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Dynamical Characteristics of Atmospheric Aerosols over IG region

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ABSTRACT

The dynamical characteristics of atmospheric aerosols over the Indo-Gangetic (IG) region are primarily dependent on the geographical settings and meteorological conditions. Detailed analysis of multi satellite data and ground observations have been carried out over three different cities i.e. Kanpur, Greater Noida and Amritsar during 2010-2013. Level-3 Moderate Resolution Imaging Spectroradiometer (MODIS) terra daily global grid product with spatial resolution of 1° × 1° shows the mean AOD at 500 nm wavelength value of 0.73, 0.70 and 0.67 with the standard deviation of 0.43, 0.39 and 0.36 respectively over Amritsar, Greater Noida and Kanpur. Our detailed analysis shows characteristic behavior of aerosols from west to east in the IG region depending upon the proximity of desert regions of Arabia. We have observed large influx of dusts from the Thar desert and Arabia peninsula during pre-monsoon season (April–June), highly affecting Amritsar which is close to the desert region.

1. INTRODUCTION

The densely populated and heavily aerosols laden Indo-Gangetic plains (IGP) region, is one of the atmospheric polluted with poor air quality regions suffer with dense haze, fog and smog during winter season. Due to population growth, the energy demands, and use of fossil-fuel and bio-fuel have increased that have enhanced greenhouse emissions [1]. Variable sources of aerosols origin, deposition and their transport mechanism play an important role in spatial and temporal inhomogeneities which greatly affect the Earth's radiation budget. Numerous studies have been carried out using multi satellite and ground data to study the variability of aerosol optical depth over different locations in the Indo-Gangetic basin [2-5]. Kaskaoutis et al. found strong aerosols dynamics due to biomass-burning over Punjab, transported further in the Ganges valley from west to east [6]. Some of the process like gas-to-particle conversion, particle enlargement by maturation; coagulation and extended carrying, contribute a lot to modify the aerosols properties over Indo Gangetic Plain [6]. The aerosols generated through local and regional emission mainly affects the boundary layer while the long range-transport aerosols found just above the boundary layer height (BLH). The changes in boundary layer height over the urban region mainly depend on the local meteorological parameters and on anthropogenic aerosols emissions rate. Distinctive effects on atmosphere like formation of fog, haze and smoke, especially in the lower troposphere are mainly associated with the variety of aerosols. The dynamical characteristics of atmospheric aerosols over the IG region are primarily dependent on the elementary geography in longitudinal direction from west to east as well on variable meteorological conditions of the region[7]. In the western part of IGP region, the Thar Desert and Arabian Sea make their presence whereas the eastern region has closer proximity with the Bay of Bengal. Due to this exclusive topography over IGP region, human and anthropogenic activities show seasonal variability of aerosols[8-10]. Singh et al. have shown that many factors are responsible for the dynamical properties of atmospheric aerosols over IGP[3]. During 2004-2014 extensive aerosols studies were carried out related to aerosols spatial and temporal variations, aerosol characterization,

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and dynamics of aerosols and trace gases over IGP and Himalayan region[2, 11-15]. Most of the earlier observations over different locations [16-17] show different types of identification and classification schemes. The seasonal dependency of aerosols show different types of aerosols over IGP and sometime creates a real challenge to discriminate the aerosols due to its modification processes in the atmosphere [8, 18]. Satellite and ground based sun photometers have emerged as an important tool for monitoring atmospheric aerosols and to study the dynamics of aerosols. The aerosols physical and chemical compositions mainly depend on locations and meteorological conditions. Kothai et al. studied the chemical characteristics of particulate matter (PM) aerosols and their related source identification over an urban site of Navi Mumbai, India [19]. In order to recognize the dynamics and variability of atmospheric aerosols over IGP, efficient measurements of aerosols properties are require at different locations.

Figure 1: Location of three different Indian cities over the IGP (Amritsar, Greater Noida and Kanpur)

In the present study, we have selected three Indian cities over the IGP (Amritsar, Delhi and Kanpur, (Figure 1)), diagonally west to east to demonstrate the dynamical characteristics of aerosols.

