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DEPENDENCE OF THE ANGSTROM EXPONENTS ON WAVELENGTHS AND RELATIVE HUMIDITIES FOR FOUR TYPES OF AEROSOLS

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ABSTRACT

In this paper, the spectral aerosol optical depth (AOD) and Angstrom exponents (αs) and their relations with relative humidities (RHs) were determined and analyzed to obtain information about the adequacy of the simple use of α for characterizing aerosols. The data were taken from four selected OPAC models and compared with AERONET stations for four sites, which are representative of four aerosol types as biomass burning, urban pollution, desert dust and maritime. Using regression analysis, the αs were determined in the spectral interval 350–900 nm, along with the coefficients α_1 andα_2 of the second order polynomial. The results show that the spectral curvature can provide important additional information about the different aerosol types but depending on the RH. We also determined good correlations between the αs and the coefficients α_1 and α_2 of the second-order polynomial fit but it is higher for larger particles and decreases with the decrease in particle size. The relations of αs with RHs show increase and decrease of αs and changing in the sign of α_2 from negative to positive and vice versa which seem to be closely related to the hygroscopic growth factor of the mixture of the aerosols with the increase in RHs. Finally the relationship between α and wavelength is determined.

INTRODUCTION

Atmospheric aerosols are very important in climatic forcing. The climatic effect of aerosols depends strongly on their optical properties and these are dependent on size distributions, shapes, chemical compositions, and mixing states, all of which can be greatly influenced by hygroscopic growth as result of the changes in RHs (Mikhailov et al., 2006; Garland et al., 2007;Pilinis et al., 1995). Water uptake as a result of the increase in RHs affects aerosol atmospheric lifetime and composition, which in turn affect atmospheric visibility, direct radiative forcing of climate (IPCC, 2007) and cloud microphysics (Lohmann and Feichter, 2005). The importance of the aerosol optical depth (AOD), the Angstrom parameter, and the aerosol size distribution functions, is also high for atmospheric and remote sensing studies, apart from other fields as well (Ogunjobi et al., 2004). Extensive analyses based on spectral aerosol measurements indicate that the Angstrom exponent varies with wavelengths, aerosols types and physical and chemical charateristics and that the spectral curvature of the least-squares fit to the Angstrom exponent contains useful information about the aerosol size distribution (King and Byrne, 1976; O' Neill and Royer, 1993; Eck et al., 1999, 2001a, 2001b, 2005; O' Neill et al., 2001a, b, 2003; Kaskaoutis and Kambezidis, 2006; Tomasi et al., 1983).

The wavelength dependence of AOD varies between different aerosol types because of their different physical and chemical characteristics. This AOD wavelength dependence is suitably expressed by the Angstrom-exponent (α) (Angstrom, 1929). The use of Angstrom exponent α has significantly increased in the last years, because this parameter is easily estimated using automated-surface sun photometry, while it is becoming increasingly accessible to satellite retrievals (Schuster et al., 2006). These aerosol's characterizations, based on the spectral dependence of AOD and α, are very useful for refining aerosol optical models, reducing uncertainties in satellite-aerosol observations and aerosol retrievals, and for improving the modeling of aerosol impacts on climate.

The α values were used to characterize four types of aerosols such as biomass burning aerosols in South America and Africa (Reid et al., 1999; Eck et al., 2001a, 2001b, 2003; Keil and Haywood, 2003; Kusmierczyk-Michulec & Van Eijk, 2007), urban aerosols (Eck et al., 1999; Kaskaoutis and Kambezidis, 2006), maritime aerosol component in islands (Smirnov et al., 2002; 2003) and desert dust aerosols in Sahara and East Asia (Eck et al., 1999, 2005; Masmudi et al., 2003). Large positive values of α are characteristic of fine-mode-dominated aerosol size distributions (Eck et al., 1999; 2000; 2001a, b; Ranjan et al ., 2007) while near zero and negative values are characteristic of dominant coarse-mode or bi-modal size distributions, with coarse-mode aerosols having significant magnitude (Eck et al., 1999; O'Neill et al., 2001a, b; Kaskaoutis and Kambezidis, 2006; Dubovik et al. , 2000; Prospero et al., 1979; Carlson and Caverly, 1977).

