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PARTICULATE MATTER ($PM_{2.5}$) RADIATIVE FORCING OVER THREE DIFFERENT CITIES IN INDIA

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Abstract: **This paper discusses the estimates of radiative forcing exerted by particulate matter ($PM_{2.5}$) over three different polluted cities in India. The $PM_{2.5}$ concentrations were measured during Mar 2013 - Feb 2014 periods over Chennai, Guwahati and Jabalpur in south, central and North-eastern India. $PM_{2.5}$ concentrations varied from 22.39±2.83 µg m^{-3} to 66.19±12.93 µg m^{-3} in Chennai. In Guwahati concentration ranged between 12.51±2.03µg m^{-3} to 100.69±21.41µg m^{-3} and it varied between 17.95±2.83 µgm^{-3} to 73.29±12.38 µg m^{-3} over Jabalpur. The Optical properties of aerosols and clouds (OPAC) model was used to obtain optical properties of $PM_{2.5}$. The obtained optical properties were further used in Santa Barbara Discrete Ordinate radiative transfer model (SBDART) model to estimate Radiative Forcing of $PM_{2.5}$. The radiative forcing was estimated at the surface and Top of the atmosphere (TOA) and hence the net atmospheric forcing was calculated. The estimated Atmospheric forcing (difference between surface and TOA forcing) values for PM $_{2.5}$ found to be + 5.61 Wm^{-2} to +8.69 Wm^{-2}, +3.49 Wm^{-2} to +15.86Wm^{-2} , +4.62 wm^{-2} to +9.61 Wm^{-2} respectively over Chennai, Guwahati, and Jabalpur, inducing significant climate warming over the region.**

Key words: **Particulate Matter, Radiative forcing**

I. INTRODUCTION

Aerosols are a mixture of solid particles and liquid droplets found in the air. Their concentration and chemical make-up exhibit considerable variability. In health issues, aerosol or particulate matter (PM) is typically defined by size, with the smaller particles having more health impact [1]. Commonly quoted values for PM are total particulate matter (TPM) or total suspended particles (TSP); particles with a diameter <10 µm (PM_{10}); particles with a diameter <2.5 µm ($PM_{2.5}$); particles with a diameter <1µm (PM_1). PM can be classified on the basis of size and origin [2]. Particles come from natural sources (e.g., volcanic eruptions) and human activities such as burning fossil fuels, incinerating wastes, and smelting metals. They can influence the climate by directly scattering and absorbing solar radiation [3]. Indirectly they affects the climate by changing cloud properties leading to cloud life time and albedo enhancement [4, 5]. These particles come in many sizes and shapes and can be made up of hundreds of different chemicals. Some PM are emitted directly from a source, such as construction sites, unpaved roads, fields, smokestacks or fires. Most particles form in the atmosphere as a result of complex reactions of chemicals such as sulfur dioxide and nitrogen oxides, which are pollutants emitted

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from power plants, industries and automobiles [1]. They are several determinants of PM concentration which include Weather patterns, Wind, Stability (vertical movement of air), Turbulence, Precipitation, Topography, Smokestack height and temperature of gases. In this scenario, this paper is intended to discuss the variation and radiative forcing exerted by $PM_{2.5}$ particles over three different cities in India. Data and methodology are explained in section 2, results and discussed in section 3 and summary of results are given in section 4.

II. DATA AND METHODOLOGY

2.1. Data

The radiative forcing was estimated from the datasets of Particulate matter obtained from three Metropolitan Air Quality and Weather Service (MAPAN) stations located at south, central and north eastern part of India for a period of one year (Mar 2013 - Feb 2014). MAPAN is a national network intended for the monitoring of particulate and Gaseous pollutants. One of the observational sites, Chennai (13.08°N, 80.27°E) is a metropolitan city in Southern India and is located on the Coromandel Coast off the Bay of Bengal. Chennai is characterized with a tropical wet and dry climate. Guwahati (26.14°N; 91.72°E) is one of the largest cities in north-eastern India and is situated on the South bank of Brahmaputra River. Guwahati is featured with warm, humid and temperate climate and experiences heavy rainfall during monsoon. Jabalpur (23.18°N; 79.98°E) is a City in central India and is characterized with humid subtropical climate. Fig.1 shows the location map of MAPAN Observation stations.

Fig 1: Location map of MAPAN Observation stations

Particulate Matter (PM) has been continuously monitored using a Beta Attenuation Monitor (Model BAM-1020 Met One Instruments, Inc., USA) over the above stations. BAM-1020 automatically measures and records airborne $PM_{2.5}$ concentration levels using the principle of beta ray attenuation. In this technique, a simple determination of concentration in micrograms of particulate per cubic meter of air is carried out.

