URSI - RCRS 2022, IIT (Indore), India, 1 - 4 December, 2022

Identification of aerosol types over the central Indo-Gangetic Plain using multi-satellite observations

Prayagraj Singh * (1), Bakhtawar H. Abdullah (1), Aditya Vaishya (2,3), Prabhunath Prasad (1) and Shantanu Rastogi (1)
(1) Department of Physics, Deen Dayal Upadhyaya Gorakhpur University, Gorakhpur, 273009, India
(2) School of Arts and Sciences, Ahmedabad University, Ahmedabad, 380 009, India
(3) Global Centre for Environment and Energy, Ahmedabad University, Ahmedabad, 380 009, India

Abstract

Identification and quantification of aerosol types in the central Indo-Gangetic Plain (IGP) region is done using long-term (2005 – 2019) and simultaneous datasets, from satellite and reanalysis, of aerosol optical depth (AOD), absorbing aerosol index (AAI) and Ångström exponent (α). In order to identify aerosol types in the central IGP, we used two classification methods by assigning the predefined thresholds of (i) AOD and α and (ii) AOD, α and AAI. Results derived from Method 1 suggest anthropogenic aerosols (AA) are dominant during the study period followed by mixed type (MT) and biomass burning (BB) aerosols over Gorakhpur. From Method 2, it is apparent that absorbing aerosols dominate during pre-monsoon (PM), post-monsoon (PoM) and winter (W) seasons, and non-absorbing aerosols during monsoon (M). BB aerosols derived from method 1 and carbonaceous aerosols from method 2 showed the highest contribution during PoM and W season. This is due to increased burning of agricultural waste and forest fires in the IGP region during this period. Dust aerosols derived from both methods showed maximum contribution during PM season, with marginal contributions during M and W seasons, respectively, and negligible during PoM season.

1. Introduction

Atmospheric aerosols are widely recognized as important constituents of the earth-ocean-atmosphere system [1]. They exhibit different climatic effects due to their size, composition and hygroscopic nature [2]. Aerosols, due to their direct, indirect, and semi-direct effect, play a significant role in modulating the radiative forcing [3]. Absorbing aerosols such as mineral dust and black carbon (BC) can scatter and absorb the shortwave radiation, leading to positive and negative atmospheric radiative forcing. While non-absorbing aerosols such as sea salt, sulphate and nitrates are highly reflecting in nature and thus exert a negative atmospheric radiative forcing. Thus, it is important to identify major aerosol types and their optical properties in order to understand and reliably estimate the aerosol radiative forcing [4].

The Indo-Gangetic Plain (IGP) in South Asia is well recognized for high aerosol loading [5, 6] and important aerosol source region where strong intra-seasonal to inter-annual variability is influenced by various natural and anthropogenic emission processes [7, 8]. During the past few decades, an increase in industrialization and urbanization in this region has led to a significant rise in anthropogenic emission sources and thus exhibited seasonal heterogeneity in aerosol types. This has affected the precipitation patterns during the Indian summer monsoon [9] and also the regional as well as global climate system [10-12]. Aerosol types and their abundance are linked to different emission sources, ambient weather conditions and unique topography of the region. IGP region is mostly dominated by wind-driven mineral dust, which is transported from central, south-west Asia and the Thar desert [13] especially in the pre-monsoon (PM) season, with the contribution of aerosols from anthropogenic activities [14]. In addition, agricultural residue burning in the open fields during post-monsoon (PoM) season and forest fires also contributed to a significant amount of aerosols and trace gases over the IGP [15-17]. During winter (W) season, dense smog events at several locations of the IGP is associated with enhanced anthropogenic emissions and ambient meteorological conditions like weak convection, calm winds, high relative humidity and low boundary layer height. Smog can be transported to distant locations of the IGP leading to deterioration in visibility, poor air quality and adverse effects on human health.

In the present study, two classification techniques have been used to identify aerosol types during different seasons over Gorakhpur, a semi-urban location in the central IGP.

