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Impacts of Reduced Anthropogenic Aerosols on The Atmospheric Parameters and Radiative Forcing Around a Highly Pollutant Metropolis

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Abstract

Present study aimed towards investigating the aerosol environment of the region around a pollutant metropolis Kolkata (22° 34′E, 88° 22′N) and comparing the atmospheric parameters in the pre-monsoon periods of 2019 and 2020. The pre-monsoon period of 2020 experienced the nationwide lockdown in India due to COVID-19 pandemic. A significant reduction in the anthropogenic activities can be seen in the satellite measurements of BC in the 2020 which is the dominant absorbing aerosol for solar radiation. The reduction in BC emission leads to lowering of near surface temperature at and around the city. Angstrom exponent values, indicative of different sources of BC, show lowering of fossil fuel emission. The source identification using back-trajectory and concentration weighted (CWT) trajectory analysis has been made to present different scenarios in the two-consecutive years. The changes in the anthropogenic emission resulted in decreased single scattering albedo showing an increased positive radiative forcing at the top of the atmosphere.

1 Introduction

The particulate matters (PM) in urban areas are the resultant of incomplete fossil fuel combustion, industrial emissions, and of biomass burning and natural wildfires [1]. PM generated from the combustion of both fossil fuel and biomass burning consists of black carbon (BC) and organic carbon (OC) respectively [2]. Although BC is a short-lived pollutant (<5 days), the absorption of incoming solar radiation by black carbon significantly affects the radiative properties, resulting in a significant positive forcing effect [3]. The increase in radiative forcing due to the absorption of solar energy by BC has a significant impact on global warming [4]. It has been reported that BC emitted by fossil fuel combustion causes much more warming of the atmosphere than that from biomass burning [5]. The current COVID-19 pandemic situation has forced the Governments all over the globe to impose countrywide partial or complete lockdown, limiting anthropogenic activities to a large extent [6]. In India, to contain the spread of COVID-19, a nationwide lockdown was implemented during the pre-monsoon period (March-May) of 2020 in different phases. Kolkata (22° 34′E, 88° 22′N), a metropolitan city, one of the most densely populated cities in India. The traffic load is quite heavy in the city and surrounding areas throughout the year. Months of March to May are considered as the pre-monsoon season when ambient temperature is higher compared to the other seasons [7]. Hence in the present study the changes in radiative forcing have been assessed over Kolkata during the lockdown period when usual anthropogenic activities drastically reduced. The study has utilized BC measurements from an aethalometer, satellite data and model outputs. This will help to formulate the BC mitigation strategies in future once the lockdown is over.

2 Data & Methodology

A seven-channel aethalometer (AE-31; Magee Scientific) is operated at Institute of Radio Physics and Electronics, University of Calcutta to measure near-surface black carbon concentration at seven wavelengths (370, 470, 520, 590, 660, 880, and 950 nm). The aethalometer intakes ambient air through a cyclone inlet with 5 min interval at a selected flow rate of 3 l/min. Absorption Angstrom Exponent (AAE) is calculated from the aerosol absorption coefficient (b_{abs}), which is a product of BC concentration and Mass Absorption Efficiency (MAE). MAE for 370, and 880 nm wavelengths are 18.47, and 7.77 m^2 g^{-1}, respectively provided by the aethalometer manufacturer. In the present study, AAE values are calculated for two-wavelength pairs (370 and 880 nm) using the relations presented by Goel et al. (2020). The probable BC source identification has been done considering AAE values. The lower values are associated with the fossil fuel sources, and the higher values show influence of biomass burning [8].

Satellite reanalysis data from MERRA-2 have been used to investigate the variations of temperature and black carbon extinction coefficient during the pre-monsoon of 2019 and 2020. OMI data of single scattering albedo (SSA) from NASA data archive have also been used in the present work to study the radiative forcing.

National Centers for Environmental Prediction and National Center for Atmospheric Research (NCEP/NCAR) global reanalysis data products of National Oceanic and Atmospheric Administration (NOAA) (ftp://arlftp.arlhq.noaa.gov/pub/ archives/reanalysis) have been used in back trajectory analysis. The trajectories are drawn by using TrajStat (Trajectory Statistics) software using Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model for atmospheric trajectory and dispersion calculations. Concentration Weighted Trajectories (CWT) analysis has also been made to show the probable sources of BC [2].