In the analysis of spectral measurement of AOD in locations dominated by biomass burning, urban, marine or desert dust aerosols, a significant curvature in the lnτ versus lnλ relationship was observed (Eck et al., 1999) and as a result of that a second order fit to the lnτ versus lnλ is proposed to provide better estimates than linear fit (Eck et al., 2001a, b; Kaskaoutis and Kambezidis, 2006; Kaskaoutis et al., 2006). Additionally, Schuster et al. (2006) investigated the sensitivity of Angstrom exponent to both monomodal and bimodal aerosol size distributions by using multi wavelength Mie computations, and they explored the information content in the curvature of α. They found that different values of the fine-mode fraction strongly modify the curvature changing its sign from negative to positive.

The focus of this paper is to determine the relationship between the spectral dependence of optical depth with the Angstrom exponents at RHs of 0, 50, 70, 80, 90, 95, 98, and 99% for four types of aerosols atmospheric models extracted from OPAC at spectral intervals of 0.35mμ to 0.9μm and to compare them with that of data analysed from four selected AERONET sites in key locations around the world, which are representative of different aerosol environments (Kaskaoutis et al., 2007a, b). The models extracted are (i) urban aerosols, (ii) continental polluted, (iii) deseart and (iv) the maritime average and are compared with (i) the Ispra (Italy), an urban area/industrial area with significant of anthropogenic and industrial activities (ii) Alta Floresta (Brazil) which is a rural area influenced by biomass burning smoke during fire season, (iii) Solar village (Saudia Arabia), a continental remote site with significant contributions of desert particles and finally (iv) Nauru, a remote island in the pacific characterized by very small aerosols load respectively. Finally, we determined the relationships of α with wavelengths and RHs.

METHODOLOGY

The models extracted from OPAC are given in table 1.

Aerosol model types	Components	Concentration N_i (cm^{-3})
Urban	WASO	28,000.0
	INSO	1.5
	SOOT	130,000.0
	Total	158,001.5
Continental polluted	WASO	15,700.0
	INSO	0.6
	SOOT	34,300.0
	Total	50,000.6
Desert	WASO	2,000.0
	MINM	269.5
	MIAM	30.5

	MICM	0.142
	Total	2,300.142
Maritime tropical	WASO	590.0
	SSAM	10.0
	SSCM	0.0013
	Total	600.0013

Table 1 Compositions of aerosols types (Hess et al., 1998).

where : N_i is the mass concentration of the component, water soluble components (WASO, consists of scattering aerosols, that are hygroscopic in nature, such as sulfates and nitrates present in anthropogenic pollution), water insoluble (INSO), soot (SOOT, not soluble in water and therefore the particles are assumed not to grow with increasing relative humidity), mineral nucleation mode (MINM), mineral accumulation mode(MIAM) , mineral coarse mode (MICM), Sea salt accumulation mode (SSAM) and Sea salt coarse mode (SSCM).

The spectral behavior of the aerosol optical thickness, with the wavelength of light (λ) is expressed as inverse power law (Angstrom, 1961):

$$\tau(\lambda)=\beta\lambda^{-\alpha} \quad (1)$$

where β is the turbidity and α is the Angstom exponent (Liou,2002; O'Neill and Roer, 1993). The formula is derived on the premise that the extinction of solar radiation by aerosols is a continuous function of wavelength, without selective bands or lines for scattering or absorption (Ranjan et al., 2007). The wavelength dependence of τ(λ) can be characterized by the Angstron parameter, which is a coefficient of the following regression:

$$\ln\tau(\lambda) = -\alpha\ln(\lambda) + \ln\beta \quad (2)$$

The Angstrom exponent itself varies with wavelength, and a more precise empirical relationship between aerosol extinction and wavelength is obtained with a 2nd-order polynomial (King and Byrne, 1976; Eck et al., 1999; Eck. et al., 2001a, b,; Kaufman, 1993;O'Neill et al., 2001a, 2003; Pedros et al, 2003; Kaskaoutis and Kambezidis, 2006) as:

$$\ln\tau(\lambda)=\alpha_2(\ln\lambda)^2 + \alpha_1\ln\lambda + \ln\beta \quad (3)$$