2. Data and methodology

Simultaneous datasets of aerosol optical depth (AOD), Ångström exponent (α), and absorbing aerosol index (AAI) for the period of 2005 – 2019 has been utilized for the identification of aerosol types and sub-types over Gorakhpur. In this study, daily mean AOD at 550 nm from Moderate Resolution Imaging Spectroradiometer

(MODIS) level 3 combined DB-DT retrieval of Terra (MOD08_D3) and Aqua (MYD08_D3) satellites, at a spatial resolution of 1° X 1° were used. Hourly α at 470 – 870 nm were obtained from Modern-Era Retrospective Analysis for Research and Applications, Version-2 (MERRA-2) reanalysis (M2T1NXAER_V5.12.4) at a spatial resolution of 0.5° X 0.65° and computed as daily averaged for further analysis. Ozone Monitoring Instrument (OMI) Level 3 (OMTO3d_003), 1° X 1° gridded daily AAI observations are also used in this study. In order to identify aerosol types and sub-types during each season, daily values of AOD, α and AAI are sorted according to pre-monsoon (PM), monsoon (M), post-monsoon (PoM) and winter (W) season.

The aerosol type classification based on AOD and α values (hereafter referred to as Method 1) is widely used to identify aerosols originating from natural and anthropogenic sources that exhibited different physical and optical characteristics. For differentiating the major aerosol types over the study region, the threshold values of AOD and α were adopted from the studies which were investigated over different locations of the IGP [10, 18, 19]. Selected thresholds for the present study are AOD > 0.5 and α < 0.6 for desert dust (DD), AOD in the range of 0.2 – 0.5 and α < 0.8 for polluted continental (PC; anthropogenic aerosols with dust), AOD in the range of 0.3 – 1 and α > 1 for anthropogenic aerosols (AA), and AOD > 1 and α > 1.2 for biomass burning (BB) aerosols. Other values of AOD and α within the abovementioned threshold range represent the mixed type (MT) aerosols. For further quantification of aerosols into absorbing and non-absorbing types, we have adopted MODIS-OMI algorithm [20] to categorize aerosols which are based on their optical (i.e., aerosol size) and absorption properties [21]. This method (hereafter referred to as Method 2) is used to sub-categorize aerosols into sea-salt, dust, carbonaceous, sulphate along with their mixed types such as sea-salt + dust, sea-salt + sulphate and dust + carbonaceous. Simultaneous availability of AOD, α, and AAI values present during the study period are used for aerosol type classification and their thresholds are given in Table 1.

3. Results and discussion

Based on simultaneous measurements of AOD, AAI, and α, different aerosol types within the study region have been identified on a seasonal and annual basis, by following the two different methods. Figure 1 and 2 illustrates different aerosol types and sub-types on seasonal and annual basis observed during the study period, as determined by method 1 and 2, respectively.

Central IGP has maximum aerosol loading of AA type, as obtained from Method 1. This is mainly due to emissions from anthropogenic activities and vehicular exhaust. Seasonally the loading of AA type aerosols are maximum in PoM (72.6%), followed by M (59.9%), and W (56.2%).

Table 1: Method 2 - threshold values of AOD, AAI and α for aerosol sub-type classification adopted from Sreekanth, V. [22]

	Absorbing Aerosol Index (AAI)	
	AAI ≤ 0.7	AAI > 0.7
α < 0.8	Sea salt Sea salt + sulphate (if AOD > 0.2)	
α < 0.7		Dust Sea salt + dust (if AOD ≤ 0.2)
α > 1	Sulphate	
α > 1.2		Carbonaceous
0.8 < α > 1.2	Sea salt + sulphate	
0.7 < α > 1.2		Dust + carbonaceous Sea salt + carbonaceous (if AOD ≤ 0.2)

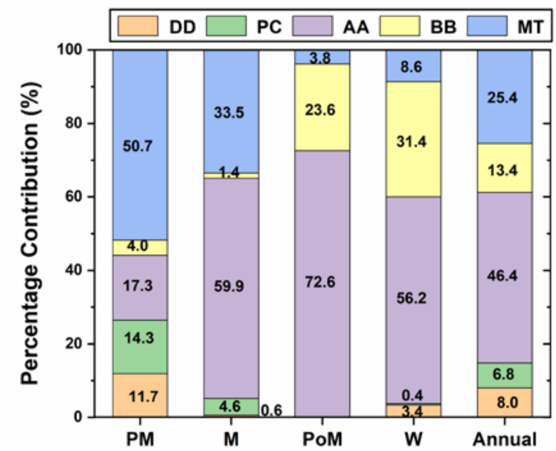

Figure 1: Percentage contribution of different aerosol types on a seasonal and annual basis using Method 1.

