Ocean swell parameters retrieval using Sentinel-6 FF-SAR spectra

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ABSTRACT

Swell, an essential component of wave dynamics, holds significant influence over oceanographic systems. Thus, accurate determination of swell wave parameters is considered of high interest. While SAR techniques have long been employed for swell retrieval, radar altimetry presents challenges due to its unique geometry and limited spatial resolution. Traditionally, operational satellite radar altimeter missions processed data with spatial resolutions around 300 metres, which were insufficient for estimating short-period swell parameters. However, recent advancements, such as the Fully-Focused SAR (FF-SAR) backprojection algorithm and the 2D frequency algorithm, have substantially improved processing techniques, increasing along-track resolution to the meter-scale.

In 2022, Altiparmaki et al. [1] demonstrated the feasibility of retrieving swell wave parameters through the analysis of intensity modulations in the waveform tail, paving the way for the development of altimeter-based swell products. However, interpreting swell retrieval in radar altimetry differs substantially from conventional SAR due to differing geometries, ushering in new perspectives. In this context, monitoring swells plays a critical role in discerning the influence of wind waves and swell within the sea-state bias.

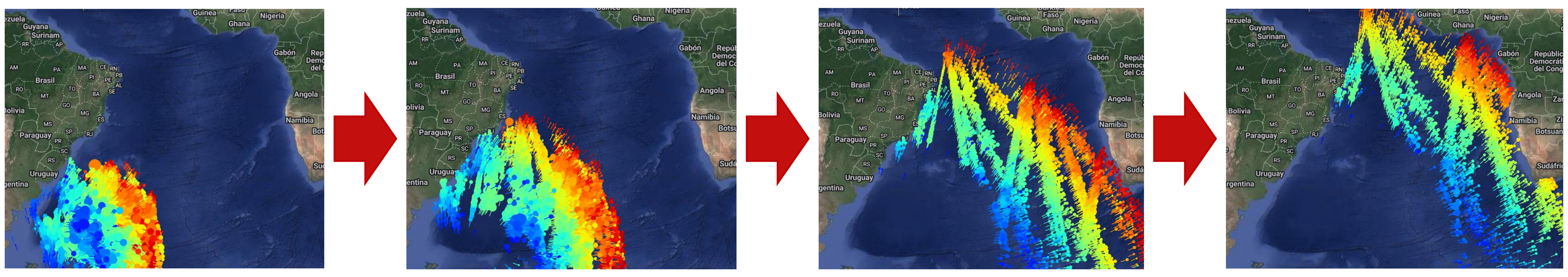
Additionally, the process of swell-flagging is vital for identifying potential biases of SSH in retracker.

Moreover, swell observations derived from altimetry facilitate their cross-calibration originating from various platforms, contributing to a more comprehensive understanding of swell dynamics. Ongoing projects, such as SARWAVE [2], funded by the European Space Agency (ESA), are actively involved in researching efforts to provide a detailed understanding of changes in swell intensity. This includes cross-spectra analysis, aimed at enhancing the accuracy of retrieving swell-wave parameters as it has been proven feasible by [3].

In line with these efforts, we introduce a methodology for extracting swell parameters from Sentinel-6 radar altimeter data thousands of kilometers away from storm surges using fireworks data from CFOSAT. The data are processed with the Omega-K (WK) algorithm ([4] and Poster 30YPRA #252 [5]) and submitted to spectral analysis to retrieve the parameters. Along track swell shows better results than that oriented across-track.

Swell propagation from storm surges

The aim is to detect the swell wavelength using altimetry data from Poseidon-4 altimeter. To do so, swell is isolated using a third-party validated source: CFOSAT-SWIM fireworks vectors grid (ovl.oceandatalab.com) and S6 tracks are selected by co-location with this data along the swell direction. Here we provide an example of the swell caused by a storm in southern Atlantic ocean on June 11th, 2023.