2. DATA USED AND METHODOLOGY

The present aim of this paper is to study the dynamical characteristics of atmospheric aerosols over IGP. We have used long term ground based AERONET and MODIS Satellite data. We have considered the Moderate Resolution Imaging Spectroradiometer (MODIS) data onboard the Terra and Aqua satellites. The Terra satellite is launched on 18 Dec, 1999 (10:30 AM equator crossing time, descending) and Aqua satellite was launched on May 04, 2002 (1:30 PM equator crossing time, ascending) for global monitoring of the atmosphere, terrestrial ecosystems, and oceans. The Aqua and Terra satellites offer daily global data of aerosols characteristics at high radiometric sensitivity (12 bit) in 36 spectral bands ranging from visible to thermal infrared (0.41–14.38 μm). Out of 36 spectral bands, 29 spectral bands with 1km, 5 spectral bands with 500m, and 2 spectral bands with 250-m nadir pixel dimensions cover the aerosols characteristics.

3. RESULTS AND DISCUSSION

3.1 Daily Variability of Aerosols

In the present paper, we have now analyzed daily aerosols optical data (AOD_{500}) at 500 nm wavelength from Kanpur AERONET station during the period January 2001 to December 2013 which is shown in Figure 2.

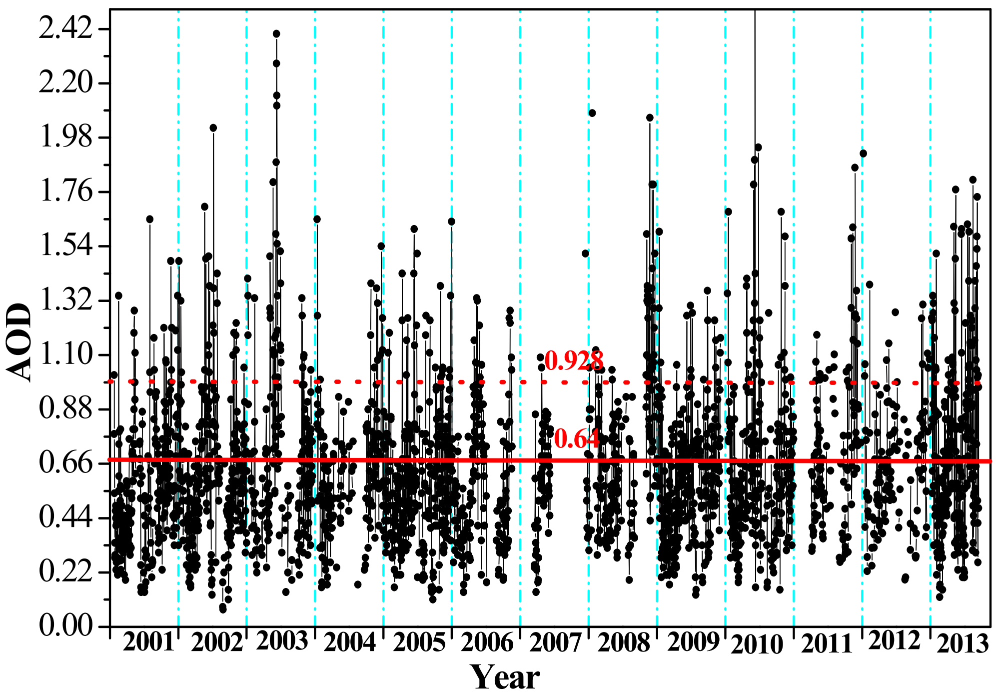

Figure 2: Daily variation of AOD at 500 nm using IIT Kanpur, AERONET station during the period January 2001 to December 2013. The mean value (in bold red) and the upper threshold (mean+stdev) showing the aerosol events are also given.

