Tracing optical - parameters of cirrus clouds containing hexagonal ice- crystals using Surface Integral Equation Method of Muller type (SIEM/M)

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1. Abstract

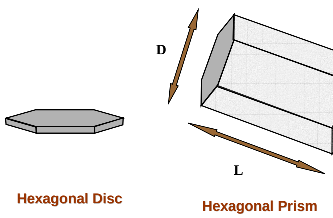
Cirrus clouds play key role in Earth's radiation budget and hence it is important to understand the optical properties of the ice-crystals in cirrus clouds. Cirrus ice-crystals are generally modeled as hexagonal column and hexagonal plates. Optical properties of homogeneous hexagonal ice-crystals have been calculated using Surface Integral Equation Method (SIEM) based on Maxwell's equations for size parameter, α, (1-25), complex refractive index (1.39, -6.99e-3) and aspect ratio (1). Q_{ext} obtained for spherical particle by SIEM has shown good agreement with exact Mie results (Nakajima, 2001). Phase functions have been calculated for homogeneous hexagonal crystals. The phase functions of a hexagonal column with aspect ratio 1.0 and size-parameter 10 have shown deviation from that of spherical particle with same size-parameter that may be due to non-sphericity arising at high size-parameter.Non-absorbing hexagonal column showed more scattering nature in compared to that of absorbing column at high size-parameter. Currently SIEM/M is being modified for remote sensing of hexagonal ice-crystals in cirrus cloud for large size-parameter using visible to IR remote-sensor.

2. Introduction

Cirrus clouds are high, thin cold clouds composed of asymmetric ice particles. They play significant role in controlling the earth's radiation budget. The Global frequency of their occurrence is 28 to 42% and zonal frequency is 7 to 61% (Lynch, 1996). The real picture of the earths atmospheric radiation-budget can be better accounted by taking non-spherical particles in the Cirrus cloud as scattering and absorption vary with the shape and size of the particle. Complete understanding of non-spherical particles together with their optical properties is highly desired to understand the interaction of radiation with such particles in cirrus clouds.

Latest model obtained by Geometrical Optics Approximation (GOA) (Kokhanovsky and Nakajima, 1998) can compute scattering properties of non-spherical particles with only very large size parameter ($\alpha = 2\pi r/\lambda$), Problem arises when we do remote sensing of ice-cloud using near infrared to infrared wavelength. In this case scattering properties of non- spherical particles fall in moderate size-parameter (10-100). Therefore, an exact numerical algorithm in moderate size-parameter range is needed.

For this we use combined Surface Integral Equation Method for Muller type (SIEM/M) yielded from Maxwell's equation.



Aspect Ratio = L/D

Fig. 1 Prominent ice-crystals in cirrus cloud

3. Surface - Integral Equation Method of Muller-type (SIEM/M)

SIEM/M has been used to calculate the optical parameters of the non-spherical particles.

$$i^*E^{inc} = -\frac{(m^2+1)K}{2} - i^*\int_S \{jk_2^2 J(m^2G_1 - G_2) + k_2K^*\nabla'(m^2G_1 - G_2) + j(J.\nabla')\nabla'(G_1 - G_2)\}ds' \quad (1)$$

$$i^*H^{inc} = J - i^*\int_S \{jk_2^2 K(m^2G_1 - G_2) - k_2J^*\nabla'(G_1 - G_2) + j(K.\nabla')\nabla'(G_1 - G_2)\}ds' \quad (2).$$

Where, E^{inc} and H^{inc} are the incident electromagnetic fields, J and K are unknown surface electric and magnetic current, j is the imaginary unit, m is the relative complex refractive index of the scattering particle, i is the normal vector on the surface of the scattering particle and k2 is the wavenumber of the incident electromagnetic wave. The stability of the fredholm`s 2nd kind formulations was well examined by Mano (2000).

