CHAPTER IV

RESULTS AND DISCUSSIONS

This chapter described the outputs and results of this study which consisted of data selection, analysis of time variation of AOT, Angstrom exponent and aerosol volume size distribution data. Also, the analyses on the variation of AOT and meteorological data as well as PM10 Time Series were in this chapter.

4.1 Data Selection

The daily average AOT data of level 1.5, which were the data without calibration and quality assurance, were analyzed for appropriate data prior to using in this study. The criterions of data selection were as follows;

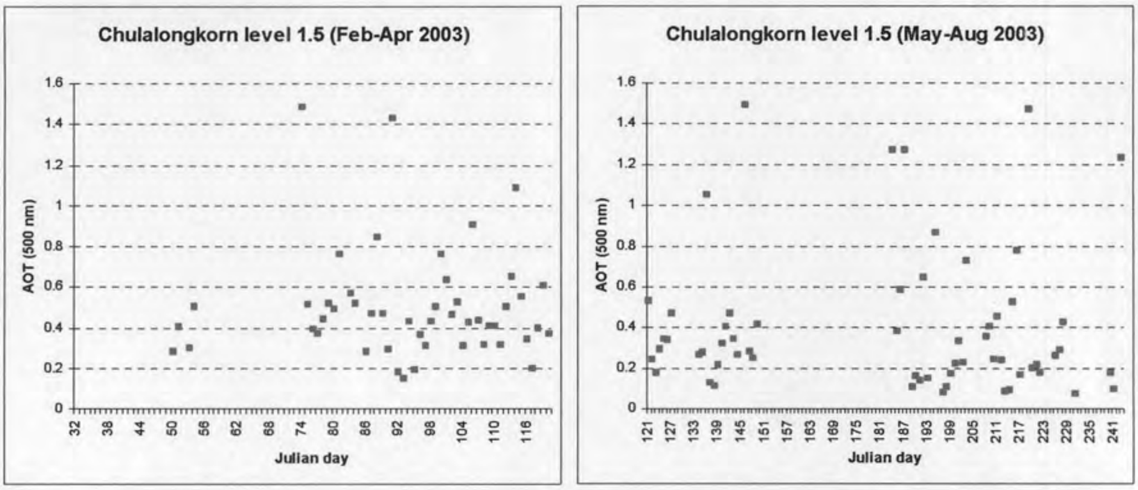
- The data with period of measurement longer than 45 second

- The data should not be unusual high values. The data values were not higher than two standard deviations. In addition to, Esposito et al (2004) suggested that the high values were resulted from cloud.

The data selection was conducted with the daily average AOT data from 5 AERONET sites. The analyzed data and the available AOT data of level 2 were analyzed for linear relationship. It was found that the two data set were almost the same with high correlation coefficient. Both data and their correlation at Chulalongkorn site have been shown on figure 4.1 and 4.2.

4.2 Analysis of Time Variation of AOT, Angstrom Exponent and Aerosol Volume Size Distribution Data

The analysis of variation with time of daily average AOT and Angstrom exponent at Chulalongkorn site were carried on by using the whole period of data during February



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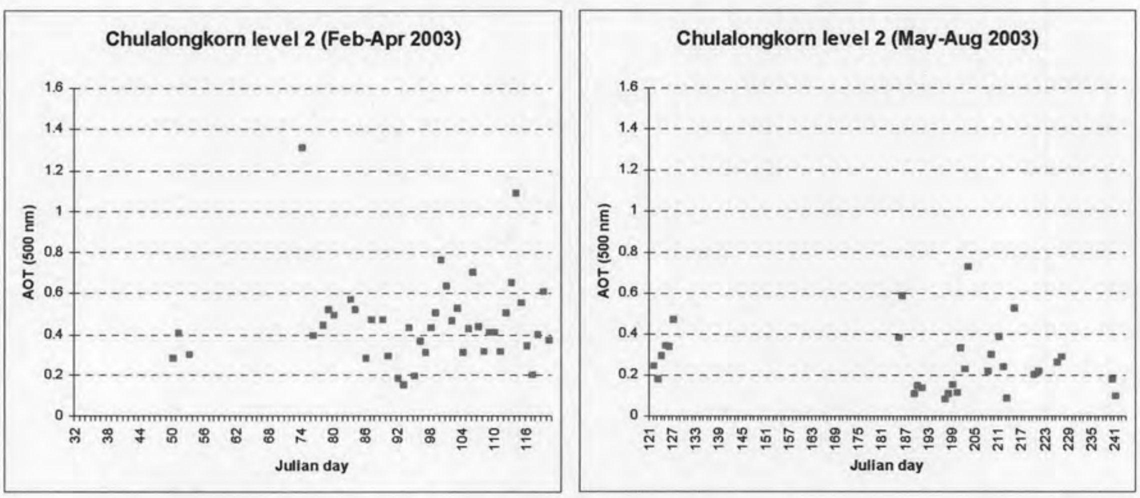

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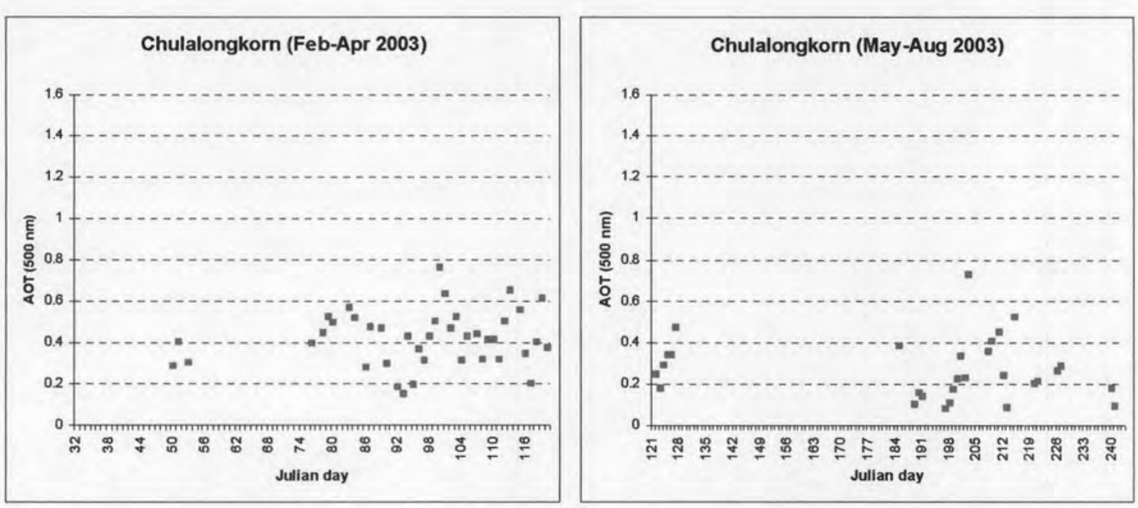

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Figure 4.1 Daily average value of AOT at 500 nm at Chulalongkorn site (a) level 1.5 (b) level 2 (c) the analyzed data.

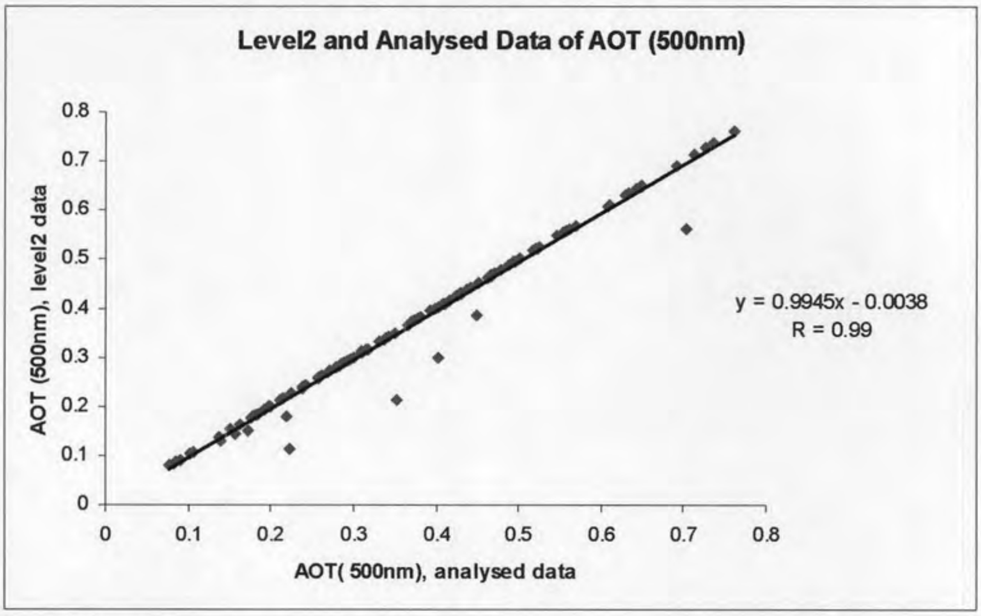


Figure 4.2 Correlation between the analyzed AOT data and the level 2 AOT data at Chulalongkorn site.

2003 - September 2004, except May - June 2003, September 2003 – January 2004 and June 2004 due to a stopped observation and calibrated instrument periods. In addition, the derived data were not continuously period with missing in someday due to cloud condition as shown on figure 4.3 and 4.4.

The daily average values of AOT at 500 nm on figure 4.3 showed that there was a very large day-to-day variation. And also, the annual pattern showed the mostly high values during February to April and October to November with the mostly values were above 0.4. This was summarized that those periods of mostly high turbidity by aerosol existed in the atmosphere because there was amount of less rainfall to remove aerosols.

In Figure 4.4 the daily average values of Angstrom exponent were mostly high in the same periods of the mostly high value of the AOT. During July to August the Angstrom exponent were mostly relatively low.

