LATEST ADVANCES OF THE SWIM INSTRUMENT

C. Tison(1), T. Amiot(1), D. Hauser(2), T. Koleck(1), P. Castillan(1), N. Corcoral(1)

(1) CNES, 18 avenue Edouard Belin, 31 400 Toulouse, France
(2) CNRS, LATMOS/UVSQ, 11, boulevard d'Alembert, 78280 Guyancourt, France
Celine.tison@cnes.fr , +33 5 61 28 24 04

ABSTRACT

The CFOSAT mission is an innovative spatial mission for oceanography: for the very first time, both wind and wave vectors will be measured at the global ocean surface. This paper presents the wave scatterometer, SWIM and its associated scientific performances.

Index Terms— CFOSAT, SWIM, ocean, directional wave spectrum, scatterometer

1. INTRODUCTION

SWIM is a wave scatterometer embarked on the Chinese-French CFOSAT mission for the observation of the ocean wave field at a global scale. SWIM flight model is now under construction. In parallel, an airborne model, KuROS, is now operational and provides some test data.

1.1. The CFOSAT Mission

The Chinese and French Space Agencies propose to jointly carry out an innovative mission, CFOSAT (China France Oceanography Satellite project) devoted to the monitoring of the ocean surface and its related science and applications. CFOSAT will embark both a wind and a wave scatterometers, enabling a simultaneous measure of the wind and the wave vectors at the ocean surface with a global coverage for the first time.

Feasibility and Preliminary Design phases (A/B phases) have been successfully carried out from 2006 to 2009. The project started Detailed Design phase C beginning of 2011 which is followed by the Manufacturing Phase D in 2014. The launch and the Assessment Phase completion should lead to deliver a fully validated system on orbit in 2018.

The primary objective of CFOSAT is to monitor, at the global scale, ocean surface winds and waves so as to improve: wind and wave forecast for marine meteorology (including severe events), ocean dynamics modeling and prediction, climate variability knowledge, fundamental knowledge of surface processes and air/sea interactions, etc. As an opportunity, CFOSAT will also be used to complement other satellite missions for the estimation of land surface parameters (in particular soil moisture and soil roughness), and polar ice sheet characteristics.

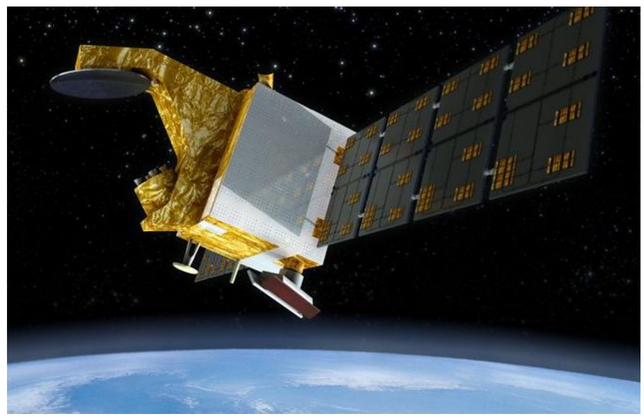

Figure 1. Artist view of the CFOSAT satellite. SWIM antenna is on the left and SCAT antenna on the bottom right. Other antennas on Earth face are for TM/TC. © CNES/ Gekko.

The satellite embarks two payloads; both are Ku-band (13.2 to 13.6 GHz) radar scanning around the vertical axis:

• the wave scatterometer SWIM, a rotating 6-beams radar at small incidence angles (0 to 10°) [3,4,6],

• the wind scatterometer SCAT, a fan-beam radar at larger incidence angles (26 to 46°) [5].

In this paper, after a short presentation of the CFOSAT mission and the associated scientific requirements, a focus on the wave scatterometer SWIM (Surface Wave Investigation and Monitoring) instrument, delivered by CNES, will be done with the up-to-date performance budgets.

