EPJ Web Conferences **237**, 08004 (2020) https://doi.org/10.1051/epjconf/202023708004
ILRC 29

ALGORITHM FOR SOLVING THE LIGHT SCATTERING PROBLEM FOR ARBITRARY SHAPED ICE PARTICLES WITH ABSORPTION

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ABSTRACT

The work presents the estimation of the absorption influence effect on the light scattering problem for atmospheric ice particles. The calculation of light scattering matrices was performed for two types of particles: the solid hexagonal columns and the arbitrary shaped particles. The range of the size for both types of particles varies from 10 µm to 1000 µm. The results of the research show an insignificant decrease of the value of the M11 element of the light scattering matrix for small-sized particles for all chosen wavelengths (0.355 µm, 0.532 µm, 1.064 µm и 1.6 µm), and a significant decrease for big-sized particles for a 1.6 µm wavelength.

1. INTRODUCTION

The light scattering problem of ice crystal particles in cirrus clouds is crucial for investigation of the solar energy transfer process. Cirrus clouds are an essential part of all clouds that covers Earth's surface because of this the recovering of their optical and microphysical properties is required to refine global climate models [1].

Cirrus clouds consist of ice crystals particles with various shape and size. For solving the light scattering problem for ice particles it is difficult to apply exact numerical methods such as the finite difference time domain method (FTDT) [2, 3] or the discrete dipole approximation method (DDA) [4, 5] due to their high requirements for computational resources for big-sized particles [6]. For this reason the problem is often solved with the geometrical and the physical optics approximation [7].

During the numerical calculation of light scattering matrices for ice particles it is important to take the specific factors that could influence on scattering into account. One of these factors is the absorption of light in ice particles.

The one of the important properties of an absorptive medium is refractive index that is complex and consists of two parts:

$$n = N_r + N_i \quad (1)$$

, where N_r is the real part and N_i is the imaginary part. When electromagnetic wave propagates in absorptive medium the amplitude of the electromagnetic field decreases. This decrease is defined by following factor:

$$\exp\left(-\frac{2\pi N_i}{\lambda}\cdot l\right) \quad (2)$$

, where λ is the wavelength, and l is the distance that optical wave passed in absorptive medium [8]. When the value of the wavelength is deep in the near infrared (IR) zone of the spectrum the value of the imaginary part of the effective refractive index increases, therefore the influence of the absorption should decrease [9].

For taking the absorption into account the new version of the modified beam-splitting (MBS-1) algorithm [10] was developed. It calculates light scattering matrices within geometrical and physical optics approximation for particles with flat facets. In addition, there is the feature that allows defining an arbitrary shaped particle in the new version of the algorithm.

2. ESTIMATION OF ABSORPTION

For estimation of the absorption influence to the light scattering process on ice particles with different shapes it was performed the calculation of light scattering matrices for the particles with two shapes: solid hexagonal column and arbitrary shaped particle (Figure 1). The calculation was performed with following parameters: random spatial orientation of particle, three different wavelengths with corresponded complex refractive indices (Table 1), and the maximal dimension of the particle varies from 10 µm to 1000 µm. The aspect ratio of hexagonal column is corresponded to D. Mitchel dependency [11]. The size of the arbitrary formed particle varies proportionally. As the maximal dimension it means the distance between two the most distant vertices of the particle.

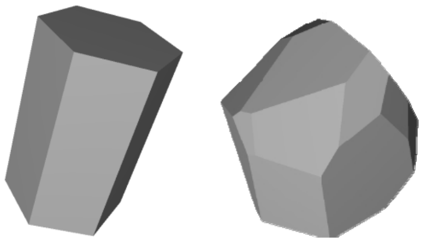

Figure 1 Particles for the calculation: the solid hexagonal column (left) and the arbitrary formed particle (right).

Table 1 Refractive indices (n) for chosen wavelengths (λ)

λ, μm	*n*
0.355	$1.3243 + i3.6595 \cdot 10^{-9}$
0.532	$1.3116 + i2.6180 \cdot 10^{-9}$
1.064	$1.3004 + i1.9000 \cdot 10^{-6}$
1.600	$1.2893 + i3.5365 \cdot 10^{-4}$

It is convenient to define the estimation quantity of the absorption influence in the backscattering direction as χ and for the whole diagram as ψ:

$$\chi = \frac{M_{11}(180°) - \bar{M}_{11}(180°)}{M_{11}(180°)} \cdot 100\% \tag{3}$$

$$\psi = \frac{\int_0^\pi \bar{M}_{11}(\theta) sin(\theta) d\theta}{\int_0^\pi M_{11}(\theta) sin(\theta) d\theta} \tag{4}$$

, where M_{11} is the intensity of the scattering light without absorption, $\bar{M}_{11}$ is the same quantity with absorption.

3. CALCULATION

For laser sounding problems only backscattering point (180°) is interesting, but the whole scattering diagram is important for radiation transfer problems. The dependency of the maximal dimension of the particle (D_{max}) on χ in the backscattering direction for the solid hexagonal column and the arbitrary formed particle is presented in Figure 2 and the dependency of D_{max} on ψ is in Figire 3a and 3b.