Here, the coefficient α_2 accounts for a "curvature" often observed in sunphotometry measurements. In case of negative curvature ($\alpha_2<0$, convex type curves) the rate of change of α is more significant at the longer wavelengths, while in case of positive curvature ($\alpha_2 >0$, concave type curves) the rate of

change of α is more significant at the shorter wavelengths (Kaufman, 1993; Eck et al., 1999; Eck. et al., 2001b; Reid et al., 1999). Eck et al. (1999) reported the existence of negative curvatures for fine-mode aerosols and positive curvatures for significant contribution by coarse-mode particles in the size distribution. Schuster et al.(2006) reported that for $\alpha_2-\alpha_1<1$ aerosol size distributions are dominated by the coarse mode (>1 μm) aerosols. The occurrence of $\alpha_2-\alpha_1>2$ represents an aerosol size distributions dominated by fine mode (<1 μm) particles and when $1<\alpha_2-\alpha_1<2$ most of the aerosols are in the fine mode.

Now differentiating equation(2) with respect to lnλ we obtained

$$\alpha = -\frac{d(\ln\tau(\lambda))}{d(\ln(\lambda))} \quad (4)$$

Also differentiating equation (3) with respect to lnλ we obtained

$$\frac{d(\ln\tau(\lambda))}{d(\ln(\lambda))} = \alpha_1 + 2\alpha_2\ln(\lambda) \quad (5)$$

Assuming that equations (4) and (5) are evaluated at a wavelength, this implies we can substitute equation(4) into (5) to obtain

$$\alpha(\lambda) = -\alpha_1 - 2\alpha_2\ln(\lambda) \quad (6)$$

Equation (6) now shows the relationship between α and wavelength.

Also differentiating equation (6) with respect to lnλ we obtained

$$\alpha' = \frac{d\alpha}{d(\ln\lambda)} = -2\alpha_2 \quad (7)$$

Now equation (7) is the second derivative of equation (3) and demonstrates a measure of the rate of change of the angstrom constant (α) with respect to wavelength.

Substituting equation (7) into (6) we obtained

$$\alpha(\lambda) = -\alpha_1 + \alpha'\ln(\lambda) \quad (8)$$

This implies that the slope of α against lnλ signifies the rate of change of α with wavelengths and that positive slope signifies dominance of fine particles while negative for coarse particles.

We also proposed a quadratic relation of the form

$$\alpha(\lambda) = \alpha_{10} + \alpha_{11}\ln(\lambda) + \alpha_{12}\left(\ln(\lambda)\right)^2 \quad (9)$$

to determine whether α_{12} can get any importance like α_2 of equation3.

In this study, the values of Angstrom-parameters (α, α_1, α_2) and (α_{10}, α_{11}, α_{12}) were computed using equations (2) and (3), and (8) and (9) respectively at the spectral interval of 350 – 900nm not as 440–870nm by Kaskaoutis et al.,(2007a, b), due to the limitation of the available data.

RESULTS AND DISCUSSIONS

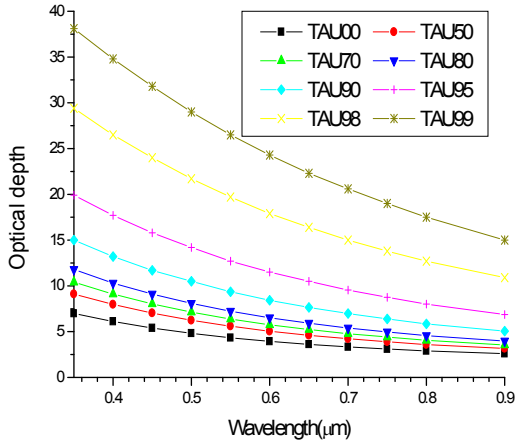

Figure 1: A graph of optical depth against wavelengths for Urban aerosols.

Figure 1 shows that optical depths follow a relatively smooth decrease with the increase in wavelengths though some are steeper than others and the steepness increases with the increase in RHs. It is evident from the figure that there is a relatively strong wavelengths dependence of optical depths at shorter wavelengths that decreases toward longer wavelengths irrespective of the RH, attributing to the presence of fine and coarse particles. The presence of fine mode particles which are selective scatters enhanced the irradiance scattering in shorter wavelength only while the coarse mode particles provide similar contributions to the optical depths at both wavelengths (Schuster et al., 2006). Additionally fine particles scatter more lights in the forward direction than coarse particles.