June 11th *June 12th* *June 14th* *June 15th*

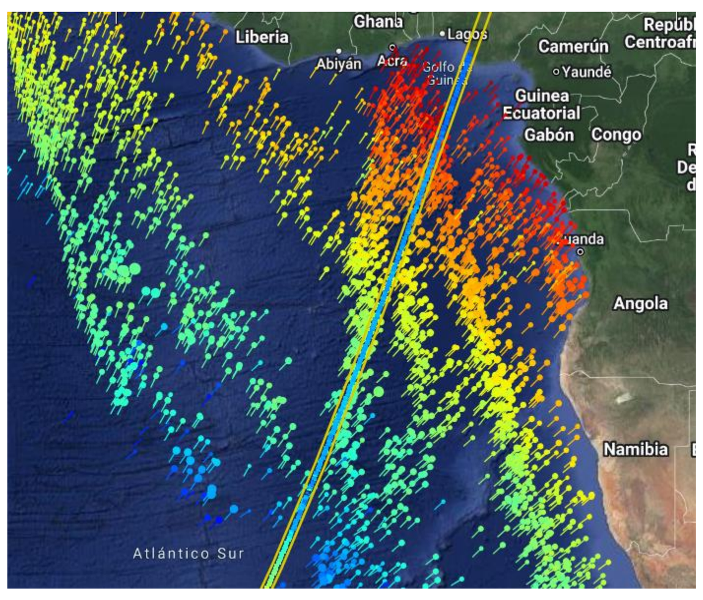
Swell propagation

The fireworks color scale represents the Dominant Wave Period of the swell (red for larger period) which is directly related to the Dominant Wavelength by the equality:

$$\lambda_{swell} = \frac{9,81}{2\pi} DPD^2$$

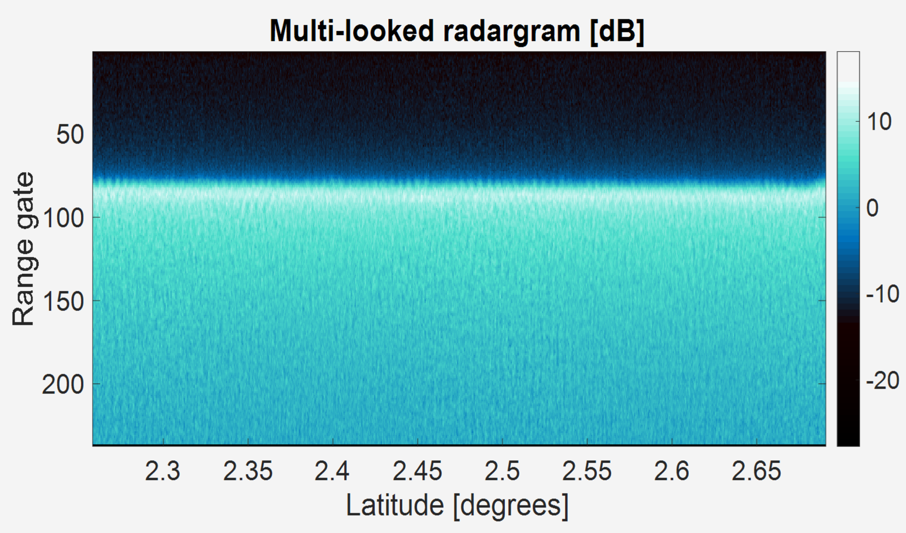
As the larger wavelengths of the swell generated from the storm travel faster, the initial components are naturally distributed along the directions of propagation.

