Detection of oil spills on rough sea surface using a three-beam laser method

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A method for detection of oil spills based on sea surface sensing by three laser beams: vertically downward, at an angle along a line of movement, and at an angle across a line of movement, is considered. It is shown that the three-beam laser method allows independent monitoring of two effects: smoothing of wind roughness of the sea surface and variation of the reflection coefficient and, therefore, detection of oil spills with high reliability.

Detection of oil spills by the method of laser sensing is usually conducted in the IR spectral region by measuring the intensity of radiation reflected from the water surface and determining the contrast between the clear water surface and an oil spill (see, for example, Refs. 1–3). The contrast is caused by two factors: oil has different reflection coefficient and it smoothes roughness of the sea surface.[4–6]

Lidar can avoid absolute measurements when detecting oil spills. In the case of airborne installation, lidar measures the return signal from water, for example, at the very beginning of measurements. When the laser beam is incident on an oil spill, the signal recorded by the lidar increases sharply and, consequently, the contrast arises between the signals coming from the areas analyzed and those coming from clear water.

For reliable detection of oil films, the contrast should be higher than some threshold value K_r (in Ref. 1 it was assumed that reliable detection of oil spills in a wide range of hydrological and meteorological conditions is possible at $K_\mathrm{r} \geq 1.5$).

The lidar method allows reliable detection of oil spills, but it has a disadvantage – sometimes clear areas are identified as oil spills; an area with the high intensity of reflected radiation may be an area with smoothed wind roughness (slick on the sea surface or wind shadow of an island) or an area with high reflection coefficient (reflection coefficient can vary not only because of oil pollution). Therefore, monitoring of only the intensity of reflected radiation (parameter accounting for both of the effects) cannot provide for high reliability of oil spill detection.

Figure 1 shows the dependence of the contrast $K = P_\mathrm{oil}/P_\mathrm{w}$ on the velocity of the surface wind U ($P_\mathrm{oil,w}$ are the powers of the received signals from the analyzed area and the clean sea surface). Curve *1* corresponds to the "oil – clear sea surface" contrast, curve *2* is for the "slick (surface area with smoothed wind roughness) – clear sea surface" contrast, and curve *3* is for the threshold value $K_\mathrm{r} = 1.5$. In our calculations, we used the equations from Ref. 3 for nadir sensing with the following parameters: the wavelength of sounding radiation was 1.06 μm, the water and oil reflection coefficients were taken to be 0.02 and 0.04, lidar height of 1 km, source divergence of 2 mrad, and receiver's field of view of 3 mrad. It was assumed that the variance of surface slopes decreases three times for oil films,[5,6] and for an oil slick it decreases by 10 times. It can be seen that the contrast is high for both the oil spill and the slick areas.

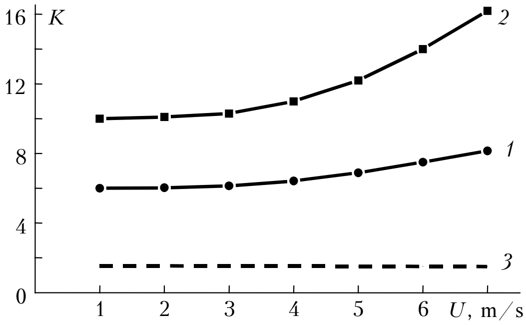

Fig. 1. Contrast as a function of the surface wind velocity U.

To improve the reliability of oil spill detection, we should simultaneously monitor two effects: smoothing of wind roughness and variation of the sea surface reflection coefficient.

This can be achieved by using the sensing scheme with three narrow laser beams directed vertically downward, at an angle θ along the flight line, and at an angle θ across the flight line. The measured parameters are the powers P_0, P_x, P_y of the return signals recorded at reflection of each of these beams from the sea surface (P_0 is for the vertically downward beam; P_x is for the beam directed at an angle along the flight line; P_y is for the beam directed at an angle across the flight line). They are used for calculating the ratios $P_{x,y}/P_0$ connected with the variances of the sea surface slopes[3,7]:

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$$P_{x,y}/P_0 \cong \exp\{-0.5\, q_{x,y}^2/(q_z^2\, \gamma_{x,y}^2)\}, \qquad (1)$$

where $q_z = 2\cos\theta$, $q_{x,y} = 2\sin\theta$; $\gamma_{x,y}^2$ are the variances of sea surface slopes in the planes XOZ and YOZ.

Equations (1) are used for calculation of the variances $\gamma_{x,y}^2$ and then the parameters M and N:

$$M = (\gamma_x^2\, \gamma_y^2)^{1/2};\ N = P_0 M \cong V^2 A/(8\pi), \qquad (2)$$

where A is some factor.

If the duration of the sensing pulse τ is chosen so that $\tau^2 c^2/16 \gg 2\sigma^2$ (σ^2 is the variance of heights above the sea surface), then A is independent of the sea surface characteristics.

Thus, the parameter M bears information only on the variances γ_x^2, γ_y^2, while the parameter N contains the information only on the reflection coefficient of the sea surface area analyzed.

To make a decision on whether an oil spill is observed or not, the contrasts K_M and K_N of the parameters M and N between the analyzed area and the clean sea surface are calculated as

$$K_M = M_{\text{oil}}/M_{\text{w}},\ \ K_N = N_{\text{oil}}/N_{\text{w}}, \qquad (3)$$

where M_{oil}, M_{w} and N_{oil}, N_{w} are the values of M and N for the analyzed and the clean surface areas.

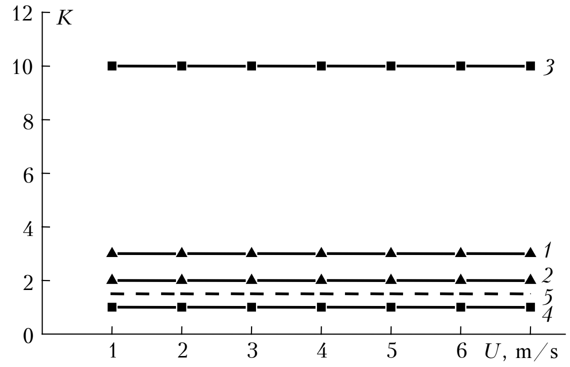

Fig. 2. Contrasts K_M and K_N as functions of the surface wind velocity U.

Figure 2 shows the dependence of the contrasts K_M (*1*, *3*) and K_N (*2*, *4*) on the surface wind velocity U. Curves *1* and *2* correspond to the "oil – clean sea surface" contrasts, curves *3* and *4* correspond to the "slick – clean sea surface" contrasts, and curve *5* corresponds to the threshold value $K_{\text{r}} = 1.5$. The calculations were performed by Eq. (3) at $\theta = 0.05$ rad. All other parameters are the same as in Fig. 1.

It is seen from Fig. 2 that the simultaneous use of the conditions $K_M > K_{\text{r}}$ and $K_N > K_{\text{r}}$ provides for high reliability in detection of the oil spills on the sea surface.

Thus, the lidar method of oil spill detection based on the specialized three-beam geometry of laser beams allows independent monitoring of the two effects: smoothing of wind roughness and variation of the reflection coefficients of the sea surface and, thus, provides for high reliability of oil spill detection. Precision fixation of sensing angles about the normal is a limitation of this method and requires special measures (for example, installation of the laser source on a gyrostabilized platform).

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