Seasonal Asymmetry of Aerosol Optical and Radiative Properties Over New Delhi, India using Ground based Observations

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ABSTRACT

Seasonal variations in aerosol optical and radiative properties were examined using data retrieved from a ground based multi-wavelength Sun-Sky radiometer over New Delhi, India during the year 2013. As aerosol optical properties are dependent on wavelength, this is a novel approach of studying the aerosol characteristics at shorter (380nm) and longer (1020nm) wavelengths in the urban capital of India. The mean annual AOD at 380 and 1020 nm wavelengths is observed to be 1.166 ± 0.240 and 0.515 ± 0.125 respectively. An increase in AOD over the urban city where man made aerosols are dominant can be ascribed to the increased use of fossil fuel and biomass burning. The annual mean value of Angstrom exponent is found to be 0.921 ± 0.130. The annual average single scattering albedo (SSA) ranged from 0.870 ± 0.041 (at 380 nm) to 0.846 ± 0.014 (at 1020 nm). SSA at Delhi is found to be in the range of 0.906 to 0.837 from March to June, indicating an increasing contribution from the mixture of anthropogenic and the effect of the non local dust aerosol transport during the month of June. Shortwave Direct Aerosol Radiative Forcing (DARF) was calculated using SBDART for the entire period at the surface and the top of atmosphere (TOA), giving an averaged atmospheric forcing which indicated significant heating of the atmosphere during the year.

Keywords: Sun-Sky radiometer, Aerosol Optical properties, Radiative forcing

1. INTRODUCTION

Delhi, the urban capital of India is known as one of the highly polluted cities in the world, with a population of about 14 million [1], a rapidly increasing number of vehicles (more than 5 million [2], thermal power plants and an increasing number of industrial units. Atmospheric processes and multi–source origin tend to generate a complex mixture of aerosol components with different optical properties. These manifold sources of atmospheric pollutants have led to a serious deterioration of air quality in the Delhi and surrounding areas. The unprecedented increase in urbanization and consequently an increase in aerosol loading have a direct impact on the global and regional climate. The reducing visibility in the mega city, Delhi is directly associated with increasing aerosol loading in the atmosphere due to rise in anthropogenic activities, which in turn is condensing Solar Radiation over the earth surface [3]. In north Indian region, many studies have been conducted on air pollution [4,5] and green house gases [6] along with their emission estimate and trends, but only few studies have illustrated the optical characteristics of aerosols and its impact on radiative flux [7, 8].

Aerosol optical properties vary in space and time and it is rather difficult to model aerosol climatology at any location. In addition, ground-based in situ measurements are considered more reliable than satellite data as they can provide continuous data with less chances of uncertainty and is also essential for validation of satellite aerosol retrievals [9]. Aerosol retrievals at different wavelengths obtained from Aerosol robotic network (AERONET) and MICROTOPS-II Sun Photometer have been reported in many studies [10, 11, 12]. However, very few studies have been conducted in north Indian region using the Sun-Sky radiometer (POM-02).

The present study is a novel approach of studying the annual and seasonal variations in aerosol optical depth (AOD), Single Scattering Albedo (SSA), Angstrom exponent and Asymmetry parameter retrieved from Sun-Sky radiometer at different wavelengths. Since a part of Delhi is adjacent to semi-arid region, it becomes imperative to estimate the impact of desert aerosols to comprehend aerosol properties and effects better. A study [7] has also shown that Delhi aerosols can be best stated as a combination of Urban and Desert type, having values of angstrom exponent approximately 0.185 and 1.28 respectively. Present study also analyzed the Direct Aerosol Radiative Forcing (DARF) during 2013 over the urban polluted city of Delhi.

2. INSTRUMENTATION AND OBSERVATION DETAILS

The data used in this study were retrieved from the Sun-Sky radiometer (POM-02, Prede Incorporated, Japan) installed at the Delhi station of India Meteorological Department (IMD) during the year 2013. The instrument was used to make measurements of both direct and diffuse sky radiances at predefined scattering angles at regular intervals.

The retrieved data has been further analyzed with the SKYRAD.PACK (version 4.2) software [13] to obtain aerosol optical depth (AOD), single scattering albedo (SSA) and asymmetry parameter. The AOD is calculated on the basis of the Beer-Lambert-Bouger law and it includes the correction for Rayleigh scattering, the change of Sun-Earth distance, and ozone optical depth based on Total Ozone Mapping Spectrometer (TOMS) data [14]. Angstrom exponent is obtained from the spectral dependence of aerosol optical depth (τ_a) observed at 400, 500, 675, 870 and 1020 nm wavelengths using the relationship $\tau_a(\lambda) = \beta\lambda^{\alpha}$, where α is Angstrom exponent and β is a turbidity coefficient [17].

The whole data has been classified into four seasons as per IMD, namely winter (December, January and February), pre monsoon (March, April and May), monsoon (June, July and August) and post monsoon (September, October and November). Delhi (28.38 N, 77.10 E, 235 masl) exhibits a semiarid climate with extreme weather conditions.

