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Variation of Aerosol Optical Depth and Radiative Forcing Over Indo-Gangetic Plain using AERONET

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Abstract

Aerosols play a crucial role in the atmosphere and significantly modify the earth's radiation budget. Due to their scattering and absorbing nature, aerosols have a significant impact on the global climate. In the present work, the monthly variation of aerosol properties has been studied over three different sites of Indo-Gangetic Plain (IGP): Kanpur, Jaipur, and Gandhi College respectively using ground-based Aerosol Robotic Network (AERONET) data. The spectral variations of Aerosol Optical Depth (AOD) with different seasons have been analyzed from June 2020 to May 2021. The high value of AOD at shorter wavelength and low value of AOD at longer wavelength was found which suggest dominancy of fine particles in the winter season and dominancy of coarse particles in the summer season. The monthly variation of Aerosol Radiative Forcing (ARF) along with trends over Kanpur, Jaipur, and Gandhi College has been analyzed. Total atmospheric radiative forcing (ARF_{ATM}) over all the locations was found to be positive suggesting warming in the atmosphere. The trend of ARF over Jaipur was found to be significantly decreasing while the trend of ARF over Kanpur and Gandhi College is insignificant. The correlation between AOD and ARF_{ATM} was calculated. It is found that Aerosol Radiative Forcing is directly proportion to the Aerosol Optical Depth having a correlation coefficient of $R^2 > 60$ % which suggests that aerosols can modify the Earth's radiation budget significantly.

1. Introduction

Atmospheric aerosols have been analyzed to study climate change, atmospheric radiation balance, and human health as well. Aerosol optical depth (AOD) is a measure of the extinction effect of atmospheric aerosols and is widely used as a key parameter for assessing the degree of air pollution [1-2]. Atmospheric aerosols have a significant role in the global and regional climate as well as environmental change which is closely related to their optical, micro-physical, and radiative properties through various atmospheric interactions [3-4]. The size of aerosol is vary from a few nm in diameter to 100 micrometers or more. The particulate matter comes from different sources, natural (volcanic eruption, sea salt, dust, etc.) and anthropogenic (produced by combustion processes such as vehicular emissions and industrial emissions, etc.) sources [5]. AOD is associated with scattering and absorption of solar radiations and is increasing continuously therefore air quality of this region is strongly affected. The effect of AOD on aerosol radiative forcing is well known, but the size distribution, SSA, and morphology also affect aerosol radiative forcing (ARF) [6]. In the present study, seasonal variation of AOD and ARF (Aerosol radiative forcing) obtained from AERONET were analyzed over Kanpur, Gandhi College, and Jaipur for the period from June 2020 to May 2021.

2. Data and Methodology

Three different locations of IGP are considered in this study. The three different sites in the north Indian region are: Kanpur (26.51°N, 80.23 °E), an urban and highly industrial area, Gandhi College (25.87 °N,84.13 °E), rural background, and Jaipur (26.91 °N, 75.81 °E) urban and desert dust influenced region, are chosen to study the parameters (Aerosol Optical Depth and Aerosol Radiative Forcing), using ground- truth AERONET observations. AERONET sun-photometer measures aerosol optical depth (AOD) at seven different wavelengths within the range from 0.34 to 1.02 µm (0.34, 0.38, 0.44, 0.50, 0.67, 0.87 and 1.02 µm) [7-8]. Aerosol optical depth data have been obtained at three different sites Kanpur, Gandhi College, and Jaipur. For the validation of satellite aerosol products, ground stations are very important. Ground-based AERONET data have been used extensively to study the variability of aerosol optical properties over the Indo-Gangetic basin. Aerosol radiative forcing (ARF) is defined as the net difference in solar fluxes in the presence of aerosols and in the absence of aerosols whether it is at top of the atmosphere (TOA) or surface (BOA) respectively; $\mathbf{\Delta F = (F_{a\downarrow} - F_{a\uparrow}) - (F_{0\downarrow} - F_{0\uparrow})}$ in the unit of W/m^{-2} where ΔF is irradiance, and $(F_{\downarrow} - F_{\uparrow})$ shows the net irradiance which is calculated in the presence of aerosol (F_a) and absence of aerosol (F_0) either at TOA or at BOA. It is one of the key parameters in the atmosphere which tells about the heating or cooling of the climate system. In this study, ARF (at TOA and BOA) is taken from the AERONET. To calculate the radiative forcing, AERONET uses a radiative transfer model. Radiative forcing for TOA and BOA is defined as [9]:

$$\Delta F_{TOA} = F_{0\uparrow,TOA} - F_{a\uparrow,TOA}$$
$$\Delta F_{BOA} = (F_{a\downarrow,BOA} - F_{0\downarrow,BOA}).(1 - SA)$$

where a downward arrow (↓) shows downward flux, an upward arrow (↑) shows upward flux, and SA is defined as the surface albedo.