In relation to RH, it shows that optical depths increase with the increase in RH. As the RH increases the optical depths continue to increase due to the increase in concentration of fine mode particles as a result of the continue sedimentation of coarse particles due to the increase in RH. And also as the RH increases there is an increase in hygroscopic growth more to fine particles than coarse particles and these hygroscopic growth behaviors reveal an

immense potential of light scattering enhancement in the forward direction at high humidities more to fine particles and the potential of these fine particles to be more highly effective cloud condensation nuclei.
It also shows monomode type of particle size distributions in the form of Junge power law in this spectral range (Eck et al., 1999) and increase in RH has caused increase in mode growth because of the increase in optical depths. The increase of AOD with RH at the delequicence point (90 to 99%) is that the growth increase substantially, making the process strongly nonlinear with RH (Fitzgarald, 1975; Tang, 1996).

	Linear			Quadratic			
RH(%)	R^2	α	β	R^2	α_2	α_1	β
00	0.999601	1.06552	2.291297	0.999628	0.020296	-1.04208	2.302994
50	0.999483	1.13364	2.817726	0.999752	-0.06845	-1.21269	2.769748
70	0.999107	1.15298	3.168080	0.999802	-0.11200	-1.28232	3.080293
80	0.998627	1.16312	3.559424	0.999856	-0.15022	-1.33660	3.427766
90	0.997269	1.16233	4.580712	0.999909	-0.22020	-1.41662	4.334505
95	0.995366	1.13372	6.317457	0.999953	-0.28336	-1.46096	5.883908
98	0.992169	1.05646	10.19067	0.999982	-0.34518	-1.45509	9.345246
99	0.989666	0.98726	14.26292	0.999986	-0.37120	-1.41594	12.99454

Table 2a: the results of the Angstrom coefficients for Urban aerosols using equations (2) and (3) at the respective relative humidities using regression analysis with SPSS15 for windows.

Table 2a shows that at 0% RH the value of α from the linear part reflects the dominance of fine particles, but the quadratic part shows the dominance of coarse particles because $\alpha_2 > 0$. However as the RH increases from 50 to 80% the value of α continues to increase and α_2 becomes negative and the magnitude of α_2 continues to increase which indicates the increase in the concentrations of fine particles with the increase in RH.

At the RH between 90 and 99% the value of α started decreasing, which implies that particles at the delinquent points appear to be large particles, because of swelling of water vapor and aging processes, exhibiting thus similar characteristics to the particles produced in arid areas (Kaskaoutis et al., 2007a, b) but it can be observed that α_2 continued to increase, and this shows that at delinquent points increase in α_2 does not reflect increase in fine mode particles..

The correlations between the Angstrom exponent α and the differences $\alpha_2 - \alpha_1$

$$\alpha_2 - \alpha_1 = 0.859653\alpha + 0.184966 \qquad R^2 = 0.88833$$

Obviously the two parameters are strongly correlated, as indicated by correlation coefficient. This implies that the Angstrom exponent α can be approximated from the difference $\alpha_2 - \alpha_1$ as determined by (Schuster et al. 2006; Kaskaoutis et al., 2007a, b).,

	Linear			Quadratic			
RH(%)	R^2	α_1	α‘	R^2	α_{10}	α_{11}	α_{12}
0	1.00000	1.042081	-0.040590	1.00000	1.042081	-0.040590	2.22E-09
50	1.00000	1.212685	0.136899	1.00000	1.212685	0.136899	-4.6E-10
70	1.00000	1.282324	0.224004	1.00000	1.282324	0.224004	0
80	1.00000	1.336602	0.300441	1.00000	1.336602	0.300441	0
90	1.00000	1.416618	0.440394	1.00000	1.416618	0.440394	-1.1E-09
95	1.00000	1.460958	0.566728	1.00000	1.460958	0.566728	-3.3E-09
98	1.00000	1.455087	0.690355	1.00000	1.455087	0.690355	-6.9E-10
99	1.00000	1.415938	0.742405	1.00000	1.415938	0.742405	0

Table 2b:The results of the Angstrom coefficients using equation(6) and (9) for Urban aerosols at the respective relative humidities using regression analysis with SPSS15 for windows.

