OVERVIEW OF THE CFOSAT MISSION

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ABSTRACT

The Chinese and French Space Agencies are jointly preparing an innovative mission, CFOSAT (China France Oceanography Satellite) devoted to the monitoring of the ocean surface and its related science and applications. This paper gives an overview of the scientific objectives, the mission and instrument characteristics, the expected data products and their performance.

Index Terms**—** satellite**,** radar, surface ocean waves, surface ocean wind, scatterometer, CFOSAT

1. INTRODUCTION

The Chinese and French Space Agencies are jointly preparing an innovative mission, CFOSAT (China France Oceanography Satellite) devoted to the monitoring of the ocean surface and its related science and applications. For the very first time, both wind and wave vectors will be measured at the global ocean surface. This will be achieved thanks to microwave two-instruments, both of them being innovative in terms of geometry and design:

- SWIM (Surface Wave Investigation and Monitoring) a near-nadir (0 to 10° incidence) real-aperture Ku-Band azimuthally scanning radar designed for measuring the directional spectra of ocean waves according (see [1]);
- SCAT a wind scatterometer SCAT to measure the wind vector, radar in Ku-Band aiming at moderate incidence angles (26° to 46°) with a rotating fan-beam antenna (see [2]).

Figure 1 is an artist view of the satellite illustrating the SWIM and SCAT implementation on the platform.

With respect to existing satellite missions, the originality of CFOSAT is that it will provide co-located wind vector fields and directional spectra of ocean waves for wavelengths larger than about 70 m. It will also provide normalized radar cross-section in multi-incidence and multi-azimuth geometry which can be used on one hand to improve the inversion algorithms for estimating wind speed and significant wave height and on the other hand to characterize the small scale roughness of all types of surfaces. CFOSAT will contribute to the global wind field observations in complement to existing scatterometer missions (e.g. ASCAT on METOP, SCAT on HY-2A), to provisioning of wind speed and and significant wave height in complement to other altimeter missions (like Jason or HY-2 series, Sentinel-3), and it will provide new information on wave properties with respect to SAR missions (like Sentinel-1), by giving access to directional spectra of ocean waves not only for the long swells but also for wind waves and mixed sea conditions whatever is the direction of these waves. Indeed, the SWIM instrument is based on the real-aperture concept rotating concept proposed by [3], specified by [4] for satellite implementation, and implemented on airplanes since the 90's [3,5,6]. This concept avoids the limitations induced by the imaging mechanism occurring with SAR data over the moving ocean surface [7].

Here, we present the general scientific objectives and main characteristics of the mission, the expected geophysical products, and we present some ongoing studies carried out in preparation of this mission.

Figure 1. Artist view of the CFOSAT satellite. SWIM antenna is on the left (parabola pointing towards the surface and rotating plate with six feed horns) and SCATdual- antenna on the bottom right. Other antennas on Earth face are for TM/TC (X and S-bands). © CNES/ Gekko.

2. SCIENTIFIC OBJECTIVES

CFOSAT is designed to provide over the global oceans, observations of surface wind and spectral characteristics of the surface ocean waves. The objective is multifold. It will serve both operational needs for the meteorological and wave forecast, and research needs to improve our knowledge on the hydrodynamics of the waves, on the interactions between waves and the atmospheric or oceanic layers close to the surface. Furthermore it will be a useful tool to better characterize the backscattering of ocean and land in a diversity of geometrical configuration, providing new information on the roughness characteristics an associated surface characterization (sea ice and ice sheet, vegetation and arid zones).

Improving the numerical modeling and prediction of ocean surface wind and waves remains a crucial need for many applications over the ocean (offshore operations and engineering, fisheries, ship routing, coastal or harbor management, etc). The performance of wave models has significantly improved in the last decade [8] thanks to improved accuracy in the forcing wind fields, as well as to improved parameterization of wave processes, and to the assimilation of significant wave heights from altimeters. However improvements are still needed, in particular for high sea-state conditions, extreme events (hurricanes, typhoons), rapidly evolving storms, and for providing accurate prediction not only in terms of wave height but also in terms of peak wavelength and direction. The accurate prediction of low frequency swell, propagating great distances from the generation regions, remains a priority for many applications.

It is known that wind forces the wave generation and that in turn surface waves modify the atmospheric surface layer and hence the air/sea exchanges both within and outside of the generation area [9]. For this reason, more and more often, atmospheric and wave models are coupled within forecast systems. Recent studies coupling wave and oceanic models [10] also show that the impact of waves on ocean surface layers greatly depends on type of sea-state (growing or dissipating stage). Hence, CFOSAT will provide original data to take wave effects into account as it will provide co-located and simultaneous measurements of surface wind and waves at scales compatible with global numerical models. This will on one hand allow to better constrain the models by the wind and wave observations through assimilation and on the other hand it will help to better quantify and parameterize the effect of waves on the atmosphere and ocean (impact on heat and momentum exchanges, impact on sea ice, impact on kinetic energy flux to the ocean,..). It will also contribute to better characterize the wind and waves in extreme events like tropical or mid latitude storms.

