Retrieval of Gravity-Capillary Spectrum Parameters by Means of Microwave Radiometric Techniques

Alexey V. Kuzmin and Michael N. Pospelov

***Abstract*—The paper presents some results obtained during a series of microwave remote sensing experiments carried out on the Black Sea coast in 1999–2002. The measurements were made from a pier at the South Department of the Shirshov Institute of Oceanology with microwave radiometers operating at wavelengths of 1.5, 0.8, 0.5, and 0.3 cm. The surface wave spectrum parameters were estimated from angular radiometric measurements using a novel approach. Microwave brightness contrasts at Ka-band (37 GHz) measured over wide range of incidence angles were used for a curvature spectrum of gravity-capillary waves and a mean-square slope of gravity waves retrieval. The evolution of spectrum parameters under variable wind (ranged from 0.5–7 m/s) was investigated. The delay of brightness variation relative to wind speed as large as 1–2 h was found. The performed spectral analysis permitted to relate the observed brightness delay to short gravity-capillary surface waves, whereas longer gravity waves followed the wind practically without any delay. It is concluded that the proposed technique of gravity-capillary wave spectrum retrieval provides a useful tool for investigation of air–sea interaction and surface wave dynamics.**

***Index Terms*—Microwave radiometry, remote sensing, spectral analysis, surface waves.**

I. Introduction

THE DETERMINATION of wavenumber spectrum of gravity-capillary waves is one of the most challenging tasks in the ocean surface study. Short wind waves play a very important role in air–sea interaction, in particular, in heat, mass, and momentum transfer between ocean and atmosphere. They are also of great importance for remote sensing techniques, governing to a large extent sea surface emissivity and reflectivity at microwaves. However, experimental study of short waves ("ripples") parameters in open sea conditions encounters difficulties. Traditional wave gauges are inapplicable for gravity-capillary waves measurements, due to surface tension effects and disturbance introduced by a gauge itself. Although a series of experiments have been undertaken over the last 20 years to collect suitable measurements by optical and radar technologies, general knowledge in this field is far from satisfactory. The variance of different models and published experimental results is dramatically large for waves shorter than 10 cm, and the predicted spectral density can differ by one order of magnitude or more.

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The authors are with the Space Research Institute, Moscow, 117997 Russia (e-mail: Alexey.Kuzmin@asp.iki.rssi.ru).

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TABLE I
PARAMETERS OF MICROWAVE RADIOMETERS INSTALLED ON A ROTATING PLATFORM

Instruments	RP-15	RP-08	R-05	R-03
Wave length λ (cm)	1.5	0.8	0.5	0.3
Frequency f (GHz)	20.0	37.0	60.0	94.0
Polarizations	V, H, ±45	V, H, ±45	V	V, H
Frequency band Δf (MHz)	2000	1600	4000	4000
Sensitivity δT (K)	0.15	0.15	0.05	0.05

Currently, three different approaches are used for gravity-capillary wavenumber spectrum investigations. The first approach is based on the measurements taken by scanning laser slope sensors (e.g., [1] and [2]). The second one considers the sea surface radar backscatter with an adjustment of spectral parameters to provide the best fit with radar data (e.g., [3] and [4]). Our approach is based on microwave radiometric measurements. It has been demonstrated recently by *Trokhimovski* that radiometric measurements taken at different incidence angles and polarizations can be converted to the mean squared slope of long waves and the curvature spectrum in the gravity-capillary interval of short surface waves [5], [6]. The separation between long and short waves is more or less relative; in this particular study we regard the waves longer than 8 cm as long, and different approaches are used to compute the short and long wave contribution to microwave brightness. The method of gravity-capillary wave spectrum retrieval suggested by *Trokhimovski* is applied hereinafter to the analysis of data obtained during a series of remote sensing experiments conducted by the Space Research Institute team in 1999–2002.

II. Experiment Description

Microwave Remote Sensing Experiments were carried out on the Black Sea coast during summer months of 1999–2002. The experiments were performed at the South Department of the Shirshov Institute of Oceanology on the shore of Blue Bay near Gelendzhik, Russia.

All equipment was installed on a pier (200 m long) 3 m above the surface; the sea depth at the site was approximately 8 m. Remote sensing measurements were accompanied by concurrent measurements of meteorological and hydrological parameters. Wind speed and direction measurements were made by vane anemometer at a height of 7 m. Air and water temperatures were registered at a height of 3 m and at a depth of 1 m, respectively.

Microwave instruments (listed in Table I) were mounted on a rotating/scanning platform (Fig. 1), which permitted measurements at incidence angles from 10° to 170° off nadir over 300° range of azimuthal angles. The platform was mounted on a 6-m