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Influence of Soot in Radiative Properties of Desert Aerosols at different wavelengths

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ABSTRACT

The study examines the variabilities in radiative properties (RP) of modified desert aerosol perturbed by soot at different concentrations and relative humidities was computed using the software package, Optical Properties of Aerosols and Cloud (OPAC V4.0). The RP are scattering, absorption and extinction coefficients, single scattering albedo and asymmetry factor at different wavelengths spectrum range were studied. It has been found that, soot have shown strong absorptions of radiations which lead to weak scattering effects in the variations of RP were pronounced for the concentrations of soot from 10 up to 500 μgm^{-3} for particle of radius 5.5 μm near UV to far infrared regions, (0.25 – 40.0 μm). However, in the absence of soot, it has shown a significance variations in the RP studied with Relative Humidities of 0,50,70,80,90,95,98 and 99% respectively. Hence, soot has strong absorption and weak scattering effects. Thus, the continuous emissions of soot may increase the global warming effects

Keywords: Soot, desert aerosols, radiative properties, albedo

INTRODUCTION

The radiative impacts of atmospheric aerosols on climate are complicated and poorly understood and attract the attention of many researchers. Soot aerosols serve as an important tropospheric absorber of radiation (Sato *et al.*, 2003), (Bond, and Bergstrom, 2006). (Bond *et al.*, 2001). They exert radiative forcing directly, through scattering and absorption of solar and infrared radiation in the atmosphere, and indirectly, by affecting cloud formation and perturbed the albedo surfaces. Knowledge of the scattering and radiative properties of desert aerosols (DA) is essential in a variety of applications such as remote sensing, optical diagnostics for industrial aerosol processes environmental studies and combustion, and astrophysical phenomena involving the effects of

interstellar grains on light propagation and scattering, (Zhou and Li., 2019). Primarily, Soot aerosols SA are emitted from various combustion systems and biomass burning. SA have been recognized as a major contributor to global warming due to their strong influence to absorb solar and other terrestrial radiations (Akhter *et al.*, 1985), (Sato *et al.*, 2003).

The current estimate of various light absorbing components in the atmosphere put soot aerosols as the second largest contributor just after carbon dioxide in terms of radiative forcing (Bond *et al.*, 2001), (Kärcher *et al.*, 2013). However, the estimate of the effect of SA to the variability of radiative characteristics of DA is neglected by many researchers and is subject to large uncertainties. One of the main reasons for such large uncertainty is due to our relatively poor

quantitative understanding of the radiative properties of DA.

1. Particle surface scattering interaction

A wide variety of computational methods is applicable for modeling interactions of light with aerosols. Real aerosol in the atmosphere always is a mixture of different components. Thus, the optical properties of aerosols and cloud (OPAC) is made possible to get optical properties of any mixtures of the basic components and to calculate optical depths on the base of exponential aerosol height profiles (Hess *et al.*, 1998), (Igor, 2010).

The OPAC compute the radiative properties describing the interactions between aerosol particle and solar radiation. the extinction scattering and absorption coefficients, the single-scattering albedo SSA, asymmetry factor AF, optical depth AOD) turbidity factor TF Changes in the amount of radiatively active atmospheric constituents can perturb the balance between solar radiation coming into the atmosphere and radiation going out (radiative forcing), (Babenko *et al.*, 2003). The complexity, heterogeneity, and strong variability of the global distribution of DA make it a very difficult object of study. Thus, OPAC is one of the most efficient applicable tools to compute these processes. Despite the vast literature on SA and experiences on DA, the impacts of soot in variability of the optical properties of DA were poorly neglected by researchers. The paper is aimed to perturb the DA at various concentrations with SA and compute the radiative properties of DA at different wavelengths spectrum range using the software package, OPAC, (Hess *et al.*, 1998),

2. Soot aerosols and global climate impacts.

Soot aerosols can result in reductions in single scattering surface albedo due to its strong absorption which results in correspondingly large positive forcing on the atmosphere. The positive atmospheric forcing is largely due to the soot and dust absorption of solar radiation. SA can be externally or internally mixed within an aerosol population, hence affecting the overall morphology of the particles. The largest concentrations of SA

affect the instantaneous forcing effects on the impact on the energy balance and climate. It introduces perturbations in the radiative energy balance at the top of the atmosphere and the surface, both of which are spatially inhomogeneous.

