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► **To cite this version:**

C Tourain, L Hermozo, Danièle Hauser, L Aouf, C Peureux, et al.. CFOSAT: Products Reprocessing and Contributions in Oceanography. IGARSS 2023 International Geoscience and Remote Sensing Symposium, IEEE, Jul 2023, Pasadena, CA, United States. pp.3958-3961, 10.1109/IGARSS52108.2023.10283105 . hal-04180798

HAL Id: hal-04180798

<https://hal.science/hal-04180798>

Submitted on 29 Aug 2023

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CFOSAT: PRODUCTS REPROCESSING AND CONTRIBUTIONS IN OCEANOGRAPHY

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ABSTRACT

Since 2018, for the first time, space measurements of co-located wind vectors and wave spectral characteristics are available thanks to the French/Chinese CFOSAT mission, which carries a wind scatterometer (SCAT) and a wave scatterometer (SWIM). Four years after its launch, CFOSAT data processing has been improved to reach a high level quality, leading to a reprocessing of the whole mission dataset. This paper focuses on the CFOSAT SWIM data reprocessing, the product performance, now homogeneous over mission lifetime, the complementarity with SAR observations and some scientific contributions to oceanography.

Index Terms— Ocean, radar, waves

1. INTRODUCTION

CFOSAT (China France Oceanography Satellite) [1] was launched on October, 29th 2018. This mission, developed under the responsibilities of the French and Chinese Space agencies (CNES, CNSA), aims at better understanding processes at the ocean surface and ocean/atmosphere interactions and improving atmospheric and oceanographic models and predictions through assimilation of observations. In this purpose, the satellite embarks two radar sensors in Ku-Band, both scanning in azimuth: SCAT, a fan-beam wind scatterometer [2], and SWIM designed for wave measurements [3], collecting collocated measurements of ocean surface wind and waves.

This paper focuses on the SWIM measurements. SWIM is an innovative Ku-band real-aperture wave scatterometer, with 6 near-nadir incidence rotating beams [3]. Thanks to SWIM, CFOSAT ground segment provides users with directional spectra of ocean waves with a real-aperture radar system, all over the globe. This usefully complements the existing missions based on SAR systems which also provide spectral information on surface ocean waves but with more limitations [4]

Since launch, CALibration and VALidation analysis was undertaken on the instrument and products, leading to various evolutions of the algorithms at the different data processing levels and to significant improvements of SWIM

products [5]. This led to a reprocessing with the latest issue of operational chains. The latest improvements are described below in section 2. In section 3 we show the complementarity of SWIM and SAR observations, by analyzing performances function of 2 wavelength categories. In section 4 we present the interest of SWIM observations for deriving the Stokes drift at the global scale.

2. CFOSAT/SWIM DATA

SWIM products

Except for L1A products, which contain calibrated and geocoded normalized radar cross section profiles, all products are made available on AVISO web site (<https://www.aviso.altimetry.fr/en/missions/current-missions/cfosat/access-to-data.html>). Users have thus access to modulation spectra in the surface geometry (L1B product), and geophysical information provided in level 2 product:

- The normalized radar cross section (σ_0), the Significant Wave Height (SWH) and wind speed from nadir measurements, estimated at 1 Hz and 5 Hz frequency using the Adaptive retracking algorithm [6].
- Wave products within each wave cell: 2D directional wave slope spectra with their associated wave parameters (SWH, wavelength and direction) [5] estimated using methods described in [7].
- σ_0 at near-nadir incidences from 2° to 10°, given at full range resolution and also averaged within 0.5° bins (mini profiles)

SWIM reprocessed data

All products have been reprocessed in early 2023, from level 1A to level 2. All SWIM data were reprocessed with the latest processing chain issue, namely the 6.0.2, which benefits of all improvements brought by successive evolutions defined thanks to product and algorithm validation. Among the main evolutions we mention here:

- The upgraded correction of the antenna gain pattern which reduces drastically the non-geophysical trend previously observed on the σ_0 fully-resolved mini-profiles with respect to incidence and azimuth [8]
- Better account of an on-board real-time anomaly occurring in 2019-2020 which induced micro-cuts in signal reception

(loss of raw samples); this correction provides a better identification of σ_0 values impacted during period of strong occurrences of microcuts (May-June 2019 and September 2019-October 2020).