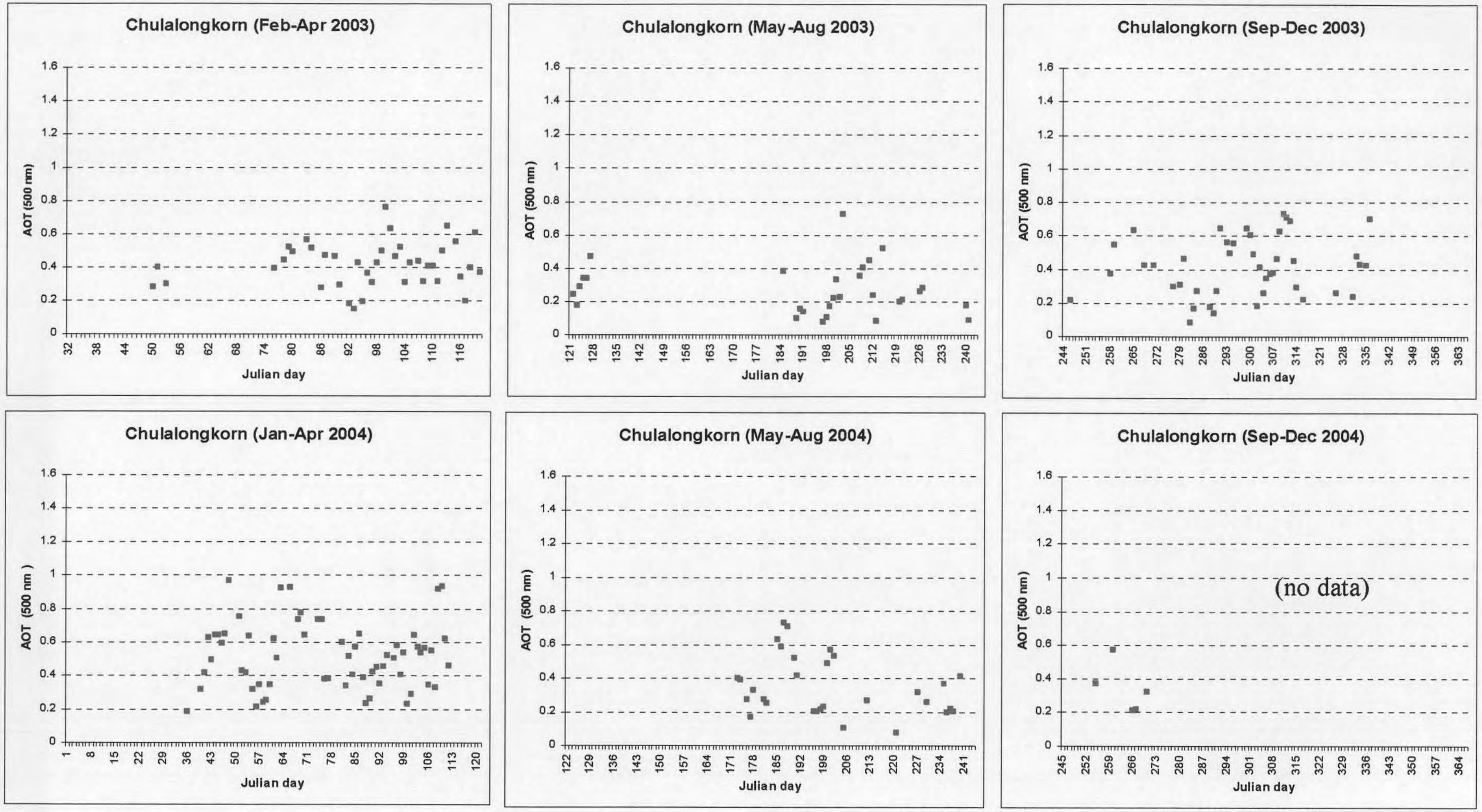


Figure 4.3 Daily average values of AOT at Chulalongkorn site.

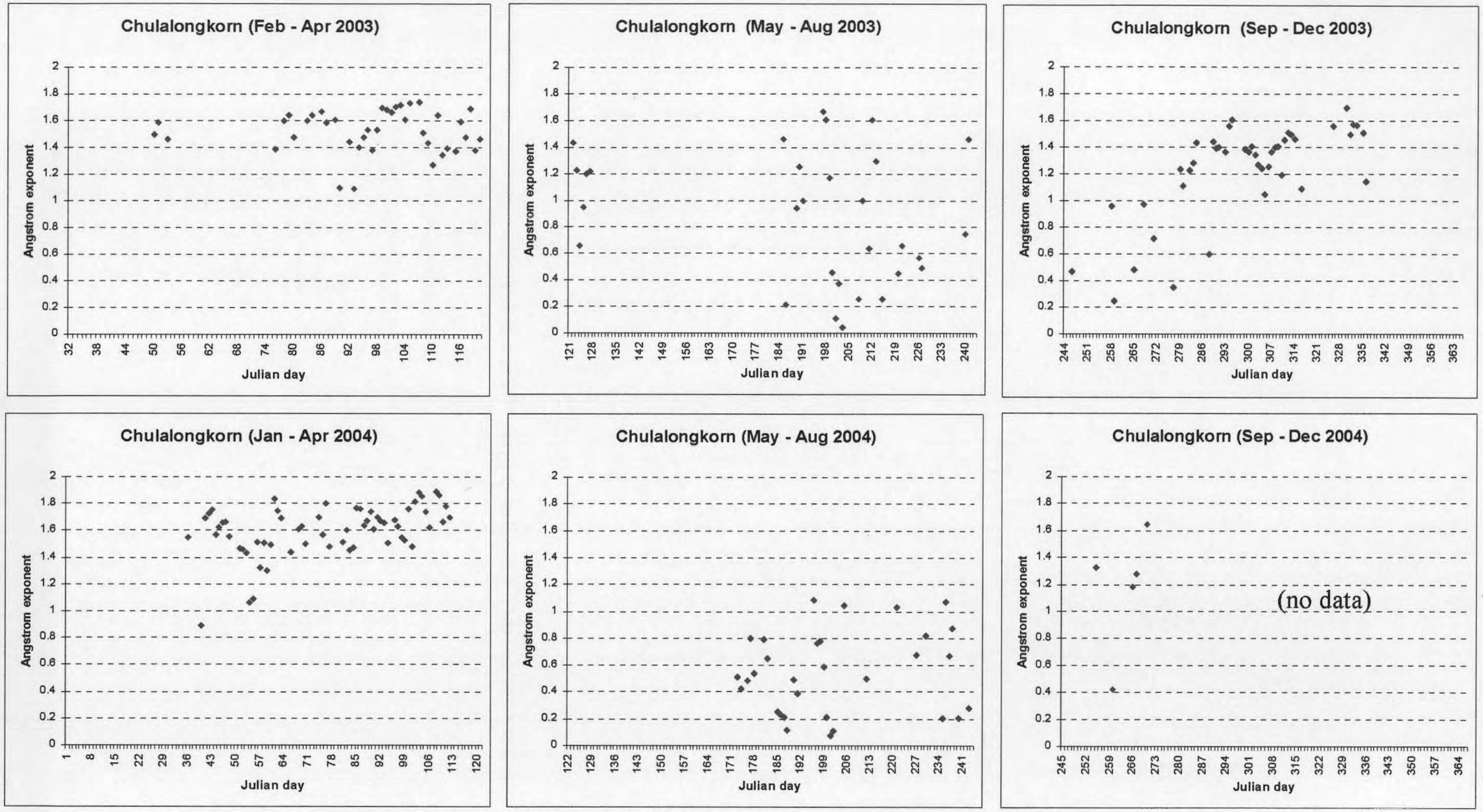


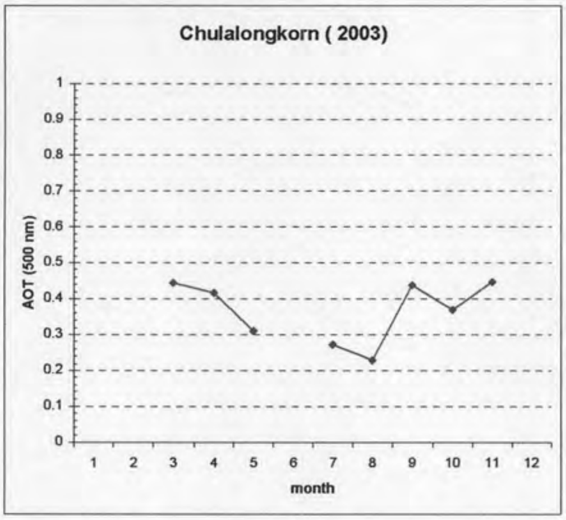
Figure 4.4 Daily average values of Angstrom exponent at Chulalongkorn site.

The different periods of the Angstrom exponent values during 2003 - 2004 have been analyzed. It was found that some daily average Angstrom exponent values during July 2003 were relatively higher than others in the same month of 2003 and 2004. Some data in September 2004 were relatively higher than in September 2003. For the analysis of Angstrom exponent data in rainy season with 3 hours accumulated rainfall data and backward trajectories during 7 days with starting levels at 500, 1500 and 3000 m a.g.l. (above ground level) was found as follows; (The trajectories were available on the website (http://www.arl.noaa.gov/ready.html)

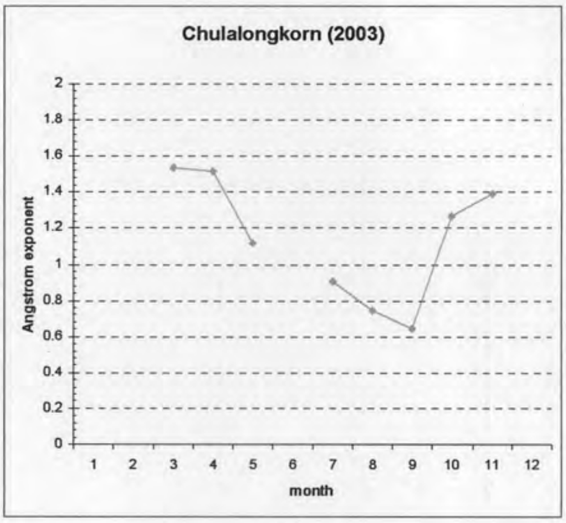
- In rainy season, air masses mostly came from the Gulf of Bengal and the Indian Ocean. The Angstrom exponent values were mostly relatively low, but sometimes those were relatively high. Therefore, from the analysis of trajectory in this study can not conclude in term of the Angstrom exponent difference.

- The Angstrom exponent values increased after continuously a large amount of rainfall. According to Iqbal (1983), rain reduces the number of aerosol particles but increases the size of those that remain. In this continuously a large amount of rainfall, the relatively higher value of Angstrom exponent aerosols might be due to the fact that large size aerosols were removed from the atmosphere and increased size of very fine cloud condensation nuclei. In case of non continuous and less amount of rainfall, it was found that the Angstrom exponent values were relatively low.

For the analysis of the monthly average of AOT and Angstrom exponent, a number of data in some months were less than 10 days. These were a limitation of data set. However, these data were used for variation analysis except the monthly average data from daily data with mostly high value or low value or only 1 data. The general variation of AOT values were found that there were relative high values in February to April and October to November, while the relative low values were in May to August, and for Angstrom Exponent with the relative low values during May to September as shown on figure 4.5. In September 2003, the monthly average AOT value was high while in



(a)



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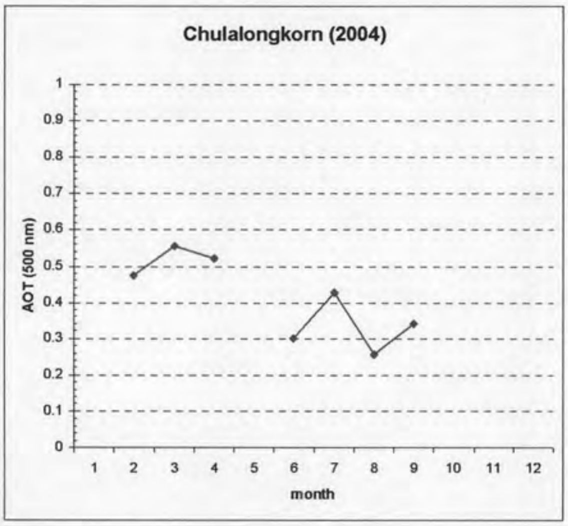

