MEASUREMENTS OF WATER SURFACE SLOPES BY MICROWAVE RADAR INSTALLED AT THE HELICOPTER

Vladimir Yurjevich Karaev, Mikhail Borisovich Kanevsky, Eugeny Mikhailovich Meshkov, Emma Mikhailovna Zuikova, Vladimir Yurjevich Gol'dblat and Viktor Ivanovich Titov

Institute of Applied Physics, Russian Academy of Science
46, Uljanov str., Nizhny Novgorod, Russia
Tel.: 7 – 8312 – 16-49-28, Fax: 7 – 8312 – 365976,
e-mail: volody@hydro.appl.sci-nnov.ru

ABSTRACT Initial results of processing data from an experiment performed in November, 2005 are given. A microwave Doppler radar with a knife-like beam (1.5^0 - 24.5^0) was installed on a helicopter. Measurements were made during a flight above the Gorky water storage basin. Power and Doppler spectra of the radar reflected signal were analyzed. The processing has shown that the algorithm developed for the retrieval of the slopes of rough water surface enables one to determine the direction of wave propagation and retrieve the variance of the wave slopes.

KEY WORDS: Remote Sensing, Retrieval Algorithm, Variance of Waves Slopes

1. INTRODUCTION

Remote sensing is the main source of information on state of the near-surface layer over vast areas of the World Ocean. Requirements for more and better information are constantly growing, which stimulates the search for new algorithms to process available data and to develop new radar methods.

Our theoretical investigation of scattering at small incidence angles has demonstrated that there is the possibility to increase the number of measured parameters by improving the radar system (Karaev, 1999; Karaev, 2002; Karaev, 2003, Karaev, 2005). To test the theoretical conclusions, a microwave Doppler radar with a knife-like beam was manufactured and measurements were carried out from a bridge over the Oka river. They confirmed the validity of the theoretical conclusions and permitted verification of the algorithms, which do not employ platform motion as an additional source of information (Meshkov, 2004; Karaev, 2005).

This paper deals with an experiment on measuring backscattering from a moving platform performed in November, 2005. The location of the first flight experiment was the Gorky water storage basin. A Doppler radar with a knife-like beam was installed on a MI-8 helicopter and measurements were carried out during a flight above the Gorky water storage basin.

2. DESCRIPTION OF THE EXPERIMENT

In the experiment a helicopter provides more flexible measuring platform during flight above a small water storage basin in comparison to a plane. It allows choice of height and speed of flight and can hover above water surface.

Figure 1 shows MI-8 helicopter with the installed antenna system. A radome with antenna was mounted under the helicopter (see the figure). Access to the radar from the helicopter cabin was provided through a hatch.

The length of the antenna is more than a meter and this results in stronger windage in flight, thus a special radome was fabricated. The assembled antenna system is shown in fig. 2

Fig. 1. MI-8 helicopter with antenna radome installed underneath before flight.

The antenna can rotate inside the radome, while the walls protect the antenna from the wind. We were interested in small incidence angles, thus the antenna was oriented vertically downward.

For the measurements we used a Doppler radar with the following characteristics: reflected power $P_{rad} = 80$ mW, radar wavelength 0.03 m (10 GHz). The beam width at the half-power level was 1.5^0 by 24.5^0 (a knife-beam).

During the flight the antenna was fixed so that the wide aperture of antenna beam (24.5^0) was oriented along the flight direction.

The experimental scheme was as follows: after take-off (from Nizhny Novgorod city airport) the helicopter settled on a course to the Gorky water storage basin. The distance to the water storage basin is approximately 80 km. The radar was switched on during flight. A reflected radar signal from the radar output, through a multichannel input board of analog signals L305 (ADC), was recorded on a computer for further digital processing. Speed and height of flight were recorded using a GPS receiver (Garmin eTrex Legend).

