RESEARCH ARTICLE

Satellite-based study of physico-optical properties of aerosols over a westernmost location of Brahmaputra valley

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Abstract: This study examines the long term trend of the radiatively active atmospheric aerosols which can influence the Earth's energy budget directly by scattering and absorbing radiation and indirectly by acting as cloud condensation nuclei. MODIS sensor on board the NASA Earth Observing System Terra and Aqua satellite based Aerosol Optical Depth (AOD) data are used for long term analysis of aerosols over Bongaigaon, Assam for the period August, 2002 to March, 2017. Highest AOD values are observed in pre-monsoon (March-May) season due to long range transportation as well as intense biomass burning activities especially as a part of Jhum cultivation. In general, AOD values are low in post-monsoon (October-November) season which may be due to wash out of aerosols by rain in the preceding months without enough replacement. The monthly AOD values vary from its highest value 0.949 in April, 2016 to its lowest value 0.107 in November, 2002 for the study period. From the comparison of MODIS Terra and Aqua AOD at 550 nm, it is clearly seen that generally Terra AOD at 10:30 hr is higher than the Aqua AOD at 13:30hr. A slowly increasing trend of both Aqua and Terra AOD at 550 nm is observed over the study location. The observed Ångström exponent value varies from its minimum value in monsoon season to its maximum value in winter season. With increasing AOD values, horizontal visibility decreases over Bongaigaon.

Keywords: AOD; MODIS; TRMM; Jhum Cultivation; Visibility.

1. Introduction

Atmospheric aerosols influence the Earth's energy budget directly by scattering and absorbing radiation and indirectly by acting as cloud condensation nuclei; so they involved in global climate change. Aerosols have direct radiative effect through scattering and absorption of electromagnetic radiation. The atmospheric aerosols concentrations and their properties vary widely over the globe in the spatial and temporal field due to their short residence times and varying distribution of sources. Therefore, the physical and optical properties of aerosols, as well as their impact on the environment, are not same for different locations. The aerosol particles are characterized by their shape, size, chemical composition and total concentration, which in turn determine the aerosol optical properties. The impact of aerosols on the Earth's climate is determined by the interaction of aerosol particles with radiation which is controlled by the optical properties of aerosols such as scattering and absorption, Aerosol Optical Depth (AOD), single scattering albedo, phase function, asymmetry parameter etc.

Several investigations[1–3] have reported that significant transport of Arabian dust to the Indian region leading to an increase in AOD during pre-monsoon period. There is an increasing trend of aerosols over the Indo-Gangetic Plain (IGP) region during pre-monsoon and summer monsoon seasons which is mainly attributed to the combined effects of dust transport and wet deposition of aerosol[4]. Many studies[5–8] have revealed the aerosol environment over Dibrugarh, a