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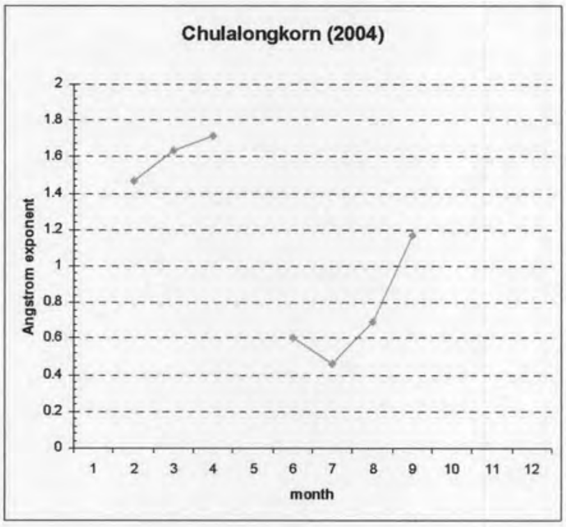
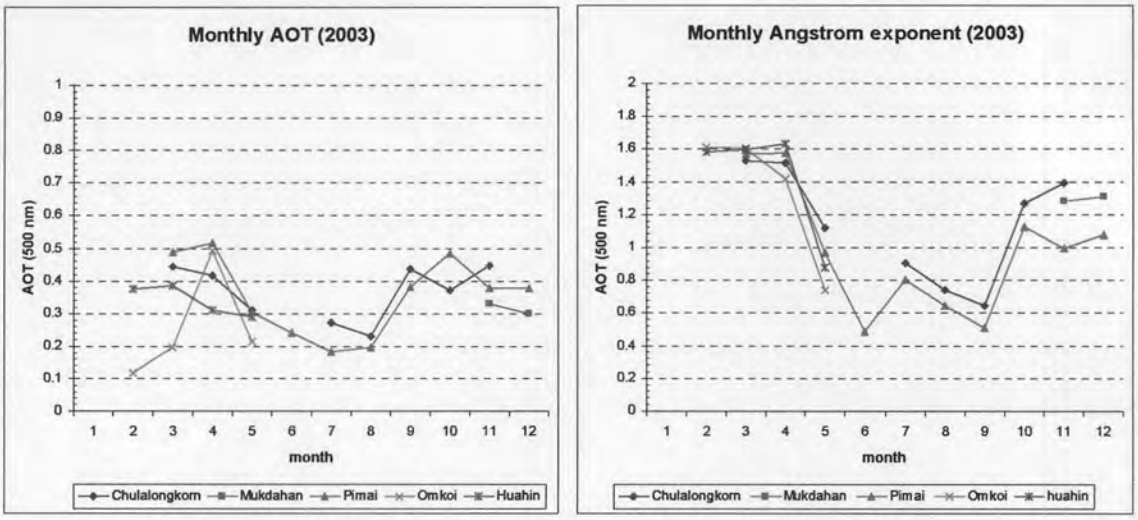


(d)

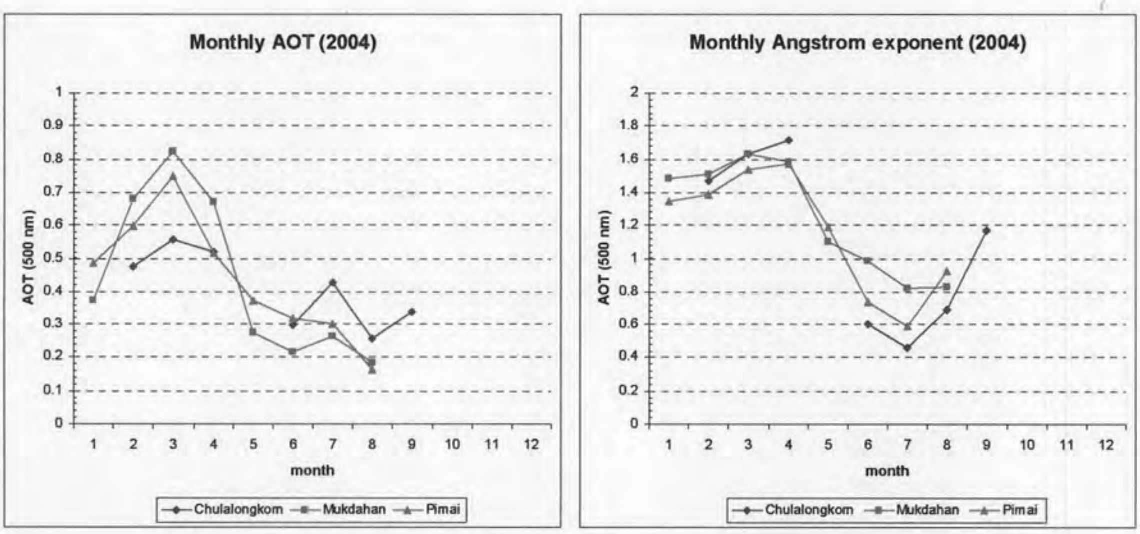
Figure 4.5 Monthly average values at Chulalongkorn site (a) AOT 2003 (b) AOT 2004 (c) Angstrom exponent 2003 (d) Angstrom exponent 2004.

September 2004 was low. These difference data values were not summarized in the inter-annual variation because a number of data for the monthly average value in September 2003 and 2004 were 6 and 5 respectively.

The comparison of the monthly average AOT and Angstrom exponent values between Chulalongkorn and other sites were shown on figure 4.6. It was found that the data variation of Chulalongkorn, Mukdahan and Pimai sites had the same pattern



(a) (c)



(b) (d)

Figure 4.6 Monthly average values at 5 sites (a) AOT 2003 (b) AOT 2004 (c) Angstrom exponent 2003 (d) Angstrom exponent 2004.

and summarized that all AOT values were high from February to April with decreasing from May to August and increasing again from October to December. The high and low values of AOT were corresponded to climatic season with low values in rainy season and relatively high values in winter and summer seasons. For the Angstrom exponent values, it was found that they were decreased during May to September. Meanwhile, during February to April, the AOT values of Mukdahan and Pimai sites were relatively high when being compared to those at Chulalongkorn site. Chulalongkorn site is located in urban area. Aerosols are mostly from fuel combustion of vehicles and industry. Mukdahan site is located in local area, where the land covers are mixture of forest and agriculture, rice and sugarcane cultivation, Pimai site is in agriculture area with sugarcane and cassava cultivation. The relatively high AOT of Mukdahan and Pimai sites due to there were aerosols from biomass burning. Farmers would burn biomass for land preparation or clearance before crop growing and after harvesting. Data from Department of Agriculture Extension, new crop growing was mostly during January to June and harvesting was during November to April. During May to November, the most of AOT values of Chulalongkorn site were higher than Mukdahan and Pimai sites. Because of in this time, the harvesting area or the biomass burning in the land nearby Mukdahan and Pimai site was less than during February to April (summer season). The fuel combustion of vehicles, industry and urban activity in Bangkok were still continued. The comparison of the AOT values of Chulalongkorn, Omkoi and Hua_Hin sites have been done during February to May 2003 because the limit of availability data at Omkoi and Hua_Hin sites. The data showed that the AOT values of Chulalongkorn site were higher than Hua_Hin and Omkoi sites. Hua_Hin site is located in coastal area. Omkoi site is located in a mountain with the land covers of forest and cultivation area like as growing rice and vegetable. In the exception of April, the AOT values of Omkoi site were higher than those of Chulalongkorn site. From data of Department of Agriculture Extension, it was new growing period of rice during May to June. Therefore, April would be a land preparation period. Then, the AOT values were high because of the present aerosol from biomass burning before plantation. The increasing of AOT of Omkoi and Mukdahan site in April 2003 was the same study result as of Eck et al. (2004).

For the analysis of the daily average and monthly average values of AOT and Angstrom exponent, it have been concluded that the period of the high and low values corresponded to the season. The time variation pattern showed that there were high values in summer and winter seasons with relatively low in rainy season.

From the analysis of frequency histograms of AOT and Angstrom exponent for daily average data, which were categorized by season, were shown on figure 4.7 and 4.8. It was found that at Chulalongkorn site in summer and winter seasons, the AOT distribution had a maximum value of 0.45 and 0.55. While the rainy season the maximum was spread around 0.15 and 0.25. For the distribution of Angstrom exponent, in rainy season, the distribution was wide and peaked around 0.5. In summer and winter seasons, the distribution was narrow with a maximum around 1.5 and 1.7. There were relatively high ratios of small particles to large particles. For rainy season, the present of aerosol in the atmosphere was less than other seasons and also, the size distribution of aerosol particles was difference from other seasons. In rainy season, there were relatively high and low values of the Angstrom exponent. This might be because of some aerosol particles that were removed from the atmosphere by rain and the remaining particles were increased in size with a highly air humidity by the hygroscopic growth.

The study of seasonal average aerosol volume size distributions, the amount of data was very little. In particular, Chulalongkorn and Pimai sites had the amounts of data in rainy season, only 1 and 3 day respectively. The data were not good representative of seasonal average data but they need to be used because of the requirement of a study for the seasonal difference data. Figure 4.9 showed the seasonal average aerosol volume size distribution at Chulalongkorn site. It was found that using a cutoff of 0.6 μm particle radius to classify the distinction (Kleidman et al., 2005) then there were two modes. A fine mode was radius less than 0.6 μm and another coarse mode was radius more than 0.6 μm. The volume size distribution was dominant by a fine mode particle, which was the same as the other sites (the seasonal average aerosol volume size distribution at other sites show on Appendix D) and correspondent with the study result of Eck et al. (2004). By the seasonal comparison of Chulalongkorn site, the magnitude of a fine and a coarse aerosol were relatively high in summer and winter seasons, when comparing to rainy season.

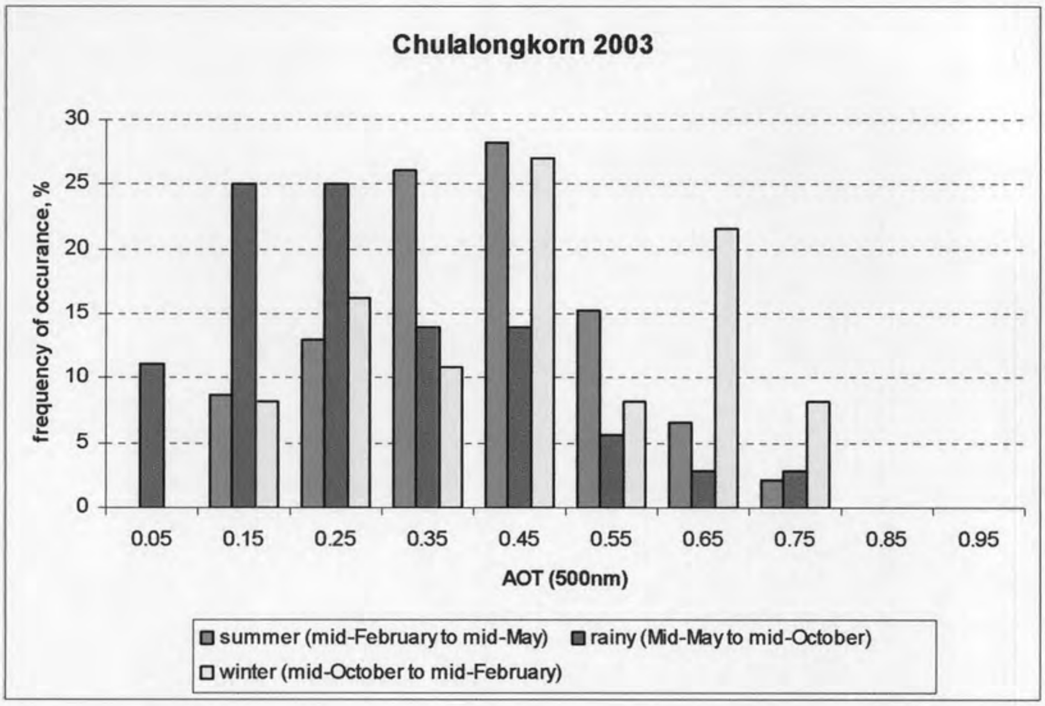


Figure 4.7 Seasonal frequency histograms of AOT at Chulalongkorn site in 2003.

