4.1. Introduction

Atmospheric aerosols are solid or liquid particles suspended in the atmosphere. Aerosols have long been identified as the major controllers of the Earth’s climate (IPCC, 2001). Despite progress achieved during the last decades in understanding the effects of aerosols on climate, their large spatial-temporal variability and heterogeneity still causes significant uncertainties at global scales (IPCC, 2007). Atmospheric aerosol is a complex dynamic system with temporal variability caused by nature of the aerosol sources, synoptic conditions (air mass changes) and the meteorological factors (humidity, precipitation). Anthropogenic and natural aerosols are important atmospheric constituents that significantly contribute to Earth's radiation budget through a variety of pathways such as direct effects on scattering and absorption of solar radiation, indirect effects on cloud microphysics (modify cloud amount and life time), and semi-direct effects (Kaufman et al., 2002; Yoon et al., 2005; Ramanathan et al., 2007; Ramanathan and Carmichael, 2008). They scatter (angular redistribution of energy) and absorb (conversion of energy into either heat or photochemical change) optical radiation depending upon their size distribution, refractive index and total atmospheric loading. This results in attenuation or extinction of solar radiation reaching the earth’s surface (Ranjan et al., 2007). On a global scale, the natural sources of aerosols are more important than the anthropogenic aerosols, but regionally anthropogenic aerosols are more important (Satheesh and Moorthy, 2005 Ramanathan et al.,
However, as a consequence of their high spatial and temporal variability, these effects are strongly regional in magnitude and sign (Nakajima et al., 2003; El-Metwally et al., 2011). Aerosol optical depth is an important parameter that characterizes the integrated extinction of solar radiation suffered in its transit through the atmosphere. Also many studies concerning atmospheric turbidity and aerosol optical properties in different part of the world have been performed (Rapti, 2000; Hand et al., 2004; Hujia Zhao et al., 2013). In order to improve our scientific knowledge of the climatic role of aerosols for the Semi-arid region, and the accuracy of radiation budget model results, more and better data on aerosol properties and loads are required.

**Theory**

The spectral dependence of AOD is used in this work to compute the Angstrom exponent ($\alpha$). The Angstrom parameters were obtained from each data point at 15 min interval AODs (440-870 nm) by using Angstrom power law. Angstrom suggested an empirical formula for the attenuation of scattering and absorption by aerosols. According to his formula, the aerosol optical depth, $AOD_\lambda$, is related to wavelength ($\lambda$ in $\mu$m) through Angstrom’s equation, given by,

$$AOD_\lambda = \beta\lambda^{-\alpha}$$  \hspace{1cm} (4.1)

where $AOD_\lambda$ is the aerosol optical depth at the wavelength $\lambda$, $\beta$ is the Angstrom’s turbidity coefficient which equals AOD at 1 $\mu$m wavelength; and
\( \alpha \) is Angstrom exponent that depends on the size distribution parameter of aerosol. The Ångstrom turbidity parameters give valuable information on aerosol properties and important aerosol types. These parameters are dimensionless measures of the opacity of a vertical column of the atmosphere and a numerical quantification of the column extinction of transmitted radiation by atmospheric aerosols from a fixed band in the solar electromagnetic spectrum (Esguerra et al., 2010; Rollin et al., 2000; Macalalad, 2004).

While classification of aerosol type observations, error occurred with a difference in wavelength dependence is recovered from linear interpolation technique to calculate the AOD at unknown wavelength (440 and 675 nm) using power law (Prasad et al., 2007) as follows,

\[
AOD_{\lambda_1} = AOD_{\lambda_2} \left( \frac{\lambda_2}{\lambda_1} \right)^{-\alpha}
\]  

(4.2)

Where \( \alpha \) is the Ångström exponent, which is determined from spectral aerosol optical depth measured by a Microtops II sunphotometer as shown in below.

