Atmospheric Pollution Research 6 (2015) 138-146

Atmospheric Pollution Research

www.atmospolres.com

Radiative implication of a haze event over Eastern India

Subin Jose [1], Biswadip Gharai [1], Y. Bhavani Kumar [2], Pamaraju Venkata Narasimha Rao [1]

[1] *Atmospheric and Climate Sciences Group, ECSA, National Remote Sensing Centre (NRSC), Balanagar, Hyderabad–500 037, India*
[2] *National Atmospheric Research Laboratory (NARL), Gadanki–517112, India*

ABSTRACT

Aerosol haze degrades visibility by the process of absorption and scattering of aerosols. In the present study an attempt has been made to characterize the physical and optical properties of aerosols during a haze event on 29 March 2012 and assess its implication on radiative forcing. In this context representative clear (2 March 2012) and normal (19 March 2012) days were identified in terms of their Aerosol Optical Depth (AOD) loading over Hyderabad. On the hazy day, a huge spread of haze was observed over the eastern part of India by MODerate resolution Imaging Spectroradiometer (MODIS) on board Terra satellite which is represented by high Aerosol Optical Depth at 550 nm. In–situ observations on hazy day showed an enhancement of columnar AOD_{500} respectively by 4.5 and 1.8 fold in comparison to clear and normal days. Significant increase in the scattering coefficient and a moderate enhancement of Single Scattering Albedo (SSA) are observed on hazy day compared to normal day. Study also showed that Diffuse–to–Direct– beam irradiance Ratio (DDR) had increased 4.5 times at 496.6 nm spectral band on hazy day. LIDAR (LIght Detection And Ranging) observations on hazy night showed a threefold increase in aerosol backscattering below the Atmospheric Boundary Layer (ABL) compared to normal representative night. The hazy day is characterized by large negative surface forcing (–87.82 W m^{-2}) when compared to normal day (–53.90 W m^{-2}). A large positive enhancement of atmospheric forcing of 30.56 W m^{-2} is observed on hazy day compared to normal day.

Keywords: *Absorption, scattering coefficient, DDR, aerosol backscattering, ARF*

Corresponding Author:
Biswadip Gharai
☎ : *+91-040-23884476*
🖷 : *+91-040-23875932*
✉ : *g.biswadip@gmail.com*

Article History:
Received: 03 April 2014
Revised: 10 August 2014
Accepted: 11 August 2014

doi: 10.5094/APR.2015.016

1. Introduction

Haziness or degree of haze is a measure of light scattering and absorption by aerosols (Husar et al., 1981). Hence it plays a vital role in Earth's radiative balance (Ramanathan et al., 2001) and in visibility degradation (Watson, 2002; Zhang et al., 2010). It is one of the visible effects of air pollution observed most widely by many researchers (Husar et al., 1981). These aerosols can be transported over thousands of kilometers under favorable metrological conditions and reside in the atmosphere for days to weeks (Houghton, 1996), creating a contiguous layer of enhanced concentration of aerosols before being removed from the atmosphere (Fearnside et al., 2005). On regional scale, large spatial extent of haze can create a significant perturbation in Earth's radiative balance as it not only restricts solar radiation to reach the surface but also reduces the rate of long wave emission from the surface (Charlson et al., 1992; Schwartz and Andreae, 1996). A solar radiation deficit of around 7.5% was reported by Ball and Robinson (1982) in some parts of the United States due to haze events.

Since late 1970's natural and anthropogenic atmospheric haze and its spatial and temporal distribution has been creating a lot of interest among the researchers and since then there is a constant effort to understand the physical and chemical properties of haze and its formation mechanisms (Husar et al., 1987). Haze is influenced by its emitting sources, transport, transformation and its removal from the atmosphere (Husar et al., 1981). Sulfate (SO_4^{-2}) has been identified as the dominant species associated with summer haze in Eastern U.S (Wolff, 1984). Tan et al. (2009) have indicated a remarkably rapid increase of secondary pollutants and a significantly higher Organic Carbon (OC)/Elemental Carbon (EC) ratio on a hazy day to a normal day in Guangzhou, China.