3. Scattering Theory

Consider the propagation of a scalar wave field in an infinite inhomogeneous medium. The field satisfies the wave equation.

$$\nabla^2 U^{(inc)}(r) + k_0^2 \varepsilon(r) U^{(inc)}(r) = -\xi(r) \quad (1)$$

where ε is the dielectric function of the medium, k_0 is the wavenumber in free space and ξ is the source. if the medium is a scattered characterized by a dielectric function with finite range. And the source creates an incident field $U^{(inc)}$, obeys the equation (Rémi and John 2021), (Rahul and Venkateshan 2023), (Rémi and John 2021).

$$\nabla^2 U^{(inc)}(r) + k_0^2(r) U^{(inc)}(r) = -\xi(r) \quad (2)$$

The solution of equation (2) in terms of free-space Green's function G_0 is

$$U^{(inc)}(r) = \int G_0(r, r') \xi(r') d^3 r' \quad (3)$$

$$\text{Where } G_0(r, r') = \frac{\exp(ik_0 |r - r'|)}{4\pi |r - r'|} \quad (4)$$

By decomposing the field into incident and scattered parts:

$$U^{(ext)} = U^{(inc)} + U^{(sca)} \quad (5)$$

Where $U^{(sca)}$ is the scattered field and satisfies the equation

$$\nabla^2 U^{(sca)}(r) + k_0^2(r) U^{(sca)}(r) = -k_0^2 \delta\varepsilon(r) U(r) \quad (6)$$

Where $\delta\varepsilon = \varepsilon - 1$. The solution of equation (6) is

$$U^{(sca)}(r) = k_0^2 \int G_0(r, r') \delta\varepsilon(r') U(r') d^3 r' \quad (7)$$

Hence, the extinction obeys the integral equation

$$U^{(ext)}(r) = U^{(inc)} + k_0^2 \int G_0(r, r') \delta\varepsilon(r') U^{(ext)}(r') d^3 r' \quad (8)$$

This result, which is known as the Lippmann-Schwinger equation, gives the solution to the wave equation (1). It plays a central role in the theory of scattering.

The Green's function corresponding to the wave equation (1) obeys the corresponding solution in terms of Green's function also satisfies the integral equation (Rémi and John 2021),

$$G(r, r') = G_0(r, r') + k_0^2 \int G_0(r, r'') \delta\epsilon(r'') G(r'', r') d^3r'' \quad (9)$$

BORN SERIES AND MULTIPLE SCATTERING

The Lippmann–Schwinger equation (8) provides only an implicit solution to the scattering

problem, since the total field $U^{(ext)}$ appears on both the left- and right-hand sides of the equation. An explicit formula for $U^{(ext)}$, involving only the incident field, can be obtained by iteration of (8). In the case of soot aerosols with strong absorptions and scattered field is much weaker than the incident field, then the Born series may be truncated at first order in $\delta\epsilon$ in (9). The expression of the field thus becomes, (Rémi and John 2021),

$$U^{(ext)}(r) = U^{(inc)}(r) + k_0^2 \int G_0(r, r') U^{(inc)}(r') \delta\epsilon(r') d^3r' \quad (10)$$

Equation (10) is accurate for small, weak scatterers. Higher-order terms in the Born series correspond to multiple scattering of the incident field.

4. Scattering Amplitude and Cross Sections

In the far-field region, the scattering amplitude A is defined by the expression

$$A = \frac{k_0^2}{4\pi} \int \exp(-ik_0(\hat{r}, r')) U^{(ext)}(r') \delta\epsilon(r') d^3r' \quad (11)$$

The scattering albedo ($\bar{\omega}$) is defined by scattering $C^{(sca)}$ and absorption $C^{(abs)}$ cross sections is defined by (Rémi and John 2021),

$$(\bar{\omega}) = \frac{C^{(sca)}}{C^{(sca)} + C^{(abs)}} = \frac{C^{(sca)}}{C^{(ext)}} \quad (12)$$

The ($\bar{\omega}$) is the ratio between the fraction of light lost due to scattering (scattering coefficient) and to extinction (extinction coefficient). The larger the single scattering albedo, the more light attenuation is caused by scattering. When integrating the extinction coefficient over a vertical column the

optical thickness τ is obtained. The aerosol optical thickness describes the degree to which aerosols attenuate light on its way through the atmosphere. The scattering, absorption and extinction efficiency factors are a dimensionless quantity and is given by

$$Q^{(sca)} = \frac{C^{(sca)}}{G}, \quad Q^{(abs)} = \frac{C^{(abs)}}{G} \quad \text{and} \quad Q^{(ext)} = \frac{C^{(ext)}}{G} \quad (13)$$

Where G is the particle cross-sectional area projected onto a plane perpendicular to the incident beam. (Zhou and Li 2019).

