DYNAMIC VALIDATION OF OCEAN SWELL DERIVED FROM SENTINEL-1 WAVE MODE AGAINST BUOYS

He Wang [1], *Alexis Mouche* [2], *Romain Husson* [3], *Bertrand Chapron* [2]

[1] National Ocean Technology Center, China
[2] Institut Francais pour la Recherche et l'Exploitation de la Mer, Plouzane, France
[3] Collecte Localisation Satellites, Plouzane, France

ABSTRACT

In wave mode, Sentinel-1A/B from ESA provide swell spectra dataset on a continuous and global basis since. In this paper, a method of a dynamical validation approach for SAR swell spectra is developed, in which the Sentinel-1A swell spectra are partitioned and propagated up to the vicinity of in-situ reference along the great circle based upon the linear wave theory. Here, sentinel-1A wave mode data for the period of three months were dynamically validated against buoys from NDBC and CDIP networks. Comparison results show a good agreement with buoy measurements. Influent of buoy types on the validation results are also discussed.

Index Terms— Sentinel-1, ocean swell, buoy, validation, swell propagation

1. INTRODUCTION

On April 3, 2014, carrying the C-band SAR, Sentinel-1A was successfully launched into orbit. Combining with the identical satellite Sentinel-1B launched in 2016, the constellation with wave mode acquisitions is providing the directional ocean wave spectra products called Ocean Swell Wave (OSW), on a continuous and global basis, making continuity measurement of SAR swell spectra at C-band with retired ERS and Envisat missions.

Traditionally, the satellite-buoy comparisons were carried out based on the collocation between the observations from satellite and buoy within a fixed spatial-temporal criterion. However, it is not straightforward to validate SAR WM directional spectra against buoy data using this classical validation method. For instance, directional spectra comparisons against with directional buoys, making swell spectra validation possible, usually resulted in an inadequate number of collocations [1]. Therefore, in most studies, the inter-comparisons were based on match-ups including non-directional buoys [i.e. 2,3]. These studies were only limited to integrated parameters, which are insufficient for evaluating the SAR directional swell spectra.

Recently, the ocean swell propagation technique, which firstly proposed by Snodgrass et al. [4] to trace back storm sources responsible for swell observations at buoy stations, has been revisited. This tool has been used to produce fireworks products by propagating the observed Envisat ASAR swell across the ocean basin [5,6]. Taking advantage of this swell propagation technique, Collard et al. [5] first presented a semi-quantitative dynamic validation for swell period and direction, by taking ASAR WM as a virtual wave observer and examining the consistency between time series from virtual and real buoy, and therefore opened up an opportunity for validating the ocean swell spectra derived from SAR WM in an alternative way.

The present work aims to propose a dynamic validation methodology by propagation of the SAR derived swell to the vicinity of buoy, and to validate Sentinel-1A wave mode swell spectra.

2. SENTINEL-1 WAVE MODE SWELL

The Sentinel-1A wave mode data used here were taken from 1st July to 13th October 2016. The Sentinel-1A Level-2 swells are analyzed to produce so called 'fireworks', using the refocusing methodology. The analysis would result in splitting all Sentinel-1A swells into swell groups generating from the same storm event, and the outliers failed to be associated to any swell origins. The main steps are as follows.

(1) Retro-propagation
Sentinel-1A Wave Mode observations are firstly propagated in space and time backward, neglecting wave-current and wind-wave interactions in deep water.

(2) Storm identification
Back-propagations are analyzed to identify the refocused region as the swell origins. As illustrated in Figure 1, storm event on 5th of August 2016, generated from southeast Pacific depicted as blue disk, is defined as by spatio-temporal convergence of the swell trajectories (gray lines) retro-propagated from the Sentinel-1A acquisitions (color points).

(3) Propagation swells from refocused & left-overs
The fireworks analysis results in splitting Sentinel-1A swell partitions into two datasets. The converging retro-propagated observations associated to storms could be defined as a new

qualified swell field called refocused data, while those failed to be linked to any storm events are referred to left-overs.