A small 14C (carbon 14) element in the analyser emits a constant source of high energy electrons known as beta particles, which are detected and counted by a sensitive scintillation detector. An external pump is employed to pull a measured amount of air through a filter tape. After the filter tape is loaded with dust, it is automatically placed between the source and the detector thereby causing an attenuation of the beta particle signal. The degree of attenuation of the beta particle signal is used to determine the mass concentration of PM on the filter tape, and hence the volumetric concentration of $PM_{2.5}$ in ambient air [6]. Span check of the instrument is automatic and measurement cycle is verified hourly [7]. The mass concentration was observed at every 5 min interval and then stored in data repository as 1-h average.

In the present work, the data from MAPAN network during a period of one year (March 2013 to February 2014) was used for the analysis. In addition to the $PM_{2.5}$ measurements; the data of visibility was obtained from India Meteorological Department and Relative humidity from Interim European Reanalysis (ERA). Ozone data was obtained from Ozone Monitoring Instrument (OMI) satellite and water vapour data sets are obtained from Moderate

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Resolution Imaging Spectroradiometer (MODIS).Monthly Aerosol optical depth (AOD) was obtained from MODIS terra at a resolution of 1 degree.

III. METHODOLOGY

To estimate the radiative forcing for Particulate matter, the PM mass concentration has been divided in to waters soluble (WS) and water insoluble (WIS) components [8]. These two components were used in the Optical properties of Aerosol and Clouds (OPAC) model to obtain aerosol optical properties such as aerosol optical depth (AOD), single scattering albedo (SSA) and asymmetric parameter (ASP) for PM at 61 wavelengths from 0.25µm to 40µm [9]. We also included the scale heights for individual months, which are calculated as the ratio between AOD and extinction coefficient (σ) as explained in [10]. AOD at 550 nm observed from MODIS satellite and σ derived using the visibility observations from India Meteorological Department were used to estimate aerosol scale height using the relation as suggested by [11, 12] and [9] i.e.,

$\sigma = 3.912/\text{visibility}$

The AODs were adjusted until the modelled and observations derived AOD's matched within ±5% deviation for every month with the MODIS satellite derived AOD for each station. Modelled spectral aerosol optical properties for PM, column water vapour and OMI column ozone over the station were incorporated in Santa Barbara Discrete-ordinate Atmospheric Radiative Transfer Model (SBDART) [12] to derive net fluxes in the spectral range 0.3 to 3 mm (shortwave range) at the surface, at the Top of the Atmosphere (TOA). Tropical model atmospheric profiles of temperature and humidity were used in SBDART for this study. The model simulations were carried out for aerosol free conditions also and the differences in net short wave radiative fluxes with and without aerosols were calculated to estimate PM direct aerosol radiative forcing, both at the surface and at the TOA [11].

3.1 Monthly Variation of Particulate Matter over MAPAN stations

The variation of $PM_{2.5}$ over Chennai, Guwahati, and Jabalpur were studied during the period March 2013-February 2014. The monthly and seasonal variation of $PM_{2.5}$ are depicted in the Fig.2. The range of $PM_{2.5}$ concentration varied from 22.39±2.83 µgm^{-3} to 66.19±12.93 µgm^{-3} in Chennai. In Guwahati concentration ranged from 12.51±2.03 µg m^{-3} to 100.69±21.41 µgm^{-3} and it ranged from 17.95±2.83µgm^{-3} to 73.29±12.38 µgm^{-3} over Jabalpur. $PM_{2.5}$ concentration showed higher concentration in winter (December–February) followed by post-monsoon (October, November), pre-monsoon (March-May), and monsoon (June-September) seasons over Chennai and Jabalpur. The concentrations respectively were 56.543±1.35 µgm^{-3}, 52.09±14.09 µgm^{-3}, 47.10±10.22 µgm^{-3},25.43±2.91 µgm^{-3} over Chennai on winter, post-monsoon, pre-monsoon, and monsoon.

