Evaluating the Sentinel-6 RAW data for the computation of SAR altimetry spectra

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Background (1/2)

Sentinel-6A, launched in 2020, carries onboard the Poseidon-4 nadir-pointing radar altimeter

Innovation: Interleaved mode that enables radar data processing on two parallel chains:

- **Low Resolution Mode (LRM):** compatible with the historical reference altimetry measurements, ensuring data continuity for long-term climate monitoring (along-track resolution ~ 7 km)
- **Synthetic Aperture Radar (SAR)** in Ku-band: enhances along-track sampling (~ 300 m) and reduces measurement noise

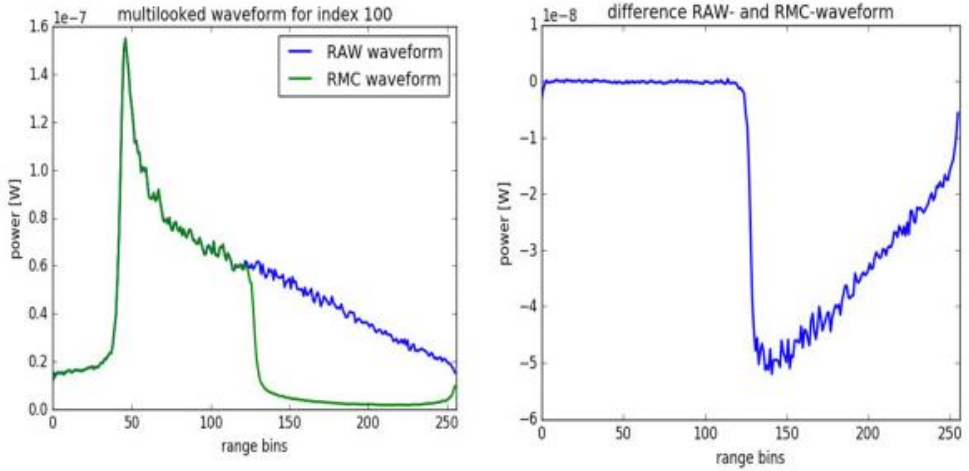
However: Data volume needs to be reduced **onboard** due to system constraints: a configurable number of samples is selected for downlink to ground

How: SAR signals are truncated onboard using the Range Migration Correction (RMC) processor, reducing the data rate by a **factor of two**

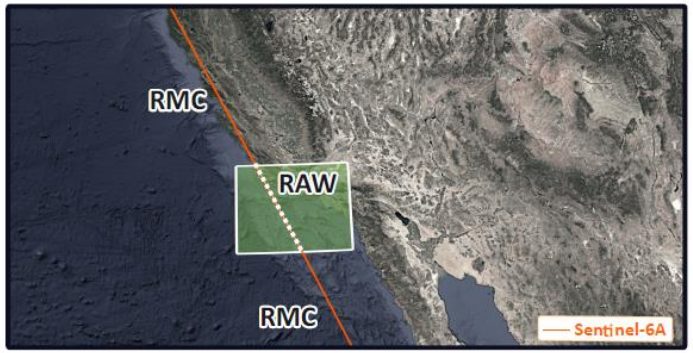
Background (2/2)

How: SAR signals are truncated using the Range Migration Correction (**RMC**) processor, reducing the **RAW** data rate by a **factor of two**

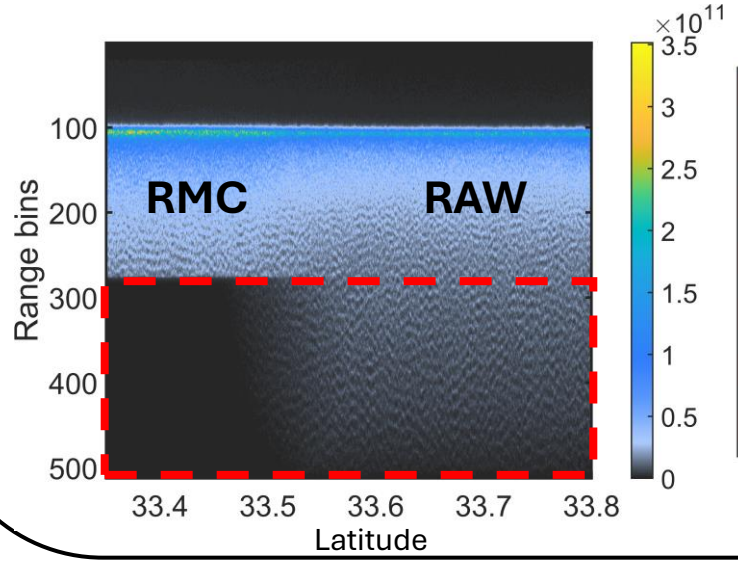
RMC (operational) **RAW** (pre-truncation)



Donlon et al. 2016



Example of successive multilooked waveforms along a track of Sentinel-6A. The colorbar represents power variations.



