


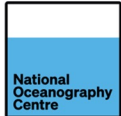



Fully Focused SAR Altimetry and Innovative River Level Gauges for Coastal Monitoring – the FFSAR-Coastal Project

David Cotton (SatOC Ltd, UK), Karina Nielsen, Mikkel Kruse, Ole Andersen (DTU Space, Denmark), Jean-Christophe Poisson (vortex.io, France), Charlie Thompson (Channel Coast Observatory, UK), Amani Becker (National Oceanography Centre, UK), Marco Restano (SERCO/ ESA), Jérôme Benveniste (ESA/ESRIN)

 <p>SATOC SATELLITE OCEANOGRAPHIC CONSULTANTS</p>	 <p>DTU</p>	 <p>VORTEX.IO</p>
 <p>National Oceanography Centre</p>		 <p>Channel Coastal Observatory</p>

FFSAR – Coastal

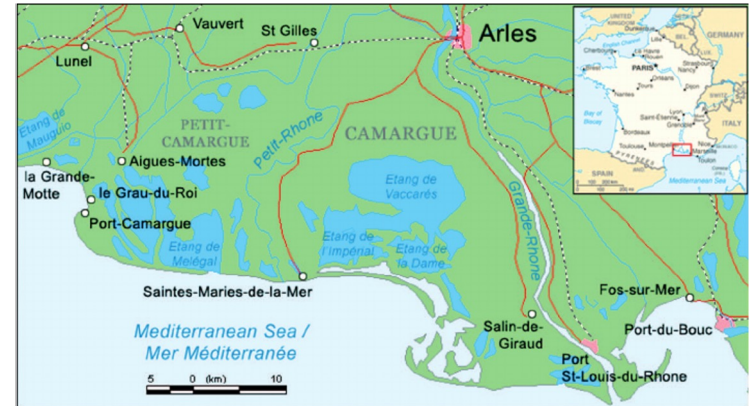
The FFSAR-Coastal Project is applying the SMAP Fully Focused SAR (FFSAR) altimetry processor on Sentinel-3A and Sentinel 3B data in order to evaluate the potential of FFSAR altimeter data to contribute to coastal and estuarine monitoring.

Two different environments :

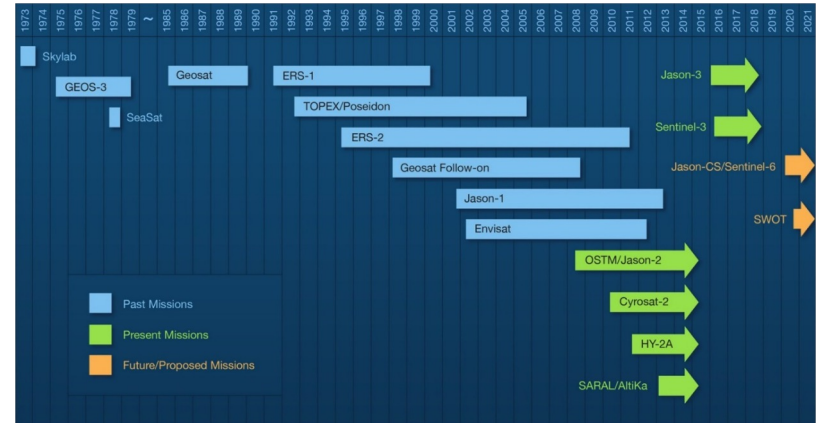
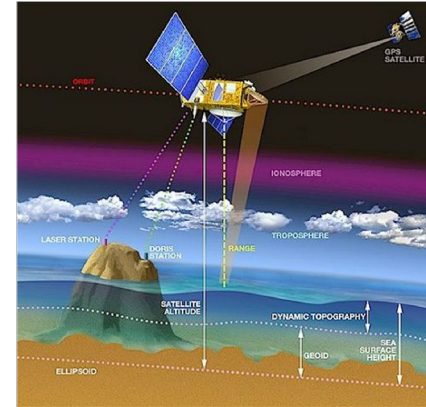
- The Severn Estuary : Highly dynamic mixed tidal estuary environment, confluence between a river and its estuary experiencing large tidal range and strong tidal currents.
- The lower Rhone Delta and Camargue: A low lying, flat river delta and wetland environment, susceptible to inundation and rising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

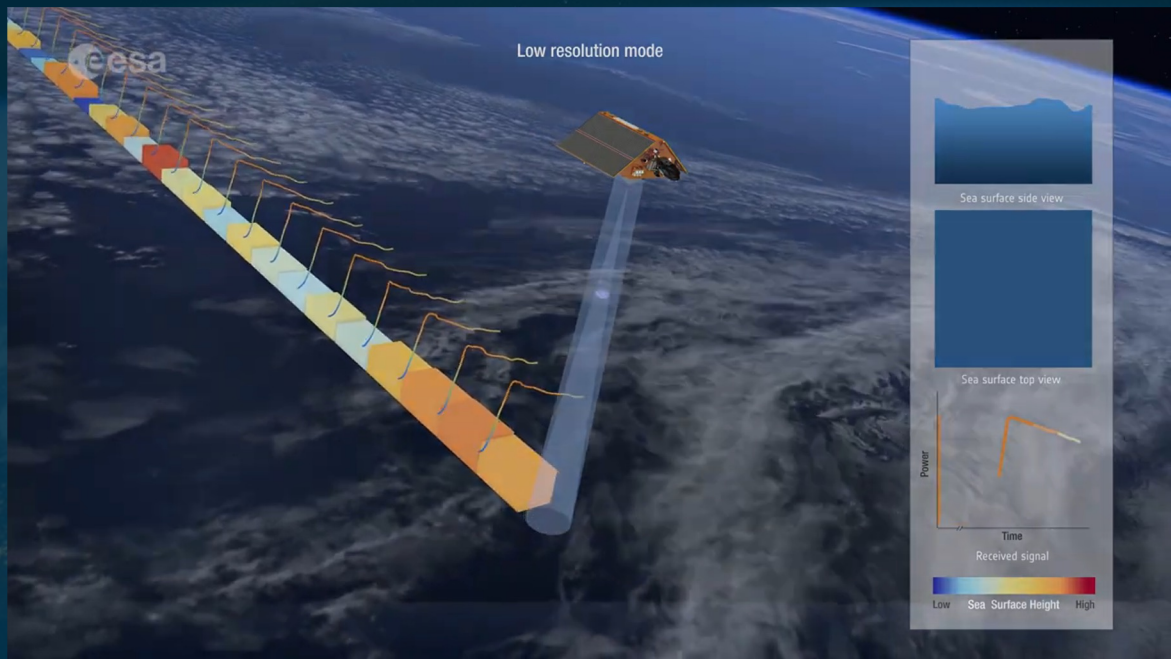
Funded by **ESA** through the EO4Society Open Call

