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Impact of Aerosols in the Atmosphere using Mie Scattering

G. Swetha[1], Dr. S. Varadarajan[2], Dr. Amit Parashuram Kesarkar [3]

PG Student (SP), Dept. of ECE, SV University College of Engineering, Tirupati, India[1]

Professor, Dept. of ECE, SV University College of Engineering, Tirupati, India[2]

Scientist/Engineer-SE, National Atmospheric Research Laboratory (NARL), Gadanki, Tirupati, India[3]

Abstract: The microwave radiations are radiated by artificial satellites revolving around the earth in low earth orbit are attenuated by various gases , particles , clouds, temperature and rain pattern in the atmosphere etc. In this paper the attenuation of microwave radiations were observed through scattering and absorption by spherical particles using Mie-scattering theory. The optical characteristics of an ensemble of spherical particles were also determined by using Scattering and Absorption of Aerosol Particles.

Keywords: Mie scattering, optical characteristics, Aerosol Particles, Scattering and Absorption.

I. INTRODUCTION

The "Atmospheric radiative transfer model" code or simulator calculates radiative transfer of electromagnetic radiation through a planetary atmosphere, such as the Earth's. The atmosphere filters the energy received from the Sun and from the Earth. The Radiative transfer describes the interaction between radiation and matter (gases, aerosols, cloud droplets). The three key processes to be taken into account are:

• Emission.

• Absorption of an incident radiation by the atmospheric matter (which corresponds to a decrease of the radiative energy in the incident direction).

• Scattering of an incident radiation by the atmospheric matter (which corresponds to a redistribution of the radiative energy in all the directions).

There are many Lower Earth Orbiting Satellites (LEOS) such as METOP, SNPP, NOAA-17, NOAA-18, etc. are being used to transmit weather information to ground station (Profiles of Relative humidity and temperature). These satellites use L-band, S-band, X-band and C-bands for transmission of this data.

II. AEROSOL

Aerosol is defined as a system of colloidal particle in suspension containing both solids and liquid in a gas. Aerosols vary greatly in size ranging between 0.002 μm to about 100 μm. They also greatly vary in source (source may be Natural or Anthropogenic), chemical composition, distribution in space and how long they survive in the atmosphere. The liquid or solid particles have diameter mostly smaller than 1 μm or so. Larger particles with a significant settling speed make the mixture a suspension, but the distinction is not clear-cut.

(A) CLASSIFICATION OF AEROSOLS

Aerosols are classified predominantly the following ways

Primary atmospheric aerosols-These are the particulates emitted into the atmosphere directly (for example sea-salt, mineral aerosols (or dust)).

Secondary atmospheric aerosols-These are particulates formed by gas-to-particle conversion process in the atmosphere (for example sulfates, nitrates).

(B) CLASSIFICATION BASED ON CRITERIA:

1) Particle size-Fine mode (d<2.5μm), Coarse mode (d>2.5μm).

2) Chemical composition-sulfate (SO4 2-), nitrate (NO3 -), soot (elemental carbon),sea salt (Nacl)

3) Geographical location-marine, continental, rural, industrial, polar, desert aerosols etc.

4) Location in the atmosphere-Stratospheric and tropospheric aerosols.

Among all the aerosols volcanic, desert dust and human-made aerosols have great effect on the atmosphere. Volcanic aerosols are formed in the stratosphere and they are eruptions of sulfuric acid droplets that can long last at least for two years and they reflect sunlight, lowering temperature. Desert dust and mineral particles are blown away to higher altitudes. They absorb heat and they are responsible for the formation of storm clouds. Human made sulfate aerosols primarily form burning oil and coal, affecting the behavior of the clouds.

Although all hydrocarbons (both liquids and solids) are aerosols, a distinction is made between such dispersions containing activated drops and crystals and aerosol particles. The presence of aerosols influences earth's climate as well as human health for a great extent.

(C) EFFECTS OF AEROSOLS

(a)Volcanic eruptions release large amounts of sulfuric acid, hydrogen sulfide and hydrochloric acid into the atmosphere. These gases represent aerosols and eventually return to earth as acid rain, having a number of adverse effects on the environment and human life.

(b)Aerosols interact with the Earth's energy budget in two ways, directly and indirectly.