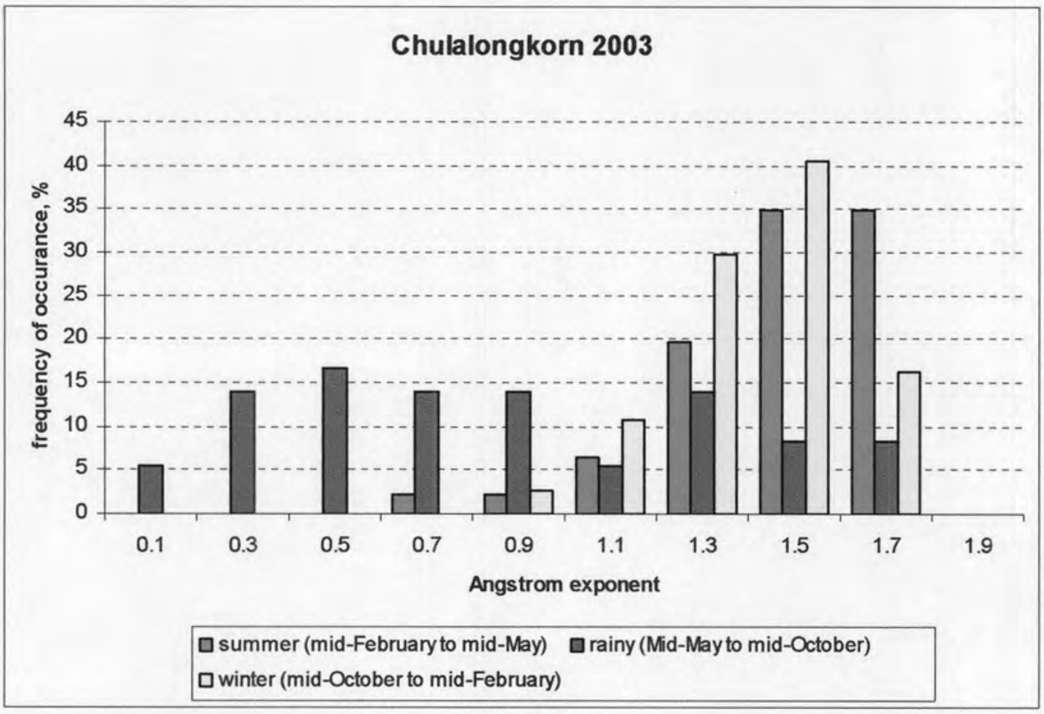


Figure 4.8 Seasonal frequency histograms of Angstrom exponent at Chulalongkorn site in 2003.

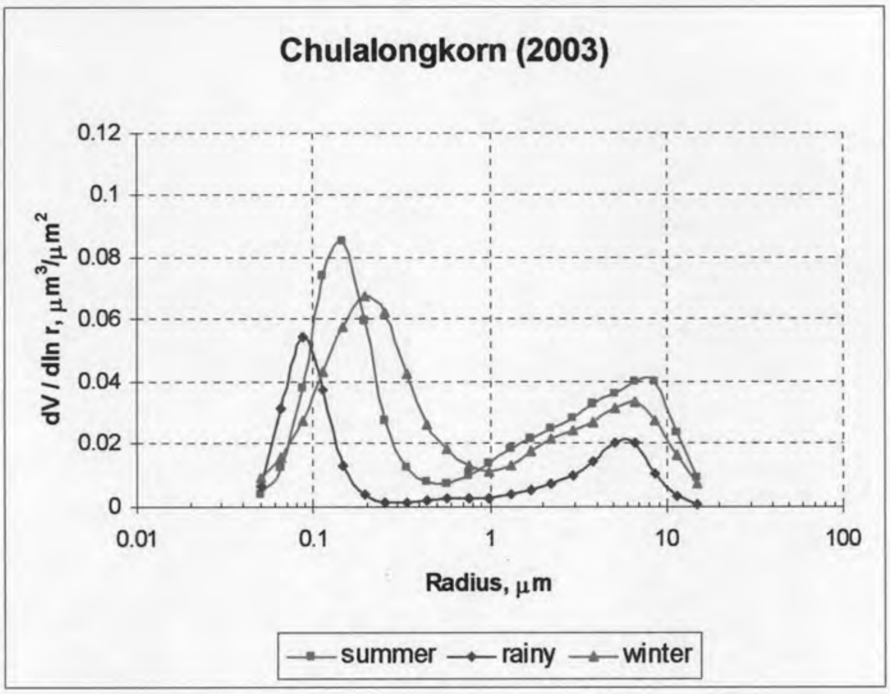


Figure 4.9 Seasonal average aerosol volume size distributions at Chulalongkorn site.

The study of seasonal average aerosol volume size distribution of the AERONET sites in the same season, it was found that the magnitude and shape were difference. As indicate of the atmosphere over the study sites were composed of the aerosol size particles in difference ratio. The analysis of AOT which were the extinction of solar radiation in difference wavelength has been performed. In order to visualize the difference of the aerosol over the study site, the AOT value in various different wavelength have been plotted to display spectral behavior or slope. The extinction of solar radiation is maximum for scattering particle diameter equivalent to wavelength and for absorbing particle diameter less than wavelength. The shorter wavelengths give information about fine particles. The longer wavelengths give information about larger particles. Therefore, whenever the atmospheric over two sites are composed of aerosol particles size in difference ratio, the slope will be different. Figure 4.10 showed the graph of seasonal average AOT in difference wavelengths of 5 study sites. The graphs revealed all sites which dominate with fine particles. In summer season, it was found that

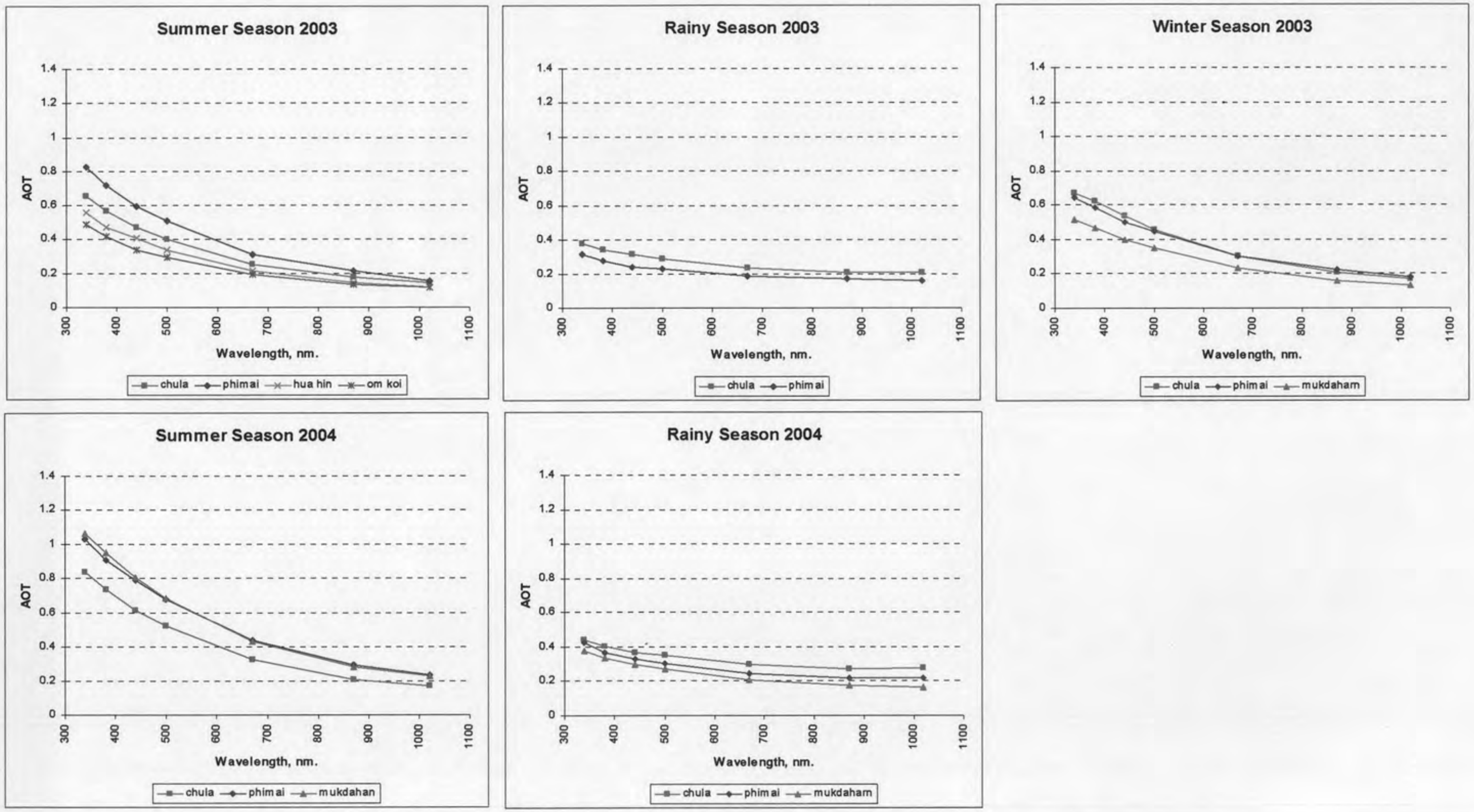


Figure 4.10 Seasonal average value of AOT at difference wavelength at 5 sites.

the slope of Chulalongkorn site were different from other sites because of the site environmental differences. The data in rainy and winter seasons had only 3 sites: Chulalongkorn, Mukdahan and Pimai. It was found that all slopes were almost the same in rainy season, it may be explained that the aerosols were removed by rain. Then the atmosphere had lower aerosols. Subsequently, the differences in the attenuation of solar radiation by aerosol at different wavelengths were less. In winter season, the slopes of Chulalongkorn and Pimai sites were almost the same but they were different from those at Mukdahan site. Although, the land covers near mukdahan site were a mixture of forest and agriculture. The biomass burning came from agricultural activity and forest fire. In winter season, the forest fire was relatively low when comparing with a summer season. Therefore, the slop of Mukdahan site was different from Pimai site. The data of forest fire area for Mukdahan in winter 2003 and summer 2004 were in Appendix E.

The study of seasonal average aerosol volume size distribution was found that there were different in each season. Then the air masses which covered Bangkok in term of backward trajectories during 8 days with starting levels at 500, 1500 and 3000 m a.g.l. as shown on Appendix F were analyzed. It was found that in winter season air masses often came from the South China Sea, the Republic of China or India. In summer season, air masses came from difference locations such as the Gulf of Thailand, the South China Sea, or the Gulf of Bengal. In rainy season, air masses mostly came from the Gulf of Bengal and The Indian Ocean. The incoming air masses to Bangkok in each season traveled from different locations, the aerosol volume size distribution in Bangkok was also different. Therefore, the incoming aerosols in air masses would effect the amount of aerosols over Bangkok and also the aerosol volume size distribution. This result was corresponded to the study of Esposito et al. (2004), said that the injection of air particles arriving from different sites causes the variation of the aerosol optical properties.

