options of 2.3s for illumination time and 1000Hz for posting rate, though it can be noted a higher posting rate could be selected to provide a higher along track resolution without a big reduction in performance.

Re-tracker Options

The output from different re-trackers (OCOG, PTR, Multi-PTR, and MWaPP) was evaluated through comparisons against ICESAT-2 and vorteX.io micro-gauge data,

at the Rhône Fos sur Mer and Port St Louis vorteX.io micro-gauge sites (Figure 2.4 and Figure 2.5).

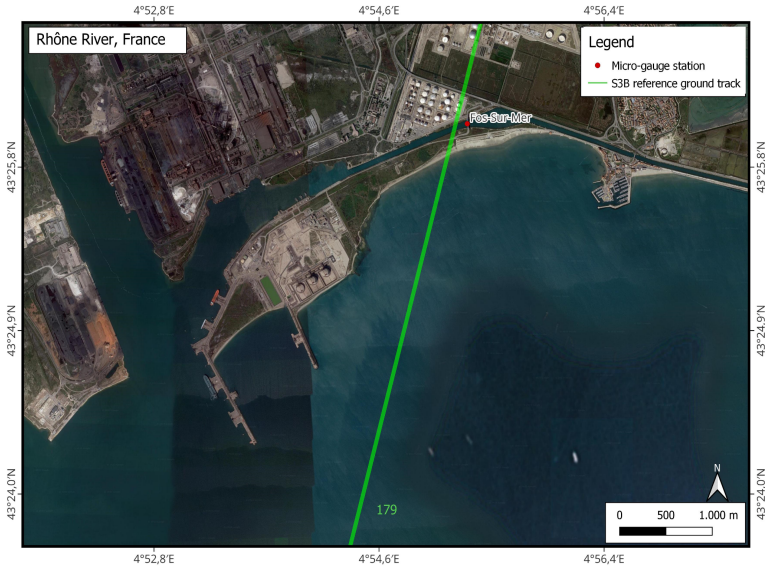

Figure 2.4 The location of reference ground track S3B-179 close to the mouth of the Rhône River in Fos-Sur-Mer. The location of the micro-gauge station installed by vorteX-io on the bridge over the canal is shown as a red dot. [Imagery © 2023 Aerodata]

From the analysis at both sites, it could be seen that the MWaPP re-tracker gave the best results in terms of rmse and correlation, with the difference at Fos Sur Mer being the strongest. This was interpreted to indicate that the MWaPP re-tracker was better than the other re-trackers at retrieving valid water levels over smaller size water bodies, whilst providing equal performance (and sometimes also better) for larger size water bodies.

A similar analysis was carried out for the two vorteX.io micro-gauges on the River Severn in the UK. Again, the MWaPP re-tracker was found to give the best performance (in terms of lowest rmse and highest correlation), though there was evidence the Multi_PTR re-tracker could be a good option for open water.

