EXPERIMENT AT THE INTERNATIONAL SPACE STATION: A MICROWAVE RADAR WITH SCANNING FAN BEAM ANTENNA AT NADIR PROBING

Vladimir Karaev, Mariya Panfilova, Yury Titchenko, Mariya Ryabkova, Eugeny Meshkov

Institute of Applied Physics, Russian Academy of Sciences, Nizhny Novgorod, Russia

Abstract

Advantage of the measurements at the small incidence angles is explained by the fact that characteristics of the backscattered radar signal is directly determined by the parameters of sea waves, because a microwave backscattering is quasi-speqular. Hence, it is possible to retrieve parameters of large-scale waves by remote sensing methods.

In our previous researches the concept of radar with fan beam antenna was suggested. Concept of new radar is based on the advanced theoretical scattering model which was developed in our group. Field experiments confirmed the theoretical conclusions.

Russian space agency supported our proposal and a new radar will be developed and tested during experiment at the International Space Station (Russian segment).

During space experiment modes will be tested : 1) measurement of mean square slopes (mss) of large-scale waves and 2) measurements of significant wave height (SWH).

After data processing the following images of sea surface will be obtained: 1) a radar image (radar cross section) 2) a mss field 3) a SWH field and 4) wind speed field. New radar is a powerful instrument for investigation of different processes on the sea surface.

1. Radar with a fan beam antenna

In the framework of the Kirchhoff approximation the theoretical analysis of the backscattering of electromagnetic waves from the ocean surface at normal incidence has been carried out for a wide radar beam and a new theoretical model of the normalised radar cross section (NRCS) has been obtained [1-4]:

$$\sigma_0 = \frac{\left|R_{eff}(U_{10})\right|^2}{2}\left(S_{xx}^2 + \frac{\delta_x^2}{5.52}\right)^{-1/2}\left(S_{yy}^2 + \frac{\delta_y^2}{5.52}\right)^{-1/2},$$

where δ_x, δ_y are the half power beam widths in two mutually perpendicular planes; S_{xx}^2 and S_{yy}^2 are the mean square slopes (*mss*) of surface slopes along and perpendicular to the footprint's major axis; U_{10} is the wind speed at 10m height. The antenna gain is assumed to be a Gaussian function. The effective reflection coefficient $R_{eff}(U_{10})$ is introduced instead of the Fresnel coefficient.

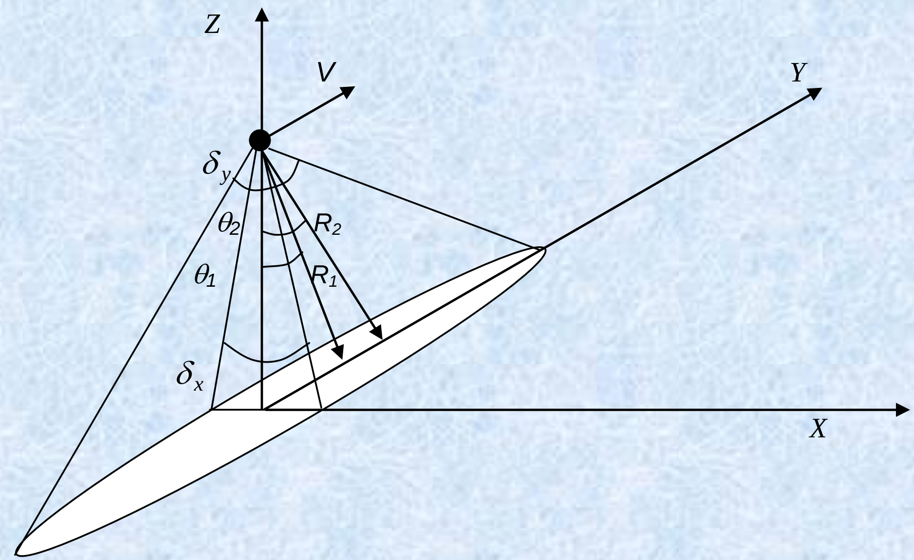

Fig. 1. Radar with a fan antenna beam at nadir probing.