doi: 10.18063/som.v3i2.699

remote continental location in North-East India on the basis of ground based observations. But such report from single location is insufficient to characterize total aerosol environment for the whole region. Extensive characterization of aerosols and their effect is still lacking in North-East India. As such the study which will conduct in different region is necessary to characterize the aerosols and their climatic impact, may further provide background information on aerosol environment in the complex terrain of North-East India. The study locations in North-East India due to less industrialization and low population density is expected to contain minimum aerosols in the atmosphere, but at the same time its unique topography acts as a sink for the transported aerosols which may sustain in the atmosphere of this particular region. Therefore this region is different to some extent from the Indian mainland because the region is an extension of IGP, surrounded by mountains and open only towards west which provides a normal entryway for transportation of aerosols through the western corridor[5,7,9,10]. The size distribution properties of columnar aerosol and types of aerosols based on measurements of physical and optical properties of aerosols had been reported earlier over Dibrugarh of North East India[6,8]. West Asian locations and the IGP are the potential source regions, which contribute to total aerosol abundance over Dibrugarh mostly in pre-monsoon and winter season as obtained from trajectory clustering and concentration weighted trajectory analysis[9]. From the ISRO-GBP land campaign conducted across the Brahmaputra Valley during late winter (February 3-March 2) 2011, it had been reported that western locations (Dhubri, Bongaigaon etc.) were rich in both particulate matter and Black Carbon (BC) concentration as compared to eastern locations of Brahmaputra valley which may be attributed to transportation of pollutants from highly populated and industrialized IGP region of India in addition to local pollution[11]. This study of ISRO-GBP land campaign also reported that the spatial heterogeneity of aerosol distributions across the Brahmaputra valley are mainly due to the fact that the Western locations are closer to BoB, the remnants of the winter haze from IGP heading towards BoB also enter North-East region of India through the corridor which results in higher aerosol loading at the western locations. AOD exhibits an east-west asymmetry within the North-East region with high values in the western locations (Agartala and Shillong) compared to the eastern locations (Dibrugarh and Imphal) because locations in the western North-East Indian region influenced by both natural (sea salt and soil dust) and anthropogenic aerosols produced locally or transported from IGPs and Bangladesh[12]. The western parts of the North-East region, close to the out flow of IGPs, showed higher values of Black Carbon concentration as well as absorption coefficient which are mostly associated with fossil fuel combustion[13]. By using satellite observations, very recently it has been reported that there is a slightly increasing trend in AOD over seven locations in North-East India for the period July 2002 to December 2013[14]. It has been seen clearly from the same satellite observations that western locations of Assam experiences higher value of AOD in comparison to that for eastern locations. There are no any ground based observations of AOD over western sector of Assam which is not far from highly polluted region, Dhaka. Therefore to study about the effects of aerosol in North-East India, it is essential to study on aerosol over at least one location in western Assam. The various complex natures of atmospheric aerosols and their radiative effects over a region make it complicated to model their effects with high confidence. Climate change, whether driven by natural or anthropogenic forcing, can cause changes in the likelihood of the occurrence or power of significant weather and climate events or both[15]. It is therefore very important to study the effects of aerosols over different locations of North-East region of India.

One of the parameter that reflect the extent of atmospheric purity is Atmospheric visibility. Measurement of surface visibility is very important for the management of air quality, human health, as well as transportation. Visibility is a basically observable indicator of air quality over a region[16]; higher value of visibility usually means good air quality[17]. Visibility can be reduced by the presence of natural as well as anthropogenic aerosols. Higher value of AOD indicates higher column of atmospheric aerosol loading and hence lower visibility[18]. There is a good relationship between remotely sensed AOD and surface visibility at airports across the East Coast of the United States[19].

The main goal of the present study is to evaluate the long term trends of Aerosol Optical Depth (AOD) and its effect on regional visibility over Bongaigaon for the period August, 2002 to March, 2017.

2. Study region, meteorology and database

The proposed study area is Bongaigaon (26.52° N, 90.5° E, 64 amsl) as shown in Figure1. The topography of Bongaigaon district represents mostly plain lands except a small portion of isolated hills in Bijni sub-division, bordering Bhutan. The study location is one of the westernmost locations of Brahmaputra Valley of Assam that falls in the corridor through which pollutants transported from west Asian locations and Indo Gangetic plain (IGP) region to North-East India. Due to less industrialization and low population density over North-East India, it is expected to contain minimum aerosols in the atmosphere, but at the same time its unique topography acts as a sink for the transported aerosols which may sustain in the atmosphere of this particular region. North-East India receives much higher rainfall than the other regions of India and neighbouring countries.