1.2. The SWIM instrument

The main objective of SWIM is to provide directional wave spectra. SWIM is a Ku-band real aperture radar following the concepts developed in [1, 2, 4]. It illuminates the surface

sequentially with 6 incidence angles: 0°, 2°, 4°, 6°, 8° and 10° with an antenna aperture of approximately 2°. In order to acquire data in all azimuth orientations, the antenna is rotating at a speed rate of 5.6 rpm. With the six beam geometry, the objective is to provide several geophysical parameters:
• significant wave height and sea surface wind speed, from the nadir beam (0°), similarly as nadir altimeter,
• directional wave spectrum (wave height as a function of wave number and direction) from the 6°, 8° and 10° beams
• roughness characterization (parameters of the slope probability density function) from the backscattering coefficient profiles from 0° to 10°.
The paper [6] provides a detailed overview of SWIM.

An airborne sensor, KuROS, has been developed by the LATMOS (CNRS, France) to get data similar to SWIM and SCAT. Several campaigns have been performed over the Atlantic ocean (near Brest, France) and the Mediterranean Sea. A rich variety of sea conditions has been encountered. These data enable to prepare the ground segment algorithms. The paper [7] presents KuROS and the very first results.

2. THE MEASURED GEOPHYSICAL PARAMETERS

As explained the different beams enable to measure different geophysical parameters of the sea surface.

2.1. Backscattering coefficient

Internal calibration [6] is used to reach high precision on the backscattering estimation. Preliminary budgets based on in-laboratory measurements and system analysis show that:
• the absolute calibration will be better than ±0.9 dB with a strong bias contribution (Tab. 1)

		0°	2°	4°	6°	8°	10°
Absolute error on σ0	Total	0,75	0,77	0,77	0,77	0,81	0,81
	Bias	0,62	0,62	0,62	0,62	0,62	0,62
	Random	0,13	0,15	0,15	0,15	0,19	0,19

Table 1. Absolute error on backscattering coefficient estimation for the six beams.

Once the bias is estimated (with a priori knowledge on the instrument and with inter-calibration with other instruments or ground references), the precision can be better than ±0.2 dB. This accuracy is required for wind retrieval from nadir σ^0 and for the modulation transfer function estimation for the wave spectrum computation [7].

• the relative calibration between each beams will be better than ±0.2 dB, which is a little higher than required (±0.1 dB in the requirements).

2.2. Nadir beam

The random error on the significant wave height (SWH) has been estimated using the analytical model of Hayne [8] of the nadir waveform, and a Least Square Estimator for the retrieval of SWH. Figure 2 shows that the accuracy is .similar to the one obtained on the JASON-2 altimeter (Fig. 2).

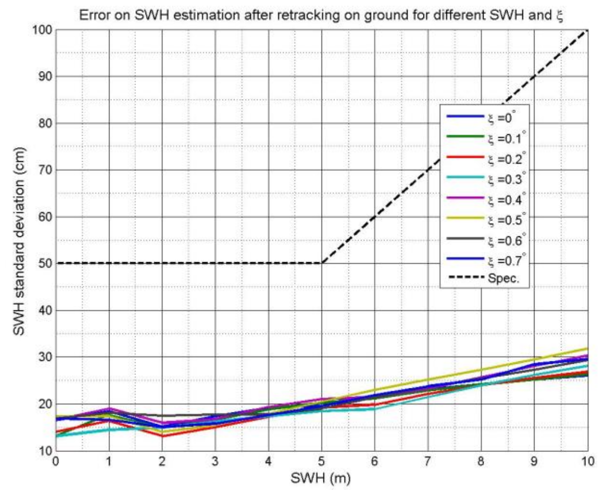

Figure 2. Expected error (standard deviation) on the SWH as a function of SWH (from 0m to 9m) and to the mispointing ξ (from 0° to 0.7°, different color, see insert).

2.3. Wave spectra

This is the most innovative products as no spatial instrument enables yet to get a complete directional wave spectrum with a range of [70m, 500m] in ocean wave wavelengths. The processing is under development and the first simulated results are promising, as well as the first airborne results [7].

The wave spectra are derived from the fluctuation of the backscattered power linked to the slopes of the long waves. Around 8° of incidence angle, the impact of small scale roughness (i.e. wind) is minimum and the only modulations of the backscatter coefficient are only due to surface slopes (i.e. wave). The wave spectrum is the spectral density function of the fluctuation signal corrected from speckle and thermal noise effects. The requirements are an error of less than 15° on wave direction, 15% on wavelength and 20% on energy.