Better knowledge of wind and wave climatology in the context of global climate change becomes an increasing subject of interest [11]. Although altimeter missions already provide multi-year statistics of significant wave height, and scatterometer statistics on wind speed, there is a lack of information on wave system components and their dominant frequency and direction. CFOSAT will contribute to establish a global climatology with joint statistics on wind, significant wave height, dominant wavelengths and directions. It will also be possible to relate wave climatology at certain locations to climatology of the generating mid-latitude or tropical storms, whose positions, intensity or number might be affected by climate change.

CFOSAT will also be a unique tool to study physical processes such as the interaction of long swell with wind waves and turbulence generated locally, energy focusing related to surface current or crossed seas, potentially associated with dangerous sea state. This will also permit to characterize the swell propagation and its dissipation over long distances under various wind and surface current conditions. Furthermore, thanks to its multiple incidence configuration CFOSAT will provide information on short ripples on the surface (of the order of a few centimeters), intermediate waves (few tens of centimeters to a few meters and long waves (several tens to several hundred of meters). Exchanges of energy take place between these different ranges of waves, which also depend on external conditions such as surface current. So there will be a unique opportunity to study the time and space evolution of the waves at different scales, taking into account their propagation direction. Thanks to its multi-incidence configuration which will provide simultaneous information on short waves (Bragg scattering from SCAT at medium incidence), mean square slope (from low incidence angle observations), and long waves, CFOSAT will be a strong opportunity to progress in the understanding of the relations between wind, wind stress, wind-generated waves, and long waves.

Mean momentum from the atmosphere is transferred to the ocean in two ways, i.e. as direct surface stress-driven Ekman currents, and as mean drift associated with the wave motion. Processes like surface winds, viscous dissipation and wave breaking will alter the wave amplitude in time and space, converting mean momentum from waves to ocean currents. Hence measuring simultaneously wind and wave fields including the directional properties of waves, will help to better understand the transfer of momentum from atmosphere to ocean and take it into account in ocean modeling.

Finally multi-angular (incidence and azimuth) Ku-Band backscattering from SWIM and SCAT over land, sea ice and polar ice-sheet will provide new information to characterize these types of surface and their seasonal or multi-year evolution.

3. THE CFOSAT MISSION: MAIN CHARACTERISTICS

The system consists of a LEO polar sun-sun-synchroneous orbit system with local time ascending pass at the equator at 7:00 am. The orbit altitude will be about 519 km altitude at the equator. The cycle will be a 13 days cycle (see Figure 2), able to permanently gather data and deliver the scientific telemetry to the related Mission Centers. In addition, the system will have the capability to achieve a near-real time transmission (i.e. less than 3 hours after the acquisition) of the data to the main centers which run operational atmospheric or wave prediction models, so that the data can be used in assimilation processes and forecast procedures.

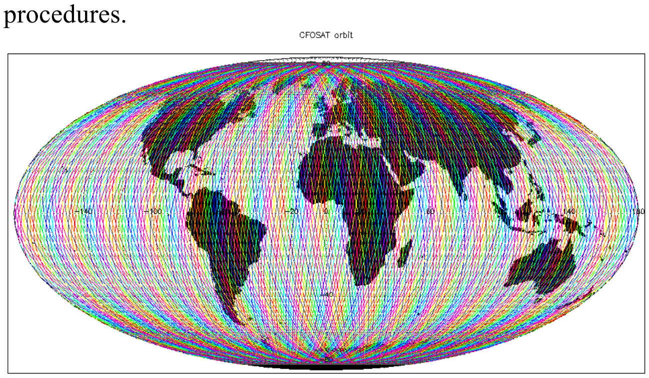

Figure 2: 13 days orbit track of CFOSAT

CFOSAT is a common initiative of the Chinese and French Space Agencies (resp. CNSA and CNES) started in 2006. China provides the satellite platform (a "CAST 2000" platform), the satellite launch (a CZ-2C rocket), the satellite control, and the wind Ku-Band scatterometer (SCAT). France provides the wave Ku-Band scatterometer (SWIM). Both countries contribute to the ground segment. The Chinese contribution to the Ground Segment is composed of a "Satellite Control Center" located in Xian (China), several telemetry, tracking and command ground stations, 3 X-band receiving stations located in China, and a Mission Center for data processing, distribution and archiving. The French CFOSAT Ground Segment is composed of 2 X-band Stations, located in Kiruna (Sweden) and Inuvik (Canada), and two mission centers: one operated by CNES in Toulouse (France) for near-real time processing distribution of data, and data archiving, and a second one for differed-time data processing, distribution and archiving operated by Ifremer in Brest (France). From The CNES Center, the near-real time wind and wave products shall be made available at final users in operational centers within 3 hours from acquisition time, with an availability of 75% - goal 85%. This scheme is completed in France by expert groups for wind and wave products and by instrumental expert group.