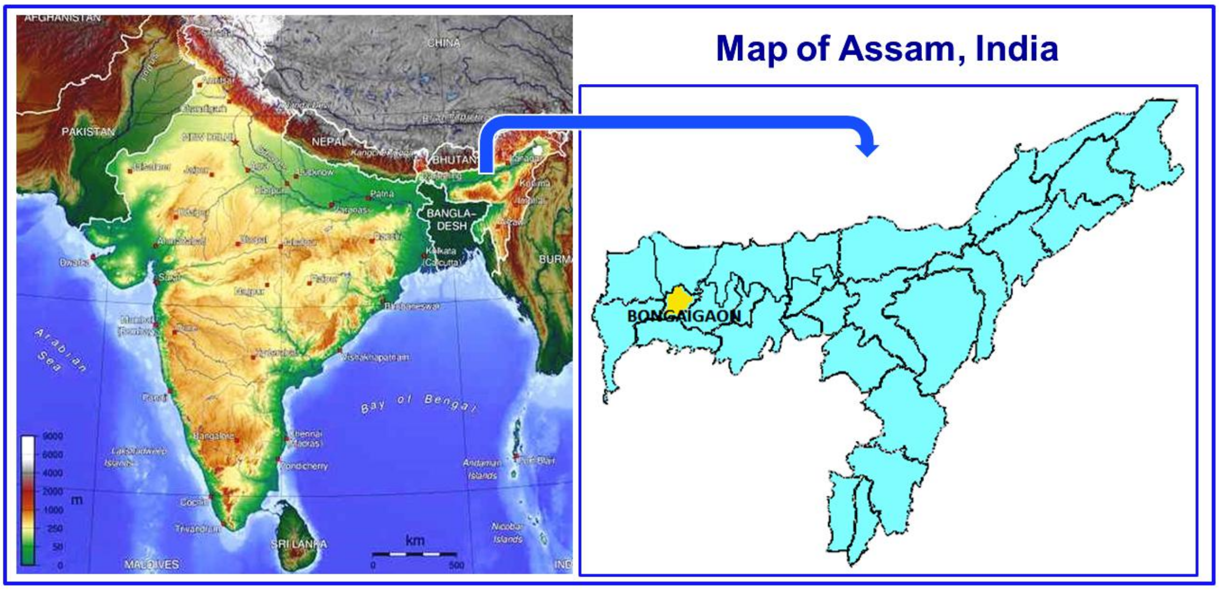

Figure 1. Map of India showing the study location, Bongaigaon in Assam.

To analyse the meteorological condition over the proposed study location some ground based and satellite data have been used. Tropical Rainfall Measuring Mission (TRMM) data have been used to study the monthly variation of rainfall over Bongaigaon for the period January, 2008 to December, 2016. TRMM is a joint space mission between NASA and the Japan Aerospace Exploration Agency (JAXA) which is used to study tropical rainfall. The monthly variation of rainfall over the study location is shown in **Figure 2.** From the 9 year averaged data it is clearly seen that rainfall is minimum during the period November to February, and then it starts to increase from the month of March, reaches its peak value in the month of either June or July and after that again starts to decreases towards winter months. The total monthly rainfall for the study period varies from a minimum value ~0.66 mm/hr to a maximum value ~159/hr mm over Bongaigaon.

Automatic Weather Station (AWS) data have been used to study the monthly variation of temperature and relative humidity over Bongaigaon for the period January, 2008 to December, 2016 (**Figure 2**). Relative humidity shows relatively lower value in dry season compared to the wet season. In general relative humidity starts to increase from April, exhibits high values in monsoon period, then starts to decrease and in March it is the lowest. Temperature is low during January month, than it starts to increases and attains a peak in summer months and again decreases towards the month of December.

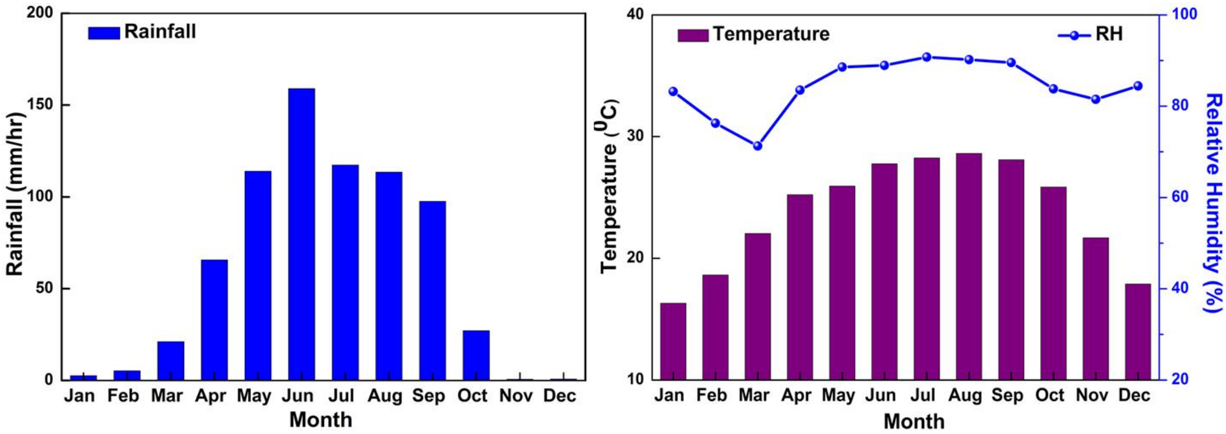

Figure 2. Monthly variation of rainfall, temperature and relative humidity over Bongaigaon for the period January, 2007 to December, 2016.

