CONTRIBUTION OF STEEP IRREGULARITIES TO THE RADIO-BRIGHTNESS TEMPERATURE OF THE OCEAN

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We propose a new mechanism of a change in the brightness temperature of the ocean due to the contribution from steep mesoscale waves and estimate the contribution of such waves to the brightness temperature of the ocean. A steep wave is simulated by an inclined surface. The estimates show that variations in the radio-brightness temperature due to steep irregularities can reach several kelvins at low grazing angles. For short observation distances and low grazing angles, the brightness temperature has bursts similar to those observed in the case of backscattering. These bursts occur when breaking waves hit the observation area.

1. INTRODUCTION

Recent studies have indicated the important role played by sharpened breaking waves in the backscattering of radio waves of the X range [1-4]. In this paper, we show that breaking mesoscale waves can also make a pronounced contribution to the radio-brightness temperature of the ocean. This new phenomenon is described by a simple model of steep irregularities in the form of an inclined surface.

At present, we know of two mechanisms of the formation of radiothermal emission of the ocean. The first, nonresonance, mechanism is related to the influence of the slopes of large-scale waves on the absorption properties of the surface [5-8]. This mechanism allows us to explain the difference $\Delta T_B$ between the brightness temperature of the ocean and that of the plane surface, which is of the order of several kelvins. However, the explanation of the observed anisotropy of thermal emission by the nonresonance mechanism is far from being sufficient. It turns out that the azimuthal dependence of the microwave emission of the ocean is due not only to the variation of slopes of the large-scale component of waves (nonresonance mechanism) but also (and rather) due to the resonance phenomena that appear in the case of a certain relationship between the wavelength $\lambda$ of electromagnetic radiation and the capillary-gravity wavelength $\Lambda$. Such resonance phenomena, which were theoretically predicted in [9] and experimentally observed in [10], are called the "critical phenomena." The resonance phenomena are related to the existence of thermal surface electromagnetic waves propagating along the water-air interface. Such waves are not observed on the plane water surface. However, in the presence of small-scale capillary-gravity perturbations with wavelengths of 0.5 to 5.0 cm, the centimeter surface electromagnetic waves can be transformed to volume propagating modes due to diffraction from the surface grating formed by small-scale waves.

No one of the above-mentioned mechanisms is known to describe the phenomena related to the presence of mesoscale (with a height from 10 to 20 cm) steep sharpened waves on the sea surface. Such waves give rise to two new phenomena. First, the steep waves bring about additional absorption of electromagnetic radiation scattered by the sharpened edge of the wave during the secondary reflection of radiation from the water surface (Fig. 1a). We imply the scattering of auxiliary waves used for calculating the absorption...
Fig. 1. Mechanisms of additional absorption related to the steep sharpened waves: (a) the absorption of the edge waves formed on the edge of the sharpened wave and (b) an increase in absorption due to double reflection of rays. 1 and 2 are the rays subjected to double reflection.

in accordance with the Kirchhoff law by which the intensity of emission of a surface is proportional to its absorption coefficient. Second, the steep waves make the double reflection of an incident auxiliary wave possible (Fig. 1b), which leads to an increase in absorption and, consequently, in the brightness temperature.

Let us estimate the contribution of the two phenomena. The edge scattered wave is formed near the peak of a sea wave in the region whose dimension is comparable with the wavelength $\lambda$ of electromagnetic radiation. The region in which the double reflection occurs has dimension of the order of the height $h$ of a breaking wave. For our case of radio waves in the $X$ range ($\lambda \sim 3$ cm) and steep waves with a height of the order of 10 cm [1-4], this means that the ratio of the contribution from the edge wave and that from the double reflection, estimated as $\lambda/h$, is small. Therefore, our consideration is confined to the phenomenon of double reflection.

Let us emphasize that the influence of multiple reflections on the brightness temperature of the ocean emission was already estimated in [11], where it was shown that their contribution is small for the sea surface. However, in [11] the wave spectrum was assumed to be Gaussian, which does not hold in the presence of breaks. Neither the wave spectrum, which would allow for the wave breaking, nor its dependence on the state of the surface and the internal waves are known to us. Therefore, to allow for steep irregularities, it seems more expedient to use an approach based on the calculation of emission from individual breaking waves and on the subsequent averaging instead of the method based on the complete knowledge of the wave spectrum.

2. ESTIMATES OF THE BRIGHTNESS TEMPERATURE OF THERMAL EMISSION IN THE MODEL OF A STEEP WAVE IN THE FORM OF AN INCLINED PLANE SURFACE

In accordance with the Kirchhoff law, the brightness temperature of equilibrium thermal emission of the sea surface is determined as

$$T_B = AT,$$

where $A$ is the absorption coefficient of the surface for the given polarization and $T$ is the physical temperature of the ocean. We are interested in the brightness-temperature variation due to the presence of a steep irregularity,

$$\Delta T_B = T_B - T_B^0,$$

where $T_B^0$ is the brightness temperature of a perfectly plane surface for the given polarization, rather than in the brightness temperature itself.

The absorption coefficient is determined as a ratio of the absorbed and incident energies.