The Republic of China is the main sources of aerosols that transport to anywhere in the world (Alles, 2005). In case of Thailand, we have the AOT measurement site in Bangkok. Therefore, we choose to study the track of aerosols to Bangkok by trajectory. The comparison of haze and pollution over the eastern China from satellite image in figure 4.11 with the investigation of station models on weather maps in figure 4.12 (The detail of weather map were in Appendix G) was conducted. It was found that the smoke and haze covered these areas during 10, 13 and 16-30 October 2003. Also, the upper winds at 5000 ft during 16-30 October flow from the eastern China area mostly northeast direction toward Thailand. The example of upper wind on 22 October 2003 at 00 UTC was shown on figure 4.13 (a). Therefore, the analysis of back-trajectory with starting point at 500, 1500 and 3000 m a.g.l. and daily average AOT values at 500 nm wavelength of AERONET sites has been performed. The AERONET sites on the upper winds passage from China to Bangkok were available of AOT data in this period such as Chen-Khun_Univ in Taiwan, Bac_Giang in Vietnam, Pimai and Chulalongkorn in Thailand as shown on figure 4.13 (b). The AOT values of those sites were shown on Figure 4.14. It was found that at Chen-Khun_Univ site when AOT values were high, the back-trajectories of the air mass at altitude 500 and 1500 m came from the smoke and haze areas at the level lower than 3000 m. Whereas, when the AOT values were low, these air masses often came from the same China areas but came from the level higher than 3000 m. This might be caused by the concentration of aerosol at that altitude was lower. At Bac_giang site, the AOT values were increased from 18 October. Trajectories revealed that the air mass for two low levels at 500, 1500 m during 18-30 October mostly came from the smoke and haze areas. Also, the air mass at Pimai site for two levels at 500, 1500 m during 21-26 October mostly came from the same smoke and haze areas in eastern China and the AOT values were high throughout the period. At Chulalongkorn site, AOT data was unavailable during 23-25 October. However the trajectories revealed that during 20-29 October, the air mass mostly came from the same smoke and haze areas to Chulalongkorn site and the AOT values were also high during 20-22 and 26-28 October. Especially on 29 October, the AOT values decreased because the air mass

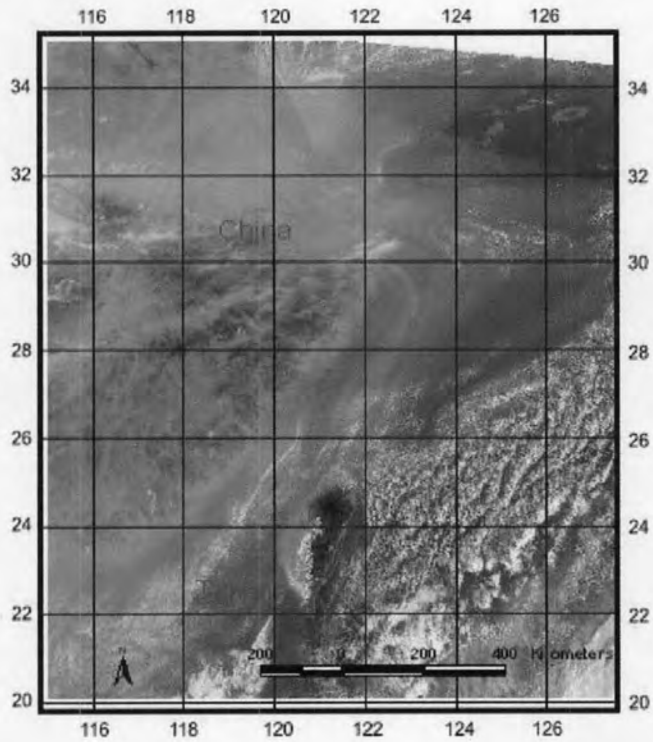


Figure 4.11 the SeaWiFS satellite image on 22 October 2003 shows haze and pollution over China. (From http://earthobservatory.nasa.gov/NaturalHazards/)

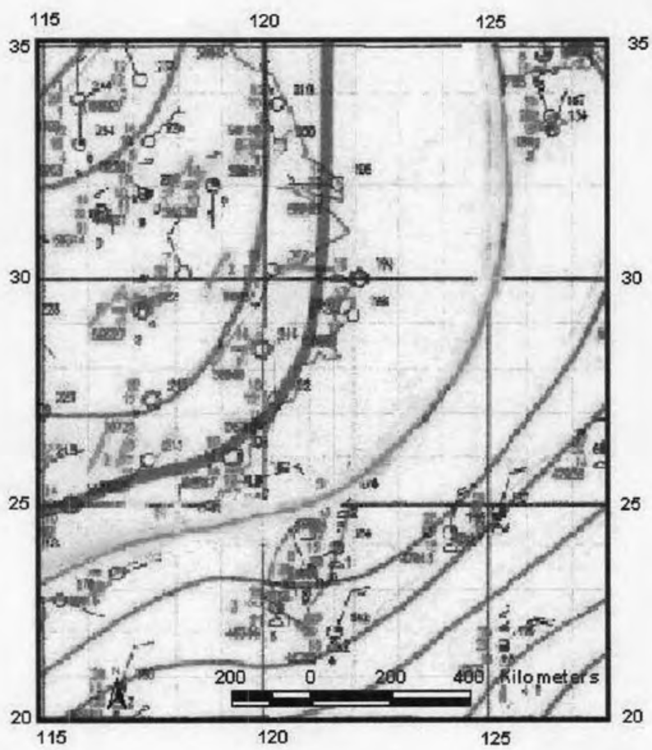


Figure 4.12 Weather map on 22 October 2003 at 00 UTC (weather symbol ∞ = Haze). (From Thai Meteorological Department)

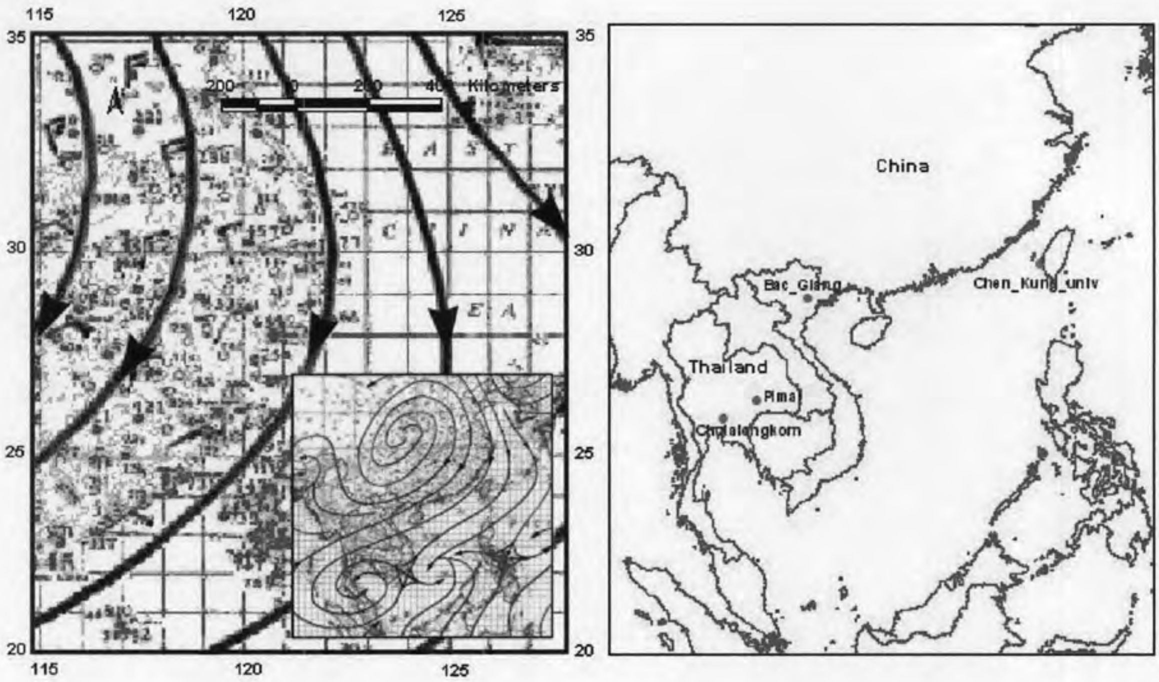


Figure 4.13 (a) Upper winds at 5000 ft on 22 October 2003 at 00 UTC. (From Thai Meteorological Department) (b) The location of the AERONET sites in this case study.

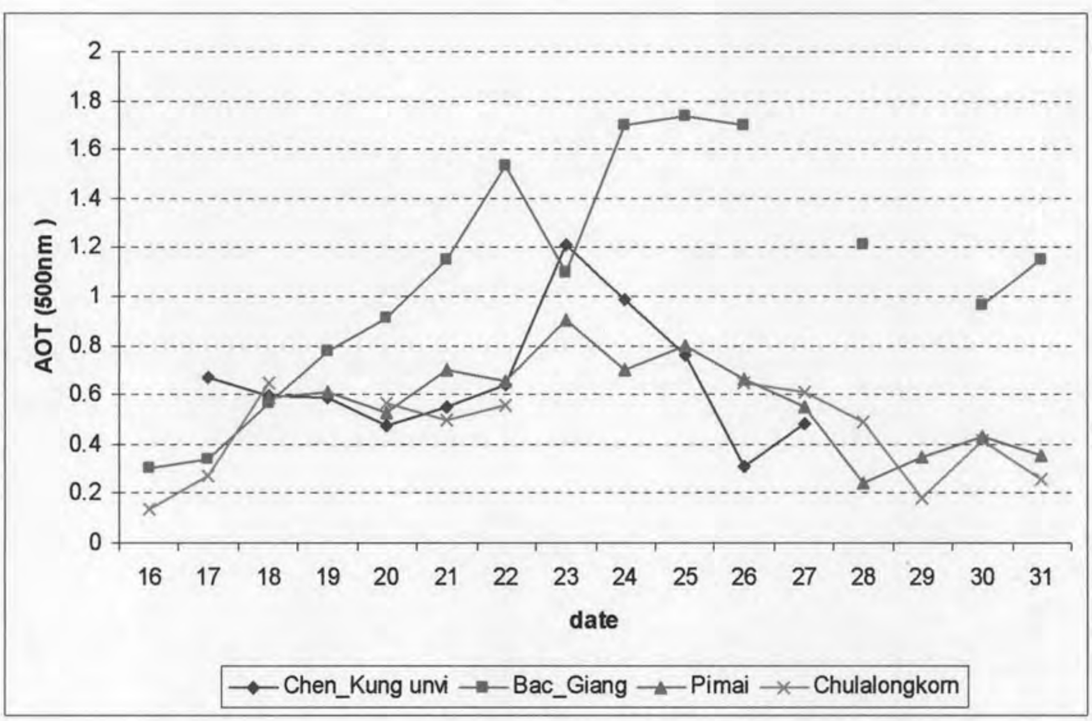


Figure 4.14 Daily average values of AOT at AERONET sites, which are located on the upper winds passage from China to Bangkok.

from the same smoke and haze areas has traveled longer across the South China Sea prior to Thailand. This traveling was not the same as the others with shorter traveling day as shown on figure 4.15. In last summary, from the analysis of AOT values and trajectories, it was found that the AOT values of the AERONET sites were high when trajectories revealed that at least two levels came from the smoke and haze areas in eastern China. It was revealed that during 20-28 October 2003 in period of the northeast monsoon, the aerosols from the eastern China area have dispersed to the Southeast Asia toward Thailand.