These signals are **NOT** transmitted for on-ground processing

Motivation

Although the RMC signal truncation processing does not impact the retrieval of key geophysical parameters (i.e., significant wave height, wind speed, sea surface height), Altiparmaki et al. 2022 suggests that the truncated signal contains valuable information on **swell properties** (long ocean waves generated by storms).

•**Project Goal**:
Assess the impact of the RMC processor on the retrieval of swell wave characteristics

•**Approach**:
Cross-comparisons of swell-induced fully-focused SAR modulation spectra between **RMC** (operational) and **RAW** data (pre-truncation) against wave-modeled parameters (ERA5)

•**Required Input**:
High-resolution **Fully-focused SAR data (Level-1b)**

Access to High-Resolution Level-1b Data with EarthConsole

Thanks to the **ESA NoR sponsorship**, EarthConsole provided high-resolution Level-1b data required to meet the needs of this projects:

➢ **Why EarthConsole?**

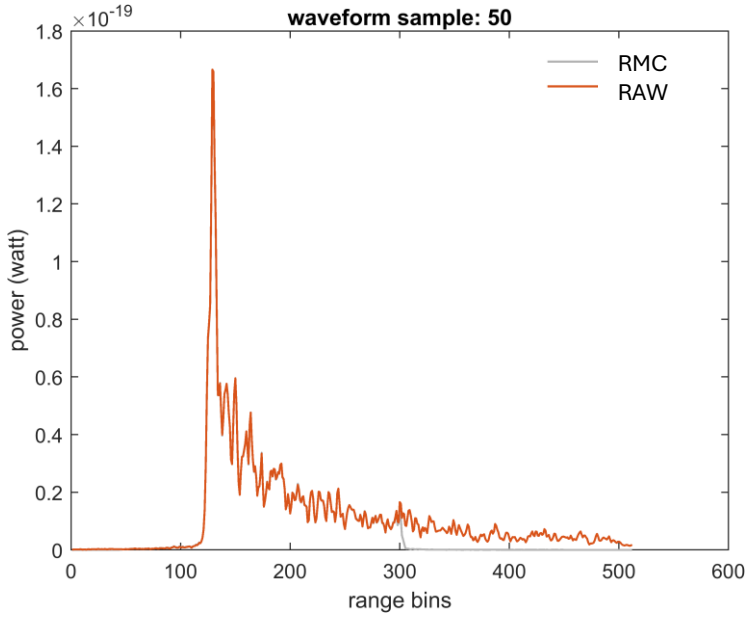
- **Challenge**: Fully-focused SAR (FFSAR) Level-1b data are not operationally available
- **Solution**:
  - Provides fast and reliable high-resolution FFSAR data
  - Applicable for diverse environments: **open oceans, sea ice, and inland waters**

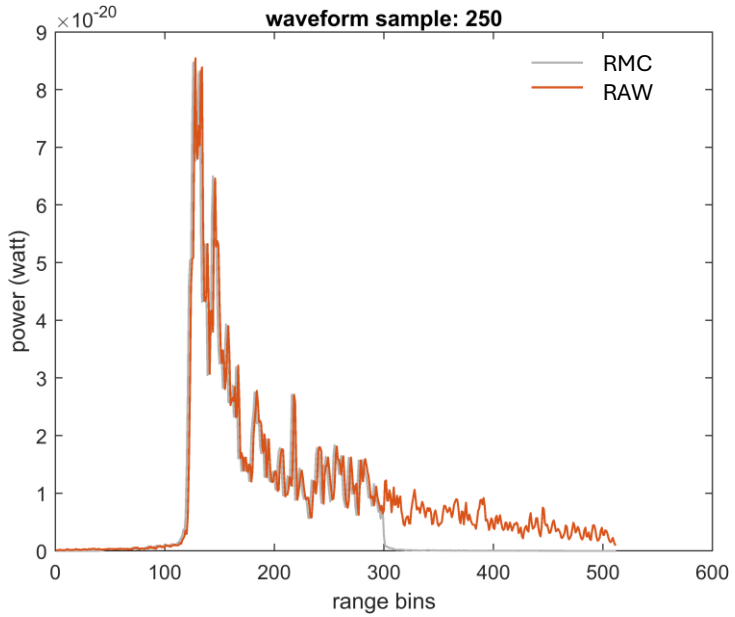
➢ **FFSAR Data Processing Requirements:**