The variability of AOD_{500} is found to be similar showing strong seasonal variations in aerosol trends [10]. AOD_{500} varies in the range 0.07-2.58 (mean value 0.64 and standard deviation 0.31). The analyzed results show the minimum (0.07) AOD_{500} during 26 August 2002 whereas 5 June 2010 shows high AOD_{500} value 2.58. The long term AOD_{500} data shows that 2007 and 2008 are the period with minimum (0.57) and maximum (0.74) AOD_{500} values. The results reveal a pronounced daily variability in AOD_{500} influenced by local and regional meteorological and atmospheric conditions, i.e. rainfall, air mass trajectories and aerosol emission rates. Anthropogenic emissions and dust transport also contribute a considerable function influencing aerosol loading and properties, especially during the extended dry period, i.e. from October to June over the northern parts of India. In contrast, the IGP experiences an enhanced convective and turbulent boundary layer and witnesses a large influx of westerly wind driven dust-laden air masses during the pre-monsoon/summer season (April–June) [20-21].

Figure 3 shows satellite derived mean AOD_{550} at 550 nm over three different locations of IGPs i.e. Amritsar, Greater Noida and Kanpur, using Level-3 MODIS terra (MOD08_D3, http://modis-atmos.gsfc.nasa.gov) daily global grid product at spatial resolution of 1° × 1°.

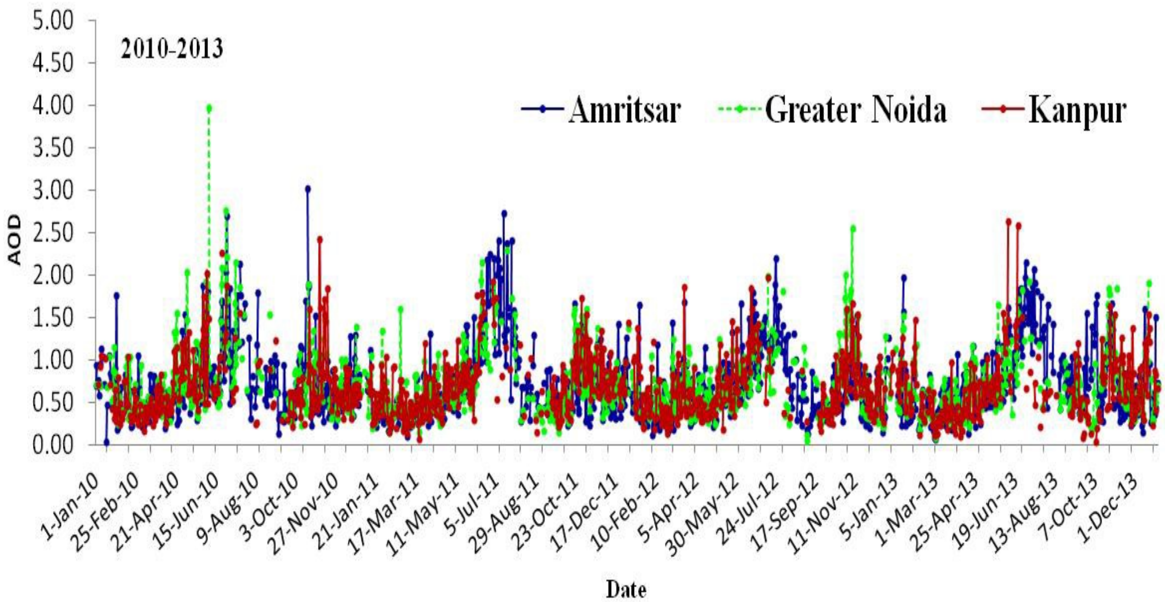

Figure 3: Daily variation of AOD at 550 nm wavelengths over Amritsar, Greater Noida and Kanpur using MODIS TERRA Satellite measured data during January 2010 - December 2013.