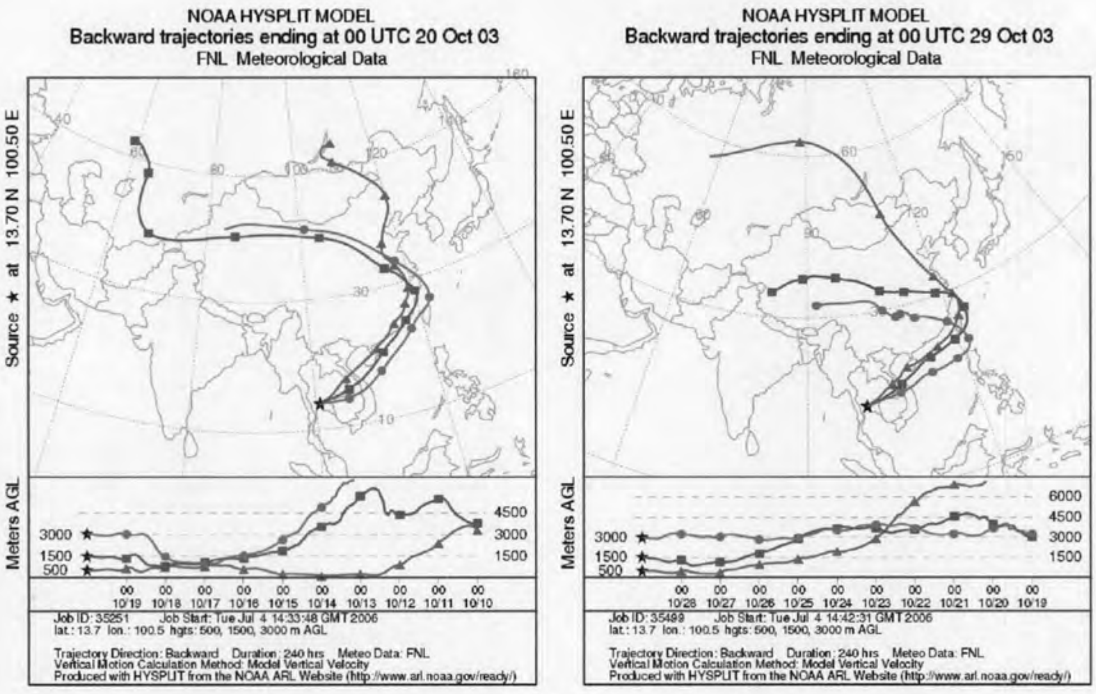


Figure 4.15 Back trajectory of Chulalongkorn site on 20 and 29 October 2003.

(From http://www.arl.noaa.gov/ready.html)

4.3 Variation of AOT and Meteorological Data

Because aerosols have the seasonal variation, this study has used the meteorological factors such as temperature, wind speed and direction and rainfall to analyze the variation of AOT in each season.

From the analysis of the daily average AOT data at Chulalongkorn site and daily average daytime air temperature data of Bangkok was show on graph of the two data set in Appendix H. It was found that in summer and rainy season when the daytime air temperature increased, AOT also increased in 1-2 days later. Especially, when the daytime air temperature was greater than 33 degrees celsius, the AOT values were greater than 0.4. The same result was found in winter season when air temperature variation was low (less than 2 degrees celsius). The analysis of correlation between the day time air temperature and AOT in two day later in these periods as shown on figure 4.16, it was found that the two data sets were correspondent with each other in a statistical significance on the same direction. In summer season the daytime air temperature increased with a maximum temperature about 34-39 degrees celsius. This high temperature causes the heating convection which uplifts dust particles from surface to the atmosphere. In winter season although the daytime air temperature were not as high as in summer season. This effect was the local variation of air temperatures. According to Chabangborn (2003) who studied the atmospheric boundary layer at Sukhothai revealed that the atmospheric boundary layer top height in winter was almost constant and lower than that in summer season. Therefore, the aerosols were confined in this atmospheric boundary layer. They could not be dispersed to upper high level of the atmosphere and less distribution to other places. Subsequently, the AOT values were high. The analysis of the daily average data of AOT and daytime air temperature of the other sites as show on Appendix H has the same results as Chulalongkorn site.

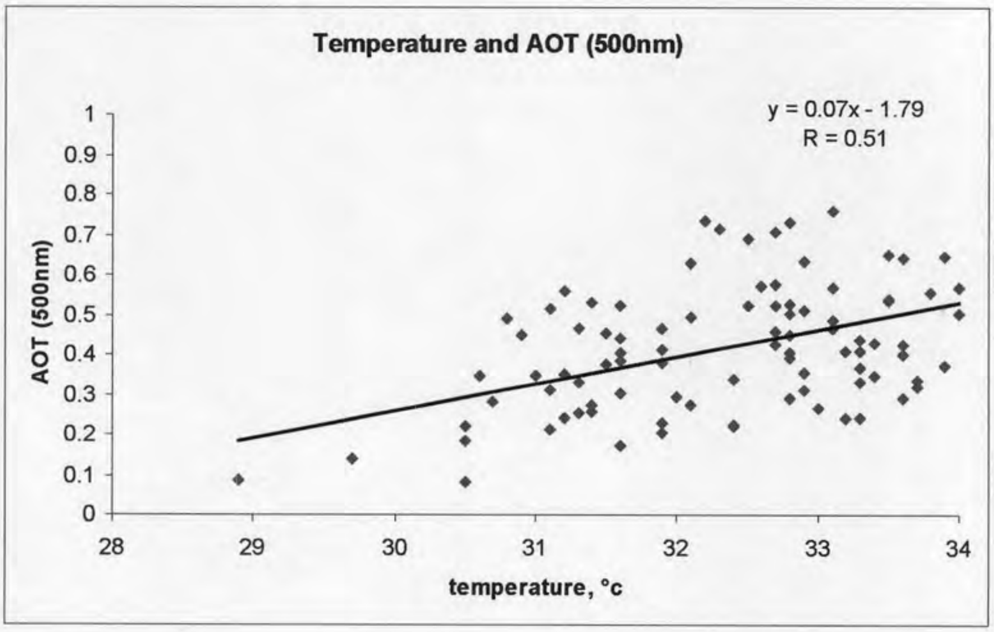


Figure 4.16 Correlation between the daily average daytime air temperature and the AOT data in two day later at Bangkok.

In winter season, AOT increased after the daytime air temperature decreased at least 2 degrees celsius in 1-2 days. This was eventually happened, because of the influence of high pressure area from the Republic of China which covered the upper Thailand which caused of air temperature was decreased and air mass was stable. Aerosols were confined and lower dispersed to other places. The correlation of the two data set in the period of daytime air temperature decreased at least 2 degrees celsius in 1-2 days as shown on figure 4.17.

The analysis of the variation of AOT value also found that the period of variation was 4-7 days, which was corresponding to the variation of daily average daytime air temperature. Especially, in summer and winter seasons the AOT increased within 1-2 days after the air temperature increased. Conversely, when the air temperature decreased, the AOT also decreased within 1-2 days later. As warm air expands, its density decreases. So it becomes lighter than colder air surrounding it, and tends to rise. For many substances, expansivity varies with temperature (Smith, 2001). Therefore,

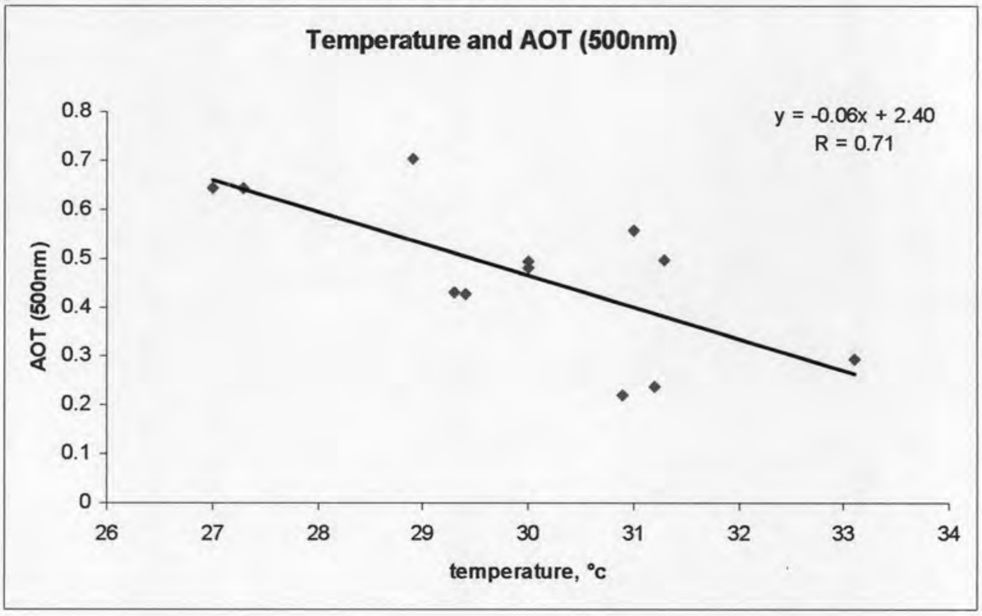


Figure 4.17 Correlation between the daily average daytime air temperature data and the AOT data in period of decreasing of temperature in winter season at Bangkok.

during the period of decreasing temperature, there is less air expansion. So, the chance for aerosol particles to deposit onto surface is much more due to gravity force. This is consistent with the report of World Meteorological Organization (1991) that the time period of a particle in the atmosphere is a strong function of its size. Particle smaller than 0.01 μm grow to larger sizes by condensation or are incorporated into larger particles by coagulation or attachment to cloud droplets in the cloud phase on a time scale of 10 hours. Particles larger than about 10 μm are removed primarily by surface deposition with a time constant in the order of hours. Time for particles to fall 1 km due to the force of gravity has been showed on Appendix I.

The analysis of the daily average AOT data at Chulalongkorn site and wind speed data at 850 hPa of Bangkok were shown in figure 4.18. It was found that in summer and winter seasons when the wind speed was less than 4 m/s, the AOT values were relatively low. When the wind speed was more than 4 m/s, the AOT values