1. Radar with a fan beam antenna

For the case of nadir probing with a knife-like antenna pattern we have the following formula for the width of the Doppler spectrum at the -10dB level:

$$\Delta f_{10}[Hz] = \frac{4\sqrt{2\ln 10}}{\lambda} \cdot \frac{V\delta_y}{\sqrt{5.52 + \delta_y^2 / S_{yy}^2}}$$

where λ is the radar wavelength of the radar signal.

A radar with a narrow beam does not "see" the ocean surface and the spectral characteristics of the reflected signal depend on the velocity of the platform up to several degrees. However, as the radar beam width increases the difference between wind speeds becomes evident. For the antenna beamwidths larger than a few degrees, the reflected signals contain information about the sea surface in the Doppler spectrum and it becomes possible to retrieve the wave slope variance.

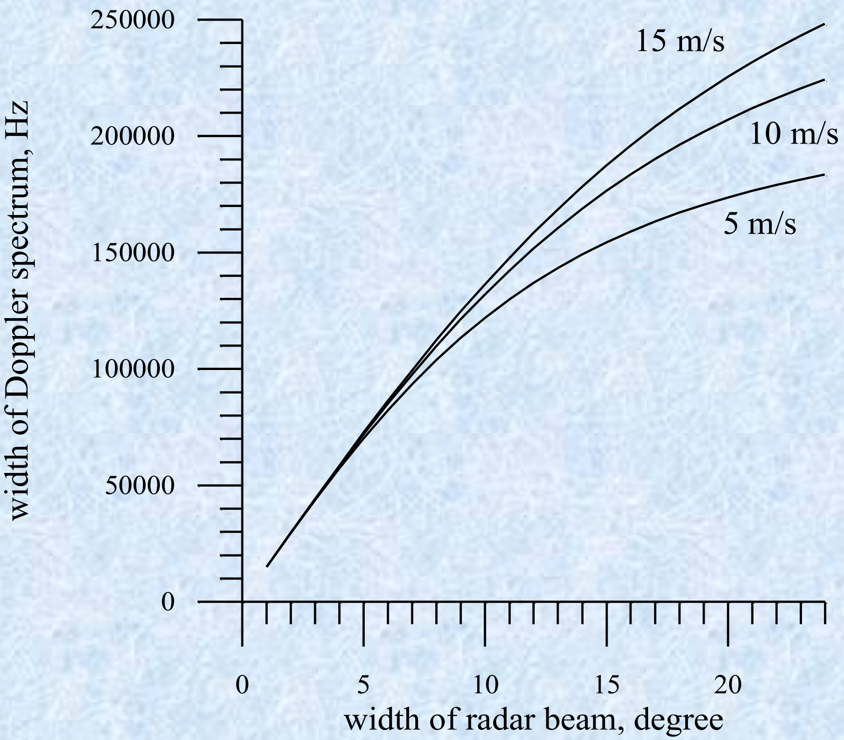

Fig. 2. Dependence of the width of the Doppler spectrum on the antenna beam width for three wind speeds (5m/s, 10m/s, 15m/s). Platform velocity is 7000m/s, direction of wave propagation is along *Y* axis.

1. Radar with a fan beam antenna

To calculate the ***mss***, we can use both the backscattering radar cross section and the Doppler spectrum width and therefore can compare operation of the algorithms [5, 6].

Backscattering radar cross section.
The ***mss*** of the scattering surface along the ***Y*** axis is found by the formula:

$$S_{yy}^2 = \frac{\delta_y^2 \sigma_{0y}^2 - \sigma_0^2 \delta_x^2}{5{,}52\left(\sigma_0^2 - \sigma_{0y}^2\right)} ,$$

where σ_{0y} is the backscattering radar cross section for a fan beam antenna pattern and σ_0 is the radar cross section for a narrow-beam.

Doppler spectrum width.
If the Doppler spectrum is used, the *mss* along the direction of flight is calculated by the formula:

$$S_{yy}^2 = \frac{\delta_x^2 \lambda^2 \Delta f_{10}^2}{32\delta_x^2 \ln 10 \cdot V^2 - 5{,}52\lambda^2 \Delta f_{10}^2}$$

2. Experiment at the International Space Station

A few concepts of space microwave radar for remote sensing of ocean were considered [7-9].

