Volume 2 No.9, September 2012 ISSN 2224-3577
International Journal of Science and Technology

http://www.ejournalofsciences.org

Columnar Aerosol Optical Depth and its changes over Kannur, A Coastal Site in South India

Praseed K.M [1,2], Nishanth T[2,3], Rajan K[4]., Satheesh Kumar M.K[2]

[1] Department of Physics, Sir Syed College, Taliparamba, Kerala, India
[2] Department of Physics, Govt. Brennen College, Thalassery, Kerala, India
[3] Department of Atmospheric Science, Kannur University, Kerala, India- 670 567
[4]Department of Statistics, Nehru arts &Science College, Kanhangad, Kerala

ABSTRACT

The increase in the aerosol loading over Indian sub continent thanks to the growing population, industrialization and urbanization, has a significant impact on the ambient air quality, local weather and global climate. Thus the potential role of aerosols on the radiative forcing that tunes variation in climate is to be explored with the aid of modeling studies. This work describes analysis of ground based observation of spectral Aerosol Optical Depth (AOD) carried out during a period of three years (2009-2012) at a rural coastal location, Kannur (11.9^{o}N, 75.4^{o}E) in South India. This investigation reveals that AODs are influenced by seasonal variations at this site. One of the significant features is that AODs are quite higher in April (~0.401 at 440nm) and relatively low during November-December (~0.208 at 440nm). Thus this observation throws light to the mounting concentrations of particulate matter present in the atmosphere during the co-ordinate fireworks associated with the Vishu festival in the month of April which causes a abrupt rise in AOD which persists for 2-3 days. The analysis of last twelve years MODIS data indicates an increasing trend of AOD over this location which is one of the methods to estimate air quality.

Keywords: *Atmospheric aerosols, Angstrom parameters, MICROTOPS, Vishu festival, Kannur.*

1. INTRODUCTION

Atmospheric aerosols are particles of solid or liquid phase dispersed in the atmosphere. [1]. Aerosols are produced by a variety of natural and anthropogenic processes [2-4]. They vary in size from 10^{-3} to 10^{2}µm depending upon the source and production mechanism. Small aerosols (<1µm in size) are formed mostly through gas to particle conversion process. They often grow in size due to coagulation and by condensation of water vapor. Large aerosols (>1µm in size) are formed directly by mechanical processes such as windblown dust, sea salt droplets produced by breaking air bubbles on the sea surface, pollen grains etc,. Aerosols can both scatter and absorb the solar radiation and is termed as direct effect [5]. The extinction of sunlight reaching the ground by a vertical column of atmosphere due to aerosols is often termed as aerosol optical depth (AOD). The scattered intensities of various wavelengths present in the solar radiation depend on the size of the particles dispersed in the atmosphere. The angstrom parameters, alpha (α) and beta (β) are usually classified to retrieve the relative abundance of fine to coarse mode particles and turbidity of the atmosphere [6-8].

Aerosols have an indirect effect on clouds by altering the cloud albedo and cloud life time [9, 10]. Radiatively absorbing aerosols warm the atmosphere leading to suppression of precipitation due to the evaporation of clouds [11, 12]. Aerosol particles of different sizes and composition play a significant role in visibility, atmospheric electricity and air quality [13]. Radiative forcing due to aerosols is one of the major sources of uncertainties in estimating climatic perturbations, since aerosols vary spatially and temporally over the globe, regional wise studies are quite significant.

Extensive research programmes are in progress to retrieve the impact of aerosols through ground based and satellite observations all over the globe [14-17]. The Asian monsoon region is reported to have high concentration of anthropogenic aerosols and is significantly influencing the regional climate through direct radiative forcing [18, 19]. In Indian region, concentration of aerosols is found to be increasing alarmingly and the analysis shows that the AOD over northern part of India is much higher than that in the southern part [20, 21]. Frequently occurring dust storms in Indo Gangetic Basin (IGB) of North India during pre-monsoon (March-June) seasons play a considerable role in loading aerosols in the northern part of India and this is one of the reasons for high aerosol concentration in northern part of India. This dust originates from three main sources: Oman, Southwest Asian basins and Thar Desert in Rajasthan [22]. During summer season, along with the dust, the wind carries heavy metals to the IGB causing heavy air pollution [23]. Moorthy et al reported that dust over the Indian desert is more absorbent than the African dust [24]. The Central Pollution Control Board (CPCB) has revealed that the concentrations of Respirable Suspended Particulate Matter (RSPM) found at many Indian cities have exceeded the National Ambient Air Quality Standards (NAAQS) [25]. This large increase in aerosols can have a direct impact on agricultural yield in

International Journal of Science and Technology

http://www.ejournalofsciences.org

India as in China, as reported by Chamudes et al [26]. Kerala is the largest producer of varieties of spices (cardamom, tea, black pepper, and cocoa) which are highly sensitive to the climate and hence any slight variation would affect the crop yield [27].

This work is an attempt to investigate the seasonal variations of AOD over Kannur, a coastal tropical site located close to the Arabian Sea in the west and Western Ghats in the east. The AOD measured with the aid of a MICROTOPS II Sunphotometer (Soar Light Company, USA (2002)) for three years since 2009 have been analyzed. Thus this study reveals the variation of abundance in aerosols over north Kerala where industrial pollution is relatively low compared to the other regions in the state. A spontaneous change in AOD and aerosol size distribution due to the fireworks festival 'Vishu' in the month of April is discussed. Moreover, a long term variation of AOD over this region is analysed using MODIS data.

2. OBSERVATIONAL SITE AND GENERAL METEOROLOGY

The sampling site is at Kannur University Campus (KUC), (11.9^oN, 75.4^oE 5m ASL), lying in the northern part of Kannur district, a tropical coastal site in South India. It is a rural area with no major industrial activity except for a few small scale industries.