We propagate the left-overs observation forward until land. For the refocused data, swell observations propagate forward and backward in the ocean basin according to the linear wave propagation theory [5].

$$H_s(\alpha) = H_s(\alpha_0)\sqrt{\frac{\alpha_0 \sin \alpha_0}{\alpha \sin \alpha}}\, exp\left(-\mu \frac{\alpha-\alpha_0}{2}\right) \quad (1)$$

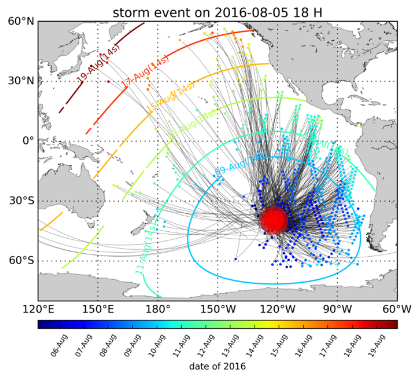

Figure 1. Example of Sentinel-1A wave mode fireworks for storm event on 5th of August 2016. The refocused Sentinel-1A wave mode observations are represented in dots with colors indicating the acquired time, while gray lines indicating their retro-propagated swell trajectories.

3. BUOY SWELL MEASUREMENTS

In situ directional ocean wave data used here are obtained from the 3 m heave-pitch-roll buoys and Datawell Waverider buoys in the networks of National Data Buoy Centre (NDBC) and Coastal Data Information Program (CDIP) respectively. A total of 25 buoys measuring 2D ocean wave spectra, are selected to offer the ground truth reference in the validation, with their locations depicted in Figure 2. The directional spectrum was reconstructed from measurements provided by buoys using the Maximum Entropy Method (MEM) [7].

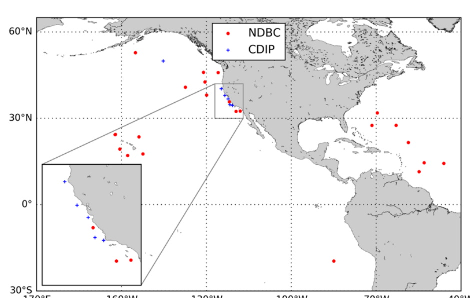

Figure 2. Location of directional wave buoys from NDBC (red dots) and CDIP (blue crosses) network.

4. DYNAMIC COLLOCATION

As illustrated in Figure 3, the buoy observation and propagated swell trajectory from Sentinel-1A fireworks are dynamically collocated in space and time windows of 100 km and 1 h respectively, whenever the propagation distance is less than 3000 km.

For every dynamic collocation, there may be several swell partitions from the same observed buoy spectrum, resulting in different SAR-buoy swell partition pairs. Thus, for all possible partition associations, the spectral distance D_{spec} is computed following the definition by [8]

$$D_{spec} = \frac{1}{q}\left(|D_1 - D_2| mod 360 + \frac{|T_1-T_2|}{T_1+T_2} r\right) \quad (2)$$

where Di and Ti refer to the peak propagation direction and peak period of each partition respectively, and the factors q = 30, r = 250. The peak-to-peak association is then determined by the shortest spectral distance, and therefore the best SAR-buoy match-up is selected.

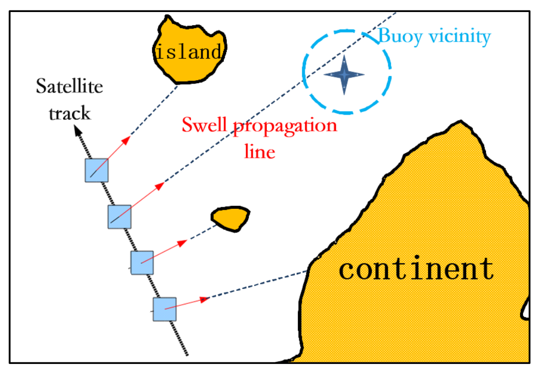

Figure 3. Sketch of the geometry of the dynamic collocation.