G1 and G2 are the Green's function of 3-dimensional Helmholts equation per the incident wavenumber k2 for inside and outside of the scattering object.

$$G_1(r,r') = \frac{e^{-jk_2|r-r'|}}{4\Pi k_2|r-r'|}$$

$$G_2(r,r') = \frac{e^{-jk_2|r-r'|}}{4\Pi k_2|r-r'|} \quad (3).$$

Where, r and r` denote nodal point and integration point on the surface. Once J and K are obtained by Eqs (1) and (2), scattering amplitude F, the scattering cross section C_s, and the extinction cross section C_e are given by,

$$F(r) = \frac{jk_2^2}{4\Pi} *[i_r * \xi i_r * \int_S J\exp(jk_2 r'.i_r)ds' + i_r * \int_S K\exp(jk_2 r'.i_r)ds'] \quad (4)$$

$$C_S = \frac{1}{k_2^2 A_0^2} * \int |F|^2 d\Omega \quad (5)$$

$$C_e = -\frac{4\Pi}{k_2^2 A_0^2}\mathrm{Im}\{A_0^*.F(r_0)\} \quad (6).$$

Flow chart for the SIEM/M code

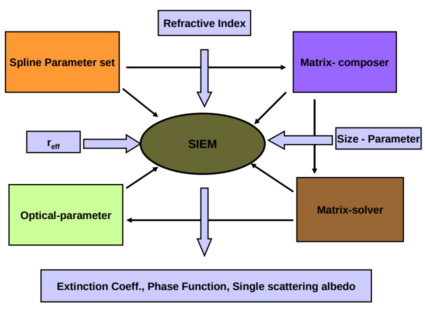


Fig. 2 Simplified Flow diagram for SIEM/M

4. Particle definition

Particle has been defined using 3-dimensional spline function. Initially fundamental nodes are set on the particle surface. Spline generates much closer nodal position (fig-3) to fulfill numerical requirement of particle optics simulation efficiently.

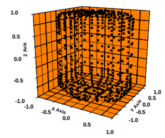
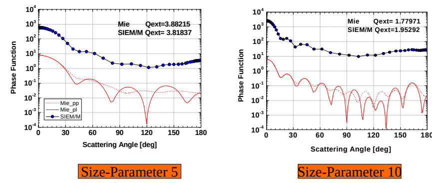


Fig. 3 Definition of hexagonal column

5. Comparison of some optical parameters



Size-Parameter 5

Size-Parameter 10

Fig. 4 Phase-functions calculated from SIEM/M for size-parameter 5 and 10 for absorbing hexagonal column with random orientation have been shown with scattering angle and compared with the phase functions calculated from Mie code for both parallel (pl) and perpendicular (pp).

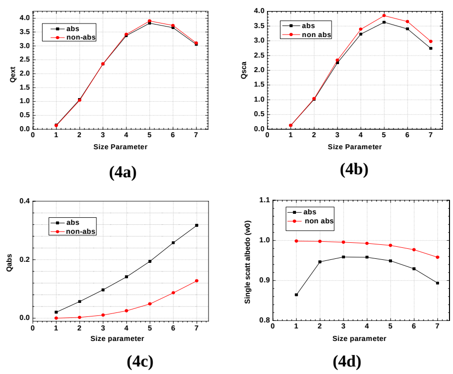


Fig. 5 The optical parameters such as Qext, Qsca, Qabs and single scattering albedo (w0) have been compared for absorbing and non-absorbing Hexagonal crystal with random orientation in fig a,b,c and d respectively.The refractive index of absorbing column is m=(1.39, -6.99*e-3) while non-absorbing column has m=(1.39, 0.00).

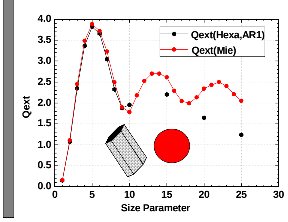


Fig.6 Shows a comparision of Qext calculated from SIEM/M and Mie for AR= 1 and m=(1.39, -6.99*e-3)

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6. Conclusion and Future plans

We are modifying present version of SIEM/M so that it can be used for large size parameters. Efforts are also being made to parallelise the present code for more efficient computing.

Acknowledgements

This research is partly supported by GOSAT project in National Institute for Environmental Studies (NIES), Japan.