At 0% RH, the slope is negative, and this shows the dominance of coarse particles. But as the RH increases, there is an increase in the slope which indicates increase in the rate of change of the angstrom constant with RH. Comparing with the quadratic part, it can be observe that $\alpha_1 = \alpha_{10}$ and $\alpha' = \alpha_{11}$ to six places of decimals.

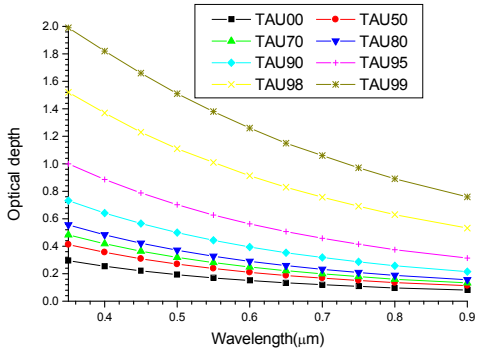

Figure 2: A graph of optical depth against wavelength for Continental Polluted aerosols.

Comparing figures 1 and 2, it can be observed that they are similar, though figure 1 has higher optical depth than figure 2.

	Linear			Quadratic			
RH(%)	R^2	α	B	R^2	α_2	α_1	β
0	0.996843	1.37761	0.072535	0.999882	-0.28006	-1.70103	0.067613
50	0.995881	1.38012	0.101381	0.999939	-0.32433	-1.75467	0.093458
70	0.995312	1.36803	0.120428	0.999950	-0.34383	-1.76510	0.110475
80	0.994798	1.35026	0.141720	0.999963	-0.35823	-1.76397	0.129538
90	0.993661	1.30148	0.197084	0.999975	-0.38200	-1.74263	0.179072
95	0.992157	1.22822	0.291376	0.999984	-0.40166	-1.69207	0.263443
98	0.989717	1.10892	0.501702	0.999988	-0.41594	-1.58927	0.451985
99	0.987510	1.02200	0.723095	0.999989	-0.42300	-1.51049	0.650285

Table 3a: the results of the Angstrom coefficients for Continental polluted aerosols using equatins (2) and (3) at the respective relative humidities using regression analysis with SPSS15 for windows

Table 3a. shows that the values of α and α_2 indicate the dominance of fine mode particles, and as the RH increases α_2 continues to become more negative which indicates increase in the concentrations of fine particles. However at the deliquence point (70 to 99%) α started decreasing and this shows that different particles have different behavior at the delinquent point as compared to urban. As the RH increases the value of α stated decreasing as from

70%, which implies that particles are becoming quite large in size, because of swelling of water vapor and aging processes, exhibiting thus similar characteristics to the latter particles produced in arid areas (Kaskaoutis et al., 2007a, b). This implies a decrease in the α value indicates the relative increase in the amount of bigger particles, and in the hygroscopic growth of particles as a result of increase in relative humidities. It also shows a trend of increasing α_2 with RH, and this indicates increase of curvature with the increase in RH.

The correlations between the Angstrom exponent α and the differences $\alpha_2 - \alpha_1$

$$\alpha_2 - \alpha_1 = -0.95256\alpha + 0.116806 \qquad R^2 = 0.999035$$

Obviously the two parameters are strongly correlated, as indicated by correlation coefficient. This implies that the Angstrom exponent α can be approximated from the difference $\alpha_2 - \alpha_1$ as determined by (Schuster et al. 2006; Kaskaoutis et al., 2007a, b).

Table 3b:The results of the Angstrom coefficients using equations(6) and (9) for Continental Polluted aerosols at the respective RHs using regression analysis with SPSS15 for windows.

	Linear			Quadratic			
RH(%)	R^2	α_1	α‘	R^2	α_{10}	α_{11}	α_{12}
0	0.999999	1.701035	0.560035	0.999999	1.700826	0.559073	-0.00083
50	0.999999	1.754672	0.648571	0.999999	1.754430	0.647457	-0.00096
70	0.999999	1.765107	0.687567	0.999999	1.764850	0.686386	-0.00102
80	0.999999	1.763969	0.716364	0.999999	1.763702	0.715133	-0.00107
90	0.999999	1.742627	0.763884	0.999999	1.742342	0.762572	-0.00114
95	0.999999	1.692074	0.803196	0.999999	1.691775	0.801816	-0.00119
98	0.999999	1.589269	0.831757	0.999999	1.588959	0.830329	-0.00124
99	0.999999	1.510501	0.845881	0.999999	1.510185	0.844428	-0.00126

The values of α’ are positive throughout and it increases with the increase in RH, which indicates that increase in hygroscopic growth causes the curvature to increase despite the fact that α decreases for fine particles at higher RHs. The quadratic part shows that the relation of α and lnα can be non-linear.