3 Results and Discussions

The present study highlights the changes in aerosol environment around Kolkata in 2020 compared to 2019 pre-monsoon period. The black carbon extinction coefficients from MERRA-2 are shown in Figure 1 which indicate significant reduction in BC values around Kolkata. In situ BC measurement reported earlier by Jana et al. (2021) and Rakshit et al., (2021), also supported the reduction in anthropogenic emission.

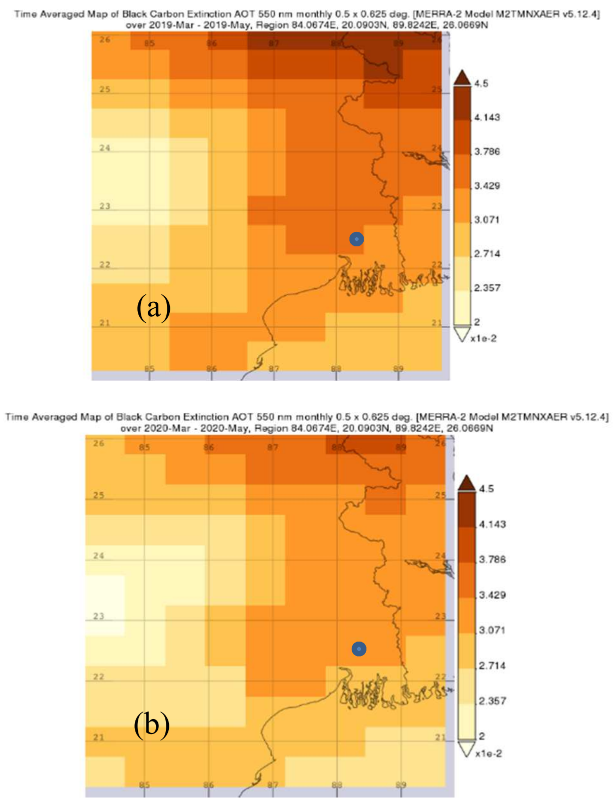

Figure 1. The mean BC extinction coeffoicient from MERRA-2 model data for the pre-monsson period of (a) 2019 and (b) 2020. Dot indicates the location of Kolkata.

Since BC particles are good absorber of incoming solar radiation the reduction in the BC particles could decrease the near surface temperature. Figure 2 represent the 10 m air temperature from MERRA-2 data which shows a very sharp decrease in temperature in pre-monsoon of 2020 compared to the 2019.

The BC particles can be mainly of two different sources in the study location, one is biomass burning and other is fossil fuel. The nationwide lockdown reduces the fossil fuel emission so it could be expected that the biomass burning will be the main source of BC. To support the fact the aerosol angstrom coefficient is calculated using BC measurements at 370nm and 880nm from the aethalometer which shows the higher values in 2020 lockdown period indicating the reduction in fossil fuel emission (Figure 3 (a)).

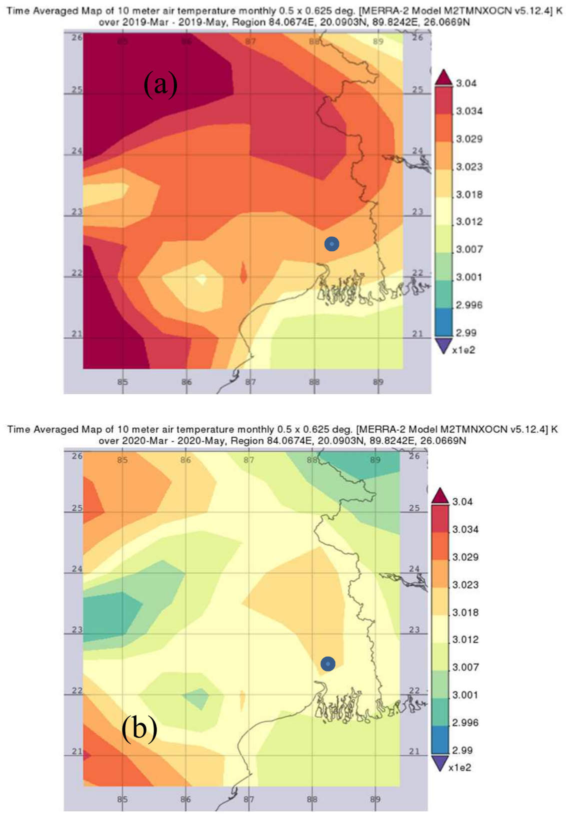

Figure 2. The mean 10-meter temperature from MERRA-2 model data for the pre-monsson period of (a) 2019 and (b) 2020. Dot indicates the location of Kolkata.