The National highway NH47 is 1 km away from the observation site. The air distance from the site to the Arabian Sea shore is 4 km and that to the Western Ghats is 50 km. The most important meteorological feature of this region is the monsoon season. The south west monsoon is active during June-August and the north east monsoon during October-November. The south west monsoon brings heavy rains as compared to the north east monsoon which is moderate in character, accompanied by thunder and lightning.

The intensity of the summer heat is masked by the heavy south west monsoon set off in June. The region gets its maximum exposure to sun shine from December to March and minimum from June to August. The months December-February with low rain and relative humidity constitutes the winter season, while from March-May constitute summer with high convective activities on the surface. The location of observation site is shown in figure 1.

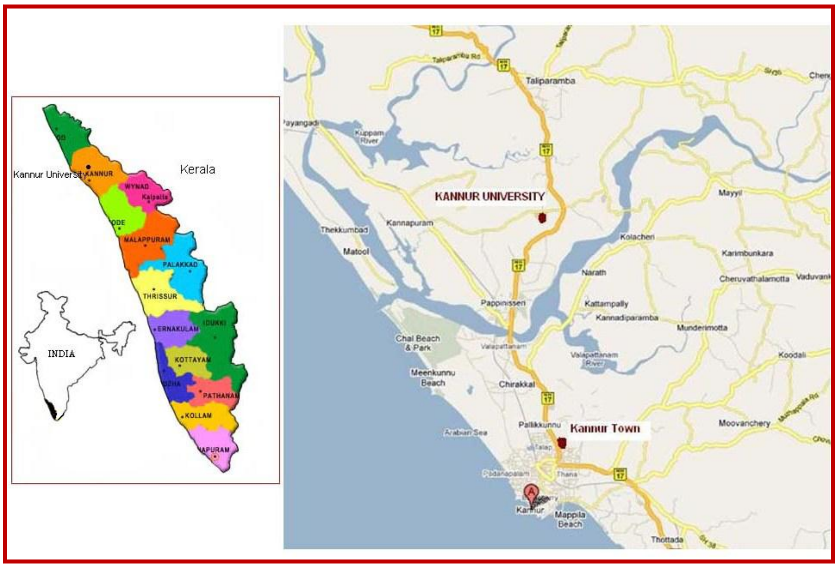

Figure 1: Location of Observational Site

3. INSTRUMENTATION

With the availability of modern, hand held sun-photometers, direct monitoring of AOD is rather easy and can be carried out at any desired observation site. In this study, a MICROTOPS II (Microprocessor Controlled Total Ozone Portable Spectrometer) fitted with narrow-band interference filters are employed to estimate the AOD at wavelengths 340nm, 440nm, 675nm, 870 nm and 1020nm. The attenuation of solar radiation by the aerosols strongly depends on the size of the particles and wavelength interval considered. The complete details of the sun photometer and the measuring technique have been described by Morys et al., 2001 [28]

4. DATA AND METHODOLOGY

This investigation pertains to the seasonal variation of AOD over this region during the period from November 2009 to

May 2012. Subsequently, AODs have been recorded with a MICROTOPS II on all clear sky days from 09.00-17.00 hrs (IST), at 30 minutes interval period. Extreme precautions are adopted to avoid strong seasonal effects such as gusty wind, cloudy sky and drizzle. The daily average is estimated only for those days having at least six clear observations. For a given spectral range the variation of AOD follows Angstrom power law given by Angstrom in 1964 [29] as

$$\tau = \beta \lambda^{-\alpha}$$

where λ is the wavelength in micrometer. Angstrom exponent α is a rough indicator of the size distribution of aerosols in the column. A low value of α indicates the dominance of bigger size particles and high value of α indicates domination of smaller-size particles [30]. The Angstrom parameters are retrieved by least square fit on a log -log scale plot of the observed AOD versus wavelength.

5. RESULTS AND DISCUSSION

(i) Analysis of Microtop Result

The mean value and standard deviation of AOD at five wavelengths are made known in figure 2. It is observed that the AODs are fairly high in summer (March-May), moderate in monsoon seasons (June-November) and low in post monsoon and winter seasons (December-February). During monsoon, especially in the month of July, the data are missing due to the inclement weather conditions, which is a constraint for reliable measurements using sun photometers. The low value of AOD found in post monsoon and winter seasons is due to the clear sky environment resulting in the settling of aerosols during monsoon season and subsequent gradual development in winter. Moreover during winter months the atmospheric boundary layer is shallow which ensures a minimum mixing volume for the particles. While, in summer months, the boundary layer is relatively high owing to the hectic convective activities and therefore pollutants have additional volume for scattering and absorption of solar radiations passing through them.

