CFOSAT: Latest Improvements in the Swim Products and Contributions in Oceanography

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CFOSAT: LATEST IMPROVEMENTS IN THE SWIM PRODUCTS AND CONTRIBUTIONS IN OCEANOGRAPHY

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ABSTRACT

For the first time, co-located wind vectors and wave spectral characteristics are available thanks to the French/Chinese CFOSAT mission, which includes a wind scatterometer SCAT and a wave scatterometer SWIM. Three years after its launch, CFOSAT data is thoroughly qualified and various scientific work has been undertaken. This paper focuses on CFOSAT SWIM data, its performance and scientific contribution to oceanography, coastal and sea ice study.

Index Terms— Oceanography, scatterometer, waves

1. INTRODUCTION

Since October, 29th 2018, the new space-borne system CFOSAT (China France Oceanography Satellite) [1] is in operation for measuring ocean surface winds and surface wave parameters. This mission developed under the responsibilities of the French and Chinese Space agencies (CNES, CNSA) is composed of two radar sensors both scanning in azimuth: SCAT, a fan-beam wind scatterometer [2], and SWIM designed for wave measurements [3]. With its collocated measurements of ocean surface wind and waves, CFOSAT aims at better understanding processes at the ocean surface and ocean/atmosphere interactions and improving atmospheric and oceanographic models and predictions by feeding forecast systems through assimilation. This paper focuses on the SWIM measurements. SWIM is an innovative Ku-band real-aperture wave scatterometer, with 6 low-incidence rotating beams [3]. This new instrument allows for the first time the systematic production of directional spectra of ocean waves with a real-aperture radar system. 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 (CAL/VAL) analysis were 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 surface and wave products. The latest improvements will be described in section 2. In section 3 and 4, we present the studies performed by the science teams, showing the potential of CFOSAT mission for several Oceanography applications and even more.

2. CFOSAT SWIM PRODUCTS AND LATEST IMPROVEMENTS

2.1. CFOSAT SWIM products

Thanks to its original acquisition geometry, SWIM level-2 products provide various geophysical information:

- Normalized radar cross section ($\sigma 0$), Significant Wave Height (SWH) and wind speed from nadir measurements, estimated at 5 Hz frequency using the Adaptive retracking algorithm. Performances of these parameters are described in [5].
- $\sigma 0$ at various incidence angles ranging between 2° and 10°, which can be used either at the full range resolution or as averaged profiles within 0.5° bins (called mini-profiles in this case). Performances with respect to model and GPM datasets are analyzed in [6].
- Wave products within each wave cell: 2D directional wave slope spectra with their associated wave parameters (SWH, wavelength and direction) estimated using the empirical speckle correction and Modulation Transfer Function (MTF) methods described in [9]. Performances and implemented and planned improvements are shown in [6] and [9] respectively.

2.2. Evolutions and improvements

Various evolutions of the SWIM processing algorithms, implemented to mitigate instrumental aspects and software anomalies, were applied in the latest version of the operational SWIM products (version 5.2 of the processing chain, in operation since July, 2021). They are described hereafter.

2.2.1 Micro-cuts anomaly

Since the end of March 2019, signal transmission perturbations through the rotary antenna part, named micro-cuts hereafter, had been identified during the CALVAL phase, resulting in an intermittent loss of power in the σ0 profiles from nadir and off-nadir beams. This phenomenon is currently detected in the level-1A processing chain and monitored on a daily basis. Since January 2021, such micro-cuts have drastically decreased to under 1% of the total data and have even disappeared for most of the orbits. As for periods with high micro-cut rates (between end of 2019 and mid-2020), various CALVAL analysis have underlined the impact of such σ0 decrease on nadir wind speed, and on off-nadir wave spectra. One of the latest improvements of the level-2 processing thus consists in the definition and use of a micro-cut flagging to avoid biases in the nadir wind speed and wave spectra. This processing evolution will be applied to the future reprocessing of SWIM data.

