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SEASONAL VARIATIONS OF AEROSOL OPTICAL DEPTH OVER INDIAN SUBCONTINENT

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ABSTRACT

Atmospheric aerosols are considered to be one of most complex and important parameter affecting the climate change. According to IPCC Scientific understanding of Atmospheric Aerosol forcing on climate change is very low. Estimating the impact of Atmospheric Aerosols on climate is very complex as they differ in chemical composition and optical properties viz. Scattering and absorbing. Precipitation phenomena is influenced by aerosols hence study of atmospheric aerosols over Indian sub continent is necessary as the Indian economy is highly dependent on Monsoon rainfall. AOD (Aerosol Optical Depth) from MODIS (MODerate Resolution Imaging Spectroradiometer) onboard Terra and Aerosol Index (AI) from OMI (Ozone Monitoring Instrument) onboard Aqua to study the seasonal variation of Aerosols. Study of Aerosols during Monsoon is highlighted to investigate their behaviour during this season. Aerosol loading is found to be more in the study region during Monsoon(June, July, August, September) and less in Post monsoon (October, November). Effect of Topography on Aerosol loading is observed and Aerosol loading is less over elevated regions. The COV (Coefficient of Variation of AOD is high over elevated regions showing high variability. High Aerosol Index over Arabian Sea and western India, and wind direction during monsoon indicates high aerosol loading transported through westerlies. This also supports the statement that the high values of AOD is not due to cloud contamination but due to presence of high amount of Aerosols and most of them are found to be transported from Arabian desert and Africa through Arabian sea.

INTRODUCTION

The Indian sub continent comprises of a wide range of weather across a large geographic scale and varied topography. India has extraordinary variety of climatic regions, viz. tropical wet and tropical dry in the south, semiarid in the central part of southern peninsular India, arid and semi arid regions in the west, temperate and cold winter climate near the Himalayas (Lohmann et al, 1993). The region's climate is strongly influenced by the Himalayas and the Thar Desert. The Indo Gangetic plain is the most densely populated region. The river Ganges is a perennial river, owing to this lot of polluting industries are established near by the river. Most of the thermal power stations are situated in this region due to the availability of water throughout the year (http://www.cpcb.nic.in , 2012). The North western part of India is also affected by dust plumes due to the presence of Great Indian Desert in Rajasthan and this dust is transported with wind to northern part of India.

Southern peninsular India is comparatively less polluted and the reason may be transport from and towards the water bodies surrounding it (Niranjan et al, 2008). The air quality is highly affected by the emission from the transportation vehicles, Industries and household cooking hence observations of atmospheric aerosols throughout the subcontinent are necessary. As the present ground based observation sites are limited, Satellite observations has to be used for studying the whole region. Seasonal variation of Atmospheric aerosols over India is taken up in this study using MODIS aboard Terra and OMI aboard Aura satellites.

The economy of India depends heavily on agriculture and agriculture depends mainly on the monsoon rainfall which occurs in the period between June and September. Atmospheric aerosols over a region can affect precipitation [Ramanathan et al., 2001], and thus aerosol research is very important in the Indian context. Many groups are actively involved in the aerosol research in India with ground based as well as satellite observations. A review of aerosol measurements in India was described by Dey and Girolamo, (2010). Efforts have been put by different groups in India to measure Physical, Chemical and optical properties of atmospheric aerosols. We studied seasonal variation of aerosols over India using MODIS AOD and Aerosol Index from Ozone Monitoring Instrument. MODIS AOD is used for study of Aerosol loading over the region whereas Aerosol Index is used to study the absorbing aerosols.