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



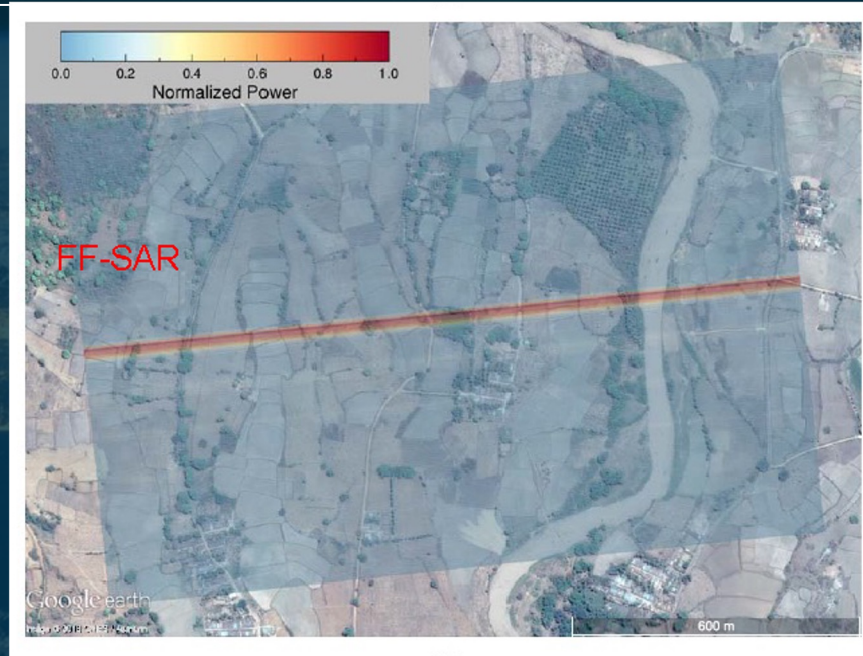
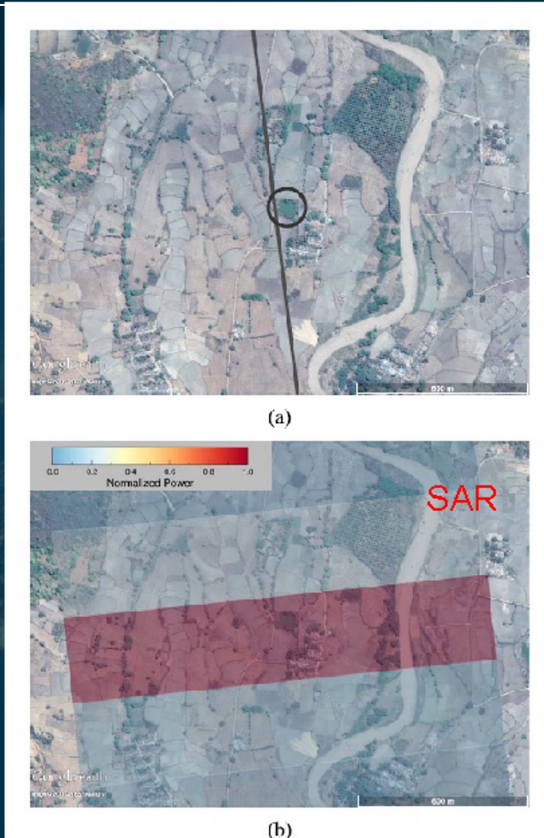
- Satellite altimeter data – highly accurate water level underneath the satellite track
- Low Resolution Mode (LRM) altimetry, continuous coverage since 1991. ERS-1, ERS-2, Envisat, Jason1, 2, 3
- SAR Altimetry (Cryosat-2, Sentinel-3, Sentinel-6: Splits altimetry beam, several looks at single location
 - Unfocused SAR altimetry along track resolution up to around 300m
 - FFSAR altimetry, new processing approach – along track resolution up to 0.5m





- The antenna beam is split in several sub-beams.
- During the overflight, the same point on ground can be observed by different beams from different locations.
- The combination of the waveforms from the different beams leads to the creation of the SAR altimetry waveform, which differs from LRM, and
 - improves the quality of the estimates (lower noise)
 - is associated with an improved resolution in the direction of flight (along-track direction).
- Typically, in the SAR mode, a waveform is returned every 300 m (20-Hz posting rate)

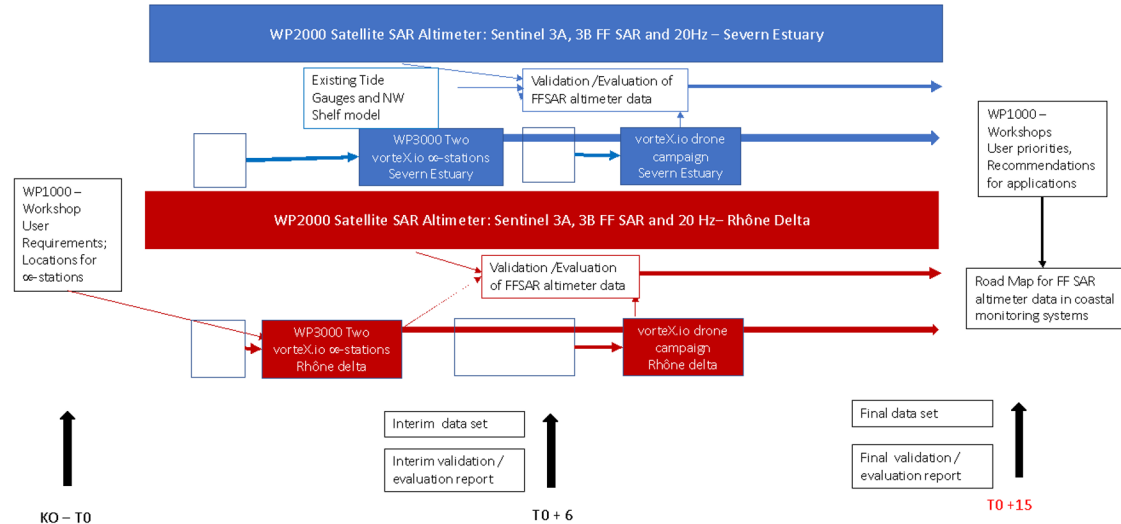
Fully-Focused (FF) SAR Processing vs Unfocused SAR



FF-SAR reduces the impact of land contamination in the footprint (red area, smaller) and allows resolving smaller targets than SAR.