Methodology

The DA model extracted from optical properties of aerosols and cloud (OPAC) represents a generalized description of typical atmospheric conditions. The model is a complex process because of the great variability in the physical, chemical, and optical properties of aerosols in both time and space gives the microphysical properties and constituted four components of the DA; Water soluble (waso), mineral nucleation (minm), mineral accumulate (miac) and **mineral coarse (micm) [7]**. **For this** research, we introduced soot to perturb the DA at various concentrations to determine its effects in scattering processes. The direction of scattered light can be described by the asymmetry factor g , which is the fraction of the incident light scattered in forward direction. If all light is scattered forward, the asymmetry factor is 1 and if it tends towards -1, more light is scattered backwards.

7. Anisotropy Nature Of Atmospheric Aerosols

The structural and chemical composition of DA is widely diversified and quantitative content of the different mineral within them depend on source, which form an aerosols background. All kind of processes of natural and anthropogenic character accompanied by SA may be served as the anisotropic aerosol sources. Thus, the anisotropic particles are also non-spherical and is likely to

have a stronger effects on the scattering patterns than their anisotropy. All those factors have been considered in the new version of the OPAC FORTRAN source code 4.0.

Table 1: The microphysical properties and constituted four components of the Desert Aerosols.

Aerosol model	Total components	Concentration n_i (cm^{-3})
Desert Aerosols	water soluble (waso)	2000
	mineral nucleation (minm)	269.5
	mineral accumulate (miac)	30.5
	mineral coarse (micm)	0.142

Table 2 The microphysical properties and constituted five components of the Modified Desert Aerosols.

Aerosol model	Total components	Concentration N_i (cm^{-3})
Modified Desert aerosols	water soluble (WASO)	2000
	mineral nucleation (MINM)	269.5
	mineral accumulate (MIAC)	30.5
	mineral coarse (MICM)	0.142
	Soot (SOOT)	0 – 5000

The model is treated within 61 λ (0.25 - 40 μm). The data are given in each case for 1 particle cm^{-3} ,

which describes the effective properties of the mixture of all particles in the size distribution. for those aerosol components that are able to take up water, the models are treated for eight values of RH (0%, 50%, 70%, 80%, 90%, 95%, 98%, 99%) .

8. Results and discussions

The results obtained from the FORTRAN software package (OPAC) were plotted and presented graphically.

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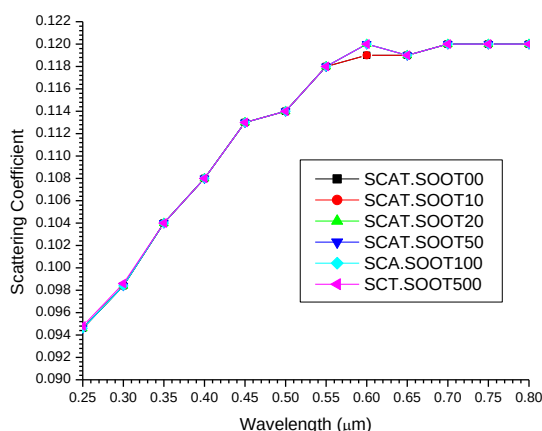


Figure 4.1, Spectral variations in scattering coefficients ($\lambda = 0.25 - 0.80 \mu\text{m}$) for the soot concentrations from (0 – 500 gcm^{-3}).

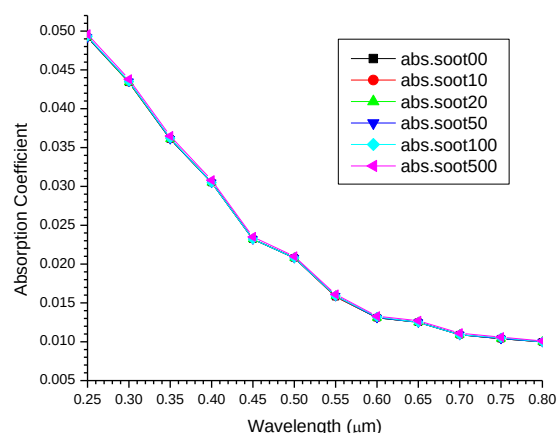


Figure 4.2, Spectral variations in absorption coefficients ($\lambda = 0.25 - 0.80 \mu\text{m}$) for the soot concentrations from (0 – 500 gcm^{-3}).