DATA AND METHODOLOGY

The region, within 40° N and 5° N and 65°E and 99°E is selected for the study and it is subdivided into 7225 grids each of size 0.4° × 0.4°. Level 2 of Collection 5 MODIS aboard Terra AOD data for a period of Five years (2005-2010) has been used for this study (MODIS Website 2012). The resolution of the actual data is 0.1° × 0.1° (approximately 10Km) at nadir (Satvencho et al 2004). The quality of MODIS AOD has been well documented by Levy et al. (2007), (2010) and Remer et al. (2005). The data has been separated for each season namely Summer (March, April and May), Monsoon (June, July, August and September), Post monsoon (October and November) and winter (December, January and February). AOD over each grid is averaged to represent the aerosol loading over the study region during that season. A statistical parameter 'Coefficient of variation (COV) is used to analyse the temporal variability of aerosol optical depth. COV is a ratio of standard deviation to the mean of the data set. COV normalizes the standard deviation and makes them comparable across the region. COV of AOD is proportional to its variability over the region. NCEP/NCAR Reanalysis data has been used to investigate the Relative Humidity and wind pattern over the study region. Relative humidity influences the size as well as life time of Aerosols and wind influences the amount of Aerosols through transportation.

Aerosol Index (AI) from Ozone Monitoring Instrument aboard Aura satellite has been used to study the absorbing aerosols over the study region. OMI Aerosol index Level 2 data has been used for the study. The resolution of the data is 0.25° × 0.25°.Values of Aerosol Index greater than 0.5 indicates presence of absorbing aerosols. Negative values indicate non absorbing aerosols or clouds. Our objective in using AI data is to study absorbing aerosols. As Aerosol Index is retrieved in UV region, Absorbing aerosols can be detected even in the presence of clouds, snow and ice. In fact the retrieval will be more effective in presence of clouds (Torres et al, 2007, Manoj et al, 2010).

OBSERVATIONS AND RESULTS

Climatology of Wind over the study region:

The 10 year (2001-2010) monthly mean Humidity and vector wind data from NCEP/NCAR reanalysis data available at a resolution 2.5 º x 2.5 º has been used in this present study to assess the aerosol loading in Indian region. The wind vectors over the study region for each month are plotted with humidity as background. During winter season (DJF) the winds are North easterlies and humidity is less over the central part of India, continuing up to the April month. During May and June the summer monsoon arrives with persistent south westerly's, which bring a lot of moisture to the Indian subcontinent, resulting in high humidity (i.e., 90%) over south peninsular and central part of India. This continues up to the end of September. It is well known that the meridional circulation over the Indian region reverses direction from summer to winter. As the south west monsoon retreats from the Indian region, the north easterlies prevail over south peninsular India with the commencing of North east monsoon. During the month of October it is clearly noticed that the south westerly's are slowly turned in to north easterlies prevailed over the southern peninsular India, and persists up to the month of December. In the month of October, high humidity is confined to southern peninsular i.e.70%, and slowly decreases as the NE monsoon recedes, which indicates fair weather.

Seasonal variation of Aerosol Optical Depth over India:

Seasonal variation of Aerosol optical depth is studied by plotting Aerosol optical depth over India in different seasons. All the AOD over the study period has been averaged to investigate the Average Aerosol loading over each region in the Indian Sub-continent. The Indian Sub-Continent has different geographic regions with many mountain ranges, Great Plains and plateaus. Figure.1 shows the mean AOD for the study period. The northern part of India, North Western India, Indo Gangetic plain and some of the eastern parts of India are found to have high AOD. The south peninsular India seems to have less AOD when compared to that of the North India and it may be due to the transport of Aerosols due to the Land-Sea winds. The population density is also more in North India when compared to that of the south (Census 2010) which may be contributing to high anthropogenic emissions. More number of industries and thermal power stations are concentrated in the North India. The topography of the indo Gangetic plain does not allow the aerosols to get transported easily (Himalayas on the North and Vindhya range on the south obstructing the wind to transport Aerosols). The figure also shows that there is transport of dust from Rajasthan and other western parts of India (Pandithurai et al, 2008). Major part of Punjab, Chandigarh and Rajasthan also show high Aerosol content in par with that of Indo-Gangetic plain and this may be due to the transport of desert dust from the Great Indian Thar desert. Major part of Maharashtra, region around Hyderabad in Andhra Pradesh and some parts of Jharkand show a moderate level of Aerosol Loading. Interior parts of Kerala, Tamil-Nadu, Andhra Pradesh and major part of Karnataka are found to have less AOD but the coastal regions of the above said states have a moderate level of Aerosol loading and this may be due to the transport of Aerosols from the surrounding water bodies. The important finding is that the AOD seems to be related with the topography. Most of the elevated regions viz. Major part of Karnataka, southern Maharashtra, and western Andhra Pradesh show low AOD. This fact cannot be considered as an artefact as ground based AOD observations in those regions are agreeing with those of MODIS Ganesh et al 2008,2009; Saha et al 2005. The reason may be immediate transport due to winds at higher altitudes. The Aerosol optical depth over the oceans far away from the land has less AOD when compared to those nearer to the land indicating high Anthropogenic loading over the land.

