ON THE PROBLEM OF DOPPLER SPECTRUM OF MICROWAVE SIGNAL AT SMALL INCIDENCE ANGLES AS APPLIED TO REMOTE SENSING OF SEA SURFACE*

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ABSTRACT

The remote sensing of the surface of seas and oceans is important for solution of various tasks, for example, safety of navigation, improvement of reliability of weather forecasts, ecological monitoring of ocean. The paper is devoted to studying the properties of Doppler spectrum (DS) and development of new methods of defining sea surface characteristics. The research the dependence of DS shift and width on conditions of observation (incidence angle, velocity the plane) and state of sea surface (speed and direction of wind) for a wide antenna beam is made for the first time in this paper. The method and algorithms of determination at DS measurements the direction of wave propagation, variance of surface slopes, and phase speed and the length of mean surface wave is proposed.

INTRODUCTION

The determination of parameters of the sea surface using radar remote sensing is important for solution of various applied tasks, for example, for safety of navigation and ability to live in coastal regions, provision of ecological monitoring of ocean.

Radars based on measuring the power of the reflected electromagnetic signal (a scatterometer, a radioaltimeter etc.) are applied now in remote sensing. The effect of the antenna pattern and sea surface state on the shift and width of Doppler spectrum (DS) is considered in this paper. New algorithms for the retrieval of the parameters (direction of wave propagation, variance of slopes, the phase velocity or length of the surface wave) using DS are developed.

MODEL OF DOPPLER SPECTRUM

Within the framework of the Kirchhoff theory a new theoretical model of the Doppler spectrum of the microwave signal backscattered from the sea surface at small incidence angles is developed [1].

The research of dependencies of shift and width of a Doppler spectrum on conditions of observation (incidence angle, velocity of the plane, width of radar beam) and state of the ocean upper layer (speed and direction of the wind) is fulfilled.

The scheme of the measurement is shown in Fig. 1, where V - speed of the plane, θ_0 - angle of incidence, φ_0 - angle of rotation of the antenna, ϕ_0 - direction of wave propagation, R_0, R_1 - distances to the center of the footprint and to the point of reflection respectively. It is shown that more information on the sea surface can be extracted from the Doppler spectrum (variance of a slopes, phase speed and the mean length of a surface waves) than from the normalized radar cross section.

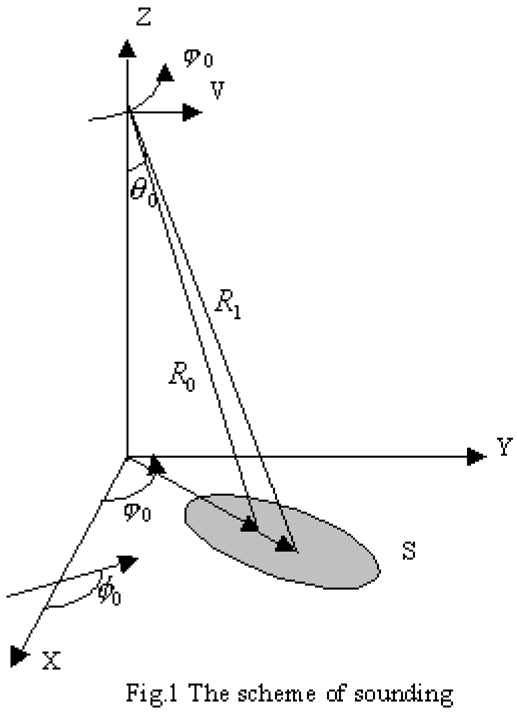

Fig.1 The scheme of sounding

The study shows that the width of antenna pattern strong influences on the Doppler Spectrum (Fig.2). Calculation is made at the angle of incidence of 10 degrees, the wavelength of the radar 3 cm, velocity of the plane - 300 m/s. In the case of the narrow antenna pattern and a movement of radar, we can

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retrieve only velocity of the radar movement. Increasing of width of antenna beam leads to a widening of the Doppler spectrum, which parameters is associated with the variance of the slopes. This allows to measure the variance of surface slopes using the shift and width of the measured backscattered microwave Doppler Spectrum.

As a result of studying DS the algorithm of measuring the variance of slopes and direction of wave propagation is proposed.

