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Investigation on seasonal variations of aerosol properties and its influence on radiative effect over an urban location in central India

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HIGHLIGHTS

- ADRE at TOA during winter is −11.7 Wm^{-2} and in pre-monsoon it is −5.5 Wm^{-2}.
- An enhancement of atmospheric forcing of ~50 Wm^{-2} is observed during pre-monsoon.
- Heating rate due to biomass burning and dust storm on local atmosphere are ~2.26 and 2.08 K day^{-1}, respectively.

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ABSTRACT

Aerosol plays an important role in modulating solar radiation, which are of great concern in perspective of regional climate change. The study analysed the physical and optical properties of aerosols over an urban area and estimated radiative effect using three years *in-situ* data from sunphotometer, aethalometer and nephelometer as input to radiative transfer model. Aerosols properties indicate the dominance of fine mode aerosols over the study area. However presence of coarse mode aerosols is also found during pre-monsoon [March-April-May]. Daily mean aerosol optical depth showed a minimum during winter [Dec-Jan-Feb] (0.45–0.52) and a maximum during pre-monsoon (0.6–0.7), while single scattering albedo (ω) attains its maximum (0.78 ± 0.05) in winter and minimum (0.67 ± 0.06) during pre-monsoon and asymmetry factor varied in the range between 0.48 ± 0.02 to 0.53 ± 0.04. Episodic events of dust storm and biomass burning are identified by analyzing intrinsic aerosol optical properties like scattering Ångström exponent (SAE) and absorption Ångström exponent (AAE) during the study periods and it has been observed that during dust storm events ω is lower (~0.77) than that of during biomass burning (~0.81). The aerosol direct radiative effect at top of the atmosphere during winter is −11.72 ± 3.5 Wm^{-2}, while during pre-monsoon; it is −5.5 ± 2.5 Wm^{-2}, which can be due to observed lower values of ω during pre-monsoon. A large positive enhancement of atmospheric effect of ~50.53 Wm^{-2} is observed during pre-monsoon compared to winter. Due to high aerosol loading in pre-monsoon, a twofold negative surface forcing is also observed in comparison to winter.

1. Introduction

Atmospheric aerosols and their impact on climate have gained considerable attention from scientific community and policy makers during past recent years [IPCC, 2013]. Aerosols effects on climate are mainly classified into two viz. aerosol direct radiative effect (ADRE) and indirect radiative effect. ADRE [Charlson et al., 1992] is associated with scattering or absorbing of incoming solar radiation by aerosols thereby, producing a negative or positive radiative effect at Top of the Atmosphere (TOA). Scattering aerosols like sea salt, sulphate etc. induce climate cooling, while absorbing aerosols like black carbon (BC) induce a warming effect at TOA [Bond et al., 2013]. Indirect radiative effect is the mechanism by which aerosols alter microphysical and radiative properties of clouds, thereby influencing albedo, lifetime and precipitation of clouds [Ramanathan et al., 2001]. Jacobson [2001] has pointed that radiative properties of aerosols depends also on its mixing state, that is the degree to which chemical components occur as independent particles (external mixing) as compared to a component mixture in each individual particle (internal mixing). Mixing state

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of aerosols will be extremely important while considering impact due to long range transported aerosols [Chinnam et al., 2006]. Global estimation of ADRE is found to be varied from −0.85 to +0.15 $Wm^{-2}$with an uncertainty of 1 Wm^{-2} [IPCC 2013]. Uncertainty involved in ADRE estimation is due to ambiguities associated with sources, lifetime, distribution etc. [Anderson et al., 2003].

Uncertainty associated with ADRE can be minimized to some extend by their accurate characterization [Quinn et al., 1998]. Towards this, many international and national efforts have initiated like Aerosol Robotic Network (AERONET) [Holben et al., 1998], SKYNET [Takamura and Nakajima, 2004], Aerosol Radiative Forcing Over India Network (ARFI Net) [Moorthy et al., 2009] etc. to list a few. In addition to this, past decade have viewed a number a campaigns for regional aerosol characterization over water bodies like INDOEX [Ramanathan et al., 2001]; ACE-1 [Bates et al., 1998] and also over distinct land masses like ACE-Asia [Huebert et al., 2003]; SAFARI-2000 [King et al., 2003] etc. These efforts have brought out diverse physical and optical properties of varied aerosol species, which in turn has helped to minimize their uncertainty in determining their radiative effect.

Because of their high spatio-temporal heterogeneity it is speculated that aerosols may be more capable of altering atmospheric and oceanic circulation, especially on regional scale, than greenhouse gases [Ming and Ramaswamy., 2011]. Present study aims at better estimation of ADRE over an urban location, Hyderabad in Central India using *in-situ* data of 2010–2012 as input to radiative transfer model. Novelty of this study is that critical aerosol optical parameters (viz. Aerosol Optical Depth (τ or AOD), Single Scattering Albedo (ω or SSA) and asymmetry factor (g) etc.) required for estimation of ADRE are either measured or derived from *in-situ* observations.