- The selection of Modulation Transfer Function (MTF). The choice of the so-called MTF3 method [7], provides wave spectral energy fully consistent with the SWH measured at nadir.

- The along-track speckle noise mitigation [5] reduced the strong energy observed in the 0-15° azimuth range due to speckle noise, this allowed to provide the whole wave slope spectra in the product, with also a positive impact on wave parameters.

Reprocessed SWIM data has thus reached a high quality, observable through wave parameters consistency compared to either model or in situ observations. Fig.1, shows the significant wave height, the dominant wavelengths and the dominant directions obtained from SWIM compared to the results of the wave model MFWAM. For SWH the consistency is very high with a correlation coefficient of 0.99, a mean bias of only 3 cm and a rms difference of 20 cm. For the dominant wavelength, the correlation is less but still good ($r=0.75$) and we observe a mean bias of about 43 m which is mainly due to the fact that the comparison is made between dominant wavelengths of the slope spectrum of SWIM and of the height spectrum of MFWAM. After accounting for the 180° ambiguity in direction of SWIM data, the directions are also well correlated ($r=0.90$) with the MFWAM values and exhibit very small bias; rms differences on directions are of the order of 24°.

Figure 2 shows a good consistency of σ_0 mini profiles when compared to GPM results. Compared to the previous processing version, this comparison is improved thanks to an improved filtering of σ_0 profiles before mini-profiles construction. Some discontinuity between mini-profiles is however evidenced. This should be corrected in future versions.

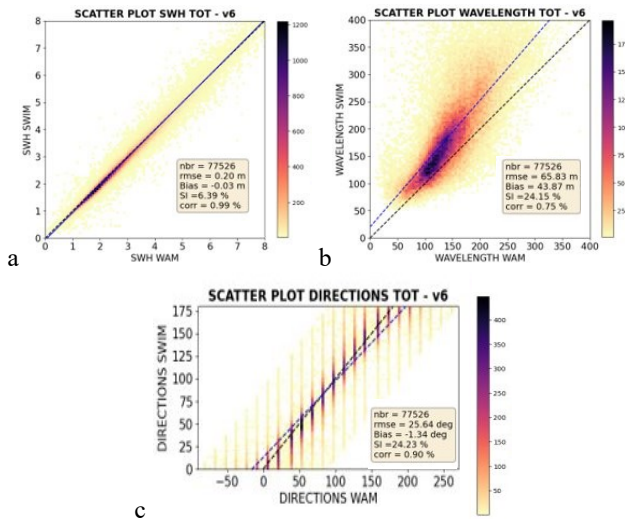


Figure 1. SWIM wave parameters compared to MFWAM for observations from January 28th to February 10th, 2021, a: SWH, b: dominant wavelength, c: dominant wave direction.

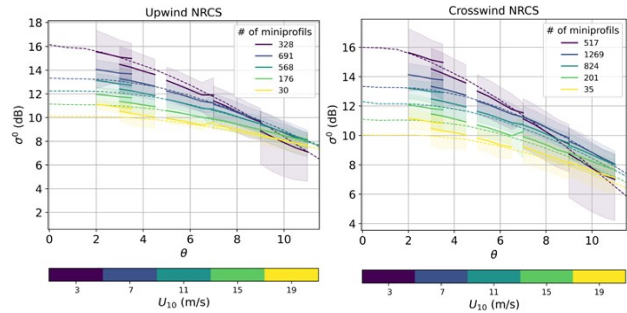


Figure 2. SWIM σ_0 mini profiles compared to GPM for observations from 30 January 2020 to 12 February 2020

COMPLEMENTARITY OF SWIM AND SAR OBSERVATIONS

Currently, only two types of missions can provide the directional spectra of ocean waves and the related parameters: SAR missions like Sentinel-1 (S-1), Radarsat-2, Goafeng-3, and CFOSAT with the SWIM instrument.