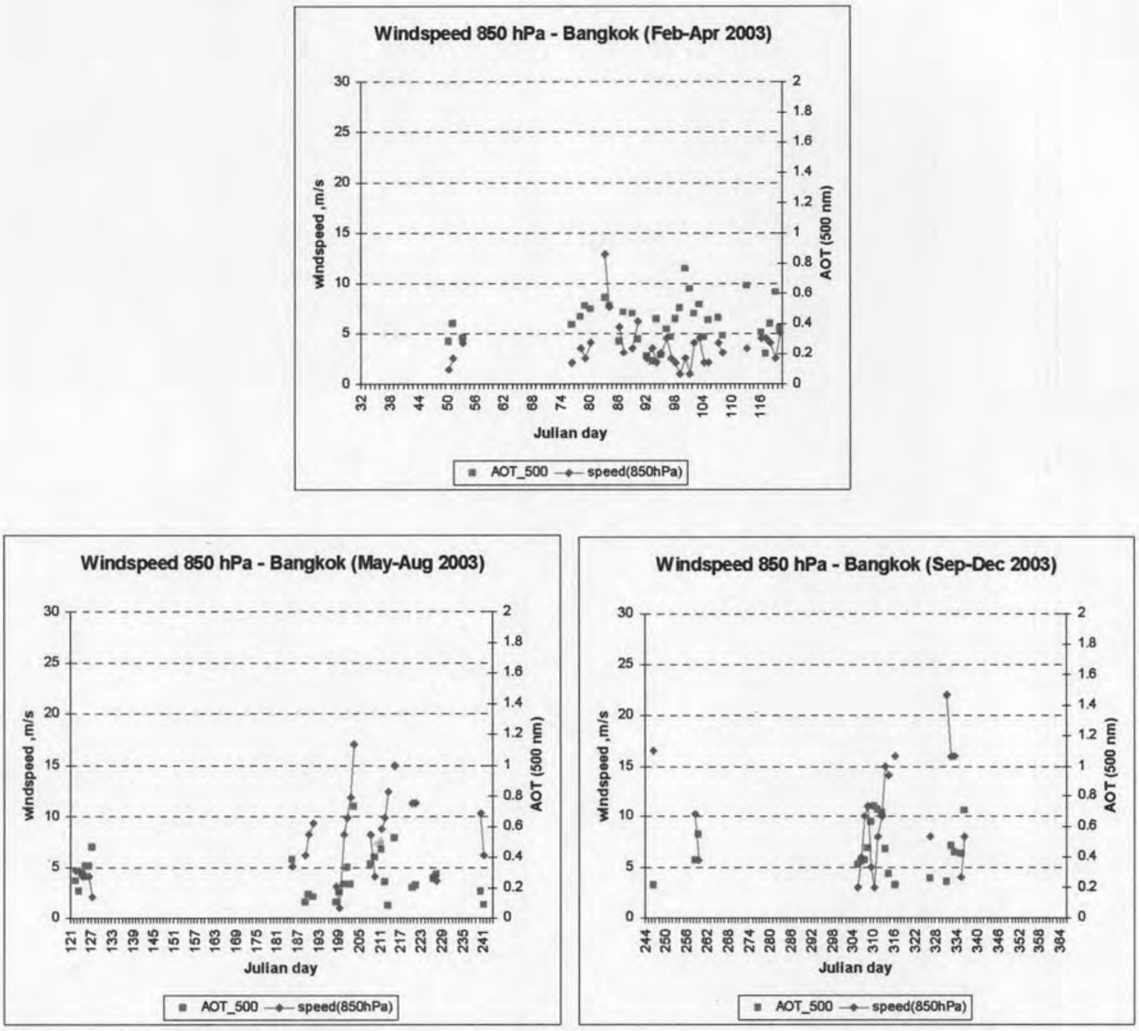


Figure 4.18 Daily average values of AOT and wind speed at 850 hPa at Bangkok in 2003.

were uncertain pattern. In rainy season the AOT were almost low although the wind speed was variable. It seemed that the wind speed was not the main factor in changing of the amount of aerosols.

The daily average AOT data at Chulalongkorn site and wind direction data at 850 hPa of Bangkok were analyzed. It was found that in rainy season mostly wind directions were from between southwest and west and the AOT values mostly less than 0.4 as shown on figure 4.19 which this area was under line 0.4, there was a large number of data. The winds from the directions that blew across the sea with high humidity may

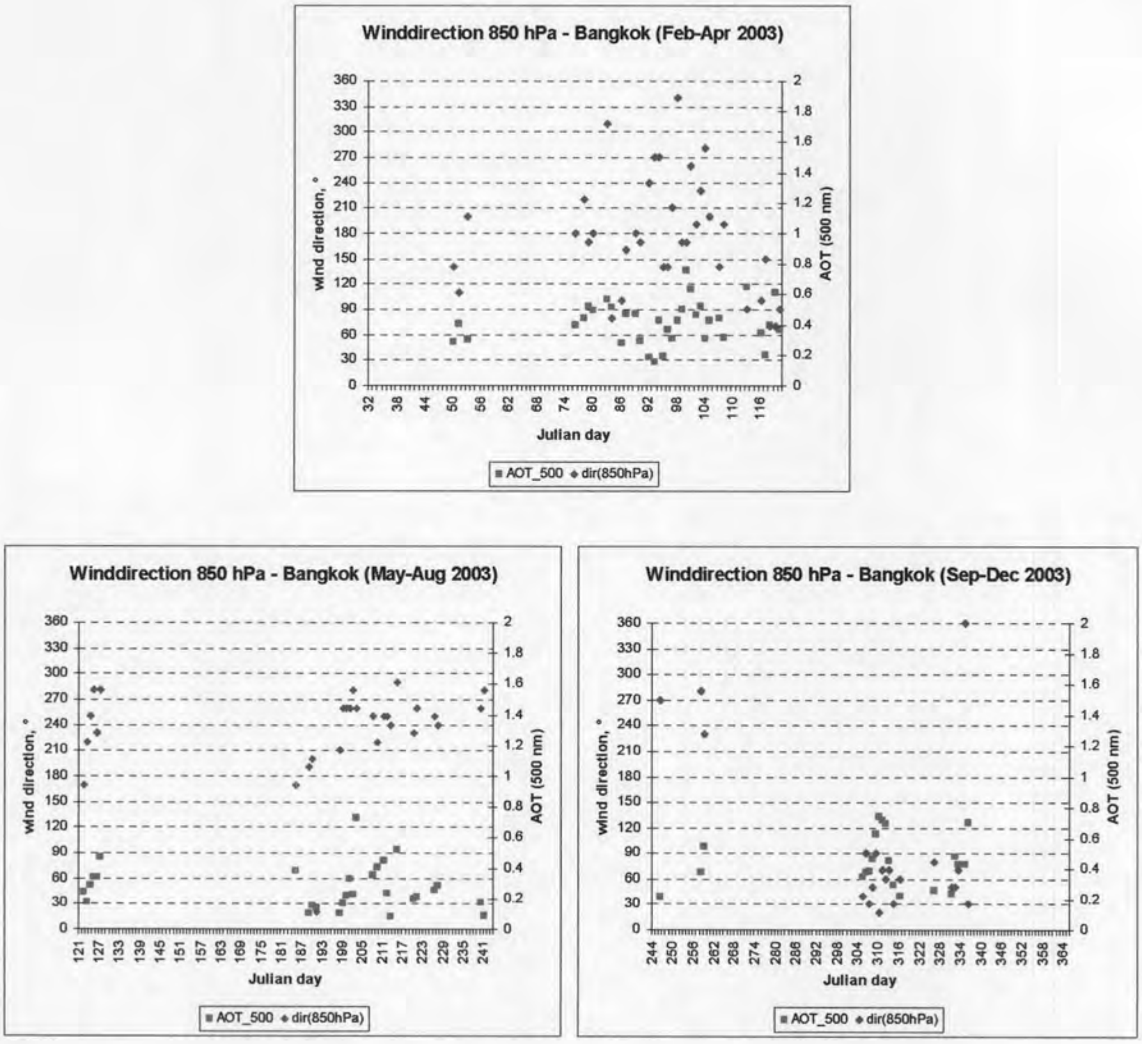


Figure 4.19 Daily average values of AOT and wind direction at 850 hPa at Bangkok in 2003.

make an occurrence of rainfall washout or wet deposition of aerosols. Aerosols were lower before the blown air reaches Bangkok or may make an occurrence of rainfall in Bangkok, which removes aerosols from the atmosphere. In winter season, mostly the wind directions were from between north and northeast and the AOT had mostly values greater than 0.4. The wind from these directions blew across land surface with low humidity. Therefore aerosols remain suspended in the atmosphere and less removed by rainfall, which were the important factor for the decrease of aerosols in the atmosphere. In summer season, the wind came from different directions and the AOT had indefinite pattern with wind direction. From the analysis of daily average AOT data with wind speed and direction data at 850 hPa of Pimai site in summer and rainy seasons as shown on Appendix H, the same results as at Chulalongkorn site were found. The upper wind data at Pimai did not exist in the winter season.

The analysis of the daily average AOT data at Chulalongkorn site and 3 hours accumulated rainfall of Bangkok were shown Appendix H. It was found that the AOT values decreased after the 3 hours accumulated rainfall or continuous rainfall amount was greater than 10 mm. In case of rainfall amount was less than 10 mm, the AOT values fluctuated in both of increasing and decreasing. It seemed that the less amount of rainfall might not decrease the aerosol in the atmosphere. The correlation between rainfall amount greater than 10 mm and the AOT value after the rainfall was shown on Figure 4.20. The AOT was decreased due to the removal of aerosols by rain or wet deposition. In comparison at Mukdahan, Pimai and Hua_Hin sites, the same results were found (Daily average values of AOT and 3 hours accumulated rainfall at these AERONET sites shown on Appendix H).

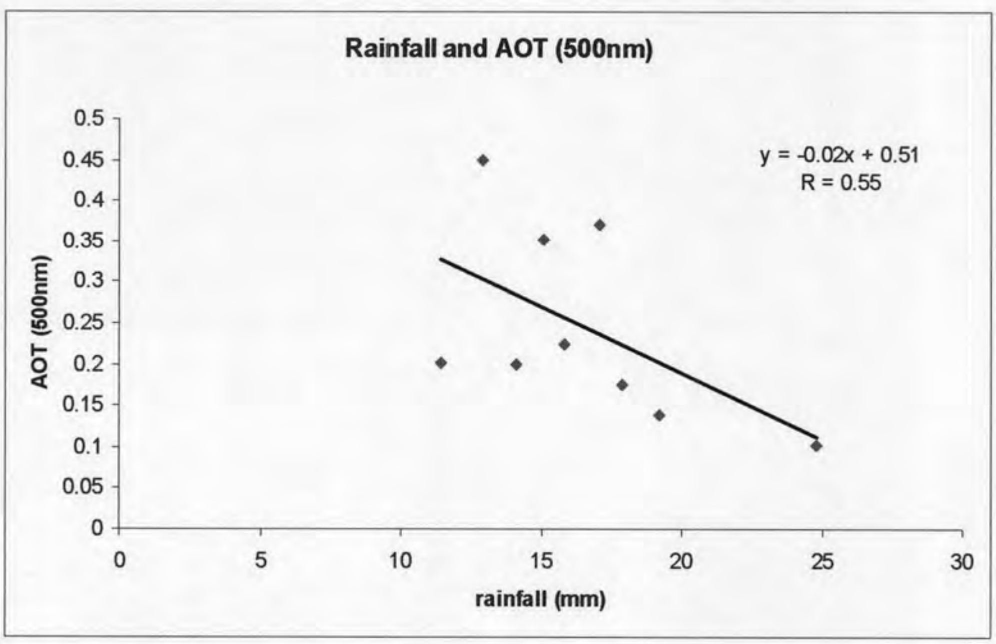


Figure 4.20 Correlation between the rainfall amount greater than 10 mm and the AOT data after the rainfall at Bangkok.

4.4 Relationship between AOT and PM10

From Jin et al. (2005) which has been studied about the weekly cycle of AOT over New York shows the high values during weekdays and low values on weekends as well as the AOT variation depending on surface traffic and overlying atmospheric wind. As aforementioned study, the concept of this study was concluded that aerosols at surface level would be effect on the upper level aerosol. Therefore, this study analyzed the relationship of the daily average PM10 data which was measured at surface level of Nonsi Vitthaya School and daily average AOT data that was measured by taking the integrated columnar aerosol loading at Chulalongkorn site during February 2003 - September 2004. The graph of PM10 and AOT was shown on Appendix J.

From the analysis of linear relationship of the two data, the correlation coefficient is equal to 0.41. It implied that the two data sets were weakly related as shown on Figure 4.21.