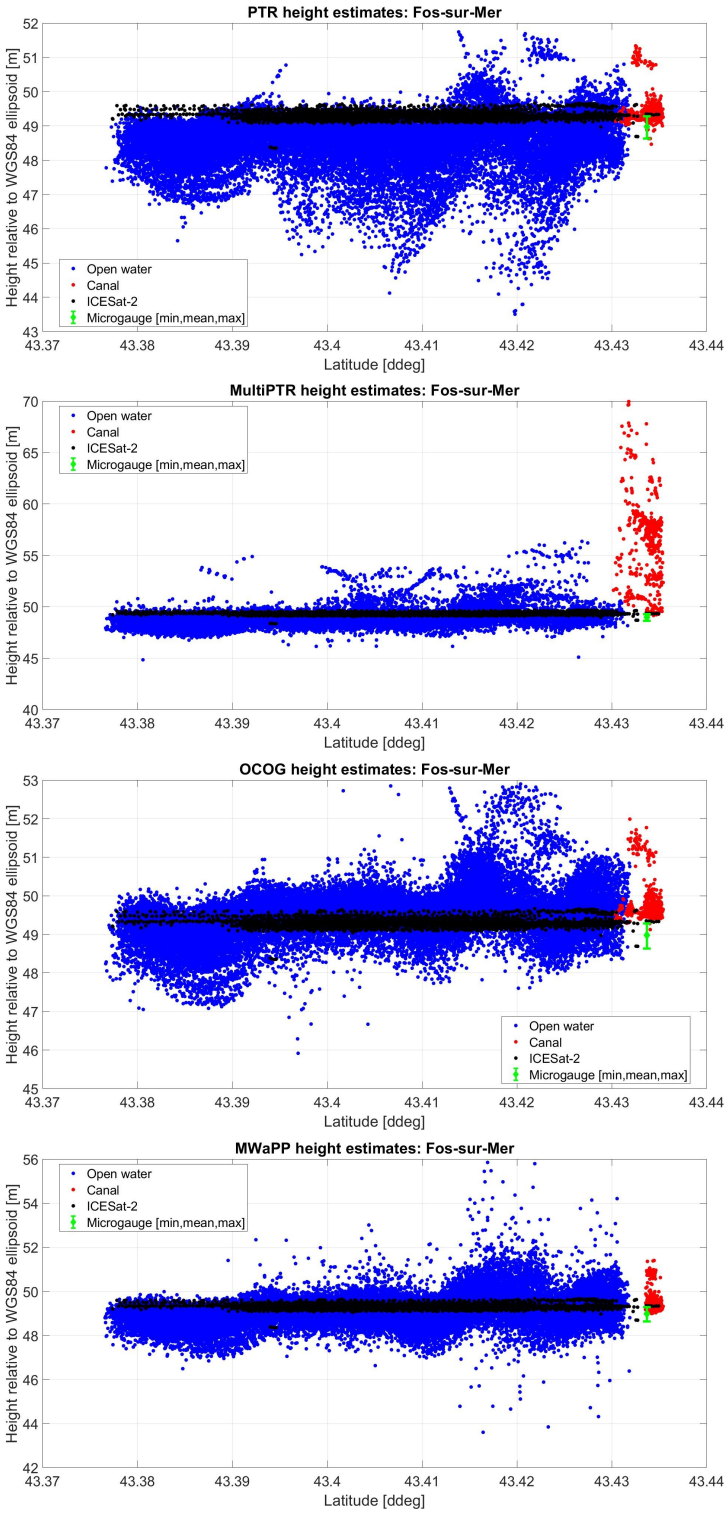

Figure 2.5 : FFSAR water levels estimated by the PTR, Multi-PTR, OCOG and MWaPP re-trackers (track S3B-179) close to the Fos sur mer vorteX.io micro-gauge, as a function of latitude. The blue data points are over open water, the red dots in the canal. The black data points are ICESat-2 data with the same spatial and temporal origin as the FFSAR data. The green error bar represents the variance in the observed micro-gauge signal, with the minimum, median and maximum values defining a reference interval.

Validation against Long-Term Tide Gauge Data (River Severn)

The FFSAR processed data were also validated against long-term data from UK Tide Gauges operated by the National Tide and Sea Level Facility. (Figure 2.6 and Figure 2.7). The results showed a high correlation (0.98 and 0.99) and rmse of about 0.5m).

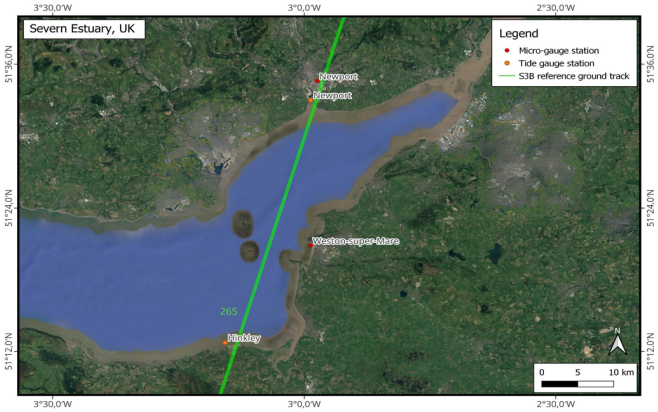

Figure 2.6 Location of the ground track for RON 265 in the Severn Estuary lying at the end of the Bristol Channel, UK. The location of the vorteX-io micro-gauge stations and NOC tide gauge stations are marked as red and orange dots respectively. [Imagery © 2023 TerraMetrics, Map data © 2023 Google]