A radar with a scanning fan beam antenna has the advantages of nonrotating and rotating antennas. In this case we change the incidence angles.

Scanning enables to see each elementary scattering cell for the all time as in the case of a nonrotating antenna. Therefore, the synthetic procedure can be used for data processing.

Radar also has a wide swath as in the case of a rotating antenna. Hence we can analyze the sea surface image as in the case of scatterometer. JAXA used such approach in precipitation radars (TRMM and GPM missions).

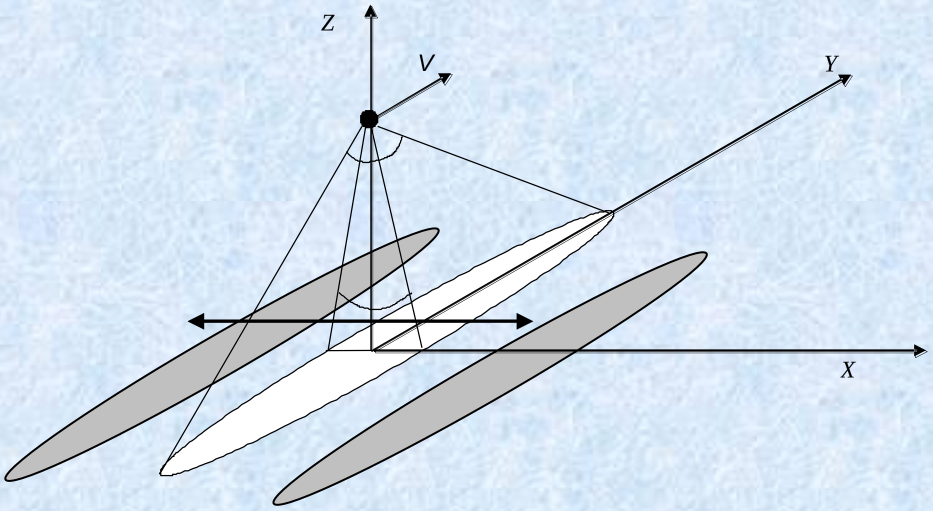

Fig. 4. Probing scheme. Scanning antenna.

2. Experiment at the International Space Station

Title of space experiment:

Measurement of the mean square slopes of large-scale waves, the significant wave height and the wind speed in the channel of near the nadir probing

The main purpose of the space experiment is to develop methods for remote sensing of the Earth to obtain new information about sea waves and determine the wind speed above the surface of the oceans in the channel of the near Nadir sensing.

The physical basis of the scientific tasks of this experiment is the dependence of the measured radar cross section and the waveform of the reflected pulse on the mean square slopes and the significant wave height.

To carry out the experiment, a radar (wavelength ~ 0.03 m) will be developed and fabricated with a fan beam (1ºx30º) based on the active phased array antenna.

Duration : 01.2018 - 02.2023

2. Experiment at the International Space Station

Table 1. Operating mode - ALTIMETER

Item	parameter	Description
Transmitted waveform	chirp modulation center frequency pulse width bandwidth pulse repetition frequency burst period number of pulses	Linear FM sweep 9.55 GHz 300 μs 300 MHz 910 Hz 5.5 ms 3

Table 2. Operating mode – DOPLER RADAR

Item	parameter	Description
Doppler radar	signal type pulse duration pulse repetition period	Unmodulated 2.6 ms 5.85 ms

2. Experiment at the International Space Station

Table 3. Antenna system

Item	parameter	Description
antenna	type	Active Phased Array Radar
	beam width	1.5° x 30.8°
	dimensions	1500 mm x320 mm x100mm
	scan angle	+/- 13°
	weight	35 kg
	swath (H = 400 km)	~ 180 km
	resolution	~ 11 km x 11 km

