

The Aresys FF-SAR Service for Cryosat-2 at ESA GPOD



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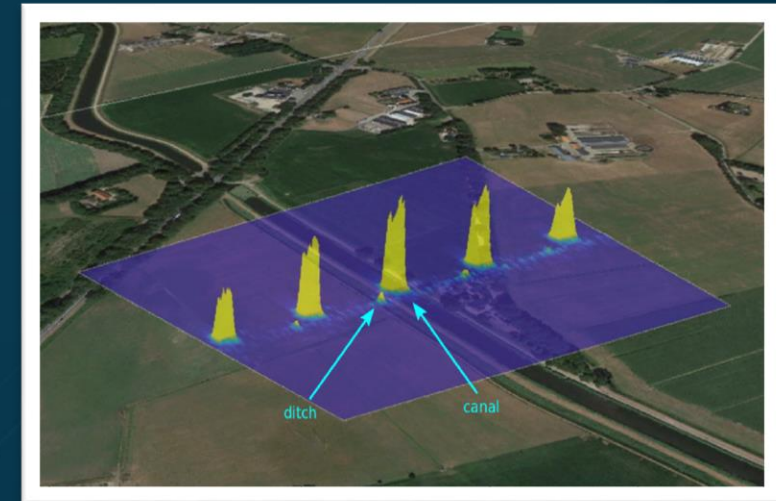
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Intro and Objectives of the Activity

- The Fully-Focused SAR (FF-SAR) processing, introduced in Egido and Smith, 2016, allows obtaining a maximum resolution of 0.5 m in the along-track direction. It provides significant benefits for inland water altimetry investigations allowing the successful investigation of small canals (Kleinherenbrink, 2020->) that typically cannot be analyzed by using unfocused Delay-Doppler SAR (DD-SAR) data (300 m resolution in the along-track direction).
- In its development, two major limitations were associated with the FF-SAR processing: 1) the presence of evenly spaced high sidelobes in the PTR due to the close-loop burst mode implemented in Sentinel-3 & Cryosat-2 altimeter payloads, used for initial FF-SAR investigations, and 2) the heavy computational burden with respect to the unfocused DD-SAR processing.
 - The first limitation can be overcome by designing the radar system differently and adopting an open-loop transmission scheme as, for instance, the one implemented in the altimeter payload of the Sentinel-6 Michael Freilich mission, scheduled for this year.
 - The second limitation has been addressed in research works following Egido and Smith, 2016 indicating that an improvement in terms of processing speed can be achieved by adopting algorithms in the frequency domain (Guccione et al., 2018).



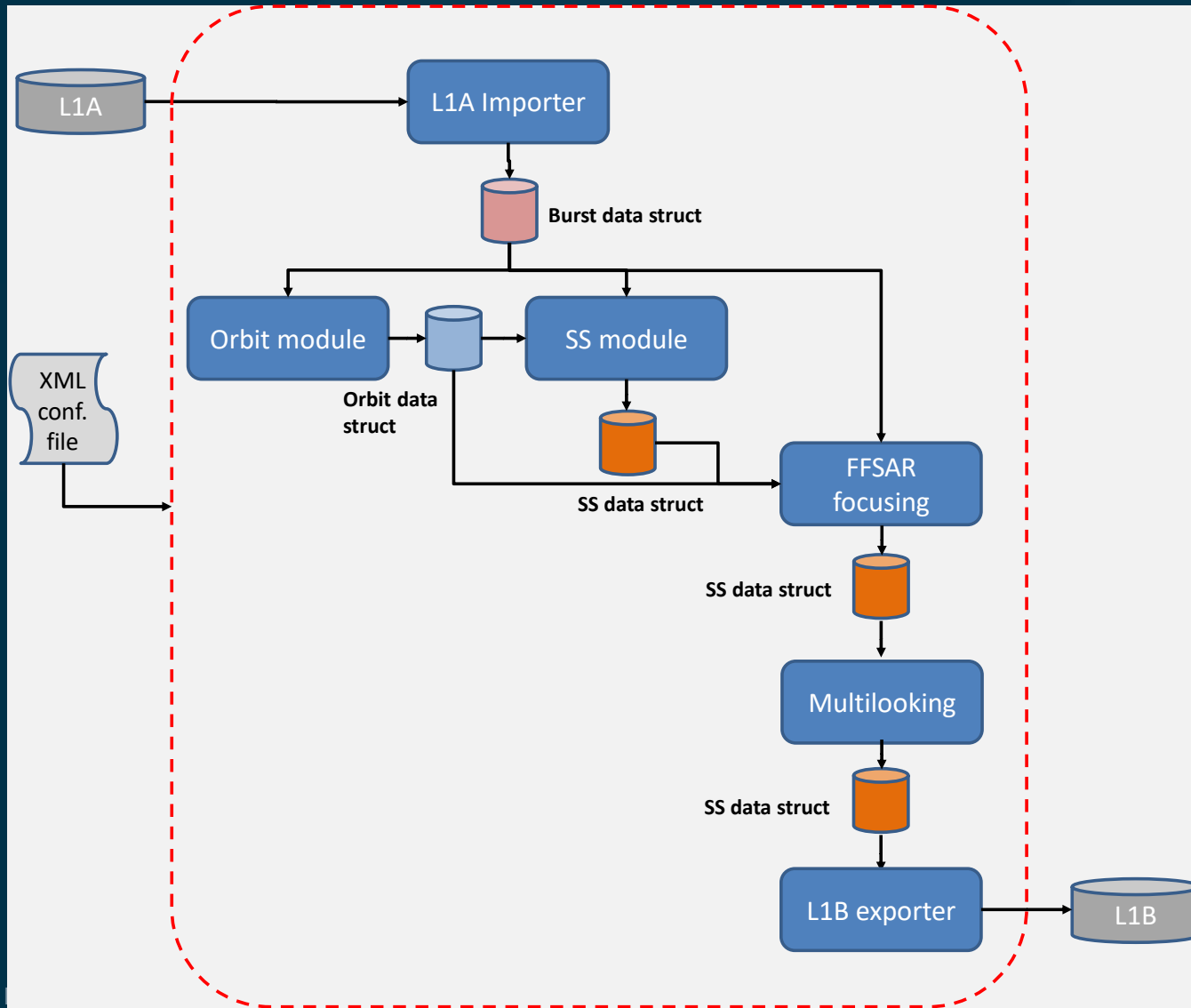
Intro and Objectives of the Activity (2)

- Being the role of FF-SAR for future inland water altimetry well understood, along with the possibility to see it implemented with reduced drawbacks during the future Sentinel-6 Michael Freilich mission, a collaboration has started between the ESA GPOD Team, already hosting the successful SARvatore services portfolio for unfocused SAR & SARin altimetry, and Aresys.
- Aresys has developed a generic FF-SAR prototype processor, that is able to process data acquisition from different instruments and exploiting the frequency-domain Omega-K algorithm. In particular, the algorithm can focus a point target with accuracy comparable to that of the reference Back Projection algorithm in Egido and Smith, 2016 while sensibly reducing the computational burden.