Credit: "Fully Focused SAR Altimetry: Theory And Applications"
by Egido And Smith (2016) Doi: 10.1109/Tgrs.2016.2607122

- Fully Focused SAR processing (DTU)
 - Apply CLS/ESA/CNES SMAP FFSAR processor for S3A, S3B data in Severn and Rhône areas
 - Validate against in-situ data, evaluate ability to map key features
 - Identify optimum processing choices
- Vortex.io micro-gauges
 - Install 4 micro-gauges (2 per region) for in situ validation
 - Drone campaigns to map water level from in situ sites to satellite track
- User Engagement / Application Road Map (NOC, CCO)
 - Workshops > Roadmap for FFSAR processing in Coastal Monitoring Systems



NB – The SMAP processor may be downloaded from github at:
<https://github.com/cls-obsnadir-dev/SMAP-FFSAR>

Workshops held in UK and France to introduce project and understand key requirements from coastal users.

Priority interests and requirements were identified

UK Users require coastal water levels for

- Flood and erosion modelling
- Planning coastal developments
- Interpretation and prediction of sea level trends or significant coastal flooding events
- Not accustomed to satellite products

Gaps in water level data provision

- At the coast where in-situ data are not available
- In shallow inter-tidal regions
- Away from the coast-line for model validation
- Shallow water bathymetry
- For storm surge events
- Gridded coastal sea level products

French Users: requirements at the coast

- Not accustomed to satellite products.
- Coastal flooding and erosion
- Water quality and salinisation

French Users: Rivers

- River water levels and discharge
- Flooding extents
- Monitoring levels on small tributaries in catchment areas.
- Wider spatial coverage than available from in-situ stations

Vortex.io “micro” Gauges

- LiDAR
 - cm-level accuracy
 - 50 cm to 25 meters range
- 8 Mpx Camera
 - Water surface velocity
 - Contextual images and video
- Fully autonomous
 - Energy (solar panel & battery)
 - Network (GSM)
- Fully connected
 - Real time measurements
 - Full House Keeping telemetry
 - Remote control
- Lightweight and compact
 - Fast installation & commissioning
 - very discreet

- 4 Vortex.io micro-gauges installed for FFSAR Coastal
- 2 in UK (Severn)
 - 2 in France (Rhône)



Severn

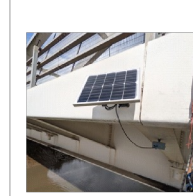
S3A and S3B tracks



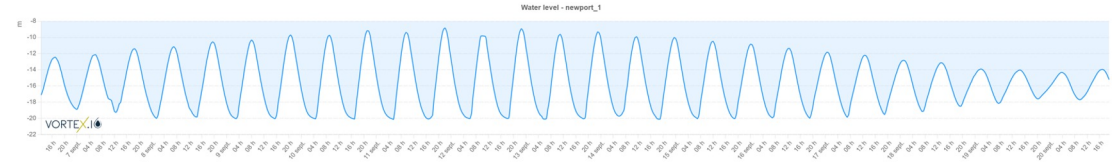
Rhône

VorteX.io in-situ gauges – UK

Newport



ID	newport_1
Watercourse name	Severn estuary
Coordinates	LAT: 51.576861 LON: -2.974263
Altitude of the station (Ellipsoidal)	Not computed yet
Date of the first measurement	06/09/2022
Power supply	Solar panel and internal battery
Mounting system	Solar Panel: 4 neodymium magnets Micro-Station: 1 Neodymium magnet



-8m
-22m

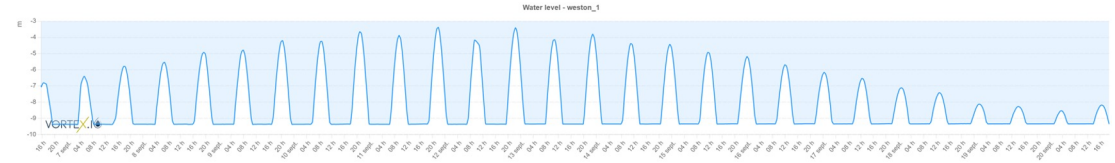
FFSAR Coastal Installations
 Severn Estuary:

- Newport & Weston Super Mare* (06/09/22)
- * Replaced 6th April 2023

Weston Super Mare



ID	Weston_1
Watercourse name	Severn estuary
Coordinates	LAT: 51.347779 LON: -2.984121
Altitude of the station (Ellipsoidal)	Not computed yet
Date of the first measurement	06/09/2022
Power supply	Solar panel and internal battery
Mounting system	Solar Panel: 4 neodymium magnets Micro-Station: 1 Neodymium magnet



-3m
-10m

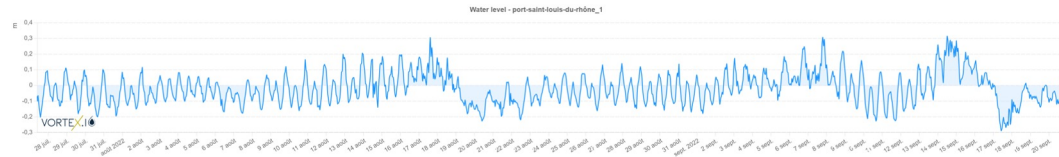
VorteX.io in-situ gauges - France

Port St Louis du Rhône



	ID	port-saint-louis-du-Rhône_1
	Watercourse name	Rhône delta
Coordinates	LAT: 43.428108 LON: 4.763323	
Altitude of the station (Ellipsoidal)	10.262 m	
Date of the first measurement	07/27/2022	
Power supply	Solar panel and internal battery	
Mounting system	Solar Panel: 4 neodymium magnets	
	Micro-Station: 1 Neodymium magnet	

- FFSAR Coastal Installations
 Rhône delta:
- Port St Louis du Rhône
 - Fos sur Mer (27/07/22)