MODIS sensor on board the NASA Earth Observing System (EOS) Terra and Aqua satellite based AOD data are used for the period of Aug, 2002-March, 2017 over Bongaigaon. MODIS is a NASA's on board twin satellites for example Terra and Aqua that performs near global daily observations of atmospheric aerosols with 36 spectral channels covering from the visible region to the thermal infrared region. The daily Level 3 data set of aerosol optical depth at 550 nm and Ångström exponent with quality assured (QA) Collection 6 data has 1°×1° global resolutions[20]. All the necessary data sets are obtained from the Giovanni web service (http://disc.sci.gsfc.nasa.gov/giovanni), which provides a very simple way to visualize, examine as well as access enormous amounts of Earth science remote sensing data. For this study, the monthly mean level-3 collection-6 MODIS AOD data on a 1°×1° latitude-longitude grid data has been used.

3. Results and discussions

Bongaigaon, western most part of Assam falls in the corridor trough which pollutants transported from highly polluted and populated IGP region to North-East India. Through Bongaigaon is a less industrialised area, it experiences a high value of AOD as seen from satellite observations. The monthly variations of AOD at 550 nm over Bongaigaon for the period Aug, 2002 to March 2017 is shown in Figure3a. The monthly AOD values vary from its highest value 0.949 in April 2016 to its lowest value 0.107 in Nov, 2002 for the study period over Bongaigaon. Also we have compared the MODIS Terra and Aqua AOD at 550 nm over the study location. From the comparison, it is clearly seen that generally Terra AOD at 10:30 hr (Terra overpass local time) is higher than the Aqua AOD at 13:30hr (Aqua overpass local time). From Figure:3a it is clearly seen that there is a slowly increasing trend of both Aqua and Terra AOD at 550 nm for the study period. The seasonal variation of AOD over the study location is shown in Figure3b (left). From the figure it can be clearly seen that generally AOD values are low in post-monsoon season which may be due to wash out of aerosols by rain in the preceding months without enough replacement except for the year 2003, 2005 and 2015 where minimum AOD is observed in December. Highest AOD values are observed in Pre-monsoon season (generally peak in April) due to long range transportation as well as intense biomass burning activities whereas the same shows in June month for the year 2003 and 2015. A similar seasonal variation of AOD had been reported earlier over Dibrugarh[7].

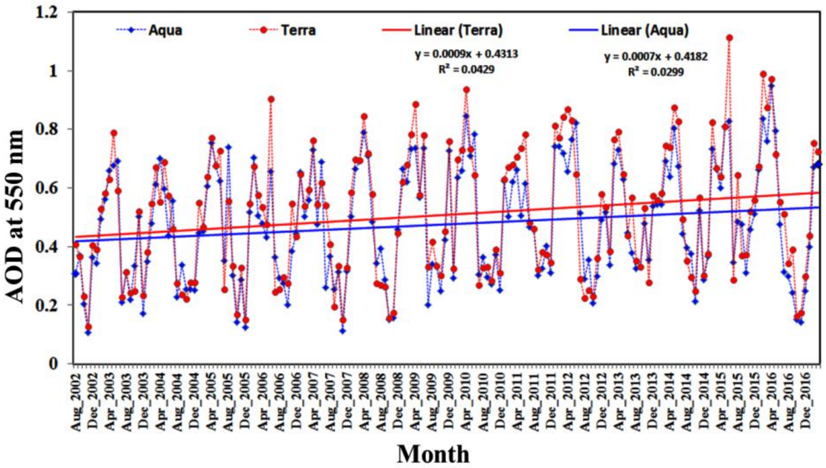

Figure 3a. Monthly variation of MODIS AOD (Aqua and Terra) at 550 nm over Bongaigaon for the period Aug, 2002 to March 2017.

The seasonal variation of Ångström Exponent is shown in Figure3b (right). The Ångström parameter is usually used to estimate the size of atmospheric aerosol particles and the relative dominance of fine mode aerosols over the coarse mode aerosol particles. Ångström exponent values which lying between 1 and 1.5 indicates major contributions of aerosols from accumulation mode aerosols to the AOD[21]. The observed Ångström exponent value varies from its minimum value (~1.01) in monsoon to its maximum value (~1.3) in winter season over Bongaigaon. This in fact indicates that the size of aerosol particles in winter season is smaller than that in monsoon season. Similarly, higher value of Ångström exponent in winter season compared to the pre-monsoon season with increasing trends of 25.3% per decade has been reported over Pune, India[22].