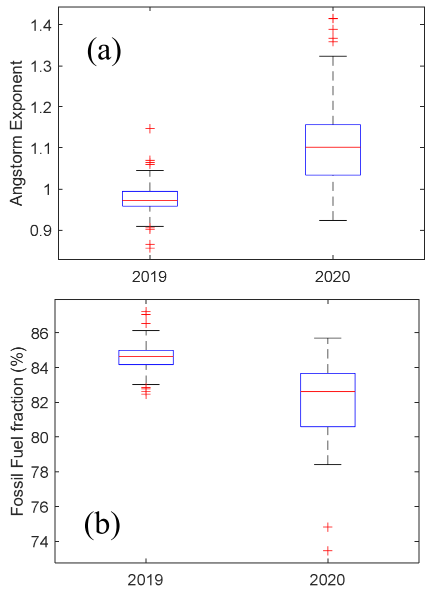

Figure 3. The (a) aerosol angstorm coefficient values and (b) fossil fuel fraction for the pre-monsson period of (a) 2019 and (b) 2020 at the study location.

Previous studies in the Indian regions showed that the higher angstrom exponent indicates reduction in BC from fossil fuel [8]. The source apportionment technique also supports the above fact showing a significant reduction in fossil fuel fraction (Figure 3(b)). The changing scenario in the anthropogenic aerosol emission led us to investigate the source of the emission using air parcel trajectory analysis. The 5-day HYSPLIT back trajectory analysis is done along with the CWT analysis which can indicate the probable source region of BC (Figure 4).

The reduction in heat absorbing aerosol concentration can also reduce the re-radiation [4] which can be reflected in single scattering albedo (SSA). SSA data from OMI sensor of Aura satellite shows a significant reduction in albedo (Figure 5) around the heavily pollutant region of Kolkata indicating the reduction in aerosol scattering and positive top of the atmosphere (TOA) radiative forcing [11].

