ESTIMATE OF "OIL FILM – UNPOLLUTED SEA SURFACE" CONTRASTS FROM LIDAR SENSING AT 10.6 μm WAVELENGTH

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"Oil film – unpolluted sea surface" contrasts in laser pulsed sensing within the middle IR range at 10.6 μm *are studied in a wide region of wind velocities over the sea surface, including high velocities of the wind at which a foam on the sea surface is produced. The equation for the above lidar contrast is derived for the monostatic sensing scheme. It is shown that the contrast at a wavelength of* 10.6 μm *not only exceeds that at* 1.06 μm, *but also depends differently on the wind velocity.*

An urgent problem of ecological monitoring is the monitoring of water areas aimed at detection of oil films on the sea surface. It is one of the "hottest" problems for shelf zones of Russia, which are especially prone to pollution with oil and oil products.[1]

An "oil film – unpolluted sea water" contrast was studied in Ref. 2 for the case of pulse laser sensing of the sea surface in the near infrared at 1.06 μm. In Refs. 3–5 this contrast was considered under continuous irradiation at 10.6 μm and at low wind velocities. In this paper the contrast is examined for the case of pulsed sensing in the middle infrared at 10.6 μm. The wind velocity is considered varying in a wide range, including strong wind producing foam on the sea surface.

The wavelength of 10.6 μm is rather promising for obtaining the maximum "oil film – unpolluted sea surface" contrast from the viewpoint of spectral behavior of the oil and water reflection coefficients. The "oil–water" spectral dependence was calculated in Refs. 3 and 4 for the water surface coated with a thick oil film. The water surface was assumed undisturbed by sea roughness. An analysis of this dependence shows that the "oil–water" contrast is maximum just in the wavelength range from 8 to 12 μm.

Let us estimate the value of the "oil film – unpolluted sea surface" contrast in the case of pulsed sensing as follows:

$$K = P_{\rm oil}/P_{\rm max},$$

where K is the contrast; $P_{\rm max}$ is the power of a maximum recorded return backscattered from unpolluted sea surface; and $P_{\rm oil}$ is that for the sea surface coated with the oil film.

Using the expression for mean power of the return recorded by a lidar receiver at exposure of the sea surface to pulsed irradiation[6] we can derive the following equation for the contrast K at slant monostatic sensing of the sea surface:

$$K = (V_2^2 \exp(-0.5\, q_x^2 \,/\,(q_z^2\, \gamma_{2x}^2))/(8\pi(\gamma_{2x}^2\, \gamma_{2y}^2)^{1/2}) \times$$
$$\times \{(1 - S_{\rm f})\, V_1^2 \exp(-0.5\, q_x^2/(q_z^2 \gamma_{1x}^2))/(8\pi(\gamma_{1x}^2 \gamma_{1y}^2)^{1/2}) +$$
$$+ S_{\rm f}\, A_1 \cos^2\theta/\pi\}^{-1} \times$$
$$\times \left[\frac{\tau^2 c^2/16 + 2\sigma_1^2 + \sin^2\theta/(q_{\rm s} + C_{\rm r})}{\tau^2 c^2/16 + 2\sigma_2^2 + \sin^2\theta/(q_{\rm s} + C_{\rm r})}\right]^{1/2}. \qquad (1)$$

Here $q_x = 2\sin\theta$; $q_z = 2\cos\theta$; σ^2 and $\gamma_{x,y}^2$ are variances of heights and tilts of the rough sea surface; V^2 is the Fresnel coefficient for the plane sea surface at vertical sensing; τ is the duration of a sensing pulse; $S_{\rm f}$ is the foamed part of the sea surface; θ is the sensing angle (between the direction of the lidar optical axis and the nadir direction); A is the albedo of an elementary area of the foamed sea surface; $C_{\rm s,r} = (\alpha_{\rm s,r}\, L)^{-2}$ (for the transparent aerosol atmosphere); $2\alpha_{\rm s,r}$ is the source divergence angle and the receiver field-of-view angle; L is the distance between the lidar and the sea surface.

The subscript 1 in the V, A, γ, and σ parameters corresponds to the unpolluted sea surface, while the subscript 2 corresponds to the sea surface coated with oil film.

When deriving Eq. (1), we assumed that $\theta \ll 1$ and $\alpha_{\rm s,r}^2 \ll \gamma_{x,y}^2,\ \theta^2$.