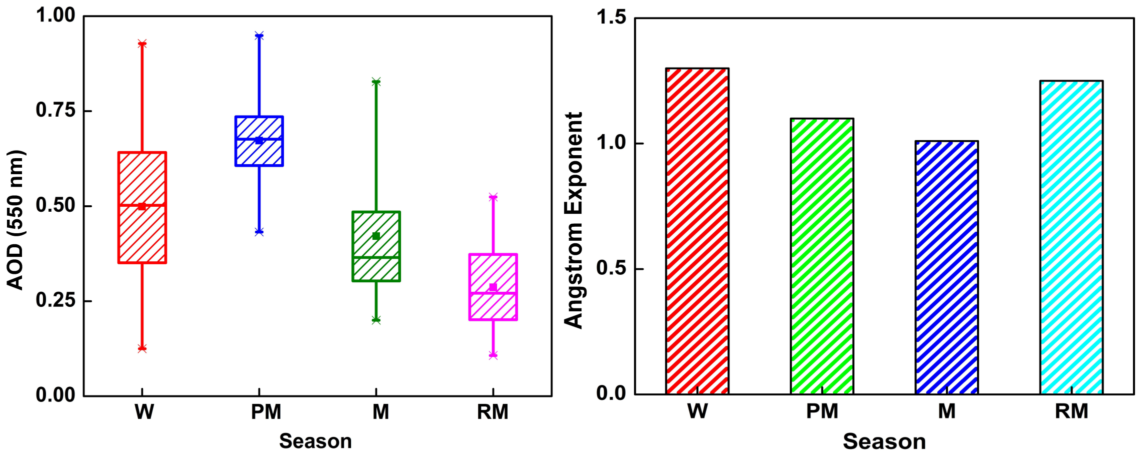

Figure 3b. Seasonal variation of MODIS AOD at 550 nm (left) and Angstrom Exponent (right) over Bongaigaon for the period Aug, 2002 to March 2017.

Using the National Atmospheric and Oceanic Administration Hybrid Single-Particle Lagrangian Integrated Trajectory (NOAA-HYSPLIT) model[23], 5-day isentropic air mass back concentration weighted trajectories are computed to find out the probable flow paths and source regions of air flow with time over Bongaigaon. These back trajectories are mostly calculated from the observed vertical wind and pressure fields. HYSPLIT model is used to find whether upper levels of air pollution at one location are influenced by transport of air contaminants from another location. The seasonal mean concentration weighted trajectories for the year 2013 arriving at the study location Bongaigaon at altitude 500m AGL and 3500 m AGL are shown in **Figure 4**a and **Figure 4**b respectively following some considerations[24]. During pre-monsoon season, there is a distinct difference between the pathways of the air masses at lower altitude 500m AGL and higher altitude 3500m AGL. At lower altitude trajectories are basically from Bay of Bengal (BoB) as well as Himalayan region but as the altitude increases the entire trajectories are confined within the highly polluted IGP region. At 3500m AGL almost all the trajectories are from West Asia, traversing the IGP region for the study location. During pre-monsoon season there is a probability of transport of dust aerosols from Sahara and other African regions to Dibrugarh at 3600m AGL[8].