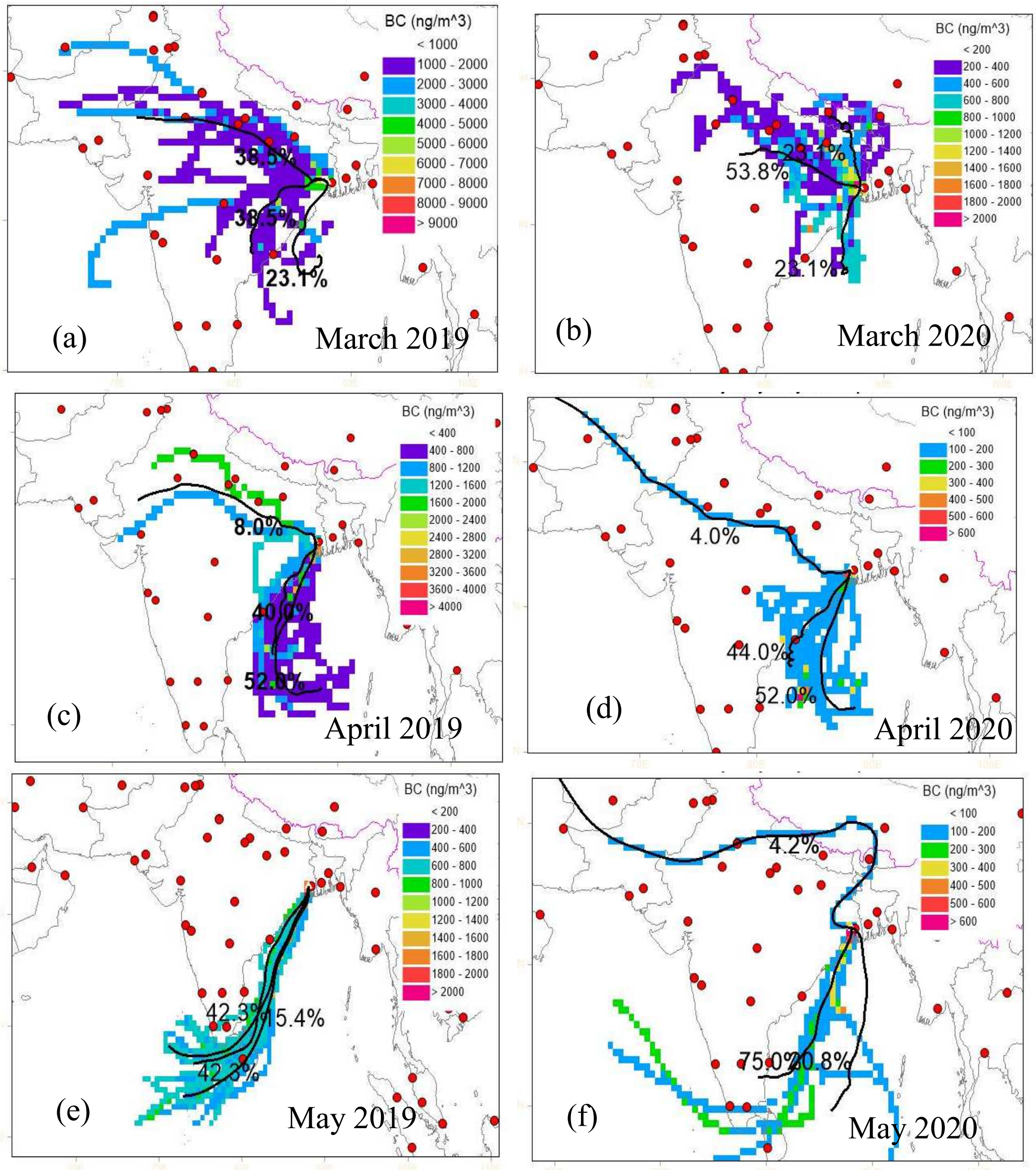

Figure 4. Back-trajectory and CWT analysis for pre-monsoon months of 2019 and 2020. Red dots indicates the location of heavily populated cities

Figure 4 shows the CWT analysis for three pre-monsoon months of both the years in which some significant differences can be noted. The month of March shows a different source region (North of study location) consisting about 23% of trajectories in 2020 which is not present in 2019. In the months of April, the Bay of Bengal influence increased in 2020. In May 2019 a coastal influence can be seen which is not present in 2020. Moreover, the influence of the polluted Indo-Gangetic plain is reduced in the year of 2020.

4 Conclusions

Present study indicates the sudden change in anthropogenic emissions have great impacts on atmospheric parameters and radiative forcing. The study shows that the reduction in BC could results in cooler temperature. The change in angstrom coefficient and source apportionment results indicated the reduction in fossil fuel burning which has more heating effect than biomass burning in the atmosphere [6].

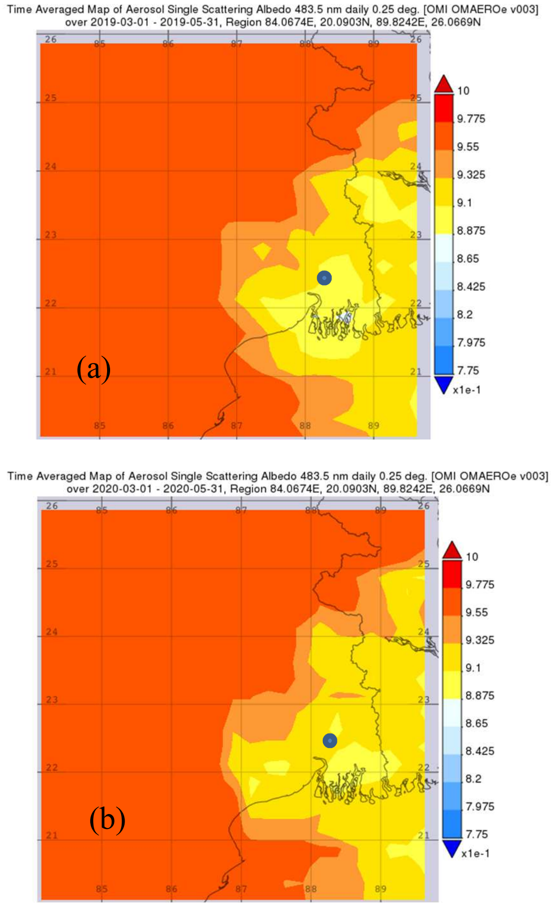

Figure 5. The average aerosol single scattering albedo values for the pre-monsson period of (a) 2019 and (b) 2020 at the study location. Dot indicates the location of Kolkata.

The reduction in near surface temperature leads to different trajectory of air parcel transportation shown by the back-trajectory analysis. The influence of highly populated Indo-Gangetic plain on BC sources can be seen in the CWT analysis. Finally, the reduction in SSA values can be seen in the pre-monsoon of 2020 clearly indicating the significant reduction in scattering aerosol mass contributing to the positive TOA forcing [11].

6 Acknowledgements

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