RADIATIVE PROPERTIES OF AEROSOL MIXTURES OBSERVED OVER ARID AND ISLAND AERONET STATION

Dr. Sandeep R. Varpe

International Institute of Information Technology, Pune 411 057

Abstract

We have examined multiyear observational data at the AERosol RObotic NETwork (AERONET) sites at Jaipur (26.90° N, 75.80° E), and Hanimaadhoo (6.74° N, 73.17° E), were utilized to study the climatological characteristics of aerosol radiative properties. Both sides shows linear fall in SSA against FMF suggests aprobable combination of a linear mixture of fine and coarse aerosol components. Under clear sky conditions, change in the sign of radiative forcing from negative (cooling) to positive (warming) occurs at SSA about 0.85, while in the presence of clouds it can occur even at higher SSA due to the semi-direct effect. A change of 0.07 in SSA is shown to produce a 21% change in radiative flux at the top of the tropopause over the ocean at constant aerosol optical depth. The refractive index (RI) is one of the important optical parameters providing information relating to the nature of aerosols and is highly dependent on the chemical composition of the aerosols. Values of RI give an indication of highly scattering (real RI) or highly absorbing (imaginary RI) aerosol types.

Keywords: AEROSOL RADIATIVE FORCING, SINGLE SCATTERING ALBEDO, REFRACTIVE INDEX, HEATING RATES.

INTRODUCTION

Aerosols participate in the Earth's energy budget "directly" by scattering and absorbing radiation and "indirectly" by acting as cloud condensationnuclei and, thereby, affecting cloud properties [1]. Moreover, the direct absorption of radiant energy by aerosols can influence the atmospheric temperature structure and, thereby, cloud formation - a phenomenon that has been labelled the "semi-direct effect" [2]. The indirect effect of aerosols on weather and climate system takes place through the modification of cloud optical and microphysical properties [3]. A large number of studies have found that the anthropogenic aerosols change clouds and their optical properties [4, 5, 6]. Atmospheric aerosols change the concentration and size of the cloud droplets which in turn lead to a change in cloud albedo, its lifetime and thereby affect the precipitation [3, 7]. The picture of aerosols is more complex due to their large spatio – temporal ambiguity, diversity in the atmosphere associated life span [8, 9, 10, 11]. The addition of anthropogenic aerosols to the atmosphere may change the radiative fluxes at the top-of-atmosphere (TOA), at the surface, and within the atmospheric column. A positive radiative effect at the TOA indicates the addition of the energy to the earth-atmosphere system (i.e., a warming effect) whereas a negative effect indicates a net loss of energy (i.e., a cooling effect).The aerosol single scattering albedo (SSA), the ratio of scattering to extinction

coefficient, is one of the most important, yet sparsely characterized,parameter aerosol radiative forcing studies.

Figure 1: Map shows AERONET sites Jaipur and Hanimaadhoo. (Source: Google maps)

STUDY SITE AND METHODOLOGY

Multiyear observational data at the AERONET sites at Jaipur (26.90° N, 75.80° E), an arid AERONET observing site in north-west India and Hanimaadhoo (6.74° N, 73.17° E), an island geographical part of Thiladhunmathi Atoll in the north of the Maldives [12], were utilized to study the climatological characteristics of aerosol radiative properties. For this characterization, the AERONET retrieved radiative products based on the direct and almucantar measurements (for a period of 5-9 years) have been analyzed.

The CIMEL sun-sky spectral radiometer (Model CE-318), which measures the direct sun radiances at eight spectral channels centered at 340, 380, 440, 500, 670, 870, 940 and 1020 nm, installed at the Maldives Climate Observatory-Hanimaadhoo (MCOH) and at Jaipur (India), is one of the standard instruments in AERONET. It is a convenient and powerful tool for investigating the aerosol content and the related parameters in the ground-based measurements. The fine mode fraction (FMF) of AOD computed from the spectraldeconvolution algorithm (SDA) and spectral SSA has been included in the present analysis.