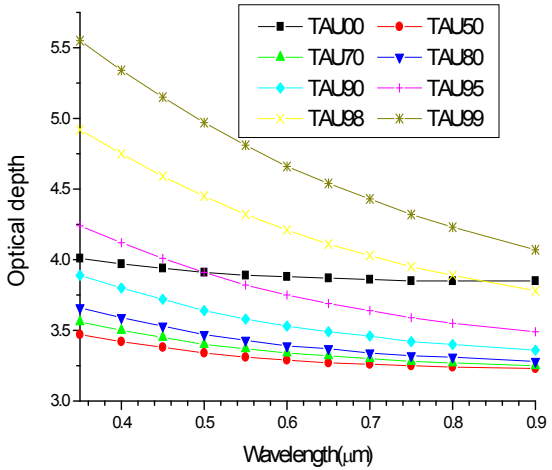

Figure 3: A graph of optical depth against wavelength for Saharan aerosols.

The nature of the graphs in figure 3 shows that the graph of 0% RH reflects the dominance of coarse particles this is because it looks like a horizontal straight line. As the RH increased to 50% the optical depth decreased. This is because the increase in RH has caused some of the bigger coarse particles to sediment. As the RH continues to increase, the optical depths also continued to increase because of the hygroscopic growth of the remaining fine particles. The nature of the plots as from 50 is similar to figures 1 and 2 except that the optical depth is smaller.

	Linear			Quadratic			
RH(%)	R^2	α	β	R^2	α_2	α_1	β
0	0.926290	0.04314	3.807827	0.998068	0.04417	0.007864	3.850243
50	0.966011	0.07965	3.172490	0.999136	0.054249	-0.01701	3.215949
70	0.975408	0.09892	3.190355	0.999316	0.056963	-0.03314	3.236261
80	0.981394	0.11794	3.211925	0.999415	0.058787	-0.05006	3.259632
90	0.989707	0.15904	3.271963	0.999479	0.058130	-0.09192	3.320014
95	0.995511	0.21141	3.382511	0.999511	0.049293	-0.15449	3.424587
98	0.99928	0.28622	3.645238	0.999518	0.016216	-0.26750	3.660093
99	0.999302	0.33309	3.931732	0.999557	-0.01958	-0.35569	3.912477

Table 4a: the results of the Angstrom coefficients for Saharan aerosols using equations (2) and (3) at the respective relative humidities using regression analysis with SPSS15 for windows.

Table 4a shows the value of α that reflects the dominance of coarse particles, which is also confirmed by α_2 being positive. But as the RH increases, we noticed increase in α which indicates increase in the concentration of fine particles. But at the RHs 90 to 99%, we noticed a decrease in curvature which shows increase in the dominance of fine particles and finally at 99 α_2 becomes negative which shows the dominance of fine particles. This is because at these points the bigger particles because of their sizes and densities have sedimented leaving mostly water soluble, which are very hygroscopic.

The correlations between the Angstrom exponent α and the differences $\alpha_2 - \alpha_1$

$$\alpha_2 - \alpha_1 = 1.034147\alpha - 0.01183 \qquad R^2 = 0.999457$$

Obviously the two parameters are strongly correlated, as indicated by correlation coefficient. This implies that the Angstrom exponent α can be approximated from the difference $\alpha_2 - \alpha_1$ as determined by Schuster et al. (2006).

	Linear			Quadratic			
RH(%)	R^2	α_1	α'	R^2	α_{10}	α_{11}	α_{12}
0	0.999999	-0.00786	-0.08833	0.999999	-0.00783	-0.08818	0.000131
50	0.999999	0.017005	-0.10848	0.999999	0.017045	-0.10830	0.000161
70	0.999999	0.033144	-0.11391	0.999999	0.033186	-0.11371	0.000169
80	0.999999	0.050063	-0.11756	0.999999	0.050106	-0.11736	0.000175
90	0.999999	0.091922	-0.11624	0.999999	0.091965	-0.11604	0.000173
95	0.999999	0.154492	-0.09857	0.999999	0.154529	-0.09840	0.000147
98	0.999999	0.267498	-0.03243	0.999999	0.267510	-0.03237	4.82E-05
99	0.999999	0.35569	0.039146	0.999999	0.355676	0.039079	-5.8E-05

Table 4b:The results of the Angstrom coefficients using equation(6)and (9) for Desert aerosols at the respective RHs using regression analysis with SPSS15 for windows.

