OSTST Meeting at Sentinel-6B Launch

Altimetry reference mission: past, present and future

Advanced Processing Features for Enhanced Sentinel-6 Products

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Abstract

The **Sentinel-6 mission (S6)** provides high-resolution radar altimetry data that are fundamental for ocean and climate monitoring. To further improve the quality and versatility of S6 products, isardSAT has developed a new set of advanced processing features aimed at improving the overall accuracy and precision, by enhancing focusing performance, calibration accuracy, and processing efficiency.

These developments include:

1. **Fully-Focussed Capabilities**: Implementation of an Omega-K algorithm that coherently averages echoes, frequency based, to improve processing time, and, most importantly, a Fully-Focussed Accelerated BackProjection optimised and implemented for **GPU** processing, significantly reducing computation time while maintaining full focusing capabilities compared to the Omega-K.
2. To support flexible trade-offs between resolution and noise, an **Unfocussed (sub-looked) BackProjection** mode has been introduced.
3. Enhanced spectral processing is achieved through a Chirp-Z transform with range walk correction and a configurable posting rate, allowing more **precise control of the along-track sampling**.
4. A **Complex Calibration** solution has been developed that ensures improved phase and amplitude instrumental calibration across scientific measurements of different acquisitions.
5. Finally, the development of new methodologies and monitoring tools for **external calibration** based on **passive reflectors**, proven to be necessary to meet the drift uncertainty requirements of the future missions.

While some features are already planned for next year's development roadmap, others are shared here to gather community feedback on their potential inclusion in future releases.

This presentation will detail the implementation and validation of these new features, their impact on data quality and processing performance, and how they contribute to the **readiness and optimisation of Sentinel-6B products**. These advancements represent an important step in ensuring continuity and improvement of the high-precision ocean topography record provided by the Sentinel-6 mission.

1. Fully-Focussed Capabilities

FF-SAR Algorithms

(Up to 0.5 m of along-track resolution)

Back-projection | Omega-K | Accelerated Back-projection

- **FF-SAR processing** [1] reaches the theoretical maximum along-track resolution, enabling new Earth Observation applications.
- **FF-SAR Omega-K** [2, 3] can produce global products for inland water, sea-ice monitoring [4], and ocean swell retrieval from Sentinel-6 [5], even without high computational resources.
- **FF-SAR Accelerated Back-projection** [6] improves runtime over the classic back-projection algorithm with no loss of accuracy.
- **GPU implementation (C++ and NVIDIA CUDA)** [7] reduces processing time drastically, from hours to minutes

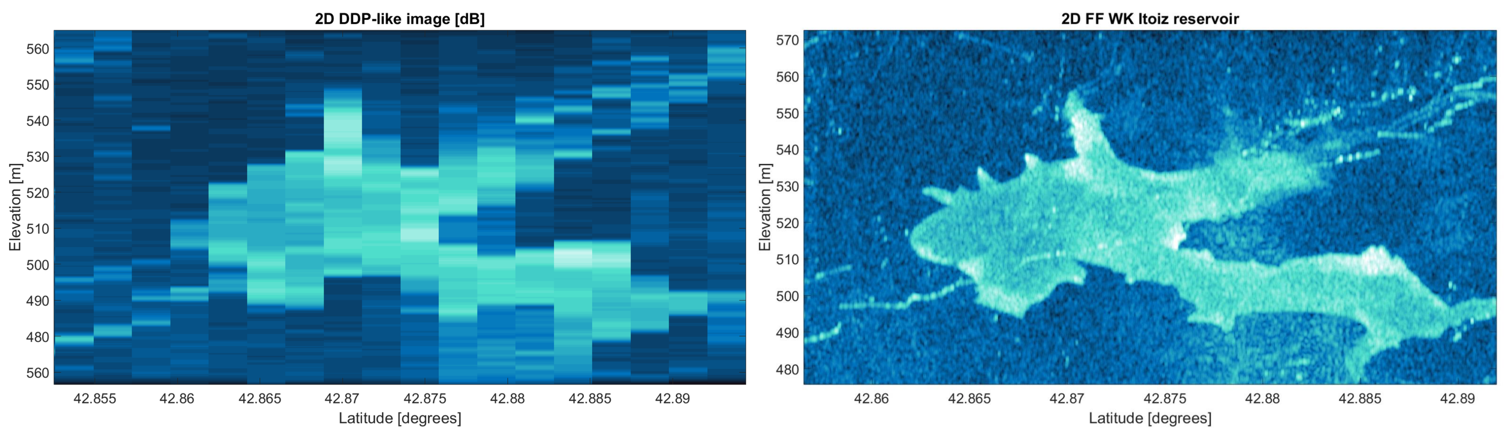


Figure: Radargram of a Sentinel-6 pass over the Itoiz Reservoir (Navarra). Comparison between Delay/Doppler (300 m along-track resolution) and Fully-Focused Omega-K (20 m after multi-looking).