The aerosol radiative forcing produced due to the change in the environment is defined as the change (ΔF) in the net flux (F), either at the top of the atmosphere (TOA) or at the bottom of the atmosphere (BOA, i. e. at the surface). In case of aerosol radiative forcing (ARF),

$$(\Delta F)_{TOA,\,BOA} = [F_{NA}]_{TOA,\,BOA} - [F_A]_{TOA,\,BOA} \qquad (1)$$

Where, the F_A and F_{NA} are respectively the net fluxes with and without aerosols. The net atmospheric forcing is defined as:

$$(\Delta F)_{ATM} = (\Delta F)_{TOA} - (\Delta F)_{BOA} \qquad (2)$$

$(\Delta F)_{ATM}$ represents the amount of energy trapped within the atmosphere due to the presence of aerosols. For positive $(\Delta F)_{ATM}$, aerosols produce a net gain of radiative flux to the atmosphere

leading to a hearing, while a negative $(\Delta F)_{ATM}$ indicates a net loss and thereby cooling [13]. Radiative and hence the climate implications of aerosols are assessed in terms of the atmospheric heating rates. Atmospheric forcing in equation (2) is used to estimate atmospheric heating rate ($\frac{\partial T}{\partial t}$, $Kday^{-1}$) due to aerosol absorption, following equation (3).

$$\frac{\partial T}{\partial t} = \frac{g}{C_p}\frac{(\Delta F)_{ATM}}{\Delta P} \qquad (3)$$

where, g isthe acceleration due to gravity, C_P is the specific heat capacity of air at constant pressure (~1006 J kg^{-1} K^{-1}) and ΔP is the atmospheric pressure difference between top and bottom boundary region.

RESULTS AND DISCUSSION

A. Aerosol Radiative Forcing (ARF)

The monthly average ARF variations at TOA, at the surface and in the atmosphere for the AERONET observing sites Jaipur and Hanimaadhoo for the respective periods are shown in Figure 1. Seasonally, for Hanimaadhoo, the ARF in the atmosphere is found to be 18.96 ± 2.06 Wm^{-2}, 11.63 ± 2.01 Wm^{-2}, 8.03 ± 5.95 Wm^{-2}, and 20.70 ± 7.95 Wm^{-2} for pre-monsoon, monsoon, post-monsoon and winter seasons respectively. The corresponding ARF values in the atmosphere for Jaipur are 44.85 ± 2.73 Wm^{-2}, 43.10 ± 4.76 Wm^{-2}, 35.01 ± 3.42 Wm^{-2}, and 45.66 ± 8.27 Wm^{-2}. At both the observing sites the ARF in the atmosphere is found to be high in winter and pre-monsoon seasons and low during monsoon and post-monsoon seasons. However, the ARF values at Jaipur are about 2.2 to 4.4 times higher than equivalent ARF values at Hanimaadhoo. Such high ARF values in the atmosphere further produce considerably higher heating in the atmosphere over at Jaipur which is noted to be 1.26 ± 0.08, 1.21 ± 0.13, 0.98 ± 0.10, 1.28 ± 0.23 for pre-monsoon, monsoon, post-monsoon and winter seasons respectively.