The antenna with a knife-like pattern (wide and narrow in two mutually perpendicular directions) is proposed to be used to measurement the direction of wave propagation.

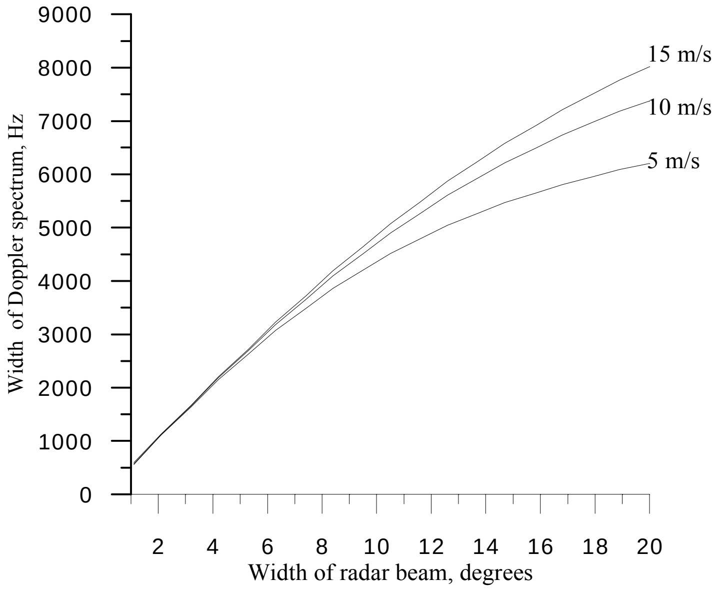

Fig.2 Dependence of DS width on the width of radar beam

ALGORITHMS OF RETRIEVAL THE PARAMETERS OF THE SCATTERING SURFACE

The procedure of measuring the characteristics of surface waves consists of two parts. First of all at the circular mode of flight and the footprint orientation along movement of plane the dependence of DS width from the azimuthal angle is measured.

In Fig. 3 the theoretical dependence of the width of DS is given at the circular motion of the plane (velocity of the plane 300 m/s, the width of radar a beam is 16 degrees on the axis X, and 1 degree on the axis Y, angle of incidence is 0 degrees, the footprint is oriented along the motion, the curves are plotted for a few wind speeds - 15 m/s, 10 m/s and 5 m/s).

The smaller maximum corresponds to the motion along the direction of wave propagation, the greater maximum corresponds to the toward direction.

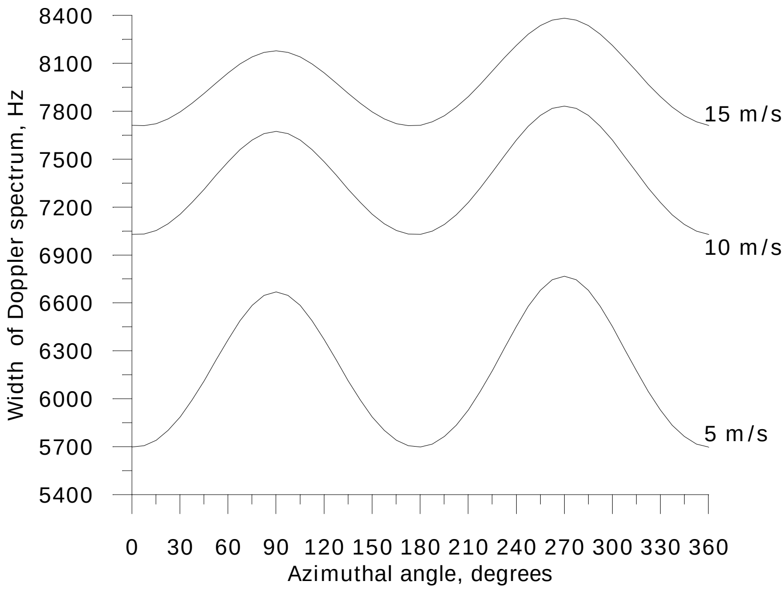

Fig.3 Dependence of DS width on direction of flight

Due to this circle flight we know the direction of wave propagation. A plan will fly along direction of wave propagation. We make subsequent measurements of DS shift and widths, for two orientations of the footprint (parallel and perpendicularly to the velocity of the plane). In this case it is possible to measure the variance of slopes of large-scale (in comparison with the wavelength of radar) waves, phase speed and the length of the mean surface waves. The variance of slopes in the direction the motion of the radar - σ_{yy}^2 can be found by the following formula:

$$\sigma_{yy}^2 = \frac{2 f_{см,\|}^2 \lambda^2 \delta_x^2 (\delta_y^2 - \cos^2(\theta_0)\delta_x^2) - 2(A_\perp^2 - A_\|^2)\sin^2(\theta_0) 11.04\delta_y^2}{(A_\perp^2 - A_\|^2)\sin^2\theta_0 \cos^2\theta_0 11.04^2 - \cos^2(\theta_0) f_{см,\|}^2 \lambda^2 11.04(\delta_y^2 - \cos^2(\theta_0)\delta_x^2)}$$

The variance in the perpendicular direction - σ_{xx}^2 is calculated as

$$\sigma_{xx}^2 = \frac{f_{см,\|}(\cos^2(\theta_0)\delta_y^2 - \delta_x^2)(11.04K_{yy} + \delta_x^2)}{f_{см,\|} 5.52(11.04K_{yy}\cos^2(\theta_0) + \delta_y^2)}$$

variance of orbital velocity - σ_{tt}^2 is calculated as

$$\sigma_{tt}^2 = \frac{A_{\|}^2}{4\cos^2(\theta_0)} + \frac{K_{yt}^2}{2\sigma_{yy}^2} - (\frac{2K_{yt}}{\sigma_{yy}^2} - 2V)\frac{K_{yy}\delta_{xx}^2}{4(11.04K_{yy} + \delta_x^2)}$$

where coefficients

$$A_{\|} = \frac{\lambda\Delta f_{10,\|}}{4\sqrt{\ln 10}};\ A_{\perp} = \frac{\lambda\Delta f_{10,\perp}}{4\sqrt{\ln 10}};$$

δ_x^2, δ_y^2 - widths of the antenna pattern at the level -3 dB on power, $\Delta f_{10,\|}, \Delta f_{10,\perp}, f_{см,\|}, f_{см,\perp}$ - widths at the level 10 dB and shifts of DS for two measurements in mutually perpendicular footprint orientations, θ_0 - incidence angle, V plane velocity, λ - wavelength of the radar.
The cross-correlation function between surface slopes in the direction of the plane motion and the vertical component of orbital velocity - K_{yt} will be written:

$$K_{yt} = 2VK_{yy} - \frac{f_{см,\|}\lambda(11.04K_{yy} + \delta_x^2)}{\sin(\theta_0)}$$

It can be easily to show that the following coefficient has the meaning of a certain mean phase speed of surface waves:

$$V_{\phi} = \frac{K_{yt}}{K_{yy}} = 2V - \frac{f_{см,\|}\lambda(11.04K_{yy} + \delta_x^2)}{\sin(\theta_0)K_{yy}}$$

Knowing the wave phase speed one can calculate it length.
There is a more simple, but less precise method of determination the variance of slopes in the direction of motion. In this case it is enough to measure only DS width at the orientation of the footprint along the motion of the radar. The measurements are supposed to be carried out in a nadir. For calculation of the variance of slopes the following formula is used:

$$\sigma_{yy}^2 = \frac{2A_{\|}^2\delta_x^2}{\cos^2(\theta_0)4V^2\delta_x^2 - A_{\|}^2 11.04}$$

Thus it is possible to measure the variance of slopes along the direction of motion, also when its the radar motion changes (for example to carry out measurements along the circle or when the plane flight changes is direction of motion to the perpendicular one) one may also measure the variance of the slopes in any direction and to determine a direction of wave propagation.

CONCLUSIONS

It is shown in the present work that Doppler spectrum measurements provide more information on the state of the ocean surface than the normalized radar cross section. The theoretical analysis leads to new methods for the remote sensing of the sea state and algorithms for the retrieval of sea surface parameters.

REFERENCE

1. E.M.Meshkov, V.Yu.Karaev. The features of the Doppler spectrum of microwave signal backscattered by see surface at small incidence angels. (in Russian), Technical report № 565, 24 p., IAP RAS., Nizhny Novgorod–2001.