Verification of the Sea Surface Radar Models from Collocated Radar Observations and Stereo-Photo Imaging

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1. Introduction

Microwave radars are known to be powerful and promising tool for ocean remote sensing. Launching of the satellites with radar onboard allowed to achieve a giant progress in ocean monitoring and forecasts. For this reason, radar backscattering from the sea surface is one of the urgent and topical issues in radiophysics. Despite a lot of efforts the problem is still not finally resolved.

To extract information about sea surface from the radar data, a physical model that relates parameters of the scattered fields and parameters of scattering surface is required. At low incidence angles (angle between vertical axis and look direction) specular point model [1] was shown to be in good agreement with observations. With increasing of incidence angle resonant or Bragg scattering becomes more prominent. This mechanism was accounted for in terms of two-scale model (TSM) [2] which treats surface as a short Bragg ripple distributed over long waves. In spite of its popularity the TSM significantly underestimates polarization ratio, i.e. the ratio of radar cross-sections (RCS) at horizontal and vertical transmit and receive polarizations, and unable to reproduce azimuthal behavior of the normalized radar cross-section (NRCS).

To avoid this inconsistence so called “double structure” of the sea surface was proposed [3] [4] to account for backscattering from breaking waves which produce nonpolarized radar return. Recently it was shown [5] that extension of the Kirchhoff approximation up to first order is able to explain polarization sensitivity by curvature properties of the surface.

Obviously, to verify any model at least two things are necessary: description of the scattering surface (to evaluate model prediction) and radar measurement (to compare with model prediction). As a rule, the former is estimated indirectly with use of wind/wave models and the latter is frequently calculated using numerical methods, such as method of moments. The both approaches may cause unforeseen mistakes. Apparently, the most natural way is to compare direct surface elevation measurements with direct radar observation of a given sea surface area. A number of such works was carried out in laboratory tanks where real sea surface was unreproducible. Trying to fill this gap, we report on results of the recent experiment that was carried out in field conditions with use of novel technique of the sea surface elevation estimation which was never used before for analysis of the radar backscattering.

2. Experiment

Experiment was carried out in the Black Sea at MHI Research platform in September-October 2011. The platform is fixed on the seabed at 30 m depth 600 m offshore. Installation of the instruments on platform is shown in Fig. 1

2.1 Radar

K_a-band dual-polarized continuous wave radar was used for measuring of the NRCS of the sea surface. The radar combined two conical horn antennas for transmitting and receiving. Polarization of the transmitted wave was inclined at 45°. At the receiving channel the signal was separated into horizontally and vertically polarized waves yielding horizontally (HH) and vertically (VV) polarized channels on the transmitting and receiving.

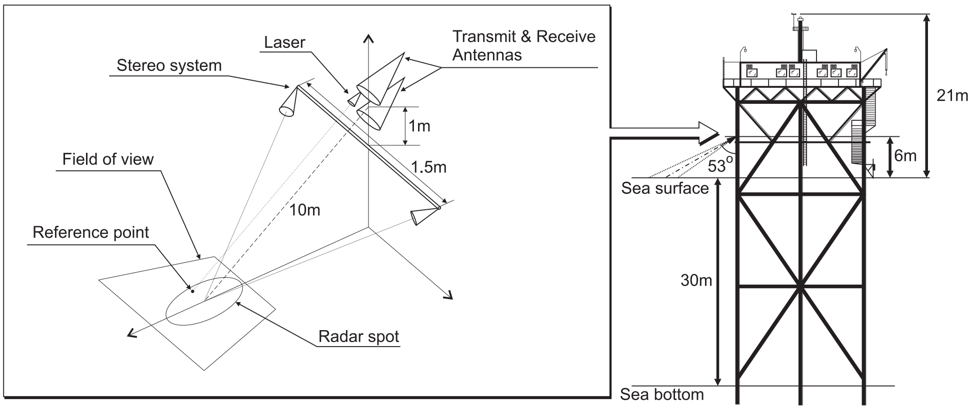


Figure 1: Experimental setup: radar and stereo system installed on the platform.

Each data acquisitions lasted 30 minutes. Raw signals from the radar were digitized with PC based ADC at 40 kHz sampling frequency. Estimation of the received power was performed by calculation of standard deviation over 0.1 s intervals (4000 samples).

The radar was mounted at 6 m height over the mean sea level. Incidence angle was determined by joint radar-stereo system configuration and equaled to 53°.

Absolute calibration of the radar was conducted using metal spheres and corner reflectors that were hanged in front of the radar.

2. 2 Stereo system

Stereo system consisted of the pair of synchronized digital photo cameras that were firmly fixed on the titanium pipe so that optical axes of the both cameras were in the same plane.

Shots were made manually during each acquisition with 5-10 s intervals. The number of stereo pairs was near 100 per each record. Synchronization with the radar with the accuracy better than $25\,\mu$s was performed by recording of the flash lock pulses along with radar signals.

The products of the stereo processing were the instant sea surface topographies with about 10 cm precision over 2 m by 2 m surface patch. Using the method combing both stereo and brightness processing [6], the wavenumber spectra were obtained in the range 20-1500 rad m^{-1}.

Stereo system was installed near the radar so that the middle of the stereo base was on the same vertical axis with the radar and both of them looked approximately at the same point on the sea surface.

2. 3 Spatial matching procedure

In this experiment a very precise spatial matching between radar and stereo system footprints was necessary. For this reason radar pattern was determined with use of digital video camera and laser pointer that were fixed on the radar body and looked at the same direction as the radar.