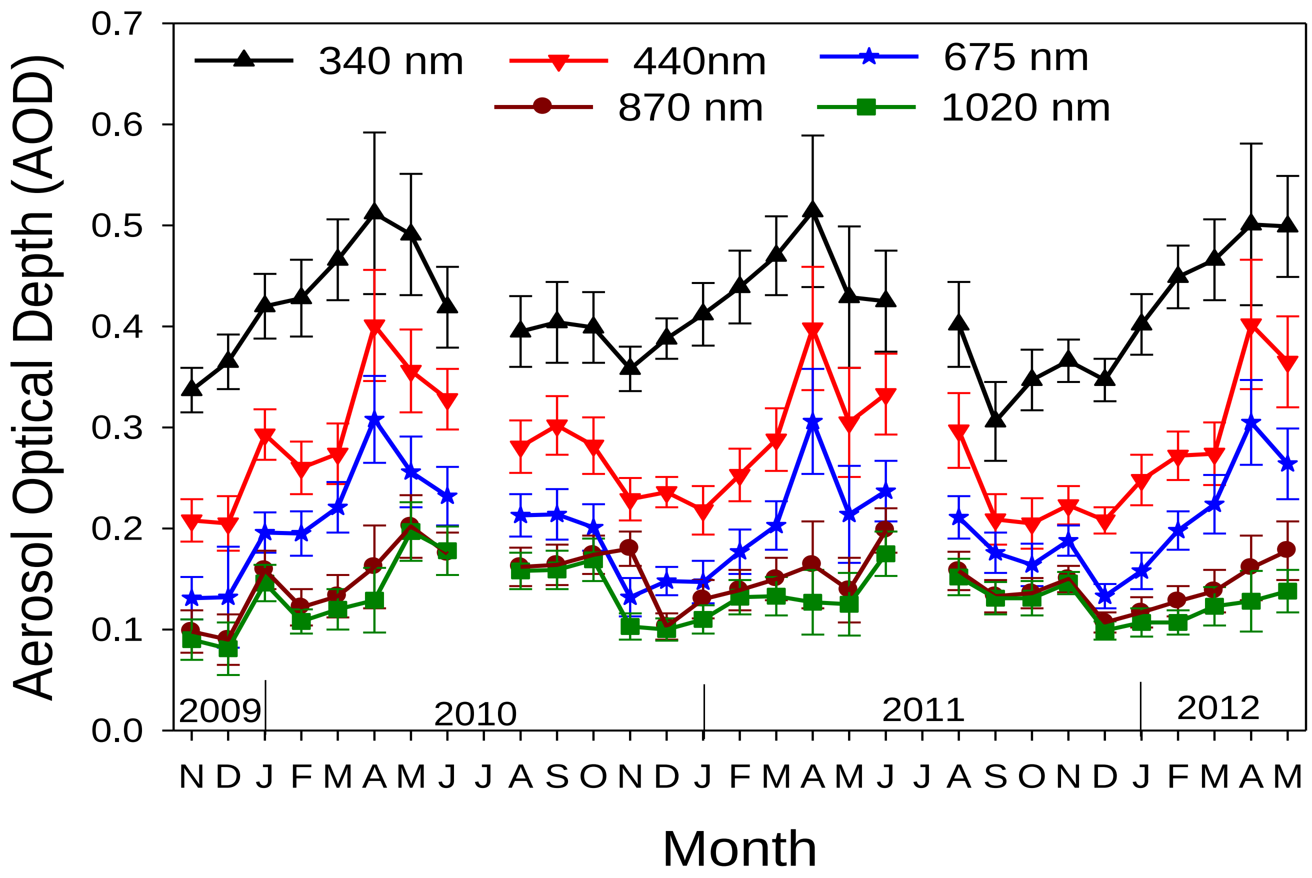

Figure 2: Monthly variation of AOD at Kannur

International Journal of Science and Technology

http://www.ejournalofsciences.org

The influence of air mass movement from the western side of this location indicates a strong marine influence during pre-monsoon and monsoon seasons. The marine hygroscopic aerosols can uptake water and grow in size [31] and influence the solar and terrestrial radiations. To validate the seasonal variation in AOD, backward air mass trajectory analysis was carried out using the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model [32] during the period of observation. The seven day back trajectories for the year 2010 (at 0800 UTC for 500, 1000 and 1500 m above the ground level) are represented in figure 3. From this, it is obvious that the air mass movement during winter (December through February) and summer (March through May) is from east of this site, and during monsoon (June to August) and post monsoon (September to November) is from the western Arabian Sea. As the experimental site is far from the industrial sources, the occurrence of fine-mode aerosol particles, on most of the observation days, especially in summer could be due to long-range transport of aerosols from distant source regions. During the monsoon and post monsoon seasons, the movement of air mass trajectories originated over the Arabian Sea and traversed through a smaller area of landmass before reaching Kannur. As the air mass passed over the Arabian Sea, marine aerosols which are coarse in nature dominate at the lower level (1000m). In order to classify the variation of fine and coarse mode particles, changes in the Angstrom parameters are employed. The seasonal variations of Angstrom parameters α and β retrieved are shown in figure 4. This shows an inverse relationship between α and β values. Such a trend is found in many other observational sites in India and elsewhere [33-35]. The α values are found to be maximum in summer and minimum in monsoon seasons. The high value of α in summer is attributed to the domination of fine mode aerosols over coarse mode aerosols.