3. Result and Discussion

In the current analysis whole period of study is classified into four seasons viz. Pre-monsoon, Monsoon, Post-monsoon, and winter. January and February are considered Winter, March, April, and May as Pre-monsoon, June, July, August, and September as Monsoon, and October, November, and December as the Post-monsoon period consecutively.

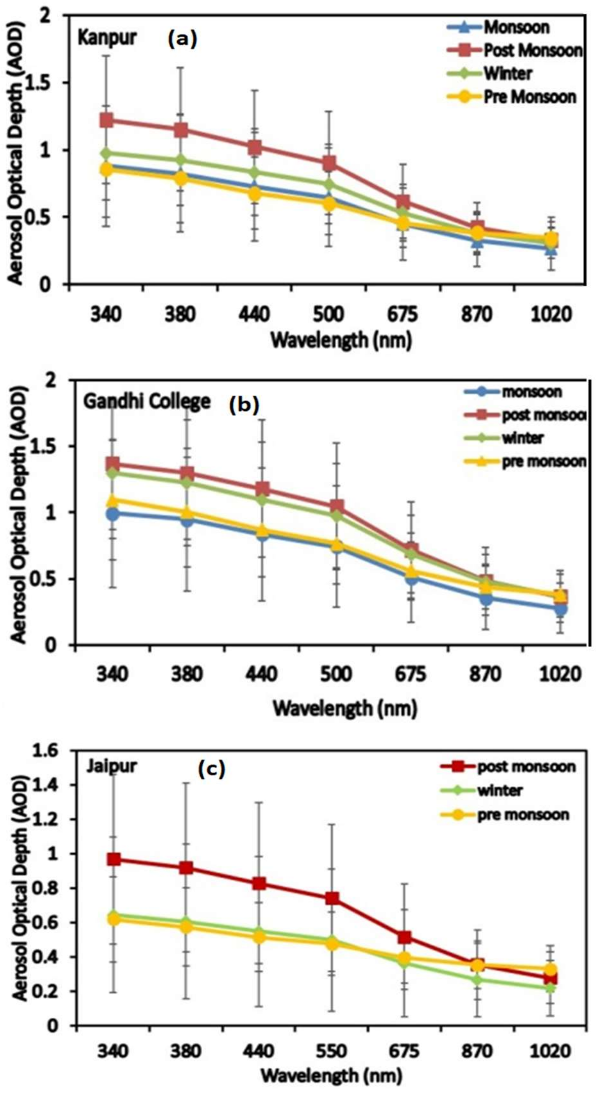

Figure 1. Spectral variation of aerosol optical depth for different seasons over (a) Kanpur, (b) Gandhi College and (c) Jaipur respectively during June 2020 to May 2021.

Figure 1 shows variation in AOD for all the seasons over (a) Kanpur, (b) Gandhi College and (c) Jaipur respectively in which it can be easily observed that the highest AOD value is observed during Post-monsoon and after then in the winter season whereas the lowest value in monsoon season. In general, many locations show a low AOD during winter and high AOD during the summer season. They have shown that the seasonal AOD characteristics are dependent on the type of aerosols, aerosol optical depth, and fine mode fraction (FMF) [10-13].

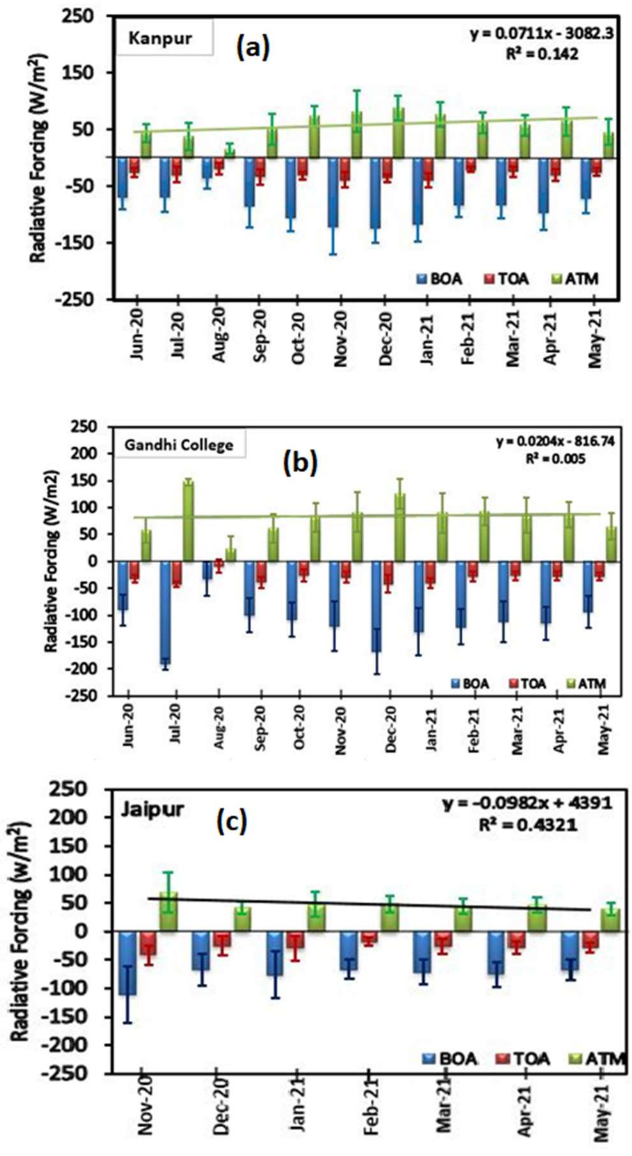

Figure 2. Variation of aerosol optical depth over (a) Kanpur, (b) Gandhi College and (c) Jaipur respectively during June 2020 to May 2021.