Equation (1) is a generalized expression for the contrast derived in Ref. 2. It does not require the condition $\theta \ll (\tau\, c/4)\,(q_{\rm s} + C_{\rm r})^{1/2}$ to be fulfilled, while the results of Ref. 2 are valid only under this condition.

Figures 1 and 2 show the angular dependence of the contrast K for the case of sensing at the wavelength of 10.6 μm with different velocity of the surface wind U. The calculations were made by Eq. (1) at the following values of the parameters: $\tau = 10^{-12}$ s (see Fig. 1); $\tau = 10^{-8}$ s (see Fig. 2); $\alpha_{\rm s} = 1$ mrad; $\alpha_{\rm r} = 2$ mrad; $L = 3$ km; $U = 2$ m/s (curve *1*), 6 (curve *2*), 10 (curve *3*), 14 (curve *4*), and 18 m/s (curve *5*).

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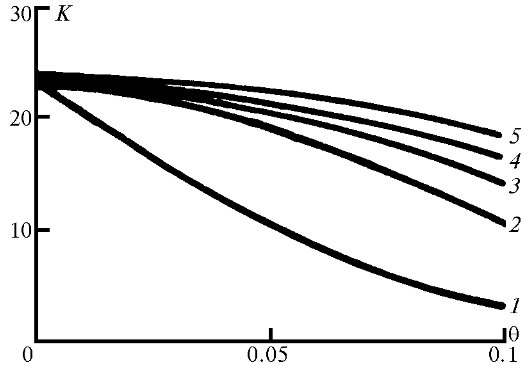

FIG. 1. Angular dependence of the contrast K. $\tau = 10^{-12}$ s.

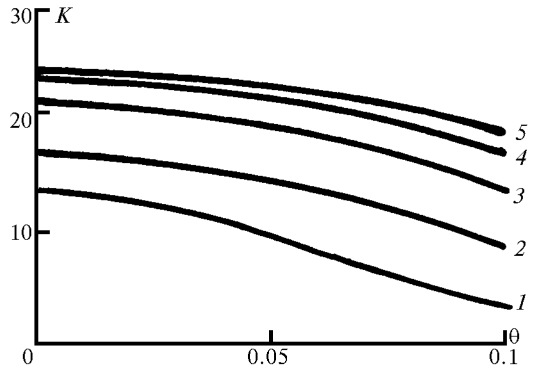

FIG. 2. Angular dependence of the contrast K. $\tau = 10^{-8}$ s.

In our calculations we took into account that the oil film smoothed out sea roughness and had a different reflection coefficient. As in Ref. 3, we assumed (based on the Cox and Munk results[7]) that for the sea surface coated with oil films the wave tilts remained normally distributed, but their variance was three times smaller. The variance σ^2 of the wave heights was also assumed three times smaller than that for the unpolluted sea surface. For sensing at the wavelength of 10.6 μm $V_1^2 \cong 0.009$, $V_2^2 \cong 0.04$ (Ref. 3).

The values of γ_{1x}^2 and γ_{1y}^2 were calculated using the Cox and Munk expressions[7]:

$$\gamma_{1x}^2 = 0.003 + 1.92{\cdot}10^{-3}\,U; \quad \gamma_{1y}^2 = 3.16{\cdot}10^{-3}\,U.$$

To estimate the σ_1^2 and S_f parameters, the following expressions were used[8,9]:

$$\sigma_1 = 0.016\,U^2;$$

$$S_f = 0.009\,U^3 - 0.3296\,U^2 + 4.549\,U - 21.33,$$

where U is the velocity of the surface wind, in m/s.

The reflection coefficient of the sea surface at 10.6 μm was assumed independent of whether the sea surface was coated with foam or not (on evidence from Ref. 10, the foam on the sea surface has practically no effect on the thermal radiation from the sea surface in the 8–13 μm window).

Analysis of the figures allows the following conclusions to be made:

1. The contrast K at the wavelength of 10.6 μm is higher than that at 1.06 μm. Besides, it depends differently on the velocity of the surface wind.

2. At strong wind, when the sea surface is coated with foam, the contrast at 10.6 μm increases as opposed to sensing at 1.06 μm (in the latter case the contrast drastically decreases, when the velocity of the surface wind increases).

3. As for the wavelength of 1.06 μm, the contrast K at 10.6 μm depends on duration of the sensing pulse. An increase in the velocity of the surface wind results in significantly weaker dependence of the contrast on the sensing angle.

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