The AOD_{550} over Amritsar, Greater Noida and Kanpur respectively is found to be 0.73, 0.70 and 0.67 with the standard deviation of 0.43, 0.39 and 0.36. Over all the three locations the aerosols vary in the range (0.03-3.02) [Amritsar], (0.05-3.98) [Greater Noida] and (0.03-2.98) [Kanpur] during 2010-2013. The daily mean AOD_{550} data shows higher mean AOD_{550} over Amritsar as compared to Greater Noida and Kanpur. Higher AOD_{550} over Amritsar clearly shows influence of near sources like dust, biomass burning and industrial emissions bringing air mass due to strong westerly wind. Recently, five years AOD_{550} data were used over IG plain [22] showing higher elevated aerosol loading compared to other cities. During the period (2001-2013), total 3288 days observations were analyzed out of which 1210, 1091 and 987 days respectively correspond to Amritsar, Greater Noida and Kanpur. Highest mean AOD_{550} (0.76±0.45) during 2013 for Amritsar which is similar to the value observed (0.76±0.45) over Greater Noida during 2010. Kanpur shows highest mean AOD_{550} (0.69±0.34) for the year 2011 and the minimum value (0.65±0.35) in the year 2012. Approximately 8.26 % (229 out of 1210) days show high AOD_{550} values more than 0.93 due to anthropogenic activities. Over Greater Noida, 20.99% (229 out of 1091) days correspond to high values greater than 0.93. Similarly Kanpur shows only 3.95 % days with AOD_{550} values greater than 0.93. The mean AOD_{550} values decrease with latitude and longitude, moving from Amritsar to Kanpur.

Figure 4 shows comparison of the daily mean AOD_{550} values using MODIS TERRA Satellite over Greater Noida and Amritsar for the period January 2010 - December 2013. In general, AOD_{550} is found be higher over Amritsar compared to Greater Noida. Sometime, AOD_{550} is higher over Greater Noida compared to Amritsar due to local anthropogenic activities and outflow from Delhi and emissions from nearby coal based thermal power plants, industries and construction activities.

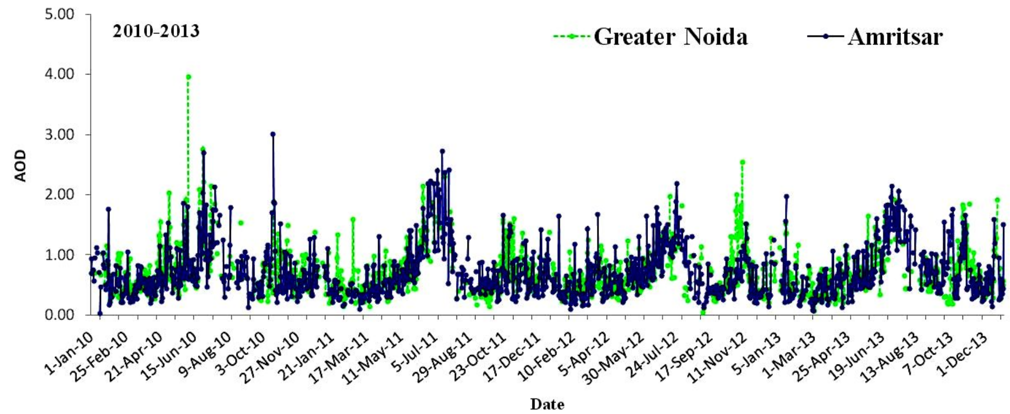

Figure 4: Daily variation of AOD at 550 nm wavelengths over Greater Noida and Amritsar using MODIS TERRA satellite measured data during the period January 2010 - December 2013.

The daily mean variations of AOD_{550} from MODIS TERRA satellite data over Greater Noida and Kanpur (Figure 5) for the period January 2010 to December 2013 showing similar behavior.

