APPLICATION OF THE NEW OBSERVING TECHNIQUES FOR REMOTE SENSING OF SEA SURFACE[1]

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ABSTRACT

The present work continues our research on electromagnetic scattering from the sea surface at small incidence angles as applied to remote sensing. Our analysis is based on the developed theoretical models of normalised radar cross section and Doppler spectrum for a radar with a wide antenna pattern. Analyses have shown that such radar system allows to obtain an important information about sea surface which can not be measured from space now. The numerical simulation confirmed our theoretical results and allowed the investigation of the properties of the new system for various radar and ocean parameters. This has helped to determine the optimal characteristics of the radar system. The new microwave radar has a nadir-probing asymmetric knife-like antenna and its Doppler discrimination abilities offer the possibility of measuring a number of key sea state parameters such as the long wave slope, the direction of wave propagation and a wind speed or a friction velocity.

INTRODUCTION

Measurement of the global wave climate is critical for the improvement of the sea state forecasts as well as for climate research, transport, offshore exploration, and coastal defenses. The assimilation of sea state data provided by satellite altimeters or SAR is the main requirement for solution of this problem. However, conventional altimeters measure only significant wave height, by itself a poor sea state descriptor, and extraction of spectral information from satellite SAR imagery is hampered by complex processing and high ocean wavelength cut-off (~100m).

The new microwave radar has a nadir-pointing rotating asymmetric knife-beam antenna and its Doppler discrimination abilities offer the possibility of measuring a number of key sea state parameters such as the long wave slope, the direction of wave propagation and wind speed. In a space-borne scenario, backscattered signals may be isolated for scattering cells of the order 14x14 km over a swath approximately 250km wide, which will improve our knowledge about ocean wave processes. Such global sea state information would be of great value in improving and validating ocean forecasting models.

INITIAL ASSUMPTIONS

Making nadir measurements with a radar with a knife-beam antenna pattern, gives information on the scattering surface along-track. If the radar is mounted on a plane, by choice of flight pattern, it is possible to collect directional information on wave phenomena on the ocean surface. From space, only data on waves along the satellite track are accessible to measurement. As the distance between adjacent tracks may be some hundreds kilometers [1], the information about wave phenomena will be fragmentary.

The low repeatability of viewing the same area of ocean by an altimeter leads to poor sampling on the majority of wave processes on a surface. One way to solve this problem is to increase the number of satellites [2]. Instead we propose to use a Doppler radar with a rotating knife-beam antenna pattern, for example 1^0 x 25^0. At a height of 800 km the size of the footprint at the half-power level will be approximately 14 x 350 km.

In modern numerical wave models, grids with cells 50x50 km in the open ocean and 25x25 km in the coastal seas are used [1,3]. Thus, the proposed resolution along one direction (14km) is quite satisfactory for the study of ocean wave processes. The improvement of the resolution in the range direction is possible, using time or Doppler selection. The features of radar system with knife-beam radar oriented along the track were considered in our previous research [4, 5]. Here we consider a radar with a rotating antenna system.

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In Fig.1 we see the scheme of observation. Let the flight direction be oriented along the Y-axis. Here V is the velocity; θ_1, θ_2 are incidence angles; R_1 and R_2 are slant ranges to two different scattering points. Now we introduce a second system of coordinates X'Y', connected with the footprint: the axis X' is oriented along a longitudinal axis of the footprint on a surface and the angle with the first system of coordinates is equal to φ_1.

The advantage of such system consists in a wide swath. The new system may collect data in this swath with a resolution, for example, 14x14km.

APLICATION OF TIME OR DOPPLER SELECTION FOR SPACE-BORNE RADAR

A satellite-borne radar (~800km altitude) with asymmetric knife-beam antenna pattern (1^0x25^0) will have a large footprint (~200-300km). How is it possible to improve the spatial resolution?

Due to the narrow beam width across the footprint (1^0), the across-range resolution will be of the order of 14km, which is acceptable for wave studies.