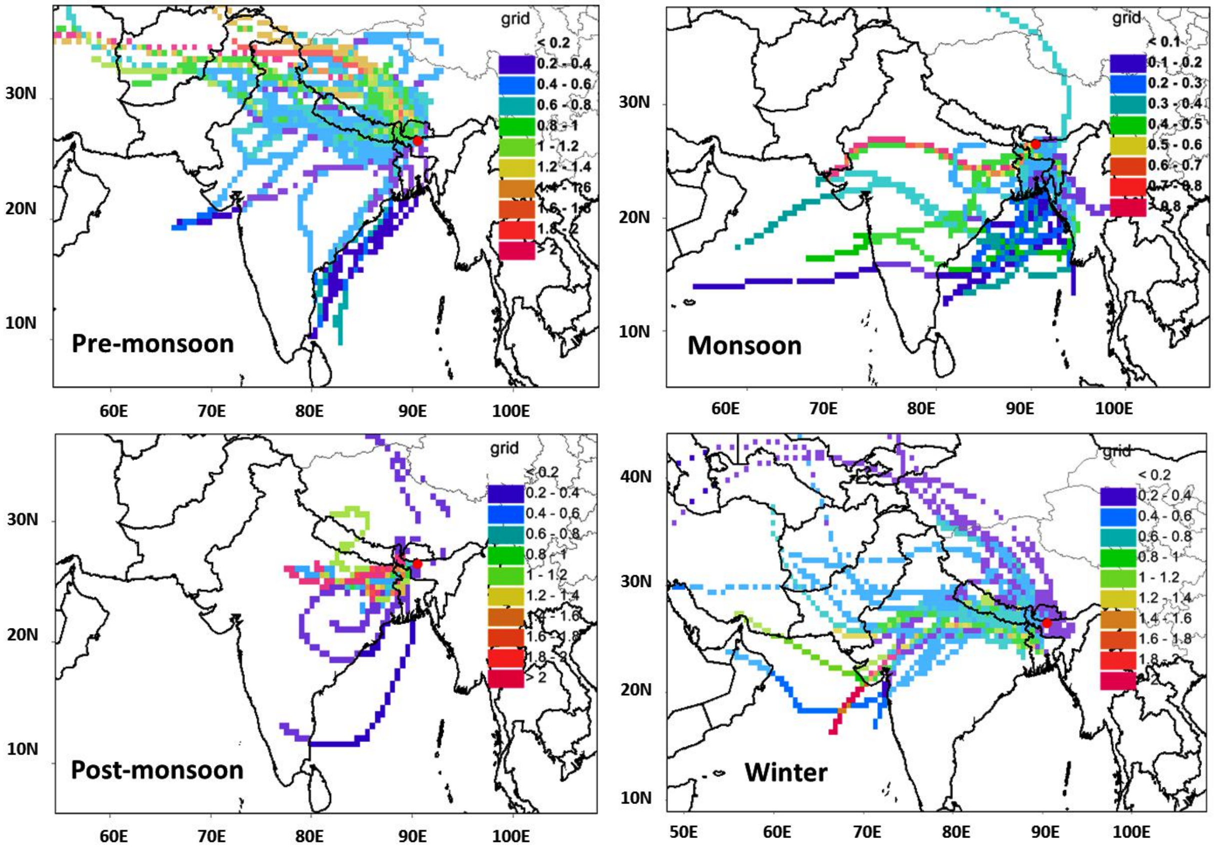

Figure 4a. Seasonal representation of 5-days concentration weighted isentropic HYSPLIT back trajectories at 500 m AGL to Bongaigaon.