Metal sphere was oscillated in front of the radar and video camera so that the radar return could be estimated for each position of the sphere in the video frame. In this manner two-way radiation pattern was measured at both HH and VV polarizations.

Direction of the laser beam relative to the radar pattern was fixed at the moment when the the sphere crossed the laser pointer beam. The same laser beam was imaged by the stereo system in the darkness hours after the instruments were installed and preliminary aligned. The point where the beam entered the water was assumed as the reference point for the radar and stereo system.

3. Results

Data acquisitions were made under different wind conditions. In the dataset presented here the wind speed varied from 6 to 18 m s^{-1}. Azimuthal look direction of the instruments relative to the waves was determined by sun glitter and was mainly upwave but not more than 40° from the wave propagation direction.

The specular point model was not considered here because at the incidence angle we used (53°) specular reflections from the regular sea surface are improbable. To calculate prediction of the TSM the radar footprint was divided into 30 cm by 30 cm patches. In-plane and out-of-plane tilts of every patch were computed from the stereo topography and then were used to estimate radar NRCS from the well known expressions given in [7]. Spectral density at the Bragg wave-number was extracted from the spectra obtained from the processing of stereo images.

The scatter plots of the experimental data and TSM predicted values for all runs are shown in Fig. 2. It clearly seen from the figure that the TSM significantly underestimates NRCS at HH polarization, while at VV polarization the values are almost the same.

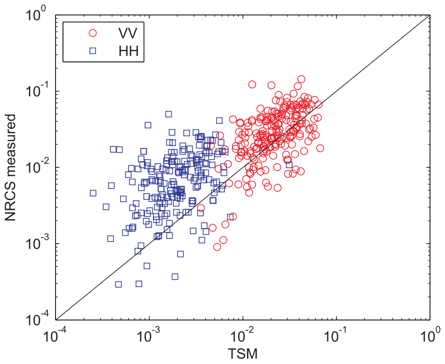


Figure 2: Scatter plot between measured and TSM predicted NRCS at VV and HH polarization.

It was mentioned above that the one of the ways to explain this inconsistence is to account for the backscattering from the breaking or near breaking waves. The influence of these waves was estimated by extraction of the white features from the stereo images. This procedure was done manually yielding three types of features: passive foam, active breaking and microscale breaking waves (microbreaking waves). The last type have to be commented. Manifestation of the microbreaking waves on the images could be clearly seen as bright stand-alone glints. These glints were not associated with the regular sun glitter that is always seen at the sun azimuth because the cameras were oriented perpendicularly to the sun azimuthal direction.

To obtain quantitative characteristic of the features, the coverage of the radar spot by a given type of feature was computed for every stereo pair.

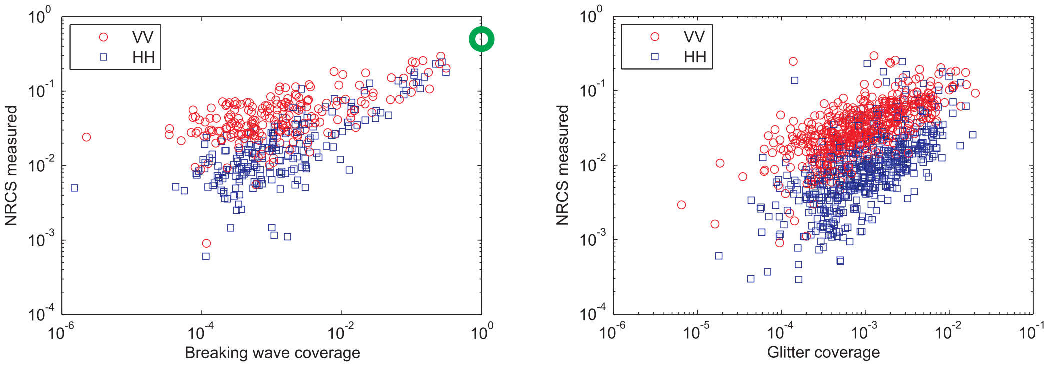
As expected, no correlation was found between passive foam and radar return. On the contrary, strong correlation was found between active breaking coverage and radar NRCS (see Fig. 3). Noteworthy that the pure NRCS of breaking area (extrapolation to full coverage) agrees well with the value obtained in laboratory at X-band [8]. Nevertheless, the active breaking is quite rare event in our data set, so the inconsistence of the TSM cannot be explained by the breakers only.

In contrast to active breaking waves the microbreaking waves were almost always present in the radar footprint. Fig. 3 shows strong correlation between NRCS and observed glitter (or microscale breaking) coverage, suggesting that backscattering from these features can be an explanation for the underestimation of the TSM.

4. Conclusion

In this paper we introduced some of the results that were recently obtained from the joint radar and stereo-photo field experiment. The technique described above allows for reliable verification of various models of radar backscattering from the sea surface.

As the first step we found that in K_a-band the well-known inconsistence of the popular TSM cannot be explained by visible breaking waves only. Strong correlation between radar return and small scale



(a) (b)

Figure 3: Measured NRCS versus breaking wave (a) and microscale breaking (b) coverage at VV and HH polarizations. Green bold circle indicates extrapolation to the pure NRCS of the breaking area.

glitters associated to microbreaking waves clearly demonstrate that the curvature effects are important to reproduce radar backscattering.

Acknowledgments

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