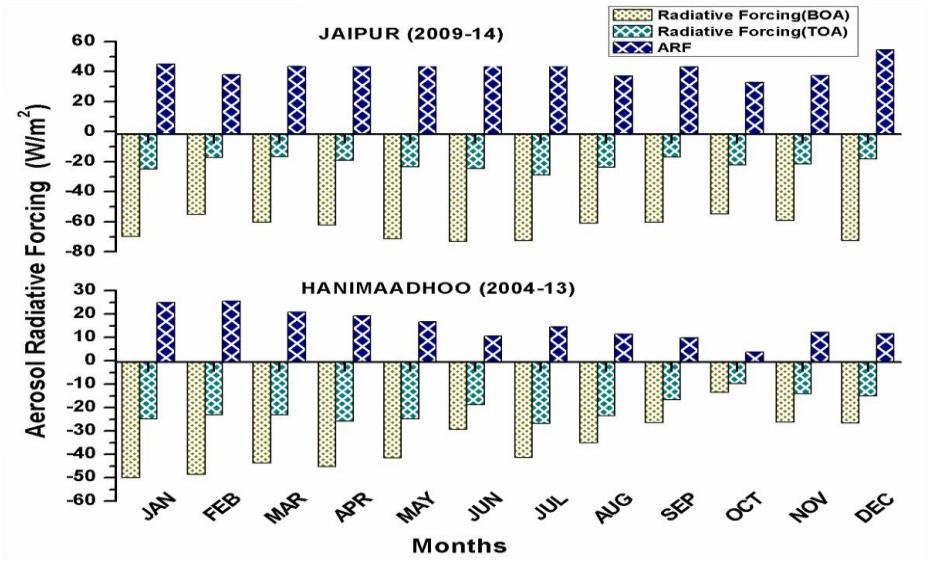

Figure 2: Monthly AERONET retrieved aerosol radiative forcing (ARF) at the Jaipur and Hanimaadhoo.

Fig. 2 also demonstrates that there are large ARF differences between TOA and surface causing the absorption of solar radiation within the atmosphere which consequently heat the atmosphere reducing eddy heat convergence and inducing a reduction in the surface temperature [14]. Further heating due to absorption of solar radiation by aerosol reaches its maximum close to its uppermost level where the heating is stabilized. This, in turn, may suppress convective activity and prevent cloud formation. It can be concluded that the presence of atmospheric brown clouds over observing sites can considerably decrease the surface and TOA forcing enhancing the atmospheric forcing.

B. SSA as a function of FMF at 674 nm

The SSA plotted as a function of FMF at 674 nm, for both sites, shown in Figure 3 depicts that the plot is nearly linear at wavelengths 674, 870 and 1020 nm for FMF < 0.55. A reduction in the slope, levelling off and finally an increase in SSA is observed as FMF increases. The nearly linear fall in SSA against FMF suggests aprobable combination of a linear mixture of fine and coarse aerosol components and hence SSA which are combined in this range of FMFs. An increase in SSA at higher FMFs, however, is partly due to the increase in fine mode particle radius which increases the relative scattering efficiency.

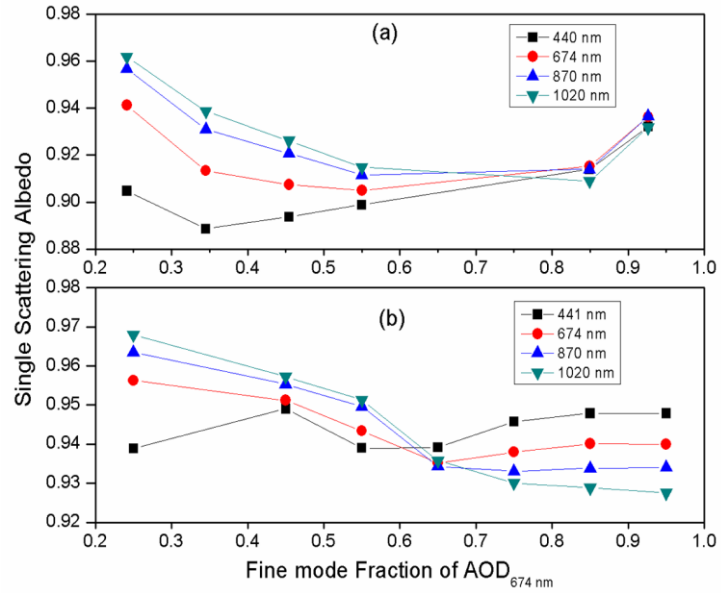

Figure 3: Spectral single scattering albedo as a function of fine mode fraction of $AOD_{674\,nm}$ at (a) Jaipur and (b) Hanimaadhoo.