Data co-location with Sentinel-6

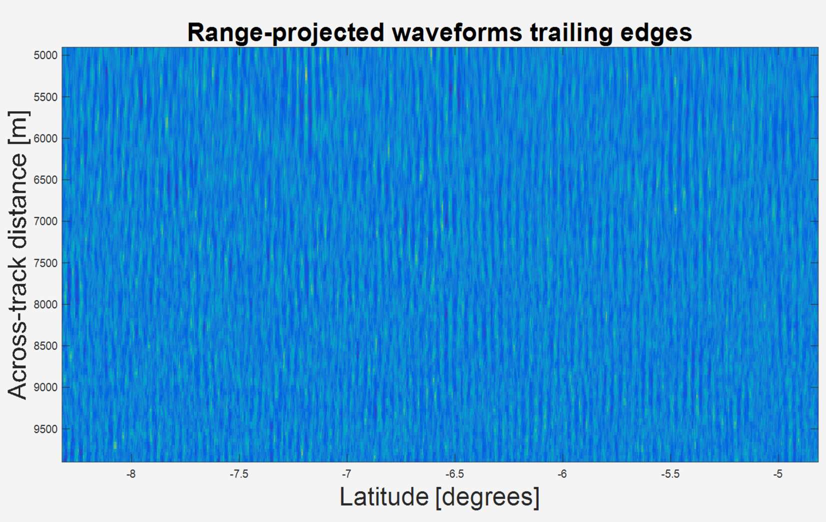


S6 track (211) co-located along swell. June 15th, 2023

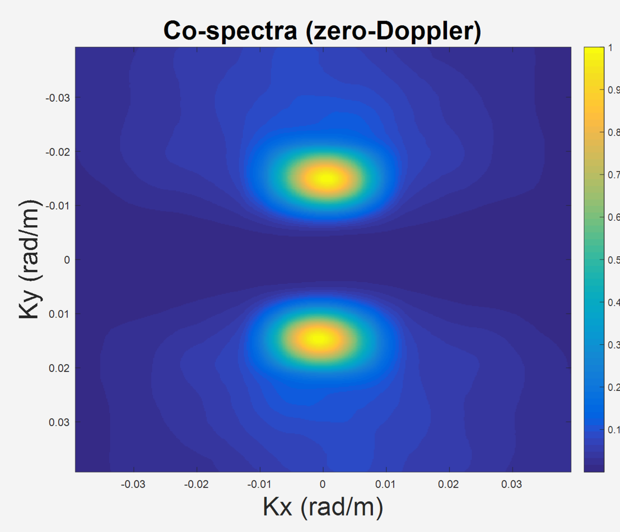
Methodology



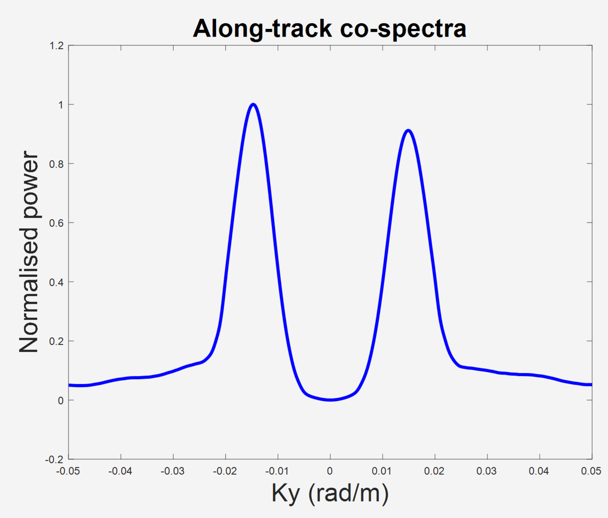
The selected data are processed with the Ωk processor and Multi-looked with **42 m spatial resolution, block length of 20 s and integration time of 1 s**. First inspection shows a clear wave pattern.



Waveforms are sliced to the trailing edge, which is normalized for range decay to proceed spectral analysis



Co-spectra are obtained by applying a 2-D Fourier transform (Zero padding: 8) to blocks of fixed length along the radargram. Then, a gaussian filter is passed for smoothing the result



Finally, the along-track co-spectra result from taking an average along the Kx axis, so we end up with a Ky profile of the spectrum analysed. Dominant wavelength is calculated by taking the Ky value of the maximum point of this function and applying:

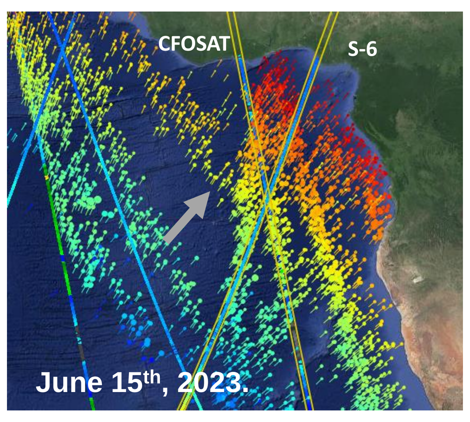
$$\lambda_{dom} = \frac{2\pi}{K_y(max)}$$