The monthly variation of aerosol radiative forcing (ARF) at the TOA, BOA, and in the atmosphere (ATM) over Kanpur, Gandhi College, and Jaipur is shown in Figure 2a, Figure 2b, and Figure 2c respectively. Positive radiative forcing in the atmosphere (ATM) indicates warming and negative forcing shows cooling of the atmosphere. Radiative forcing is event-specific i.e. it is also affected by special events like dust storms, biomass burning, forest fires, etc [14]. Radiative forcing also shows seasonal dependency [15]. In Kanpur and Gandhi College there is positive radiative forcing in the atmosphere (ATM) indicates warming on the other hand in Jaipur there is negative radiative forcing in the atmosphere (ATM) indicates a cooling effect. The trend of ARF_{ATM} over Kanpur and Gandhi College was found to be higher than those of Jaipur. A less negative value of TOA forcing is due to low surface albedo which leads to the higher value of ATM forcing, TOA forcing depends on AOD. Correlation between AOD and ARF was calculated at three different sites Kanpur, Gandhi College, and Jaipur as shown in Figure 3a, 3b, and 3c respectively.

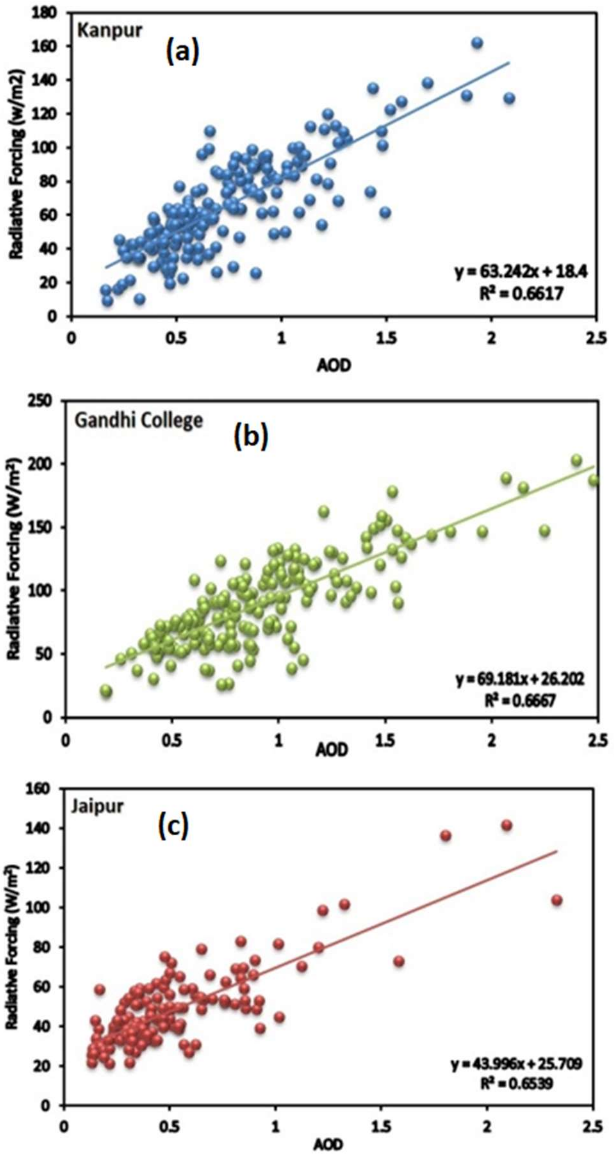

Figure 3. Correlation between aerosol optical depth and aerosol radiative forcing at Kanpur, Gandhi College, and Jaipur respectively during June 2020 to May 2021.

Since, ARF_{ATM} directly depends on AOD, so positive trend of AOD leads to the increasing trend of ARF_{ATM}. It is found that Aerosol Radiative Forcing is directly proportion to the Aerosol Optical Depth having a correlation coefficient of $R^2 > 60$ % which suggests that aerosols can modify the Earth's radiation budget significantly.

4. Conclusion

Spectral variation of aerosol optical depth over Kanpur, Gandhi College, and Jaipur were investigated for different seasons. The concentration of fine mode particles was found to be higher in the post-monsoon and winter season. On the other hand, the monthly variation of ARF suggests an increasing trend over Kanpur and Gandhi College while decreasing trend over Jaipur. In addition, the correlation between AOD and ARF was found to be greater than 60% which suggests that radiative forcing is affected by aerosol particles into the atmosphere.

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