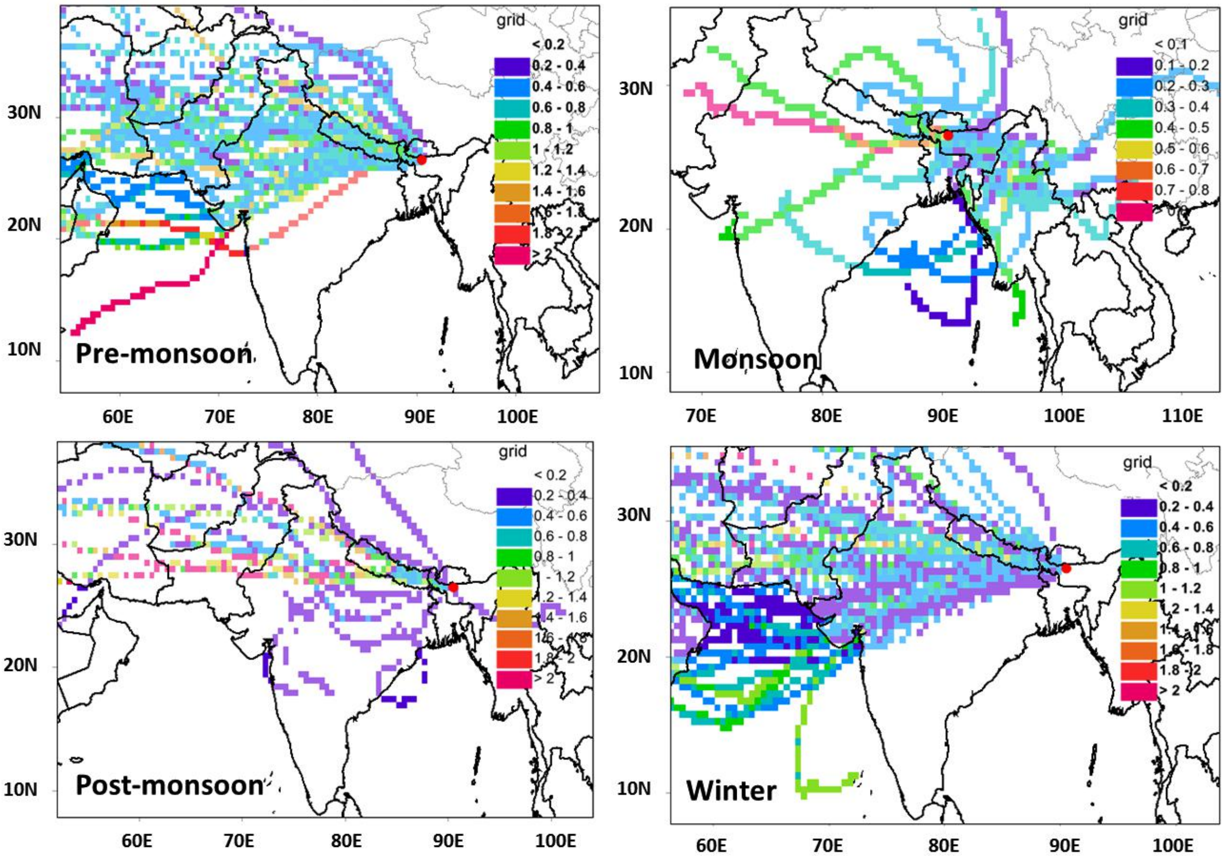

Figure 4b. Seasonal representation of 5-days concentration weighted isentropic HYSPLIT back trajectories at 3500 m AGL to Bongaigaon.

During monsoon season, the dominant trajectories at 500m AGL are arising from Arabian Sea and reach the study location via BoB carrying marine aerosols. Significant numbers of trajectory arise from Himalayan region and reach the study region at 3500m AGL. In post-monsoon season due to low wind speed, considerable numbers of locally originating trajectories are observed for the study location at 500m AGL. Air mass trajectories during post-monsoon season do not show a clear pattern and more than 50% trajectories are local over Dibrugarh[8]. In this season, few trajectories are arising from North of Afghanistan and Pakistan at all the proposed study region at 3500m AGL. In winter season at 500 m AGL transportation of air masses through IGP is noticeable with less possibility of transportation of air masses along the Himalayan region. But at 3500 m AGL almost all the trajectories originates from densely populated IGP, Pakistan or West Asian region. In the extremely urbanized as well as industrialized IGP region intense fog as well as haze conditions frequently occur during the winter season[25] and can produce anthropogenic fine aerosol particles which may be transported over long distances by the air mass trajectories before they settle down due to gravity[26].

The relationship between AOD and visibility is presented in Figure5. Horizontal visibility is a simply observable indicator of air quality over a region. A high value of visibility commonly indicates good air quality. A relationship between visibility (V) and aerosol optical depth has been established[27] to be used for Visible Infrared Imaging Radiometer Suite (VIIRS) data onboard the National Polar-orbiting Operational Environmental Satellite System as shown in equation 1. This equation is not valid for AOD≤0.08498. From Figure5 it is clearly seen that visibility is minimum during pre-monsoon months which may be due to higher values of AOD for the season over the study location. The monthly average visibility is highest in the month of October, reaching a minimum in the month of April.

