Validation of Wave Spectral Partitions from SWIM instrument on-board CFOSAT against In-situ Data

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Background

Surface Waves Investigation and Monitoring (SWIM) instrument, the first space-borne 'wave spectrometer' in the world, was successfully launched on China-France Oceanography SATellite (CFOSAT) on 29 October 2018.

After a space-borne earth observation sensor is launched, a necessary procedure is to validate the data product. The correct understanding of uncertainties would determine the natural limits and possible scenarios of data application.

Validation of remotely sensed Integral Wave Parameters (IWPs) is relatively simple and the method is relatively mature. Both wave buoys and well-calibrated altimeters can provide fairly reliable measurements of SWH, and are widely used in the validation of remotely sensed SWH.

Validation of remotely sensed directional wave spectra from a space-borne sensor, such as those from SWIM, is more complicated. There seems to be no common approach for comparing two sets of directional wave spectra.

This study tried to validate the Partitioned IWPs (PIWPs) from SWIM against data from the National Data Buoy Center (NDBC). Since there is no consensus on how PIWPs from two data sources should be compared, we used in-situ spectra from two buoys that are close in space distance to discuss this open question before the validation.

Data

- SWIM Data: Wave spectra from Level-2 products of SWIM (version 5.1.2).
- Buoy Data: Wave spectra from 34 NDBC buoys in the open ocean with spectra reconstructed by MEM method.
- All spectra are partitioned using watershed algorithm.

Cross-assignment of wave partitions

"Cross-assignment" is an idea that has been used in the validation of spectral partition information from SAR and the assimilation of spectral partitions into wave models. Given a partition in one wave spectrum, the aim of "cross-assignment" is to identify its corresponding partition in the other wave spectrum.

In this study, we cross-assign the two partitions with the smallest spectral distance, the spectral distance is defined as:

$$D=\sqrt{\left(\frac{T_a-T_b}{1\text{s}}\right)^2+\left(\frac{\theta_a-\theta_b}{\theta_{coef}}\right)^2}$$

T and θ are Partitioned Peak Wave Period (PPWP) and Partitioned Peak Wave Direction (PPWD), respectively, and the subscripts a and b denote the parameter from two different sources. $\theta_{coef}=25^\circ$ is a weighting factor that needs to be tuned and the error metrics between two spectra are dependent on this parameter. The way of obtaining this value is not detailed here and can be found in the paper.

Comparison of wave partitions

The spectral distance is computed for each pair of partitions for two collocated wave spectra, and, and the pair of partitions (from different spectra) with the shortest spectral distance were cross-assigned. Two buoys, 51001 and 51101, located only ~13 km away from each other during May 2019 to April 2020, were used to demonstrate this process.

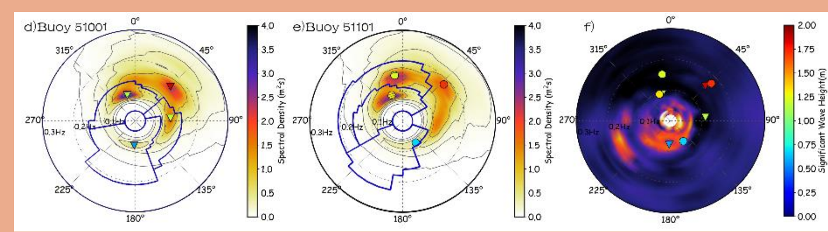

Fig.1 Directional wave spectra obtained at May 9, 2019 from buoy (a) 51001 and (b) 51101, and (c) the CC of spectral density between spectra from the two buoys over one year. Triangles and circles represent the partitions derived from the spectra from buoy 51001 and 51101, respectively. The colors of triangles and circles indicate PSWHs and the locations of them indicate PPWPs and PPWDs. The blue solid lines in (d) and (e) are the boundaries on different identified partitions.

Not all partitions from the two spectra can be rightly cross-assigned due to the noise of the spectra. Such conditions of wrong cross-assignment occur frequently because missing or spurious partitions are common in both observed and modelled wave spectra. This will induce many outliers in the comparison of the cross-assigned partitions.