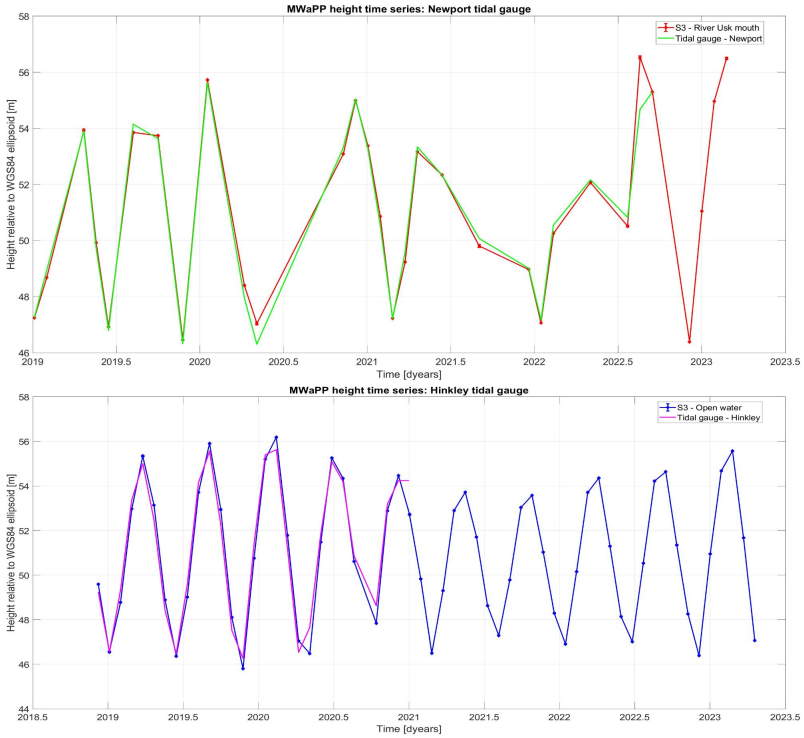

Figure 2.7 Time series of FFSAR water levels (MWaPP re-tracker) and (re-aligned) Tide Gauge data for two locations in the River Severn. Top: Newport in the mouth of River Usk. Bottom: Hinkley Point. Note the Hinkley Point tide gauge data end late 2020.

2.4.3 Evaluation of Fully Focused SAR Data to monitor small scale signals

DTU carried out an evaluation of the capability of FFSAR data to monitor small scale signals, again fully described in the document: FFSAR-Coastal Product Validation and Evaluation Reports (RD-04).
The overall aim was to investigate the ability of FFSAR to detect small-scale physical signals (surface gradients, currents, roughness signatures) in highly tidal regions and to investigate the applicability of FF-SAR to detect and measure tidal asymmetry/gradients across estuaries not seen with conventional altimetry. We were limited to look at height related quantities (surface gradients, and currents) as we only used empirical re-trackers which do not provide measurements of surface roughness.

There were two aspects to the study, the first was an investigation into small scale tidal signals in the River Severn, and the second looked at gradients in water levels close to the mouth of the Rhône River.

Tidal Signals in the River Severn

FFSAR data from S3B Track 265 (cycles 19-65), processed with the MWaPP re-tracker, were used for this study. Along track smoothing was applied to the retrieved Sea Level Anomalies (relative to the DTU21 mean sea surface surface) to remove the effects of “snagging” (erroneous water levels, resulting from reflections from off-nadir reflecting surfaces, thought to be from “locked” harbours). Large tidal slopes (1m in 30km) were evident in the data for individual passes across the estuary (Figure 2.8).

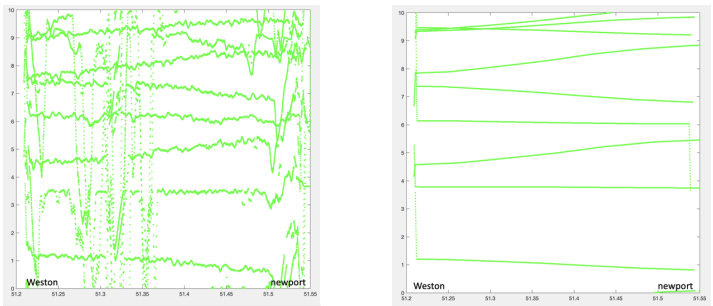

Figure 2.8 Left: Sea Level Anomaly for the first seven cycles of S3B smoothed over 100 meters. Right: FES2014 ocean tide correction.