1) Time selection. Let us introduce the pulse duration τ. Hence, the slant range for two successive scattering points in the footprint is $R_2 = R_1 + c\tau/2$, where c is the speed of electromagnetic waves. For such an observation scheme (see figure 1) the range resolution will be equal to $\Delta y = y_2 - y_1$, which after simple geometric considerations reads:

$$\Delta y = H_0 \left(\sqrt{\frac{(1 + c\tau \cos\theta_1 / (2H_0))^2}{\cos^2\theta_1} - 1} - \tan\theta_1 \right) \qquad (1)$$

2) Doppler selection. Due to the motion of the radar, the reflected signal will display a frequency shift with regards to the carrier frequency, which depends on the incidence angle and the velocity of the satellite. If ΔV is the width of the filter velocity, the formula for the range resolution with Doppler selection is:

$$\Delta y = H_0 \left(\frac{\sin\theta_1 + \Delta V / V}{\sqrt{1 - (\sin\theta_1 + \Delta V / V)^2}} - \tan\theta_1 \right) \qquad (2)$$

Here we assume an azimuthally narrow radar beam ($\delta_x \sim 1^0$) and don't take into account any changes in azimuthal angle within the antenna footprint.

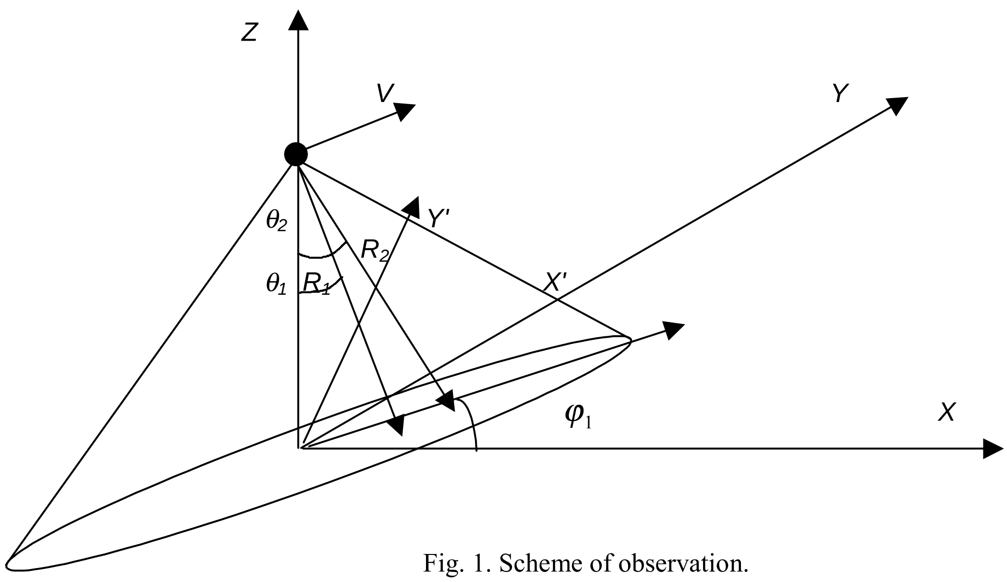

Fig. 1. Scheme of observation.

RETRIEVAL ALGORITHMS

At small incidence angles a backscattering is quasispecular and takes place from the facets of the ocean surface oriented perpendicularly to the incident electromagnetic wave.

As well known, for radar with narrow radar beam the radar cross section is determined by the following formula [6]:

$$\sigma_0 \cong \frac{\left|R_{eff}(U_{10})\right|^2}{2\cos^4\theta_0 \sigma_{x1}\sigma_{y1}} \exp\left[-\frac{tg^2\theta_0}{2\sigma_{x1}^2}\right], \tag{3}$$

where σ_{x1}^2 and σ_{y1}^2 - variance of surface slopes along and perpendicularly to the footprint orientation (direction of probing, X'); U_{10} - wind speed at 10m height; θ_0 is the incidence angle; $R_{eff}(U_{10})$ - the effective reflection coefficient.

For measurement of slope variance in a wide swath the following algorithm is offered. In the case of the knife-beam antenna the large footprint with the help of time or Doppler selections can be divided on elementary scattering cells. Two neighbouring along an axis X' cells will be differ by incidence angles. For small cells, for example 14 x 14 km, are possible to neglect change of parameters of sea waves both inside a cell, and between the neighbouring cells. Then for retrieval of slope variance along a direction of probing we may calculate by the following formula:

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

where θ_1 and θ_2 - incidence angles for two neighbouring elementary cells and $\sigma_0(\theta_1)$ and $\sigma_0(\theta_2)$ - radar cross sections for these cells correspondingly (see fig.1) where the following correction for radar cross sections must be done:

$$\sigma_{0cor}(\theta_1) = \sigma_0(\theta_1) \cdot \exp\left[-2{,}76 \cdot \sin^2\theta_1 / \delta_x^2\right] \tag{5}$$

Here the Gaussian antenna pattern are suggested and δ_x - the beam width at the half power level along X' axis.

