Active and Passive Remote Sensing Measurements of the Sea Surface Waves

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Abstract

The sea surface wave spectrum and the sea surface wave parameters are retrieved from acoustic wave gauge measurements and CCD receivers. The measurements took place on the offshore platform in the Black Sea. The acoustic wave gauge was installed near the platform in August-October 2019. In September-October 2019 the optical measurements were taken. The string wave gauge is working on the platform constantly. The first results of simultaneous measurements of the sea surface waves using active and passive remote sensing are presented. An algorithm for variance of slopes of the large-scale (in comparison with the wavelength of the incidence radiation) waves retrieval is introduced.

1 Introduction

An acoustical wave gauge was developed in the Institute of Applied Physics RAS for surface wave measurement. A number of experiments were conducted using this instrument [1, 2]. An acoustic wave gauge can measure Doppler spectrum of the reflected signal and it also scans the sea surface using ultrasonic pulses. Only pulse channel measurements are introduced in this paper. In [3] a method for slope variance retrieval using dependency of the RCS on the incidence angle was introduced and validated. In this paper the method for slope variance retrieval from ultrasonic pulse measurement is introduced. Also measurements of the sea surface wave spectrum using underwater acoustic wave gauge and the string wave gauge are compared and the method of using the optical RTI images (range-time-intensity) for two-dimensional spectrum measurements [4] are discussed. An acoustic wave gauge measurements can be used for satellite measurements validation.

2 Description of the Experiment

Experiment took place on the offshore platform of the Black Sea Gydrophysics Facility near the Katsiveli settlement. Platform is located approximately 500 m to the south from the shore in the open sea; the sea depth at the platform location is 28 m. The optical instruments stood on the south side of the platform; they were fixed at a height of 15 m above the sea surface. The acoustic wave gauge was installed underwater at the depth of 28 m. The string wave gauge is installed on the east corner of the platform. The speed and direction of the wind at a height of 30 m were measured simultaneously.

Underwater acoustic wave gauge has a frequency of 200 kHz (wavelength is 8 mm). The antenna pattern is wide (15°x15°), pulse length is 40 μs.

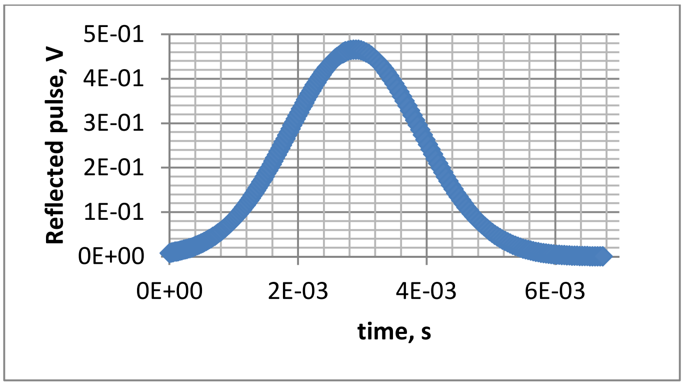

Figure 1. Reflected pulse.

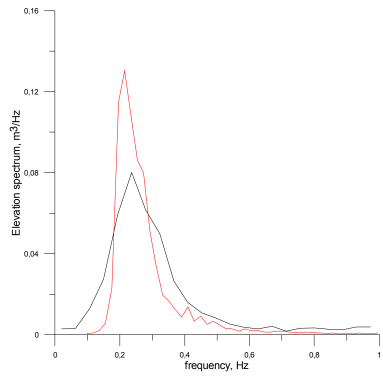

Figure 2. Sea surface waves spectrum measurements. The black line – acoustic wave gauge, the red line – string wave gauge.

An example of the acoustic pulse reflected from the sea surface (4th of September, 04:28-04:38 am) is shown on the Fig.1. The pulse is averaged over the period of 10 minutes. A few thousand pulses are averaged over that time period. The maximum of the pulse reflection corresponds to the reflection from the water surface (wave). That allows us to write the dependence of the distance between wave gauge and the water surface. This is basically the same thing that the string wave gauge measures. The difference is that acoustic wave gauge can measure waves of any height and has a wide antenna pattern while the string wave gauge is limited by the string length and measures wave spectrum in one point.

An example of the sea surface spectrum measurements using acoustic wave gauge and string wave gauge is shown on the Fig.2. The amplitudes of the spectra are different but the frequencies of the maximum are the same.

3 Retrieval of the slope variance

The measurement scheme of an acoustic wave gauge is similar to an altimeter. However, the wide antenna pattern allows to measure variance of slopes of the large-scale waves (in comparison to the wavelength of the incidence radiation).

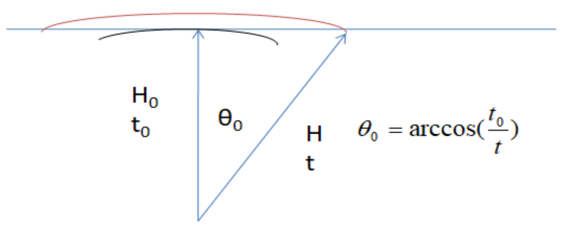

Figure 3. Measurement scheme of an acoustic wave gauge.