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(D)DENSITY PROFILE OF ATMOSPHERE:
The density of air δ, is the mass per unit volume of earth's atmosphere. Air density, like air pressure, decreases with increasing altitude. It also changes with variation in temperature or humidity
The density of atmosphere is

$\delta=\delta_0 \exp^{-(\frac{Z}{H})}$

Where δ = density of atmosphere
z=height
δ_0= surface density of atmosphere (1.2 g/kg).
H = scale height of atmosphere (approximately 8km)

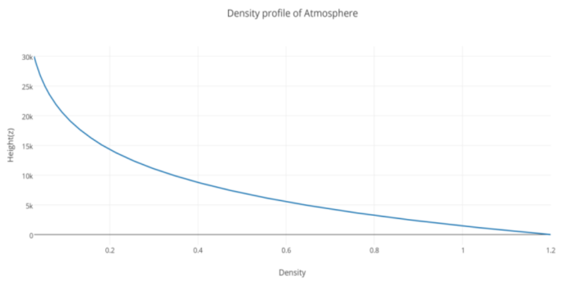

Fig 1: Density profile of atmosphere

The density profile of atmosphere shows the distribution of air density with altitude. The air density decreases with increasing altitude.

(E)SPECIFICATION

Parameter	Range or Value
Microwave wavelength	100 cm - 0.1cm
Diameter of aerosol	0.1μm – 1000μm
Refractive index	1.002
Scattering angle	0-90 degrees

III. MIE SCATTERING

Mie Theory describes the scattering and absorption of electromagnetic radiation by spherical particles through solving the Maxwell equations.

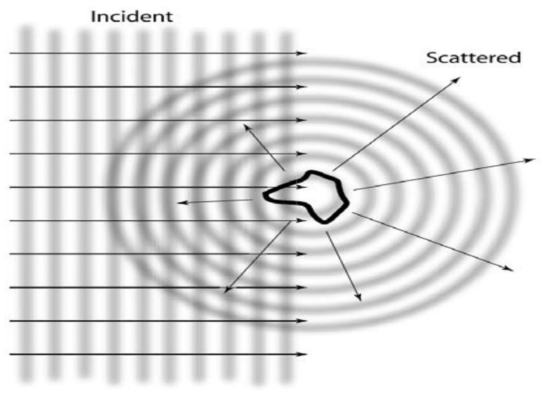

Fig 2: Simplified visualization of scattering of an incident electromagnetic wave by particle.

Key Assumptions:
(1) Particle is a sphere;
(2) Particle is homogeneous (therefore it is characterized by a single refractive index m=n - ik at a given wavelength);
NOTE: Mie theory requires the relative refractive index that is the refractive index of a particle divided by the refractive index of a medium. For air m is about 1, so one needs to know the refractive index of the particle (i.e., refractive index of the material of which the particle is composed).
NOTE: If a particle has complex chemical composition such as some atmospheric aerosols, the effective refractive index must be calculated at a given wavelength.

Overview of Mie scattering solution for spheres:
• It begins with Maxwell's equations
• To derive a wave equation in spherical polar coordinates
• To provide boundary conditions at surface of a sphere
•To solve the partial differential wave equation for dependence on r, θ, φ.

IV. OPTICAL PARAMETERS

TheOptical characteristics of an ensemble of spherical particles as explained below:

Parameters governing scattering
(i) The wavelength (λ) of the incident radiation
(ii) The size of the scattering particle, usually expressed as the non- dimensional size parameter, x

$$x=\frac{2\pi a}{\lambda}$$

a is the radius of a spherical particle, λ is wavelength
(iii) The particle optical properties relative to the surrounding medium: the complex refractive index scattering regimes:
• x << 1 : Rayleigh scattering
• x ~ 1 : Mie scattering

Mie Theory
For a single spherical particle, the mie theory gives the scattering cross section σs, absorption cross section σa, extinction cross section σe and scattering phase function P11(θ).

Scattering Cross Section
The scattering cross section can be expressed in terms of the scattering efficiency Q_s is

$$\sigma_s = \pi r^2 Q_s$$

$$Q_s = \frac{2}{x^2}\sum_{n=1}^{\infty}(2n+1)(|a_n|^2 + |b_n|^2)$$

. Where x = size parameter
a_n And b_n are the mie coefficients.