The orbit of Sentinel-3 is sun-synchronous, which prevents the determination of certain tidal constituents. However, the M2 component is well-defined, with an alias period of 230 days for S3A and S3B, and so suitable for investigation. A Tidal Analysis was performed on the M2 constituent for 45 cycles of data, at 1000 Hz (6m resolution) and significant residuals to the FES2014b model were found, ranging up to 1.6m (See Figure 2.9). Closer inspection revealed that these tidal variations were highly correlated with the two islands called Flat Holm and Split Rock located in the centre of the Estuary. Between the two islands, there is an opening that ranges between hundreds and meters at low tides and several kilometres at high tides. The water depth also varies from a few meters to 20 meters depending on the tidal height. We expect

this variation in width and depth to be responsible for creating large variations in the tidal range close to the islands.
It was concluded that further S3A/B data should be re-tracked and analysed to investigate and validate these findings for the M2 constituents. Such extended analysis could also be designed to deal better with the very severe problem of snagging which was seen in many places and which is dependent on the magnitude of the tides when the tidal locks are in place in several locations.

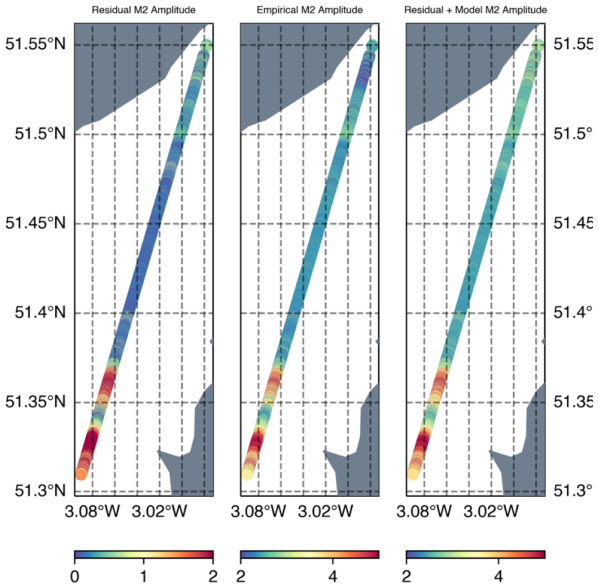

Figure 2.9 Left figure: Residual M2 tidal estimate (meters) to FES2014b along the transect from Weston to Newport. Central figure: Tidal estimate from the full sea surface height signal. Full tidal estimate (Residual + FES2014b)

Slopes and Currents

The FFSAR data were also assessed in terms of their potential to measure surface slopes on small scales for both the Severn and Rhone rivers.

Although some individual water level profiles from FFSAR processed data do show gradients of water level along track (seen in Figure 2.8), an attempt to compare along track water level profiles with data from the vorteX.io drone flights (Section 2.4) identified major difficulties, preventing a meaningful interpretation. For the River Rhône, the issue was that the satellite data encountered “snagging” from off nadir targets, and for the Severn estuary data the problem was the large tidal variations, meaning that, unless the drone and satellite data were exactly co-located in time and space, tidal variability overwhelmed any other sea level signal. This points to the importance of accurate high resolution tidal models for coastal estuaries.

However, along river gradients could be estimated for the River Rhône where the river bends so that the same satellite track crosses the river at different points.

2.4 Installation and operation of micro-stations and drone campaign (WP3000)

This work package was carried out by vorteX.io. The main activities were the installation of four vorteX.io micro-gauges (two in the UK and two in France), and then to carry out two drone campaigns, one in each region. Together these data sets provided in-situ data for validating the FFSAR processed altimeter data. They also provided a demonstration of the capability of micro-gauges for the validation of satellite measurements. A full in-situ data campaign report is provided in RD-05.

2.6.1 vorteX.io Micro-gauges

The vorteX.io micro-gauge is a small, autonomous and easy to install water level gauge. It provides accurate water levels and water surface velocities and transmits data through the GSM mobile data network. It can also be remotely controlled through the GSM connection. It is powered by an internal battery and a solar panel, so requires no external power supply.