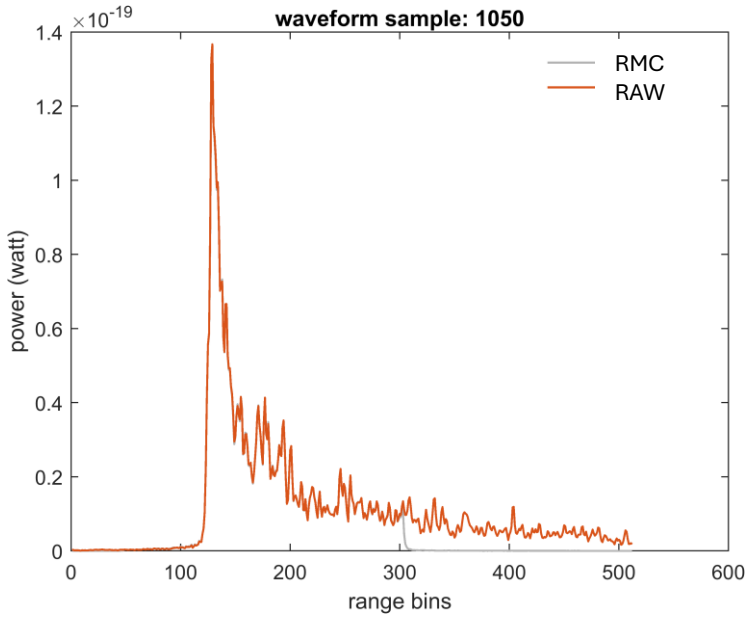
- **Technical Expertise**:
  - Knowledge of low-level data processing
  - Software development.
- **Powerful Systems**:
  - High-capacity processing units
  - Storage for Level-1A data (1 pass ~ 15 GB)

RMC versus RAW waveform analysis

The first step is to confirm that RAW and RMC data are identical, as expected, up to the truncation point. This ensures that the truncation process does not introduce discrepancies in the signal prior to the cutoff.



