Satellite Hydrophysics

Short-wave radiolocation in oceanography*

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Abstract — This paper reports on the application of coastal radar systems operating in the short-wave frequency band (wavelengths from 10 to 100 m), designed to determine the parameters of wind fields over the sea surface, as well as those of waves and currents. The regularities of radar signal generation by the sea surface and the propagation of short-frequency radiowaves are discussed. The possibility of employing radars in oceanography (including CODAR systems), using ionospheric and ground beams, is considered.

PREFACE

Our objective is to familiarize fellow oceanographers with the possibilities, problems, and prospects of utilizing short-wave frequency radars with the purpose of determining parameters of the rough sea surface and those of the wind field over it.

The survey is based on data compiled by various researchers from 1970 to 1991 and published in the proceedings of international conferences, workshops, symposia, etc., focusing on the problems of remote sensing (IGARSS’81–90) and oceanic investigations (OCEAN’71–90), as well as in the scientific journals IEEE Trans. Antennas and Propagations, IEEE J. Ocean. Eng., Science, Sea Technology, and Proc. IEEE.

Unfortunately, the restricted length of the paper does not allow us to cite a complete list of references. Hence, we have indicated only fundamental works, as well as papers containing an extensive bibliography.

INTRODUCTION

The dramatic progress in science has facilitated the development of a new direction in physical oceanography, called radio-oceanography [1]. The use of satellite-borne radiophysical equipment over the last 10–15 years [2] has caused a decline in interest in land-mounted radio-oceanographic facilities functioning in the diverse parts of electromagnetic wave spectrum. However, as demonstrated below, these represent a fine tool for conducting regional monitoring, particularly in coastal and dynamically-active ocean areas, as they seem to be more flexible and operationally efficient compared with satellites.

We will concentrate here on short-wave radar systems and consider not only the major trends in their use and the data acquired, but also the basic regularities in the propagation of short radiowaves in the near-earth space and their scattering by a rough sea surface.

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PROPAGATION AND SCATTERING OF SHORT RADIOWAVES

Radiowave propagation

According to the commonly adopted classification, we attribute to the category of short waves, radiowaves with lengths ranging from 10 to 100 m (with frequencies varying from 3 to 30 MHz). Waves from this wave range propagate in the near-earth space either close to the earth's surface (ground waves) or by virtue of the refraction and reflection from ionized atmospheric layers (ionospheric waves).

Ground radiowaves propagate as far as several hundred kilometres owing to diffraction, and are then absorbed by the underlying layers (propagation being restricted over the sea surface and extensive over land).

Ionospheric radiowaves propagate over great distances (in excess of 1000 km) owing to refraction and reflection in the ionosphere from areas having high electron concentrations and located at altitudes of 60-4000 km. The conditions of ionospheric radiowave propagation depend on the time of day and year, on solar activity, etc.

Radiowave scattering by the sea surface

Theoretical and experimental investigations [1, 3, 4] have shown that, with the sea surface being observed at small angles of slide, which is typical for ship-mounted and coastal radars, scattering proves to be selective. Of all the types of surface waves, radiowaves are known to scatter only those whose length is coupled with that of the surface-illuminating wave by the relation

\[
\Lambda_0 = n\lambda/2 \cos \psi, \quad (1)
\]

where \( n = 1, 2, 3, \ldots \) is the integer determining the mode of scattering and \( \psi \) is the slip angle measured from the horizontal surface.

The power of the radar signal being received, \( P_{\text{rec}} \), is proportional to the spectral density \( S(\chi_0) \) of the roughness resonance (1) components

\[
P_{\text{rec}} \sim S(\chi_0), \quad (2)
\]

where \( \chi_0 = 2\pi/\Lambda_0 \) is the wavenumber.

As the scattering waves (1) translate over the sea surface, the radar signal generated by them is shifted in frequency relative to the radiated signal by \( \Delta F \), defined as

\[
\Delta F = \sqrt{ng \cos \psi/\lambda\pi}, \quad (3)
\]

where \( g \) is the acceleration of gravity.

With the sea surface roughness being stabilized, the Doppler spectrum of the scattered signal proves to be rather time-stable, too. So, in experiments [1] conducted for a long time period (16 min), the Doppler shift frequency (3), equal to 0.135 Hz, varied by \( \pm 0.001 \) Hz at most.

Thus, the rough sea surface may be considered in the short-wave frequency band as a sort of a refraction lattice formed by sea waves 5-50 m long.

RADAR CHARACTERISTICS OF THE ROUGH SEA SURFACE

The properties of the sea surface as a source of secondary radiowave frequency radiation are termed in the radiolocation 'a specific effective scattering surface (area)', \( \sigma^0 \). According to theoretical data and data obtained experimentally through the use of an overhorizon-illuminating, low-resolution radar (about 37 km in range), with waves being