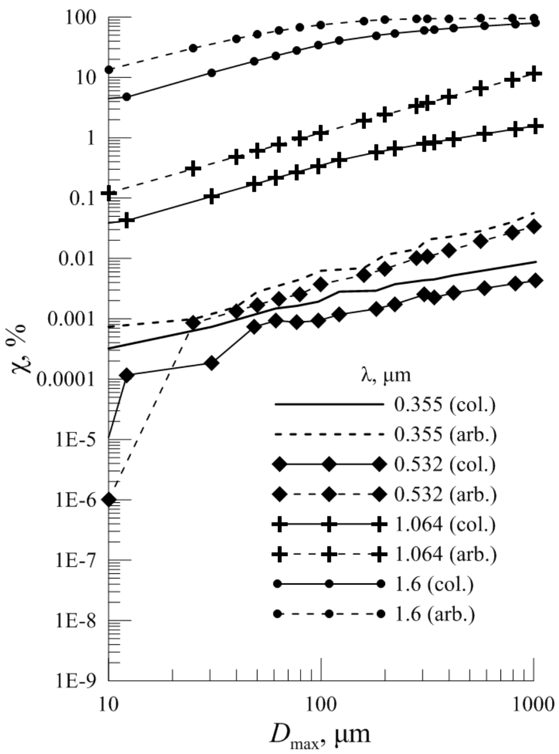

Figure 2 Dependence of D_{max} on χ for the solid hexagonal column and the arbitrary formed particle

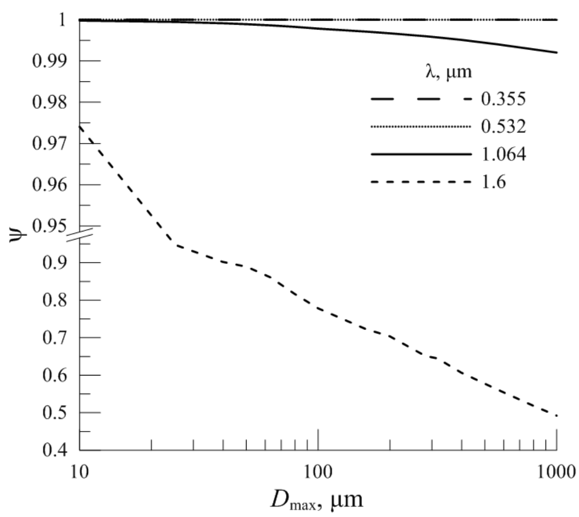

Figure 3(a) Dependence of D_{max} on ψ for the solid hexagonal column

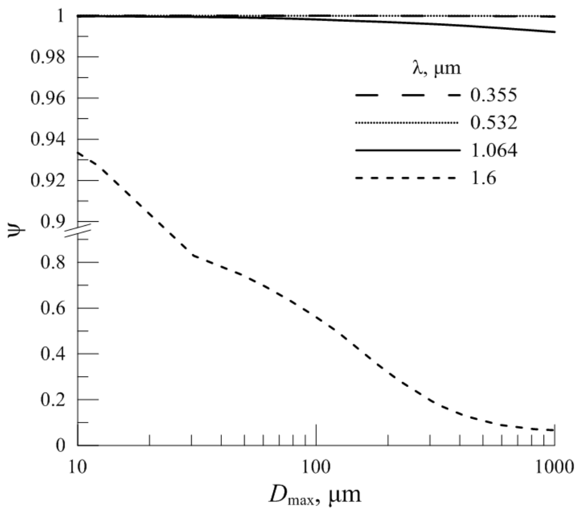

Figure 3(b) Dependence of D_{max} on ψ for the arbitrary formed particle

4. CONCLUSIONS

The analysis of results show that the absorption influence is insignificant for the ultraviolet and visible zone of the spectrum (0.355 μm and 0.532 μm wavelengths) for solving of the light scattering problem for ice crystal particles of cirrus clouds, because it's value is less than basis points of percent regardless to the shape, orientation, and size of particle. However in the near IR zone the absorption influence could reach several dozen percent almost in the whole range of the shape and size of particles. It is convenient to choose 1.064 μm with the value of imaginary part of the refraction index (N_i) $1.9 \cdot 10^{-6}$ as the threshold value of the wavelength where the absorption is significant. Thus for the wavelengths with N_i less than $1.9 \cdot 10^{-6}$ (near IR zone) it is obligatory to take the absorption into account for solving the direct light scattering problem. Moreover the absorption influence significantly depends on shape and size of particle for the 1.064 μm wavelength. In conclusion, the absorption influence is less than 2% for the chosen range of size for hexagonal ice particles.

ACKNOWLEDGEMENTS

This work is supported by the Russian Foundation for Basic Research under Grants no. 18-05-00568, no. 18-55-53046, and no. 19-01-00351 and supported in part by Russian Science Foundation (18-77-10035).

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