Over India, one of the highly populated and fast developing countries, haze/fog is a frequent phenomena under favorable meteorological conditions during the winter but the causes of summer haze are different. Summer haze over these regions is mainly caused by forest fires and agricultural crop residue burning which emits remarkable amounts of carbonaceous and traces gases to the atmosphere (Tripathi et al., 2006; Ramanathan et al., 2007; Badarinath et al., 2009). By these emissions, atmospheric chemistry gets altered and thereby radiative budget of the troposphere. A specific thrust was given during 1999 INDian Ocean EXperiment (INDOEX) campaigns, to understand the role of anthropogenic emissions in formation of Asian haze and its effect on altering radiation budget (Ramanathan et al., 2001). Over Indo Gangetic Plain (IGP), which is characterized as a hot spot of anthropogenic emissions in south Asia (Ramanathan et al., 2007), a nearly 30% increase in EC, OC and Water Soluble Organic Carbon (WSOC) was reported by Ram et al. (2012) during haze and fog events.

Aerosol Radiative Forcing (ARF) can be defined as the variations in the radiative flux at the surface and Top of the Atmosphere (TOA) due to change in aerosol amounts in the atmosphere. ARF depends upon not only aerosols' physical and optical properties but also their horizontal and vertical extent. Based on different kinds of natural or anthropogenic sources of origin, physical and optical properties of aerosols are varying. Aerosols can change their properties during transport as different aerosols often clump together to form complex mixtures. The sign

and magnitude of the aerosol radiative forcing changes based on different aerosol properties (Satheesh and Moorthy, 2005). Sulfate aerosols back scatter the solar radiation and thereby enhance the planetary albedo. In these process sulfate aerosols cools the Earth surface (negative forcing). While in case of absorbing aerosols like Black Carbon (BC), they can change the sign of forcing from negative to positive causing a heating effect (Heintzenberg et al., 1997). When black carbon particles from soot or smoke mix with nitrates and sulfates, or coat the surfaces of dust, they create hybrid particles and thereby alter radiative forcing in a complex way. Because of the inherent problems with satellite observations it is very difficult to characterize the atmospheric aerosols, which enhance the uncertainty in estimating their overall climatic effect (Morgan et al., 2006; Remer and Kaufman, 2006; Yu et al., 2006). Therefore to reduce the uncertainty in estimating ARF, well calibrated in–situ observations are required in conjunction with radiative transfer models and satellite observations.

The main objectives of the present study were to analyze the aerosol properties during a typical hazy day and their implications on radiation using in–situ and satellite based observations. Aerosols' radiative implications during haze event were compared with a clear and a normal day.

2. Site Description

Present study was conducted at the premises of National Remote Sensing Centre (NRSC), Hyderabad (17.47 N, 78.43 E). Hyderabad is the capital of the 5th largest populated state, Andhra Pradesh (84.7 million) in India. Hyderabad alone has a population of 4.01 million (http://censusindia.gov.in/). Vehicular and other anthropogenic emissions are the major sources in the city but episodic long–range transport of dust and emissions from forest fires and agricultural residue burning also influence the city. The four dominant seasons prevailing here are winter (December–February), pre–monsoon (March–May), monsoon (June–September) and post–monsoon (October–November). Fifty years (1951–2000) climatology data of Hyderabad obtained from India Meteorological Department (www.imd.gov.in) shows the maximum and minimum temperatures occur during the months of May and December respectively. The peak maximum temperature of 41.4 °C was recorded during the year 1984 and the lowest value of minimum temperature (10.1 °C) was recorded during 1970. The average annual rainfall of Hyderabad is ~830 mm.

3. Data Sets and Methodology

A number of in–situ along with satellite based measurements were used to study the impact of aerosols on solar radiation during a haze event and are listed in Table 1. Following are the satellite, ground based instruments and radiative transfer model used in the present study.