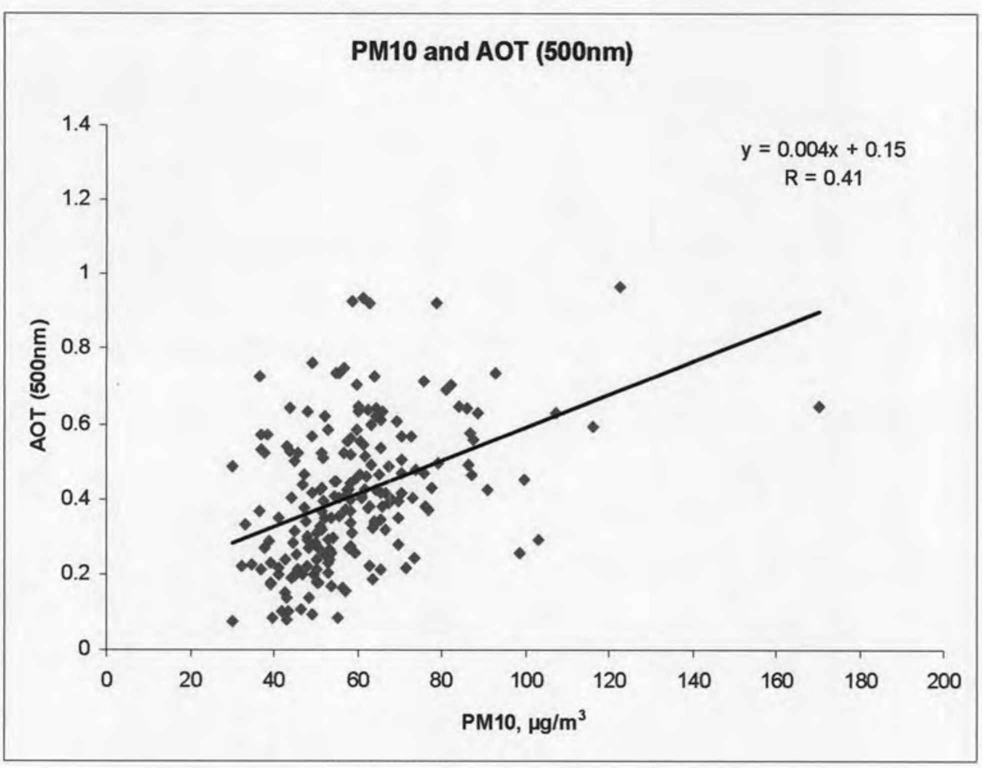


Figure 4.21 Correlations between PM10 and AOT (500nm) at Bangkok in 2003.

The weak relation might be because of the two data measurement were difference in sizes of particle and height of instrument that PM10 was at 3 m but those of AOT was higher at 115 m. Also, the PM10 might be not dispersed to high atmospheric level.

4.5 PM10 Time Series

The daily average PM10 data at Nonsi Vitthaya School during 1997-2004 were used to study the variation of PM10 and time. The selected method as state in 3.3.3 was analysis of time series decomposition into its basic component variation such as trend, cyclical, seasonal and irregular variation for better understanding on the behavior of the series.

In the analysis of time series, the PM10 data were examined. It was found that mostly PM10 values during weekends were relatively low, compared to weekdays. The calculation of seasonal variation which used 7 days moving average and obtained seasonal index were shown on figure 4.22 and in Appendix K. The high values were during weekdays and low values on weekends. The peak appears on middle of the week. The seasonal index implied that the weekly variation was the result of human activities in Bangkok.

Trend and cyclical variation were obtained from the analysis of time series as showed on figure 4.23 (b) and (c) respectively. Trend of the PM10 have decreased from 1997 to minimum value in 2001 and increased again to 2004. The decreasing of the PM10 since 1997 might be a result from the amount of fuel usage which causes of aerosol emission in Bangkok. The data of a fuel consumption volume in Bangkok Metropolis during 1997 to 2004 from Department of Energy Business in the table 4.1 found that the use of diesel and fuel oil, which were the significant sources of aerosols,

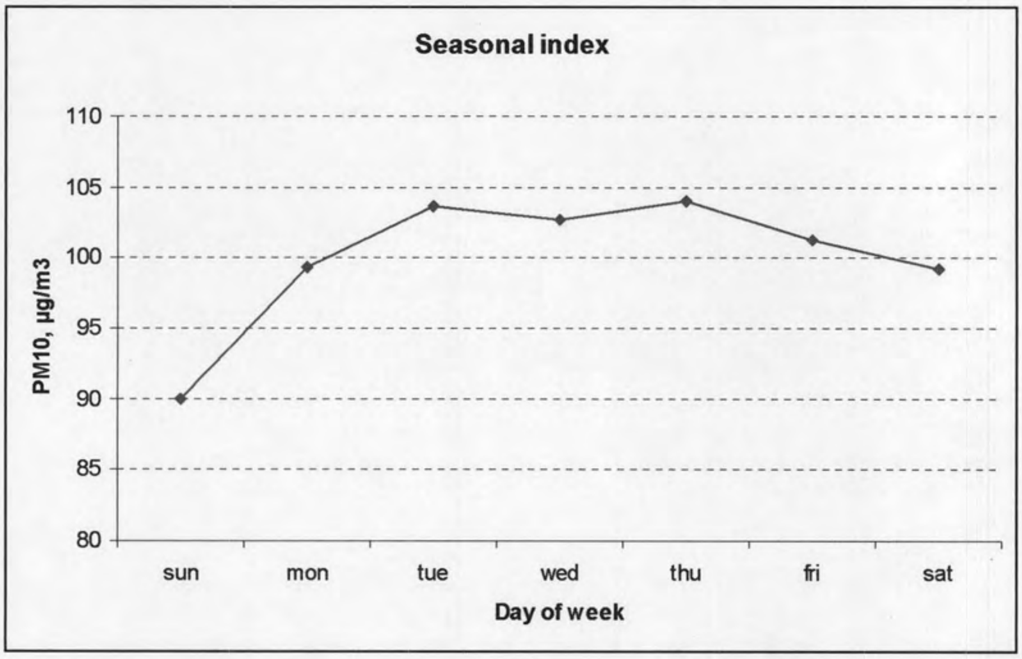
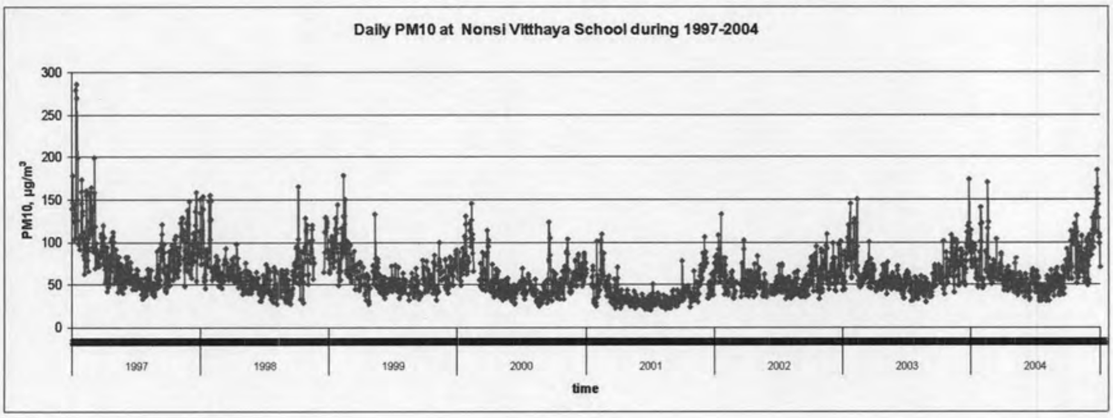
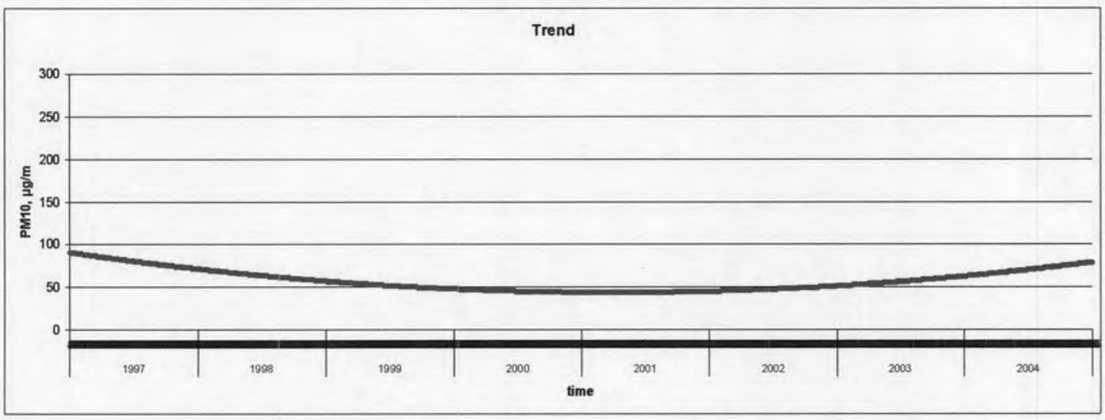


Figure 4.22 seasonal index of the PM10 time series.

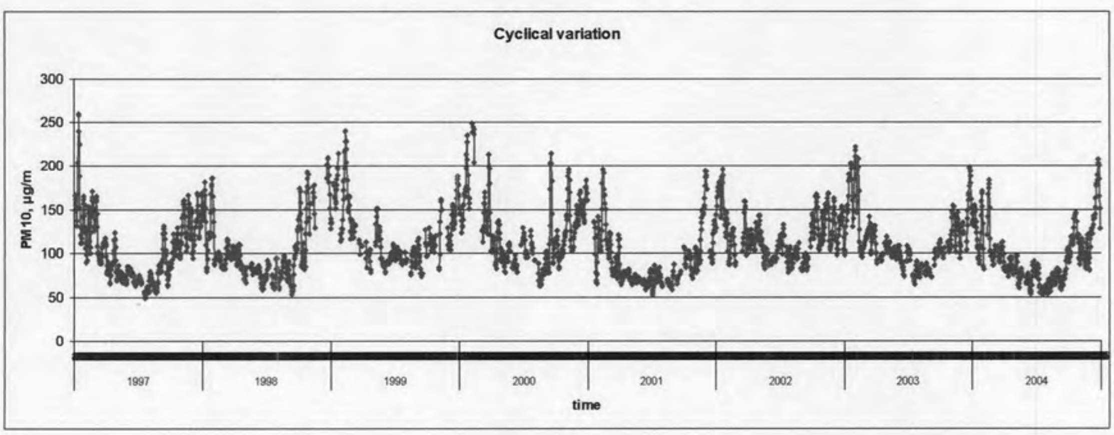
had decreased during 1997 to 2000. During 2001 to 2004, the use of fuel oil had not increased but the use of diesel had increased. These reasons had corresponded with the increasing of PM10 trend. Cyclical variation of the PM10 data had corresponded with climatic seasonal variation of Thailand. PM10 had low values in rainy season and relatively high values in winter and summer seasons.



(a)



(b)



(c)

Figure 4.23 (a) Daily average PM10 data at Nonsi Vitthaya School during 1997-2004 (b) Trend (c) Cyclical variation.

Table 4.1 Volume of fuel treading in Bangkok.

year	Gasoline		Diesel		Fuel oil
	Octane 91	Octane 95	High Speed	Low Speed	
1997	397,310	2,187,452	3,641,076	116,036	3,587,275
1998	536,574	2,055,108	3,896,333	87,696	3,408,140
1999	579,367	1,936,950	3,331,260	85,680	3,290,748
2000	1,059,760	1,384,107	3,531,022	72,971	2,534,776
2001	1,259,614	1,232,547	4,246,706	83,881	1,943,729
2002	1,479,212	1,253,301	4,912,599	95,620	1,746,937
2003	1,545,364	1,303,814	5,660,832	80,538	2,010,754
2004	1,696,001	1,304,402	6,608,816	63,699	1,850,518

unit: thousand liters

Source: Department of Energy Business