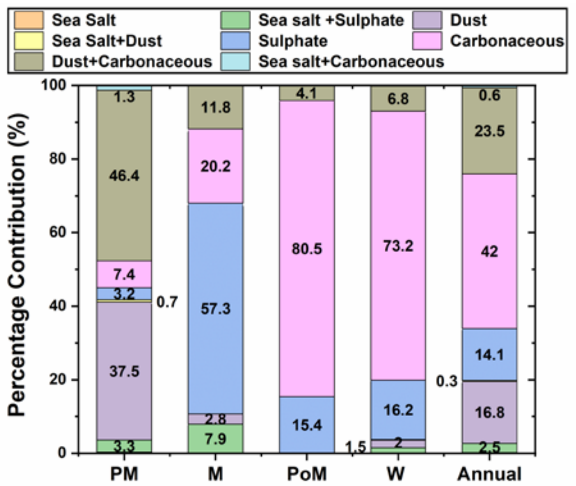

Figure 2: Percentage contribution of aerosol sub-types on a seasonal and annual basis using Method 2.

In addition, the contribution of BB aerosols is highest during W (31.4%) and PoM (21.6%) suggesting increased biomass burning activities, such as crop residue burning and forest fires in the study region. PM (4%) and M (1.4%) season showed less contribution of BB aerosols during the study period. From Figure 2, it is observed that carbonaceous aerosols had a maximum contribution in PoM (80.5%) and W (73.2%) seasons, followed by M (20.2%) and PM (7.4%). Carbonaceous aerosols load derived from Method 2 are comparable with AA and BB aerosols load derived from Method 1. Due to presence of non-carbonaceous aerosols in AA, Method 1 showed an overestimation in carbonaceous aerosols when compared with Method 2.

The contribution of MT aerosols, as inferred from Method 1, is highest during PM (50.7%) followed by M (33.5%), W (8.6%), and PoM (3.8%) seasons. MT aerosols are produced by coagulation of different sized aerosols from varying sources. The mixture of sea salt and dust with sulphate and carbonaceous aerosols (i.e. sea salt + sulphates, sea salt + dust, dust + carbonaceous and dust + carbonaceous) obtained from Method 2 showed maximum contribution during PM (49.7%) followed by M (19.7%), W (8.7%), and PoM (4.1%) seasons. During PM, PoM and W seasons, the contribution of MT aerosols from Method 1 are comparable to the total contribution of mixtures of sea salt and dust with sulphate and carbonaceous aerosols obtained from Method 2.

According to Methods 1 and 2, dust aerosols contributed the most to PM (11.7% and 37.5%) season, with marginal contributions during M (1.4% and 2.8%) and W (0.4% and 2%) seasons, respectively, however PoM showed no significant presence of dust aerosols over the region. Dust aerosols derived from Method 2 clearly overestimated the contribution compared to Method 1. Following Method 1, PC aerosols (anthropogenic aerosols containing dust particles) were also identified over the study region where its contribution was seen only in PM (14.3%) and M (4.6%) seasons. Contribution of non-absorbing aerosols such as sulphates derived from Method 2 showed maximum contribution during M (57.3%) followed by W (16.2%) and PoM (15.4%) season. Other non-absorbing aerosol such as sea salt have no significant contribution.

In general, throughout the year Central IGP (Gorakhpur) was dominated by aerosols from anthropogenic activities i.e. AA (46.4%) followed by MT aerosols (25.4%), BB aerosols (13.4%), PC aerosols (8%) and DD aerosols (6.8%). Whereas, identifying aerosol type using Method 2 indicated the dominance of absorbing aerosols with maximum contribution from carbonaceous aerosols (42%) followed by Dust + carbonaceous (23.5%), Dust (16.8%), and with an insignificant contribution of 2.5% and 0.6% due to sea salt + sulphate and sea salt + carbonaceous aerosols.