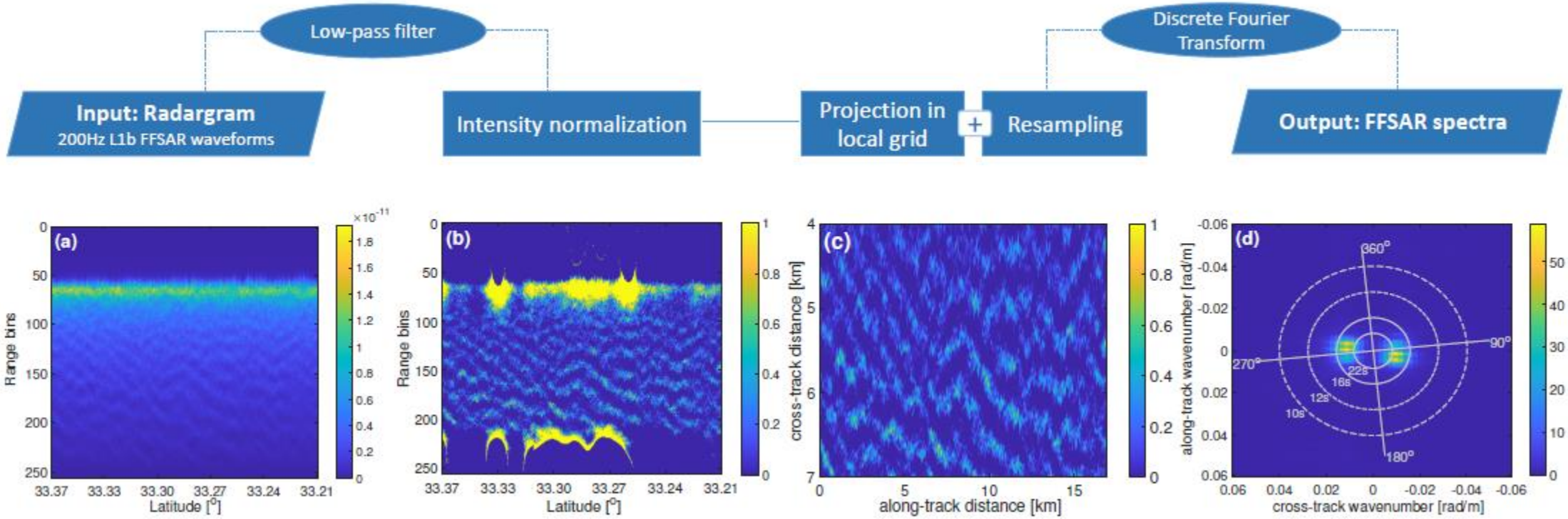




Qualitative analysis demonstrates that signals from both modes align perfectly. The middle panel highlights a minimal shift in the RAW waveform, less than 1/3 of one range bin, which is negligible and is not expected to affect data quality.