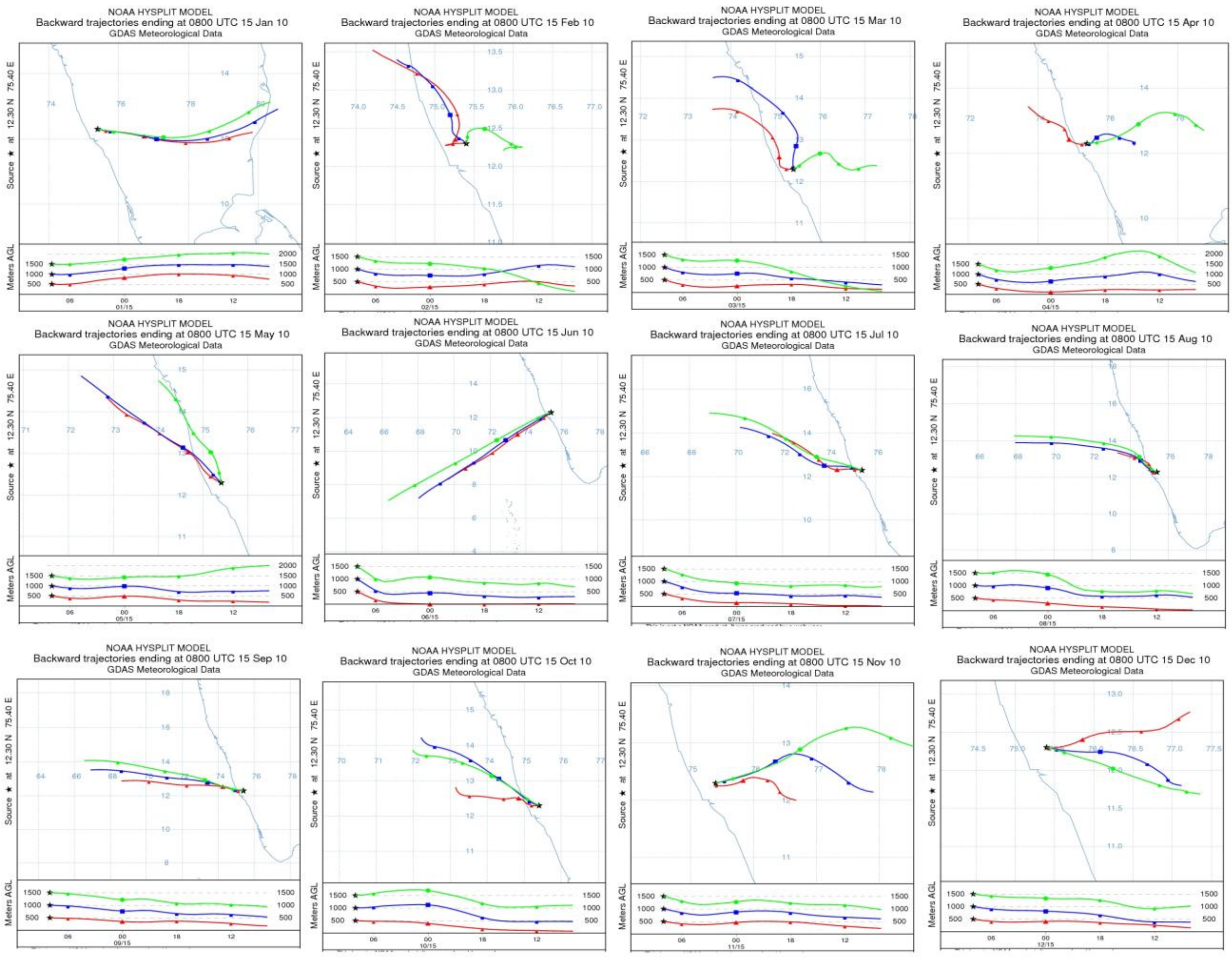

Figure 3: Backward air trajectories during January to December 2010at Kannur using HYSPLIT model

Volume 2 No.9, September 2012 ISSN 2224-3577
International Journal of Science and Technology

http://www.ejournalofsciences.org

The air mass movement during winter and summer is from east of this site, and it is from the west and the air moves over the western Arabian Sea during monsoon as depicted in fig.3. This brings quite a lot of marine aerosols which are hygroscopic in nature to the land. The high humidity prevailing during monsoon season contributes to the domination of coarse mode aerosols at this site. However, the fine mode aerosols also dominate in summer due to the flow of air mass is received at this site is from local industrialized areas.

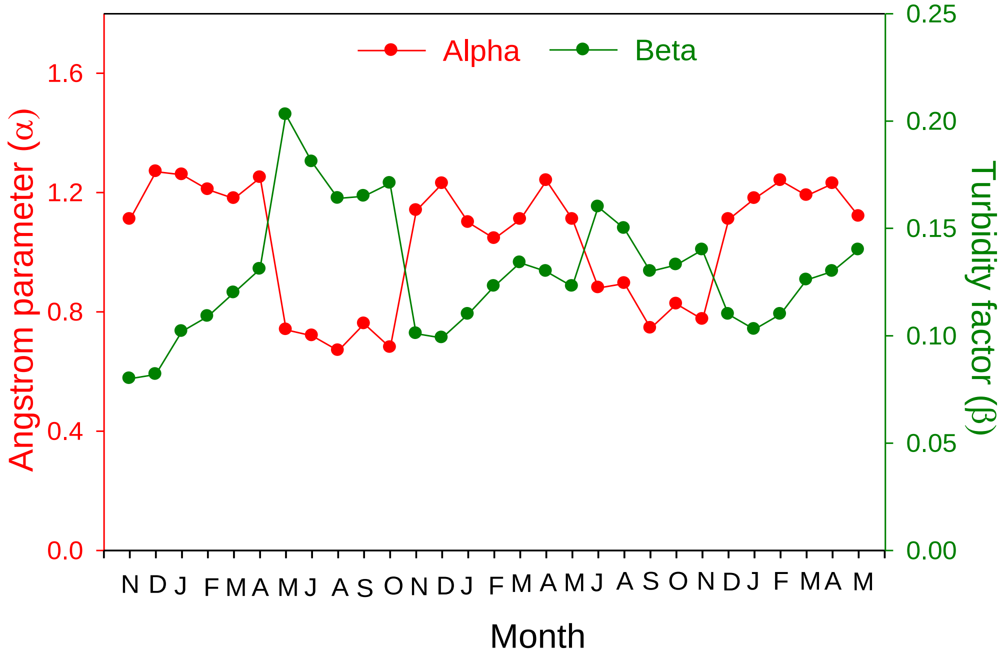

Figure 4: Seasonal variations of α and β

(ii) Analysis of sudden rise in Aerosol Optical Depth associated with Vishu festival

