ARTICLE IN PRESS
STOTEN-21504; No of Pages 10
Science of the Total Environment xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Science of the Total Environment
journal homepage: www.elsevier.com/locate/scitotenv

Atmospheric aerosol radiative forcing over a semi-continental location Tripura in North-East India: Model results and ground observations

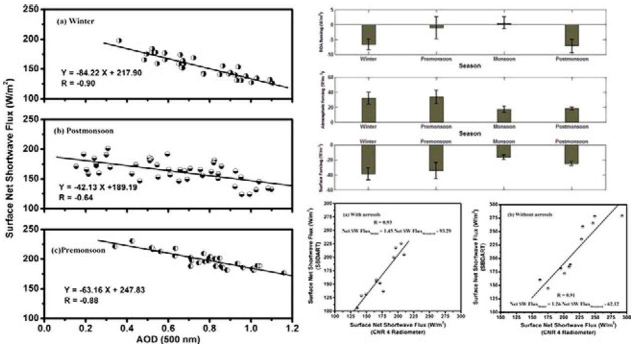
Pranab Dhar [a], Barin Kumar De [a], Trisanu Banik [a], Mukunda M Gogoi [b], S. Suresh Babu [b], Anirban Guha [a],*

[a] *Department of Physics, Tripura University, Suryamaninagar 799022, India*
[b] *Space Physics Laboratory, Vikram Sarabhai Space Centre, Thiruvananthapuram 695022, India*

HIGHLIGHTS

- The top of the atmosphere (TOA) forcing is negative during all the seasons.
- High atmospheric forcing corresponds to high aerosol optical depth (AOD) value.
- The increased atmospheric forcings are observed during winter and premonsoon.
- Net shortwave surface fluxes from model and observations are highly correlated.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 12 August 2016
Received in revised form 25 November 2016
Accepted 27 November 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Black carbon concentration
Aerosol optical depth
Single scattering albedo
Aerosol radiative forcing

ABSTRACT

Northeast India (NEI) is located within the boundary of the great Himalayas in the north and the Bay of Bengal (BoB) in the southwest, experiences the mixed influence of the westerly dust advection from the Indian desert, anthropogenic aerosols from the highly polluted Indo-Gangetic Plains (IGP) and marine aerosols from BoB. The present study deals with the estimation and characterization of aerosol radiative forcing over a semi-continental site Tripura, which is a strategic location in the western part of NEI having close proximity to the outflow of the IGP. Continuous long term measurements of aerosol black carbon (BC) mass concentrations and columnar aerosol optical depth (AOD) are used for the estimation of aerosol radiative forcing in each monthly time scale. The study revealed that the surface forcing due to aerosols was higher during both winter and pre-monsoon seasons, having comparable values of 32 W/m^2 and 33.45 W/m^2 respectively. The atmospheric forcing was also higher during these months due to increased columnar aerosol loadings (higher AOD ~0.71) shared by abundant BC concentrations (SSA ~0.7); while atmospheric forcing decreased in monsoon due to reduced magnitude of BC (SSA ~0.94 in July) as well as columnar AOD. The top of the atmosphere (TOA) forcing is positive in pre-monsoon and monsoon months with the highest positive value of 3.78 W/m^2 in June 2012. The results are discussed in light of seasonal source impact and transport pathways from adjacent regions.

1. Introduction

Aerosols are known to influence the energy budget of the Earth-atmosphere system broadly in two ways. The first is the direct effect in which aerosols scatter and absorb the incoming solar and outgoing

---

* Corresponding author.
E-mail address: anirban1001@yahoo.com (A. Guha).

http://dx.doi.org/10.1016/j.scitotenv.2016.11.200
0048-9697/© 2016 Elsevier B.V. All rights reserved.

Please cite this article as: Dhar, P., et al., Atmospheric aerosol radiative forcing over a semi-continental location Tripura in North-East India: Model results and ground obser..., Sci Total Environ (2016), http://dx.doi.org/10.1016/j.scitotenv.2016.11.200

terrestrial radiations, thereby altering the radiative balance of the Earth-atmosphere system (Haywood et al., 1999). While scattering results in an increase in the atmospheric albedo and a consequent decrease in the amount of radiation reaching the Earth's surface and therefore represent a cooling effect (Charlson et al., 1992), aerosols such as black carbon (BC) and dust significantly absorb in the visible and IR spectrum leading to atmospheric warming and a surface cooling (Ramanathan et al., 2001). The second effect is the indirect involving aerosols modifying and altering the microphysical and optical properties of cloud such as cloud albedo, lifetime of clouds, and drop size distribution (Twomey, 1977; Boucher et al., 1998; Heymsfield and McFarquhar, 2001; Satheesh and Moorthy, 2005; Hansen et al., 2005).

The radiative impacts of aerosols depend mostly on the relative abundance of these scattering and absorbing species. Also, as a result of changes in airmass types and prevailing meteorological conditions, prominent variations in abundance of aerosol can occur regionally and seasonally at locations far away from potential sources (Babu and Moorthy, 2002). Therefore, radiative forcing presents a way to specify and determine the contribution of aerosol over surface and atmosphere by altering the incoming and outgoing radiative energy fluxes.