In this presentation, the FF-SAR prototype processor for CryoSat is described and the outcome of some preliminary validation activities, performed by the ESA-ESRIN Altimetry Team, are reported.

The Aresys FF-SAR prototype processor



Generic FFSAR processing chain

- Able to ingest FBR/L1A products from different instruments (CryoSat, Sentinel-3, Sentinel-6)
- Importer is the only module mission dependent
- Computationally efficient focusing method in 2D frequency domain
- Focusing for instrument based on deramping and matched filter on-board
- Multilooking block to obtain waveforms at desired posting rate
- FFSAR L1b in NetCDF with format coherent with the L1b product format for S6 L1b simulator

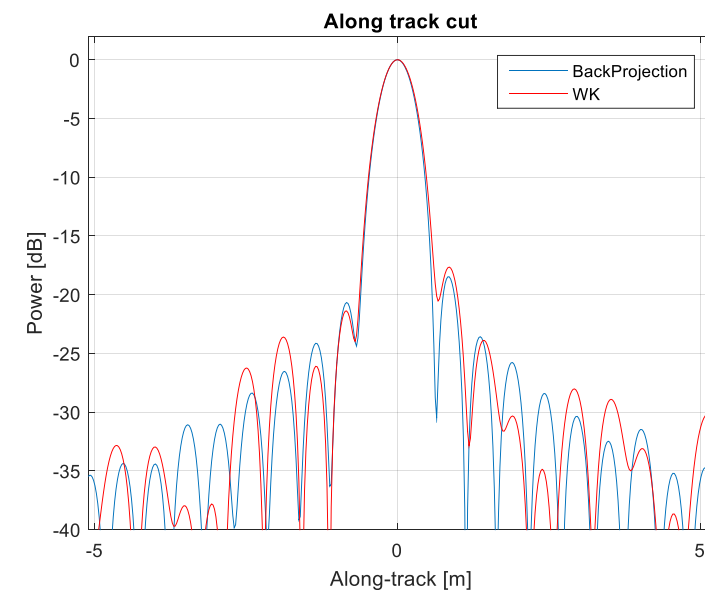
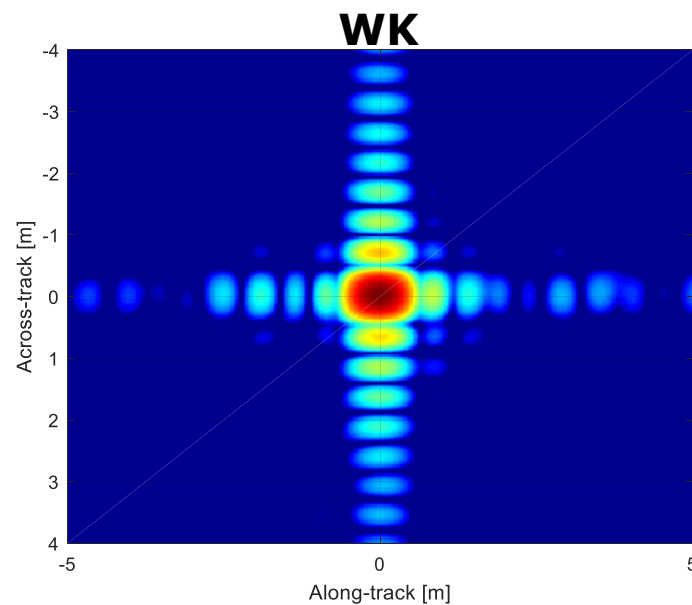
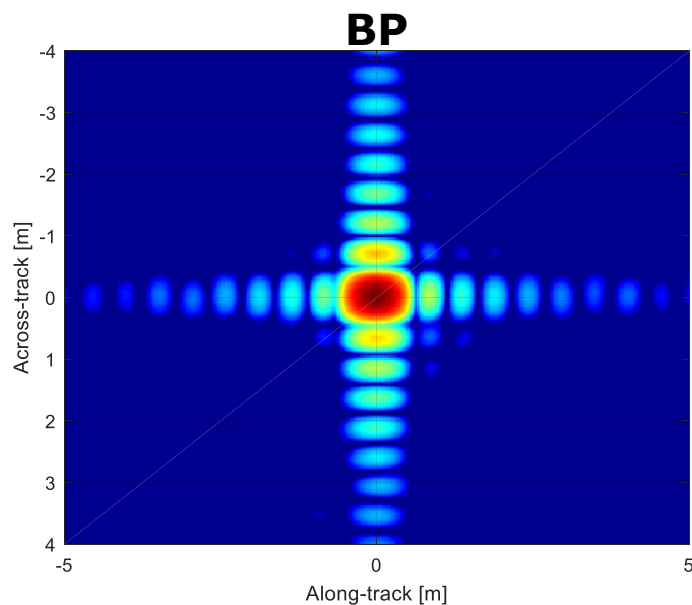
The Aresys FF-SAR processor: WK focusing

FFSAR algorithm in time domain is based on Back Projection (BP): it aims basically at the progressive compensation of the different phase terms in the impulse response function.