3.1. Satellite based observations

Terra/Aqua–MODIS. MODerate Resolution Imaging Spectroradiometer (MODIS) (Salomonson et al., 1989; King et al., 1992) is a key instrument onboard TERRA/AQUA satellites having 36 spectral channels. It acquires data in three different spatial resolutions of 250 m (channels 1 and 2), 500 m (channels 3 to 7), and 1 km (channels 8 to 36) covering visible, near infrared, short–wave infrared, and thermal–infrared channels capable of remote sensing clouds, aerosols and water vapor. In the present study, reflective data during a hazy day was obtained from LAADS web site (Level 1 and Atmosphere Archieve and Distribution System). Level 1 MODIS data (HDF EOS), channels 1 (0.645 µm), 3 (0.469 µm) and 4 (0.555 µm) was passed through HDF–EOS Geo Tiff Conversion Tool to reformat and re–project the data. True color composite (Channels 1, 4, 3 combination) of Terra MODIS was used for visual analysis. Level 3 MODIS AOD data at 550 nm obtained from Giovanni site (http://disc.sci.gsfc.nasa.gov/giovanni) was used to analyze the spatial variations of aerosol loading.

3.2. Ground based observations

Sun Photometer. Ground based measurements on aerosols and columnar water vapor content were carried out using Microtops–II sun photometer (Solar instruments, USA) at wavelengths 380 nm, 440 nm, 500 nm, 675 nm, 870 nm and 1 020 nm (Morys et al., 2001). It provides instantaneous AOD by measuring instantaneous solar flux in conjunction with a set of calibration constants and location information from an in–built GPS receiver. Angstrom coefficients (α and β) were calculated using Angstrom relation (Angstrm, 1961; Angstrom, 1961) as:

$$AOD_\lambda = \beta \lambda^{-\alpha} \quad (1)$$

where, AOD_λ is the approximated aerosol optical depth at the wavelength λ, β is the Angstrom's turbidity coefficient, which equals AOD_λ at λ=1 µm, and α is the Angstrom exponent. The Angstrom parameter α is a measure of the ratio of accumulation mode to coarse mode concentrations of the columnar aerosols with higher values representing increased abundance of accumulation mode aerosols (Dumka et al., 2011). The turbidity coefficient β is a measure of the total aerosol loading in the atmosphere (Shaw et al., 1973; Satheesh and Moorthy, 1997). In general uncertainty in microtops measurement are <0.02 for lower wavelength and it is <0.01 for higher wavelengths (Porter et al., 2001; Ichoku et al., 2002) and uncertainties associated with pressure correction for molecular optical depth estimation is ~0.3% at the pressure of 1 013 mb.

Aethalometer. Absorbing black carbon measurements were carried out using AE31 Aethalometer (Magee Scientific, USA). In this instrument, air was passed through a quartz fiber filter tape for a fixed amount of time with a pre–selected flow rate of 3 LPM. Due to deposition of aerosols on fiber tape, light attenuated and this attenuation was measured by Aethalometer at seven wavelengths (370 nm, 470 nm, 520 nm, 590 nm, 660 nm, 880 nm and 950 nm) with 880 nm being the recommended channel for BC measurements. In the present study, spectral absorption coefficient (b_{abs}) was calculated from the attenuation measurements at different wavelengths by adopting the method suggested by Weingartner et al. (2003). Inherent uncertainties in the filter based absorption measurements were discussed elsewhere (Arnott et al., 2005). Uncertainty associated with the Aethalometer measurement is around 10% as reported by the manufacturer.

Nephelometer. Using a well calibrated integrated Nephelometer (TSI 3563, TSI Inc, USA), total and back scattering coefficients of aerosols were measured at three wavelengths (450 nm, 550 nm and 700 nm) during study days. Subsequently aerosol scattering coefficients (σ) were calculated after removing the angular non–idealities following the method suggested by Anderson and Ogren (1998). Details of uncertainties associated with Nephelometer measurements were described by Anderson et al. (1996). They have experimented using nearly monodisperse particles in laboratory and found that predicted and actual Nephelometer (TSI 3563) measurements agreed within experimental uncertainties of ±10%.

Calculated absorption and scattering coefficients were used to derive important aerosol optical properties like extinction coefficient (ε), Single Scattering Albedo (SSA) and asymmetry factor (g). SSA is defined as the ratio of the scattering to the extinction, which can be written as:

$$SSA = \sigma/\varepsilon \quad (2)$$

where, ε is the extinction coefficient defined by the summation of absorption and scattering coefficients.