3. RESULTS AND DISCUSSION

3.1 Aerosol Optical Depth (AOD) and Angstrom Exponent (α)

In this section, the monthly average values of AOD and α have been calculated from the daily data retrieved from SKYRAD.PACK, to further estimate the seasonal average values. Fig. 1 represents the seasonal variation of AOD (at 380 nm and 1020 nm) and Alpha for 2013. AOD exhibits strong seasonal and wavelength dependence. Higher AOD is observed with corresponding lower α values during monsoon season. During winter, the AOD values are relatively higher and corresponding α value are also high as evident from December to March, indicating prominence of fine mode particles during winter. However, significant increase in AOD is observed from April onwards with maximum in July (1.75±0.52 and 0.82±0.32) at 380 and 1020 nm respectively, reflecting the influence of coarse mode dust aerosols as well as aerosols of anthropogenic origin. Higher α value is found during post monsoon, associated with lower values of AOD, due to wash out of dust by rain. It is evident that there is relatively strong spectral dependence of optical depth at shorter wavelengths (380nm) than longer wavelengths (1020nm), as the magnitude of AOD decreases with increase in wavelength in every month which indicates the presence of high ratio of small particles to large ones [15].

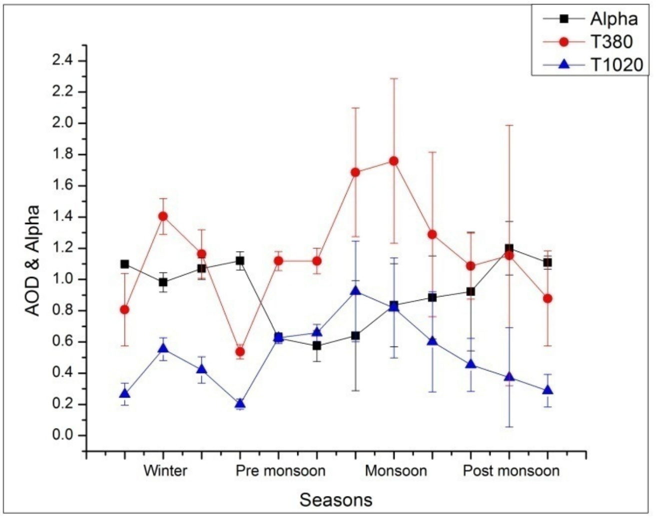

Fig.1 Seasonal variation of AOD (at 380 & 1020nm) and Angstrom Exponent (Alpha) over Delhi during 2013.

3.2 Single Scattering Albedo (SSA) and Asymmetry parameter (ASY)

SSA and ASY are critical parameters for estimation of aerosol radiative forcing. SSA is defined as the ratio of scattering efficiency to total extinction efficiency of an aerosol particle that is exposed to an incident electromagnetic wave and is given by: SSA = $\sigma_{scat}/(\sigma_{scat} + \sigma_{abs})$ where σ_{scat} is scattering coefficient and σ_{abs} is the absorption coefficient [16]. The asymmetry parameter (ASY) is a single-valued representation of the angular scattering and a key property controlling the aerosol contribution to radiative forcing.

SSA thus obtained from SKYRAD.PACK at wavelengths 380 and 1020 nm has been plotted as monthly average during 2013 along with the Asymmetry Parameter in Fig. 3. Both the parameters show large spectral dependence with lower values at longer wavelength in all seasons, except that SSA shows a reversed trend in monsoon months. The summary of seasonal average values of Alpha, AOD, SSA and ASY are depicted in table.1.

Table .1: Seasonal mean Alpha, AOD (T380 &T1020), SSA (S380 &S1020) and ASY (A380 &A1020) along with ± 1σ standard deviation at Delhi during 2013.

Seasons	Alpha	T380	T1020	S380	S1020	A380	A1020
Winter	1.050±0.023	1.125±0.059	0.413±0.008	0.886±0.002	0.848±0.003	0.715±0.002	0.643±0.004
Pre-monsoon	0.773±0.033	0.924±0.022	0.495±0.014	0.865±0.004	0.841±0.002	0.736±0.004	0.697±0.009
Monsoon	0.786±0.050	1.578±0.066	0.781±0.001	0.846±0.002	0.857±0.005	0.731±0.002	0.677±0.008
Post-monsoon	1.077±0.170	1.039±0.336	0.371±0.110	0.883±0.017	0.837±0.019	0.721±0.004	0.661±0.019