It is difficult to study the temporal variation of each location in the study region directly, hence we used a statistical parameter Coefficient of variation (Here after referred to as COV) to study the variability of Aerosol optical depth over the study region. As the COV represents the variability regions of high and low variability of AOD can be figured out. The Indo-Gangetic plain represents a region of low COV obviously as the region is loaded with aerosols throughout the year irrespective of the season. Most of the elevated regions show high COV indicating high variability of Aerosols over the region. This may be due to the quick transport of Aerosols due to the wind. This indicates that topography is also factor influencing the aerosol loading over a region and it cannot be considered as an artefact as topography is taken care in the MODIS algorithm (Levy et al, 2007) and ground based observations are agreeing with that of MODIS observations. Ganesh et al, 2008 and 2009 and Saha et al, 2005, have reported a maximum value of AOD as 0.327 over Mysore. Vinoj et al, 2004 have shown a high annual variability of aerosols for the period 2001 to 2003 over Bangalore. Singh et al, 2004 showed that the frequency distribution of AOD over Kanpur (located in Indo Gangetic plain) is almost similar in all seasons which indicate that aerosol variability is less and there is a constant source of aerosols in the region. High population density and more industries in this region are sources of aerosols.

The aerosol optical depth is separated for each season viz. Summer (March, April and May), Monsoon (June, July, August and September), Post monsoon (October and November) and winter (December, January and February) and plotted separately (figure 3). During summer and Monsoon winds are westerlies. Hence the dust may be transported from the Arabian desert. We have plotted Aerosol index for different seasons for the same region to check whether they are due to high aerosol loading or presence of clouds. Aerosol Index can be measured even in the presence of clouds. Positive values of Aerosol Index indicate desert dust and we find Aerosol Index (Figure.4) is high over the north western part of India and Indo Gangetic plain during summer and monsoon. Hence it can be interpreted that large amount of dust is transported towards north India through the north western part of India. The Great Indian Desert is also a source of dust. This feature is not pronounced in post monsoon and winter. Hence most of the aerosols may be due to transport through wind and the wind direction from **Figure.1** also strengthens this statement. AOD is almost greater than or equal to 0.3 in the southern part of India. The Arabian Sea and Bay of Bengal show high AOD during monsoon. AOD is more over Arabian Sea than over Bay of Bengal which supports the fact that aerosols during monsoon are brought by westerlies. High AOD during monsoon can also be attributed to presence of clouds. This doubt can be cleared by using the Aerosol Index data as it can be retrieved even in the presence of cloud and a cloudy sky will give a more amplified signal (Torres et al, 2007, Manoj et al, 2010).The Aerosol Index also found to be high in monsoons similar to that of AOD supporting MODIS observation of high AOD during monsoon. High Aerosol index values over the Northern India suggest the presence of absorbing aerosols in that region. In the summer north eastern part of India and Bay of Bengal show high AI values whereas north western part of India and Arabian Sea show high AI values during Monsoon.AI values are less in south peninsular India throughout the period of study. This may be due to transport from land to sea. The presence of Absorbing aerosols is evident as AI values are greater than 0.5 over a major region. High Aerosol Index over Arabian sea during Monsoon indicates the presence of dust (dust being Absorbing aerosol) Figure.3. shows that the sub continent is highly loaded with Aerosols in the monsoon when compared with other seasons. The Bay Bengal, Arabian Sea and Indian Ocean seem to be highly loaded in the monsoon. The Indo Gangetic plain and the north western part of India show high concentration of Aerosols throughout the year. It has considerable aerosol amount even in post monsoon where most of the Aerosols are supposed to be washed out by monsoon rainfall. This strengthens the fact that the aerosols are mainly due to the constant sources present in this region. The population density has increased in states like Bihar, West Bengal Orissa and Tamil Nadu when compared to that of 2001(Census, 2010).The cause for the high aerosol content is presence of industries, mainly coal based thermal power plants (http://www.cpcb.nic.in ,2011)., anthropogenic activity due to dense population.

