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NUMERICAL MODEL FOR INVESTIGATION OF CHARACTERISTICS OF HIGH-INTENSITY LIGHT ENERGY REFLECTED FROM WAVY SURFACE

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ЧИСЛЕННАЯ МОДЕЛЬ ДЛЯ ИССЛЕДОВАНИЯ ХАРАКТЕРИСТИК ВЫСОКОИНТЕНСИВНОЙ ЛУЧИСТОЙ ЭНЕРГИИ, ОТРАЖЁННОЙ ОТ ВОЛНОВОЙ ПОВЕРХНОСТИ

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Аннотация. *Для численного исследования эффекта аномального обратного рассеяния предложена оптическая модель среды, состоящая из плоских частиц. Представлены результаты численного исследования, иллюстрирующие ярко выраженную спектральную зависимость эхо-сигнала от оптических и микрофизических параметров среды. Показана возможность оценки оптических и микрофизических свойств среды по данным аномального обратного рассеяния. Комплекс программ, реализующий оптическую модель среды для расчета характеристик коэффициента обратного рассеяния для плоских и сферических частиц был разработан на кроссплатформенной среде Qt* .

During the observation of atmospheric crystal formations and water surface, a bright reflected light can often be noticed. A number of optical effects occurring in nature, such as sunlight columns, false sun, hotspots or bright flares at water surface, can be explained by the interaction of sunlight (or moonlight) with the flat surface of water or crystals [1-3]. The high-amplitude lidar returns research is prosperous due to the fact that reflective property is primarily found in oriented particles with flat faces as well as unperturbed water surface. Additionally, during the remote laser sensing a high-amplitude signal can occur due to reflection from water surface which has large radius of curvature. Defining the parameters of medium component that provide an anomalous backscattering can be used as a tracer to evaluate the physical properties of the test object.

To calculate the anomalous backscattering coefficient we are using the following equation [2]:

$$\beta_\pi = \int_a S_\pi(a) \cdot N(a)\, da \ , \qquad (1)$$

where β_π – backscattering coefficient, S_π– backscattering cross section for a particle, N(*a*) – function of the particle size distribution. Using the method physical optics while considering the incident light polarization, the derived equation can be used to calculate the backscattering cross section [4]:

$$S_\pi = W \cdot (M_{11} + \frac{I_2}{I_1} M_{12} + \frac{I_3}{I_1} M_{13} + \frac{I_4}{I_1} M_{14}), \qquad (2)$$

where I_i (*i*=1, 2, 3, 4) – Stokes vector parameters for incident light, M_{ij} – Mueller matrix elements. The W multiplier is determined by wavenumber and angle function that is Fraunhofer diffraction equation.

As a separate scatterer, let's take a round plate with *a* radius and *d* thickness. The particle has a complex refraction index $\tilde{n} = n + i \cdot \chi$ (*n*− refraction index, χ− absorption index). Since the particle distribution can be adequately described by a modified gamma-function [2], we will use the following equation:

$$N(a) = C \cdot \frac{\mu^{\mu+1}}{G(\mu+1)} \cdot \frac{1}{a_m} \cdot \left(\frac{a}{a_m}\right)^{\mu} \cdot exp\left(\frac{-\mu \cdot a}{a_m}\right). \quad (3)$$

Formula (3) includes the following parameters: C– plate concentration, a_m – plate radius corresponding to the N(*a*) maximum, μ− dimensionless parameter, characterizing the steepness of the function maximum, G (μ+1) – gamma-function. Additionally, the dependency between plate radius *a* and its thickness *d* is taken in account as following: $d=2.020\cdot(2\cdot a)^{0.449}$ [2].

With the normal (orthogonal) plate crystal position relative to ray direction, we can simplify (1) as following:

$$\beta_\pi(\vartheta = 180°) = \left|(\tilde{n}-1)/(\tilde{n}+1)\right|^2 k^2 \pi \int_a N(a)\, a^4 da \ , \quad (4)$$

where ϑ is diffusion angle, *k*− wavenumber (*k*=2π/λ, λ− wavelength of incident radiation).

We have done a numerical research of anomalous backscattering coefficient for the light reflected from the system of plate crystals using (4). For the calculations, the following input parameters were used: wavelength (λ), particle geometrical dimensions (*a*, *d*), complex diffraction index values (*n*, χ), parameters for particle size distribution (C, μ, $\bar{a}$), considering (3), $\bar{a} = a_m(1+1/\mu)$.

The fig. 1*a* displays the calculation results for anomalous backscattering coefficient depending on incident radiation wavelength at the different values of refraction index. It is clear that material optical properties have significant influence on the reflected light intensity. Changing the real part of refraction index by a fraction of a unit leads to increase in β_π by an order of magnitude.

