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Inferring Angstrom Exponent and Aerosol Optical Depth from AERONET

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ABSTRACT

We present optical analysis of aerosol from September-November 2012, include aerosol optical depth, Angstrom exponent numbers and related parameters of the fine modes derived from ground-based measurements of AERONET. This project is part of the collaboration with the National Aeronautics and Space Administration (NASA) and Universiti Sains Malaysia (USM), Penang in Distributed Regional Gridded Observation Network (DRAGON) campaign which is an initiative to measure and study the regional aerosol. This research was located at Universiti Teknologi MARA (UiTM) Penang and is expected to provide further insight on the characteristics of regional aerosol optical environment in terms of particle size distribution and optical depth.

Key words: Aerosol, AERONET, angstrom exponent, optical depth

INTRODUCTION

AERONET is a global network for automatic sun photometer, which accounted for global data collection for spectral aerosol optical thickness and aerosol microphysical properties (Holben *et al.*, 1998). AERONET has been widely used as a standard option for comparison and verification of the results of the measurement using satellite aerosol. Aerosol optical depth (AOD or τ_a), which is an integral atmospheric extinction coefficient of the surface to the upper atmosphere, is an important and useful parameter to study the incidence of visual deterioration (due to atmospheric pollution), solar radiation extinction, climate effects and rectification troposphere the remote sensor (Dubovik *et al.*, 2002). Aerosol Optical Depth (AOD) is a quantitative measurement of the extinction of radiation by aerosol scattering and absorption between the observation point and the top of the atmosphere. AOD value measurements derived from active or passive satellite has relatively low accuracy in the ocean, vegetated land, deserts and urban areas. AOD is a unique parameter to determine the atmospheric aerosol load using ground-based equipment, which is the easiest, most precise monitoring and easy to operate and maintain the system (Holben *et al.*, 2001). Good understanding of the spectral dependence of AOD is essential to properly model the effects of aerosols on the radiation budget of Earth's atmosphere or to accurately measure the aerosol optical parameters of readings from satellite remote sensing (Eck *et al.*, 1999). AOD wavelength dependence is according to differences in aerosol because of disparities in the physical characteristics and chemical. A value at different wavelengths region is a very useful tool to distinguish and characterize aerosol type.

Radiation from the sun, when it hits the surface of the earth, whether reflected by the surface, sent to the surface or absorbed and emitted by the surface. Electromagnetic radiation interaction, experience some change in the magnitude, direction, wave polarization and phase. These changes can be detected by using the remote control sensor and allows interpreters to obtain useful information about the object of interest. Remotely sensed data has spatial information (size, shape and orientation) as well as spectral information (tone, colour and spectral signatures). It has being a useful tool for measuring the value of AOD in the entire shortwave spectrum. Dust and smoke particles interacting with a shorter wavelength and will reflect light back to the sensor while the larger dust will interact with infrared wavelengths (Kaufman and Nakajima, 1993). For measurements of optical thickness $\tau_{\lambda 1}$ and $\tau_{\lambda 2}$ taken at two different wavelengths λ_1 and λ_2:

$$\alpha = -\frac{\ln -\frac{\tau\lambda_1}{\tau\lambda_2}}{\ln \frac{\lambda_1}{\lambda_2}}$$

The value of Angstrom exponent (a) is also a qualitative indicator for the size of aerosol particles or fine mode fraction. In addition, there is also a relationship between these parameters with aerosol size distribution (Schuster *et al.*, 2006). For example, the value of a has been used to characterize biomass burning aerosols in South America and Africa (Eck *et al.*, 2001; Reid *et al.*, 1999), measuring the distribution and characteristics of urban aerosols (Eck *et al.*, 1999; Kaskaoutis and Kambezidis, 2006), the maritime component of aerosol in the islands (Smirnov *et al.*, 2003) and desert-dust aerosols in the Sahara and East Asia (Masmoudi *et al.*, 2003).