The wavelength dependence of \( AOD_\lambda \) can be characterized by the Ångström parameter, which is a coefficient of the following regression.

\[
\ln AOD_\lambda = -\alpha \ln \lambda + \ln \beta
\]  

(4.3)

The value of \( \alpha \) is approximately 1.3 for average normal size distribution. Value higher than 1.3 are resulted in by the relatively higher frequency of smaller particles as compared with the large particles having a radius greater
than 0.5 μm. (Zoltán Tóth, 2013). The variation in α with wavelength is related by empirical relationship between aerosol extinction and wavelength, when it is simulated by a second order polynomial fit (pedros et al., 2003, Kaskoutis and Kambezidis, 2006)

\[
\ln \text{AOD} = a_2 \ln \lambda^2 + a_1 \ln \lambda + a_0
\]  

(4.4)

Where the coefficient \(a_2\) accounts for a curvature often observed in Sun photometry measurements. The curvature can be an indicator of the aerosol particle size, with negative sign indicating the aerosol size distributions dominated by fine mode and positive curvature is indicated by the size distributions with significant contribution by coarse mode aerosols (Schuster et al., 2006; Balakrishnaiah et al., 2011). In addition, the coefficients \(a_1\) and \(a_2\) are obtained from the second order polynomial fit to the AOD values at four channels (380, 500, 870 and 936 nm). For choosing the selected range of wavelengths relies on the fact that these are highly accurate channels of the sunphotometer. AOD at 1020 nm values were omitted from the fits because it contains larger uncertainties due to the water vapor effect.

For the classification of aerosol types, AOD and alpha values have to be used (Holben et al., 2001). In the present study, the contour maps were constructed using 0.3 and 1.0 steps for both \(\text{AOD}_{500}\) and \(\alpha_{380-870}\) values, respectively. The threshold values are basically deduced by a statistical analysis of the frequency distribution of those quantities. In these maps, the rectangle areas denote different aerosol types, namely, coarse/dust (CD),
anthropogenic/burning (AB), clean continental (CC) and coarse/marine (CM) aerosols, and boundaries of these areas correspond to the selected threshold values, of \( \text{AOD}_{500} \) and \( \alpha_{380-870} \). Therefore, (1) values of \( \text{AOD}_{500} < 0.3 \) with \( \alpha_{380-870} > 1 \) represent clean continental (CC) aerosols, (2) \( \text{AOD}_{500} > 0.3 \) with \( \alpha_{380-870} > 1 \) can be used to characterize anthropogenic biomass burning (AB) aerosols, (3) \( \text{AOD}_{500} < 0.3 \) associated with \( \alpha_{380-870} < 1 \) are indicative of coarse marine (CM) aerosols and (4) \( \text{AOD}_{500} > 0.3 \) with \( \alpha_{380-870} < 1 \) are considered as coarse dust (CD) particles. This method has been used in a number of studies (Elias et al., 2006; Kalapureddy et al. 2008; Kaskaoutis 2009 and Obregon et al., 2012) and is based on the sensitivity of the two parameters to different, somewhat independent, microphysical aerosol poeeties. The Angstrom exponent depends on particle size distribution while \( \text{AOD}_{500} \) depends mainly on the aerosol column density.

To analyze the aerosol modifications processes, we follow Gobbi et al., (2007) proposed scheme, to visualize the contribution of fine aerosols to AOD and it reveals the modal radius of the fine particles \( (R_f) \). We define the Angstrom exponent difference \( \Delta \alpha (\alpha_{440-675} - \alpha_{675-870}) \) as a measure of the Angstrom exponent curvature \( \Delta \alpha / \Delta \tau \). In these coordinates, we further classify aerosols by representing their AOT by different colors. To interpret data in these coordinates, we determine reference points corresponding to bimodal size distributions characterized by a variety of fine mode \( (R_f) \) and coarse
mode ($R_c$) modal radii combined to lead to prescribed fractions ($\eta$) of the fine mode to total AOD (at 500 nm).

### 4.2 Results and discussion

#### 4.2.1. Diurnal and Monthly variation of AOD and Angstrom exponent

Figure 4.1 shows the diurnal variation of average aerosol optical depth (AOD) at all wavelengths and angstrom exponent ($\alpha$) during the study period over the measurement site. The morning values are generally higher than those of afternoon because of capping action of aerosols released due to various anthropogenic activities by previous night. By noon or shortly after, the radiative inversion normally starts to break up under the action of solar heating. In general, this type of behaviour of AOD has been observed on most of the days during the study period. Devara et al., (1996) have observed similar variation in diurnal pattern of AOD at pune. The daily variation of the AOD lies in the range of 0.15 to 0.71 over the Anantapur.