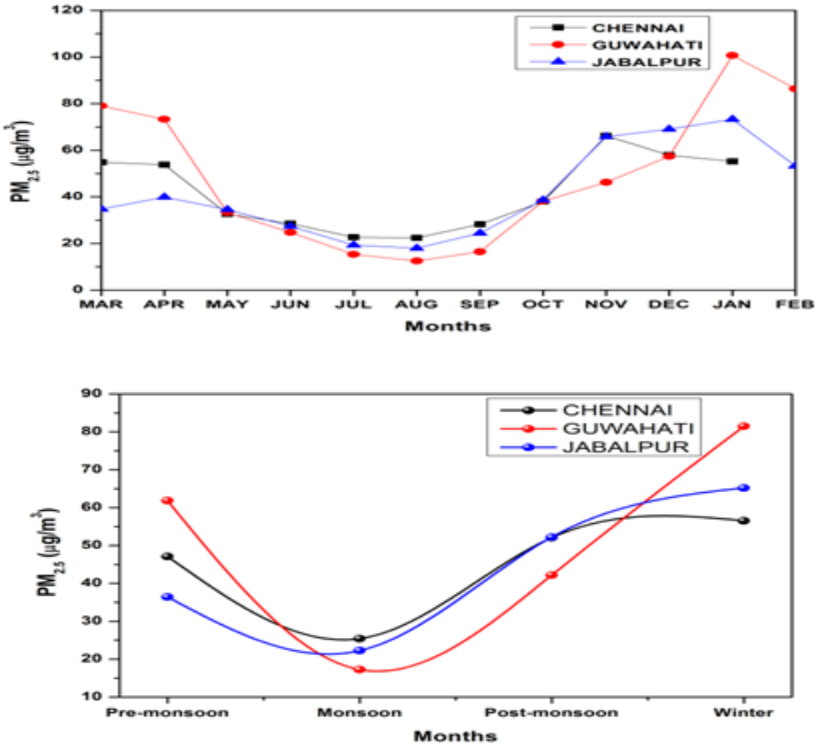

Fig 2: Monthly and seasonal variation of $PM_{2.5}$ over three stations

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The concentrations over Jabalpur was 65.20 ±8.61 μgm^{-3} on winter and it was 52.23± 13.61 μgm^{-3} , 36.40±2.48 μgm^{-3}, 22.26± 3.83 μgm^{-3} respectively on post-monsoon, pre-monsoon, and monsoon. However, it showed higher winter concentrations (81.49±17.99) μgm^{-3} followed by pre-monsoon 61.85±20.38 μgm^{-3} , post-monsoon 42.20±4.05 μgm^{-3},and monsoon 17.26±4.56 μgm^{-3} over Guwahati. The major reason for higher winter concentration of pollutants is associated with temperature inversions, which leads to trapping of particles with small sizes in lower atmosphere [13, 14]. Post monsoon peaks also could also be associated with inversions. Also long range transport of agricultural Crops also could be other reason for high PM in this season [15]. The higher concentration of PM in pre-monsoon season may be associated with the higher temperature during this season leading to excessive convection and hence lifting of dust over the regions [16]. Another reason could be associated with the influx of aerosols from adjacent areas [17]. The obvious reason for lower monsoon concentration is associated with the rain out and washout of particles during monsoon rain events.

3.2 Estimation of Direct Radiative Forcing

The OPAC model simulates the aerosol optical properties in the entire solar spectrum at eight different relative humidity conditions for a given aerosol chemical composition. In this study, we modelled aerosol optical properties such as AOD, SSA, and ASP at different RH levels over the experimental stations. The comparison of OPAC derived AOD values for PM at mid-visible wavelength 550 nm (adjusted for scale heights as explained in section 2.2) and those obtained from MODIS TERRA satellite are shown in Fig. 3. The modelled AOD's at 550nm found to be comparable to MODIS-AOD with in ±5% error level in prevailing humidity conditions during different months. Hence it is assumed that AOD and other optical parameters in other wavelengths are reasonable to be used for estimating radiative forcing. The radiative forcing values over Chennai, Guwahati and Jabalpur for $PM_{2.5}$ at surface and TOA are shown in Fig. 4. In Chennai, RF value ranged from -13.5Wm^{-2} to -18.53 Wm^{-2} at the surface, -6.78 Wm^{-2} to -10.3 Wm^{-2} at TOA and +5.61 Wm^{-2} to +8.69 Wm^{-2} in the atmosphere.