The usage of Angstrom exponent a has increased significantly lately, because this parameter can be estimated by using the automatic sun photometry and it is located at the surface (Schuster *et al.*, 2006). Angstrom parameters calculated from the AOD at wavelengths measured by the AERONET. Overall uncertainty in AOD data, in cloud-free situation, is ±0.01 for λ>440 nm and ±0.02 for shorter wavelengths. Errors in the amount of aerosol size distribution is estimated to ~15-25% of the radius between 0.1 and 7 μm (Dubovik *et al.*, 2002; Dubovik and King, 2000). AOD can be evaluated by the parameter called Angstrom exponent. Angstrom exponent (noted as a and also named Alpha) can be obtained from the spectrum AOD using Angstrom power law (Angstrom, 1964; Cachorro *et al.*, 1987, 2000):

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

In this study, the data set level version 2.0, was used. This is because the version of the Level 2.0 data is data that has been through a cloud filtering procedure to remove data that has been contaminated by clouds. It also has a quality assured data because it goes through the end of the calibration standards set after the measurement campaign (Holben *et al.*, 1998).

MATERIALS AND METHODS

The sun photometer performs two basic measurements, either direct sun or sky, both in some sequences that were programmed automatically. Measurements are made in eight spectral bands, namely 340, 380, 440, 500, 670, 870, 940 and 1020 nm, where it takes about 10 sec. Direct measurement sky were on the spectral bands 440, 670, 870 and 1020 nm as well as perform two basic sky observation sequence of "almucantar" and "principal plane" (Holben *et al.*, 2001). Measurement at 940 nm spectral bands is used specifically for water column abundance.

Fig. 1: Map showing the location of AERONET located in UiTM Penang (Lat: 5N, Long: 100E). Map courtesy of Google Earth©

Fig. 2: AERONET installed on the roof of the academic block (BKBA) UiTM Penang. Map courtesy of Google Earth©

Beer-Lambert-Bouger used as the basis for calculating the optical depth of the water column where it is calculated from the extinction of direct beam radiation spectrum at each wavelength.

Aerosol optical depth (AOD or τ_a) at wavelengths is one of the standard parameters that can be derived from total columnar atmospheric optical depth as measured by the sun photometer from AERONET. AOD can be obtained by making a correction to the optical depth for attenuation due to Rayleigh scattering, absorption by ozone and gas pollutants. In direct sun measurements uncertainty values were within ±0.01 for the longer wavelengths (longer than 440 nm) and ±0.02 for shorter wavelengths (Holben *et al*., 1998; Eck *et al*., 1999). These data were analysed to measure aerosol columnar volume size distribution, phase function and single-scattering albedo through the following methods that have been shown by Holben *et al*. (1998) and Dubovik and King (2000) which is also known as "inversion method". AOD and the first and second spectral derivative with respect to wavelength λ is used to describe the relationship between the load and the size of aerosol particles. Angstrom exponent number (AE or α) gives an average aerosol measurement of dimensions in the sub-micrometre range and super-micrometre particle size (Angstrom, 1929). Moreover, the second derivative, the derivative AE (α') provide a good overview of the particle size regime as shown in Fig. 1 to 3.

Fig. 3: AERONET sun photometer placed on the roof of the academic building at UiTM Penang