Extinction Cross Section
The extinction cross section can be expressed in terms of the extinction efficiency Qe is

$$\sigma_e = \pi r^2 Q_e$$

$$Q_e = \frac{2}{X^2}\sum_{n=1}^{\infty}(2n+1)(a_n + b_n)$$

Where x = size parameter
a_n and b_n are the mie coefficient.

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Absorption Cross section

The difference of the extinction cross section and scattering cross section is called the absorption cross section

$$\sigma_a = \sigma_e - \sigma_s$$

Scattering phase function

The scattering phase function, gives the angular distribution of light intensity scattered by a particle at a given wavelength

For a scattering phase function of a particle is

$$P_{11}(\Theta) = \frac{2\pi}{K^2 \pi r^2 Q_S}\left[|S_1(\Theta)|^2 + |S_2(\Theta)|^2\right]$$

Where

$S_1(\Theta)$ *and* $S_2(\Theta)$ are the scattering amplitudes

K=2π/λ

Q_s =scattering efficiency

Integration over the size distribution N(r)

For a single spherical particle, the mie theory and integration over size distribution N(r), gives scattering coefficient Ks, extinction coefficient Ke, absorption coefficient Ka, scattering phase function P(θ).

Here size distribution N(r) is taken as the guassian distribution function.

$$N(r) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(r-\mu)^2/2\sigma^2}$$

Where μ is the mean.

σ is standard deviation.

Scattering Coefficient

The scattering coefficient can be expresses in terms of the scattering cross section and size distribution

$$K_s = \int_{r_1}^{r_2} \pi r^2 Q_s N(r) dr$$

Extinction Coefficient

The extinction coefficient can be expresses in terms of the extinction cross section and size distribution

$$K_e = \int_{r_1}^{r_2} \pi r^2 Q_e N(r) dr$$

Absorption Coefficient

The absorption coefficient can be expresses in terms of the absorption cross section and size distribution

$$K_a = \int_{r_1}^{r_2} \pi r^2 Q_a N(r) dr$$

Scattering phase function

The scattering phase function, gives the angular distribution of light intensity scattered by a particle at a given wavelength.

For a scattering phase function of particles characterized by the size distribution N(r) dr

$$P(\Theta) = \frac{\int_{r_1}^{r_2} P11(\theta) \pi r^2 Q_s N(r) dr}{\int_{r_1}^{r_2} \pi r^2 Q_s N(r) dr}$$

Where

P11(θ)=Scattering phase function of a particle

IV. RESULTS

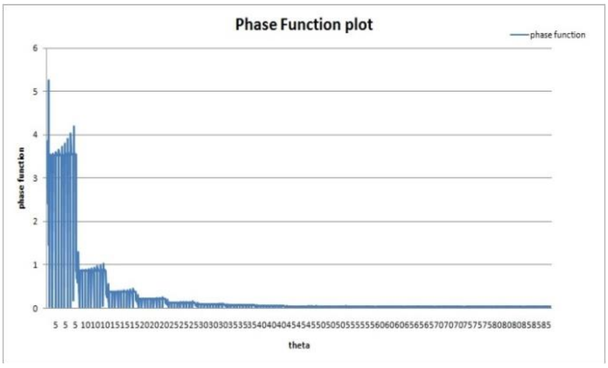

Fig 3: Scattering phase function of a particle.

The figure3 shows that scattering phase function of a particle with scattering angle. The scattering angle decreases with increase in scattering phase function.

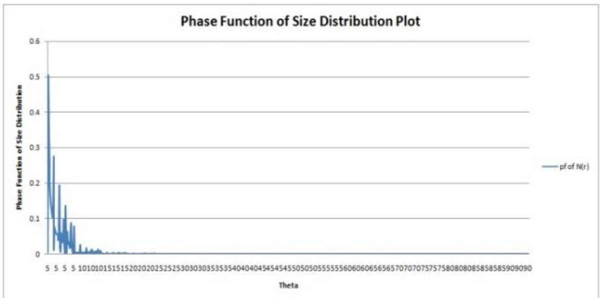

Fig 4: Phase function of size distribution.

The figure shows that scattering phase function of particle by size distribution with scattering angle. When the scattering angle decreases with increasing scattering phase function of particle by size distribution.

V. CONCLUSION

The attenuation of microwave radiation was observed in microwave region using mie scattering theory. The optical characteristics of spherical particles are calculated using Scattering and Absorption of Aerosol Particles. The optical characteristics are used for optical depth, scattering coefficients and cross sections.

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