BP: Very accurate but computationally expensive

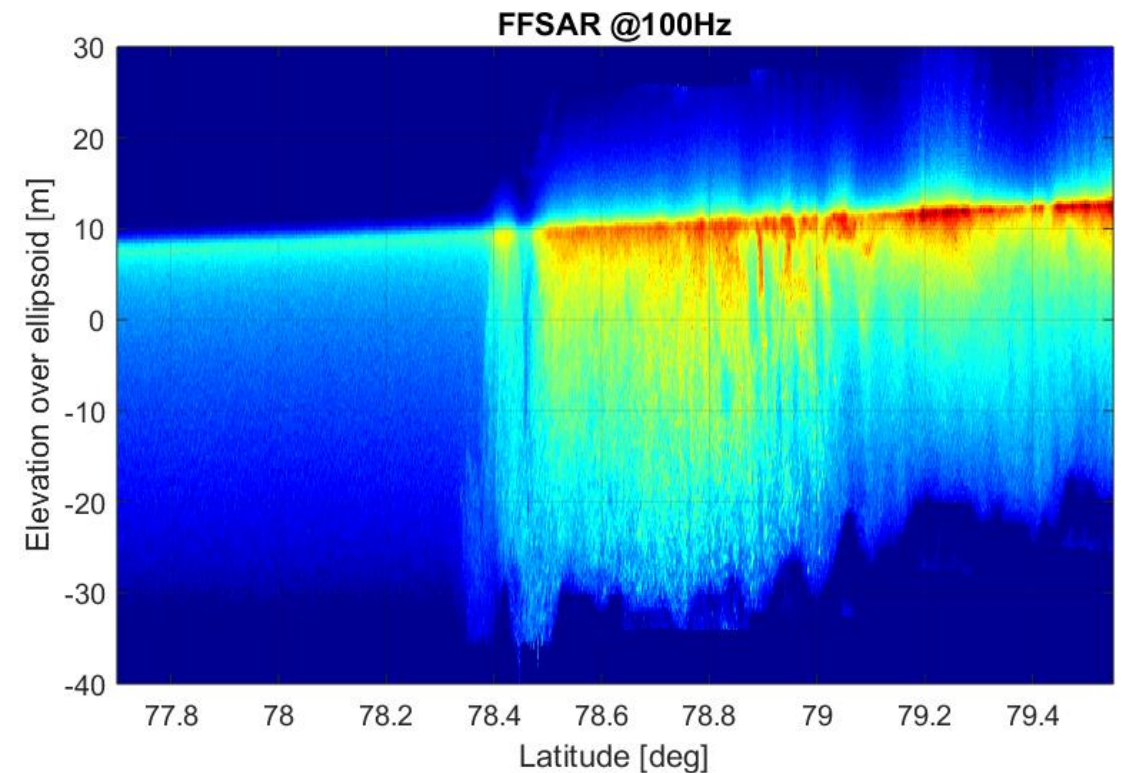
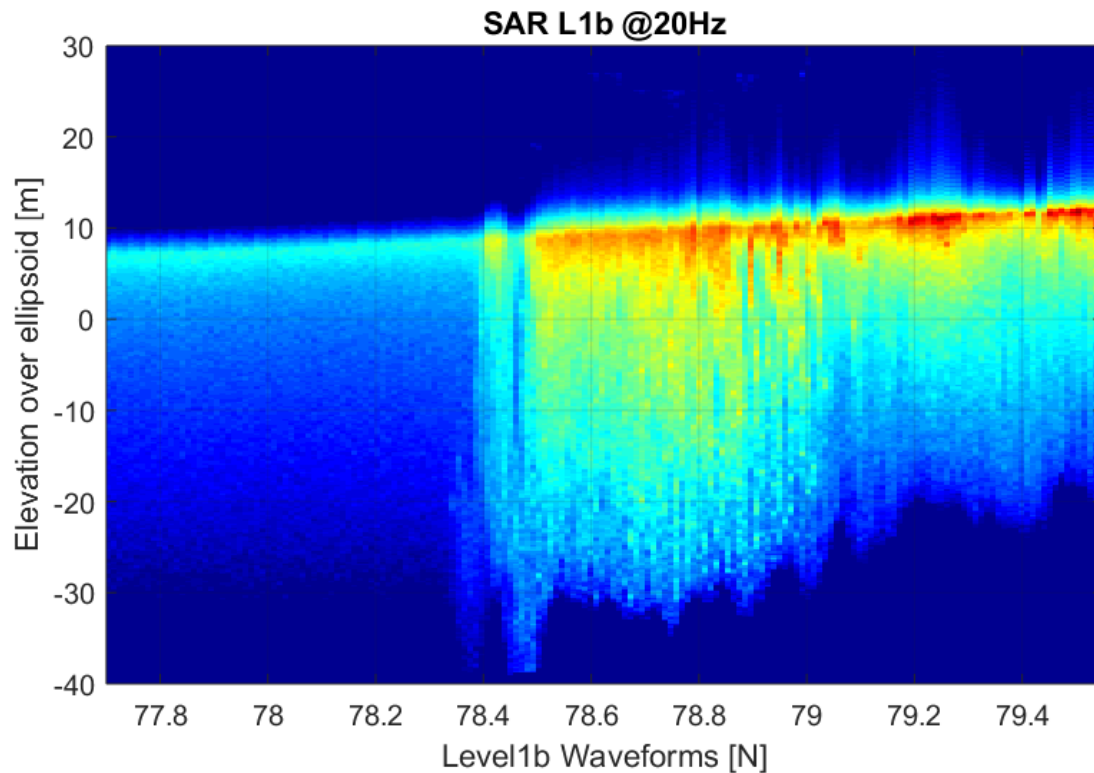
Omega-K (WK) focusing algorithm, that operates in the 2D frequency domain, was adapted for FFSAR processing of altimeters data. It was proven to provide a good trade-off between quality of the Impulse Response Function and the computational complexity.