Air quality deterioration resulting from intense fireworks and its impact on health has been noted by several groups in the world and they were observed an increased levels of pollutants such as SO_2, NO_2, Total Suspended Particulate Matter (TSP), PM (Particulate Matter), trace metals, aerosol black carbon, and Polycyclic Aromatic Hydrocarbons (PAH) due to fireworks. In India, it has become a practice to celebrate various occasions (weddings, birthday parties, New Year, post-election/sports results, and various festivals) by setting off fireworks. Vishu is a major festival in Kerala which celebrates on 14^{th} or 15^{th} of April in every year. This festival is celebrated in northern part of Kerala by cracking intense fireworks which usually set off in the eve of Vishu and the fireworks continue for 2-3 days. Such incessant firework at houses, public places and temples during night time impairs air quality over this region [36]. The impact of such extensive fireworks over this region and associated enhancement of toxic organic and inorganic particulate matter in air as a result of Vishu episode is already classified [37]. The variation of AOD and particle size distribution before and after Vishu festival is precisely analyzed by using second order polynomial fit in the log λ versus log τ graph. A negative curvature in the log λ versus log τ graph implies the presence of significant amount of fine mode aerosols in the atmosphere. [38]. The AODs observed in April- May are much higher than other seasons over this location. However, one of the unique features of the observation is a slight elevated magnitudes of AODs observed in April, which is mainly due to the anthropogenic activities followed by festivals in this region. Analysis of the results further reveals a sudden change in AOD, alpha and beta values with the burning of fire crackers associated with the Vishu festival. The variation of AOD on pre and post Vishu episodes is shown in the figure 5.

ISSN 2224-3577
International Journal of Science and Technology

http://www.ejournalofsciences.org

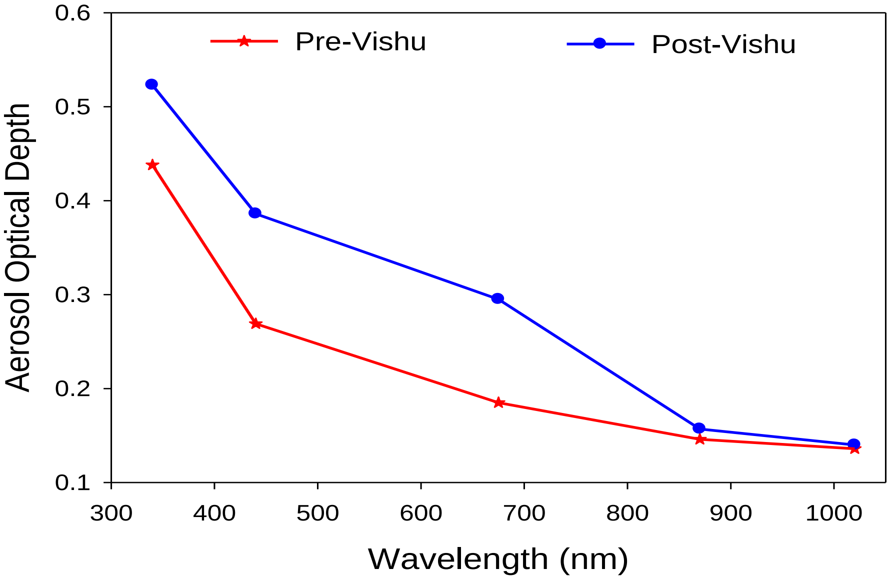

Figure5: Variation of aerosol optical depth during Vishu episode

The increase in AOD is found to be higher at the lower wavelength region which reveals the emission of fine particles along with the intense smoke emitted from intense fireworks. The mean AOD values and subsequent Angstrom parameters during 9 to 11 April 2012 (pre- phase) and 15 to 17 April 2012(post- phase) is shown in table1. In order to explore aerosol size distribution in detail, a polynomial fit is used to investigate the relation between ln λ and ln τ. The positive curvature in the pre-phase (figure 6) and negative curvature in the post-phase (figure 7) indicate the fingerprint of the domination of fine mode aerosols produced from the burning of crackers [39]. Nishanth et al., have [37] reported an increase in PM_{10} from 56 μgm^{-3} to 118 μgm^{-3} on Vishu day as a consequence of co-ordinate fireworks in April 2011. Student's t test value and one tailed p value indicate that, at the lower wavelength region, the increase is statistically significant at 95% confidence level. The higher value of coefficient of variation (standard deviation/mean) indicates that the aerosol variability is more in the post Vishu period. The fine particles present in the smoke can induce respiratory disease and this projects a serious health issue [37].

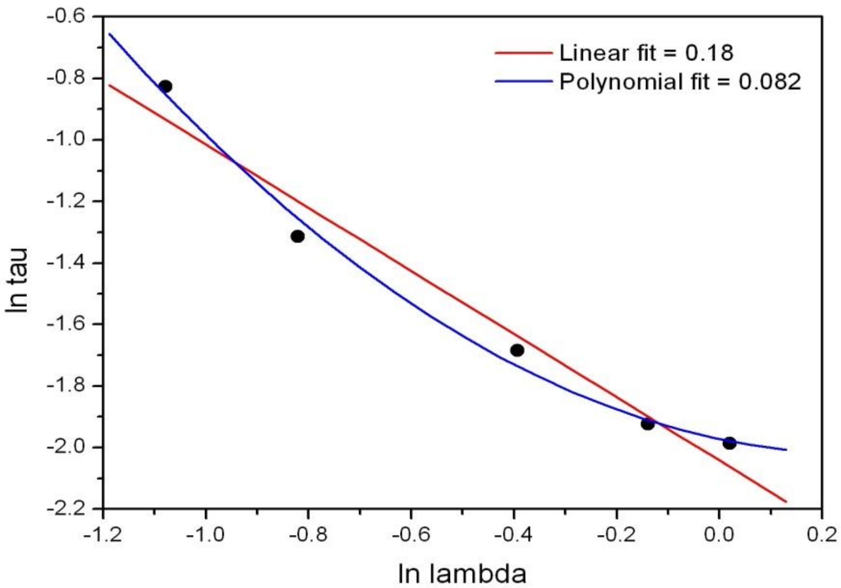

Figure 6: ln λ vs ln τ (pre-vishu) norm of residuals for linar fit and for polynomial fit