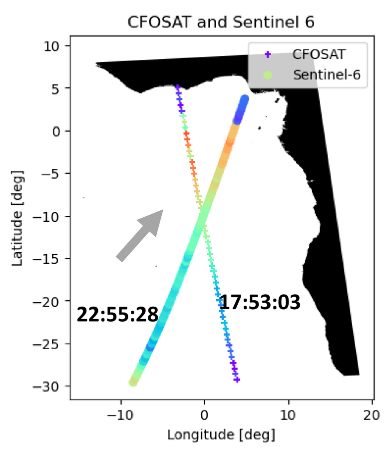
Comparison vs CFOSAT

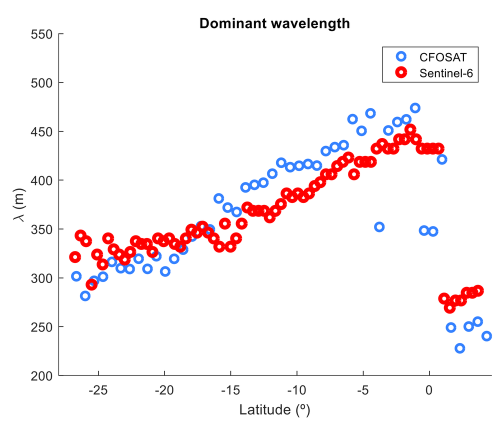
The methodology described above allows to estimate the dominant wavelength of the swell (one per block). This parameter is compared with the one retrieved by CFOSAT-SWIM. Four scenarios are analysed, and for each of them the following figures are shown: (1) Swell fireworks with Sentinel-6 and CFOSAT tracks, (2) Sentinel-6 and CFOSAT geolocated plots with swell dominant wavelength and (3) 1-D plots of the dominant wavelength as a function of latitude, since most passes sample a swell propagation which is typically traveling south to north (*see grey arrows indicating swell travelling direction*). The time separation is of few hours, which means that the measured dominant wavelengths by the different instruments may be slightly different.

The first three examples correspond to along-track swell relatively aligned with the Sentinel-6 track, while the last one is relatively across-track. In the first result we can see consistent measurements between instruments, what confirms the success of the measurement of swell dominant wavelength with radar altimeters. Moreover, as the wavelength gradually increases, it can be inferred the direction of the swell along track.

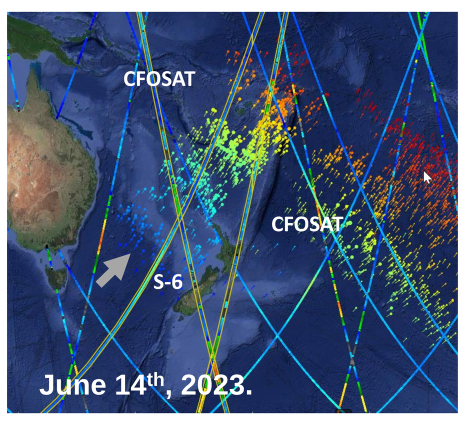
Case 1: S6 (T.211) aligned with swell (Gulf of Guinea): Good agreement

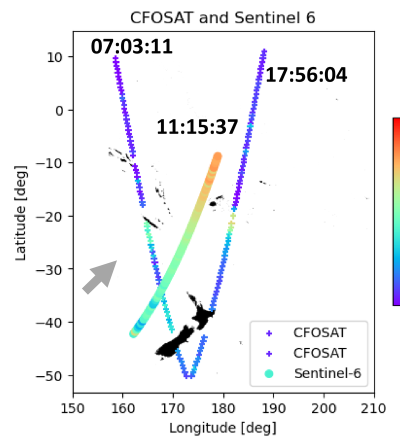


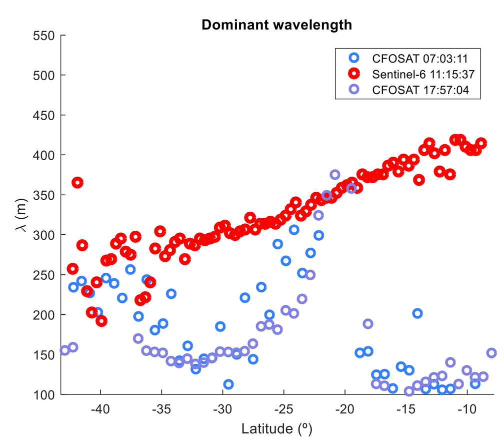




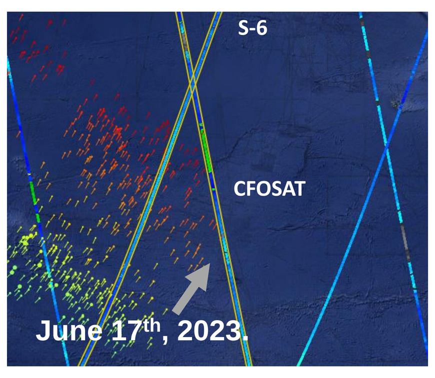
Case 3: S6 (T.173) aligned with swell but over complex scenario: Partial success