CONCLUSIONS

Seasonal variations of Aerosol optical depth is studied over Indian Sub continent using MODIS AOD and OMI AI. Aerosol loading is more over North India when compared to that of South India. AOD is more in monsoons and less in winter for the whole study region. Aerosol Index is also high during monsoons which support the presence of high AOD as AI can be retrieved in the presence of clouds. Major part of Karnataka show low AOD throughout the year. In the summer and monsoon season AOD and AI are high and the winds are westerlies indicating the transport of dust from Arabian Desert and Africa. The Arabian Sea shows more AOD than that of Bay of Bengal which strengthens the above statement. AOD is less in winter and the winds are easterlies. As the land is far way from Indian region there is less transport towards India. AOD is less over the high altitude regions and the reason is immediate transport through winds as COV plot shows high variability of AOD over high altitude regions. Aerosol loading is less over elevated regions and the reason may be immediate transport due to wind.

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REFERENCES

1. Central Pollution Control Board (CPCB) website, www.cpcb.nic.in/annualreport.php, Accessed on 26 April, 2012.
2. Dey, S., and Di Girolamo, L. (2010). Climatology of aerosol optical and microphysical properties over the Indian subcontinent from 9 years (2000–2008) of Multiangle Imaging Spectroradiometer (MISR) data.J. Geophys. Res., *115*(D15), 1-22. doi: 10.1029/2009JD013395.
3. Ganesh, K. E. (2009). Aerosol Optical Thickness Measurements on Tsunami Day at a Continental Station, Mysore. *Aerosol*

and Air Quality Research, *9*(1), 94-104. doi: 10.4209/aaqr.2008.08.0035.