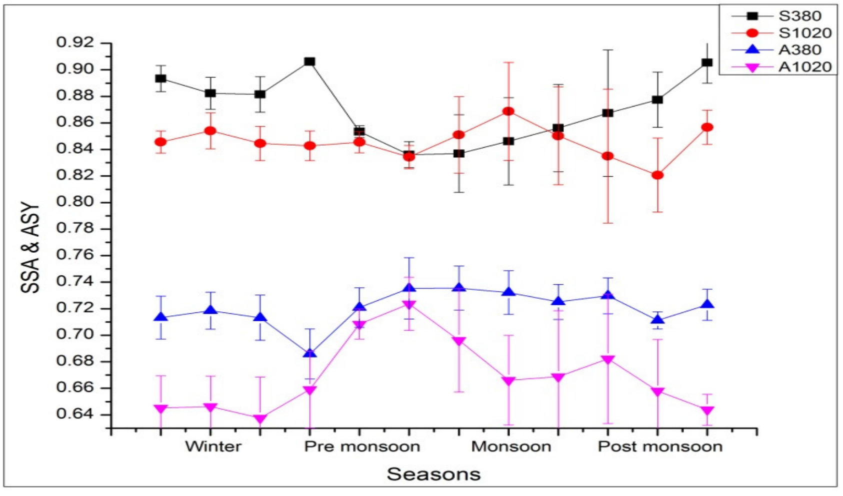

Fig. 2: Seasonal Variation of SSA and ASY (at 380 & 1020 nm) over Delhi during 2013

From Fig.2, average SSA is observed to be more than 0.8 during all seasons at both the wavelengths. Higher SSA is observed during winter season. Whereas, relatively lower values in pre-monsoon is attributed to abundance of desert dust aerosols over Delhi, which are absorbing in nature. The average ASY during the period had a minimum value at 0.715±0.002 and 0.643±0.004 during winter and maximum at 0.736±0.004 and 0.697±0.009 during pre monsoon.

3.3 Direct aerosol radiation forcing

Aerosol Radiative Forcing (ARF) at any layer of the atmosphere is defined as the difference of net fluxes at the Top of the atmosphere (TOA) and at the surface with and without aerosols, keeping all other parameters constant [7]. In the present study, direct aerosol radiation forcing (DARF) has been estimated at the surface and at top of the atmosphere. The sky radiometer derived aerosol properties have been used as input into the SBDART (*Santa Barbara DISORT Aerosol Radiative Transfer)* model, to compute DARF. The parameters critical for DARF estimations are the AOD, single scattering albedo (SSA), asymmetry parameter, surface albedo, profiles of atmospheric parameters (temperature, humidity, ozone and other gases), and solar geometry of location. The average variation in DARF obtained over Delhi at surface; TOA and atmosphere every month during 2013 is depicted in Fig. 4. The DARF at the surface is found to be maximum (negative) during monsoon months of June (-117 W m^{-2}) and minimum (negative) during March (-33.6 W m^{-2}). Similarly, the TOA forcing was maximum in September (-48.8 W m^{-2}) and minimum during March (-14.8 W m^{-2}). The DARF in the atmosphere showed maximum value in June (90.6 W m^{-2}) and minimum in March (18.8 W m^{-2}).The general trend in radiative forcing was found to be decreasing during winter and increasing during summer or monsoon months over Delhi.

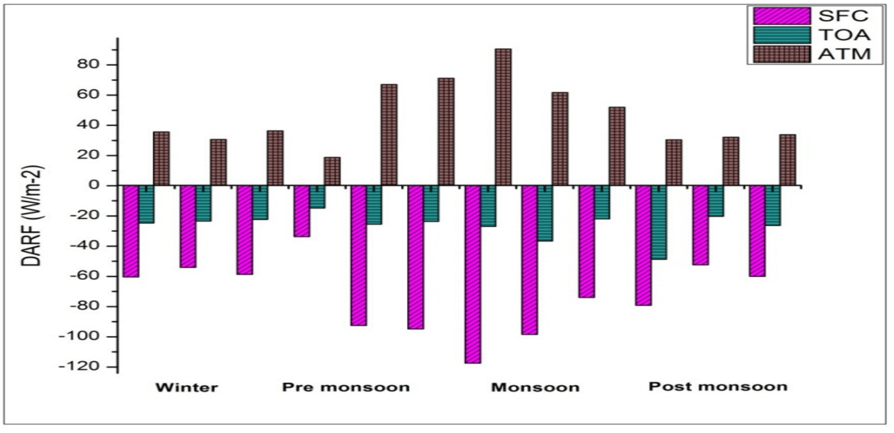

Fig.4: Seasonal variation DARF at Surface (SFC), Top of atmosphere (TOA) and Atmosphere (ATM)

4. CONCLUSIONS

The monthly and seasonal variations in AOD, Angstrom Exponent, SSA and Asymmetry parameter were investigated over Delhi during the period of one year using Sun-Skyradiometer retrievals. The data were explored over shorter (380nm) and longer (1020nm) wavelengths to study the spectral dependence of aerosol optical properties. The AOD showed peaks during pre monsoon months due to heavy load of desert dust. Maximum value of alpha occurred in March 1.12±0.06, indicating prominence of fine mode particles and minimum value of 0.57±0.09 in May indicating presence of large size dust particles. The monthly average SSA over Delhi is found to be in the range 0.83 to 0.90 at 380nm which is largely affected by aerosols produced by anthropogenic activities and 0.82 to 0.87 at 1020nm. The monthly average DARF in the atmosphere was found to be in the range 18.82 to 90.63 W m^{-2} throughout the year at Delhi.

5. ACKNOWLEDGEMENT

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