To calculate the complete variance of slopes it is necessary to measure the variance in this cell under another azimuthal angle using rotation of the antenna (see Fig. 2). The squares in Fig.2 were used for the conditional image of cells, i.e. visually to separate two neighbouring cells. The index "x1" in the formula (4) means only that the variance of slopes is retrieved along an axis *X'*.

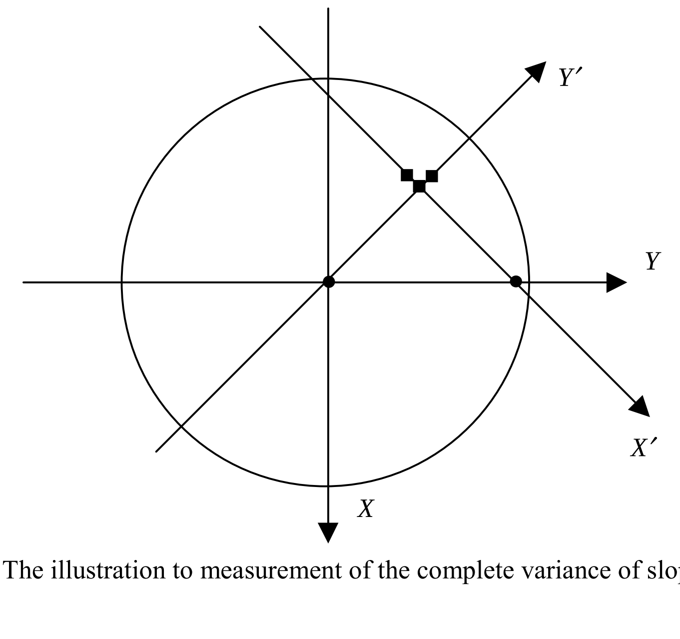

Fig.2. The illustration to measurement of the complete variance of slopes.

SWH RETRIEVAL

The simplest variant of the retrieval of significant wave height in wide swath may be based on the next way. It is necessary for each elementary scattering cell to input the reference point. We suggest to use the frequency filters to introduce these points for all cells. The reflected signal will be seen in each filter (cells) only a short time which depends on a pulse duration, a significant wave height and a variance of sea wave orbital velocity. The SWH of sea waves may be retrieved from leading edge of impulse as SWH in the case of a conventional altimeter.

DATA PROCESSING

Let's define the order of data processing at a panoramic mode of radar work. At movement radar along an axis *Y* the swath of the review in 350 km is covered. In view of restriction, which we introduce for azimuthal angles ($>90^0$), the width of the "qualitative" swath decreases up to 250 km.

Assuming, that the step on a incidence angle will be approximately equal to 1 degree, we shall divide all footprint on cells by the size, for example, 14 x 14 km (see fig.3). After data processing we will know the variance of slopes, wind speed, direction of wave propagation and SWH in each cell.

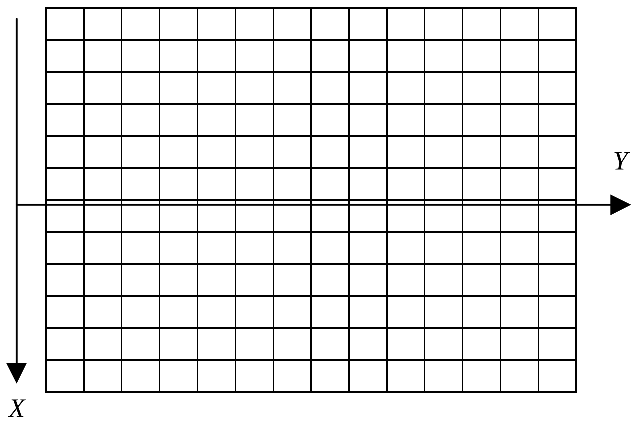

Fig.3. Illustration of transformation of wide swath in set of cells.

CONCLUSION

The Doppler radar with knife-beam antenna pattern is discussed. The analysis is based on the developed advanced theoretical models of normalised radar cross section and Doppler spectrum for a radar with wide antenna pattern, on the experimental data and on the numerical simulation.

Due to knife-beam antenna pattern a new radar will be able to illuminate a wide swath. The solution of improvement of resolution problem is based on of time/Doppler selections, which permit to work from space with an acceptable size of elementary cells, for example, 14 km x 14 km.

New algorithms will allow to retrieve in an each elementary cell the variance of slopes, to determine the direction of wave propagation, wind speed. The advanced version of radar system permits to retrieve the significant wave height and wind stress.

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