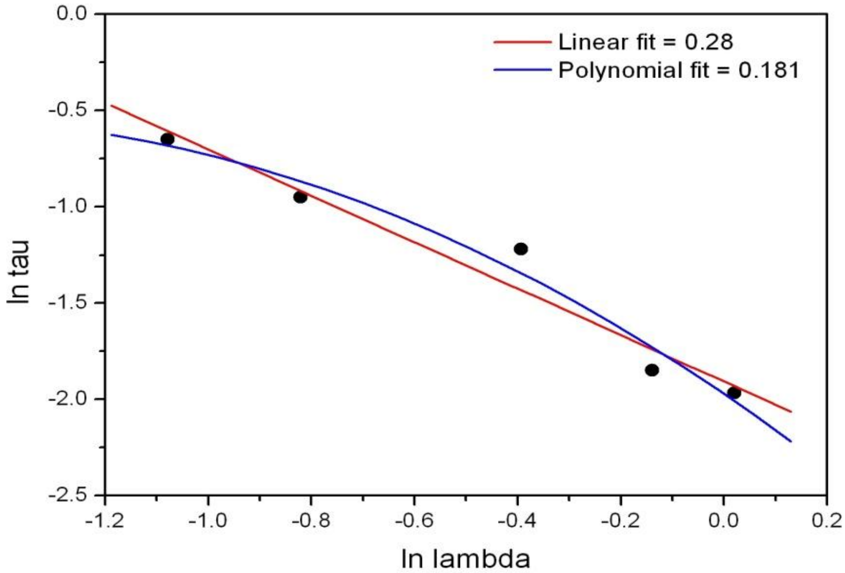

Figure 7: ln λ vs ln τ (post-vishu) norm of residuals for linar fit and for polynomial fit

Table 1 depicts the mean AOD, α and β values, coefficient of variation, computed values of Students t test and one tailed p value in the pre-Vishu and post Vishu days.

	340nm	440nm	625nm	870nm	1020nm	Alpha (α)	Beta (β)
Pre-Vishu	0.438	0.269	0.185	0.146	0.136	1.02	0.1305
Post-Vishu	0.523	0.387	0.296	0.158	0.14	1.28	0.143
C.V(pre-Vishu)	0.033	0.042	0.066	0.086	0.083	0.081	0.090
C.V(post-Vishu)	0.074	0.065	0.091	0.137	0.118	0.055	0.086
Value of ‘t’	-5.04	-10.5	-9.2	-1.1	-0.05	-6.04	-1.90
P value (one tailed)	0.00035	1.13E-06	2.91E-06	0.135	0.029	7.36E-05	0.041

Table1.The mean AOD, alpha and beta values, coefficient of variation, calculated value of Students t test and one tailed p value in the pre-Vishu and post Vishu days.

(iii) Long term variation of Aerosol Optical Depth over Kannur

The festival season in Kerala enhances pollution in the ambient air and a growing trend of suspended particulate matter is observed. This in turn reflects an increase in AOD in this region and an attempt is made to explore the long term trend of aerosol abundance over this region using satellite data. MODIS is a remote sensor onboard two Earth orbiting systems, Terra and Aqua satellites which provide an opportunity to study aerosols from space with good accuracy [40]. To substantiate a long term variation of AOD and its trend over this region, level 3 MODIS C005 atmospheric daily global product AODs at 550nm at 1 ^{o} x 1 ^{o} grid derived from both Terra and Aqua satellites are utilized. Both satellites operate at an altitude of 705 km with Terra space craft crossing the equator at about 10.30 IST and Aqua crossing the equator at about 13.30 IST. The monthly mean AOD at 550 nm MODIS data provided by the GES DISC is used to investigate the long term variation of AOD over Kannur. The last twelve years data show a growing trend shown in figure 8 which is quite similar to Indian sub continent and around the globe. Thus it is evident that this rural area which is devoid of large scale industries and believed to be a pristine location is gradually transformed into a polluted region. This is further substantiated by the ground based sun photometer observation being carried out at Kannur which is depicted in table 1.