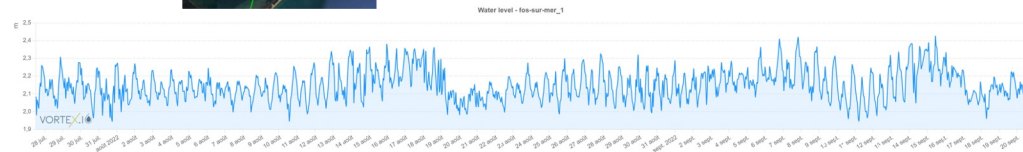


0.4m
-0.3m

Fos sur Mer



	ID	fos-sur-mer_1
	Watercourse name	Rhône delta
Coordinates	LAT: 43.434624 LON: 4.921933	
Altitude of the station (Ellipsoidal)	14.25 m	
Date of the first measurement	07/27/2022	
Power supply	Solar panel and internal battery	
Mounting system	Solar Panel: 4 stainless steel screws of 8 mm on the deck cornice	
	Steel plate: 4 stainless steel screws of 8 mm und @ the bridge	
	Micro-Station: 1 Neodymium magnet on the steel plate	



2.5m
1.9m

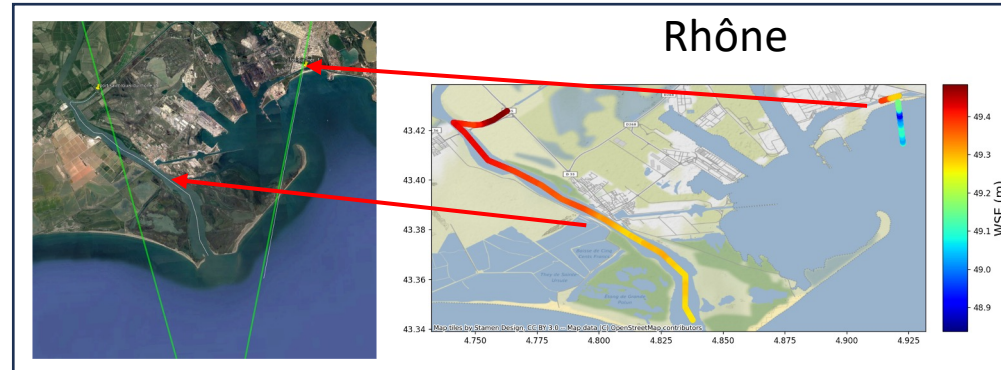
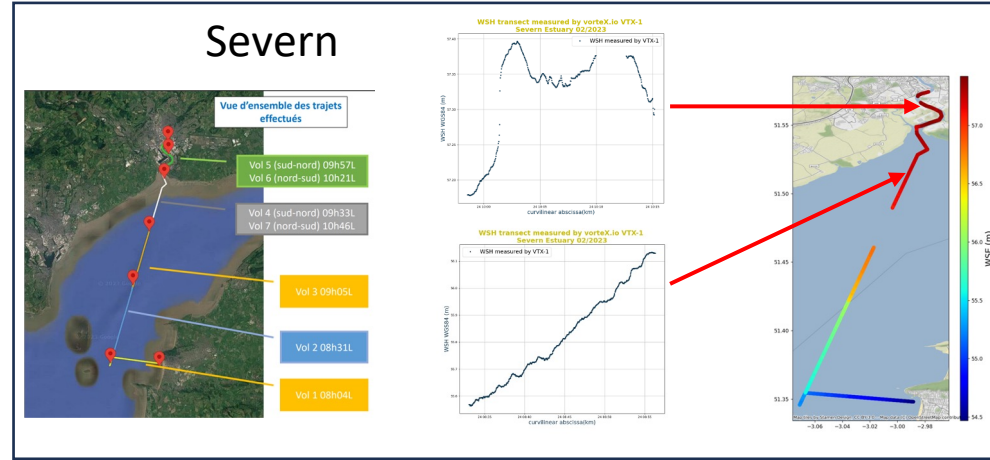
Objective:

To connect water level at gauge to satellite track at the time of overpass.

- LiDAR: cm level accuracy, 50cm to 90m range
- 8Mpx camera: water mask, orthophotos
- 900g

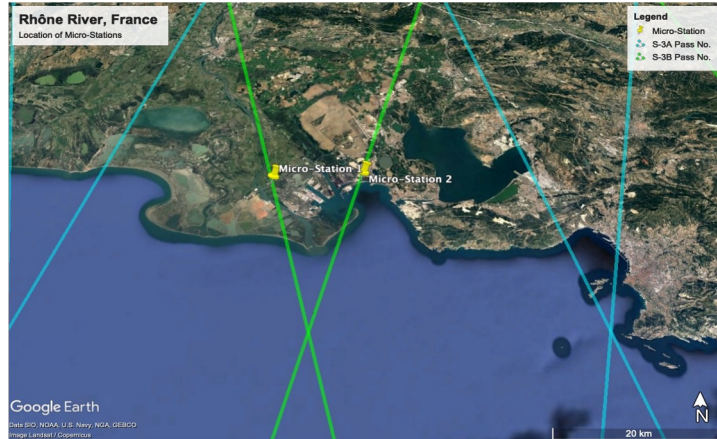
Deployments:

- Severn Estuary – 24/02/23 (from boat)
- Rhône Delta – 13/04/23 (from land)
- Timed to coincide with Sentinel 3B passes
- Data used to geo-reference micro gauge water levels
- Data available on-line



- Apply SMAP (Standalone Multi-Mission Altimetry Processor) to Sentinel 3A and 3B data
- Initial results used to identify the optimum processing choices, then applied to generate time series of data for selected tracks.
- Validation against in-situ data.
- Evaluate how well FFSAR altimeter data can resolve fine scale features in two different environments.
- Severn Estuary: Ability to capture small scale physical signals (surface gradients, currents) in highly tidal regions and to detect and measure tidal asymmetry/gradients
- Rhône delta: Ability of FFSAR data to accurately map small channels.

Rhône Delta, FR



Severn Estuary, UK



- Sentinel 3a (blue) and 3b (green) passes
- L1a files downloaded from scihub.copernicus.eu
- Open source SMAP FF-SAR Processor (developed by CLS/ESA/CNES) implemented by DTU Space.
- User can determine number of looks used to derive the surface height
- Possible to increase along-track resolution to 50cm
- Water levels are found by combining SMAP output with L2 files from ESA/scihub.