RESULTS AND DISCUSSION

The basic methodology for detecting electromagnetic radiation is clear that based on the knowledge that everything in nature has its own unique distribution of reflected, transmitted and absorbed radiation. If these spectral features exploited wisely, it can be used to separate one thing from another or to obtain basic information about the shape, size and other physical characteristics and chemistry. Dust particles have a combination of clay, quartz and hematic possess strong absorption in the blue spectral wavelength (440 nm) with a low absorption in the visible and infrared wavelengths (Sokolik and Toon, 1999). For fine mode particles (r<1.0 mm), hygroscopic aerosol particles (e.g., sulphate) have negligible spectral dependence and high dispersion (Dubovik *et al.*, 2002). Particulate Black Carbon (BC) has the strongest absorption in near-infrared, while aerosols consisting of brown carbon (BRC) or Organic Carbon (OC) possess strong absorption in the ultraviolet and visible band (Eck *et al.*, 2009). The exploitation of the different parts of the electromagnetic spectrum, the development of sensor technology, the use of spacecraft platform for remote sensing, the emphasis on the use of spectral features compared to spatial information, advances in image processing and automatic image analysis in addition to interpretation manually are some comparisons between the characteristics of conventional aerial photography with modern remote sensing systems.

Angstrom exponent has an inverse relationship associated with the average size of the particles in the aerosol that is when the smaller the particle size, the greater the exponent. Thus, the Angstrom exponent is a quantity which is very useful and important for assessing the size of atmospheric aerosol particles or cloud and the dependence of the optical properties of aerosols waves or clouds. For example, for droplets, cloud droplets usually have a large size and then, very small Angstrom exponent (a almost approaching zero) and is spectrally neutral, which means, for example, the optical depth does not change with wavelength. Exponent is now routinely estimated

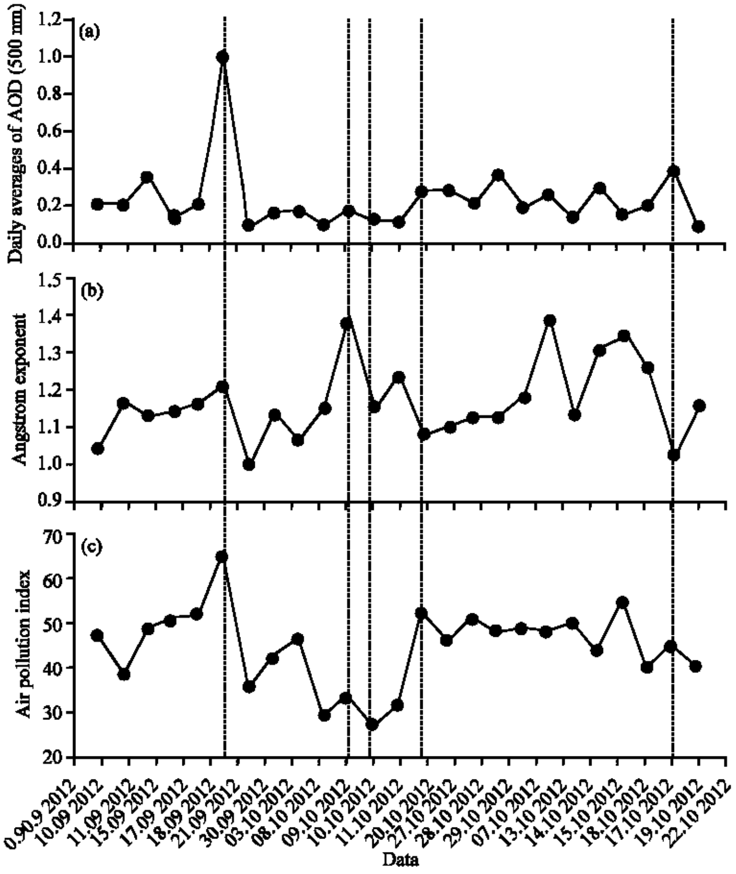

Fig. 4(a-c): Daily series of (a) AOD, (b) Angstrom exponent and (c) Air pollution index

by analysing the measured value of radiation in Earth Observation platforms, such as aerosol robotic network, or AERONET.