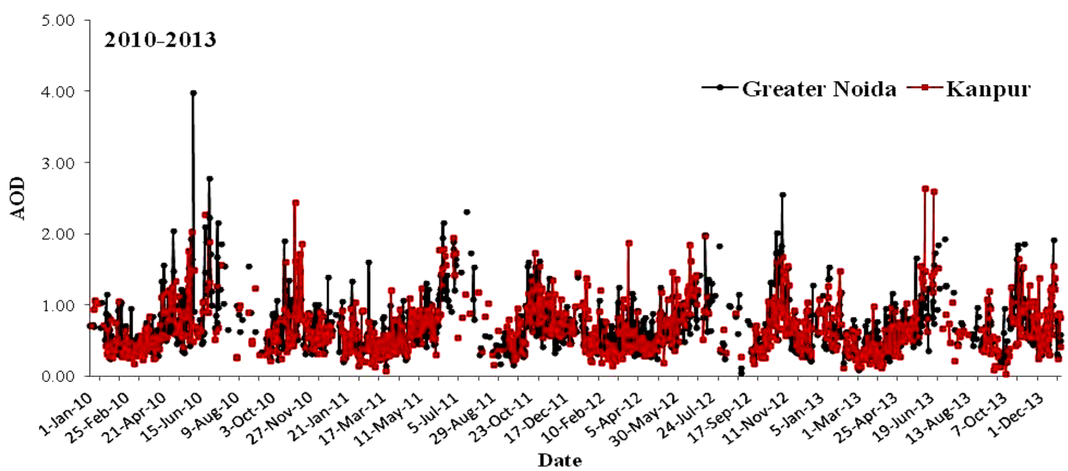

Figure 5: Daily variation of AOD at 550 nm wavelength over Greater Noida and Kanpur using MODIS TERRA Satellite measured data during the period January 2010 - December 2013.

During pre-monsoon period AOD_{550} is higher over Greater Noida compared to Kanpur due to long range transport of dust. During winter season, some days AOD_{550} is higher over Greater Noida and some days higher over Kanpur depending upon the meteorological conditions. Such high and low AOD_{550} values vary over Kanpur or Greater Noida depending on meteorological conditions, wind and relative humidity that cause dense haze, fog and smog in the IGP region.

3.2 Seasonal Variation of Aerosols

Figures 6a-d show strong seasonal variability of AOD_{500} over Amritsar, Greater Noida and Kanpur for the period 2010-2013. During winter season (Dec-Jan-Feb) (Figure 6a), the mean AOD_{550} over Amritsar, Greater Noida and Kanpur, respectively, vary 0.57±0.24, 0.60±0.18 and 0.62±0.20.

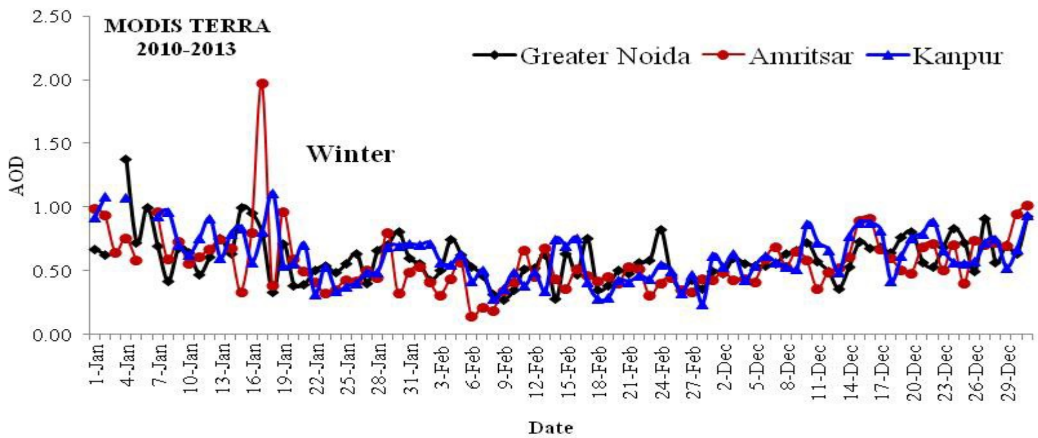

Figure 6 (a): Mean seasonal variation of AOD at 550 nm wavelengths over Winter period using MODIS TERRA Satellite during January 2010-December 2013 over Greater Noida, Amritsar and Kanpur.

About 55.68% AOD_{550} values over Greater Noida show 5% increase from the mean AOD_{550} value from Amritsar and 51.13% AOD_{550} values over Kanpur show higher value compared to Greater Noida. The AOD_{550} shows an increasing trend during winter season moving from west to east in the IG region.

During pre-monsoon season (Mar-Apr-May) the mean AOD_{500} value 0.59±0.17, 0.60±0.14 and 0.57±0.18 respectively observed over Amritsar, Greater Noida and Kanpur (Figure 6(b)).