2.2.2 Antenna gain pattern calibration

σ0 profiles are also improved thanks to an updated correction of the antenna gain pattern. This correction now uses as first guess the on-ground measured antenna gain pattern for various antenna azimuths and relies on the estimated SWIM radar echo data averaged globally over a large period to represent the most possible geophysical conditions. This hybrid method reduces drastically the non-geophysical trend previously observed on the σ0 fully-resolved mini-profiles with respect to incidence and azimuth. This improvement increases the number of valid σ0 profiles used to estimate the wave spectra and thus reduces the statistical noise.

2.2.3 Wave peak direction correction

The estimation of the dominant wave direction, either on the full wave spectrum or on its partitions, has also been improved in the latest operational products version.

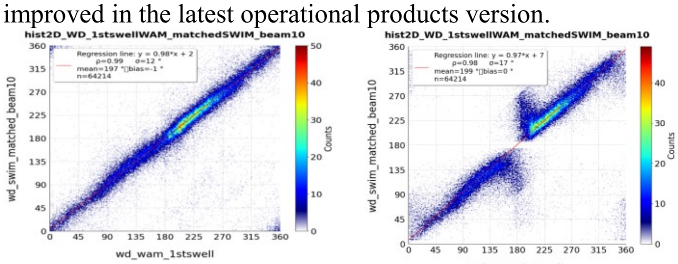

Figure 1 Scatter plot of the SWIM (10° beam)-estimated swell dominant direction wrt its counterpart provided by the MF-WAM model, after applying a cross-assignment of partitions as in [6]. Right (resp. left): before (resp. after) the software anomaly correction.

The correction of a software anomaly at L2 processing - related to an erroneous processing of the 0°/180° directions - significantly improves the wave direction performance as illustrated in Figure 1 for SWIM versus MF-WAM model swell direction. The number of outliers for directions around 0° and 180° are now greatly reduced.

3. SUMOS (SURFACE MEASUREMENTS FOR OCEANOGRAPHIC SATELLITES) IN-SITU AND AIRBORNE CAMPAIGN

As a supporting contribution to the validation of SWIM observations, the SUMOS campaign was conducted in February and March 2021 by CNES and several research teams from CNRS, Météo-France and Ifremer. Its main objective was to provide a diversity of SWIM co-located observations to further validate and calibrate SWIM wave products and improve the on-ground inversion algorithms. As a secondary objective, data from the SUMOS campaign provides material to study wave hydrodynamics and wind/wave/flux interaction under specific turbulent conditions.

Two national platforms were deployed in the Bay of Biscay (Atlantic Ocean): F-HTMO, the ATR-42 research aircraft operated by SAFIRE (Météo-France/CNRS/CNES) and the French Oceanographic research vessel L'Atalante operated by Genavir. L'Atalante operation plan was designed to deploy drifting wave buoys (Spotter buoy from the SOFAR company), wave and surface flux buoys (FLAME prototype developed by LOPS), and to carry out wave measurements from on-board devices such as an X-band radar (operated by Helmholtz-Zentrum, from Geesthacht, Germany), a stereo video and polarimetric imaging system (deployed by LOPS). The ATR-42 airplane carried the airborne Ku-band Radar for Observation of Surfaces (KuROS, operated by LATMOS), so as to provide directional wave spectra along flight patterns coordinated with the CFOSAT passages. The campaign operation plan was defined as to optimize the co-locations with CFOSAT passes and SWIM measurements. A large set of high-quality data has been acquired in a wide range of weather conditions, enabling to reach all the campaign objectives. The first results of this campaign are very promising. Airborne radar and buoy measurements show overall consistent wave parameters with SWIM data as illustrated in Figure 2 for the case of February 16th morning, which correspond to a swell-dominated case.

Figure 3 shows a comparison of the 1D wave height spectra obtained from SWIM, buoy, and the X-band marine radar, on February, 28th, for a case of mixed sea (SE wind sea, swell from the West) with a 2.8 m sea wave height. This example confirms the ability of SWIM to measure the wave energy in the 50m-500m wavelength range despite a small positive bias on the energy from SWIM with respect to buoy data.