Figure 4a shows the average values of AOD during this study. AOD time series show high aerosol loadings between the 3rd weeks of September which showed high peak AOD. On 18 September, AOD showed the highest value approaches the value of 1.0. Comparison with the Air Pollution Index (API) from the Department of Environment (DOE) Malaysia shows that the API reached the highest value even at that date. This gives an indication that AOD influence API. On 10 October, the API has given the lowest value among the whole day during the three month period. It can be regarded as the cleanest air on the API that has been measured. In comparison, AOD also showed a low reading of $0.1 < \tau_a < 0.2$ at the date referred to. API value has increased significantly during the Oct 20 until it reaches±50. The escalation can also be seen at the AOD on that date although the rise is not so great on display. Angstrom exponent also gives an indication of the type of aerosol. Take a day as an example, namely on October 9, the value of the Angstrom exponent has the highest value toward the value 1.4. This gives an indication of the type of aerosol distribution on the day that can be said is dominated by fine-mode particles.

The rain rate is found to have significant impact on AOD, aerosol size and its characteristics (Saha and Krishna Moorthy, 2004). Malaysian Meteorological Department, Ministry of Science, Technology and Innovation (MOSTI) has reported that Malaysia has experienced inter-monsoon season begins in mid-September 2012. Generally, normal rainfall was recorded at most stations.

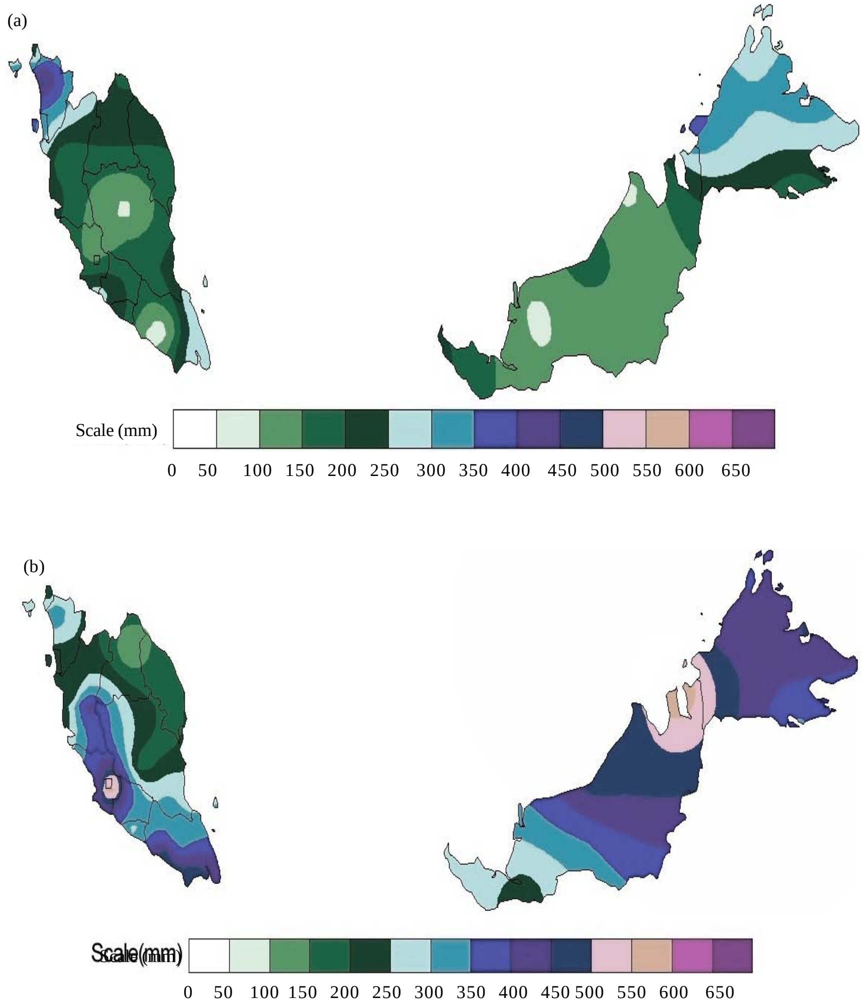

Fig. 5(a-b): Rainfall map of Malaysia, (a) September 2012 and (b) November 2012. Credit to: Malaysian Meteorological Department