Four vorteX.io micro-gauges were installed for the FFSAR-Coastal project, two at locations on the Severn Estuary in the UK (Newport and Weston Super Mare), and two at locations near the mouth of the River Rhône in the south of France (Fos Sur Mer, and Port St Louis du Rhône (Figure 2.10).

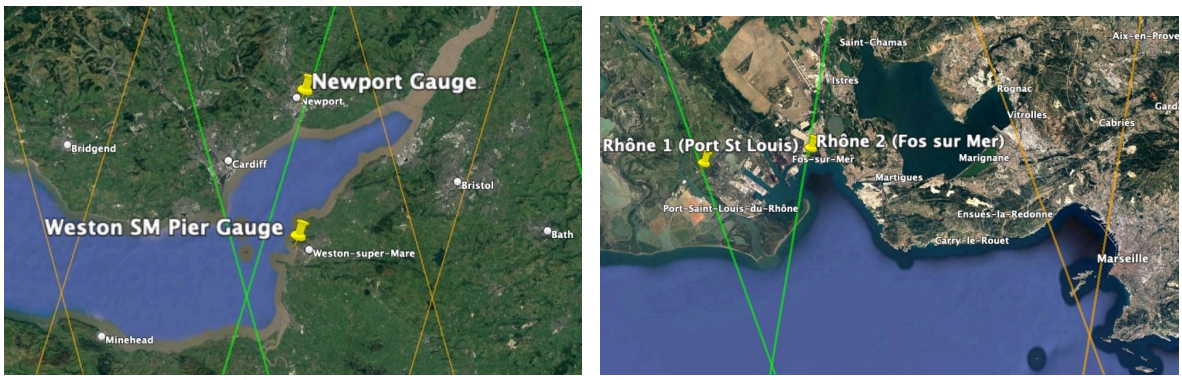

Figure 2.10 Locations of the vorteX.io micro-gauges. Left: on the Severn Estuary (UK), Right: on the River Rhône (France). The yellow pins show the locations of the gauges, the brown and green lines show the sub-satellite tracks of the Sentinel 3A and 3B satellite respectively.

The micro-gauges were installed on bridges across inshore canals at Fos Sur Mer at Port St Louis du Rhône on 27 July 2022. Base station GNSS measurements were made at the same time to provide accurate geo-referencing for the water level measurements. Both stations continue to provide water level measurements. The tidal signal is small at these locations and the water level signal tends to be dominated by river flow variability.

The micro-gauges were installed at Newport and Weston Super Mare on 6 September 2022. At gauge at Newport was installed under a road bridge across the River Usk, the gauge at Weston Super Mare was installed on the end of a pier. Base station GNSS measurements were not made at the time. Geo-referencing was later provided through the drone campaign. A fault developed on the gauge at Weston Super Mare, and it was replaced on 6th April 2023.
The tidal signal is large at both locations, over 10m at Newport and 6m at Weston Super Mare. The water dries out at just below half tide at the location of the Weston Super Mare gauge, whereas the Newport gauge is over the lower reaches of the River Usk, so whilst it is always over water, at low tide the level is sometimes determined by the river outflow.

2.6.2 vorteX.io drone campaigns

Two drone campaigns were carried out by vorteX.io. The aim was to connect the water level at the locations of the vorteX.io micro-gauges to the nearby Sentinel-3 satellite track, at the time of the satellite pass, and also to provide along river and along track water level profiles for further analysis. The data were also used to geo-reference the micro-gauge water level measurements. The drone carries a lidar and camera and can be remotely operated from land or boat deployments.
The drone campaign over the River Severn was successfully carried out, via boat deployments, on the 24th February 2023. There were seven individual flights over nearly 3 hours (see Figure 2.11). Further flights were cancelled because of high winds.
The drone campaign over the Rhône was successfully carried out, via land deployment, on the 13th April 2023. There were six individual flights, four close to the Port Saint Louis du Rhône, and two close to Fos sur Mer (see Figure 2.12).
All necessary flight permissions were obtained in advance of both campaigns.