5. VALIDATION RESULTS AND DISCUSSIONS

5.1. General Statistics

Based on the dynamic collocated dataset A, validation results against buoys are given in Figure 4 for swell wavelength, swell propagation direction and swell wave height in the vicinity of buoy derived from Sentinel-1A fireworks respectively.

5.2. Refocused observations *vs* left-overs

The firework analysis categorized the Sentinel-1 swell observations into two groups: refocused ones and left-overs. Here, the swell wavelength and direction from refocused and left-overs observations were dynamically validated against buoy data, as shown in Figure 5. It could be found that refocused data present a much better accuracy, implying that outliers (left-overs) were filtered out through the firework procedure.

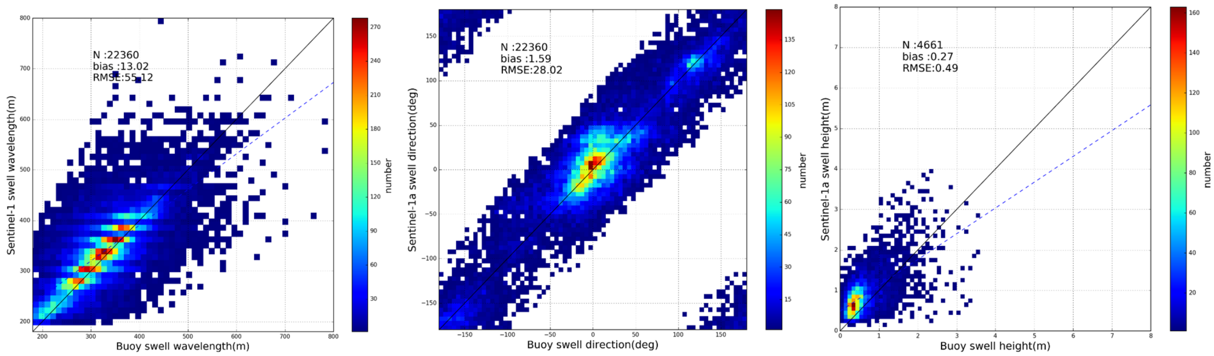

Figure 3. Scatter plots of swell wavelength (left), swell direction (middle) and swell significant wave height (right) comparison for buoy versus Sentinel-1A.