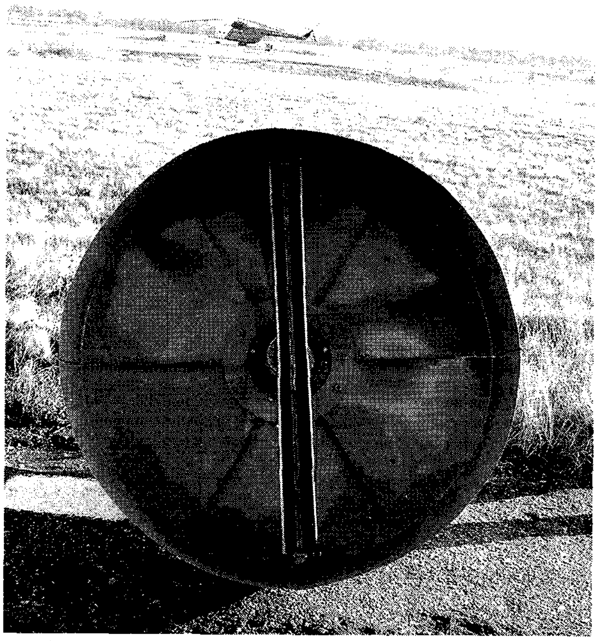

Fig. 2. Knife-like antenna mounted inside of radome.

2. PROCESSING OF EXPERIMENTAL DATA

The experiment was carried out on November 19, 2005. The height of flight above water surface was about 150 m and the speed was about 100 km/h. The flight path is shown in fig. 3.

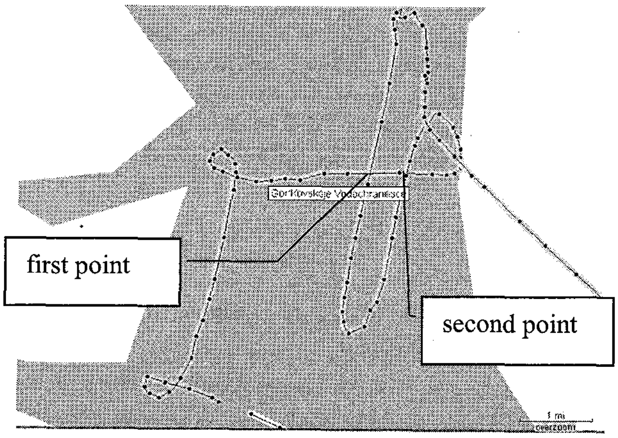

Fig. 3. Flight path above the Gorky water storage basin.

To measure the full variance of slopes in two mutually perpendicular directions, with a non-rotating antenna, it is necessary to fly along the direction of wave propagation and across it. In the present paper we consider two points on the path shown in fig. 3. Unfortunately, the angle during flight was not perpendicular and this will cause an additional error in data processing.

At the first point the helicopter flew from left to right (42, see Table 1) and, after a turn, from the bottom upwards (82, see Table 1). At the second point the helicopter moved from left to right (45) and, after a turn, from top to bottom (see fig. 3).

The wind direction was along the water storage basin, which provided a longer fetch for the waves.

The surface was photographed with a digital camera during flight. A characteristic view of the surface when the helicopter flew along the propagation direction is shown in fig. 4.

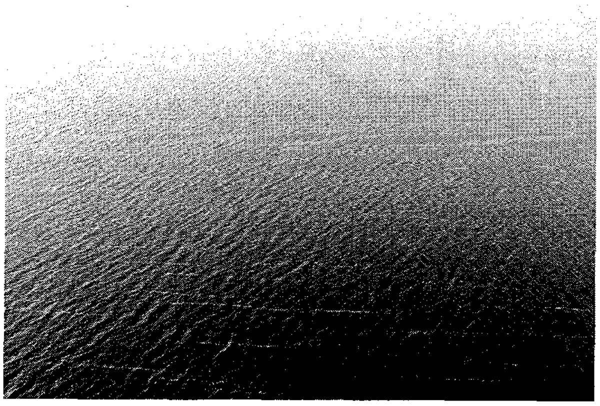

Fig. 4. Photograph of water surface from helicopter

The structure of the wind waves is seen in the figure. At the time the photograph was taken the helicopter flew along the direction of wave propagation.