The values of $\alpha$ undergo a change throughout the day because of changes in the atmospheric meteorological parameters and anthropogenic activates. These changes may either decrease or increase in the values of the Angstrom parameters. In general, everyday observations show that an increase in $\alpha$ during forenoon followed by a slight decrease throughout day. The dominance of small particles (during morning hours) coupled with high values of $\alpha$ point indicates the possibility of the aerosol loading mainly from the vehicular emissions coming from nearby areas (Rama Gopal et al., 2014b).
4.2.2 Monthly variation of AOD and Angstrom exponent

The monthly mean variations of aerosol optical depth for the entire period over the site are shown in Fig. 4.2 for all wavelengths. The figure reveals that the AOD$_{500}$ attains peak (0.58 ± 0.1) in the month of May while dip (0.3 ± 0.12) is seen in the September. The maximum AOD values were

![Graph showing monthly variation of AOD and Angstrom exponent](image-url)
observed from March to May. A possible explanation for high AOD during the summer is due to the forest fires in central and northern India and transport of biomass burning plumes or dust transport by northerly winds (Badarinath et al., 2009, 2010). Coarse particles presence in the summer attributed to the lift of the loose soil through high wind speed prevailing in that region. From July to September low AOD values obtained can be attributed to the effects of strong wet removal process of aerosols (Kumar et al., 2010; Balakrishnaiah et al., 2011). Furthermore drastic reduction in anthropogenic activities like biomass brining, bricks making etc due to the after rains in the observed site.

In the post-monsoon season, the aerosol production mechanism related to wind and surface conditions and they are weak. During the December through February, AOD is slightly lower as mostly associated with fine-mode particles. The variations in meteorological parameters are the characteristics of the environmental changes in the months/seasons of a year. It is, therefore expected that the atmospheric aerosols be subjected to changes in number and size distribution. The $\alpha$ is an index for the aerosol size distribution and depends on the ratio of the concentration of small to large aerosols, whereas, $\alpha$ decrease with increasing AOD values and vice-versa. In sharp contrast, the $\alpha$ values show a pronounced decrease in the monsoon months.
**Fig. 4.2.** Monthly mean aerosol optical depth (at different wavelength) and Angstrom exponent at Anantapur.
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This strong decrease in $\alpha$ value may partly be attributed to cloud contamination in the retrievals caused thin undetected cirrus clouds. Minimum values of $\alpha$ in the monsoon indicate the presence of coarse-mode aerosol particles during this period. A high value of $\alpha$ during the summer is the indication of the presence the contribution of fine-mode particles. A possible explanation for this can lie on the fact that this is the time with peaks in forest fires in central and northern India (Badarinath et al., 2007a) and transport of biomass burning plumes by northerly winds (Badarinath et al., 2009).

4.2.3 Angstrom exponent ($\alpha$) versus turbidity factor ($\beta$)

In order to classify the variation of fine and coarse mode particles, changes in the Angstrom parameters are employed. In Fig. 4.3 (in monthly scale), it is seen that there is an anti-correlation between $\alpha$ and $\beta$ indicating the continuous redistribution of fine and coarse particles under the influence of meteorological parameters. This shows an inverse relationship between $\alpha$ and $\beta$ values. Such a trend is found in many other observational sites in India and elsewhere (Dani et al., 2003; Xin et al., 2007; Vijakumar et al., 2012). The $\alpha$ values are found to be maximum in the summer and minimum in the monsoon seasons. The high value of $\alpha$ in the summer is attributed to the domination of fine mode aerosols over coarse mode aerosols. And the greenery which is abundant at the observation site undergoes photosynthetic action due to sun shine this is the reason for the produce small size aerosol (during the summer).
The higher value of $\beta$ (and smaller value of $\alpha$) during the monsoon and post monsoon signifies higher relative abundance of coarse (super micron) aerosols in the atmosphere. Normally $\beta$ increases with increasing AOD values and vice-versa, whereas, $\alpha$ decrease with increasing AOD values and vice-versa.

### 4.2.4 Spectral variation of AOD

Fig. 4.4 indicates the spectral variation of AOD for different seasons at the measurement site. It is evident from the figure that there is relatively strong wavelength dependence of optical depth at shorter wavelengths that gradually decreases towards longer wavelengths irrespective of the seasonal change attributing to the presence of fine to coarse particles. (The curve is steeper during the summer and relatively less steeper during the monsoon)
The presence of high concentration of the fine-mode particles selectively enhances the irradiance scattering at lower wavelength and therefore, the AOD values are high at the shorter wavelengths. Likewise, the coarse-mode particles provide similar contributions to the AOD at relatively larger wavelengths (Schuster et al., 2006). It is noticed that the magnitude of mean AOD is higher at longer wavelengths throughout the monsoon months, which indicates the dominance of coarse mode aerosols due to the condensation growth and coagulation mechanism of submicron aerosols, which are more efficient in producing larger aerosols. This type of spectral AOD is consistent with the Mie scattering theory for aerosol particles. There are no significant changes found for the near infrared channels at 870, 936 and 1020 nm. This could also be interpreted that the regional pollutants have high concentrations of finer particles.

