Joint retrieval of directional ocean wave spectra from SAR and RAR

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Abstract: This study proposed a joint method to retrieve directional ocean wave spectra from synthetic aperture radar (SAR) and real aperture radar (RAR). The method broke through the limitations existed in the single-sensor wave retrieval, by combining two sensors' characteristics. First, the H_s was estimated from the SAR cutoff using an empirical model. On the other hand, the relative wave spectra at large scale were derived from RAR modulation spectra. After that, the first guess spectra were estimated by relative wave spectra and SAR-derived H_s. Finally, the full wave spectra at small scale were retrieved from the SAR image cross spectra with the help of first guess spectra using the Max-Planck-Institute scheme. The 180° ambiguity of retrieved wave spectra was removed using the imaginary part of SAR cross spectra. Both simulation and collocated data were used to validate the joint method. This method helps to complement traditional wave retrieval methods.

Keywords: Synthetic Aperture Radar (SAR); wave spectrometer; directional ocean wave spectrum; joint method

INTRODUCTION

The measurement of ocean wave fields is important for many industries including shipping, fisheries, and oil extraction, and is also important for the safety and security of nations with coastal borders. Currently, Synthetic Aperture Radar (SAR) [1] and wave spectrometer [2][3] are the only spaceborne radar systems available to measure the directional characteristics of ocean wave fields. The two systems use different measurement scales and principles.

The objective of this paper is to overcome limitations to the retrieval of wave spectra data from SAR and wave spectrometers by combining the output of the two systems. Both simulated and collocated data were used to validate the method. We propose that this method could be used to complement traditional retrieval methods.

DATA

In this section, collocated data were used to validate the proposed method. Data were collected from ENVISAT ASAR Single Look Complex (SLC) images, from the airborne wave spectrometer STORM, from the PHAROS buoy, and from the European Centre for Medium-Range Weather Forecasting (ECMWF) numerical model. The collocated in situ measurements were obtained from observation buoy data, while the reanalysis data were obtained from the ECMWF. These data were compared with SAR-derived and wave spectrometer-derived data. The locations of collocated data used in this study are shown in Fig. 1 and details of the data are listed in Table 1.

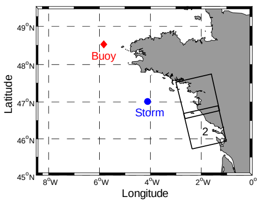

Fig. 1 Map of the study area. The diamond indicates the location of the buoy observations and the circle indicates the location of the STORM observations. The frames indicate the extent of ENVISAT ASAR 1 and ASAR 2 coverage as shown in Table 1.

Data	Acquired Time (UTC)	Central location	Polarization	Mode
Buoy	2002-10-20 11:00:00	48° 31'42"N 5° 49'03"W	/	/
STORM	2002-10-20 10:54:00	47° 03'56"N 4° 09'72"W	HH	/
ASAR 1	2002-10-20 21:43:51	47° 07'45"N 2° 07'52"W	HH	IMS
ASAR 2	2002-10-20 21:43:37	46° 17'34"N 1° 51'22"W	HH	IMS

Table 1 Lists of collected buoy, STORM, and ENVISAT ASAR data with associated records

METHOD

To overcome the limitations of data retrieval from SAR and wave spectrometers, a joint method is proposed. First, the *SWH* is derived from SAR data to estimate the sensitivity coefficient, which is then used with wave spectrometer data to retrieve wave spectra at large spatial scales. Next, wave spectrometer-derived spectra are used as first guess spectra in SAR retrieval procedures, to retrieve full wave spectra at small spatial scales. Finally, the 180° ambiguity of both retrieved spectra is removed using SAR image cross spectra.