Comparison of point target response from Svalbard transponder with BP and WK



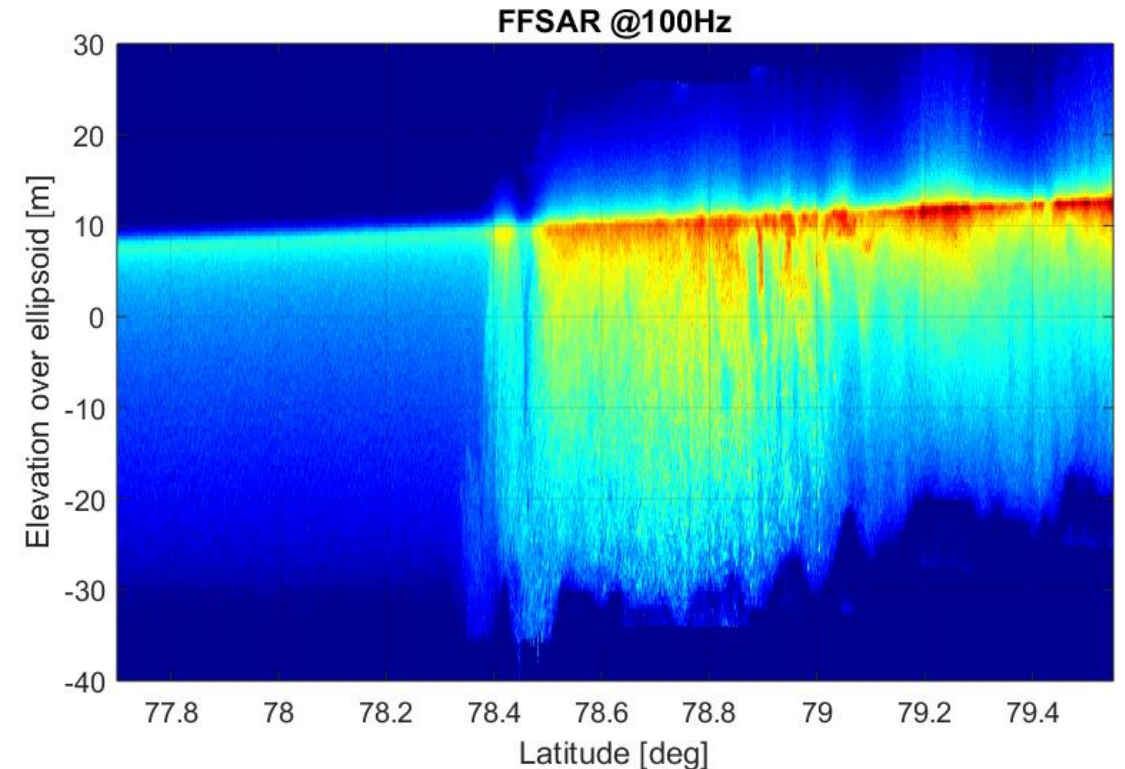
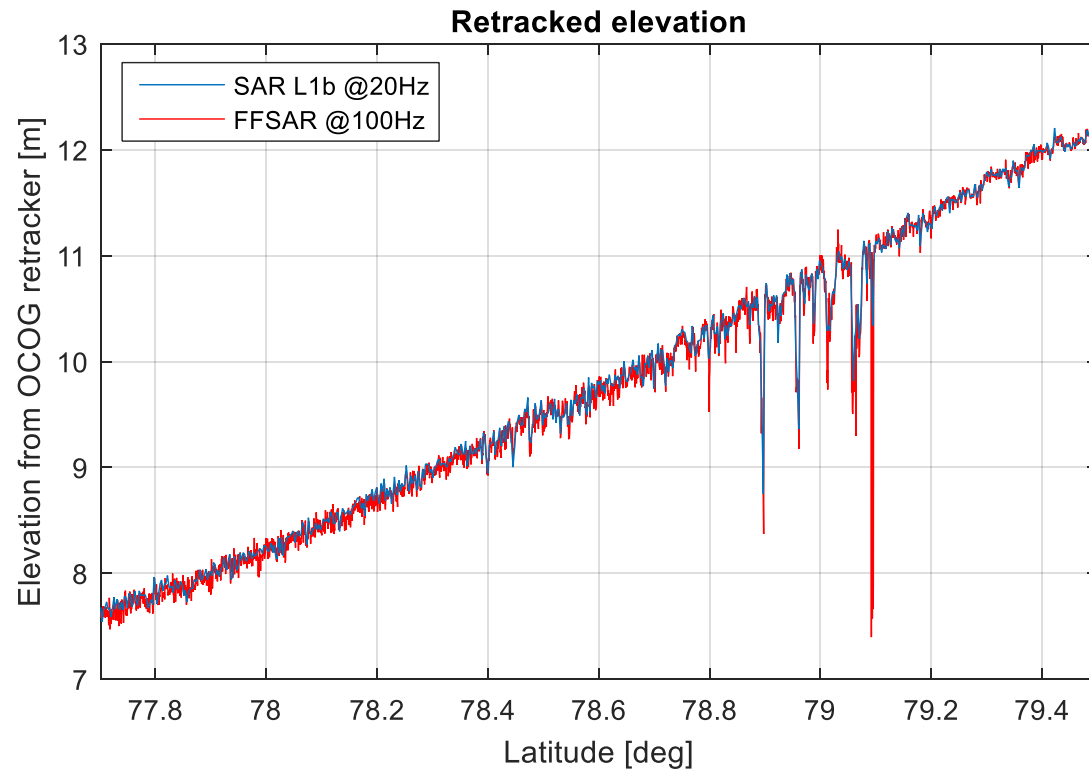
The Aresys FF-SAR processor: results

Comparison of radargram from CryoSat operational SAR L1b product @20Hz and FFSAR L1b product @100Hz



The Aresys FF-SAR processor: results

Comparison of retracked elevation from CryoSat operational SAR L1b product @20Hz and FFSAR L1b product @100Hz



The ESA GPOD System

The **ESA Grid Processing on Demand (G-POD)** system is a generic GRID-based operational computing environment providing users with a fast computational facility without the need to handle bulky data. It consists of:

- Over **600 CPUs** in about **90 Working Nodes**
- Over **400 TB** of **local on-line Storage** + flexible capacity of EO Data accessed directly from the PACs
- Access to Cloud processing and data resources on demand