The dry weather has been experienced in some areas, particularly in parts of the west coast of Peninsular Malaysia. Total solar radiation, temperature and evaporation rate recorded somewhat higher than the long term average in most locations. Almost all areas in Malaysia recorded the temperature is higher than the long-term monthly temperature. The Malaysian Meteorological Department has also been reported that in November 2012, the Northeast Monsoon season has started since October 22, 2012, bringing wet weather conditions in the states west coast. Dry weather conditions have also been experienced in the eastern coast of the peninsula. The total solar radiation, temperature and evaporation recorded somewhat higher than the long term average in the majority. Almost all regions of the country recorded the temperature is higher than the long-term monthly temperature.

Measurement of air pollution in certain areas by using the synergy analysis for AOD (τ) and Angstrom exponent (α) is an effective method for analysing the density and size of aerosol distribution. Figure 5 also shows that most of the data accumulated overlap between $1.0 <\alpha< 1.4$ and $0.05<\tau_a<0.4$. Majority of the aerosols in the period under review are type of fine mode particles

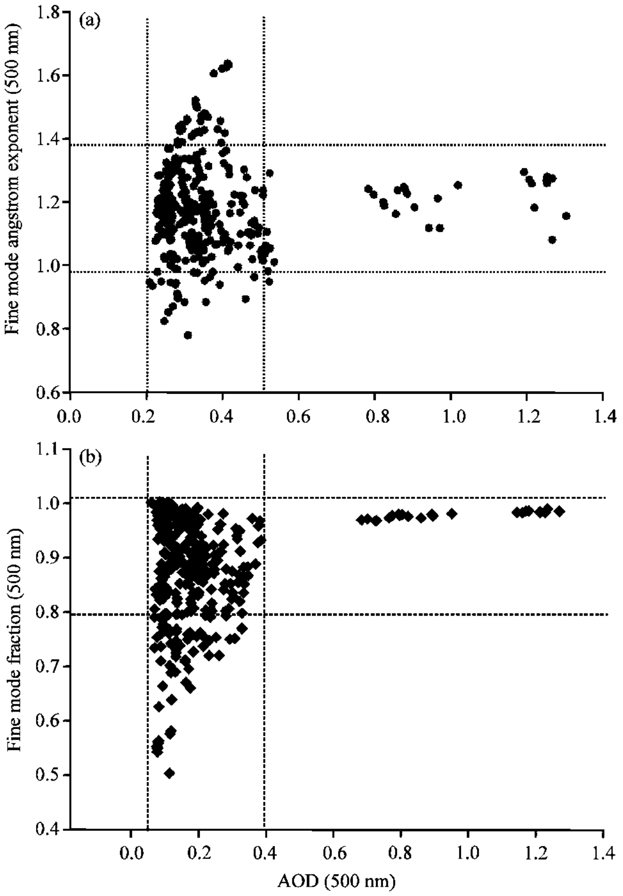

Fig. 6: Fine mode fraction vs. fine mode AOD

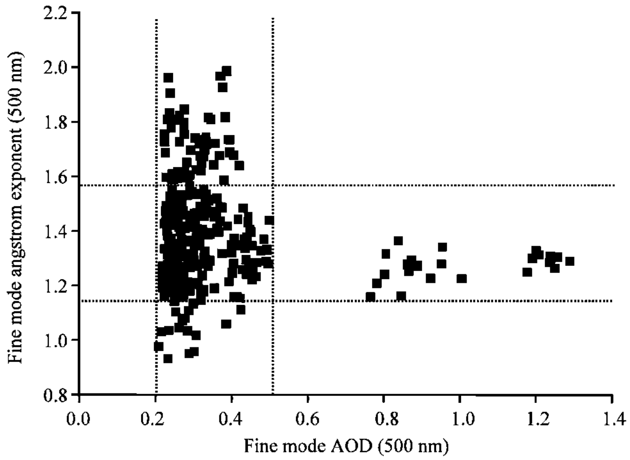

Fig. 7: Fine mode angstrom exponent vs. fine mode AOD