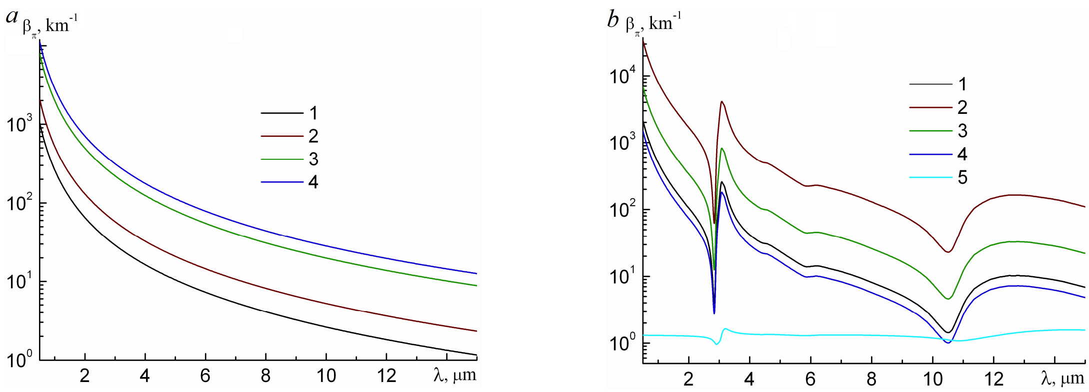

Fig. 1. (a) Dependence $\beta_\pi(\lambda)$ for different n: n=1.21 (curve 1); n=1.31 (curve 2); n=1.71 (curve 3); n=1.91 (curve 4); $\bar{a}$ =100 μm, C=1 l^{-1}, μ=5, $\chi=10^{-4}$. (b) Dependence $\beta_\pi(\lambda)$ for different $\bar{a}$ and μ: $\bar{a}$ =100 μm, μ=5 (curve 1); $\bar{a}$ =200 μm, μ=5 (curve 2); $\bar{a}$ =100 μm, μ=1 (curve 3); $\bar{a}$ =100 μm, μ=10 (curve 4); C=1l^{-1}, $\tilde{n} = \tilde{n}(\lambda)$ [5]; n=n(λ) for ice (curve 5).

Figure 1*b* displays spectral dependence of $\beta_\pi(\lambda)$ at $\tilde{n} = \tilde{n}(\lambda)$ for ice [5] with different parameters $\bar{a}$ and μ. The curve 5 at fig. 1*b* shows the relation between real part of complex refraction index of pure ice and wavelength. At fig. 2 it is shown that $\beta_\pi(\lambda)$ curves have features similar to *n*(λ). Moreover, such features are most pronounced for $\beta_\pi(\lambda)$. Particle size distribution parameters have a significant influence on the β_π. Clearly, an increase in the dimensional parameter ($\bar{a}$/λ) leads to increase in the reflected light amplitude. Despite the unified change tendencies of $\beta_\pi(\lambda)$ change with the varying distribution parameters ($\bar{a}$, C, μ), they have different influence during the data analysis with fixed wavelength.

An uncertainty during the anomalous backscattering evaluation can be eliminated by taking a priori information in account as well as considering the normalized characteristics. It should be noted that researching the reflected light properties while considering a possibility of small-angle scanning and using bistatic sensing scheme can allow to receive informative data for a high-probability calculation of optical, microphysical and dynamic environment properties despite having an unstable and wavy surface. Our general research direction is related to development of ways to use optical methods to determine the physical parameters of the medium. Currently, the following task becomes relevant for the ranged surveillance of water surface layer and atmosphere crystal formations to find solutions for ecological problems, to study the light transfer through layered media containing primarily oriented plate particles.

As a part of this work, a software complex was designed to employ the optical environment model. The project was creating using the C++ programming language and Qt cross-platform framework, which allows easy compilation for any of the modern operation systems or mobile platforms. The software displayed at fig. 2 and fig. 3 utilizes the functions necessary for calculation of anomalous backscattering coefficient for sphere and plate

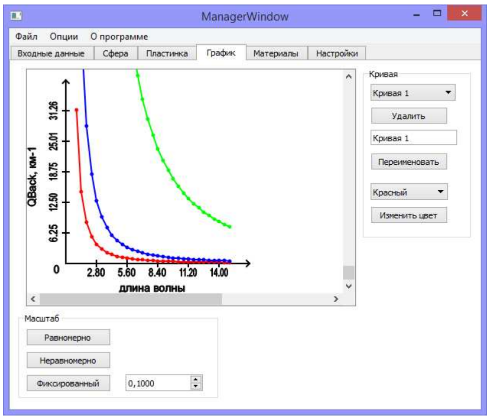

Fig. 2. Application graph window

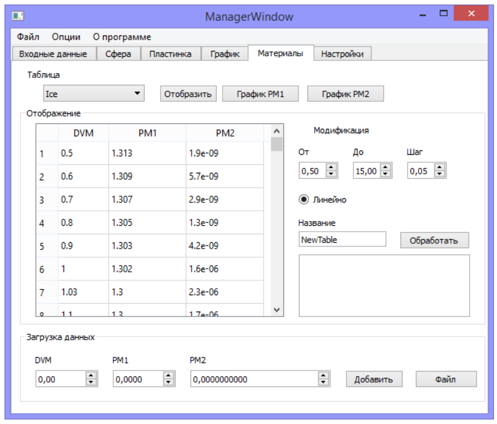

Fig. 3. Application database window

particles using a wide array of input data. Additionally, the program uses a database with tables that contain refraction index spectral dependency on the wavelength of incident radiation for a specific material (in particular, for ice, gypsum, and oil).

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