Fig. 4.4. Spectral variation of AOD for different seasons over Anantapur.
4.2.5 Frequency distribution

Frequency distribution of AOD$_{500}$ and $\alpha$ $(380-936)$ over a period of October-2012 to September-2013 is shown in Fig. 4.5. It can be seen from the figure that more than 600 points of the AODs are lie in between 0.3-0.4 and only 150 points of the AODs are below 0.2.

**Fig.4.5.** Frequency distribution of AOD$_{500}$ and Angstrom exponent (380-870) for the period of study at sampling site.
About 150 points of AOD values greater than 0.6 were noticed in the entire data sets. The frequency distribution histogram of $\alpha$ clearly indicates the presence of a mixture of fine and coarse particles during study period.

The range of $\alpha$ varies mainly from 1.0 to 1.3 which covers about 66% in the total occurrence, with a peak between 1.1 and 1.2. However it is interesting to note that the values of $\alpha$ lies in > 40% of the daily mean values and the remained is < 1. This clearly indicates the dominance of fossil fuel and biomass burning aerosols in modifying the aerosol optical depth at Anantapur. On other hand 35% (< 300 points) of the lower values of $\alpha$ (< 1) indicates the contribution from coarse mode aerosols. Such larger influx of coarse maritime and dust aerosols are associated in the atmosphere. The increase wind speed which subsequently enhances the sea-salt generation and desert (Arab countries) respectively. The model value is around 1.3. Below 0.5 $\alpha$ values indicates the dominance of fine mode aerosols originating from biomass burning and fossil fuel combustion sources mainly and the enrichment of maritime air by sea spray aerosol component respectively.

4.3.6 AOD$_{500}$ versus curvature $a_2$

The optical properties of aerosols alone cannot provide information about the aerosol types. Indeed, further investigation is required which is the estimation from coefficients of second order polynomial fit. It is more appropriate for the discrimination of aerosol size and the types. Fig. 4.6 shows the correlation plot between the spectral coefficient $a_2$ (curvature in the
polynomial fit) and AOD$_{500}$ to discriminate the four dominant aerosol types depending on seasons. The correlation between $a_2$ and AOD$_{500}$ provides the information on the atmospheric conditions under which $\alpha$ is independent from wavelength (Sharma et al., 2010), so the spectral variation of AOD can be accurately described by the simple Angstrom formula (Angstrom, 1964). The data points lying on or around $a_2 = 0$ indicate a bi-modal aerosol distribution without curvature (Schuster et al., 2006; Kaskaoutis et al., 2007).

![Fig.4.6. Seasonal correlation between coefficient $a_2$ and AOD$_{500}$ for each aerosol type over Anantapr.](image-url)
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The negative values of $a_2$ suggest the presence of significant fraction of fine mode aerosols and positive values of $a_2$ provide the information about coarse mode aerosols. It is concluded that the different aerosol types are rather difficult to be distinguished based on the $a_2$ values, in contrast to the results in the study by Kaskaoutis et al., (2007a) and Kalapureddy et al., (2009). For the low AOD ($< 0.1$), there is a wide variability in $a_2$ values (positive and negative) thus implying large curvature which increases the uncertainties in the polynomial fit dramatically as well as the errors in the $a_2$ values. However, these researchers investigated the aerosol properties in different environments, where the aerosol types were clearly distinguishable. The present study focused over Anantapur where aerosols from different origins are mixed. Except Coarse/Marine (CM), Coarse/Dust (CD), Anthropogenic/Burning (AB) and Clean Continental (CC) the other types are still unable to be discriminated unambiguously. Different graphs are drawn for each season. Furthermore, some positive $a_2$ values are presented for the Anthropogenic Burning aerosol type, thus showing that the initial fine-mode aerosols have been modified by coagulation, condensation and gas-to-particle conversion resulting in greater size and less negative or even positive $a_2$ values (Schuster et al., 2006). In winter and summer $a_2$ shows low negative values (in the majority of the cases) for low AOD$_{500}$. These low negative values at low AOD are likely due to large uncertainty in computed $a_2$ for these cases, due to AOD uncertainty. The $a_2$ values during the monsoon are mostly negative and AOD$_{500}$ values are lower. It is interesting to note that the smaller fractions of positive $a_2$ values are
observed in the winter and pre monsoon, indicating the presence of the great fraction of fine-mode particles. The observed generated of coarse-mode particles are predominant during the post monsoon and monsoon and may be due to the lower turbidity coefficient (beta) and also associated with meteorological parameters.