FF SAR Processing Options



Investigated different options involving series of trade offs:

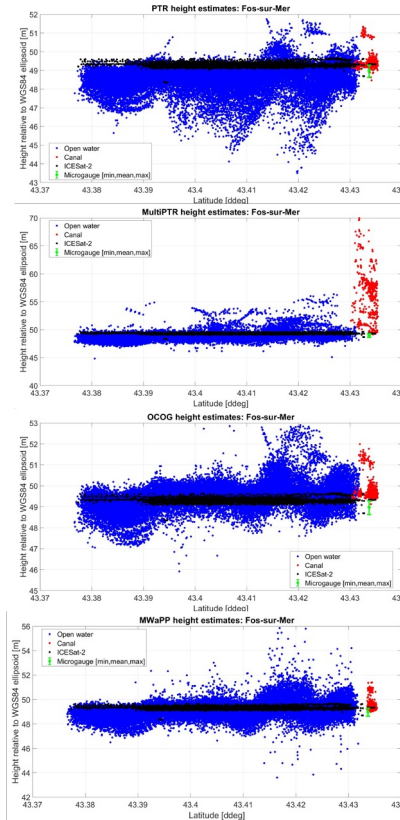
- “Noise” v along-track resolution
- Processing speed v precision
- Open ocean v enclosed water (canal) performance
- Used in-situ data and ICESAT-2 data for reference

Final choices for both locations:

Illumination Time: 2.3s

Posting Rate: 1000 Hz

Re-tracker: DTU MWaPP (Multi-Waveform, Persistent Peak)



Re-trackers

PTR

“Multi” PTR

OCOG

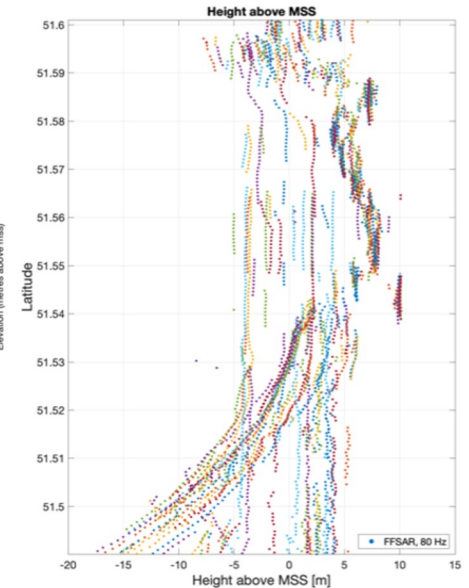
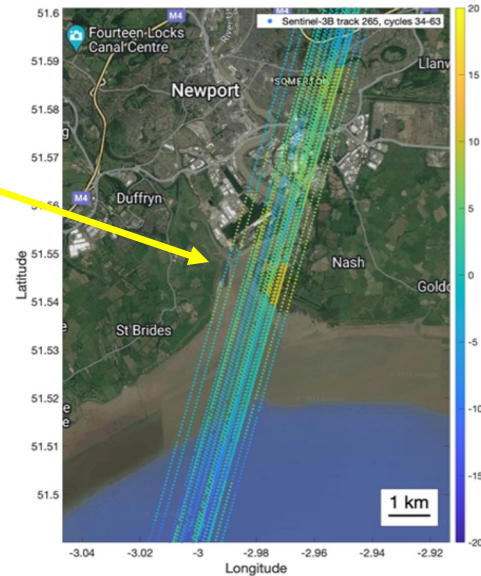
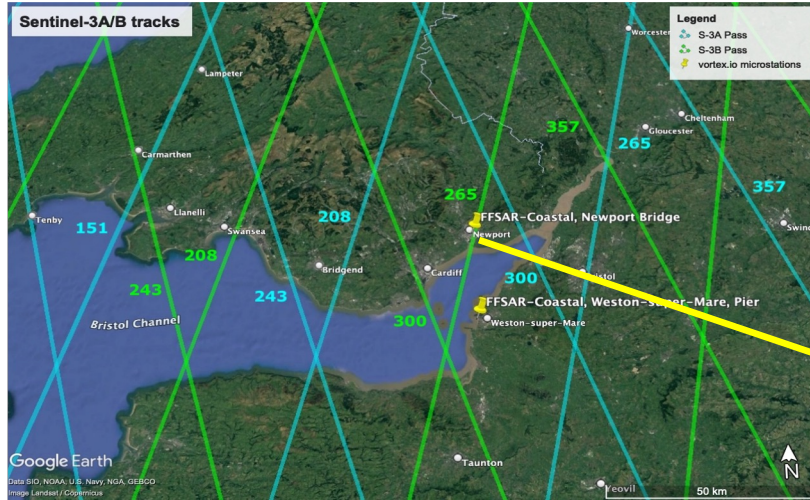
MWaPP

FFSAR open ocean water levels

FFSAR enclosed water (“canal”) water levels

In-situ gauge water levels

Ice-Sat2 output



Sentinel 3B track 265 data processed

Some variation of exact orbit path within allowed “dead-band”.

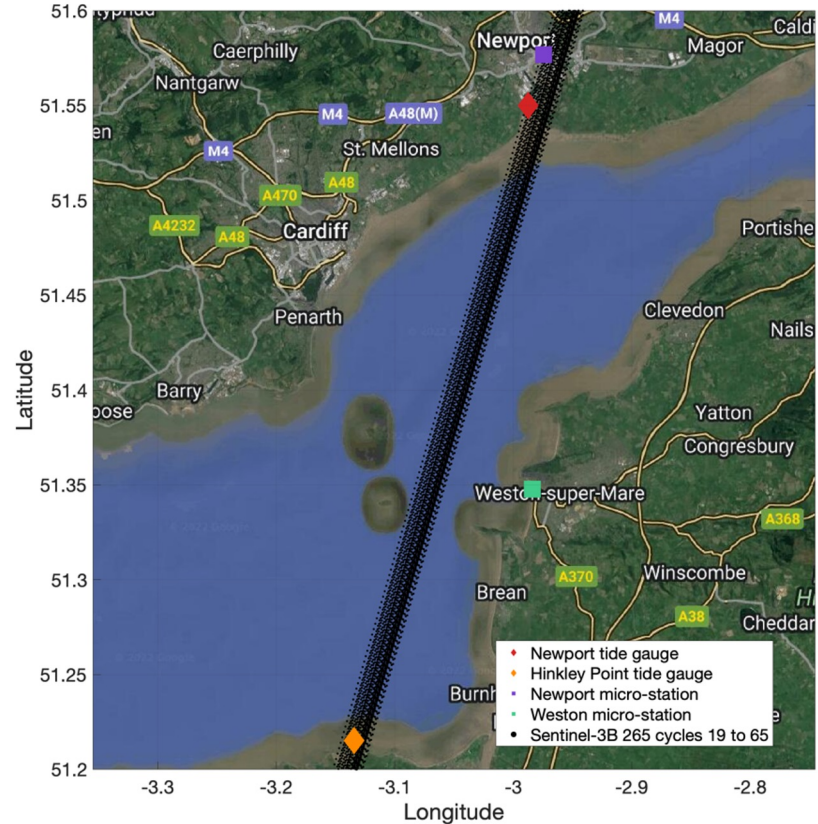
Echoes from off-nadir reflectors (“snagging”) show anomalously low heights)