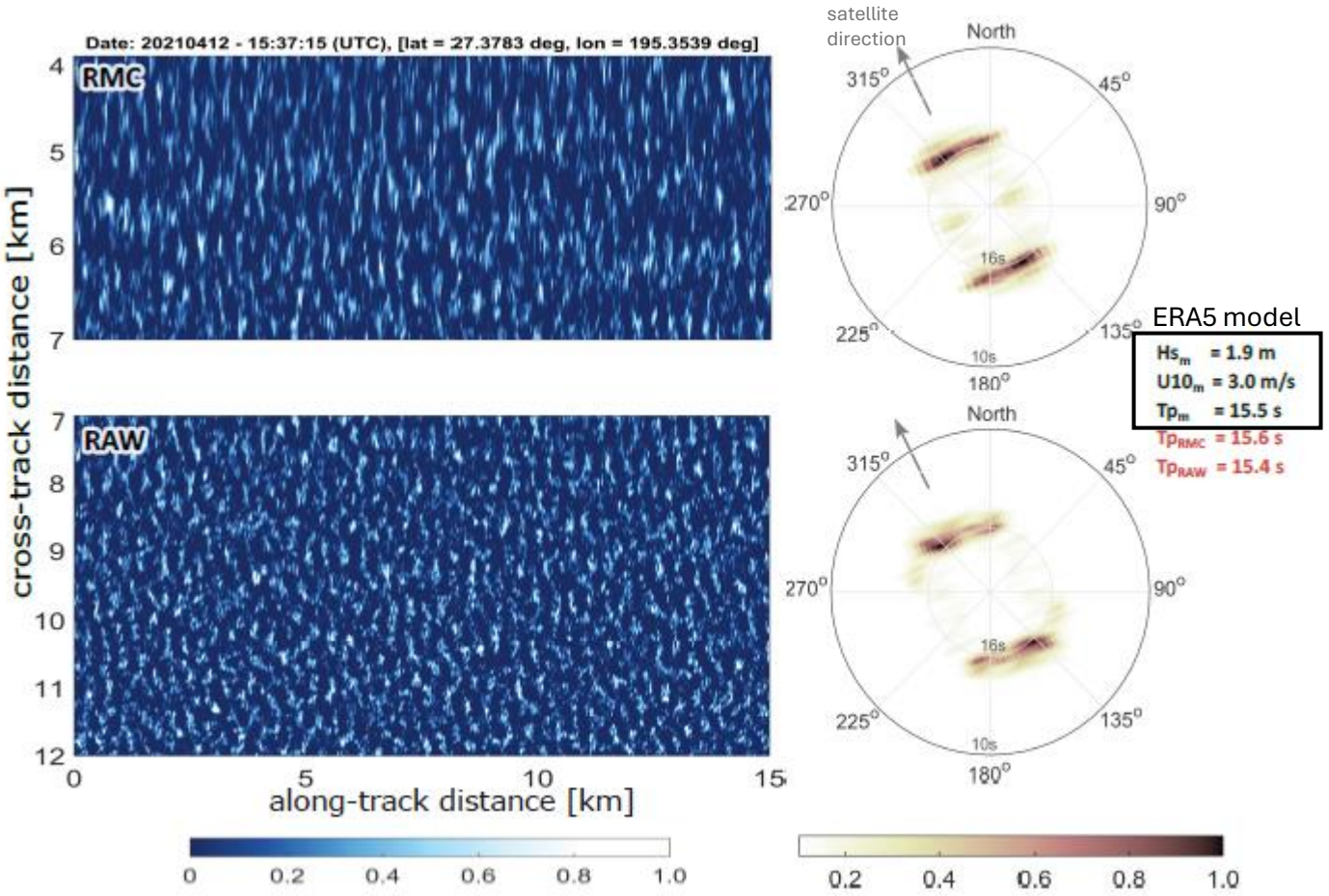
FFSAR modulation spectra computation

The second step involves computing the swell-induced FFSAR modulation spectra, following the methodology described in Altiparmaki et al. (2022). This approach enables detailed analysis of swell-related features in the radar signal.



Altiparmaki et al. (2022)

Cross-comparisons (1/2)



Altiparmaki 2025 (*Ph.D. thesis*)

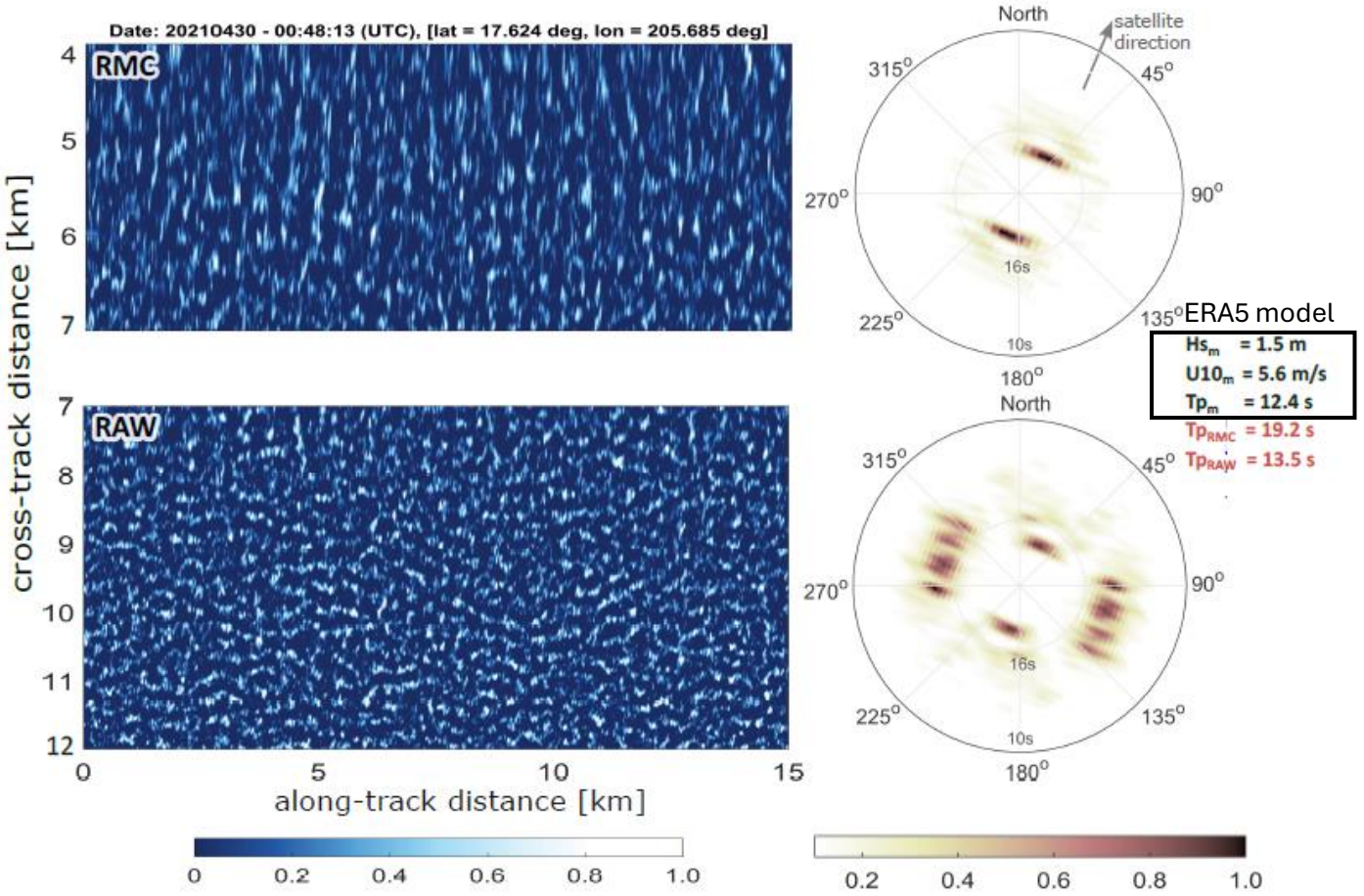
*Case 1: Swells are traveling **along-track***