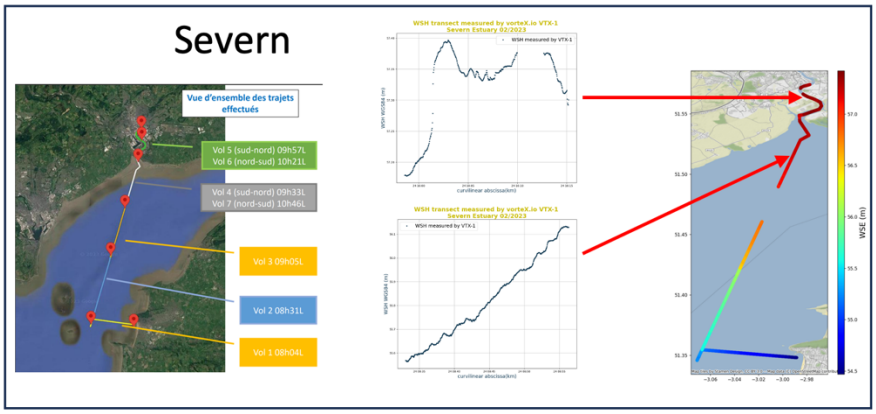

Figure 2.11 The vorteX.io drone campaign over the Severn Estuary (UK). Left panel shows the locations of the individual flights; the centre panels give the water level profiles for flight segments 4 and 5; the right panel shows the along track water surface elevations.

2.6.3 vorteX.io data

All micro-gauge and drone data are available via a dedicated page on the UK coastal monitoring website (https://www.coastalmonitoring.org/ccoresources/FFSAR-Coastal/). The in-situ data are described in RD-06.

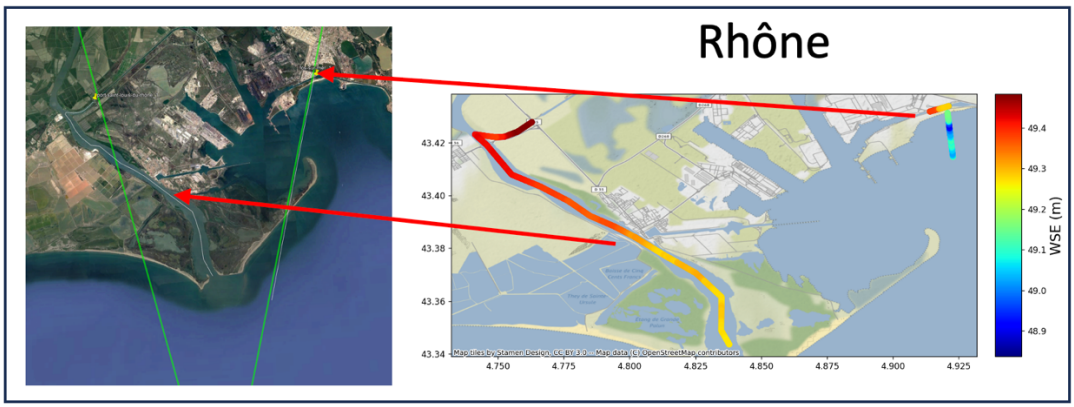

Figure 2.12 The vorteX.io drone campaign over the Rhône (France). Left panel shows the locations of the individual flights; the right panel shows the along track water surface elevations.

2.5 Issues Impacting the Project

A number of issues have had an impact on the FFSAR-Coastal project.

At the start of the project (March 2022), there were still some restrictions in place on travel and meetings due to the COVID-19 pandemic. As a result, initial meetings were held online. Although most restrictions across Europe were lifted soon after the project kick-off, the initial user workshop was also held online. There were no subsequent impacts from COVID-19 on the project.

It had been planned to install the vorteX.io micro-gauges as soon as possible after project kick-off, to maximise the available data collection time. In practice it took some time to identify suitable locations, gain permission for the installations and to engage rope access specialists to carry out the installations. Thus it was not until 27th July 2022 when the two vorteX.io micro-gauges were installed at the locations close to the mouth of the Rhône, and 6th September 2022 when the gauges were installed at Newport and Weston Super Mare. At this point a three-month extension to the project was requested, and granted, to allow for a minimum 9-month data collection period across all sites.