Track 265 from Sentinel-3B is close to several tide gauges and to the micro-stations

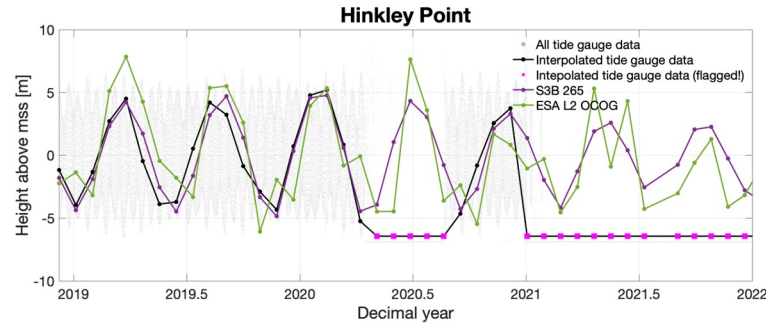
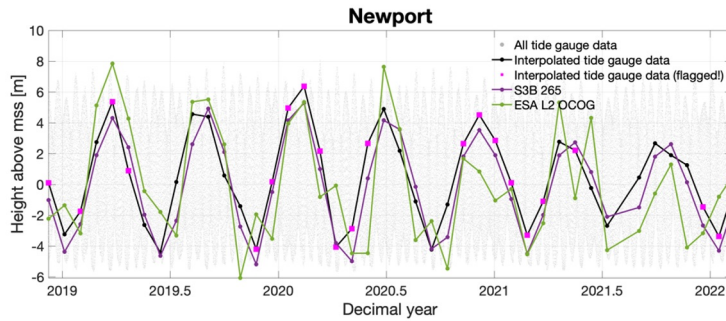
Tide gauges used for validation of FFSAR data:

Newport

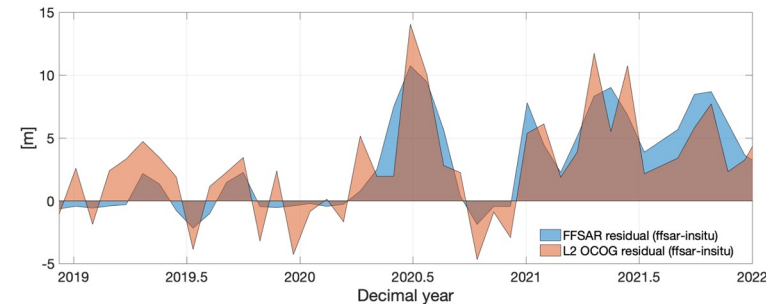
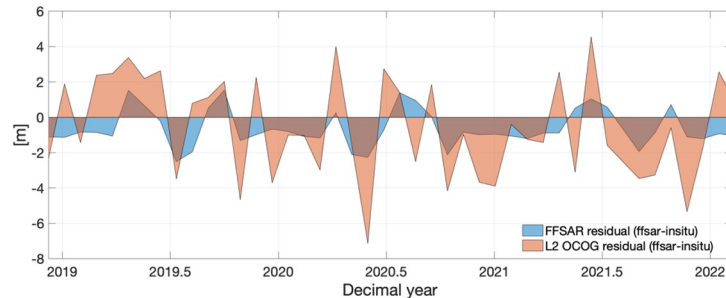
Hinkley Point



Time Series comparison with Tide Gauges (FFSAR data processed with Multi-PTR re-tracker)



Generally good agreement but RMSE of 1.2 m.



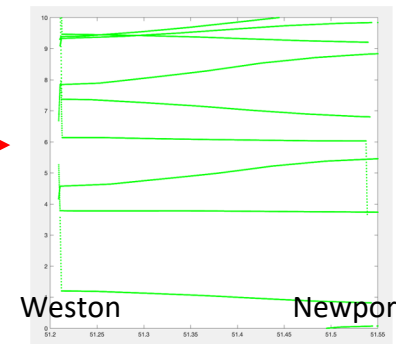
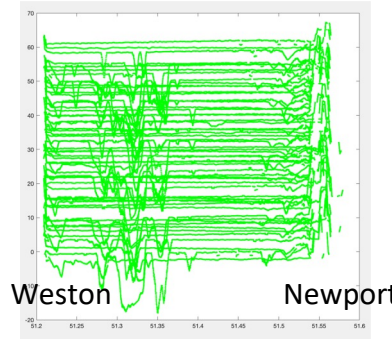
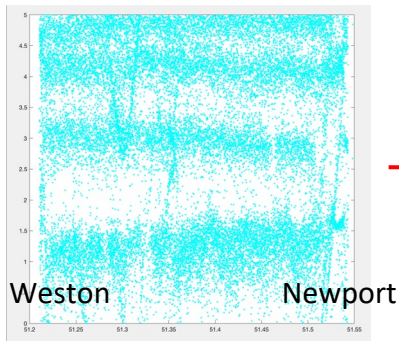
Improvement on RMSE ~3m from ESA OCOG retracker!