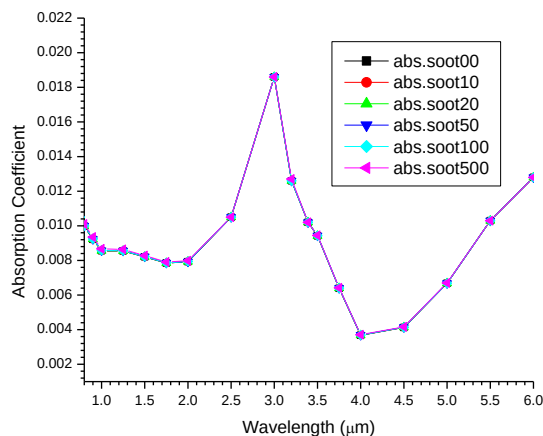


Figure 4.3. Spectral variations in absorption coefficients ($\lambda = 1.0 - 6.00 \mu\text{m}$) for the soot concentrations from ($0 - 500 \text{ gcm}^{-3}$).

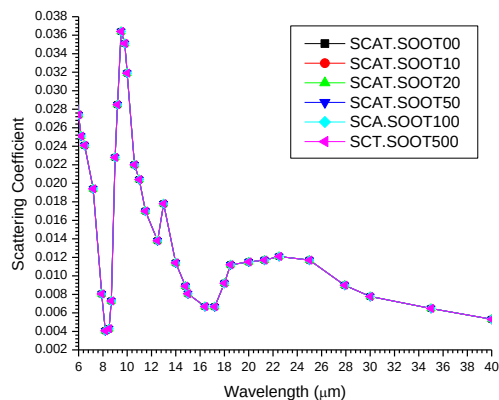


Figure 4.4. Spectral variations in scattering coefficients ($\lambda = 6.0 - 40.0 \mu\text{m}$) for the soot concentrations from ($0 - 500 \text{ gcm}^{-3}$).

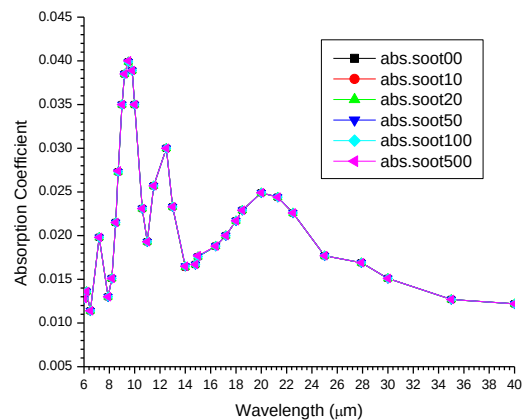


Figure 4.5. spectral variations in absorption coefficients ($\lambda = 6.0 - 40.0 \mu\text{m}$) for the soot concentrations from ($0 - 500 \text{ gcm}^{-3}$).

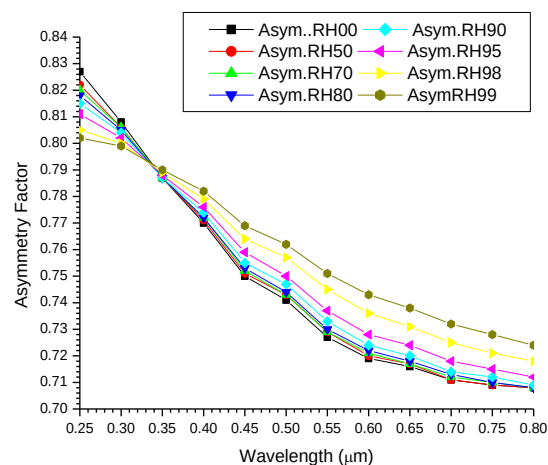


Figure 4.6a

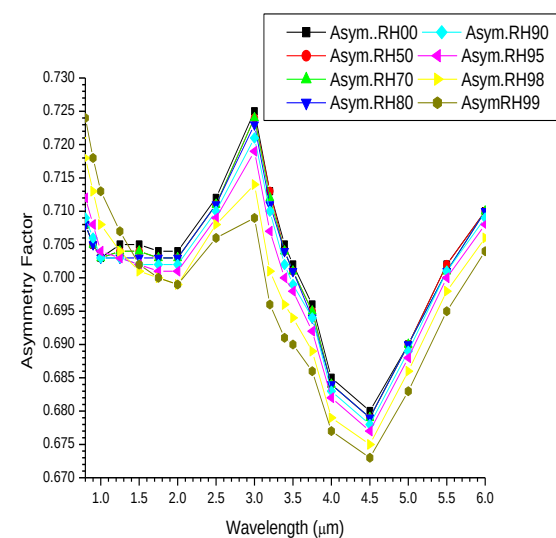


Figure 4.6b. Variations of asymmetry factor in DA with RH in the absence of soot (a) ($\lambda = 0.25 - 0.80 \mu\text{m}$) (b) ($\lambda = 0.25 - 0.80 \mu\text{m}$).