C. Spectral variation of real and imaginary parts of refractive index as a function of FMF at 674 nm

The magnitudes of the real and imaginary parts of refractive indices (RI) are generally used provide an indication of high scattering and high absorbing type of aerosols. In order to investigate this aspect, five to nine years of RI data at Jaipur and Hanimaadhoo were used to compute mean spectral refractive indices for AOD < 0.4. These values were averaged for the 674 nm fine mode fraction of AOD bins with bin centres in the range 0.25 - 0.95 at an interval of 0.05. Results are given in Figure 4(a, b) and Figure 4(c, d) for Jaipur and Hanimaadhoo respectively. From the figures, it is seen that the real part of RI is in general high at larger

wavelengths than at shorter wavelengths due to higher absorption in the near infrared spectral band by coarse mode particles. The imaginary part of RI also depicts wavelengths dependence with a monotonic decrease in its value as wavelength increases. The higher imaginary part values at the two shorter wavelengths viz., 440 and 670 nm suggest absorption due to organic/black carbon aerosols.

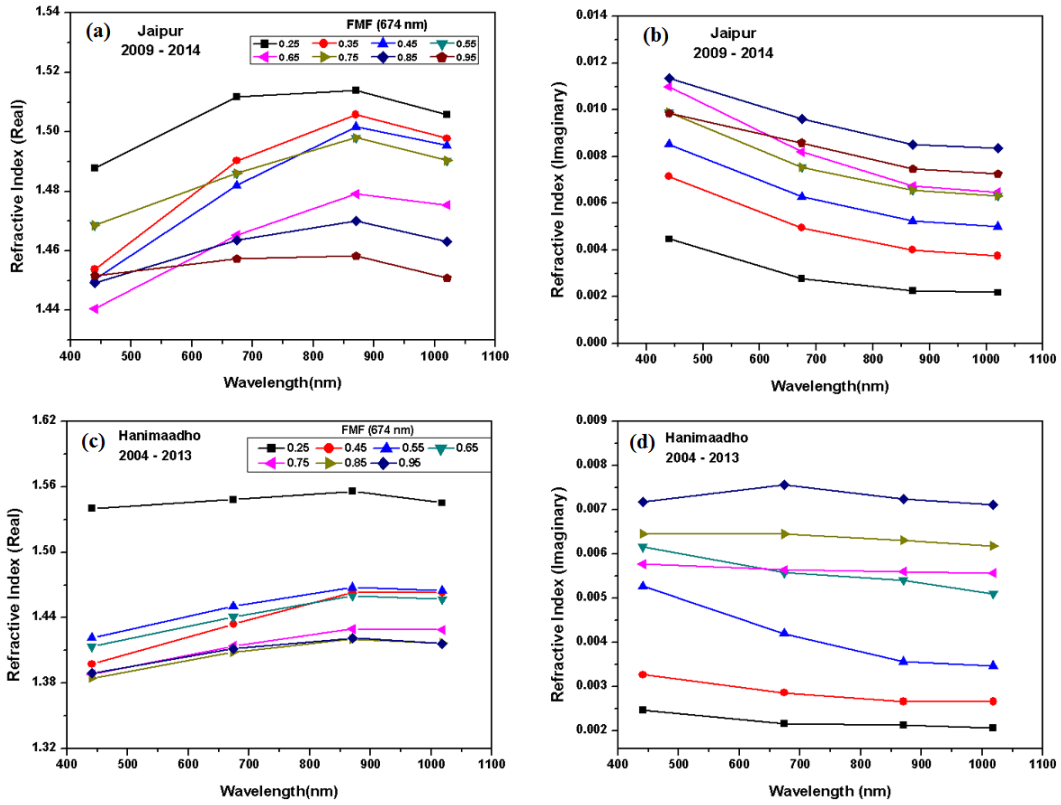

Figure 4 (a, b, c, d): Spectral variation of the real and imaginary component of refractive indices at two AERONET sites.