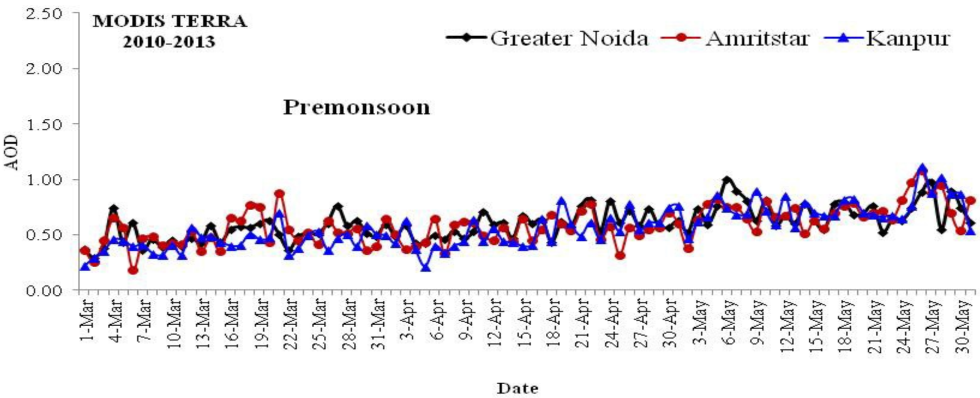

Figure 6 (b): Mean seasonal variation of AOD at 550 nm wavelengths over pre-monsoon period using MODIS TERRA Satellite during January 2010-December 2013 over Greater Noida, Amritsar and Kanpur.

May and March months respectively show the maximum and minimum AOD_{550} at all the three locations, the monthly mean AOD_{550} increases from the month of March until May. The standard deviation ±0.17 (Amristar), ±0.14 (Greater Noida) and ±0.18 (Kanpur) show a good consistency in the observed AOD_{550} values. During monsoon season a diverse characteristic of air mass showing strong daily variations in AOD_{550} values (Figure 6c).

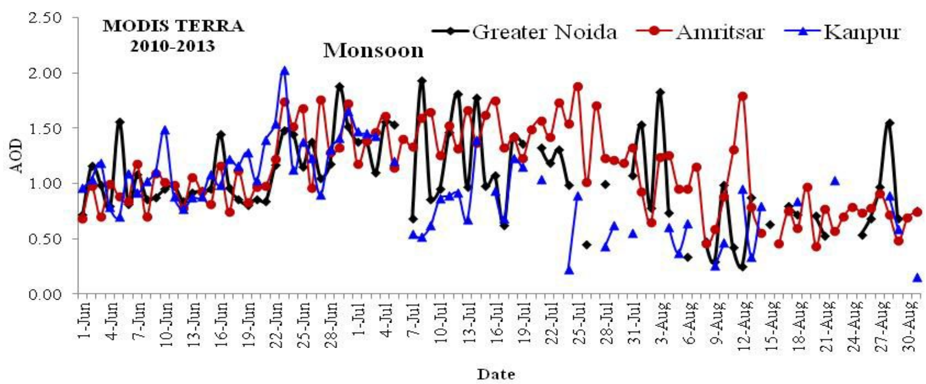

Figure 6 (c): Mean seasonal variation of AOD at 550 nm wavelengths over monsoon period using MODIS TERRA Satellite during January 2010-December 2013 over Greater Noida, Amritsar and Kanpur.

Figure 6(d) shows mean AOD_{550} 0.65±0.18, 0.71±0.30 and 0.69±0.27 respectively over Amritsar, Greater Noida and Kanpur during post-monsoon season (Sep-Oct-Nov).

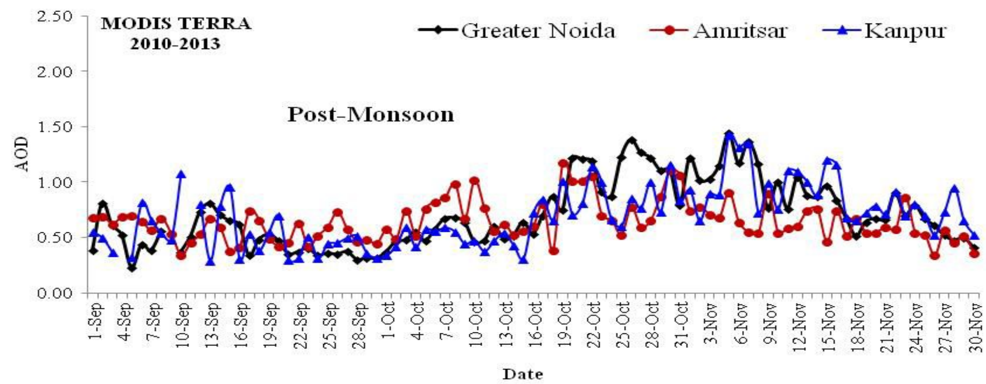

Figure 6 (d): Mean seasonal variation of AOD at 550 nm wavelengths over post-monsoon period using MODIS TERRA Satellite during January 2010-December 2013 over Greater Noida, Amritsar and Kanpur.