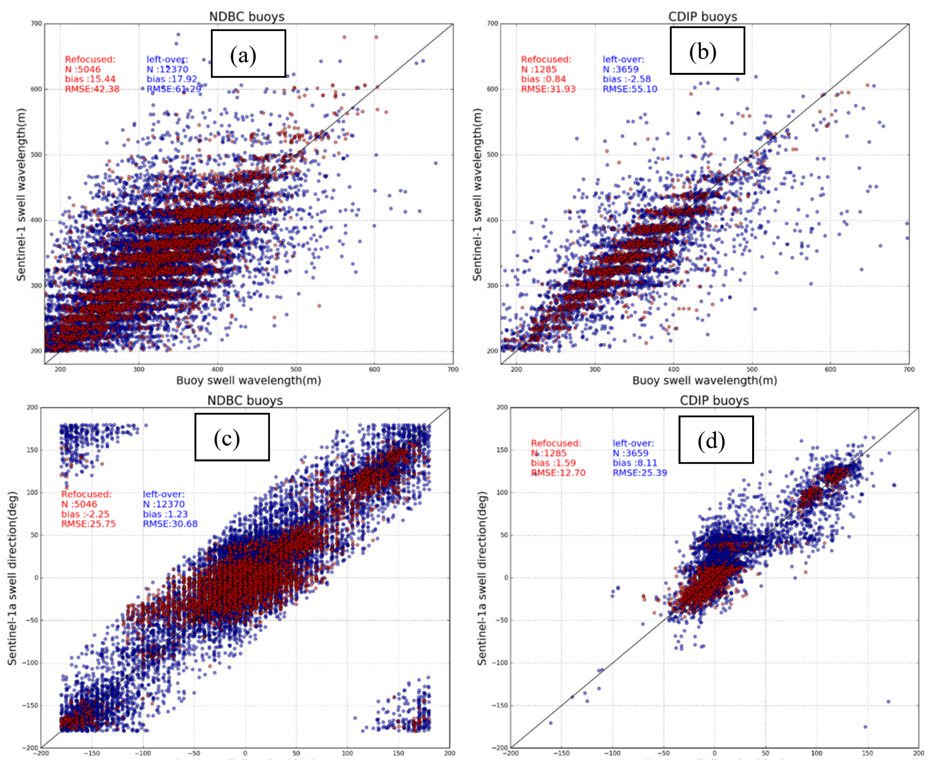

Figure 3. Scatter plots of swell wavelength (a, b) and swell direction (c, d) comparison for buoy from NDBC (a, c) and CDIP (b, d) versus Sentinel-1A.

5.3. Influence of buoy networks

There are known biases on directional spread in measurements by some types of buoy [9]. In this work, dynamic validation results against buoy from different networks (NDBC and CDIP) are given in Figure 3 for swell wavelength and swell propagation direction comparisons. It is shown that Sentinel-1 derived swells are more consistent with measurements from waverider buoys in CDIP than 3m discus buoys in NDBC networks.

6. CONCLUSIONS

In this paper, a method of a dynamical validation approach for SAR swell spectra is developed, in which the Sentinel-1A swell spectra are partitioned and propagated up to the vicinity of in-situ reference along the great circle based upon the linear wave theory.

Based on this novel validation methodology, sentinel-1A wave mode data for the period of three months were validated against buoy measurements from NDBC and CDIP networks. Comparison results show a good agreement with buoy measurements. Influent of buoy types on the validation results are also discussed.

7. ACKNOWLEDGMENTS

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8. REFERENCES

[1] N. Violante-Carvalho, I.S. Robinson, and J. Schulz-Stellenfleth, “Assessment of ERS synthetic aperture radar wave spectra retrieved from the Max-Planck-Institut (MPI) scheme through intercomparisons of 1 year of directional buoy measurements”, *J. Geophys. Res.*, vol.110, doi:10.1029/2004JC002382, 2005.

[2] X.M. Li, T. König, J. Schulz-Stellenfleth, and S. Lehner, “Validation and intercomparison of ocean wave spectra inversion schemes using ASAR wave mode data,” *Int. J. Remote Sens.*, vol. 31, no. 17-18, p. 4969–4993, 2010.

[3] H. Wang, J. Zhu and J. Yang, “Error Analysis on ESA’s Envisat ASAR Wave Mode Significant Wave Height Retrievals Using Triple Collocation Model,” *Remote Sens.*, vol. 6, no. 12, p. 12217-12233, Dec. 2014.

[4] F. E. Snodgrass, G. W. Groves, K. Hasselmann, G. R. Miller, W. H. Munk, and W. H. Powers, “Propagation of ocean swell across the Pacific”, *Philos. Trans. R. Soc. London*, Ser. A, 249, p. 431– 497, 1966.

[5] F. Collard, F. Ardhuin, and B. Chapron, “Monitoring and analysis of ocean swell fields from space: New methods for routine observations”, *J. Geophys. Res.*, vol. 114, no. C07023, doi:10.1029/2008JC005215, 2009.

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

[7] A. Lygre, and H. Krogstad, “Maximum entropy estimation of the directional distribution in ocean wave spectra”, *J. Phys. Oceanogr.* vol.16, no. 12, p. 2052-2060, 1986.

[8] Husson R, “Development and validation of a global observation-based swell model using wave mode operating Synthetic Aperture Radar”, Doctoral dissertation, IUEM, 2012.

[9] W. C. O’Reilly, T. H. C. Herbers, R. J. Seymour, and R. T. Guza, “A comparison of directional buoy and fixed platform measurements of pacific swell”, *J. Atmos. Oceanic Technol.*, vol. 13, p. 231–238, 1996.