As their concepts are completely different, it is useful to study their complementarity in different wavelength domains. Indeed, it is known that spaceborne SAR do not provide information for waves shorter than about 200m in wavelength, when they propagate close to the along-track direction.

We have carried out such a study to compare the retrieved wave parameters (dominant wavelength and direction), from collocated SWIM and S-1 data and by sorting this collocated data set according to the sea-state conditions: dominant wavelength less than 200m (class 1) and between 200 and 500m (class 2).

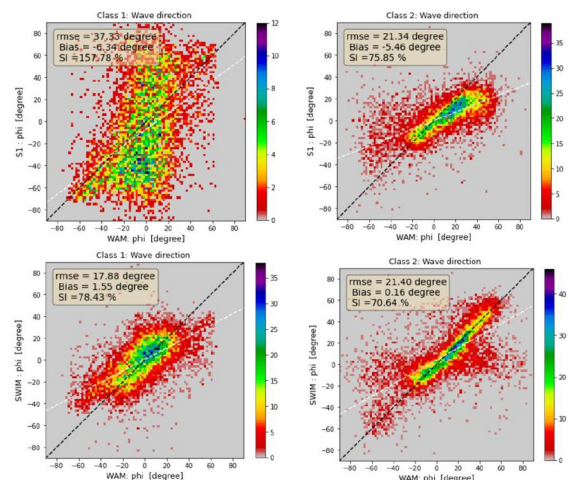


Figure 3. Dominant wave direction retrieved by SWIM (bottom panels) and Sentinel-1 (top panels) compared to the MFWAM model values, for conditions with dominant wavelength less than 200m (left) and between 200 and 500 m (right), over April, May and June 2021

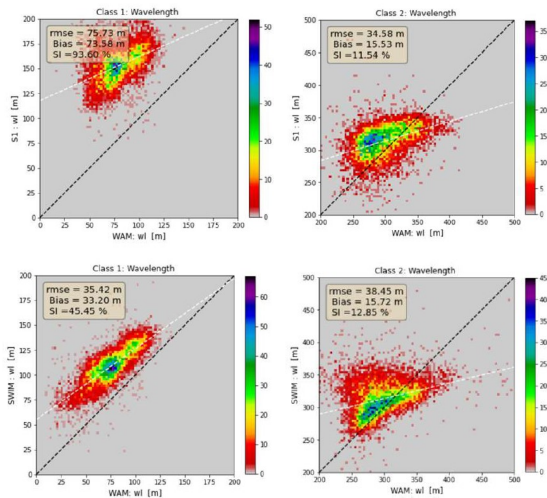


Figure 4. Same as Fig.3 but for the dominant wave wavelength

Fig. 3 and 4 show comparisons of SWIM and S-1 dominant wavelength and dominant direction for each class against the MFWAM model parameters. Compared to S-1, SWIM presents a better consistency with the model for wavelengths below 200m and equivalent for wavelengths between 200 and 500m. For wavelengths longer than 500m SWIM has no output as it is above the detectability limit, whereas Sentinel-1 outputs show good consistency for these sea state conditions (not shown).

These results highlight the complementarity of SWIM observations with those of Sentinel-1 SAR, due to its better detectability of wavelength in the range [50-200m], which comes in addition to a better spatial coverage, thanks to its global acquisition of wave spectra (no geographic dependent wave mode).

In another study based on local observations of coral reef islands (French Polynesia, Pacific Ocean), Oruba et al [19] show several cases illustrating the important distortion of the S-1 wave spectrum due to the azimuth cutoff compared to the SWIM spectrum, the in situ measurements and the MFWAM model spectrum. Oruba et al [19] also shows that in opposite, the S1-SAR provides better estimates of wave parameters in case of low sea-state conditions (below 1.5 m in significant wave height).

3- USEFULNESS OF WAVE SPECTRA MEASUREMENTS TO ESTIMATE THE STOKES DRIFT

The Stokes drift is the main contribution from ocean surface waves to particles drift in the ocean's upper layer. Until now, estimates of the Stokes drift at the global scale rely only on numerical models, due to the unavailability of such measurements from space.