which can be ascertained by reference to Fig. 6 that indicates the fine mode fraction (η) is higher than 0.7 (η>0.7). Figure 6 also demonstrates the majority of the plot points located between 0.8<η<1.0 and $0.05<\tau_f<0.4$. Fine mode fraction is the ratio of fine particles to the number of particles detected. In addition, most of the detected aerosol have been in the low value of AOD ($\tau_a<0.4$). This is reinforced by Fig. 7 which exhibit improved results that showed a high density of fine mode AE

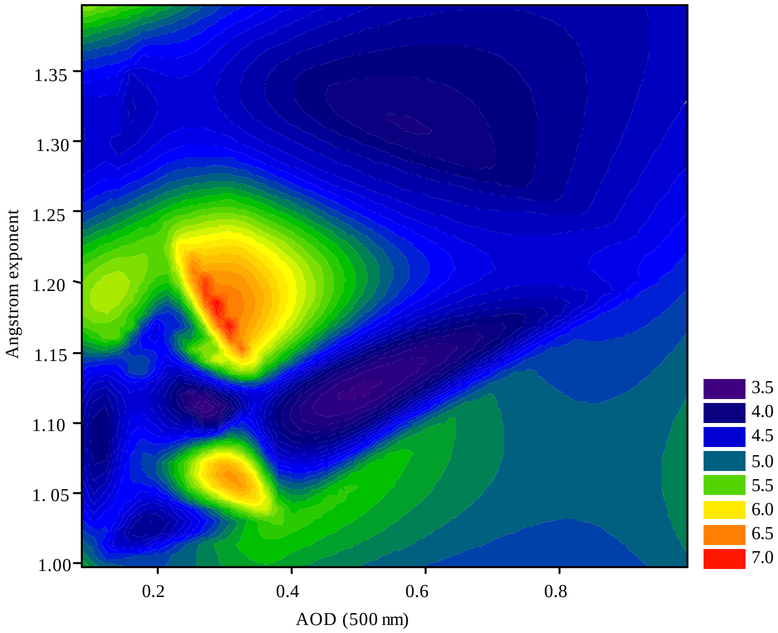

Fig. 8: 3-D contour map

($1.1<\alpha_f<1.5$) at low AOD ($\tau_a<0.4$). No negative fine mode AE worth particles ($\alpha_f<0$) was found, which indicates the presence of particles due to dust course mode can be neglected. Most of the types of aerosol particles in the sample area are mostly from typical urban and fossil fuels.

Further analysis using 3-D simulation plot of the relation between angstrom exponent and AOD on the duration and location of the study found that the most AOD lies between 0.2 and 0.4 ($0.2<\tau_a<0.4$) as shown in Fig. 8. Referring to Angstrom exponent, the majority of values were located between.1.14 and 1.22 ($1.14<\alpha<1.22$). All angstrom exponent values indicate positive values ($\alpha>0$) which give an indication that the aerosol loading during the study period was the fine mode aerosols. High AOD values and angstrom exponent rather low values suggest a link with dust aerosols, while, for the AOD and angstrom exponent values are also high in both show that aerosols arise from anthropogenic sources. This gives a very clear statement on visualization and qualitative that the air quality of the study area during the period of monitoring is clean with low aerosol loading and size distributions dominated by fine-mode aerosols ($r<1$ μm).