The *SWH* is retrieved from SAR data using an empirical model related to λ_c. This model is derived based on RADARSAT-2 SAR data and collocated National Data Buoy Center (NDBC) buoy data. The model coefficients are obtained by retraining the data presented in Ren et al. (2014) [4] using a similar method. The expression for the model of horizontal–horizontal (HH) polarization is given by

$$SWH\left(\lambda_c\right) = 1.83 \cdot \frac{\lambda_c}{\beta} - 0.76$$

To improve the accuracy of the sensitivity coefficient α in inhomogeneous sea states, the SAR-derived and wave spectrometer-derived *SWH*s are averaged to estimate the coefficient as follows:

$$\alpha^2(\theta) = \frac{\sqrt{2\pi}}{L_y}\left(\frac{8}{SWH_{SAR} + SWH_{WS}}\right)^2 \iint \frac{P_m(k,\phi)}{k^2} k\,dk\,d\phi$$

CASE STUDY

The STORM and ENVISAT ASAR data and the corresponding spectra are described in Fig. 2 and 3. The retrieved two spectra are shown in Fig. 4, while the statistics between retrievals and collocated data are listed in Table 2.

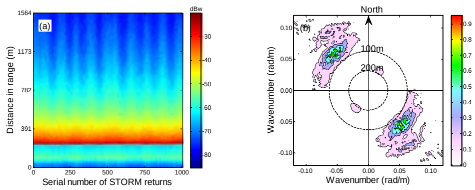

Fig. 2 STORM data. (a) The radar signal returns. (b) The normalized modulation spectrum.

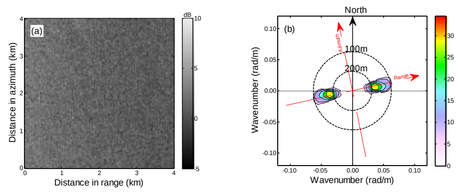

Fig. 3 ENVISAT ASAR data. (a) The NRCS imagette of an ASAR 2 image from the area outlined in Fig. 1. (b) The real part of the image cross spectrum of (a).

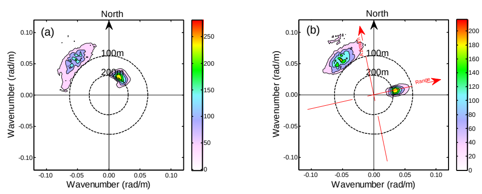

Fig. 4 The wave spectra retrieved from ENVISAT ASAR and STORM data using the joint method. (a) STORM-derived wave spectrum. (b) ENVISAT ASAR-derived wave spectrum.

Source	SWH (m)	PWL (m)	PWD (swell/wind) (° /N)	WSPD (m/s)	WDIR (° /N)
Buoy	2.9	/	/	12.4	120
STORM	2.6	89.5/198.3	355.2/43.7	/	/
SAR image 1	2.6	93.7/172.5	348.5/80.2	7.5	/
SAR image 2	2.6	92.4/165.2	331.7/41.4	8.6	/
ECMWF-STORM	2.7	102.2	334.9	11.2	147.3
ECMWF-ASAR 1	2.4	154.3	34.7	7.0	198.0
ECMWF-ASAR 2	2.3	144.1	36.1	8.6	200.9

Table 2 Wave parameters estimated from STORM data and two ENVISAT ASAR images compared with collocated wave parameters from situ buoy measurements and ECMWF numerical wave model data. PWL and PWD estimated from spectra retrieved by STORM and ENVISAT ASAR are given in terms of wind wave and swell wave components, respectively.

CONCLUSIONS

In this paper, the *SWH* estimated from ENVISAT ASAR data was used to derive the sensitivity coefficient to retrieve the wave spectra from STORM. Meanwhile, STORM-derived wave spectra were used as the first guess spectra to make up for the short waves lost in SAR retrieval. Wave parameters from STORM data and two SAR images were compared to parameters obtained from buoy and ECMWF data. Most of the retrieved parameters were comparable to reference parameters, suggesting that this joint method could be used to complement traditional methods used to retrieve wave spectra data, particularly in inhomogeneous sea states.

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