From the linear part, the slope is negative from 0 to 98% RH and this indicates the dominance of coarse particles, but at 99% it becomes positive, which is a sign for fine mode particles. The quadratic part shows that the relation of α and lnα can be non-linear.

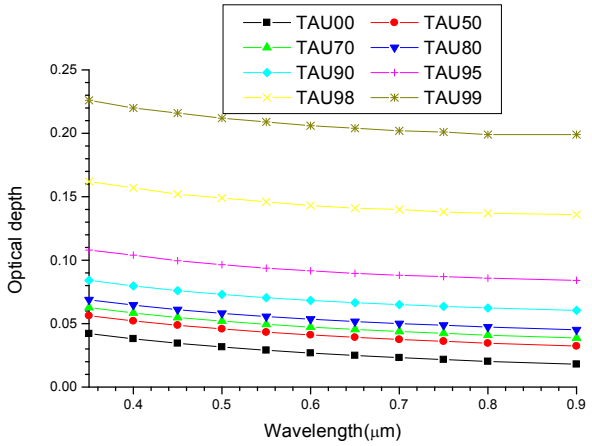

Figure 4: A graph of optical depth against wavelength for Maritime tropical aerosols.

Figure show that optical depths follow a relatively very small decrease with the increase in wavelengths for all the graphs. This reflects the dominance of coarse mode particles.

In relation to RH, the figure shows that optical depths increase with the increase in RH, but it can be seen that the sloping with respect of wavelengths is decreasing. This also indicates the increase in the dominance of coarse mode particles and increase in coarse mode size distributions.

	Linear			Quadratic			
RH(%)	R^2	α	β	R^2	α_2	α_1	β
0	0.997661	0.90175	0.01671	0.999953	-0.15915	-1.08555	0.016056
50	0.999939	0.58858	0.030403	0.999959	-0.01165	-0.60203	0.030315
70	0.999693	0.51009	0.036523	0.999919	0.028259	-0.47746	0.036783
80	0.999038	0.44804	0.042723	0.999950	0.049863	-0.39046	0.043261
90	0.995493	0.35367	0.057431	0.999944	0.087066	-0.25312	0.058700
95	0.988304	0.27071	0.080439	0.999035	0.103861	-0.15077	0.082563

98	0.978262	0.19156	0.130971	0.997975	0.100121	-0.07594	0.134303
99	0.973551	0.14083	0.193038	0.996712	0.079979	-0.04847	0.196951

Table 5a: the results of the Angstrom coefficients for Maritime tropical aerosols at the respective RHs using regression analysis with SPSS15 for windows

Table 5a. the value of α at 0% RH looks like the dominance of coarse particles, but the value of α_2 indicates the dominance of fine particles. Another surprise is that as the RH increases to 50% the value of α decreases but the curvature is still negative, though it decreases in magnitude. As the RH increased to 70% and subsequently up to 99%, α continued to decrease with RH and the positive value of α_2 also continued to increase indicating the continued increase in coarse particles. But at 98 to 99 RHs the values of α_2 started decreasing despite the fact that α continued to decrease. This is because once the sea salts are released into the atmosphere, they are subject to transport, dry deposition, gravitational settling, and wet deposition. Because of their relatively large sizes and fast growth with ambient relative humidity, sea salt particles are removed quickly from the atmosphere with an averaged lifetime of 0.6 days (Chin et al., 2002).

The correlations between the Angstrom exponent α and the differences $\alpha_2 - \alpha_1$

$$\alpha_2 - \alpha_1 = 1.051889\alpha - 0.02747 \qquad R^2 = 0.999694$$

Obviously the two parameters are strongly correlated, as indicated by correlation coefficient. This implies that the Angstrom exponent α can be approximated from the difference $\alpha_2 - \alpha_1$ as determined by Schuster et al. (2006).