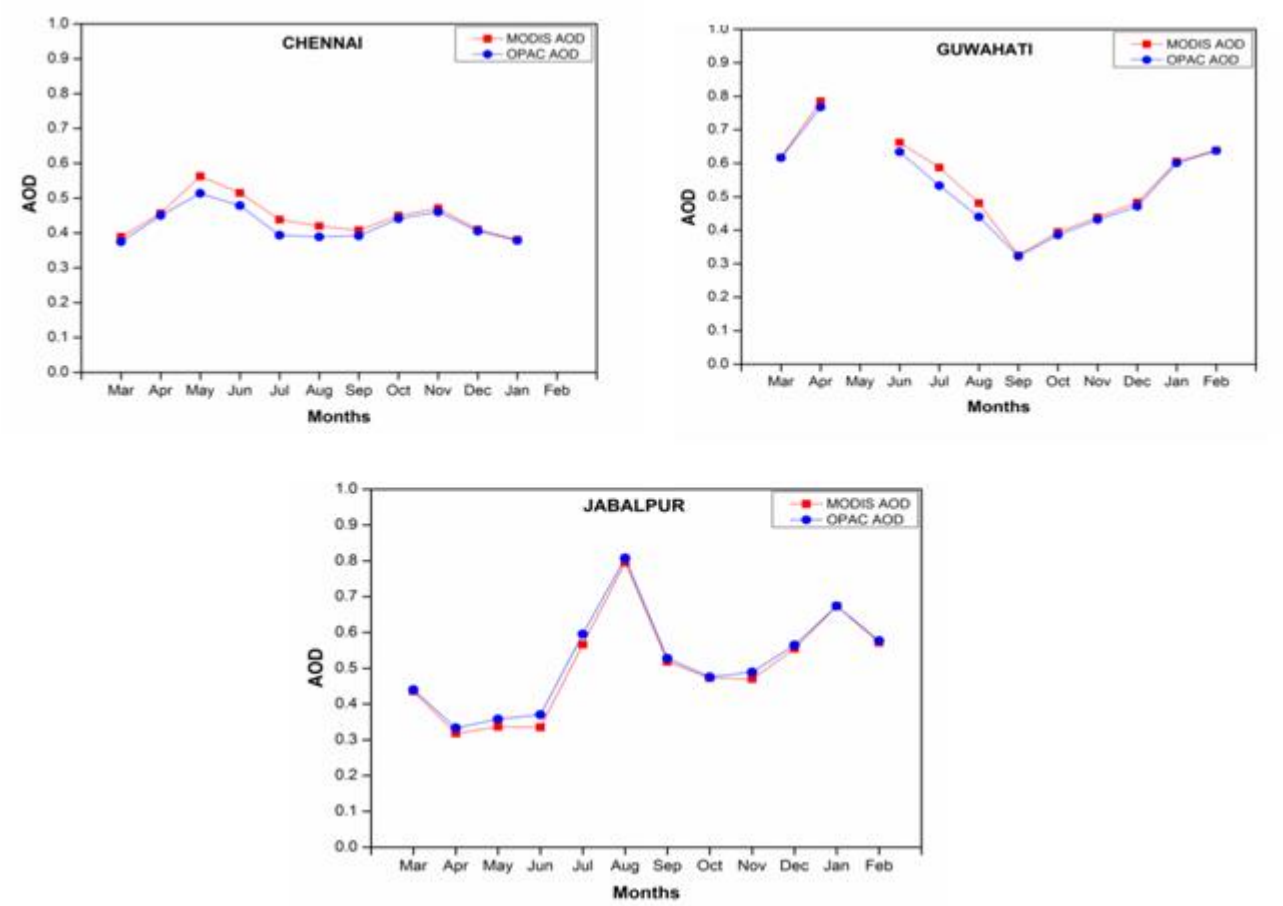

Fig 3: Comparisons between modeled and observed AOD's over the three stations

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For Guwahati, it ranged from -10.39 Wm^{-2} to -28.89 Wm^{-2} at the surface, -6.9 Wm^{-2} to -13.9 Wm^{-2} at TOA and +3.49 Wm^{-2} to +15.86 Wm^{-2} in the atmosphere. Over Jabalpur RF values were from -13.49 Wm^{-2} to -23.81 Wm^{-2} at the surface, -6.13 Wm^{-2} to -15.59 Wm^{-2} at TOA and +4.62 Wm^{-2} to +9.61 Wm^{-2} in the atmosphere. The negative surface forcing values imply a net cooling effect. The difference between the TOA and the surface gives the atmospheric forcing, indicating the net atmospheric absorption. The forcing values estimated here found to be in good agreement with the values reported over other two polluted cities in India [8].