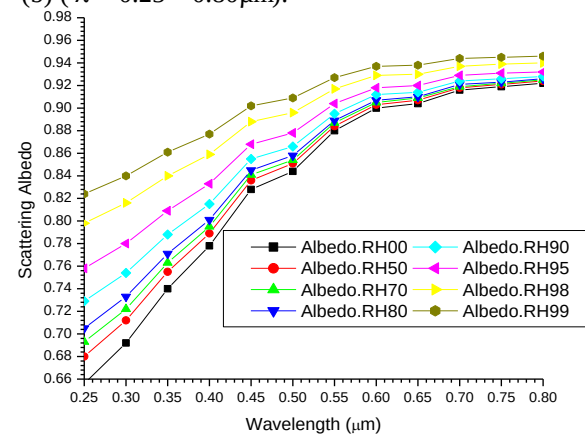


Figure 4.7a

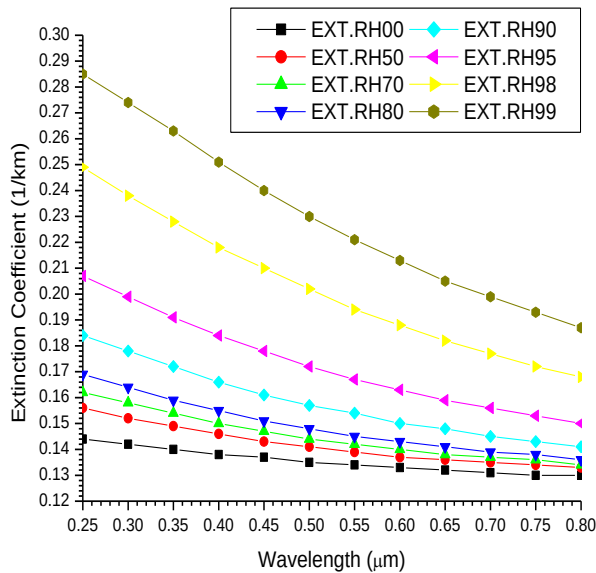


Figure 4.7b. Variations of (a) scattering albedo in DA with RH in the absence of soot near UV to visible regions (b) extinction coefficient at IR to far IR regions.

1. CONCLUSION

At present, the detailed study on impacts of soot in the optical properties of desert aerosol particles is still missing, although such knowledge is important, especially for estimating the optical properties of the turbid atmosphere and for simulating the radiative forcing. It is well recognized that radiative forcing may be caused by varying aerosol microphysical properties, including the internal topology. The optical properties of Soot particles are found to be most strongly light-absorbing particles commonly found in the atmosphere. They are major contributors to the radiative budget of the Earth and to the toxicity of atmospheric pollution (Corbin *et al.*, 2015).

The results have shown that, the strong significance absorptions effects of soot were pronounced in DA within the wide variation in wavelength spectrum ranges for all the radiative properties studied. (scattering, absorption, albedo, and asymmetry factor). However, with changes of RH in the radiative properties have shown clear significant radiative effects in the absence of soot particles. Atmosphere, condensation or evaporation of water take place on the aerosol particles and these, at the same time, change the particle optical

parameters .

It is evident that, when the RH increases, the size of an aerosol particle increases through the accretion of water. SA relatively absorbs sunlight and warm the atmosphere that leads to additional warming when it settles onto snow and ice because it makes the surface darker, which causes faster melting.

Future research activities should therefore focus to simulations of multi components particles of different sizes and shapes with different internal distributions of refractive indices. The bulk optical properties (like spectral behavior of optical depth, phase function, backscatter, polarization, single scattering albedo, asymmetry parameter, absorption, etc) need to be modelled for the polydisperse systems typically occurring in the urban atmospheres and the characteristic features of these optical properties need to be rendered. The investigations of aerosols in urban environments is of growing importance since a large fraction of the world's population lives in urban areas in order to handle the global warming solutions.

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