In order to validate the instrument definition and prepare the processing algorithms, an instrument simulator, SimuSWIM, has been developed. This is an end-to-end simulator which enables to generate a sea surface from a wave spectrum (empirical or coming from numerical wave prediction models forced by analyzed winds), to compute the radar power from the taking into account all the definition of the instrument, and to inverse the signal up to the modulation spectrum. The final performances are evaluated on the geophysical parameters (direction, wavelength and energy) estimated on the 2D spectrum with eventually several partitions of this 2D spectrum in case of mixed seas.

The global performances with respect to the scientific requirements on the quality of the wave spectra (in terms of direction, energy and wavelength) have been computed on 12 reference sea states defined by analytical empirical models:

- Wind sea: Pierson-Moskowitz (U=10m/s, U=12 m/s), JONSWAP (U=4 m/s, U=7m/s, U=10m/s with fetch = 30 km),
- Swell: SWH=1m/U=2m/s, SWH=2m/U=4 m/s,
- Mixed sea condition: swell + Pierson-Moskowitz 12 m/s (with 90° and 45° of propagation steps), swell + JONSWAP 10 m/s (with 90°, 45° and 30° of propagation steps).

Fig. 3 is an example of the obtained results for several sea conditions.

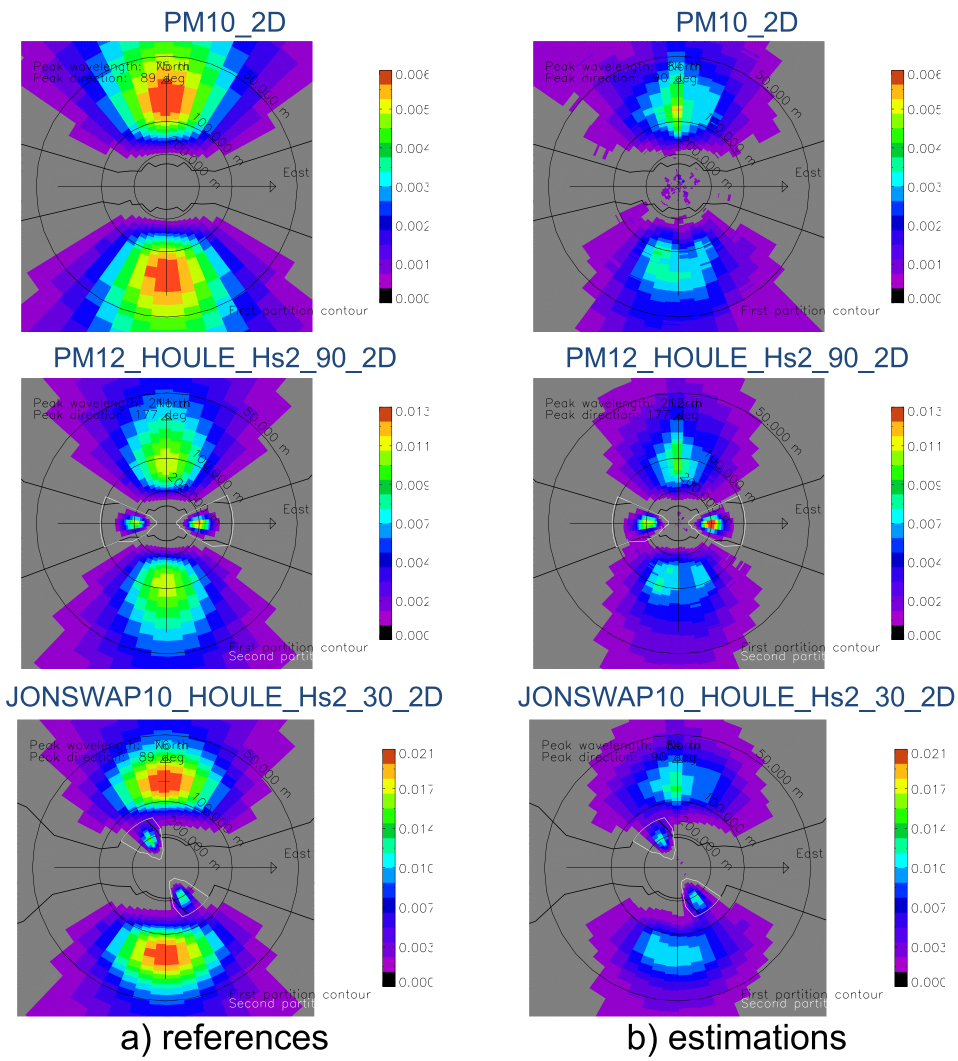

Figure 3. Examples of wave spectra simulations (1st column = references coming from analytical models, 2nd column = SWIM simulations) for three sea state conditions (wind sea Pearson-Moskowitz (PM) and mixed sea swell/wind sea with PM and JONSWAP). The spectra are in polar coordinate and they are automatically partitioned (black and white lines).