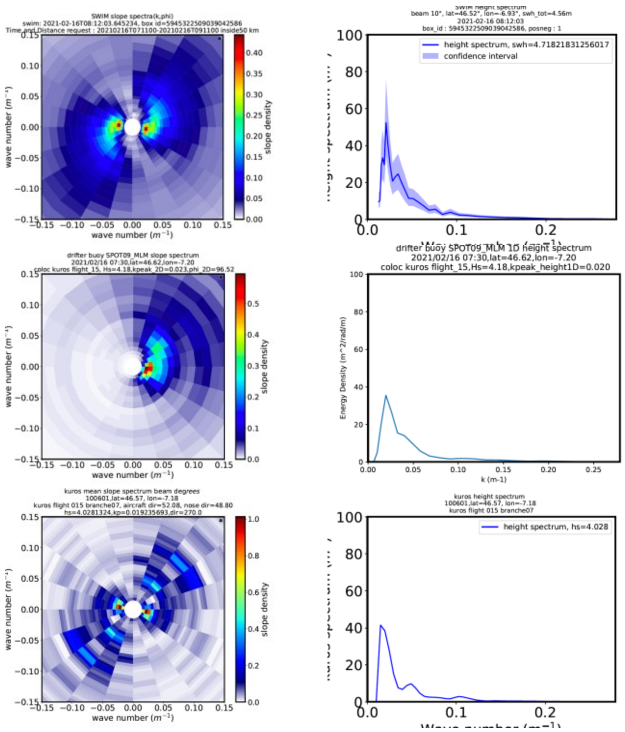

Figure 2 SWIM (top), buoy (middle) and KuROS (bottom) wave spectra for February 16th 2021 (dominating swell from West, total SWH ~4 m). Left: Directional slope spectra in a polar representation with North pointing towards the top (for SWIM and KuROS, the spectra are plotted with a 180° directional ambiguity; for the buoy the MLM method was used to construct the 2D spectrum). Right: omni-directional wave height spectra wrt wavenumber.

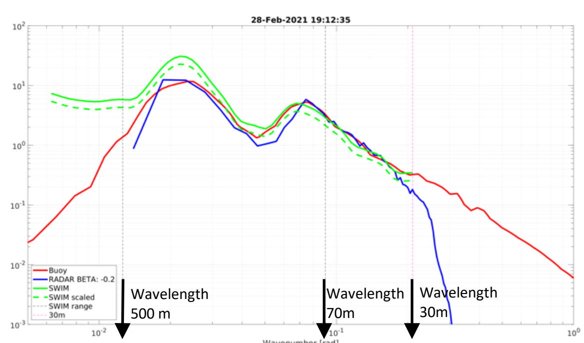

Figure 3 Comparison in a log-log representation of 1D height spectra from SWIM (green solid line), SWIM with SWH-buoy normalized spectra (green dashed line), buoy (red line), X-band marine radar (blue line).

The exploitation of SUMOS data is ongoing to further characterize the performance of SWIM data in its present processing version and to further characterize the MTF based on comparisons between SWIM modulation spectra and buoy wave height spectra.

A first campaign data set will be available in early 2022 to the scientific community.

3. CFOSAT SWIM DATA CONTRIBUTION TO OCEAN AND SEA ICE

Thanks to these very promising performances, SWIM data has shown its potential for several applications in oceanography. For example, it was shown by [11] that in regions dominated by severe storms like in the Southern Ocean, the assimilation of dominant wavelengths and directions from SWIM wave spectra better scaled the wind-wave growth of the wave model (MFWAM) than when assimilating the SWH only, as evidenced by a better agreement with independent observations from altimeters. This improvement was attributed to a more realistic energy transfer during the wind-wave growth phase in the conditions of very high winds. This result also reveals the relevance of using directional wave observations, which have a significant impact on the mixing in the upper layers of the ocean and hence on the sea surface temperature and air/sea exchanges.