4. Ganesh, K. E., Umesh, T. K., and Narasimhamurthy, B. (2008). Site Specific Aerosol Optical Thickness Characteristics over Mysore. *Quality*, *8*(3), 295-307.
5. Levy, R.C., Remer, L.A., Kleidman, R.G., Mattoo, S., Ichoku, C., Kahn, R., Eck, T.F., 2010, Global evaluation of the Collection 5 MODIS dark-target aerosol products over land. Atmos. Chem. Phys. 10:10399-10420. doi: 10.5194/acp-10-10399-2010
6. Levy, R.C., Remer, L.A., Mattoo, S., Vermote, E., Kaufman, Y.J., 2007, Second-generation algorithm for retrieving aerosol properties over land from MODIS spectral reflectance. J. Geophys. Res. 112:D13211. doi: 10.1029/2006JD007811
7. Lohmann, U., R. Sausen, L. Bengtsson, U. Cubasch, J. Perlwitz, and E. Roeckner (1993), The Koppen climate classification as a diagnostic tool for general circulation models, *Clim. Res.*, *3*, 177-193, doi:10.3354/cr003177.
8. Manoj, M. G., P. C. S. Devara, P. D. Safai, and B. N. Goswami (2010), Absorbing aerosols facilitate transition of Indian monsoon breaks to active spells, *Clim. Dyn.*, *37*(11-12), 2181-2198, doi:10.1007/s00382-010-0971-3.
9. MODIS Website, 2012, Level 1 and Atmospheric Archive and Distribution System, LAADS, Goddard Space Flight Center, NASA, http://ladsweb.nascom.nasa.gov/, Accessed on 26 April, 2012.
10. Niranjan, K., Sreekanth, V., Madhavan, BL., Devi, T.A., Spandana, B., 2008, Temporal characteristics of aerosol physical properties at Visakhapatnam on the east coast of India during ICARB –Signatures of transport onto Bay of Bengal. J. Earth. Syst. Sci. 117:421–427.
11. Pandithurai, G., S. Dipu, K. K. Dani, S. Tiwari, D. S. Bisht, P. C. S. Devara, and R. T. Pinker (2008), Aerosol radiative forcing during dust events over New Delhi, India, J. Geophys. Res, *113*(D13), 1-13, doi:10.1029/2008JD009804.
12. Ramanathan, V., P. J. Crutzen, J. T. Kiehl, and D. Rosenfeld (2001), Aerosols, climate, and the hydrological cycle., *Science (New York, N.Y.)*, *294*(5549), 2119-24, doi:10.1126/science.1064034.
13. Remer, L.A., Kaufman, Y.J., Tanre, D., et al., 2005, The MODIS aerosol algorithm, products and validation. J. Atmos. Sci. 62:947–973.
14. Saha, A., Moorthy, K.K., Niranjan, K., 2005, Interannual Variations of Aerosol Optical Depth over Coastal India: Relation to Synoptic Meteorology. J. Appl. Meteorol. 44,7,:1066-1077.
15. Savtchenko, A. Ouzounov, D., Ahmad, S., et al., 2004, Terra and Aqua MODIS products available from NASA GES DAAC. Adv. Space. Res., 34: 710–714.
16. Singh, R. P. (2004), Variability of aerosol parameters over Kanpur, northern India, J. Geophys. Res, *109*(D23), 1-14, doi:10.1029/2004JD004966
17. Torres, O., A. Tanskanen, B. Veihelmann, C. Ahn, R. Braak, P. K. Bhartia, P. Veefkind, and P. Levelt (2007), Aerosols and surface UV products from Ozone Monitoring Instrument observations: An overview, J. Geophys. Res, *112*(D24), 1-14, doi:10.1029/2007JD008809
18. Vinoj, V., S. K. Satheesh, S. Suresh Babu, and K. Krishna Moorthy (2004), Large aerosol optical depths observed at an urban location in southern India associated with rain-deficit summer monsoon season, Ann. Geophys., *22*(8), 3073-3077, doi:10.5194/angeo-22-3073-2004.