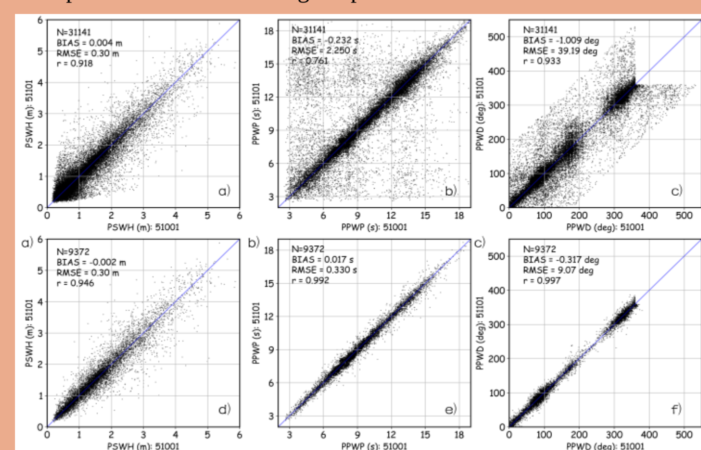

Fig.2 Comparison of PWIPs (left column: PSWH, middle column: PPWP, right column: PPWD) between buoy 51001 and 51101 over the period from May 2019 to April 2020. (a-c) All partitions are cross-assigned using the nearest distance method; (d-f) Only partitions with the minimum spectral distance for each pair of spectra are cross-assigned using the nearest distance method.

One way to solve this problem is only to compare the partitions with the shortest spectral distances. The agreement between the two buoys can be very good if we only consider one partition from one spectrum (Fig.2 d-f). But this method underestimates the error.

Using a threshold of D during cross-assignment seems to be a feasible method for removing the outliers during the comparison of partitions from two spectra. However, the number of outliers is so large that the computed error metrics are sensitive to the selection of the threshold.

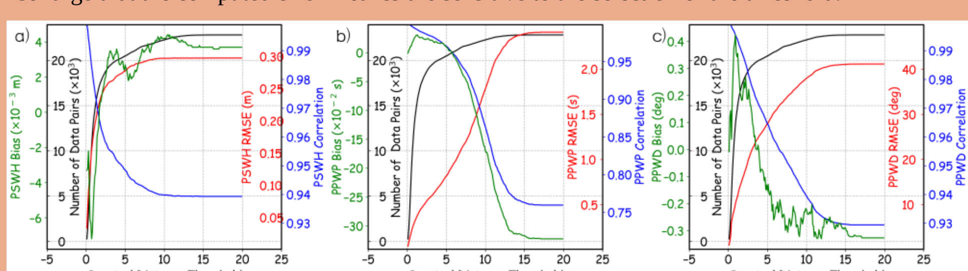

Fig.3 Number of cross-assigned data pairs (black), bias (green), RMSE (red), and CC (blue) of (a) PSWH, (b) PPWP, and (c) PPWD between buoy 51001 and 51101 as a function of spectral distance threshold for cross-assignment.

However, curves in the above Fig themselves can illustrate how error metrics change with the selection of cross-assignment threshold D, which are helpful for applications such as data assimilation. Therefore, they can also serve as a tool to demonstrate the comparison between the partitions from two sets of wave spectra. We recommend using them in the comparison of PIWPs between cross-assigned partitions from different sources of wave spectra.

The distributions of PPWP and PPWD errors of outliers seem to be uniform. Meanwhile, it is well known that the measurement error usually follows a normal distribution. Therefore, an assumption can be made that the errors in Fig. 2a, b are the superposition of a normal distribution and a uniform distribution.

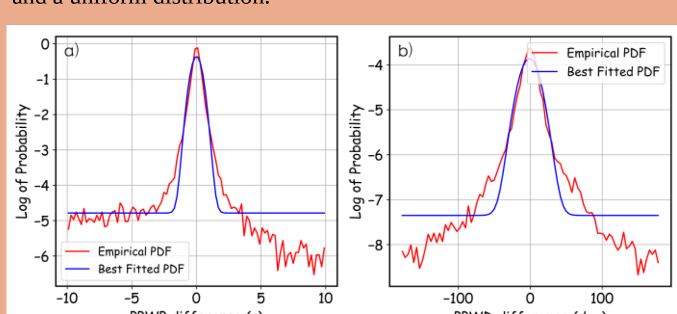

Fig.4 PDFs of (a) PPWP and (b) PPWD difference between buoy 51001 and 51101 over the study period. The red lines are empirical PDFs and the blue lines are best-fitted PDFs assuming that the errors are normally distributed and the outliers are uniformly distributed. The y-axis is in log-scale.