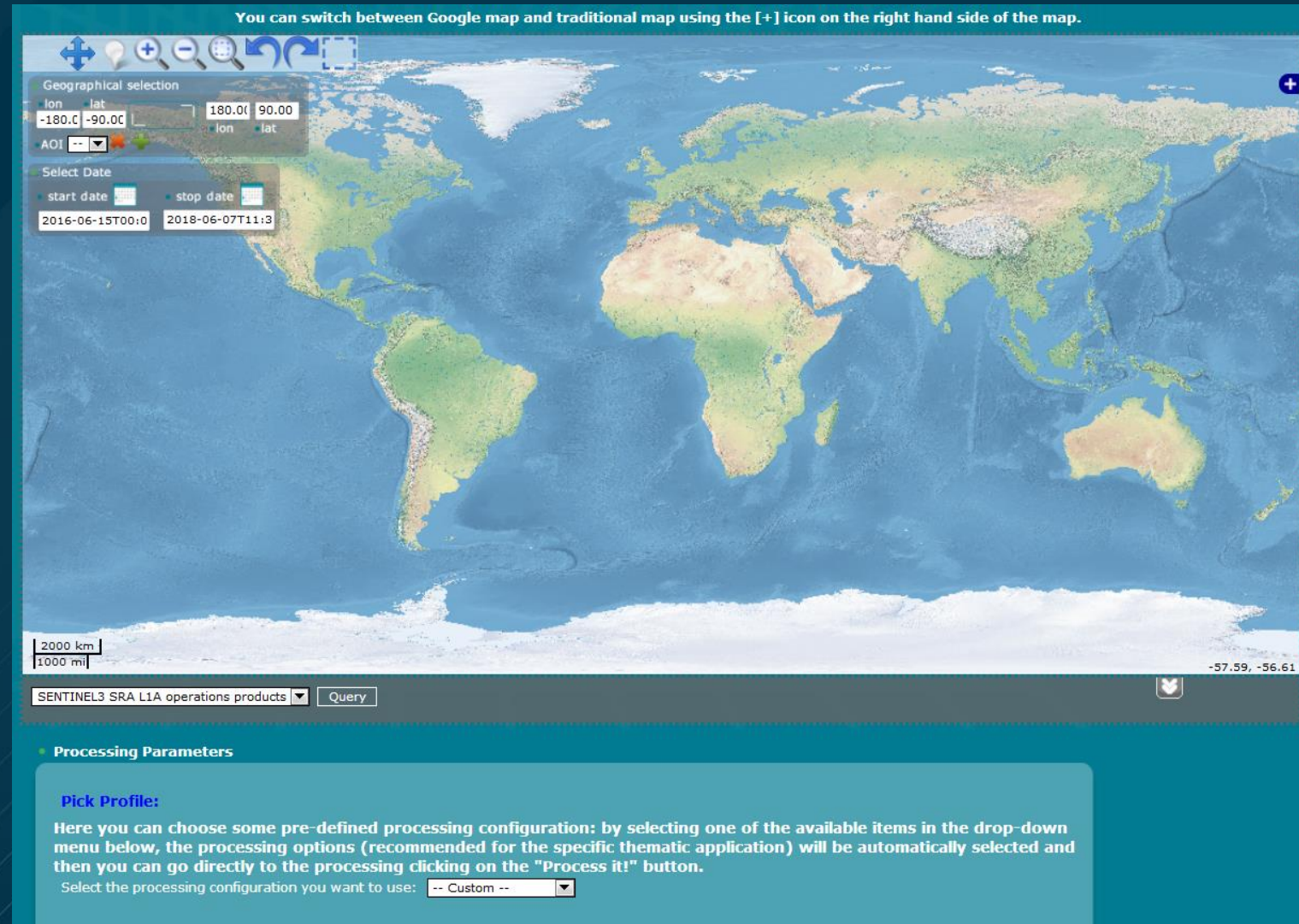


It includes the SARvatore (**SAR Versatile Altimetric ToolKit for Research & Exploitation**) for Sentinel-3 & CryoSat-2 service that is an Earth-Observation application that provides the capability to

Process remotely and on demand **Sentinel-3** SAR and **CryoSat-2** SAR/SARin data, from L1A (FBR) data products to SAR/SARin L2 geophysical data products.

GPOD/SARvatore service – Web Interface

- The service is **open, free of charge** and **accessible online from everywhere**.
- In order to be granted the **access to the service**, you need to have an **EO-SSO** (Earth Observation Single Sign-On) **ID**.
- For the **EO-SSO registration**, go at <https://earth.esa.int/web/guest/general-registration>.
- Afterwards, you need to **send an e-mail** to the G-POD team (to eo-gpod@esa.int), requesting the activation of the SARvatore service for your EO-SSO user account.



GPOD/SARvatore service – Processing Options

- The processor prototype is **versatile** in the sense that the users can customize and adapt the processing, according to their specific requirements, by setting the list of configurable options (at Level L1b and L2).
- L2 output products are provided in NetCDF format with all the scientific results.

Processing Parameters

Pick Profile:

Here you can choose some pre-defined processing configuration: by selecting one of the available items in the drop-down menu below, the processing options (recommended for the specific thematic application) will be automatically selected and then you can go directly to the processing clicking on the "Process it!" button.

Select the processing configuration you want to use: -- Custom --

Here you find a list of processing options that you can select according to the processing level

[For a wiki user manual of the service, go here: wiki](#)

[For a hands-on presentation, go here: slides](#)

L1B Processor:

- Select the data type NT/ST you want to process

Flag to process only ST (Short Time Critical) or only NT (Non Time Critical) or both data types

only NT

- Data Posting Rate

Flag to set the data posting rate: 20 Hz (canonic posting rate) or 80 Hz (finer posting rate)

20 Hz

- Hamming Weighting Window

Flag to set the application of the Hamming Weighting Window on the burst data (section 4.4 in REF1)

Apply only in coastal

- Exact Beam-Forming

Flag to set the application of exact or approximated Doppler Beam Steering (section 4.4 in REF1)

Approximated

- FFT Zero-Padding

Flag to operate the Zero-Padding prior to the range FFT (section 4.8 in REF1). Zero-Padding is indicated for coastal zone analysis

Yes, apply Zero-Pad

- Radar Receiving Window Size

Flag to select the size of the radar receiving window: 128 range bins (standard) or 256 range bins (extended). Extended window is indicated for coastal zone analysis

128 range bins

- Antenna Pattern Compensation

Flag to activate the antenna pattern compensation on the Stack Data

No

- Dump SAR Stack Data in output

Flag to dump the SAR Stack Data in the output package. Be aware that SAR Stack Data are bulky data products (around 1 GB for single pass); do not process them massively but limit yourself at around 10/20 passes at the time

No

- Custom --
- Custom --
 - Ice Sheets
 - Sea Ice
 - Open Ocean
 - Coastal Zone
 - Inland Water
 - Inland Water (HPR)
 - Official S3

L2 Processor:

- Restrict the re-tracking on specific surfaces

Flag to limit the processing on open sea or on water (open sea, coastal zone and inland water) or to process the full pass

Process only water

- PTR width alphap parameter

Use a LUT (Look-Up Table) or a constant for PTR (Point Target Response) alphap parameter

LUT

- SAMOSA Model Generation

Flag to select the generation of the SAMOSA model to use in the re-tracking. SAMOSA3 is a truncated version (only zero order term) of SAMOSA2 (REF2), SAMOSA+ is the SAMOSA2 model tailored for inland water, sea ice and coastal zone domain

Use SAMOSA2

- Dump RIP in output

Flag to append Range Integrated Power (RIP) in the output netCDF data product

No

- Dump SAR Echo Waveforms in output

Flag to append the SAR Echo Waveforms in the output netCDF data product

No

- Single-look or Multi-look Model

Flag to set the application of the Model Multilooking (Single-Look or Multi-Look). Single-Look option is indicated for quick look operations while Multi-Look is the most accurate

Multi-look

REF1: Guidelines for the SAR (Delay-Doppler) L1b Processing

REF2: SAR Altimeter Backscattered Waveform Model (SAMOSA Model Paper),

IEEE-TGARSS, Geoscience and Remote Sensing, IEEE Transactions on (Volume:53, Issue: 2)