An example of the Doppler spectrum (DS) is given in fig. 5. Circles show the measured Doppler spectrum of reflected signal, the solid line the model's spectrum.

Here, by the shift of the DS we mean shift of the spectrum maximum relative to the carrier frequency, while by the DS width at the 10 dB level we mean the width at 0.1 of the maximum.

As a model spectrum we chose a Gaussian model of the Doppler spectrum:

$$S(f) = A_0 \exp\left[-\frac{(f - f_{shift})^2}{f_{10}^2}\right], \tag{1}$$

where f_{shift} is the shift of the DS. The coefficients of the model were calculated bu fitting to the data using the method of least squares; the model spectrum is shown by solid line in fig. 5.

The width of DS at the -10 dB level is calculated by the formula (in the context of the model spectrum):

$$\Delta f_{10} = 2 f_{10} \sqrt{\ln 10}\ . \tag{2}$$

The backscattered power in the context of the Gaussian model is found by the formula:

$$P_{\text{mod}} = A_0 f_{10} \sqrt{\pi}\ . \tag{3}$$

Estimates of model power P_{mod}, shift f_{shift} and width of Doppler spectrum width Δf_{10} at the -10 dB level are shown in Table 1.

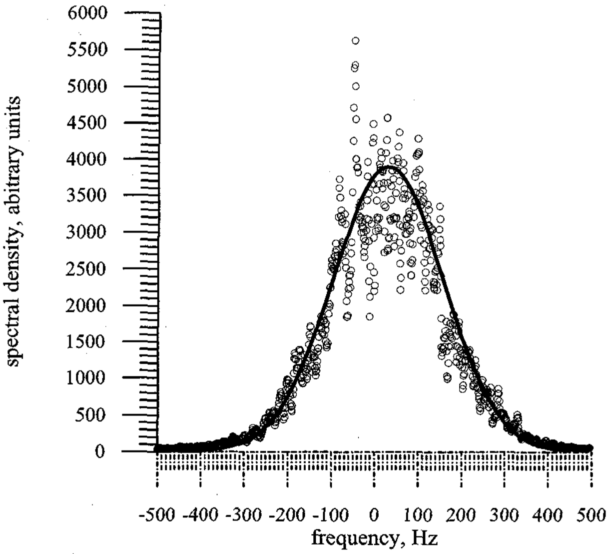

Fig. 5. Doppler spectrum (12:46:17). Circles show the measured spectrum, the solid line the model (Gaussian) spectrum.

Table 1. Parameters of reflected radar signal.

№	Averaging time interval	Power, conventional units P_{mod}	Average value, Hz f_{shift}	DS width, Hz Δf_{10}
44	12:39:01 - 12:39:36	1291	-4.4	880
62	12:41:49 – 12:42:01	1647	-50.5	1018
45	12:39:40 – 12:39:52	1430	43.2	841
82	12:46:17 – 12:46:30	1755	10.8	986

In general, a reflected radar signal "feels" wave orientation and can be used for retrieval of slope variance. The reflected signal power (radar backscattering cross-section) and the width of DS can be used for determining the wave propagation direction (in 62 and 82 the helicopter flew along the wave direction).

3. RETRIEVAL ALGORITHM

By studying backscattering at small incidence angles, we developed several algorithms for retrieval of sea wave parameters (Karaev, 1999; Karaev, 2002; Karaev, 2003, Karaev, 2005)..

In this paper we estimate the efficiency of the algorithm developed for a radar altimeter with a wide antenna directivity pattern operating in the all-round view mode (Karaev, 2006).