To estimate and determine the radiative impacts or ability to modify the Earth's radiation budget and regional climate forcing of aerosols, the microphysical and optical properties of atmospheric aerosols such as the aerosol optical depth (AOD), size distribution, single scattering albedo (SSA), scattering (s) and extinction coefficients, as well as information on their spectral dependencies are very much important (Charlson et al., 1992). The life-time of aerosol is of the order of days; they are inhomogeneous in time and in space having higher concentrations near the sources and hence are predominantly regionally distributed. The heterogeneous spatial and temporal distributions of aerosol are also responsible for different aerosol types in both spatial and temporal domain. This uncertainty can be reduced by documenting the seasonal variations in aerosol radiative forcing over different strategic locations in a region governed by different aerosol sources and also in a region which are highly affected by the advective transport of aerosol.

AOD is a key atmospheric parameter and is among the most commonly used aerosol properties to determine atmospheric aerosol loading and characteristics. It is a measure of extinction of solar radiation due to aerosol while propagating through a column of atmosphere. This parameter is of utmost importance in assessing the radiative forcing due to aerosols over a specific region. The information about the aerosol size distribution is contained in the spectral AOD which is used to compute two other important aerosol parameters, Angström exponent (α) and turbidity coefficient (β) using Angström's Power Law (Schuster et al., 2006; Kaskaoutis et al., 2007, 2010; Gogoi et al., 2008; Kedia and Ramachandran, 2009; Sharma et al., 2010, 2011). This law provides a quantitative indicator of the aerosol size distribution and provides information on the relative abundance of fine-to-coarse sized particles and a measure of total aerosol loading in a vertical column (Schuster et al., 2006; Gogoi et al., 2008; Kedia and Ramachandran, 2009; Kaskaoutis et al., 2010; Sharma et al., 2011). So, the characterization of this spectral dependence through the intuitive understanding and interpretation of optical depth spectra is very important in modeling the radiative effects of aerosols and the retrieval of its optical properties.

In light of the above, the present study focuses on the long term characteristics of aerosol optical depth (AOD) and black carbon (BC) from a rural continental site, Tripura in the North-Eastern part of India during the period from September 2010 to September 2014. The measured aerosol characteristics are analysed along with aerosol optical properties and radiative transfer models to estimate the aerosol radiative forcing over Tripura. The estimated monthly and seasonal shortwave aerosol radiative forcing is examined and reported in order to understand the climatic response of aerosol laden atmosphere over the region. In the present study we also have performed a comparison between the model estimated surface net shortwave flux and that obtained from direct measurements from observational site and obtained good correlation between model estimation and direct measurements.

2. Study location, site description and meteorology

The study location, Agartala (23.76°N and 91.26°E) is a semi-continental site in the north-eastern part of India, in the state of Tripura. The emission from a large number of automobiles that include buses, cars, two-wheelers (motorbikes and scooters), and three-wheelers (auto rickshaws), running through national highway 44A near the University campus contribute significantly to the production of aerosols, including black carbon (Guha et al., 2015). Transportation from the brick kiln around the study location also contributes to aerosol loading in addition to long-range transportation from other parts of the country. In addition, seasonal biomass burning activities in nearby villages and agricultural fields both in India and Bangladesh could be the other possible sources of aerosol loading. The state Tripura is land locked from three sides by Bangladesh and the measurement site is only 1 km away from the international border. Thus, any aerosol, if its source is at the Bangladesh, has high probability of transportation to the measuring side through advection.

For the present analysis, the months of the year are divided into four seasons, namely winter (December–February), pre-monsoon/summer (March–May), monsoon (June–September), and retreating monsoon/post-monsoon (October–November) depending on local meteorological conditions. The monthly mean minimum and maximum temperature, wind speed with wind direction, relative humidity and rainfall are shown in Fig. 1. Monthly mean minimum and maximum temperature shows higher value in monsoon (summer) season with values around 26 °C and 32 °C and is the lowest in winter with values 12 °C and 23 °C, respectively. During the study period, relative humidity is highest in monsoon with 85%– 90% and lowest is observed in premonsoon 70%–75%. Seasonally averaged rainfall is maximum in monsoon and minimum in retreating monsoon and winter. Winds are generally very weak, less than 1.2 m/s throughout the whole year showing little variation over the year. The wind speed is minimum in winter with wind speed of 0.2 m/s but it shows relatively higher value of 1.1 m/s in premonsoon and monsoon seasons. During postmonsoon and winter the observational location receives wind prominently from north direction whereas wind direction shifts to south and south east during premonsoon and monsoon seasons. The wind flow prominently from north direction in winter has a great influence in the concentration of BC aerosol and also aerosol loading in winter season.

3. Measurements

Measurements of spectral aerosol optical depths (AODs) and BC mass concentration have been made regularly employing a 5 channel Microtops Sunphotometer, and Aethalometer, respectively. The quality controlled data from September 2010 to September 2014 are used in the present study.

3.1. Aerosol optical depth

Measurements of direct solar flux were carried out in our observational site using a Microtops Sunphotometer (Solar Light Co., USA). Microtops-II is a 5-channel hand held sunphotometer used to measure the instantaneous aerosol optical depth simultaneously at five wavelength bands from individual measurements of direct solar flux, using a set of internal calibration constants. A GPS receiver attached with the photometer provides information about the location, altitude and time. The wavelengths are centred about 340, 380, 500, 675 and 870 nm, with a full width half-maximum bandwidth of 2 to 10 nm and a field of view of 2.5°. The AOD values at the respective wavelengths are recorded at an interval of half an hour from 08:00 to 17:00 IST during the days of observation. The AOD measurements are performed

Please cite this article as: Dhar, P., et al., Atmospheric aerosol radiative forcing over a semi-continental location Tripura in North-East India: Model results and ground obser..., Sci Total Environ (2016), http://dx.doi.org/10.1016/j.scitotenv.2016.11.200