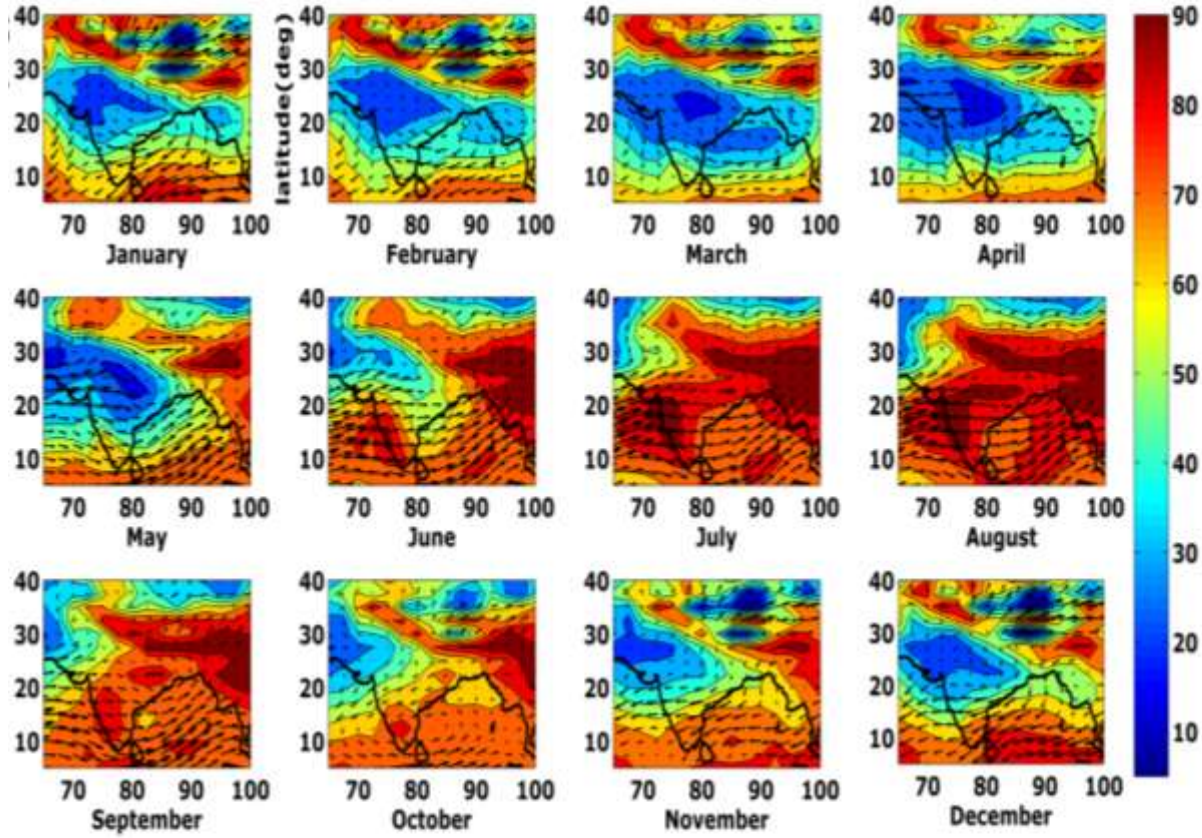

Figure 1.Climatological Wind vector plotted with Relative Humidity as back ground (NCEP/NCAR Reanalysis data)

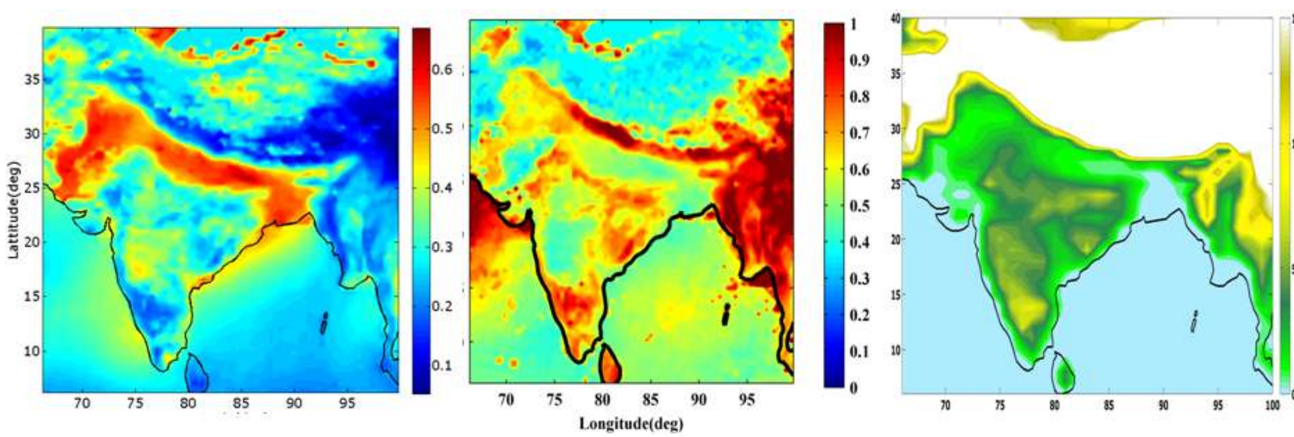

Figure 2.(a) Annual mean of AOD, (b) COV of AOD for Ten years (2001-2010),(c) Topography of India