- **Peak Wave Period (Tp)**:
Both RMC and RAW data align well with the **model-derived values (ERA5)**, confirming consistency in swell retrieval

- **Peak Wave Direction**:
Good agreement is observed between RMC and RAW data in terms of **power concentration in the spectrum**

- **Low-Frequency Noise**:
RAW data show an advantage as noisy signals in **low frequencies (>16 sec)**, observed in RMC data, are absent in RAW data

Cross-comparisons (2/2)



Altiparmaki 2025 (*Ph.D. thesis*)

*Case 2: Swells are traveling **cross-track***

•**Peak Wave Period (Tp)**:
RMC overestimates the peak wave period by **7 seconds**, while **RAW** achieves higher accuracy, remaining within a **1-second margin** compared to **ERA5**

•**Wave Energy and Direction**:
Waves traveling **cross-track** are identified as the most energetic system according to ERA5

•**Swell Systems**:
•**RAW** reveal two distinct swell systems
•**RMC** only detect the weaker of the two swell systems

•**RMC Limitations**:
•The **large cutoff wavelength** in RMC data, caused by limited cross-track resolution, restricts the operational product to detecting only **long swells (~18 seconds)**, missing the most energetic swells (12.4 seconds)

Summary

- **Objective**:
  To investigate the impact of the signal truncation processor onboard Sentinel-6A by comparing **RAW (non-operational)** and **RMC (operational)** products.

- **Input Data**:
  High-resolution data provided by **EarthConsole**, funded by the **ESA NoR sponsorship**.

- **Preliminary Findings**:
  - **RAW Data Advantage**: Higher ground resolution of the truncated signal shows potential for improved swell retrieval applications.
  - **Wave Direction Sensitivity**: Significant impact observed when waves travel across the satellite track.

- **Future Work**:
  - Assess the signal truncation impact across diverse case scenarios (wave direction, sea state).
  - Further quantify and validate results to generalize findings.

- **Takeaway**:
  RAW data offers promise for advanced wave analysis, but operational RMC products remain vital for efficient processing. Further research is required to explore the trade-offs.

References

1. Altiparmaki, O., Kleinherenbrink, M., Naeije, M. C., Slobbe, D. C., & Visser, P. N. A. M. (2022). **SAR altimetry data as a new source for swell monitoring**. Geophysical Research Letters, 49(7), Articlee2021GL096224. Advance online publication. https://doi.org/10.1029/2021GL096224

2. Craig J. Donlon, Robert Cullen, Luisella Giulicchi, Pierrik Vuilleumier, C. Richard Francis, Mieke Kuschnerus, William Simpson, Abderrazak Bouridah, Mauro Caleno, Roberta Bertoni, Jesus Rancaño, Eric Pourier, Andrew Hyslop, James Mulcahy, Robert Knockaert, Christopher Hunter, Alan Webb, Marco Fornari, Parag Vaze, Shannon Brown, Joshua Willis, Shailen Desai, Jean-Damien Desjonqueres, Remko Scharroo, Cristina Martin-Puig, Eric Leuliette, Alejandro Egido, Walter H.F. Smith, Pascal Bonnefond, Sophie Le Gac, Nicolas Picot, Gilles Tavernier, **The Copernicus Sentinel-6 mission: Enhanced continuity of satellite sea level measurements from space**, Remote Sensing of Environment,Volume 258, 2021, 112395, ISSN 0034-4257, https://doi.org/10.1016/j.rse.2021.112395