For any question, bugs and support, please contact us at: altimetry.info@esa.int

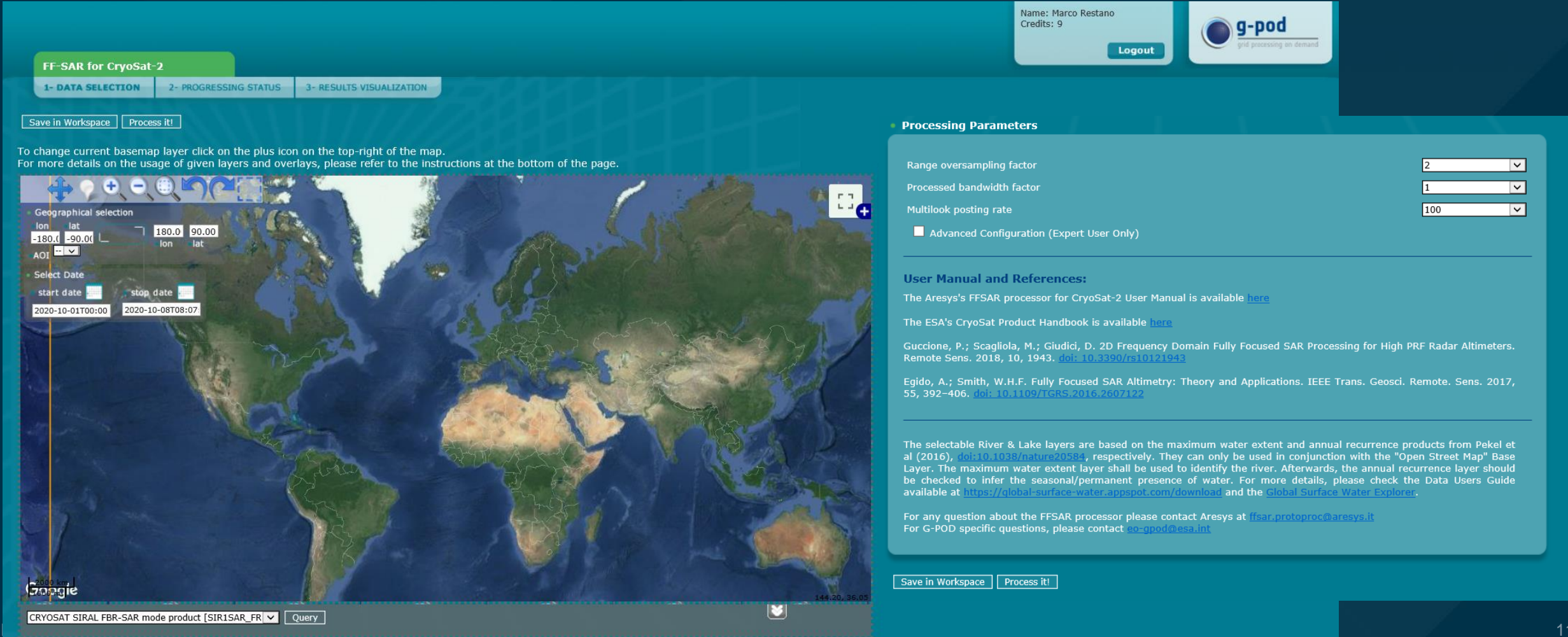
For G-POD specific questions, please contact eo-gpod@esa.int

Save in Workspace

Process it!

Aresys FF-SAR service (prototype)

- The current Aresys FF-SAR service interface is the following:



The screenshot displays the Aresys FF-SAR service interface, which is divided into three main sections: 1- DATA SELECTION, 2- PROGRESSING STATUS, and 3- RESULTS VISUALIZATION. The interface is currently in the DATA SELECTION stage.

Top Bar: Includes a "Logout" button and a user profile section for "Marco Restano" with 9 credits. The "g-pod" logo is also present.

Left Panel: Contains a "Geographical selection" section with a map of the world. The map shows the Arctic region. Below the map, there are input fields for "lon" and "lat" (ranging from -180.0 to 180.0 and -90.00 to 90.00 respectively) and a "Select Date" section with "start date" and "stop date" fields (ranging from 2020-10-01T00:00 to 2020-10-08T08:07).

Right Panel: Contains a "Processing Parameters" section with three dropdown menus: "Range oversampling factor" (set to 2), "Processed bandwidth factor" (set to 1), and "Multilook posting rate" (set to 100). Below these is an "Advanced Configuration (Expert User Only)" section. The "User Manual and References" section provides links to the Aresys's FFSAR processor for CryoSat-2 User Manual, the ESA's CryoSat Product Handbook, and several scientific papers.

Bottom Bar: Includes a "Save in Workspace" button, a "Process it!" button, and a "Query" button. The bottom status bar shows "CRYOSAT SIRAL FBR-SAR mode product [SIR1SAR_FR]".

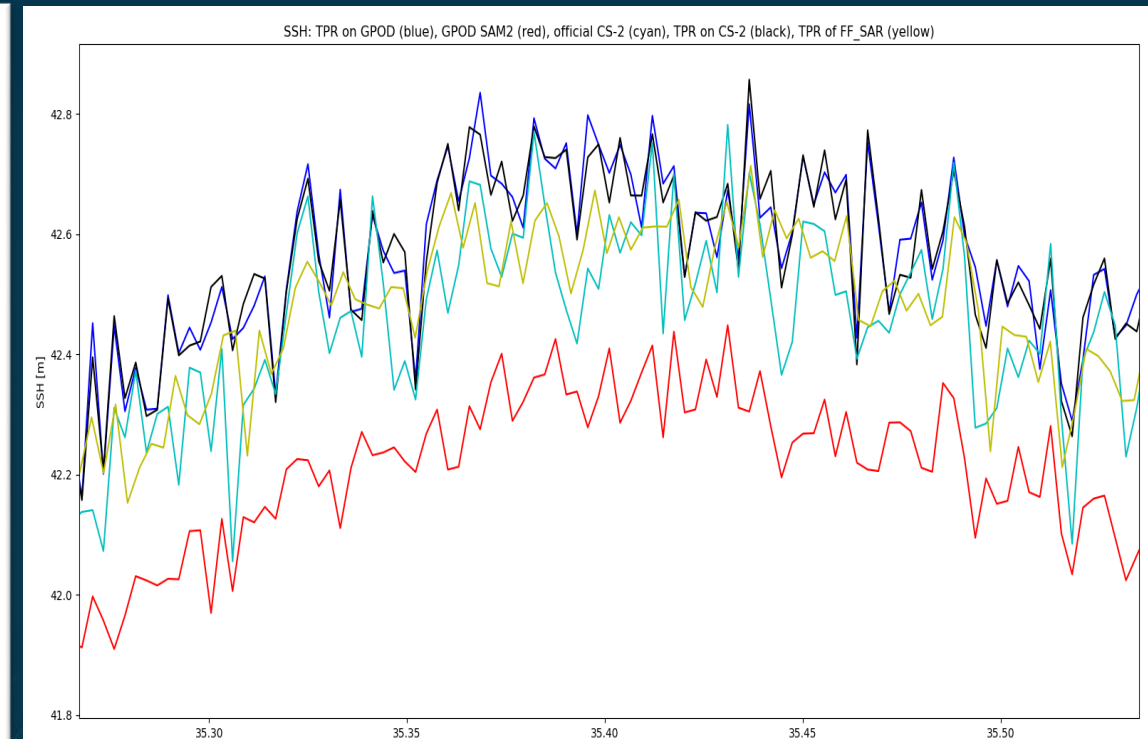
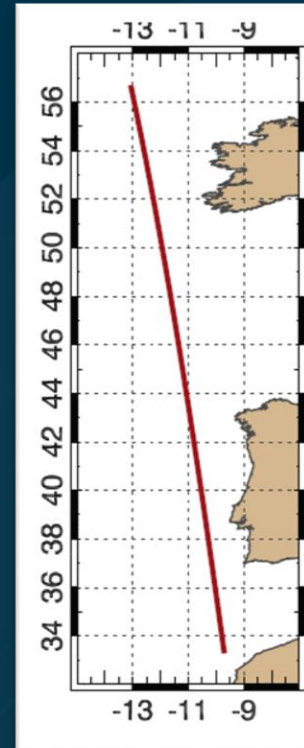
Validation – Open Ocean – Noise (FF-SAR vs SAR)

- Taking as a reference the same Atlantic ocean track in Fig. 7 of Egido & Smith, 2017 we compared the 20Hz SSH noise estimates in GPOD SARvatore for Cryosat-2 & GPOD Aresys FF-SAR services at latitudes related to the lowest SWH values (33-36 degrees north ->).
- As a proxy for noise we used the median of the absolute value of the difference in the Total Water Level Envelope (TWLE) amongst consecutive SAR records (ESA CP40 Project).