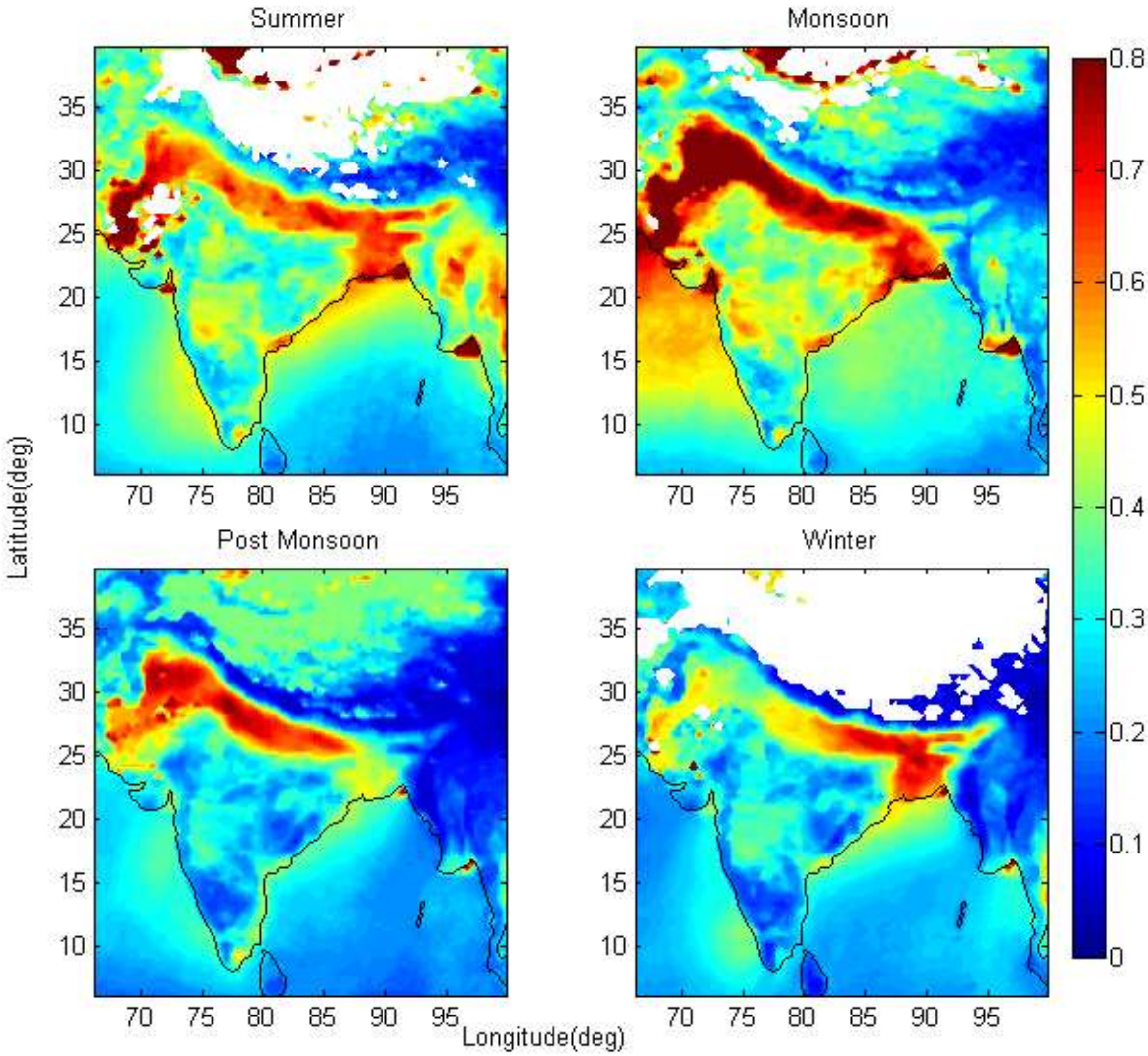

Figure 3 Seasonal variation of Aerosol optical depth over India