A series of potential dates for the drone campaigns were identified to coincide with the dates of the overflight of Sentinel 3B along the relevant tracks. Backup dates were identified in case of a requirement to postpone through bad weather. Fortunately for the Severn Estuary, the weather for the first selected date (24th February 2023) was suitable, even though increased winds later in the day resulted in a cancellation of

later flights. For the Rhône, the weather was unsuitable on two planned dates (18 February, 17th March 2023) and a third backup date was required (13th April).

The vorteX.io micro-gauge at Weston Super Mare developed a fault in February 2023, and a replacement was installed on 6th April 2023. An initial replacement was damaged by the courier in transit, further delaying the installation of the replacement micro-gauge.

2.6 Project Deliverables

The formal project deliverables are listed below. All are available through the project website: https://www.satoc.eu/projects/ffsar/

2.6.1 Reports

D1.1 FFSAR Coastal Application Road Map
D2.1 FFSAR Coastal Data Set of Processed Altimeter Data
D2.2 FFSAR Coastal Product Validation and Evaluation Report
D3.1 FFSAR Coastal In Situ Data Campaign Report
D3.2 FFSAR Coastal In Situ data set

2.6.2 Data Sets

The FFSAR Coastal data sets are available through a dedicated page on the UK Coastal Monitoring Web Site, at:
https://www.coastalmonitoring.org/ccoresources/FFSAR-Coastal/

The data sets are:

FFSAR Processed data

Along track FFSAR processed data for three Sentinel 3B tracks:

- FFSAR_S3B_265_20181208_20230419.nc (Severn Region)
- FFSAR_S3B_199_20181203_20230414.nc (Rhône Region)
- FFSAR_S3B_179_20190320_20230413.nc (Rhône Region)

Time series water level data constructed from FFSAR processed Sentinel 3B data for six locations:

- Rhone_S3B_179_open.nc
- Rhone_S3B_179_canal.nc
- Rhone_S3B_199_north.nc
- Rhone_S3B_199_south.nc
- Severn_S3B_265_open.nc
- Severn_S3B_265_tributary.nc

In Situ data

Time series data from the four vorteX.io micro-gauges

- Newport, Wales (A34 Road Bridge)
- Weston Super Mare, England (Grand Pier)
- Fos Sur Mer, France
- Port St Louise du Rhône, France

vorteX.io drone lidar water level profile data flight data, from 2 flight series

- Severn Estuary, 7 flights, filtered and unfiltered along track profiles.
- Rhône delta, 4 flights, filtered and unfiltered along track profiles.

3 Highlights of Results

3.1 User Engagement and Application Road Map

The project has successfully engaged users in the project, who have contributed to identifying gaps in data provision, and priorities for improvement. The recommendations in the Application Road Map have been developed to address these priorities.
Some users have also expressed interest in being involved in follow-up activities.

3.2 Fully Focused SAR Processing and Water Level Analysis

After an investigation of different parameter settings in the SMAP processor (for posting rate and the illumination time) and of different L1b to L2 re-trackers, an initial processing recipe is recommended (Recommendation #1).

Based on the analysis carried out, we have found that the use of FFSAR processing is highly beneficial when observing small targets, water slopes, and near coastal areas. As this study only included a few sites that in addition are very different in terms of the water level variations, it is recommended to test and evaluate the use of FFSAR-based sea levels at more coastal sites and water levels at additional river sites to get a more solid understanding of the benefits of FFSAR (Recommendation #2).

The Severn Estuary tidal study from FFSAR revealed the ability to determine tides at kilometre spatial resolution from FF-SAR altimetry. These results are novel and interesting in the sense that we do find significant tidal residuals of up to 1.6 meters for M2 along the track at the sampling rate of 6 meters relative to the state-of-the-art Ocean tide model FES2016b.

3.3 Installation and operation of micro-gauges and drone campaign

Four vorteX.io micro-stations have been successfully installed in the Rhône delta and in the Severn estuary close to, or below Sentinel-3 tracks. The measurements in all the sites are nominal and all micro-gauges are working properly. All stations have been synchronized with their respective Sentinel-3 passes. The capability and functionality of small, autonomous water level gauges for validation of satellite water level measurements has been clearly demonstrated (Recommendation #5)

Drone flights were performed successfully over the Severn and Rhône estuaries, using the vorteX-io lightweight LiDAR altimeter to measure water surface height all along the drone flight and the resulting measurements present very good quality.