2. Unfocused (Sub-looked) Back-projection

Unfocused SAR Algorithms

(300 m of along-track resolution)

Delay Doppler Approximated | Delay Doppler + Chirp Zeta Transform (3) | Sub-looked Back-projection (2)

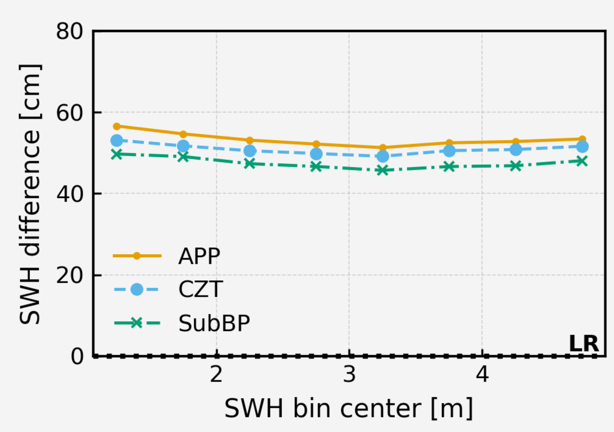


*Figure: Average SWH difference relative to the Low Resolution reference. **APP** = Delay/Doppler Approximated, **CZT** = Delay/Doppler with CZT, **SubBP** = Sub-looked Back-projection*

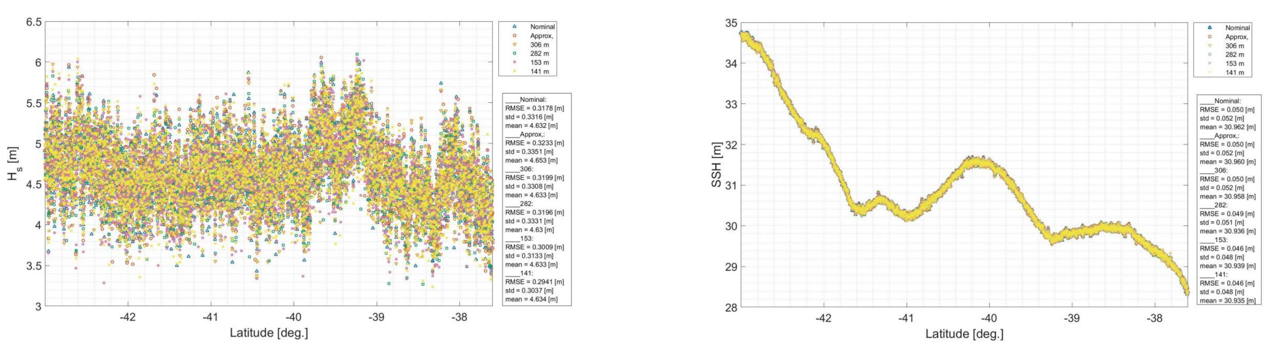
- The sub-looked back-projection method reconstructs echoes directly in the temporal domain, avoiding Delay/Doppler approximations.
- It achieves sharper focusing and higher coherence over complex surfaces.
- It provides more precise and reliable ocean measurements, reducing the biases in Sea Surface Height and Significant Wave Height when compared with Low-Resolution products.

3. Along-track posting rate control

The implementation of the **Chirp-Z Transform** (CZT) in the Sentinel-6 altimetric L1 chain represents an evolution of the conventional delay-Doppler processing, aiming to enhance the azimuthal performance while maintaining computational efficiency.

- Opposite to the FFT, the CZT [8] allows the definition of an **along-track configurable posting rate**.
- Additionally, the CZT can incorporate **range walk correction** to deliver sharper and more stable waveforms directly within the spectral transformation, offering a computationally efficient alternative to the traditional FFT exact beam steering, while having a significantly reduced processing cost.

Improved precision and consistency are observed in the retrieved geophysical parameters from Sentinel-6 MF data, in addition to the configurability of the L1B measurements posting rate.