As is known, at small incidence angles, backscattering is dominated by quasi-specular reflections from wave facets oriented perpendicularly to incident radiation field. In the general case, the radar backscattering cross-section is represented by the well-known formula:

$$\sigma_0 \cong \frac{|R_{\text{eff}}(U_{10})|^2}{2\cos^4\theta_1\sigma_{x1}\sigma_{y1}}\exp\left[-\frac{\text{tg}^2\theta_1}{2\sigma_{x1}^2}\right], \qquad (4)$$

where σ_{x1}^2 и σ_{y1}^2 are the variances of the slopes of large-scale waves along the *X'* and *Y'* axes respectively; U_{10} is the wind speed at 10 m; θ_1 is the incidence angle.

The effective reflection coefficient R_{eff} is introduced instead of the Fresnel coefficient. This coefficient takes into account the attenuation of the reflected field due to small ripples on the surface.

The footprint may be divided into elementary scattering cells using Doppler selection (Karaev, 2005). Two sequential scattering cells along the *X'* axis will differ in incidence angles. To retrieve the slope variance along the probing direction we use a formula derived from (4):

$$\sigma_{x1}^2 = \frac{tg^2\theta_1 - tg^2\theta_2}{2\ln\left(\sigma_0(\theta_2)\cos^4\theta_2/(\sigma_0(\theta_1)\cos^4\theta_1)\right)}, \qquad (5)$$

where θ_1 and θ_2 are the incidence angles of two elementary cells, while $\sigma_0(\theta_1)$ and $\sigma_0(\theta_2)$ are the radar cross sections of these cells, respectively.

When splitting an illuminated footprint into elementary scattering cells, we encounter the influence of the antenna directivity pattern. Though the beam is rather wide (24.5^0) it influences the accuracy of retrieval of the slope variance. The fact is that as an incidence angle increases, the antenna pattern decreases the power of the reflected signal (inside the illuminated footprint), and there is no complete analogy with a narrow beam antenna for which formula (5) is valid. Fortunately, this problem can be solved by processing. After splitting the footprint into elementary cells, one makes a correction for the power in each cell (for each incidence angle) and only then is formula (5) applied. Let us consider this in more detail.

The directivity diagram of the antenna is assumed to be Gaussian and is given by the following expression:

$$G(x,y) = \exp\left[-1.38\cdot\left(\frac{x^2}{R_0^2\delta_x^2}+\frac{y^2}{R_0^2\delta_y^2}\right)\right]. \qquad (6)$$

where δ_x and δ_y are the beam widths at the half power level along *X'* and *Y'* axises correspondingly.

To make the correction, one should multiply the reflected signal power in an elementary cell (radar backscattering radar cross-section) by the coefficient related to the directivity pattern of antenna. The formula is:

$$\sigma_{0K}(\theta_1) = \sigma_0(\theta_1)\cdot\exp\left\lfloor 2.76\cdot\sin^2\theta_1/\delta_x^2\right\rfloor. \qquad (7)$$

After the correction (Karaev, 2005) one may work with formulas for narrow antenna directivity pattern (see formula (5)).

The DS represents the possible Doppler velocities present in the reflected signal. If we divide the Doppler velocity axis into 26 intervals and calculate the power of the reflected signal in each interval/cell, we can perform spatial sampling using Doppler selection. Figure 6 shows the distribution of the power in the cells/angles.