Users expressed interest in the drone data because of the flexibility of the drone, which can be deployed wherever and whenever it is needed, whereas satellite data is only available according to its orbit.

Another very interesting application of drone data in coastal areas is the observation of tide signals along the satellite track. They can be used to validate the tidal correction of satellite data. Waves signals are also well measured by the drone LiDAR altimeter. There is therefore potential to exploit these data for coastal application. It is worth noting that specific processing algorithms have been developed to compute the directional swell power spectrum from drone LiDAR data. In this framework, computing the wave properties at different locations and distance from the coast in coastal areas could be a very interesting feature for future studies. (Recommendation #6)

4 Project Outreach

The FFSAR-Coastal project has been presented at a number of scientific meetings, including ESA Living Planet Symposium, the 7th Sentinel-3 Validation Team Meeting, OSTST 2022, 13th Coastal Altimetry Workshop, IUGG 2023. Abstracts have also been accepted for presentation at HYDROSPACE 2023. All presentations are available on the project website and are listed in RD-07.
It is planned to develop some of the work for scientific peer review publication. The relatively short time frame of the project did not allow sufficient time for this process to be completed.

5 Project Recommendations

The project partners compiled a series of 13 recommendations that are provided in the Application Road Map (RD-02). We list them below:

Recommendation 1 – FFSAR-Coastal Processing "Recipe"
The combination of MWaPP retracker, 2.3s illumination time, and 1000 Hz posting rate was able to provide stable and reliable measurements of water levels in both regions, on narrow (~60m wide) channels and on open coastal locations.

Therefore, this general “recipe” is recommended for initial wider scale processing.

Recommendation 2 – Further FFSAR Processing Research – Different coastal locations and environments.
There should be more extensive studies over a wide range of locations to understand if there is need for / possibility to develop an adaptive re-tracker system. This could use information on the type of environment under the satellite track and also / alternatively a waveform classification system.

Recommendation 3 – Multi-Satellite Study – Sea State impact on FFSAR
To investigate the effects of sea state on FFSAR measurements there should be a regionally focused study at a suitable well instrumented location (with e.g. wave buoys, water level / tide gauges, coastal radar).

Recommendation 4 – Isolating Nadir Reflections
We recommend further investigation into how to isolate the part of the return waveform that relates to the reflections from nadir. Reflections from off-nadir will give incorrect (low) estimates of water level, as the echo will have travelled a longer path.

Recommendation 5 – Micro-gauges for satellite data validation
The vortex.io micro-gauges have been found to be highly suitable instruments for providing ground truth to satellite water level measurements.

Recommendation 6 – Drones with lidar for research and satellite data validation
The use of drones equipped with lidar to provide a geo-referenced baseline was essential for this study. A wider research use should be considered.

Recommendation 7 – Extreme Events study
A series of extreme water level events should be identified for a selected location and cross referenced against available SAR altimeter data, which is then processed and analysed alongside storm surge model output. This would assess the potential of FFSAR altimetry to support assessment of vulnerability of coasts and to contribute to long-term planning of coastal defences.

Recommendation 8 – Priority Areas for FFSAR (and improved unfocused SAR) altimeter processing.
It is recommended that a costed proposal be put together to generate a new coastal SAR altimeter product (using Fully Focused and unfocused SAR processing) for priority coastal / island locations.

Recommendation 9 –FFSAR Altimeter Products – Coast
It is recommended to develop a costed proposal for a national UK coastal altimeter product which would combine unfocused and fully focussed SAR altimeter data.

Recommendation 12 – Guidelines for use of FFSAR processed altimeter data
An FFSAR altimeter user guide should be created, with clear guidelines for how to use the data.

Recommendation 11 – FFSAR for inter-tidal bathymetry
The use / interpretation of FFSAR processing to measure inter-tidal bathymetry should be investigated.

Recommendation 12 –FFSAR Altimeter Products – Inland Waters
We recommend the development of a proposal to further develop the capability of FFSAR processing to accurately measure water levels in narrow rivers and other inland water locations where other SAR altimeter processing fails.

Recommendation 13 –FFSAR Altimeter Products – Coast and river interface
We recommend development of further research that brings together hydrologists and oceanographers and focuses on the inland water / ocean interface.