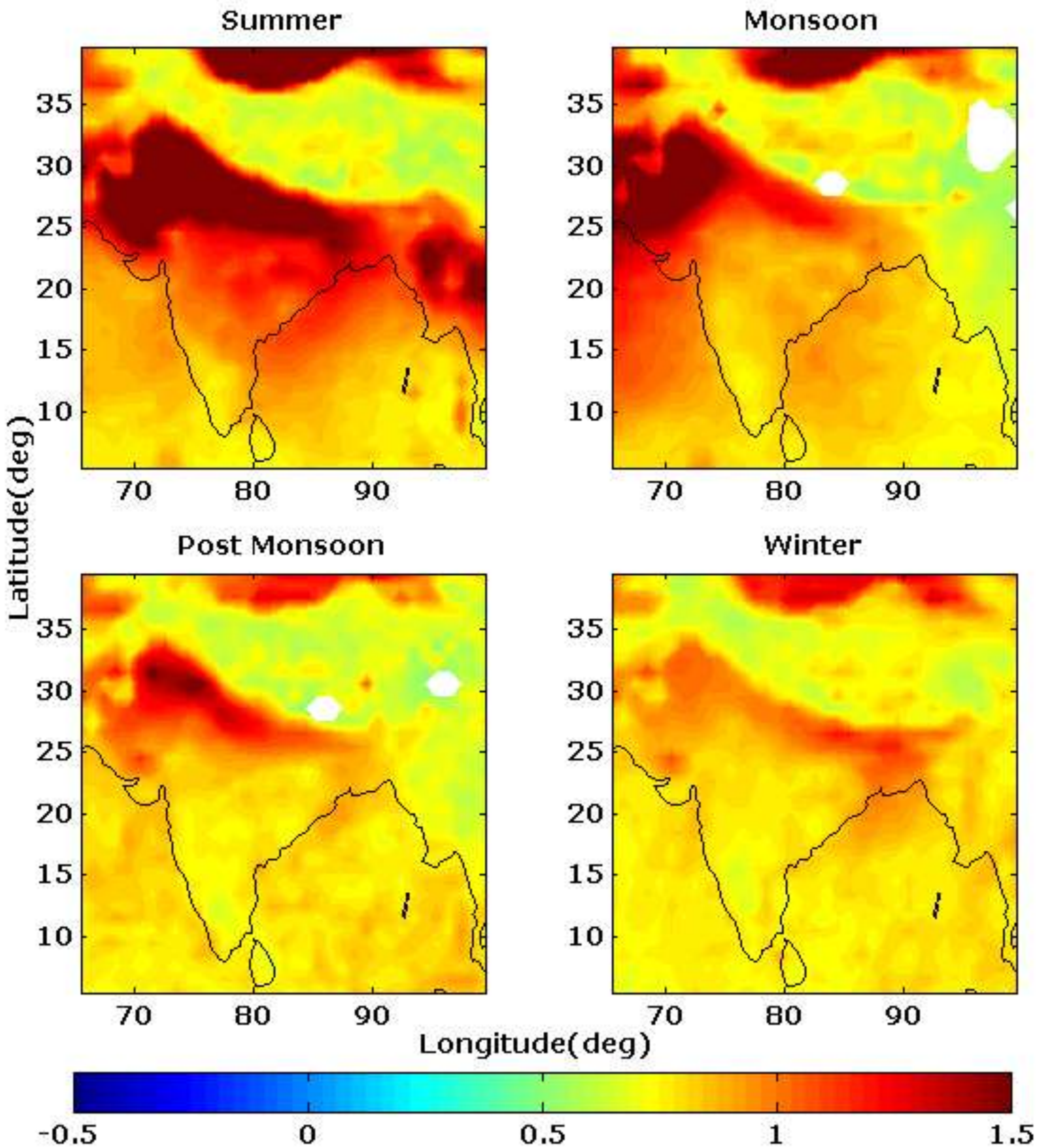

Figure 4 Seasonal Variation of Aerosol Index over India