The maximum AOD_{550} observed over Amritsar (0.74) and Kanpur (0.77) in the month of October whereas over Kanpur the November month shows the maximum AOD_{500} (0.69). During post-monsoon season, lower value of AOD_{550} 0.56, 0.48 and 0.53 respectively over Amritsar, Greater Noida and Kanpur in the month of September.

3.3 Air mass back trajectories over Kanpur

Figure 7 shows the air mass back trajectories using NOAA Hybrid Single-Particle Langrangian Trajectory (HYSPLIT) over Kanpur for different months for the year 2012 for the maximum run time of 120 hours. The trajectory analysis during different months i.e. January, March, June and October are representatives of winter, pre monsoon, monsoon and post monsoon seasons showing the transport of air mass to Kanpur through the National Capital Region (NCR).

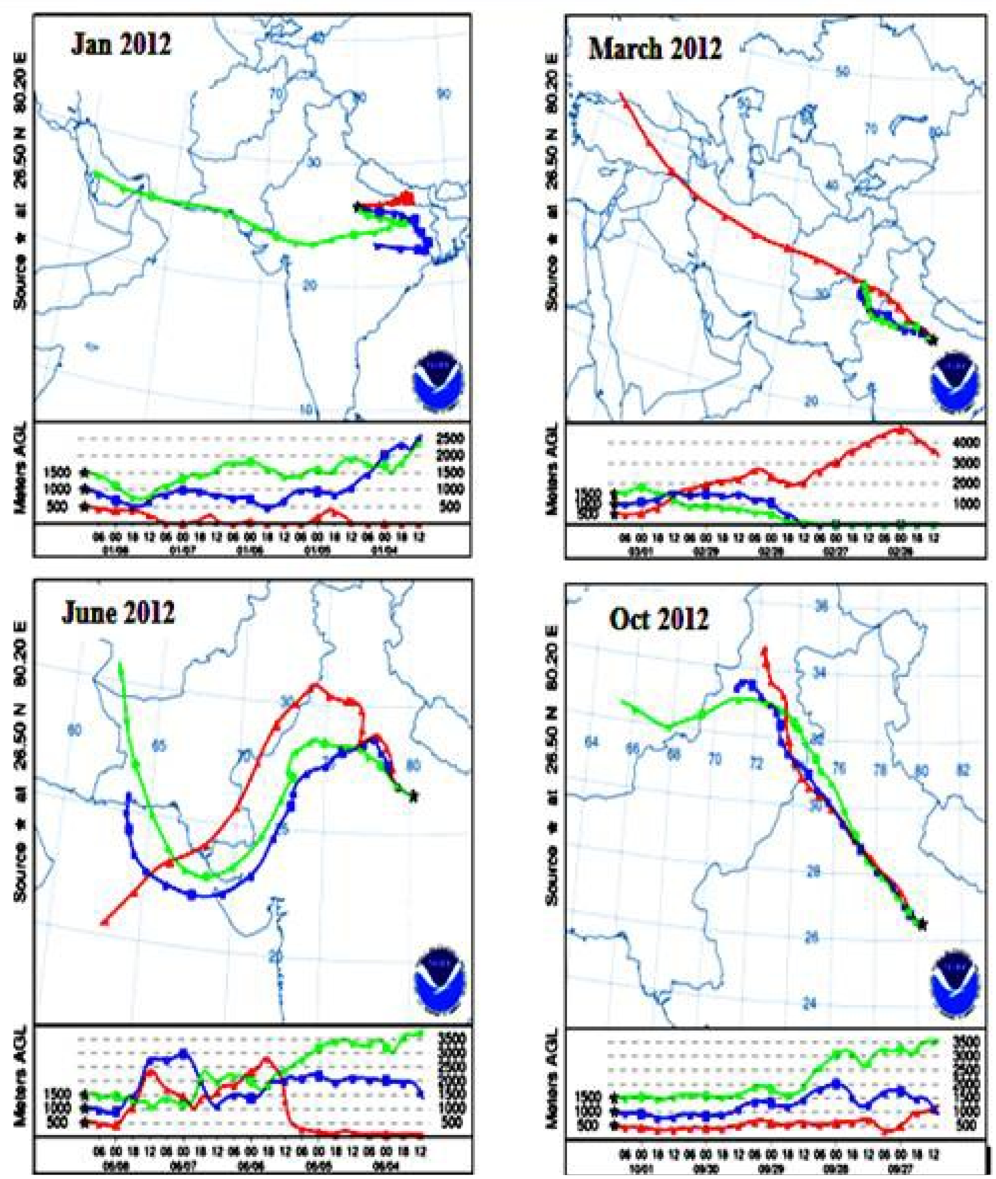

Figure 7: Hysplit back trajectories during specific days of June and Oct, 2012 over Kanpur.

The daily movement showing 24 hours progress of trajectory (arrow marks on the trajectories). The back trajectory were computed at 00:00 UTC for three distinct arrival levels, namely 500m, to give reprehensive origins of air masses near the surface, 1000 m for air masses within the boundary layer, and 1500m characterizing the lower troposphere where the pollutants are usually transported [23]. During winter month January, the air mass at the higher altitudes of 1500m seems to originate from Afghanistan, Pakistan and surroundings area and transported long distances, clearly shows its impact over Kanpur (maximum AOD_{550} of 1.91) much higher compared to the mean 0.72 during January 2012. In the month of October, the wind over Kanpur is mostly northerly to north-westerly, therefore the lower altitude trajectories at 500m (near the surface) and 1000 m (air masses within the boundary layer) seem to be originated from the north-west due to the local anthropogenic activities i.e. increased fuel usage and large biomass burning. In the month of March westerly wind transport dust from the Thar Desert located in the western part of India and Pakistan (the Great Thar Desert) and the Gulf region in the Middle East. Saharan desert is also act as a source for long-range transport of dust aerosols which is apparent from the back trajectories [24]. The dust coming from western part of India and Pakistan clearly shows their impact over Kanpur with the mean AOD_{550} value 0.57.