SWIM shows a potential to provide Stokes drift estimates from space observations. A first processing has been performed based on SWIM wave spectra to estimate an omni-directional estimate of the Stokes drift (intensity and transport). Preliminary estimates of the Stokes drift vector (based on the directional wave spectra) have also been

obtained. Due to the limit of wave detectability of the SWIM instrument, this estimation only accounts for waves longer than 30 m. Thus, without further correction the surface intensity is underestimated. However, at the global scale it is shown that these estimates are very consistent with the model values estimated at 15 m depth (cf. Fig.5).

By adding to the SWIM Stokes drift estimation a correction based on model-winds to account for the contribution of the short waves (less than 30 m in wavelength), the agreement for the Stokes drift at the surface between SWIM and model estimates are very consistent (Fig.6).

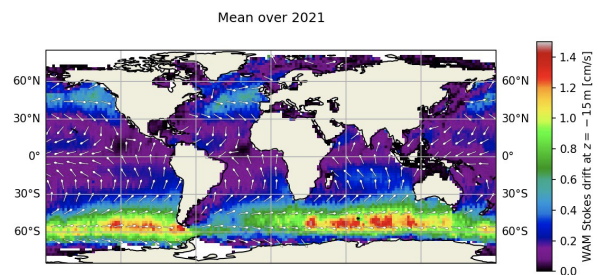
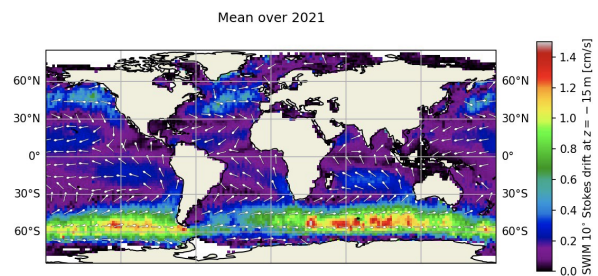


Figure 5: Mean Stokes drift vector over year 2021 (averaged in grids of $2^\circ \times 2^\circ$) from SWIM wave spectra (left) and from the MFWAM model at 15 m depth (right)

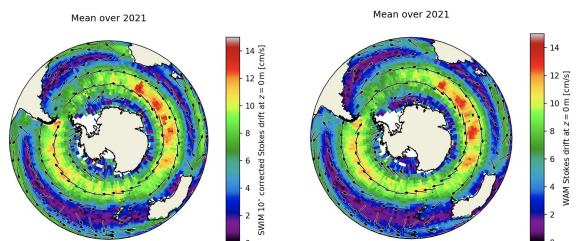


Figure 6: Mean Stokes drift vector at the surface in the Southern Ocean over year 2021 (averaged in grids of $2^\circ \times 2^\circ$) from SWIM wave spectra (left plot) and from the MFWAM model (right plot). The SWIM values have been corrected by adding a contribution from the shortest waves (less than 30 m in wavelength).

3. SYNTHESIS AND CONCLUSION

Thanks to the recent reprocessing, all CFOSAT-SWIM products are provided with a homogeneous quality over the mission lifetime, ensuring consistent scientific analyses, at the global scale and over several years.

It has been proved that SWIM observations are very useful for scientific and operational applications (see the 4-year report scientific [9] and e.g. [10-17]).

Work is still ongoing to further improve the quality of SWIM products, already at a high level. The main challenges remain to improve the speckle noise correction; a specific analysis is ongoing through the exploitation of data acquired in a specific instrument mode during one CFOSAT orbital cycle; this will give important information to improve this fundamental correction. This will also help to mitigate the presence of parasite peaks observed in certain conditions on the wave height spectra at low wave number. Further to the improvement already brought in the identification of periods when σ_0 is impacted by micro-cuts event, work is in progress to provide a concise and global index of wave spectra quality. Concerning the σ_0 profiles with incidence, it is envisaged to apply an empirical correction to avoid the discontinuity between mini-profiles obtained from the 5 off-nadir SWIM beams (see Fig. 2).

An effort is also ongoing to provide on an operational basis new parameters derived from the SWIM observations, such as Stokes drift, an index characterizing situations of extreme waves, maps of ice presence and ice concentration based on the approach proposed in [18].

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