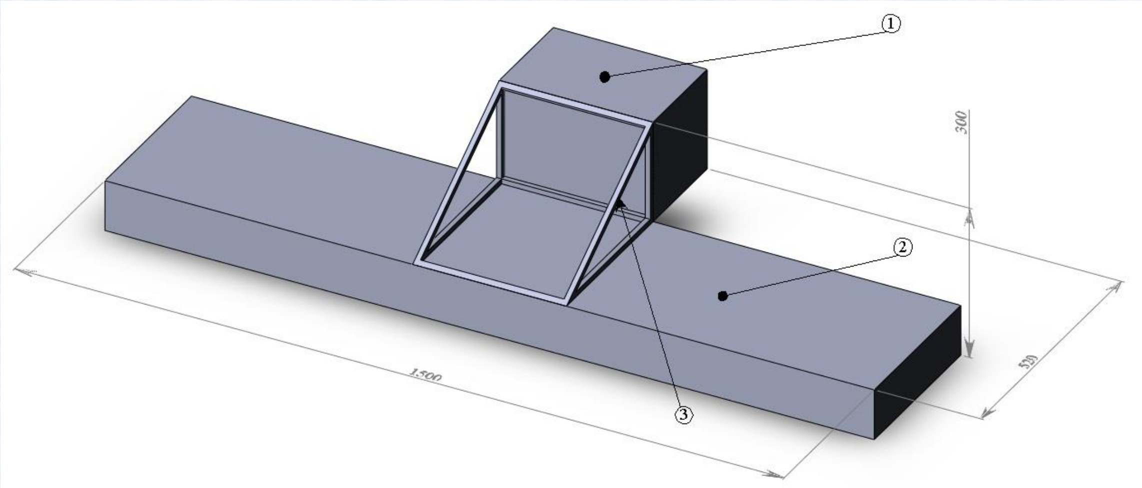

Fig. 5. General view of the equipment installed on the outer surface of the ISS

2. Experiment at the International Space Station

Microwave radar will be installed at the Russian segment of ISS.

It was planed that radar wavelength would be 2.1 cm. However, NASA has not given permission to use this wavelength, so the radar wavelength will be approximately 3 cm.

Table 4. Other parameters of radar

Item	parameter	Description
transmitter and receiver	frequency pulse power total weight total power	9.55 GHz 15 W 55 kg < 420 W