CONCLUSIONS

The study reveals the strong seasonality in aerosol radiative forcing prevalent at two contrasting observing sites. Further, the variation of SSA as a function of the function of FMF at 674 nm and the spectral dependence of refractive indices (both real and imaginary) suggest the dominance of different mixtures of aerosols in different proportions.

REFERENCES

1. *Rosenfeld, D. and Lensky, I. M., 1998. Satellite-based insights into precipitation formation processes in continental and maritime convective clouds, Bull. Am. Met. Soc., 79, 2457–2476.*
2. *Koren, I. Y., Kaufman, Y. J., Remer, L. A., and Martins, J. V., 2004. Measurement of the effect of Amazon smoke on inhibition of cloud formation, Science, 303, 1342–1345.*

3. *Miller, G., and S. Spoolman, 2011. Living in the environment: principles, connections and solutions. Cengage Learning.*
4. *Charlson, R. J., S. E. Schwartz, J. M. Hales, R. D. Cess, Jr. J. A. Coakley, J. E. Hansen, and D. J. Hofmann, 1992. Climate forcing by anthropogenic aerosols. Science, 255:423–430.*
5. *Schulz, M., G. de Leeuw, and Y. Balkanski, 2004. Sea-salt aerosol source functions and emissions. In Emissions of Atmospheric Trace Compounds, pages 333–359. Springer.*
6. *Levin, Z., and W. R. Cotton, 2008. Aerosol pollution impact on precipitation: A scientific review. Springer Science & Business Media.*
7. *Tang, I. N., and H. R. Munkelwitz, 1994. Water activities, densities, and refractive indices of aqueous sulfates and sodium nitrate droplets of atmospheric importance. J. Geophys. Res., 99:18801–18808.*
8. *Pawar, G.V., P.C.S. Devara, and G.R. Aher. 2015. "Identification of aerosol types over an urban site based on air-mass trajectory classification". Atmospheric Research 164–165: 142–155. doi: 10.1016/j.atmosres.2015.04.022.*
9. *Varpe, S. R., Aher G. R., Kolhe A. R., and More S. D. 2016a. "Aerosol-Cloud Interaction : A Case Study", Aerosol-Science and case Studies Volkov Konstantin (Ed.), InTech. Doi:10.5772/65237.*
10. *Varpe, S. R., Aher G. R., Kutal G. C., and Kolhe A. R. 2016b. "Classification of Aerosol Types over Pune". International journal of Research in advanced Engineering and Technology 4(7): 123-125.*
11. *Varpe, S. R., Aher G. R., Pawar G. V., and Kutal G. C. 2015. "Variability of Aerosol Optical, Physical and Radiative Properties at Seven Asian AERONET stations During March 012 Dust Event." International Journal of Advances in Science, Engineering and Technology 3(4): 40-44. Doi : IJASEAT-IRAJ-DOI-3381.*
12. *Varpe, S.R., A.R. Kolhe, G.C. Kutal, G.V. Pawar, S. Payra, K.B. Budhavant, G.R. Aher, and P.C. S. Devara. 2018. "Heterogeneity in aerosol characteristics at the semi-arid and island AERONET observing sites in India and Maldives". International Journal of Remote Sensing. doi: 10.1080/01431161.2018.1454622.*
13. *Alam Khan, Thomas Trautmann, Thomas Blaschke, 2011: Aerosol optical and radiative forcing over mega city Karachi. Atmospheric Research. 101:773-782.*
14. *Ge, J. M., Su, J., Ackermann, T. P., Fu, Q., Huang, J. P., Shi, J. S.: Dust aerosol optical properties retrieval and radiative forcing over north-western China during the 2008 China-US joint field experiment, J. Geophys. Res., 115 (D00k12), doi:10.1029/2009JD013263, 2010.*