AE derivative (α') of the second derivative is a good indicator of particle size regime. The AE derivative value that is large and positive is a feature to show the fine mode dominated aerosol particle size distribution. Whereas, for negative values of AE derivative shows the characteristic course dominated mode or bimodal particle size distribution has a strong influence of coarse mode (Eck *et al.*, 1999). From Fig. 9, the three-month study done of September, October and November 2012, shows that the majority of the readings have values of the ratio $\eta>0.75$ and this confirms that the aerosol measured during the study consists of pure fine mode events. Referring to the low value of AOD (Fig. 5), aerosol sources were likely derived from fossil fuel combustion from motor vehicles and urban sources.

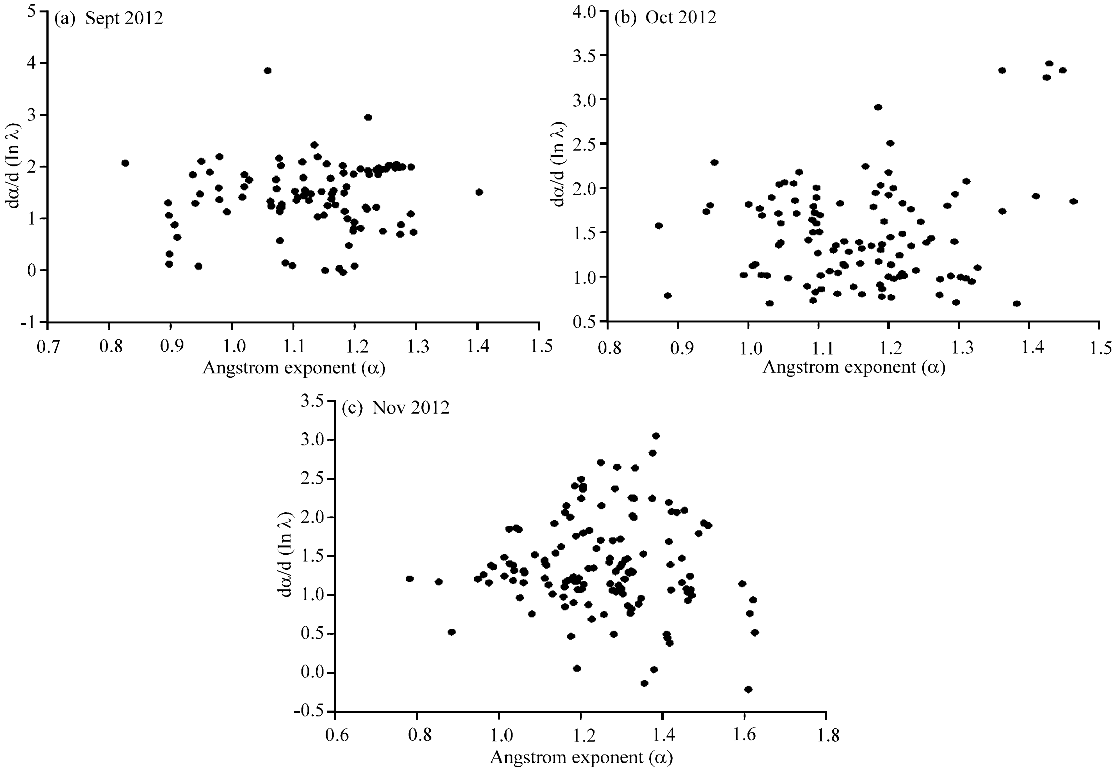

Fig. 9(a-c): Fine mode classification on an (a, a') grid for the three months (a) Sept, (b) Oct and (c) Nov 2012

CONCLUSION

This study uses a NASA project called the Distributed Gridded Aerosol observational Regional Network (DRAGON) involving UiTM Penang as one of the study locations with AERONET instrumentation placement from September to November 2012. Generally, throughout the study period, the air quality in UiTM Penang showed good quality with low aerosol loadings. From the analysis of the relevant parameters, it can be concluded that the bulk and the majority of aerosols suspended in the study location is fine mode particles. Further analysis to separate the fine mode particles resource type shows that it is derived from the burning of fossil fuels such as motor vehicle emissions and other urban pollution sources.

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