4. Conclusions

Long-term (2005 – 2019) and simultaneous observations of aerosol optical parameters were analysed to identify the aerosol types at Gorakhpur located in the central Indo-Gangetic Plain (IGP) by employing two different classification methods. Different aerosol types were identified after applying the predefined threshold values of aerosol optical depth (AOD), absorbing aerosol index (AAI) and Ångström exponent (α) on a seasonal and annual basis. The findings of the present study are summarized below:

1. Following Method 1, Central IGP region is mostly dominated by anthropogenic aerosols, AA (46.4%) followed by mixed type (MT) aerosols (25.4%), biomass burning (BB) aerosols (13.4%), polluted continental (PC) aerosols (8%) and desert dust (DD) aerosols (6.8%).

2. Absorbing and non-absorbing aerosol type derived from Method 2 indicates the dominance of absorbing aerosols, during the study period, with maximum contributions from carbonaceous aerosols (42%), followed by dust + carbonaceous (23.5%), and dust (16.8%).

3. During pre-monsoon (PM), post-monsoon (PoM) and winter (W) seasons, the contribution of MT aerosols from Method 1 are comparable to the total contribution of sea salt + dust, sea salt + sulphates, dust + carbonaceous and sea salt + carbonaceous aerosols inferred from Method 2 indicating both the methods are complementing each other.

4. Methods 1 and 2 showed that dust aerosols were the major contributor to PM aerosol load (11.7 % - 37.5 % respectively).

5. Acknowledgements

The author Prayagraj Singh is grateful to ISRO for providing financial support under the Aerosol Radiative Forcing over India (ARFI) project of ISRO-GBP (SPL:GBP:ARFI:40). The authors greatly acknowledge the Terra-Aqua/MODIS, Aura/OMI, MERRA-2 reanalysis for providing aerosol products used in this publication.

6. References

1. K.R. Kumar, N. Kang, and Y. Yin, "Classification of key aerosol types and their frequency distributions based on satellite remote sensing data at an industrially polluted city in the Yangtze River Delta, China", *International Journal of Climatology*, **38**, 1, 2018, pp. 320-336.

2. R. Srivastava and S. Ramachandran, "The mixing state of aerosols over the Indo-Gangetic Plain and its impact

on radiative forcing", *Quarterly Journal of the Royal Meteorological Society*, **139**, 670, 2013, pp. 137-151.