(1) Raw FFSAR processed data, S3B track 265.
 MWaPP retracker, 1000Hz or 6m sampling

(2) Smoothing over 15 points (80m)
 • “Snagging” is significant – “tide” related?
 • Thought to be from coastal smooth water targets (Locked harbours)

(3) Further smoothing (120m) and remove snagging
 • Different sea level slopes for different passes (different tidal conditions)
 • ~ 1.0m difference in water level over 20km



July 2023

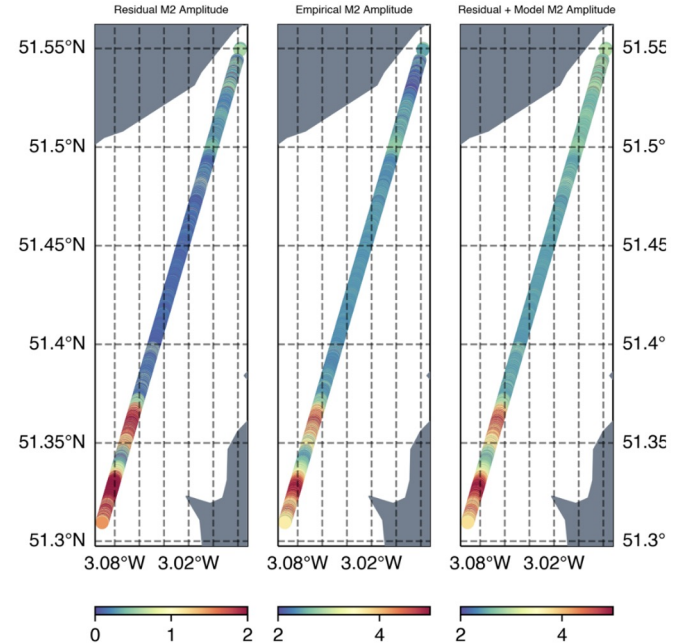
Interpretation of FFSAR data in Severn Estuary – Detailed M₂ Tidal Model

Sentinel-3 orbit means daily tidal constituents are aliased, but analysis of other constituents is possible

Initial analysis of M₂ constituent carried out at 120m resolution

Interesting high-frequency resolution, not seen in FES2014b (8 km res).

Are the amplitude variations related to flow around islands?

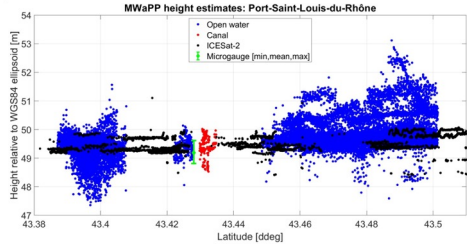


- Low-lying river delta with wetlands.
- 20 Hz resolution will provide only a single height estimate across the river.
- The high number of calm water surfaces within the altimeter footprint makes the measurements very noisy, often leading to wrong water level estimates.
- Using FF-SAR the resolution can be increased all the way up to 0.5 m.



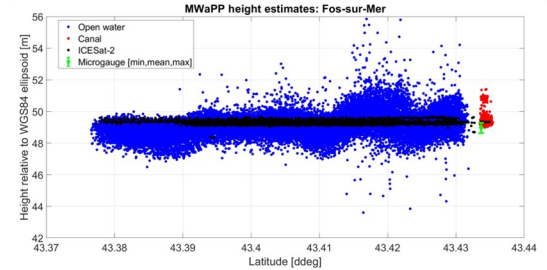
Port St Louis

Canal connected to main river



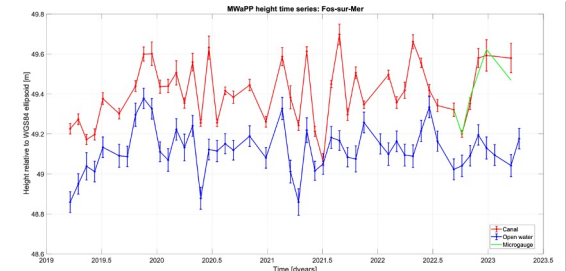
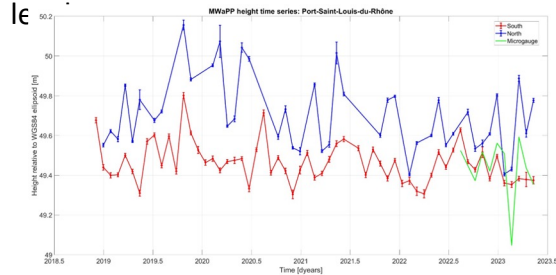
Fos Sur Mer

Narrow Canal (60m wide)



FFSAR processing (with MWaPP retracker) reliably captures canal and river water

FFSAR processing (with MWaPP retracker) reliably captures canal water levels



FFSAR processing can be used to estimate river water level gradient between **south** and **north** crossings. Changes in time.

FFSAR time series agrees with in situ gauge

- Optimal FFSAR processing options found for Severn and Rhône
- Good agreement found between in-situ data and FFSAR processed data with MWaPP retracker (improvement on standard SAR altimeter products)
- Able to measure the water level in small targets (60 m width).
- Able to measure small-scale water level variations, < 10 cm for the Rhône.
- Tracks running parallel to rivers offers detailed information on river slopes.
- Tracks across estuaries can be used to estimate along-track slopes (~100m resolution), and used for tidal analysis

FFSAR Coastal Data Sets

In situ

- Water level time series from Vortex.io micro-stations
 - Newport (06/09/22 onwards)
 - Weston Super Mare (06/09/22 onwards)
 - Port St Louis du Rhône (27/07/22 onwards)
 - Fos Sur Mer (27/07/22 onwards)
- Drone water level profiles
 - From micro-station locations, along Sentinel -3B ground tracks
 - Severn Estuary (24/03/23)
 - Rhône Delta (13/04/23)

FFSAR Processed SAR Altimeter data

- Along-track
 - Severn Estuary S3B track 265
 - Rhône Delta. S3B tracks 179 and 199
- Time series
 - Severn Estuary
 - “Tributary” - Entrance to River Usk at Newport
 - “Open” - Centre of Estuary (5km NNE of Weston SM)
 - Rhône Delta
 - Port St Louis - River North
 - Port St Louis - River South
 - Fos Sur Mer- Open
 - Fos Sur Mer- Canal

<https://cco.geodata.soton.ac.uk/ccoresources/FFSAR-Coastal/>

FFSAR-Coastal

FFSAR-Coastal

The FFSAR-Coastal is a project funded by ESA to apply the Fully Focused SAR altimetry processor on Sentinel-3 data and evaluate its potential to make a significant new contribution to coastal and estuarine monitoring systems. Innovative in situ water level gauges, and drone based Lidar flights have been used for validation.

Time series have been generated by autonomous in situ microstation gauges, and drone-mounted instruments have been used to provide water level profiles between the fixed locations and satellite tracks.

Two different environments have been considered:

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.
2. The lower Rhone Delta and Camargue: A low lying, flat river delta and wetland environment, susceptible to inundation and rising water levels.

By studying these two very different environments, the potential applicability and benefits offered by FF SAR altimeter data in other coastal, estuarine and delta locations can be demonstrated.

This page provides users with access to all the data from the two locations - data will be uploaded as it becomes available.

More information can be found on the [FFSAR-Coastal project web page](#).