4.2.7 Variation of the curvature $a_2$ with $\alpha$

Fig. 4.7 shows the variation of $a_2$ with $\alpha$ for different seasons over the site. For $\alpha > 1$, the curvature of $a_2$ is decreasing and inclined towards negative values. The increase in $\alpha$ indicates the strong presence of fine particles from biomass burning. The positive curvature of $a_2$ signifies the increase of the coarse mode. Thus, $a_2$ in conjunction with the Angstrom exponent gives an indication of the aerosol size distribution and shows the decrease of the curvature and which indicates the influence of the accumulation mode. It is verified that the curvature alone is not enough for describing the aerosol particle size and identifying the types of aerosol, as stated elsewhere (e.g., Eck et al., 1999; Kumar et al., 2013). The large positive values of $a_2$ and small magnitude of $\alpha$ indicates the dominance of coarse mode particles during the post monsoon and monsoon. The water vapour content and relative humidity seem to play an important role in the aerosol particle size, especially for water soluble anthropogenic aerosols. Similarly this study confirmed that during the winter and post-monsoon, the negative $a_2$ values indicates the fine mode aerosols dominance. The large concentration of fine mode aerosol is attributed
to anthropogenic aerosols released into the atmosphere by bio-mass burning and smoke aerosol transported from external sources.

![Graphs showing seasonal correlation between coefficient $a_2$ and alpha for each aerosol type over Anantapur.](image)

**Fig. 4.7.** Seasonal correlation between coefficient $a_2$ and alpha for each aerosol type over Anantapur.

It is also observed that the water vapour content is small during the winter. It starts increasing from the hot summer season and reaches maximum during the months of the monsoon season. It is evident from the plots that most of the $a_2$ values lies below the $a_2 = 0$ line indicating the abundance of fine
mode particles during biomass burning period. The comparison of \( a_2 \) values during the winter and summer seasons show that they lie above \( a_2 = 0 \) line during the monsoon season indicating the presence of coarse mode (CM) particles transported from Arabian and Indian oceans. In the post-monsoon, winter and summer \( a_2 \) values are low and negative (in the majority of the cases) for high \( \alpha \). Better identification of the aerosol types \( \alpha_{380-936} \) versus \( a_2 \) is yet possible with this description. This is mainly achieved for the CC and AB aerosols (high \( \alpha_{380-936} \) and low negative or near zero \( a_2 \)). In contrast, the CM type is more distinguishable in the monsoon period. Despite the great differences in the \( \alpha_{380-936} \) and \( a_2 \) values yet there is a similarity between the graphs in each season. The negative \( a_2 \) values are observed as \( \alpha_{380-936} \) increased and thus implying a general decreasing trend in their correlation. Furthermore, dominance of positive curvature (for CD aerosols) was found over Anantapur during the summer episode. The positive curvatures dominated during the monsoon days, while the negative curvatures exits during the post-rainy days indicating that the coarse-mode aerosols had a wet deposition and the fine-mode ones which are responsible for the cloud condensation nuclei (CCN).

### 4.2.8 Discrimination of aerosol types

In order to characterize the aerosol properties, data of both AOD and Angstrom exponent values have to be used (Holben et al., 2001) since they both are strongly depend on wavelength. The AOD versus \( \alpha \) patterns have
been utilized to describe different aerosol types (e.g., marine, anthropogenic and dust aerosols) at several locations (Eck et al., 1999, 2001a,b; Masmoudi et al., 2003; Kim et al., 2004). In all of the above studies a wide range of $\alpha$ value for low AOD$_{500}$ was obtained. Fig.4.8 represents the density maps of AOD$_{500}$ and $\alpha_{(380-936)}$ over a semi-arid station for representative seasons. These contour maps were constructed using 0.1 steps for both AOD$_{500}$ nm and $\alpha_{(440-870)}$ value. In these maps, the rectangle areas denotes the coarse/dust (CD), coarse/maritime (CM), anthropogenic/burning (AB) and clean continental (CC) aerosols, and boundaries of these areas correspond to the selected threshold values of AOD$_{500}$ and $\alpha_{(380-936)}$. This method has been used in a number of studies (Kalapureddy et al., 2009, Vijayakumar et al., 2012) and is based on the sensitivity of the two parameters to different, somewhat independent, microphysical aerosol properties; the Angstrom exponent depends on particle size distribution (aerosol type), while the AOD$_{500}$ depends mainly on the aerosol column density. Therefore, the AOD$_{500}$ versus $\alpha_{(380-936)}$ plot qualitatively indicates the amount and dimension of the observed aerosols.