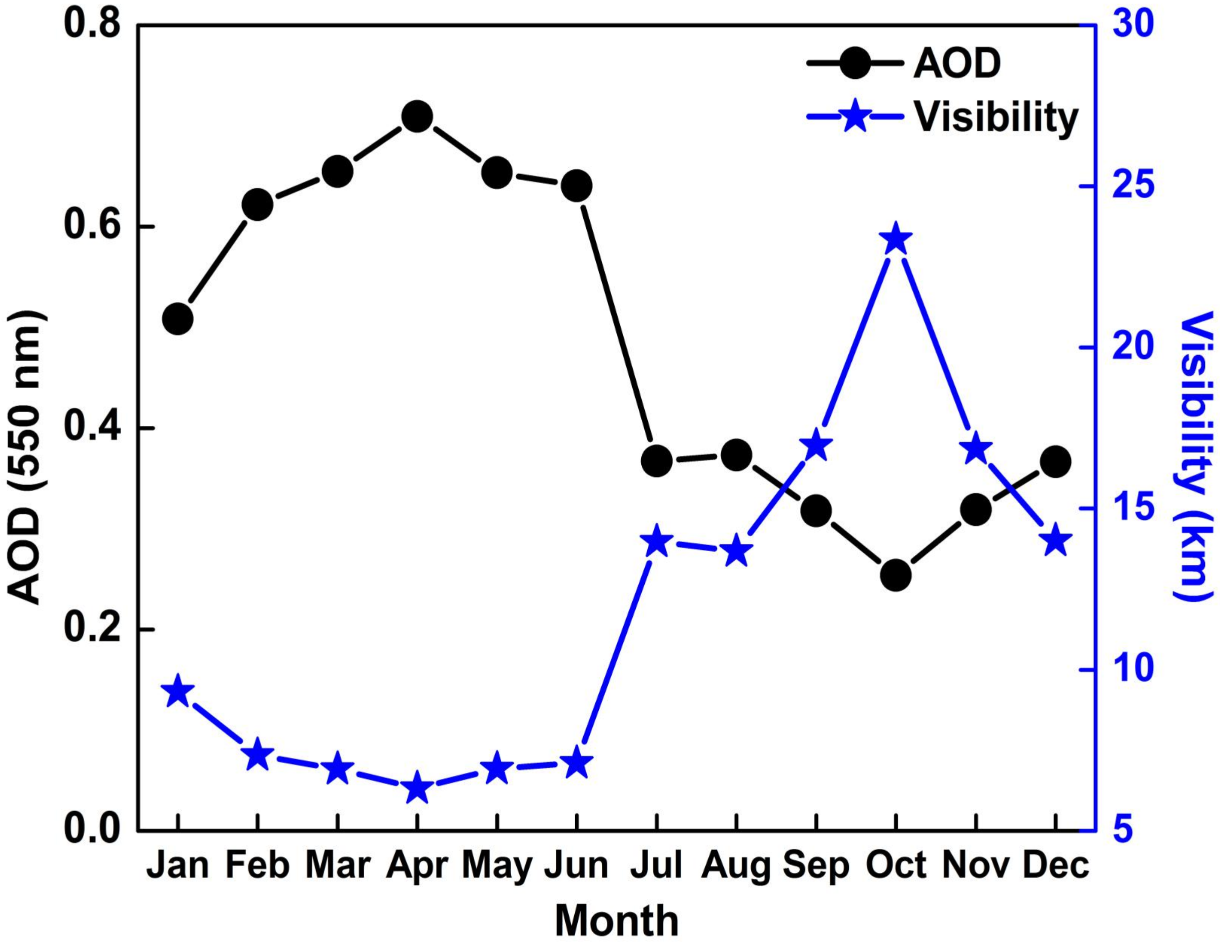

Figure 5. Monthly variation of AOD and visibility over Bongaigaon.

Equation 1:

$$\text{Visibility (V)} = \frac{3.9449}{(\text{AOD}_{550} - 0.08498)} \quad (1)$$

5. Summary

From the long term trend analysis, it has been observed that highest AOD values are found in pre-monsoon season due to long range transportation as well as intense biomass burning activities especially as a part of Jhum cultivation. In general, AOD values are low in post-monsoon season which may be due to wash out of aerosols by rain in the preceding months without enough replacement. The monthly AOD values vary from its highest value 0.949 in April, 2016 to its lowest value 0.107 in November, 2002 for the study period. From the comparison of MODIS Terra and Aqua AOD at 550 nm, it is clearly seen that generally Terra AOD at 10:30 hr is higher than the Aqua AOD at 13:30hr. There is a slowly increasing trend of both Aqua and Terra AOD at 550 nm for the study period over Bongaigaon. The monthly average horizontal visibility in Bongaigaon is highest (23.36 km) in October with a enough reduction observed during the monsoon season, reaching its minimum value (6.32 km) in April. Horizontal visibility decreases with increasing AOD values over Bongaigaon.

Conflict of Interest

No conflict of interest was reported by the author.

Acknowledgments

Author is thankful to Giovanni (https://giovanni.sci.gsfc.nasa.gov/giovanni/) science data team for the data used in this analysis. The author is also acknowledge the use of data products from the NASA Terra and Aqua satellite missions

and NOAA ARL for the provision of the HYSPLIT transport and dispersion model used in this publication.

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