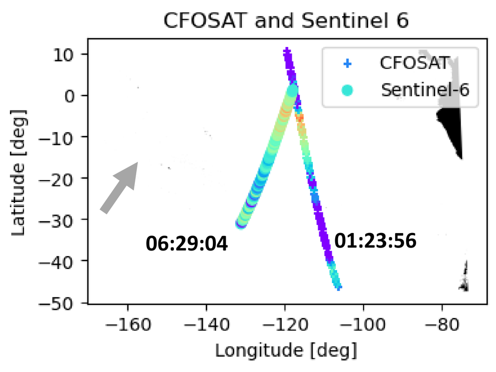


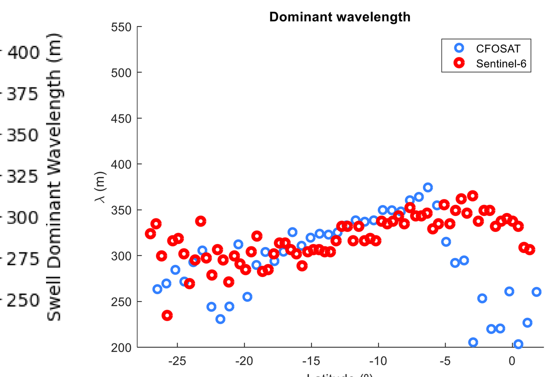




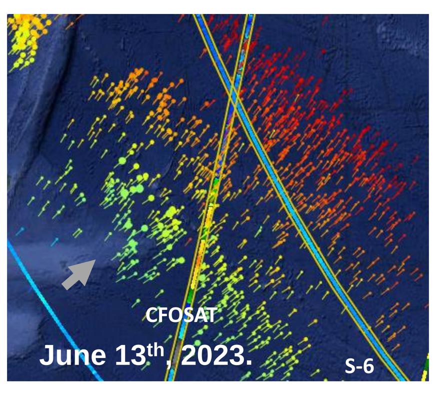
Case 2: S6 (T.247) aligned with swell (Pacific Ocean): Good agreement

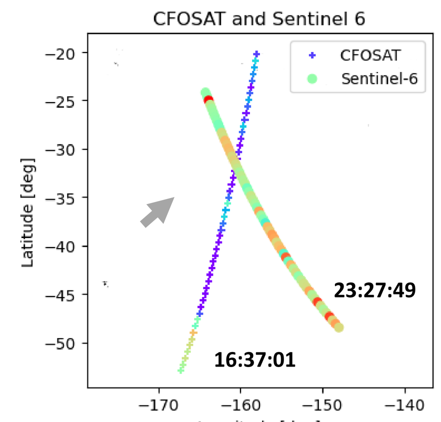


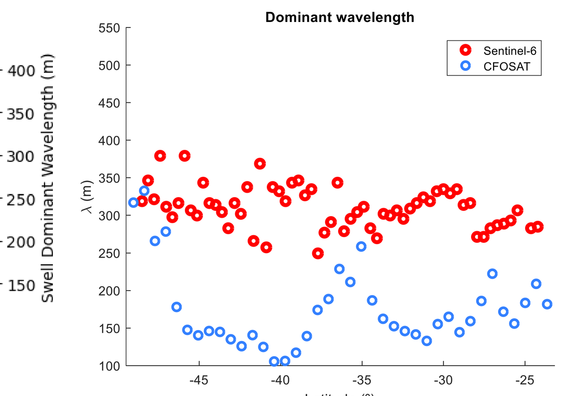




Case 4: S6 (T.160) orthogonal to swell (Pacific Ocean): Biased







References

[1] Altiparmaki, O, et al (2022). SAR altimetry data as a new source for swell monitoring. GRL, 49

[2] Project funded by the ESA. Contract No.: 4000137982/22/I-DT: www.sarwave.org

[3] M. Kleinherenbrink et al., "Cross-Spectral Analysis of SAR Altimetry Waveform Tails," in IEEE TGRS, vol. 62, pp. 1-15, 2024, Art no. 4206615

[4] S. Hernández-Burgos et al., "A Fully Focused SAR Omega-K Closed-Form Algorithm for the Sentinel-6 Radar Altimeter: Methodology and Applications," in IEEE TGRS, vol. 62, pp. 1-16, 2024, Art no. 5206016,

[5] S. Hernández et al., "An Overview of the Fully-Focused SAR Omega-K Closed-Form Algorithm." 30 Years of Progress in Radar Altimetry Symposium, 2-7 September 2024, Montpellier. Poster #252 / Abstract #380.

Conclusions

- Swell dominant wavelength can be measured by radar altimeters under specific conditions.
- Wavelength measurements comparable to CFOSAT are achieved when the swell propagation direction is aligned with altimeter track.
- The swell propagation direction can be inferred by the slope of the calculated wavelength series.
- Tracks orthogonal to swell propagation direction report bias results, attributed to insufficient modelling of cross-track effects.
- Validation to ensure good measurement accuracy will require better collocation in time and space between Sentinel-6 and CFOSAT passes.

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