In the present study it is observed during the summer period AOD$_{500}$ and moderate $\alpha_{(380-936)}$ values are relatively higher. The maximum density area was observed for the pair (AOD$_{500}$, $\alpha_{(380-936)}$) = (0.3-0.45, 0.7-1.0) which is indicative of coarse dust Particles during the summer period. Secondary maximum was found for (AOD$_{500}$, $\alpha_{(380-936)}$) = (0.4-0.55, 1.2-1.4) and which is due to the presence of anthropogenic burning type of aerosol over the station.
The winter season is characterized by moderate AOD$_{500}$ (0.1-0.45) and high alpha values (0.6-1.5).

Fig. 4.8. Contour density maps of the Angstrom exponent (380-936) versus aerosol optical depth at 500 nm.
The maximum density area of AOD = 0.2-0.35 and $\alpha_{(380-936)} = 1-1.2$ is representative of the clean continental aerosols long-range transport which is frequent over Anantapur during the season and relative influence of urban-industrial polluted aerosols under moderate-to-high turbidity conditions. As well as secondary maximum was found for $(\text{AOD}_{500}, \alpha_{(380-936)}) = (0.3-0.35, 1.0-1.2)$ and is due to the presence of anthropogenic burning aerosol type. In the post-monsoon months maximum density was observed for the pair $(\text{AOD}_{500}, \alpha_{(380-936)}) = (0.25-0.35, 1.1-1.3)$ and indicate slightly domination of anthropogenic aerosols. Therefore low density area was depicted for the pair $(\text{AOD}_{500}, \alpha_{(380-936)}) = (0.15-0.25, 0.7-1.0)$ and are represents the prance of indicative of coarse marine particles. Similarly the Monsoon period AOD$_{500}$ are ranged from 0.1 to 0.45 and $\alpha_{(380-936)}$ from 0.2 to 1.0. During the Monsoon absolute maximum density was observed for the pair $(\text{AOD}_{500} \text{ nm}, \alpha_{(380-936)}) = (0.25-0.37, 0.2-0.5)$ which suggests the domince of coarse marine and coarse dust particles.

During the winter, and summer months the analysis shows that the majority of the aerosols presence belong to be coarse dust and anthropogenic burning aerosol types. According to the back trajectory analysis, the Mixed-type aerosols that are direct combination of anthropogenically produced aerosols near the coast, sea-salt aerosols over Arabian-sea oceanic regions and concentrations of mineral dust associated with long-range transport from desert regions (Arab countries).
This is shown in Fig. 4.9 where the new groups are: sources from elsewhere and regional/local influence (including the impact from neighboring urban/industrial sites such as the Balkans and nearby biomass burning areas, but also local sources under stagnant conditions), dust, coarse marine environment and finally remote, clean areas (those cluster originating over the Arabian). The contribution of aerosols of different origin and characteristics to the atmospheric column can be strongly modified in each season. The present investigation describes the percent contribution of each aerosol types during all seasons over the measurement site. The anthropogenic burning aerosols are the most dominant with varying magnitudes ranging from 0.91% to 82% over sampling site during the study period. It has been noticed that anthropogenic burning aerosol is the most dominant contributor in the post monsoon season as well as clean continental, anthropogenic burning and coarse marine type particles are dominated throughout winter, summer and monsoon respectively.