FF-SAR (TPR_retracker): 0.05801 m
Official_CS2_SAR (TPR_retracker): 0.080712 m
GPOD_CS2-SAR (TPR_retracker): 0.08933 m

GPOD_CS2-SAR (SAMOSA_retracker): 0.050634 m

↑ The FF-SAR results are expected to be lower than GPOD Cryosat-2 SAMOSA2 results if a readapted SAMOSA2 retracker would be applied to L1b FF-SAR waveforms.



↑ Caption: TPR retracker (thv=50%) applied to Official CS-2 SAR (black), GPOD SAR* (blue) & Aresys FF-SAR** for Cryosat-2 L1b data (yellow) and compared to L2 Official Cryosat-2 (cyan) and GPOD SARvatore for CS-2 SAMOSA2 estimates (red).

<- FF_SAR estimates report a lower dynamic of oscillations (associable with a lower noise) similar to GPOD SAMOSA2 estimates.

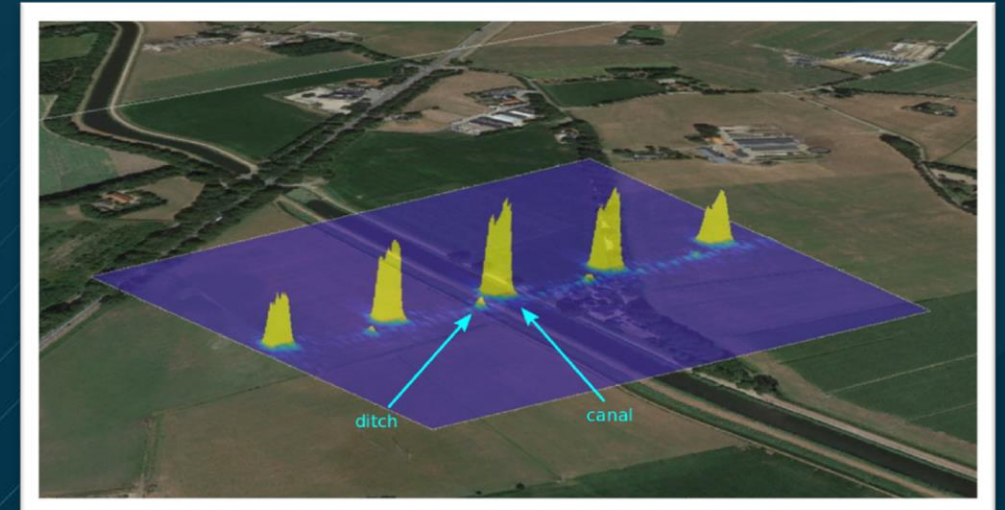
* "Official Cryosat-2" processing profile selected.

**FF-SAR processor options: Posting rate=20Hz, ZP=2, Bandwidth Processing Factor=1.

Validation – Inland Water – Target Selection

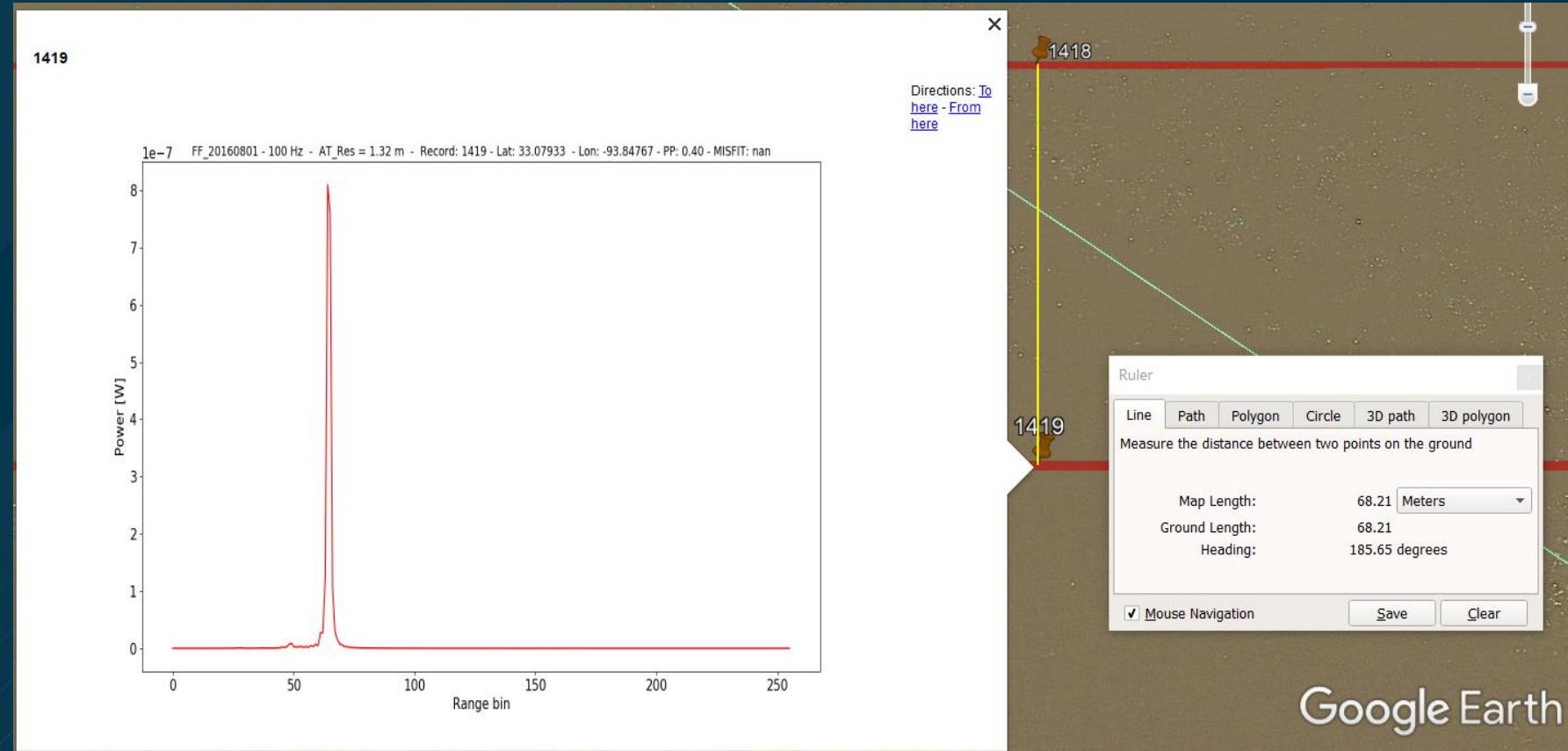
We processed some data over the Mississippi (Red River) with the FF_SAR to understand:

- 1) If Aresys FF-SAR waveforms quality is acceptable.
- 2) If the FF-SAR TPR-retracked estimates are in line with the GPOD SARvatore for CS-2 SAMOSA+80Hz estimates. These have also been used in the ESA RIDESAT Project and injected into models.
- 3) if the aliasing in FF_SAR waveforms (Figure from Kleinherenbrink et al., 2020->) is complicating the analysis in such a river (width is 100-200 m) presenting ponds and water bodies surrounding the main river curvy line. Ponds could create aliases in the main river if the pass crosses both waterbodies.



Validation – FF-SAR IW waveforms quality

- Example of Aresys FF-SAR data at 100 Hz posting rate (~68 m distance between 2 consecutive records(nr. 1418 & 1419 in the figure->).
- Peaky waveforms are produced, as expected.
- The along-track resolution is given by the formula provided in the FF_SAR files. Here it is equal to 1,32 m ->



$$\text{ground_AT_resolution} = 0.886 * \text{wavelength} * \text{altitude} / (2 * \text{satellite_speed} * \text{integration_time})$$

Validation – FF-SAR - Inland water L2 estimates quality

- A watermark (shapefile) allowed selecting 3 points for the FF-SAR and 2 points for the Unfocused SAR. Similar posting rate (100Hz, FF-SAR, vs 80 Hz, GPOD SARvatore). 300 m resolution (SAR) vs 1.32 m resolution (FF-SAR).
- Over 300 m the corrections/geoid are pretty constant, the average of the corrections in SARvatore for CS-2 estimates has been used as input to the FF-SAR analyses.
- Orthometrics heights (OH) are pretty much the same between FF-SAR & SAR confirming that Aresys FF-SAR is correctly working. Pulse peakiness is comparable.
- GPOD SAMOSA+ estimates are slightly higher but the MISFIT is also very high (>4), therefore they cannot be considered fully reliable.



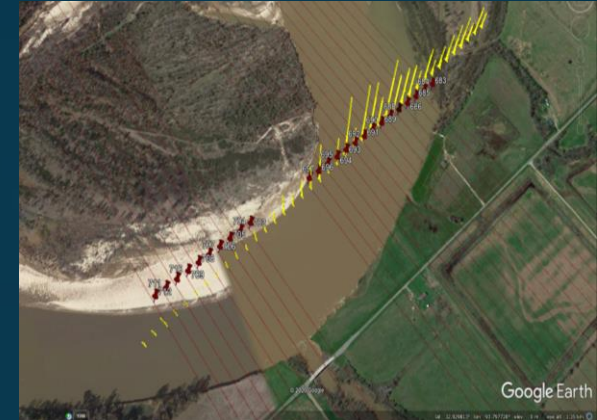
FF-SAR	PR	ZP	Band	TPR1	TPR2	TPR3	TPR4	TPR5	NPoints
Options:	100	2	0.25	0.6	0.65	0.7	0.75	0.8	
Index_FF	Lat_FF	Lon_FF	PP_FF	OH1 [m]	OH2 [m]	OH3 [m]	OH4 [m]	OH5 [m]	
1418	33.0799	-93.8476	0.463	54.149	54.123	54.092	54.061	54.03	
1419	33.0793	-93.8477	0.4038	54.181	54.167	54.153	54.139	54.126	3
1420	33.0787	-93.8477	0.4662	54.142	54.125	54.107	54.089	54.071	
Med1 [m]	Med2 [m]	Med3 [m]	Med4 [m]	Med5 [m]					
54.149	54.125	54.107	54.089	54.071					
Mea1 [m]	Mea2 [m]	Mea3 [m]	Mea4 [m]	Mea5 [m]					
54.158	54.138	54.117	54.096	54.075					

UF-SAR	PR	ZP	RET	TPR1	TPR2	TPR3	TPR4	TPR5	NPoints
Options:	80	2	TPR	0.6	0.65	0.7	0.75	0.8	
Index_UF	Lat_UF	Lon_UF	PP_UF	OH1 [m]	OH2 [m]	OH3 [m]	OH4 [m]	OH5 [m]	
1288	33.0797	-93.8476	0.4685	54.148	54.127	54.105	54.083	54.062	
1289	33.079	-93.8477	0.462	54.15	54.128	54.106	54.084	54.062	2
Med1 [m]	Med2 [m]	Med3 [m]	Med4 [m]	Med5 [m]					
54.149	54.127	54.105	54.084	54.062					
Mea1 [m]	Mea2 [m]	Mea3 [m]	Mea4 [m]	Mea5 [m]					
54.149	54.127	54.105	54.084	54.062					

UF-SAR	PR	ZP	RET						NPoints
Options:	80	2	SAM+						
Index_UF	Lat_UF	Lon_UF	PP_UF	MISFIT	OH [m]				
1288	33.07968	-93.8476	0.46845	4.547756	54.177				
1289	33.07896	-93.8477	0.461958	4.536553	54.403				2
Med1 [m]									
54.29									
Mea1 [m]									
54.29									

Validation - Aliasing in IW FF-SAR waveforms

- By considering the canal investigated in Kleinherenbrink et al., 2020 and reported before, similar radargrams can be obtained with the Aresys FF-SAR data:
- The investigations over Red River are much more complicated (larger width & ponds): aliases are on water, mixed, and L2 estimates would not be reliable.



- The Aresys FF-SAR service successfully passed preliminary tests on SSH noise estimation, waveform location and shape & L2 estimates quality in comparison to GPOD SARvatore for CS-2 estimates.
- A group of inland water altimetry experts has been formed to investigate more in detail the potential and limitations of FF-SAR and the quality of the Aresys FF-SAR processor.
- The service is scheduled to open to all GPOD users in the first semester of 2021 and will include a Forum and a Data Repository as made for SARvatore services.
- Future evolutions may include the extension of the service to Sentinel-3 and Sentinel-6 data.