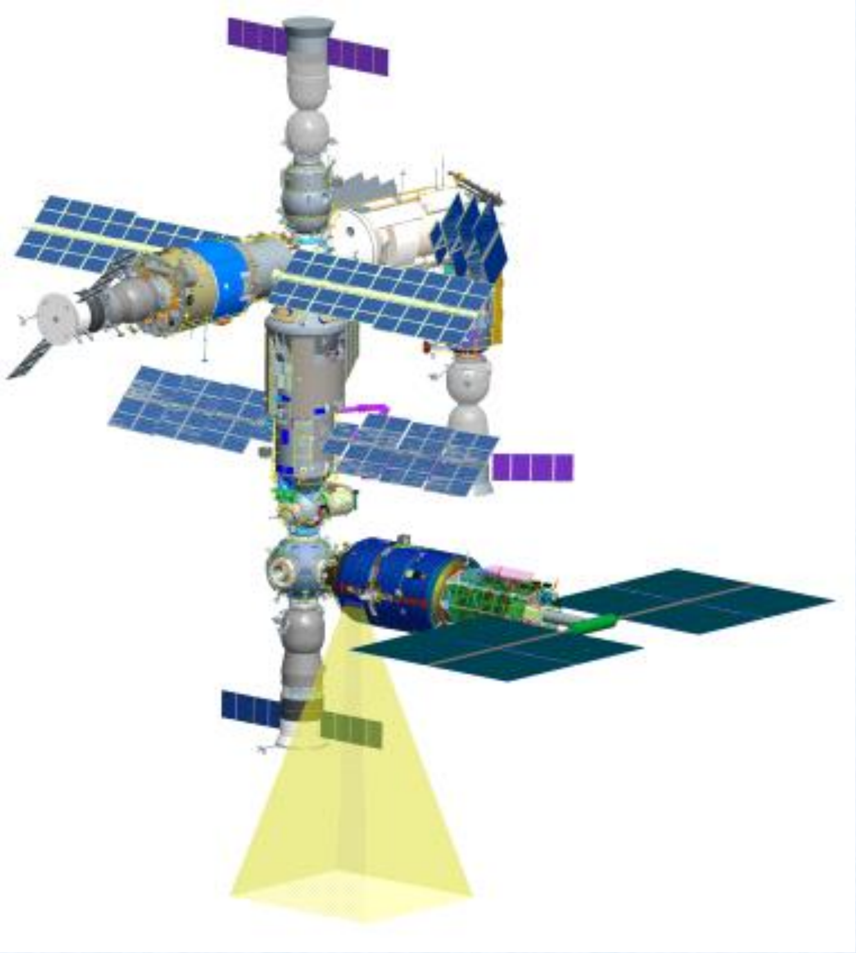

Fig. 6. Scheme of experiment at the international space station

3. Conclusions

Experiment is the next step in the development of the remote sensing of the sea surface and it permits to solve the following tasks.

1) Radar with fan beam will be installed at the Meteor-MP satellite.

2) The developed algorithms allow to measure the ***mss*** of sea surface along and across the track. In result a total ***mss*** of large-scale waves will be calculated.

3) Retrieval algorithm permits to retrieve the wind speed. The precision of the near-surface wind speed retrieval increases if information on the ***mss*** is taken into account.

4) The conventional altimeter algorithm can be used to retrieve the significant wave height H_S and to estimate the dominant surface wavelength

5) It is possible to monitor the ice cover over sea surface

6) It is possible to calculate the mean wavelength of sea waves $= H_S / mss$

As a result we will have radar image of the sea surface and three maps of the sea surface: wind speed map, mean square slopes of large-scale slopes map and significant wave height map.

References

[1] M.Kanevsky, V.Karaev, “Spectral characteristics of super high frequency (SHF) radar signal backscattered by the sea surface at small incidence angles”, Radiophysics and Quantum Electronics, 1996, v.39, N5, pp. 347-352

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

[3] V.Karaev, M.Kanevsky, D.Cotton, P.Challenor, “Is it possible to measure ocean surface slopes with a microwave radar?”, International Journal on Remote Sensing, 2002, v.23, N16, pp.3251-3262

[4] V.Karaev, M.Kanevsky, E.Meshkov, “The effect of sea surface slicks on the doppler spectrum width of a backscattered microwave signal”, Sensors, 2008, 8, pp. 3780-3801

[5] V.Yu.Karaev, M.B.Kanevsky, E.M.Meshkov, “Microwave radar probing of a rough water surface. Validation of retrieval algorithms using flight experiment data”, International Journal of Remote Sensing, 2010, v. 31, N 9, 2293-2308

[6] V.Karaev, “Measurements of significant wave height and slopes variance using radar with knife-like antenna beam: new opportunities, IGARSS'2012, Munich, Germany

[7] V.Karaev, M.Kanevsky, G.Balandina, P.Challenor, C.Gommenginger, M.Srokosz, “The concept of a microwave radar with asymmetric knife-like beam for the remote sensing of Ocean Waves”, J. Atmospheric and Oceanic Technology, 2005, N11, pp. 1809-1820

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

[9] V.Karaev, M.Kanevsky, E.Meshkov, A.Kovalenko, “The concept of the scanning radar with knife-like beam for remote sensing of the ocean at small incidence angles”, 4th Coastal altimetry workshop, 14-15 October 2010, Porto, Abstracts

2. Experiment at the International Space Station

Stages of works (titles of works)	the date of the beginning	end date	comment
1. conceptual design	15.01.2018	11.03.2019	15 months
1.1 Development of design concept documentation	15.01.2018	01.11.2018	in the work
1.2 Defense of a conceptual design	08.02.2019		
1.3 Breadboarding	15.01.2018	15.01.2019	in the work
2. Development of working design documentation for prototypes and models	12.03.2019	21.10.2019	9 months
3. Production of mock-up and prototype of radar, stand-alone tests and adjustment of working design documentation	22.10.2019	14.06.2021	19.5 months
4. Production of prototype of radar, complex and interdepartmental tests and adjustment of working documentation	15.06.2021	29.11.2021	5.5 months
5. Production of flight radar sample and flight tests	30.11.2021	23.01.2023	14 months