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

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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
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 retracted 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](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.
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.

### L1B Processor
- **- Select the data type** N/S/ST you want to process
  - Flag to select the data posting rate: 20 Hz (canonic posting rate) or 80 Hz (non posting rate)
  - Only NT
- **- Hamming Weighting Window**
  - Flag to select the application of the Hamming Weighting Window on the burst data (section 4.4 in RF1)
  - Exact Beam-Forming
  - Approximated
- **- FFT Zero-Padding**
  - Flag to operate the Zero-Padding prior to the range FFT (section 4.8 in RF1)
  - Zero-Padding is indicated for central zero padding
  - Yes, apply Zero-Padding
  - No
- **- Radar Receiving Window Size**
  - Flag to select the size of the radar receiving window: 1.28 range bins (standard) or 256 range bins (extended)
  - Extended windows are useful for coastal zone analysis
  - 128 range bins
  - 256 range bins
- **- Antenna Pattern Compensation**
  - Flag to activate the antenna pattern compensation on the Stack Data
  - Yes
  - No
- **- Dump SAR Stack Data in output**
  - Flag to dump the SAR Stack Data in this output package: Be aware that SAR Stack Data are bulky data products (around 1.0 GB for single pass), do not process them massively but limit yourself at around 1000 passes at the time
  - Yes
  - No

### 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 path
  - Process only water
- **- PTR width alphabat parameter**
  - Use a LUT (Look-up Table) or a constant for PTR (Point Target Response) alphabat 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 (RF2). SAMOSA4 is the SAMOSA2 model tailored for inland water, sea ice and coastal zone domain
  - Use SAMOSA3
  - No
- **- 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 select the operation 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
  - Single-Look
  - Multi-Look

**RF1: Guidelines for the SAR (Delay-Doppler) L1 Processing**
For any question, bugs and support, please contact us at: altimetry.info@esa.int
For G-POD specific questions, please contact esa-gpod@esa.int
Aresys FF-SAR service (prototype)

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

![Image of Aresys FF-SAR service interface]

**Processing Parameters**
- Range oversampling factor
- Processed bandwidth factor
- Multipath noise rate
  - Advanced Configuration (Expert User Only)

**User Manual and References**
The Aresys’s FF-SAR processor for CryoSat-2 User Manual is available [here](#).
The ESA’s CryoSat Product Handbook is available [here](#).

The selectable River & Lake layers are based on the maximum water extent and annual recurrence products from Pekel et al. (2016), [https://www.palmermap.org](https://www.palmermap.org) respectively. They can only be used in conjunction with the “Open Street Map” Base Layer. The maximum water extent layer shall be used to identify the “true” extent; the annual recurrence layer should be checked to infer the seasonal/permanent presence of water. For more details, please check the Data Users Guide available at [https://www.esa.int/data/esa-data-access](https://www.esa.int/data/esa-data-access) and the “Global Surface Water Explorer.”

For any questions about the FF-SAR processor, please contact Aresys at [ffsar_prototype@aresys.it](mailto:ffsar_prototype@aresys.it).
For g-pod specific questions, please contact [support@g-pod.com](mailto:support@g-pod.com).
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).

<table>
<thead>
<tr>
<th>FF-SAR (TPR_retracker)</th>
<th>0.05801 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Official_CS2_SAR (TPR_retracker)</td>
<td>0.080712 m</td>
</tr>
<tr>
<td>GPOD_CS2-SAR (TPR_retracker)</td>
<td>0.08933 m</td>
</tr>
<tr>
<td>GPOD_CS2-SAR (SAMOSA_retracker)</td>
<td>0.050634 m</td>
</tr>
</tbody>
</table>

↑ 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-retracted 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 ->

\[
ground_{AT\_resolution} = 0.886 \times \text{wavelength} \times \text{altitude} / (2 \times \text{satellite\_speed} \times \text{integration\_time})
\]
Validation – FF-SAR - Inland water L2 estimates quality

- A watermask (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.
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.
Conclusions

- 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.