Feasibility and Preliminary Design phases (A/B phases) were successfully carried out from 2006 until 2009. The project started Detailed Design phase C in 2011 and will be completed in 2016. The Manufacturing Phase will start just after, followed by integration and tests (in 2017). The launch and the assessment phase completion should lead to deliver a fully validated system in orbit in 2018. The mission lifetime is at least 3 years.

As mentioned above, the platform will embark two payloads; both are Ku-band radar scanning around the vertical axis:

- the wave spectrometer SWIM (13.575GHz), provided by CNES and manufactured by Thalès Alenia Space is a rotating 6-beams radar at small incidence (0° to 10°), see the geometry in Figure 3.
- the wind scatterometer SCAT (13.256GHz) designed by MiRS Lab of National Space Science Center, Chinese Academy of Sciences, and provided by CNSA is a rotating fan-beam radar pointing at medium incidence angles (26° to 46°) with a dual antenna system.

Details on SWIM and SCAT characteristics are given in [1] and [2], respectively.

With their respective geometry SWIM and SCAT will provide a global coverage within 3 days for wind fields (SCAT) and almost global for waves within 13 days (SWIM).

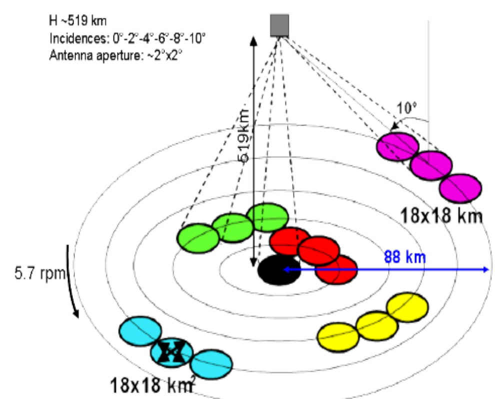

Figure 3: SWIM geometry with its six rotating incidence beams from 0 to 10°. The footprint dimension of each beam is about 18km x 18km. The diameter of the full swath is about 180 km

4. DATA PRODUCTS

The instruments and data processing have been defined in order to provide from the backscattered signals, the following level 2 products:

Surface ocean waves (from SWIM):

- Wave directional spectra at a scale of 70 x 90 km on each side of the track for wavelength range 70m-500m retrieved with a 10% accuracy on wavelength, 15° accuracy on direction (with however a 180° ambiguity in direction), about 15 to 20% accuracy in energy in the energy containing part of the spectrum;

- Significant wave height along track (SWIM) with a 10% (or 50 cm whichever is better) accuracy;

Surface wind:

- wind vector over swath of ± ~600 km across-track (SCAT) within 50 km resolution cells (25 km experimental) and an accuracy of 2m/s or 10% rms in the range 4~24m/s, and a 20° accuracy in direction;
- wind speed along track (from SWIM nadir beam) with accuracy of 2m/s rms .

Normalized radar backscattering cross-sections σ_0:

- mean profiles of σ_0 as a function of incidence angle (0-10°) and azimuth from SWIM, at a scale of 70 x 90 km on each side of the track, with a ±1 dB absolute accuracy, and ±0.1 to 0.2 dB relative accuracy;
- mean values of σ_0 within 50 km resolution cells (25 km experimental) from SCAT, with a ±1 dB absolute accuracy, and ±0.1 to 0.2 dB relative accuracy.

In addition, level-1 products (geo-localized normalized radar cross-sections, with a sampling close to the raw data) will be made available for specialized studies. Level 3 and 4 products will also be prepared for both SWIM and SCAT.

5. STUDIES IN PREPARATION TO THE EXPLOITATION

Ongoing studies in preparation for CFOSAT deal with:

- preparation and performance assessment of the two payload instruments [1,2],
- simulation studies carried out to assess the future performance of the products, [1, 12,13],
- potentiality of joint SWIM/SCAT products and tools to prepare the CAL/VAL, and the data exploitation,
- assimilation of wind or directional wave spectra in wave forecast models [14],
- analysis of normalized radar cross-section in terms of surface slope statistics [15,16] or white capping [17],
- analysis of storm-generated sea-state from combined observations of waves [18],
- potential interest for ice and continental applications [19].