The Anantapur is influenced by the densely pollution with dust in the dry period of the year, while the effect of anthropogenic pollution is limited. Besides this, significant fraction (7.89%) of coarse marine aerosols is observed in the post monsoon, where anthropogenic burning presents its higher frequency 82.89%. This indicates that the clean continental aerosols transported over Anantapur are composed of both fine and coarse particles during the winter, additionally anthropogenic burning type aerosols are slightly dominated over the site.
The coarse dust aerosols are predominant in all seasons, exhibits its higher frequency in the summer (43.64%). Next to anthropogenic burning type (45.34%) is contributing more to the total loading in the season (summer). The significant fractions are found to be 51.37% of CM, 33.64% of CD, 4.09% of CC and 0.91% of AB type particles during the monsoon. The mixing cloud be caused by a primary small and large particles, that is a mixture of fine and coarse mode aerosols resulting in decreasing $\alpha$ as the dust contribution increases. In the aerosol particle size the relative humidity plays an important

![Fig.4.9. Seasonal pie charts for each aerosol type during the study period at sampling site.](image)
role especially for the water-soluble industrial particles. The relative humidity was highly correlated with the aerosol effective radius (Ferrare et al., 2000). The optical properties of anthropogenic aerosols demonstrate a significant variability, depending on the complex combination of natural and anthropogenic factors influencing aerosol formation coating and evolution, including relative humidity, long-range transport, deposition rates, fuel types and emission characteristics.

4.2.9 Aerosol modification processes

Gobbi et al., 2007 proposed a graphical method to visualize the contribution of fine aerosols to AOD and the size of the fine particles. This classification scheme is based on Mie calculations and correlates the $\alpha$ vs $d\alpha$ plot with the fine-mode fraction at 675 nm ($\eta$) and effective radius of the fine aerosols ($R_f$) and is appropriate for identifying aerosol-modification processes. This scheme relies on the combined analysis of $\alpha$ derived for the wavelength pairs of 440-870 nm and its spectra curvature, represented by $d\alpha = \alpha(440-675) - \alpha(675-870)$. The same scheme was performed over the observation site for different seasons are shown in Fig. 4.10.

The black and blue curves represent the different value of effective radius ($R_f$) and fraction ($\eta$), respectively. The size of the symbol (different colors) presents the increasing AOD values. The negative values of $d\alpha$ associated with larger $\alpha$ indicate the dominance of fine-mode aerosols, while $d\alpha$ close to zero, or even positive, indicates significant contribution of coarse-
mode particles associated with bi-modal size distribution with similar modes. The aerosol modification processes (aging, coagulation, humidification and cloud contamination) both decrease $\alpha$, but they have different characteristics in $\alpha$ vs. $d\alpha$ plot, e.g. the cloud contamination enhances the weight of the coarse mode, while aging, humidification and coagulation increases $R_f$. The increase in AOD with coarse-mode fraction along a constant $R_f$ curve towards the origin ($\alpha = 0$, $d\alpha = 0$) indicates cloud contamination. Similarly, the increase in AOD towards lower $\alpha$ and smaller negative $d\alpha$ values indicates the dominance of either dust or maritime aerosols or a combination of both.

The increase in AOD with $R_f$ and $\alpha$ infer the hydration of aerosol particles, while increase in AOD with increasing $R_f$ and decreasing $\alpha$ suggests aging and/or coagulation and, the reverse, i.e. increase in AOD with decreasing $R_f$ and increasing $\alpha$, corresponds to freshly emitted fine aerosols (Gobbi et al., 2007; Basart et al., 2009; Kaskaoutis et al., 2011). Based on the aforementioned criteria the aerosol optical properties and the modification processes over Anantapur are discussed for the entire data set for the period October 2012–September 2013 (Fig. 4.10), on seasonal basis.