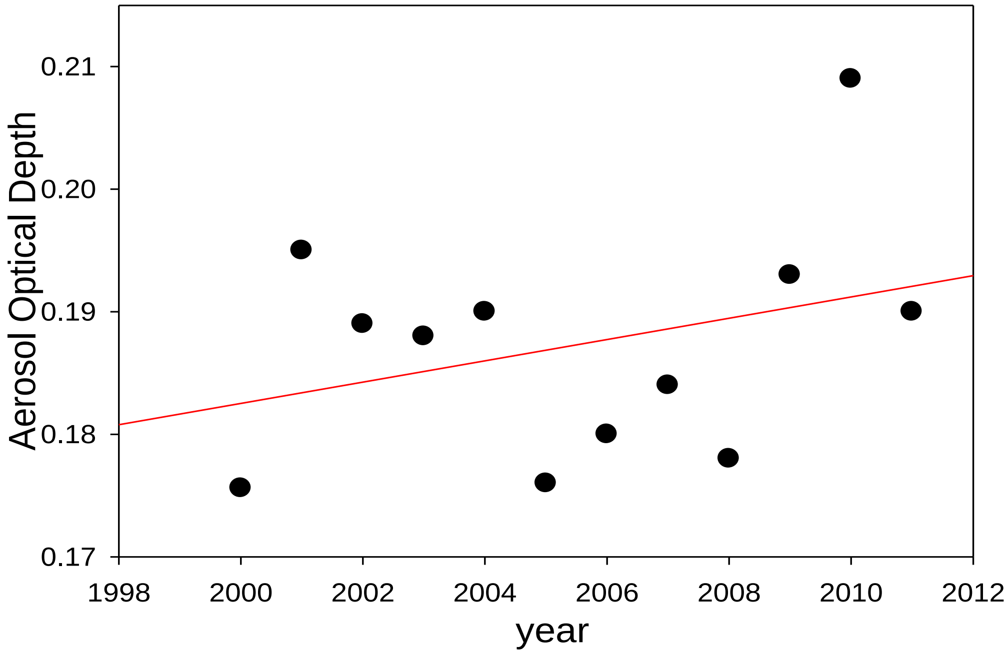

Figure 8: Annual average variation of AOD over Kannur

6. CONCLUSION

Spectral AOD variation measurements are observed at Kannur using the data derived from MICROTOPS, from January 2010 to May 2012. Angstrom parameters are derived from the Angstroms empirical relation to classify the sizes of the suspended particles. AOD values are found to be high in summer and low during winter seasons. Spectral dependence of AOD revealed high values at smaller wavelengths invariably in all seasons. But, smaller wavelength exponents and larger turbidity coefficients are observed during monsoon seasons, indicating the abundance of coarse-mode aerosols originating from marine air mass. A decline in AOD from summer to winter is observed and this is attributed to rain washout processes. Relative higher values of angstrom exponent during summer indicate the influence of fine mode particles present over this region which is getting transported from nearby local industries. The firework festival Vishu is one of the festivals in Kerala which is an occasion to disperse a huge amount of aerosols injecting into the atmosphere. Thus a sudden increase in AOD is observed due to the fine mode particles present in the smoke emitted from the fireworks. Angstrom exponent values derived from the AOD are used to classify the abundance of fine mode and coarse mode particles. This reveals the enhancement of fine mode particles during the second half of April which is a consequence of the change in air quality induced by festival of this region. The long term analysis of AOD variation indicates a gradual increase in aerosol transport and abundance over this region. This may be due to the substantial increase in the number of motor vehicles and the enhancement of polluted air by the transport of air mass from neighboring industrialized areas. This demands the need for a precise measurements and analysis, to discriminate the relative dominance of specific aerosol types, essential to retrieve the accurate aerosol radiative forcing over this region.

ACKNOWLEDGEMENTS

The authors are thankful to Kerala State Council for Science, Technology and Environment (KSCSTE) for their financial support in the form of a project granted for the study of aerosols over this region.

REFERENCES

[1] Seinfeld, J.H. and Pandis, S.N., (2006). Atmospheric Chemistry and Physics: From Air Pollution to Climate Change, *Wiley, NewYork*.

[2] Junge, C.E., (1983). Air Chemistry and Radioactivity, *Academic Press, New York*, 1963 Phys., 21, 1607–1629.

[3] Prospero, J.M. et al.,(1983). The atmospheric aerosol system – An overview. *Rev. Geophys. Space*, 21, 1607-1621.

[4] Prospero, J.M., Ginoux, P., Torres, O., Nicholson, S.E. Gill,T. E.,(2002). Environmental characterization of global sources of atmospheric

soil dust identified with the NIMBUS-7 TOMS absorbing aerosol product. *Rev. Geophys.*, 40(1), 1002.

[5] Charlson,R.J., Schwartz,S.E., Hales, J.M.,Ces,R.D., Coakley Jr., J.A.,Hansen,J.E., Hoffman,D.J., (1992). Climate forcing by anthropogenic aerosols, *Science*, 225,423-430

[6] Ångström, A., (1964). The parameters of atmospheric turbidity, *Tellus*. 16, 6475

[7] Iqbal, M., (1983)An Introduction to Solar Radiation, *Academic Press Inc., New York*

[8] Tomasi,C., Prodi, F., Sentimenti, M., and Cesari, G.,(1983). Multi wavelength sun photometersfor accurate measurements of atmospheric extinction in the visible and near- IR spectral range, *Appl. Optics*. 22, 622-630.

[9] Penner, J.E., Zhang, S.Y., Chung, C.C., (2003). Soot and smoke may not warm climate, *J.Geophys. Res.*, 108(D21), 4657, doi:10.1029/2003JD00340

[10] Twomey,S.A., (1977). The influence of pollution on the shortwave albedo of clouds, *J. Atmospheric Science*. 34, 1149-1152

[11] Ackermann, A.S., Toon, O.B., Stevens, D.E., Heymsfield, A.J., Ramathan, V., Welton, E.J. (2000), Reduction of tropical cloudiness by soot, *Science*, 288, 1042-1047,

[12] Feingold ,G., Jiang, H., Harrington, J.Y., (2005). On smoke suppression of clouds in Amazonia, *Geophys,Res.Lett*.,32.L18803,doi:10,1029/2005GL021369

[13] Prospero, J.M., Charlson, R.J., Mohnen, B., Jaenicke, R., Delany, A.C., Mayers, J. Rahn, K. (1983). The Atmospheric Aerosol System –An Overview, *Rev. Geophys. Space Phys*. 21, 1607-1621.

[14] Moorthy, K.K., Nair, P.R., Krishnamurthy, B.B., (1988). A study on Aerosol Optical Depth at a coastal station, Trivandrum. *Ind. J. Radio & Space Physics*, 17, 16-22

[15] Jayaraman, A., Subbaraya, B.H., (1993). Insitu measurements of Aerosol extinction profiles and their spectral dependence at tropospheric levels. *Tellus*, 47B, 473-478

[16] Devara, P.C.S., Saha, S.K., Raj, P.E., Sonbawne, S.M., Dani, K.K., Tiwari, Y.K., Mahesh Kumar, R.S., (2005). A four-year climatology of total column tropical urban aerosol, ozone and water vapor distributions over Pune, India, *Aerosol Air Qual. Res*. 5, 103-114.