	Linear			Quadratic			
RH(%)	R^2	α_1	α‘	R^2	α_{10}	α_{11}	α_{12}
00	0.999999	1.085551	0.318263	0.999999	1.085432	0.317716	-0.00047
50	0.999999	0.602032	0.023299	0.999999	0.602023	0.023259	-3.5E-05
70	0.999999	0.477455	-0.05651	0.999999	0.477476	-0.05641	8.41E-05
80	0.999999	0.390456	-0.09971	0.999999	0.390493	-0.09954	0.000148
90	0.999999	0.253118	-0.17411	0.999999	0.253183	-0.17381	0.000259
95	0.999999	0.150765	-0.20769	0.999999	0.150843	-0.20734	0.000309
98	0.999999	0.075939	-0.20021	0.999999	0.076014	-0.19987	0.000298
99	0.999999	0.04847	-0.15993	0.999999	0.04853	-0.15966	0.000238

Table 5b:The results of the Angstrom coefficients using equation(6) and (9) for Marine tropical aerosols at the respective RHs using regression analysis with SPSS15 for windows.

From the linear part, at 0 and 50% RHs, the slope is positive which indicates fine particles, but as the RH increases it becomes negative, which implies coarse particles. The quadratic part shows that the relation of α and lnα can be quadratic.

CONCLUSIONS

From our observations we discovered that the discrimination of aerosols with respect to curvatures α_1 and α_2 is very difficult. This is because for example in urban model at 0% RH $\alpha > 1$ but α_2 is positive while for marine at 0 and 50% RH and Sahara models at 99% RH $\alpha<1$ but both α_1 and α_2 are negatives. However between RHs 70 to 98 α_2 can be use to discriminate because α_2 is negative for urban and continental and positive for sahara and marine models. Therefore as we discovered as also as stated by Schuster et al. (2006) that, curvature can be used to improve the information about aerosol size distributions but with the addition the dependency of RH.

Also as stated by Kaskaoutis et al 2007a, b, that large negative α_1 and α_2 values correspond to biomass-burning or urban/industrial fine-mode aerosols (Alta Floresta and Ispra, respectively), while positive α_2 and near zero or positive α_1 values are indicative of large particles (desert dust, sea salt for Solar Village and Nauru, respectively), but in our models, the urban and continental are the same as theirs, but for sahara and marine there are some discrepancies because α_1 is negative. So it can be concluded that only α2 that can be used to discriminate aerosols.

Additionally in our sahara model at 0% RH, we have positive α_1 value accompanied by positive curvature, which is already stated by Schuster et al. (2006), that it can be theoretically derived for very low fine fraction ($\alpha \leq 0.3$).

Also according to Schuster et al. (2006), the absolute value of the coefficient α_1 decreases with increasing particle size for fine monomodal aerosols, but in our case it is observed that α_1 increases with the increase in RHs for sahara and marine which are coarse particles, while for urban it increases from 0 to 95 but decreases at 98 and 99 and in continental it increases from 0 to 80 but decreases from 90 to 99. So in our own case it can be concluded that sahara and marine aerosols are coarse monomodal while urban and continental are bimodal.

The low values of the Ångström coefficients at delinquent points can be closely related to the higher hygroscopic growth factor of pollution aerosols under high relative humidity. There is observational evidence that Ångström exponents decrease in value as particles grow hygroscopically (Carrico et al., 1998; Kuśmierczyk-Michulec, 2009).

Consequently, the assertion $\alpha=\alpha_2-\alpha_1$ can be considered as valid. These findings are in agreement with Schuster et al. (2006) reporting that $\alpha=\alpha_2-\alpha_1$ can be considered as valid for bimodal size distributions with similar contribution from fine-and coarse-mode having $0.8< \alpha<1.3$ (Eck et al., 1999, 2005) though from our findings, we discovered that is more accurate for monomodal because they have higher R^2 compared to bimodal.

Finally we determine shows the relationship between α and wavelength as

$$\alpha(\lambda) = -\alpha_1 - 2\alpha_2 \ln(\lambda)$$

where α_2 and α_1 are coefficients of the second order polynomial which depend the type of aerosol. From the second order polynomial as proposed, we discovered that α_2 and α_{12} have the same sign but $\alpha_2 \gg \alpha_{12}$ in magnitude, so the sign of α_{12} can also be used to discriminate between aerosols as α_2.

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