For each sea condition, 300 runs of simulation have been done in a Monte-Carlo approach. Knowing the input conditions, the estimation errors on the geophysical parameters have been computed (Fig. 4.).

The estimations are very good (below the scientific requirements) for the directions and the wavelengths, even in case of mixed sea conditions. Regarding the energy, there is a systematic under estimation in case of sea wind conditions. We do not have solved this problem yet but it seems clearly due to the simulation method itself rather than to the sensor definition. This has not been observed on the KuROS data [7].

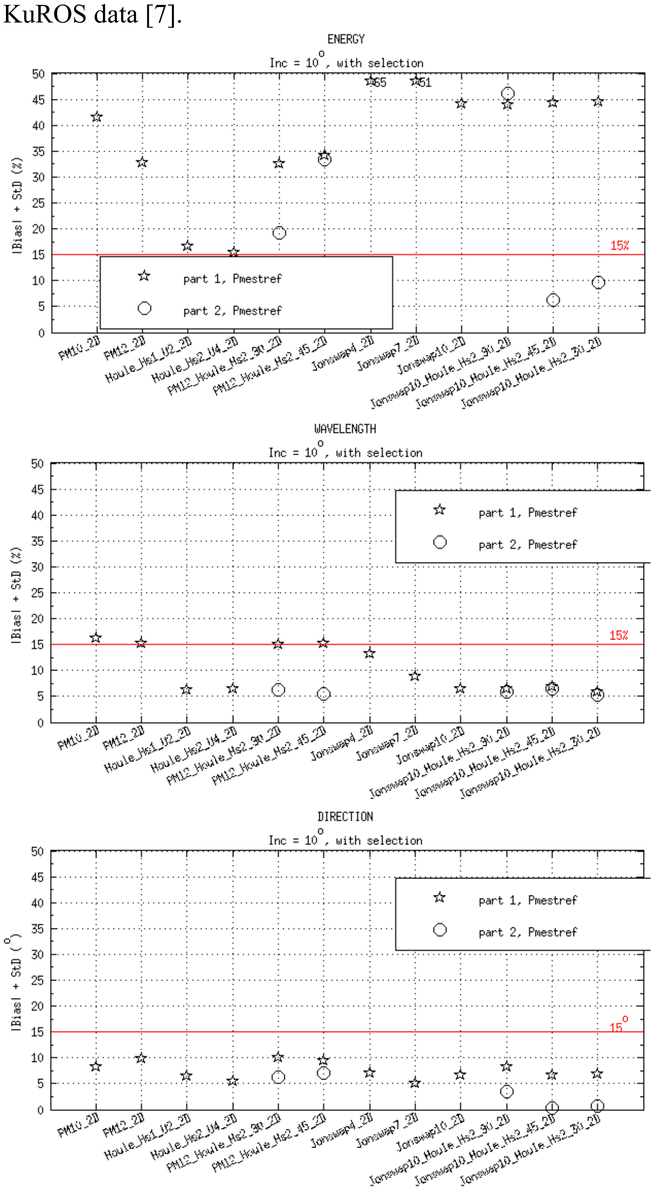

Figure 4. Estimation errors (bias plus standard deviation) of the wave spectra energy, the wavelength and the direction for the 12 sea reference conditions and the case of the 10° antenna beam. When there are two sea states, the parameters are estimated for each one. The red lines indicate the scientific requirement.

4. CONCLUSION

CFOSAT is an innovative mission jointly developed by CNES & CNSA. The unique combination of instruments will allow determining the directional wave spectra of waves in relation with surface winds, and vice versa. The application field sounds very promising both for meteorological research and climate understanding.

5. ACKNOWLEDGEMENTS

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