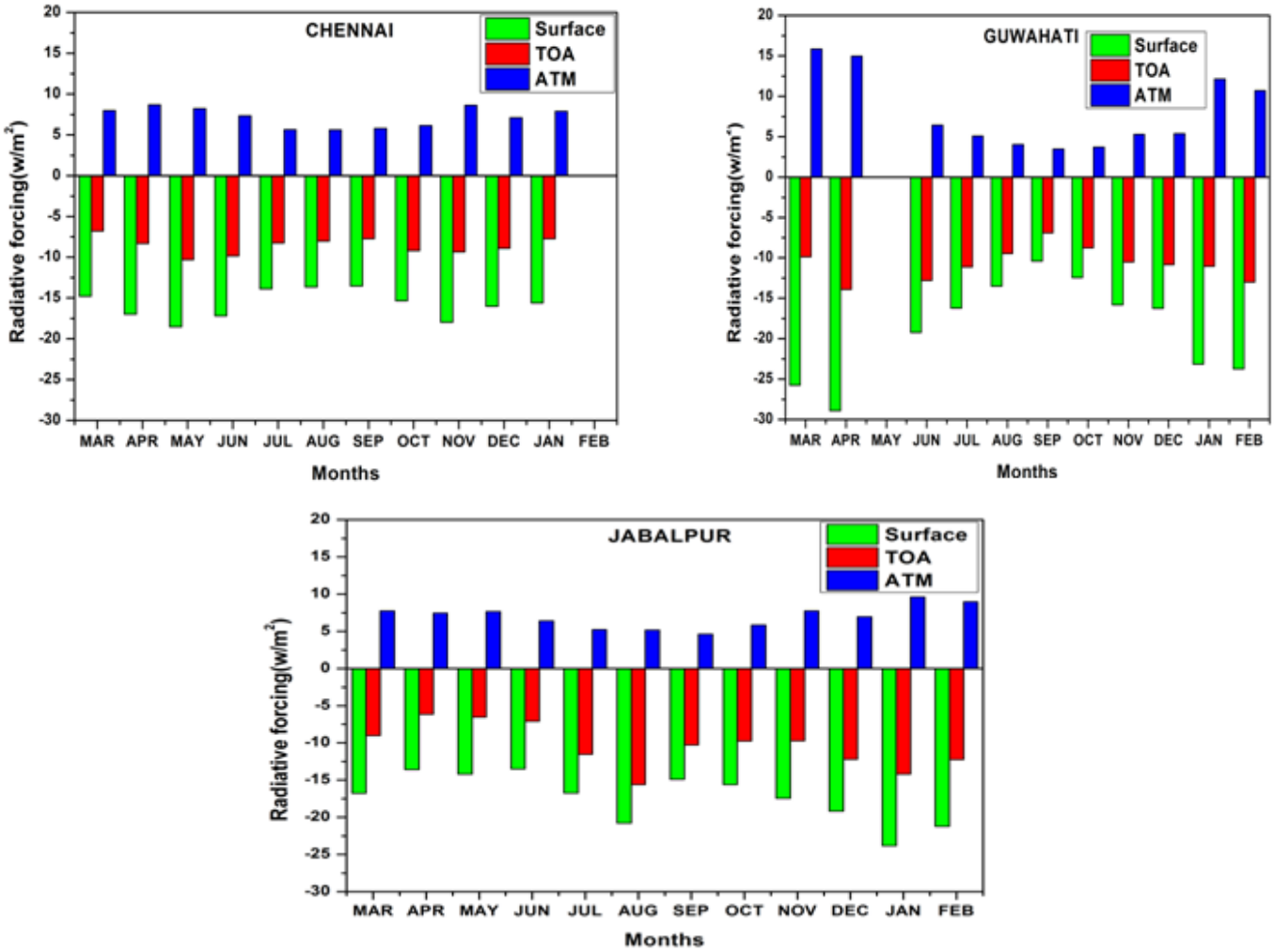

Fig 4: RF due to $PM_{2.5}$ over three stations at surface, TOA and at the Atmosphere

IV. SUMMARY

1. The variation of particulate matter ($PM_{2.5}$) and its climate forcing were estimated over Metropolitan Air Quality and Weather Service (MAPAN) stations located at Chennai, Jabalpur and Guwahati for a period of one year (Mar 2013 - Feb 2014).
2. PM concentration showed higher concentration in winter (December–February) followed by post-monsoon (October, November), pre-monsoon, and monsoon seasons over Chennai and Jabalpur. However, it showed higher winter values followed by pre-monsoon, post-monsoon, and monsoon over Guwahati.
3. The high winter concentrations are associated with the inversions, leading to lowering of boundary layer height and hence trapping of pollutants at lower levels.
4. OPAC model in conjunction with SBDART model were used to estimate Radiative Forcing of Particulate matter. For this exercise, the scale heights were tuned in OPAC model to match the simulated AOD with the MODIS satellite derived AOD's.
5. The estimated Atmospheric forcing (difference between surface and TOA forcing) values for $PM_{2.5}$ found to be

+5.61 Wm^{-2} to +8.69 Wm^{-2}, +3.49 Wm^{-2} to +15.86Wm^{-2} +4.62 wm^{-2} to +9.61 Wm^{-2} over Chennai, Guwahati, and Jabalpur respectively.

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