Base on this assumption, the maximum likelihood method can be used to derive that the RMSEs of PPWP and PPWD are ~0.5 s and ~10°, respectively, which is an acceptable accuracy to evaluate the SWIM data.

Using the above three methods, the wave spectra from SWIM can be validated against buoy data. A spatial-temporal window of 50 km×30 min were selected when collocating buoy and SWIM spectra. The SWIM spectra from 10° beam is validated due to their better quality.

Validation of SWIM partitions

- Comparing only the partitions with the shortest spectral distance.

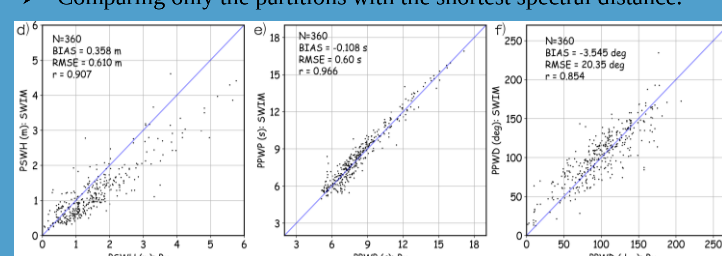

Fig.5 Comparison of (a) PSWH, (b) PPWP, and (c) PPWD between SWIM 10° beam and buoys over the period from May 2019 to April 2020. Only partitions with the minimum spectral distance for each pair of spectra are cross-assigned.

- Changing the threshold of spectral distance during cross-assignment

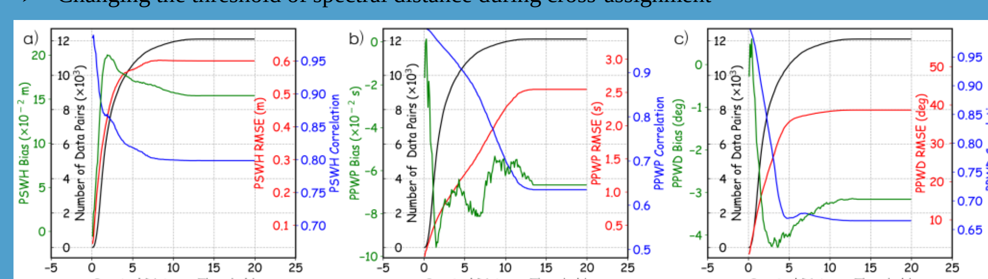

Fig.6 Number of cross-assigned data pairs (black), bias (green), RMSE (red), and CC (blue) of (a) PSWH, (b) PPWP, and (c) PPWD between collocated spectra from SWIM 10° beam and NDBC buoy as a function of spectral distance threshold for cross-assignment. The size of the spatial window of collocation is 200 km for this figure.

- Maximum likelihood estimation of root-mean-square error (RMSE) of PIWP

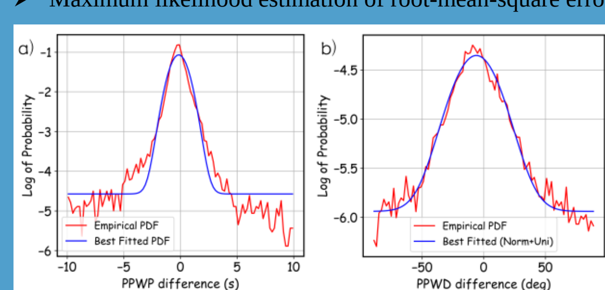

Fig.7 PDFs of (a) PPWP and (b) PPWD difference between partitions from SWIM 10° beam and from NDBC buoys over the study period. The red lines are empirical PDFs and the blue lines are best-fitted PDFs assuming that the errors are normally distributed and the outliers are uniformly distributed. The y-axis is in log-scale.

The results show that SWIM performs well at finding the spectral peaks of different partitions with the RMSE of PPWPs and PPWDs of 0.9 s and 20°, respectively, which is a useful complement for other wave observations. However, the accuracy of PSWH from SWIM is not that good at this stage, probably because the high noise level in the spectra impacts the result of the partitioning algorithm. Further improvement is needed to obtain better PSWH information.