Detailed back trajectories clearly show that the air mass originates from the arid region of western India (Thar Desert) and Pakistan during pre-monsoon reaches over Kanpur [16, 25]. During the monsoon season, wind is generally southwest and southeast directions. Winds originate from southwest travel through the continental India before reaching IGP where it is strongly mixed with the local anthropogenic emissions. The back trajectories (at 500m, 1000m above ground level) show the dust laden air masses are coming from west and southwest direction i.e., originating from arid and semiarid regions of Rajasthan (Thar Desert), Gujarat whereas the high altitude trajectories i.e. 1500 m show the air mass originate from the Arabia Peninsula.

During post monsoon season, surface (500m) and boundary layer (1000m) trajectories show that the air mass originate from Pakistan region to IGP. The high altitude (1500) trajectory shows its long range transport originated from Afghanistan region. The long range trajectory also carries a dust which further mixed with the biomass burning aerosols from Punjab region to Kanpur. During post monsoon (October-November) biomass burning is a regular practice over Punjab state. Therefore, the effect of mixed aerosol over Kanpur as a result of high mean AOD_{550} (0.70) is observed.

Conclusion: The present study shows variability and dynamics of aerosol over Indo-Gangetic (IG) region during 2010-2013. The aerosol shows month to month and season to season variability over three cities Amritsar, Greater Noida and Kanpur. The aerosol characteristics are dependent on the dust and anthropogenic activities (emissions from coal based power plants, crop residue burning and use of fossil fuels). The aerosol optical depth at three locations clearly show the influence of air mass from source region (Thar desert and Arabia desert region) and its strong mixing with the local anthropogenic emissions. The present results will help in understanding the dynamics of fog, haze and smog especially during winter season and the extent of dust from west to east in the IG region.

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