[17] King, M.D., Kaufman, Y.J., Menzel, W.P., Tanre, D., (1992). Remote sensing of cloud,aerosol and water vapor from MODIS. IEEE Trans. *Geosci. Remote sens*. 30, 2-27

[18] Ramanathan, V., Carmichael, G., (2008). Global and regional climate changes due to black carbon. *Nature. Geosci* 1, 221-227

[19] Pandithurai, G., Dipu, S., Dani, K.K., Tiwari, S., Bisht, D.S., Devara, P.C.S., Pinker, R.T., (2008). Aerosol radiative forcing during dust events over New Delhi. India, *J. Geophys. Res.* 113:D13209. Doi:10.1029/208GL035573

[20] Sarkar, S., Chokngamwong, R., Cervone, G., Singh, R.P., Kafatos, M., (2006). Variability of aerosol optical depth and aerosol forcing over India, *Adv. Space. Res.*, 37(12) 2153- 2159

[21] Goutham, R.,.Hsu, N.C., Kafatos, M., Tsay, S.C., (2007), Influence of winter haze on fog/low cloud over the Indo-Gangetic plains, *J.Geophys. Res*., 112, D05207

[22] Prasad, A.K., Singh, R.P., (2007). Changes in aerosol parameters during major dust storm events (2001– 2005) over Indo-Gangetic plains using AERONET and MODIS data, *J. Geophys. Res*., 112, D09208, doi:10.1029/2006JD007778.

[23] Yadav,S., Rajamani, V., (2003). Aerosols of NW India—A potential Cu source, *Curr. Sci*., 84(3), 278– 280.

[24] Moorthy, K.K., Babu, S.S., Satheesh, S.K., Srinivasan, J., Dutt, C.B.S., (2007). Dust absorption over the ‘‘Great Indian Desert using ground based and satellite remote sensing, *J. Geophys. Res*., 112, D09206, doi:10.1029/2006JD007690.

[25] State of the Environment, Scientific Report, Ministry of Environment and Forests (MoEF), Government of India, 2009.

[26] Chameides, W.L. et al., (1999) Case study of the effects of atmospheric aerosols and regional haze on agriculture: An opportunity to enhance crop yields in China through emission controls? *Proc. N.Y. Acad. Sci*., 96, 13626–13633.

[27] Prasad Rao, G.S., Kesava Rao, A.V.R., Krishna Kumar, K.N., Gopakumar, C.S., Impact of climate change on food and plantation crops in the humid tropics of India. ISPRS Archieves XXXVIII-8/W3 Workshop proceedings: Impact of climate change on agriculture.

[28] Morys, M., Mims III, F.M., Hagerup, S., Anderson, S.E., Baker, A., Kia, J., Walkup, T., (2001). Design, calibration, and performance of Microtops II handheld ozone monitor and sun photometer, *J. Geophys. Res*., 106, 14573–14582.

[29] Angstrom, A.,(1964). The parameters of atmospheric turbidity, *Tellus*, 16, 64–75.

[30] Dubovik, O., Holben, B., Eck, T. F., Smirnov, A., Kaufman, Y, J.,King, M. D., Tanre, D., and Slutsker, I., (2002) Variability of absorption and optical properties of key aerosol types observed in worldwide locations, *J. Atmos. Sci.*, 59, 590–608.

[31] Moorthy, K.K.; Babu, S.S., Satheesh, S.K.,(2005). Aerosol characteristics and radiative impacts over the Arabian Sea during the inter monsoon seasons: Results from ARMEX field campaign, *J. Atmos. Science*, 62, 192- 206

[32] Draxler, R.H. and Rolph, G.D.,(2003). HYSPLIT model,http://www.art.noaa.gov/ready/hysplit4.html NOAA Air Resources Laboratory, Silver, Spring, MD,

[33] Dani, K.K., Maheshkumar, R.S., Devara, P.C.S.,(2003). Study of Total Column Atmospheric Aerosol Optical Depth, Ozone and Precipitable Water Content Over Bay of Bengal During BOBMEX-99, *Proc. Indian Acad. Sci. Earth Planet. Sci*. 112, 205-221

[34] Kumar, K.R., Narasimhulu, K.K, Reddy, R.R., Gopal, K.R., Reddy, L.S.S., Balakrishnaiah, G., Moorthy, K.K., Babu, S.S., (2009). Temporal and spectral characteristics of aerosol optical depths in a semi-arid region of southern India, *Sci. Total Environ.* 407, 8, 2673-2688, DOI: 10.1016/ j.scitotenv.2008.10.028

[35] Xin, J., Wang, Y., Li, Z., Wang, P., Hao,W.M., Nordgren, B.L., Liu, G., Wang, L.; Wen,T., Sun, Y., Hu, B.,(2007). Aerosol optical depth (AOD) and Angstrom exponent of aerosols observed by the Chinese Sun Hazemeter Network from August 2004 to September 2005, J. Geophys. Res. 112, DO5203, DO1: 10.1029/2006JD007075

[36] Attri, A.K., Kumar, U., Jain, V.K., (2001). Formation of ozone by fireworks, *Nature*, 411, 1015,

[37] Nishanth, T., Praseed, K.M., Ratnakaran, K., Satheesh Kumar, M.K., Ravi Krishna, R., Valsaraj, K.T., (2011). Atmospheric pollution in a semi-urban, coastal region in India following festival seasons. *Atmospheric Environment*, 47(2012) 295-306

[38] O'Neill, N.T., Dubovic ,O., Eck, T.F., (2001). Modified Angstrom exponent for the characterization of sub micrometer aerosols, *Appl. Opt.*, 2001, 40.2368-2375,.

[39] Kaskaoutis, D.G., Kambezidis, H.D.,(2006). Investigation on the wavelength dependence of the aerosol optical depth in Athens area, *Q.J.R.Meteorol. Soc*., 132,2217-2234,

[40] Remer, L.A., Y.J.Kaufman, (2005): The MODIS aerosol algorithm, products, and validation, J. Atmos.Sci., 62(4), 947-973.