Section 2 of this paper describe about study area, data sets and methodology. Sensitivity analysis of estimated ADRE is discussed in Section 3. In Section 4, seasonal variation of aerosol radiative properties and associated radaitive effect are discussed. Further aerosol episodic events (viz. dust storm and biomass burning) which had impact on local aerosol system are identified and analysed. Conclusions are presented in Section 5.

2. Study area, data set and methodology

2.1. Study area

Hyderabad is the capital of newly formed state Telangana in Central India, with a population of more than 4 million (http://censusindia.gov.in). Altitude of the study site is ~557 m above mean sea level. It has a hot semi-arid steppe climate with four dominant seasons; winter (Dec-Jan-Feb), pre-monsoon (Mar-Apr-May), monsoon (Jun-Jul-Aug-Sep) and post-monsoon (Oct-Nov). Meteorological parameters recorded at India Meteorological Department (IMD) (www.imd.gov.in), Begumpet, Hyderabad over a period of 1997–2012 is analysed. Study revealed that long term daily mean of maximum (T_{max} = 36.1 °C) and minimum temperatures (T_{min} = 17.54 °C) are similar to that was observed during the study period of 2010–2012 (T_{max} = 36.0 °C and T_{min} 17.33 °C). However, analysis of diurnal variation of temperature recorded during study period shows that T_{max} and T_{min} are ~42 °C and ~16 °C, respectively. Long term (1997–2012) mean relative humidity varies between 40 and 80% with lowest observed during pre-monsoon and maximum during monsoon. Local wind speed varies typically from 5 to 15 ms^{-1}, with a maximum observed during monsoon. Long term (1957–2012) annual mean of rainfall over Hyderabad is ~827 mm, while annual rainfall during study period 2010–2012 is found to be 1192 mm, 625 mm and778 mm, respectively. Aerosol measurements are carried out at the campus of National Remote Sensing Centre (NRSC) (17.47° N, 78.43° E) located in heart of the city. The sampling site is near to state high way and main sources of aerosols are from vehicular emission, local/long range transport of dust aerosols, biomass burning and industrial emissions [Jose et al., 2015b].

2.2. Data set and methodology

2.2.1. Aerosol optical depth

Microtops II (Solar lights, USA) is a hand held sun photometer that measures spectral aerosol optical depth τ at five narrow spectral bands centered at 380, 440, 500, 675 and 870 nm with a wavelength precession of ±1.5 nm and a full width at half maximum (FWHM) band pass of 10 nm. Details about design, calibration and performance of Microtops are detailed in Morys et al., [2001]. It makes use of Beer-Lamberts-Bouguer law for estimation of τ. In general uncertainties associated with 'τ' measurements by Microtops is < 0.02 for lower wavelength bands and <0.01 for higher bands [Porter et al., 2001]. In the present study, data were collected only during clear days with a sampling frequency of 30 min.

Spectral dependence of τ can be expressed using well-known Ångströms empirical relation [Ångström, 1964,] where, τ_λ is the aerosol optical depth at λ, 'β' is the Ångström turbidity coefficient which equals τ at λ = 1 μm and 'α' is the Ångström exponent. 'α' provides information about aerosol size distribution and Ångström turbidity coefficient (β) gives an idea about atmospheric condition [Eck et al., 1999]. Daily observed τ and derived α is then averaged to obtain a daily mean, which forms basic data set for further analysis.

2.2.2. Aerosol scattering coefficient

A calibrated integrating Nephelometer (TSI- 3563, USA) is used to measure scattering coefficient of aerosols during the study period. It measures aerosol scattering and back scattering coefficient at three different wavelengths viz. 450, 550 and 700 nm with high sensitivity and proven accuracy [Anderson et al., 1996]. Its principle of operation is well documented in literatures [Anderson et al., 1996]. It is operated at a flow rate of 20 LPM with a data averaging time of 300 s during study period. We followed Anderson and Orgen, [1998] to correct measurement biases due to non-angular idealities.

Parameter g, which is the mean value of Cosine of scattering angle over the total solid angle weighted by the phase function is calculated using an empirical relation relating backscattering fraction (b) provided by Andrews et al., [2006]. Uncertainty associated with g calculated using the above method is generally less than 10% [Niranjan et al., 2011].

2.2.3. Estimation of aerosol absorption coefficient

Aerosol absorption measurements are carried out using a seven channel Aethalometer (AE-31, Magee Scientific, USA) for the same study period. It measures light attenuation at seven wavelengths (370, 470, 520, 590, 660, 880 and 950 nm) through a quartz filter matrix in which particles get deposited. It is operated at a flow rate of 3 LPM with a data averaging time of 5min. Differences in light transmission through particle laden spot and blank portion of filter are attributed to attenuation, which is directly proportional to raw absorption coefficient [Hansen et al., 1984]. There are several literatures explaining methodologies for rectifying the above raw absorption coefficient [Arnott et al., 2005; Weingartner et al., 2003]. In this study we adopted methodology proposed by Arnott et al., [2005]. The expected uncertainties in the estimation of σ_{abs} using this methodology are generally less than 10%.

Simultaneous measurements on absorption and scattering are