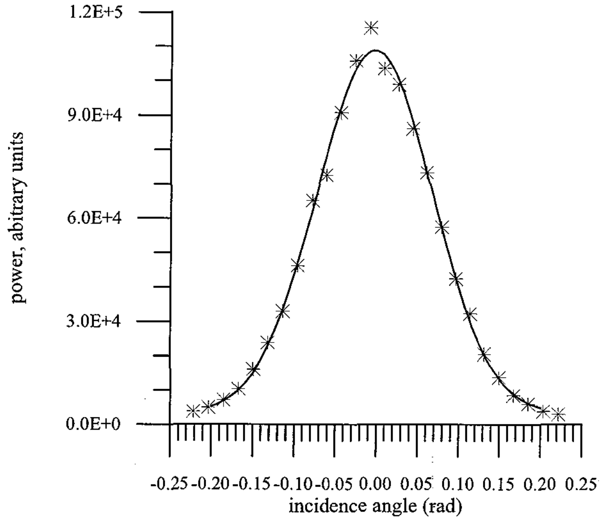

Fig. 6. Dependence of backscattering cross-section on incidence angle. Asterisks show experimental data, lines the Gaussian approximation.

Hence it is seen that the dependence of the radar backscattering cross-section on incidence angle matches the theory. The angular resolution is 1^0. The largest deviations are observed at small incidence angles. As was shown in (Karaev, 2006), the optimum angles for using the algorithm for slope retrieval are those $\geq 4^0$.

As a result of processing, we retrieved the slope variance at points 1 and 2 (see fig. 3): the slope variance along the direction of wave propagation is $\sigma^2_{xx} = 0.00721$ and in the perpendicular direction $\sigma^2_{yy} = 0.00460$ (at point 1) and at point 2: $\sigma^2_{xx} = 0.00641$ and $\sigma^2_{yy} = 0.00497$. The total slope variance at point 1 is equal to $\sigma^2_{total} = \sigma^2_{xx} + \sigma^2_{yy} = 0.0114$ and point 2 $\sigma^2_{total} = 0.0118$. The measured values of the total slope variance are very close.

5. CONCLUSIONS

The present paper describes the continuaion of our research on backscattering at small incidence angles. The newly developed radar system with a knife-like beam (X-band, 1.5^0-24.5^0) was used in new experiment (November, 2005). These were our first measurements made from moving platform (helicopter). Due to the movement of the radar we, for the first time, had the opportunity to test the retrieval algorithms using the DS parameters of the reflected signal.

Preliminary analysis of the data has shown that the retrieval algorithm is working. Good agreement between theoretical predictions and experimental data are shown.

A detailed analysis of the experimental results will be made and a detailed comparison between of retrievals and measurement is planned.

Acknowledgements. The work is supported by the Russian Fund of Basic Research (project № 06-05-64752) и Science School № 6043.2006.3.

6. REDERENCES

Karaev , V., Kanevsky M., 1999, On the problem of the radar determination of the sea surface parameters. *Issledovanie Zemli iz kosmosa*, (in Russian), 4, pp.14-21.

Karaev, V., Kanevsky, M., Cotton, D., Challenor, P., 2002, Is it possible to measure ocean surface slopes with a microwave radar? *International Journal on Remote Sensing*, 23(16), pp. 3251-3262.

Karaev V., Kanevsky, M., Balandina, G., Meshkov, Eu., Gommenginger, C., Challenor, P., Srokosz, M., 2003, Method of sea surface slopes measurements by microwave radar with knife-like antenna pattern. *Issledovanie Zemli iz kosmosa*, (in Russian), 5, pp. 51-63.

Karaev, V., Kanevsky, M., Balandina, G., Challenor, P., Gommenginger, C., Srokosz, M., 2005, The concept of a microwave radar with asymmetric knife-like beam for the remote sensing of Ocean Waves. *J. Atmospheric and Oceanic Technology*, 11, pp. 1809-1820.

Karaev, V., Meshkov, Eu., Balandina, G., Zuikova, E., Gol'dblat, V., Titov, V., 2005, Study of a backscattered microwave signal at small incidence angles: in-sity measurements, *Radiophysics and Quantum electronics*, 48(8), pp. 587-598.

Karaev, V., Kanevsky, M., Balandina, G., Meshkov, E., Challenor, P., Srokosz, M., Gommenginger, C., 2006, A rotating knife-beam altimeter for wide-swath remote sensing of the ocean: wind and waves. *Sensors*, 6, pp. 260-281.