3. R.J. Charlson, S. Schwartz, J. Hales, R.D. Cess, J. Coakley Jr, J. Hansen, and D. Hofmann, "Climate forcing by anthropogenic aerosols", *Science*, **255**, 5043, 1992, pp. 423-430.
4. O. Dubovik, B. Holben, T.F. Eck, A. Smirnov, Y.J. Kaufman, M.D. King, D. Tanré, and I. Slutsker, "Variability of absorption and optical properties of key aerosol types observed in worldwide locations", *Journal of the atmospheric sciences*, **59**, 3, 2002, pp. 590-608.
5. S. Dey, S.N. Tripathi, R.P. Singh, and B. Holben, "Influence of dust storms on the aerosol optical properties over the Indo-Gangetic basin", *Journal of Geophysical Research: Atmospheres*, **109**, D20, 2004.
6. N. Ojha, A. Sharma, M. Kumar, I. Girach, T.U. Ansari, S.K. Sharma, N. Singh, A. Pozzer, and S.S. Gunthe, "On the widespread enhancement in fine particulate matter across the Indo-Gangetic Plain towards winter", *Scientific reports*, **10**, 1, 2020, pp. 1-9.
7. M. Lawrence and J. Lelieveld, "Atmospheric pollutant outflow from southern Asia: a review", *Atmospheric Chemistry and Physics*, **10**, 22, 2010, pp. 11017-11096.
8. N.K. Lodhi, S.N. Beegum, S. Singh, and K. Kumar, "Aerosol climatology at Delhi in the western Indo-Gangetic Plain: Microphysics, long-term trends, and source strengths", *Journal of Geophysical Research: Atmospheres*, **118**, 3, 2013, pp. 1361-1375.
9. R.P. Singh, S. Kumar, and A.K. Singh, "Elevated black carbon concentrations and atmospheric pollution around Singrauli coal-fired thermal power plants (India) using ground and satellite data", *International journal of environmental research and public health*, **15**, 11, 2018, pp. 2472.
10. S. Tiwari, D. Kaskaoutis, V.K. Soni, S.D. Attri, and A.K. Singh, "Aerosol columnar characteristics and their heterogeneous nature over Varanasi, in the central Ganges valley", *Environmental Science and Pollution Research*, **25**, 25, 2018, pp. 24726-24745.
11. D.G. Kaskaoutis, E.E. Houssos, D. Goto, A. Bartzokas, P.T. Nastos, P.R. Sinha, S.K. Kharol, P.G. Kosmopoulos, R.P. Singh, and T. Takemura, "Synoptic weather conditions and aerosol episodes over Indo-Gangetic Plains, India", *Climate Dynamics*, **43**, 9, 2014, pp. 2313-2331.
12. S. Satheesh, K.K. Moorthy, Y. Kaufman, and T. Takemura, "Aerosol optical depth, physical properties and radiative forcing over the Arabian Sea", *Meteorology and Atmospheric Physics*, **91**, 1-4, 2006, pp. 45-62.
13. A. Srivastava, S. Tripathi, S. Dey, V. Kanawade, and S. Tiwari, "Inferring aerosol types over the Indo-Gangetic Basin from ground based sunphotometer measurements", *Atmospheric Research*, **109-110**, 2012, pp. 64-75.
14. K. Ram and M. Sarin, "Day–night variability of EC, OC, WSOC and inorganic ions in urban environment of Indo-Gangetic Plain: implications to secondary aerosol formation", *Atmospheric Environment*, **45**, 2, 2011, pp. 460-468.
15. D. Kaskaoutis, S. Kumar, D. Sharma, R.P. Singh, S. Kharol, M. Sharma, A. Singh, S. Singh, A. Singh, and D. Singh, "Effects of crop residue burning on aerosol properties, plume characteristics, and long-range transport over northern India", *Journal of Geophysical Research: Atmospheres*, **119**, 9, 2014, pp. 5424-5444.
16. A. Vaishya, P. Singh, S. Rastogi, and S.S. Babu. *Source apportionment of absorbing aerosols in the central Indo-Gangetic Plain*. in *SPIE, Remote Sensing of the Atmosphere, Clouds, and Precipitation VI*. 2016. Proc. SPIE 9876.
17. A. Vaishya, P. Singh, S. Rastogi, and S.S. Babu, "Aerosol black carbon quantification in the central Indo-Gangetic Plain: Seasonal heterogeneity and source apportionment", *Atmospheric Research*, **185**, 2017, pp. 13-21.
18. P. Singh, A. Vaishya, S. Rastogi, and S.S. Babu, "Seasonal heterogeneity in aerosol optical properties over the subtropical humid region of northern India", *Journal of Atmospheric and Solar-Terrestrial Physics*, **201**, 2020, pp. 105246.
19. S. Tiwari, S. Tiwari, P. Hopke, S. Attri, V. Soni, and A.K. Singh, "Variability in optical properties of atmospheric aerosols and their frequency distribution over a mega city "New Delhi," India", *Environmental Science and Pollution Research*, **23**, 9, 2016, pp. 8781-8793.
20. J. Kim, J. Lee, H.C. Lee, A. Higurashi, T. Takemura, and C.H. Song, "Consistency of the aerosol type classification from satellite remote sensing during the Atmospheric Brown Cloud–East Asia Regional Experiment campaign", *Journal of Geophysical Research: Atmospheres*, **112**, D22, 2007.
21. A. Higurashi and T. Nakajima, "Detection of aerosol types over the East China Sea near Japan from four-channel satellite data", *Geophysical research letters*, **29**, 17, 2002, pp. 17-1-17-4.
22. V. Sreekanth, "On the classification and sub-classification of aerosol key types over south central peninsular India: MODIS–OMI algorithm", *Science of the total environment*, **468**, 2014, pp. 1086-1092.