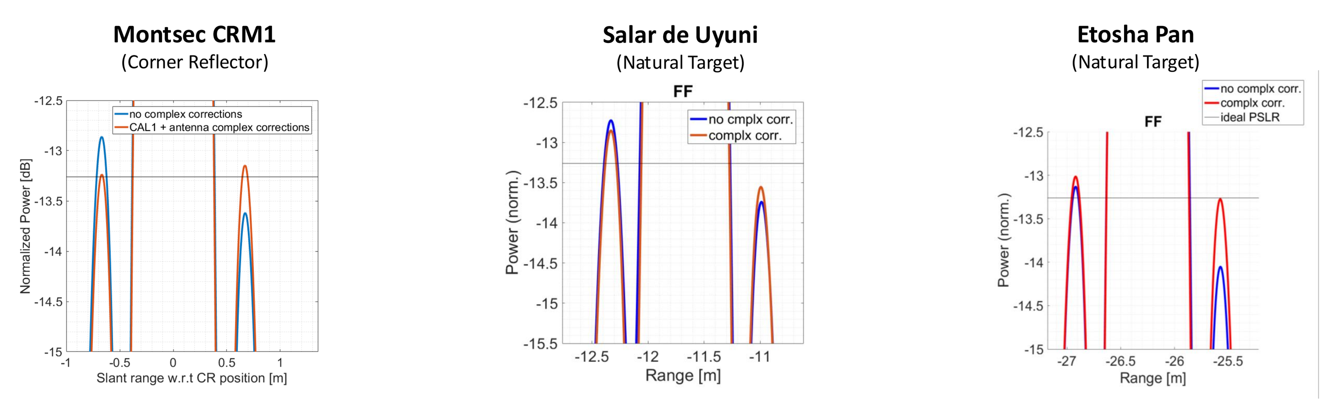


4. Complex Calibration solution

The newest addition to the suite of instrumental calibration algorithms is the CAL1 Complex Correction [9], which enables the removal of internal calibration loop distortions, both in power and phase, from the science echoes.

This correction is applied independently to each pulse along the range-bin dimension.

A robust way to validate its performance is through ultra-specular targets and the analysis of the resulting PTR shape features. This can be done over Corner Reflectors or specific natural targets:



Montsec CRM1 – Improvement

Asymmetry	PSLR
0.57 dB	0.25 dB

Salar de Uyuni – Improvement

Asymmetry	PSLR
0.31 dB	0.16 dB

Etosha Pan – Improvement

Asymmetry	PSLR
0.67 dB	0.35 dB

5. External Cal to meet drift uncertainty req.

Corner reflectors (CR) deployed for long term periods have demonstrated to be high reliable tools to assess altimeter range and range drift stability, especially if installed near permanent GNSS stations.

A specific FFSAR-based methodology developed by isardSAT allows to process and track in high precision the range bias signal from repetitive passes to build long term time series.

The current range bias series from the CR in Montsec, deployed in 2021 near Barcelona, is the longest available as of today [10].

A global network of CR could be used to proof range drift *reqs*. for next generation of altimeters.

Figure: isardSAT's Montsec trihedral CR located at the Pyrenees, with theoretical RCS of 54.9 dBm2.

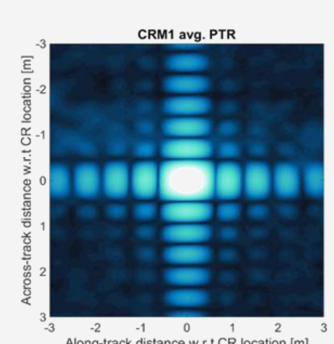


Figure: S6 PTR over the Montsec CR, matching theoretical values in both along-track and across-track with Signal-to-Clutter Ratio of 40.6 dB.

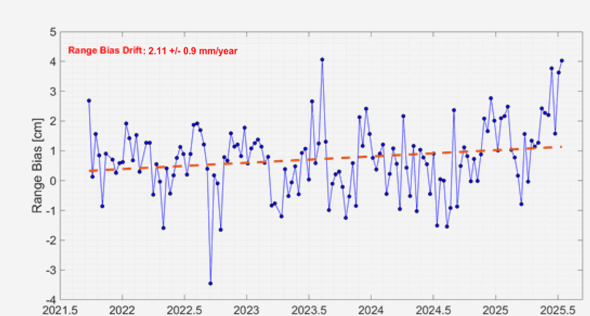


Figure: S6 range bias drift measured over the Montsec CR of 2.11 ±0.9 mm/year. Ground vertical motion preliminarily estimated at -2.4 mm/year, therefore residual range bias of 0.3 mm/year.

Current status and Conclusions

- The current Operation Products (PDAP) include:
  - Complex Calibration (**next year**)
  - Chirp-Z transform (**no configurable posting rate**)
- The Ground Processor Prototype (GPP) contains (data can be provided for testing purposes):
  - Complex Calibration
  - Chirp-Z transform with configurable posting rate
  - Fully-Focussed Back-projection, Accelerated and implemented in GPU's
- Unfocused (Sub-looked) Back-projection:
  - Provides more precise and reliable ocean measurements, reducing the biases
  - It can easily be implemented in the Operational Products
- Results obtained with current CRs (e.g. the Montsec, Pyrenees, Catalonia), prove that a global network of CRs could be used to achieve range drift requirements for next generation of altimeters.

References:

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