Severn Estuary



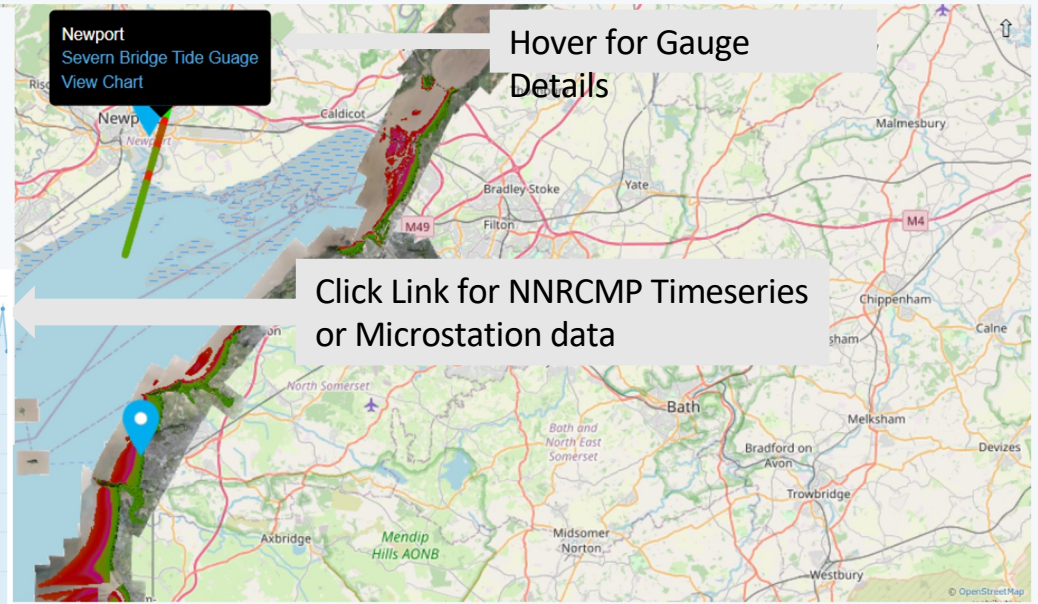
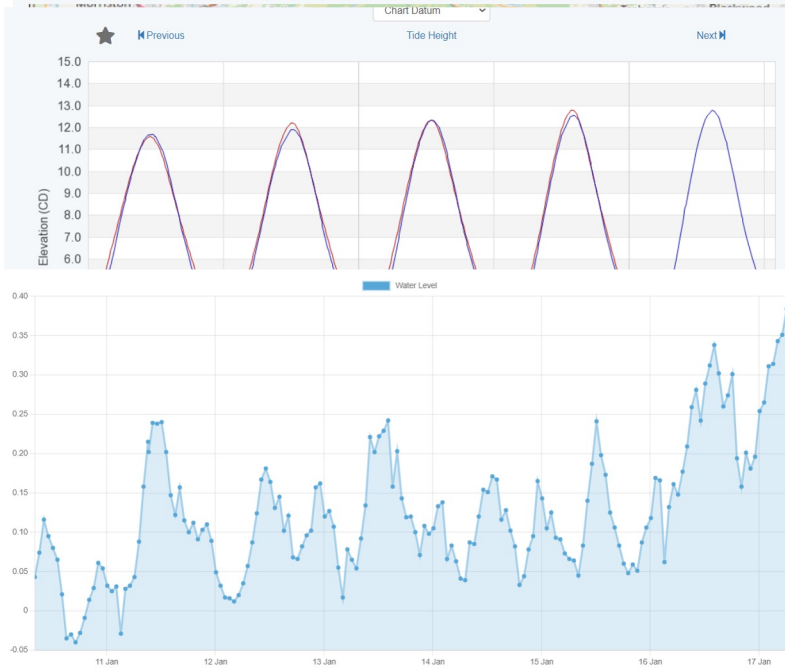
Rhône Delta

Partners



FFSAR-Coastal

Severn Estuary



↑ To Zoom: scroll Up / Down on your mouse wheel.
 ↔ To select specific data: click and drag on the data you wish to view.

[Reset Chart](#) [Close](#)

Severn Estuary - a highly dynamic mixed tidal estuary environment. Large tidal range and strong tidal currents

High variability on small spatial and temporal scales

High resolution water level data from FFSAR processing may allow retrieval of data closer to the coast than previously possible, and resolution of small scale features.

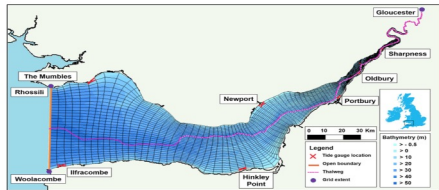
Can contribute to SWOT validation campaign.

Investigation of storm surge events

Rhône Delta- Flat, low-lying river delta with wetlands.

Low tidal range, water levels sensitive to precipitation in the watershed and to coastal flooding

FFSAR data could monitor water level changes in different channels and lakes at high resolution



1. FFSAR-Coastal processing “recipe”
2. Further FFSAR processing research – Different coastal locations and environments.
3. Multi-satellite study – Sea state impact on FFSAR.
4. Isolate Nadir Reflections.
5. Micro-gauges for satellite data validation.
6. Drones with lidar for coastal research and satellite validation.
7. Extreme Events Study

8. Priority areas for FFSAR and UFSAR processing.
9. Coastal FFSAR altimeter products.
10. Guidelines for use of FFSAR processed altimeter data.
11. FFSAR for Inter Tidal Bathymetry
12. Inland water FFSAR altimeter products.
13. FFSAR altimeter products – coast and river interface.
14. FFSAR altimeter products – Small scale variability in tides.

Data Sets

- FFSAR S3A and S3B data sets: Severn Estuary and Rhône delta
 - Along track data and time series
- Vortex.io micro-station time series data
- Drone campaign data

<https://cco.geodata.soton.ac.uk/ccoresources/FFSAR-Coastal/>

Product Validation and Evaluation Report

- Validation against in-situ and model data
- Evaluation:
 - Small scale physical signals in highly tidal regions
 - Tidal asymmetry/gradients across estuaries
 - Impact of islands on tidal components at 100m scale
 - Measurement of water levels and gradients in small inland water bodies

Application Road Map

- Key requirements from User Groups
- Recommendations for application of FFSAR in coastal monitoring systems.
- Recommendations for use of “micro” gauges as part of coastal monitoring systems

<https://eo4society.esa.int/projects/ffsar-coastal/>