The proportion of small particles during post monsoon shows that few data points having the smaller $\alpha$ ($< 1.2$) associated with the low AOD (between 0.3-0.4) cases show negative $d\alpha$ values and $\eta$~90%, and which suggest the influence of anthropogenic aerosol over the region. Dust transported downwind from source regions varies seasonally.
This is due to the well-known presence of biomass burning aerosols composed of fine aerosols originating from anthropogenic activities (Ogunjobi et al., 2008) and associated to urban-industrial pollution aerosols from local and regional activities. The summer data (AOD500, \( \alpha \), and \( \delta \alpha \)) exhibits the largest variability in values suggesting diversity in the dominant aerosol types and a mixture of both fine- and coarse-mode particles. For the higher AOD, the majority of data points lie in between \( (R_f) \) 0.1 and 0.2 \( \mu m \) lines having larger values of \( \eta (>50\%) \), revealing the abundance of fine particle and it is likely the result of secondary aerosol formation through gas-to-particle conversion due to increasing solar radiation (Sinha et al., 2012).
The $\alpha$ vs $d\alpha$ plot during the monsoon is strongly differs from those obtained during other seasons with very less amount of the points lie outside the classification scheme and the main difference being a shift towards the lower $\alpha$ (< 0.8) values with $\eta$ < 40%; thereby suggesting a dominance of aerosols of coarse-mode. The cases having AOD < 0.2 are associated with large negative $d\alpha$ values with $\eta$ > 50% ($R_f$ > 0.2) and may correspond to cases with dilution of the larger particles after rain washout. This $R_f$ value is larger than those found in other seasons, suggesting water uptake and increase in size of the water-soluble aerosols due to humidification processes (see Gobbi et al., 2007) as the RH is more over Anantapur during this season. In the winter season nearly all the points are within the classification scheme. Increasing AOD shows a shift to larger $\alpha$ values (1.2–1.7) and large negative $d\alpha$ ~ –0.5 with $\eta$ values > 70% suggest the dominance of fine-mode. The data clearly demonstrates that majority of the aerosols in the turbid atmosphere are fine-mode, mainly caused by local anthropogenic pollution or biomass burning, vehicular emissions are also more frequent in this season due to dry atmospheric conditions apart from agricultural burning. The more negative $d\alpha$ with increasing AOD is an indication of fine-mode dominance under high AODs and also observed over biomass burning regions by Eck et al., (2001) and Basart et al., (2009). As seen in Fig. 4.10, even though several conclusions regarding the aerosol characteristics over Anantapur are apparent, a large scatter in the data does lead to visual uncertainties.
4.2.10 AOD\textsubscript{500} and Alpha associated with wind direction

Figure 4.11 describes the variation of AOD\textsubscript{500} and \(\alpha\) is investigated during the period of study associated with wind direction over the site because of back trajectory air mass influence on aerosol loading and size of the particles. Increase in the \(\alpha\) indicates the evidence on the increase of the amount of small particles and is relative to the coarse particle in the ambient atmosphere.

**Fig.4.11.** Variations in AOD and Angstrom exponent with wind direction over Anantapur during the period of study.
The small $\alpha$ correspond to larger aerosols and strong dependence on wind direction is observed. All most small $\alpha$ value was found when the prevailing wind is in the south-westerly direction is actually oceanic wind, consequently larger aerosol particles can be attributed to the maritime aerosols. The extreme high AOD over the Arabian Sea is contributed significantly by the dust aerosols originated at the peninsular Arabia, which are transported by the strong north-westerly offshore wind. For the points located in the east central Pacific AOD is maximum with an east wind, indicating that the large values of AOD over these points probably relate to long-range transport aerosol from biomass burning in South America or dust from the Sahara. The contribution of wind induced marine aerosol to aerosol optical depth is found to be dominated by the coarse mode elements. Regions of moderate winds are usually characterized by a relatively small fraction of coarse mode aerosol and low values of AOD. Moreover, areas of strong annual winds are characterized by large fraction of coarse mode aerosol and high values of AOD. The AOD and $\alpha$ value are higher when wind comes from a roughly north-easterly direction.

**4.2.11 AOD correlation with solar flux and UV radiation**

The quantified negative correlation between aerosol optical depth versus solar flux and UV radiation are shown in Fig. 4.12 respectively. The solar flux decreases with increase AOD and it is mainly due to the radiation scatters back in to the space while increase the concentration of scatter
particles. The aerosol optical depth is high when the scattering and absorption particle concentration is high in the atmosphere and which results the radiation scatters and absorbs mainly due to the particles. The significant correlation $R= -0.54$ between aerosol optical depth and solar flux is obtained over the measurement site. It can be seen that unit increase in AOD can reduce the UV radiation dose rate during different seasons and is proportional to aerosol loading. The UV radiation reaching the Earth’s surface is sensitive to the solar zenith angle and cloud cover, as well as the total amount of ozone and atmospheric aerosols.

![Scatter plots between AOD and UV radiation](image1)

**Fig.4.12.** Scatter plots between AOD$_{500}$ and UV radiation (upper panel); AOD$_{500}$ and solar flux (bottom panel).
The presence of Aerosols in atmosphere can be observed through one and only parameter and is called Aerosol Optical Depth. This AOD variable is an extinction measurement (no dimension) of radiation and its relation with aerosol particles in atmosphere is mainly due to the processes of spreading and absorption. The increase in aerosol load implies a decrease in UV radiation (Correlation R= 0.51 between AOD and UV radiation). Aerosol in the atmosphere extinguishes the overall UV reaching the surface and it is an important parameter and relates to AOD which is depend on the wavelength.