6. CONCLUSION

CFOSAT is a very innovative and promising mission. Work is under progress to prepare the future use of data. After the verification and assessment phase, these data will be made available to the interested community through an international call for collaboration.

REFERENCES

[1] Grelier T., T. Amiot, C. Tison, L. Delaye, D. Hauser, P. Castillan, "The SWIM instrument, a wave scatterometer on CFOSAT mission", this issue

[2] Zhu Di, Dong XIaolong, Yun Risheng, Xu Xingou, « Recent advances in developing the CFOSAT scatterometer », this issue

[3] Jackson F. C., T.W. Walton, and P.L. Baker, "Aircraft and satellite measurement of ocean wave directional spectra using scanning-beam microwave radars", Journal of Geophysical Research, Vol. 90, No. C1, Pages 987-1004, January 20,1985

[4] Hauser D., E. Soussi, E.,Thouvenot, L. Rey, "SWIMSAT: A real aperture radar to measure directional spectra of ocean waves from space", Main characteristics and performance simulation, Jour. Atmos. and Oceanic Tech, vol 18 No3, 421-437, 2001

[5] Hauser, D., G. Caudal, G.J. Rijckenberg, D. Vidal-Madjar, G. Laurent, and P. Lancelin, "RESSAC: A new airborne FM/CW radar ocean wave spectrometer", IEEE Trans. Geosci. Remote Sensing 30 (5), 981-995, 1992

[6] Caudal G., D. Hauser, R. Valentin, C. Le Gac, "KUROS : A new airborne Ku-band Doppler radar for observation of surfaces, Jour. Atmos. and Oceanic Technology", Vol. 31, No. 10. , 2223-2245, 2014

[7] Hasselmann K., and S. Hasselmann, "On the nonlinear mapping of an ocean wave spectrum into a synthetic aperture radar image spectrum and its inversion", J. Geophys. Res Oceans , Volume 96, Issue C6, 15 June 1991, Pages: 10713–10729,

[8] HaidenT., M. Janousek, P. Bauer, J. Bidlot, M. Dahoui, L. Ferranti, F. Prates, D.S. Richardson and F. Vitart, "Evaluation of ECMWF forecasts, including 2014-2015 upgrades", ECLMWF technical memorendum 765, 2015

[9] Ardhuin F., B. Chapron, and F. Collard, 2009: "Observation of swell dissipation across oceans", Geophys. Res. Lett., 36, L06607, doi:10.1029/2008GL037030.

[10] Breivik O, K. Mogensen, J-R Bidlot , M. Alonso Balmaseda, P. A.E.M. Janssen, "Surface Wave Effects in the NEMO Ocean Model: Forced and Coupled Experiments", J. Geophys. Research, Doi: 10.1002/2014JC010565, 2015

[11] Hemer, M.A., X.L. Wang, J.A. Church and V.R. Swail, "Coordinated global ocean wave projections", Bull. Amer. Meteor. Soc., 91(4), 451-454. DOI: 10.1175/2009BAMS2951.1, 2010

[12] Xingou Xu, Risheng Yun, Xiaolong Dong, Di Zhu, "Simulation and retrieval of wind of CFOSAT rotating fan-beam, scatterometer", this issue

[13] Stoffelen A., Zhen Li, Jos de Kloe, Expected performance of the wind retrieval from the CFOSAT rotating fan-beam scatterometer, this issue

[14] Aouf L., D. Hauser, C. Tison, A. Mouche, "Perspectives for directional spectra assimilation: results from a study based on joint assimilation of CFOSAT synthetic wave spectra and observed SAR spectra SENTINEL-1A", this issue

[15]Chen Ping, D. Hauser, Qiaohua Yin, Liye Wang, "Impact of non Gaussian surfaces on the near-nadir radar cross-section and on the future analysis of CFOSAT data", this issue

[16] Li Xiuzhong, He Yijun, Zhang Biao, "Simulation and retrieval of CFOSAT at whitecap sea", this issue

[17] Mouche A., B. Chapron, H. Johnsen, F. Collar, He Wang, G. Guitton, Jinsong Yang, R. Husson, "Perspective for combining and exploiting ocean wave spectra measured from different space missions", this issue

[18] Nouguier F. , A. Mouche, N. Rascle, B. Chapron and D. Vandemark, "Analysis of dual-frequency ocean backscatter measurements at Ku- and Ka-band using near-nadir incidence GPM radar data". IEEE GRSL (accepted 2016)

[19] Prigent C., F. Aires, C. Jimenez, F. Papa, and J. Roger, "Multi-angle backscattering observations of continental surfaces in Ku Band (13 GHz) from satellites: understanding the signals, especially in arid regions", IEEE Transactions on Geoscience and Remote Sensing, vol. 53, issue 3, pp. 1364-1373, 2014, 10.1109/TGRS.2014.2338913