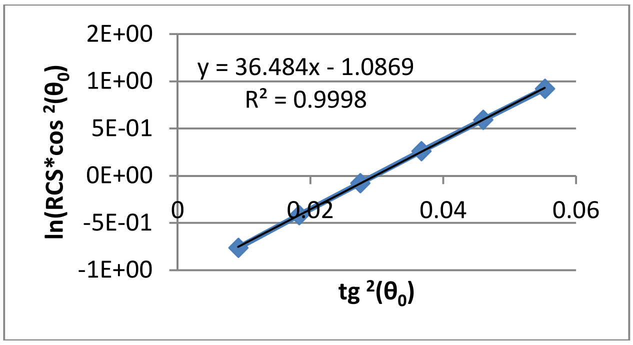

Figure 3. Measurement scheme of an acoustic wave gauge.

Measurement scheme of an acoustic wave gauge is shown on the Fig. 3. Time t_0 corresponds to the moment when pulse has reached the water surface (maximum on the Fig.1). But then the pulse continues to propagate and it forms the trailing edge of the reflected pulse. The dependence of amplitude of the reflected pulse on time can be calculated into the dependence of the RCS on incidence angle (see Fig.3).

The formula for the dependence of the RCS on the incidence angle in Kirchhoff approximation (small incidence angles):

$$RCS = \frac{A}{\cos^2(\theta_0)} exp\left(-\frac{tg^2(\theta_0)}{\sigma_{tot}^2}\right). \qquad (1)$$

According to [] to retrieve total slope variance σ_{tot}^2 we should calculate as follows:

$$ln(\cos^2(\theta_0)\,RCS) = -a tg^2(\theta_0) + b, \qquad (2)$$

where $a=1/\sigma_{tot}^2$. In that case $\sigma_{tot}^2 = 0.028$, if we integrate over spectrum measured by the string wave gauge the result will be $\sigma_{tot}^2 = 0.025$.

4 Optical measurements

Synchronously with the registration of long waves using an underwater acoustic emitter, registration of long waves was carried out using optical lines of CCD receivers. These rulers make it possible to obtain spatio - temporal images of the sea surface in the coordinates range - time. Two such images can be used to determine all the kinematic parameters of long waves. The group structure of long waves in the form of random dark stripes also appears. Based on the optical model of the visibility of waves on the sea surface, a theory has been developed to reconstruct the spectra of long-wave slopes.
An example of spatial - temporal images of long waves on the sea surface, obtained from two lines of CCD photodetectors with different directions of sight is shown on the Fig. . Images are “connected” by their beginnings. Vertical - range, horizontal - time. Altitude is 15 m. Long waves are depicted as oblique stripes. The slope of the long wavelength bands is determined by the speed of the waves.

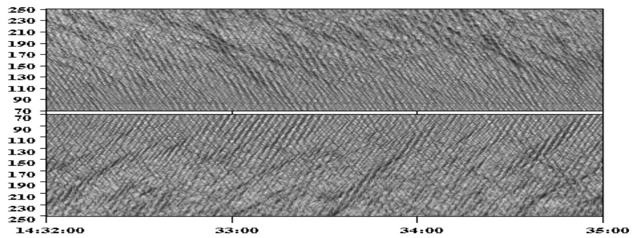

Figure 3. Spatial - temporal images of long waves on the sea surface.

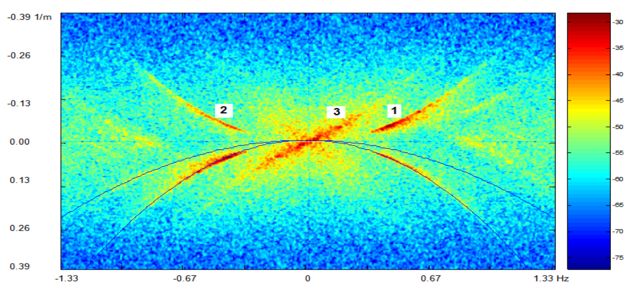

Figure 2. Spectrum of spatio-temporal image.

An example of spectrum of spatio-temporal image is shown on the Fig. .. The vertical axis is the spatial frequency, the horizontal axis is the temporal frequency. 1 — spectrum of long waves propagating to the shore, 2 — spectrum of “counterpropagating waves” with opposite propagation directions, and 3 — spectrum of the group structure of long waves. The wave spectrum is located along the parabola, defined by the equation: $k=k_d(\omega)\cos\theta$.

4 Conclusion

The variance of slopes measured using acoustic and string wave gauges are close. The method for variance of slopes retrieval that was developed for radar measurements is applicable for acoustic measurements. In the future, it is planned to compare the wave spectra obtained by different methods based on acoustic measurements, optical measurements, and contact measurements of a string wave gauge.

5 Acknowledgements

Authors express their gratitude to the Black Sea Gydrophysics Facility for the access to the platform, meteorological and wave spectrum data. Also authors express their gratitude to Roman Belyaev who has made an acoustic wave gauge. This work is supported by the Russian Foundation for Basic Research (grants 18-35-20057 mol_a_ved and 19-05-00547 a).

6 References

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