SWIM data are also very useful for better characterizing and understanding the wave field evolution in extreme events like tropical cyclones [10]. Additional useful wave parameters as the frequency width of the omni-directional spectra, the directional spread of the dominant waves, and the related Benjamin-Feir index (BFI) can been studied from SWIM data. In [12], global statistics and maps of spectral shape parameters and BFI from satellite observations were provided for the first time. This study also showed systematic differences between the wave model and observations in the shape of the frequency spectra, with observed spectra more narrow and peaked than those from the MF-WAM model, due to the simplified processing of the non-linear wave interactions term. The impact of spurious peaks at low frequency in the omnidirectional wave height spectra was also mentioned for low wave height (Hs < 1.8 m) and short dominant wavelength (λp <70m) conditions, and confirmed the importance of on-going work to filter these spurious peaks.

Combining SCAT and SWIM observations from CFOSAT also opens new opportunities for oceanography. In [13], this was used to estimate the wave induced stress was investigated at the global scale after separating the contributions of wind sea and swell in the air-sea momentum flux. In [14], a neural network method was used to extend the estimation of SWIM SWH within the SCAT swath up to ± 200 km from the nadir track, with a 25km resolution, which significantly increases the number of CFOSAT SWH observations. Assimilation of these data in the MF-WAM model has an equivalent positive impact as the assimilation of SWIM nadir SWH observations.

Preliminary results also show the benefit of SWIM 2D directional wave spectra to compute Stokes drift. Despite the limit of validity of such estimations to 30 m wavelengths, promising results are currently achieved and open the way to providing for the first time Stokes drift information at a global scale from spatial observations.

SWIM native nadir σ0 at 5 Hz sampling also offer precious high resolution information to characterize heterogeneous ocean surfaces over coastal areas. The comparison against a coastal wave model at a 200 m resolution along a French coast shows the potential of the 5 Hz-sampled nadir products with respect to the standard 1Hz products in wave/current interaction or complex bathymetry conditions, as illustrated in Figure 4. The added value of such data is underlined in an ongoing study which shows the impact of bathymetry on SWH close to coral reefs.

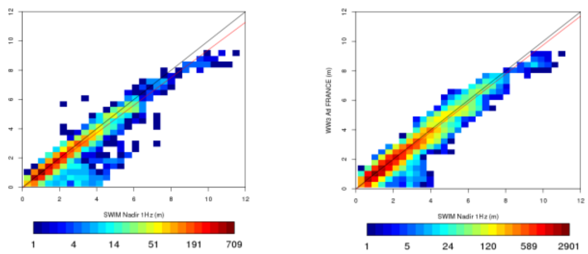

Figure 4 Scatterplot of SWH from a coastal version of the WW3 model along the French Atlantic coast wrt SWIM 1Hz (left) and 5Hz (right) from August to December 2019.

As for SWIM off-nadir σ0 data, available at various azimuths thanks to the rotating beams, they bring complementary original information for sea ice detection and characterization (ice age, type). In [7], a sea ice likelihood estimator was computed from SWIM σ0 using ancillary data (ECMWF wind speed and sea surface temperature) and an empirical knowledge of the σ0 distribution (Geophysical Model Functions) at the different incidence angles. Performances of this sea ice detection algorithm are very promising, with a 98% accuracy by comparison with model and other sensors data. The availability of such sea ice flag from CFOSAT can be very useful to improve the wave propagation in the marginal ice zone and also to better characterize wave-ice interactions in coupled earth system.

4. CONCLUSION

Thanks to its original design and observation geometry, SWIM instrument fulfills its objective by providing at the global scale, new observations with directional wave spectra, nadir parameters and σ0 profiles at off-nadir incidence angles. The high performances of SWIM data not only open the field to improvements in the ocean surface characterization and modeling, but also to new perspectives in the coastal and sea ice areas. After 3 years in orbit, the exploitation of SWIM data has shown its advanced capacities to provide SWH and wind at a 5 Hz sampling along-track for coastal applications, sea ice detection and characterization through the analysis of σ0 [7], wave field studies in the marginal ice zone and in extreme events [15] or global estimation of additional wave-related parameters (like e.g. the Stokes drift). The exploitation of co-located wind and wave CFOSAT SCAT and SWIM data, respectively, a first in the ocean remote sensing field, also broadens the possibilities of improvements of ocean modelling and characterization.

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