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Aerosol optical properties in ultraviolet ranges and respiratory diseases in Thailand

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ABSTRACT

This study investigated the values of Angstrom parameters (α,β) in ultraviolet (UV) ranges by using AERONET Aerosol Optical Depth (AOD) data. A second-order polynomial was applied to the AERONET data in order to extrapolate to 320 nm from 2003 to 2013 at seven sites in Thailand. The α,β were derived by applying the Volz Method (VM) and Linear Method (LM) at 320–380 nm at seven monitoring sites in Thailand. Aerosol particles were categorized in both coarse and fine modes, depending on regions. Aerosol loadings were related to dry weather, forest fires, sea salt and most importantly, biomass burning in the North, and South of Thailand. Aerosol particles in the Central region contain coarse and fine modes, mainly emitted from vehicles. The β values obtained were associated with turbid and very turbid skies in Northern and Central regions except Bangkok, while β results are associated with clean skies in South. Higher values of the β at all sites were found in the winter and summer compared with the rainy season, in contrast to South where the highest AOD was observed in June. The β values were likely to increase during 2003–2013. These values correlate with worsening health situations as evident from increasing respiratory diseases reported.

1. Introduction

Aerosols can significantly reduce UV radiation and also affect the radiative transfer in the Earth's atmosphere (Kumharn et al., 2012; De Bock et al., 2014). Recently, it has been observed that desert dust and aerosols from biomass burning can significantly decrease surface UV levels (WHO, 2002). In addition, absorption of solar UV radiation by anthropogenic aerosol particles in highly polluted urban areas reduces surface UV radiation, which may mask the increase in UV cause by low column ozone episodes (Sellitto et al., 2006). There is increasing concern that the recent increase in the level of aerosol particles in the northern and southern atmosphere of Thailand will reduce visibility and cause health problems. In addition, the industrial growth in Thailand which leads to the current environmental condition and what has been done and needs to be done to improve the situation. Since the UV attenuation at the earth's surface is due to atmospheric aerosols, AOD data can be used to measure the effects of aerosols on UV levels. Recently, there has been an increased interest in AOD retrieval in the UV, visible and near IR regions of the spectrum, due to the ill-defined impacts of aerosol on radiative forcing and climate change. The wavelength dependence of the AOD varies depending on the aerosol type and its physical and chemical characteristics. It is described (Equation (1)) by the wavelength exponent (α) (Angstrom, 1929), which is closely correlated to the size distribution of the aerosol particles. Therefore, AOD can be written as follows:

$$\tau = \beta\lambda^{-\alpha} \tag{1}$$

where τ is the AOD;β is the optical depth at λ=1 μm(Angstrom's turbidity);λ is the wavelength, and α is the wavelength exponent.

Currently, there are four parameters describing the atmospheric turbidity: the Linke turbidity T_L, the Unsworth-Monteith turbidity T_U, the Schuepp coefficients, B, and the Angstrom turbidity parameters, α,β, (Kambezidis et al., 2001). The Linke factor (Linke, 1922) applies to the attenuation of extraterrestrial radiation by the dry atmosphere and puts more emphasis on an atmosphere without water vapour. The Unsworth-Monteith coefficient (1973; Unsworth and Monteith, 1972) describes the absorption of solar radiation by dust with water vapour content. Lastly, the Angstrom and Schuepp coefficients (Angstrom, 1929; Schüepp, 1949) both have a spectral definition which corresponds to the AOD at 1 μm(algorithm uses the base e) and 0.5 μm(algorithm uses the base 10), respectively, and for this reason are true turbidity coefficients affected by aerosol total burden only (Gueymard and Kambezidis, 1997; Kambezidis et al., 1992). However, those coefficients differ in relation to common logarithm. Therefore, these α and β coefficients are the preferred technique used for aerosol climatology studies (Cachorro et al., 1987, 2001; Gueymard, 1998; Janjai et al., 2003; Kambezidis et al., 2001; Kaskaoutis and Kambezidis, 2006, 2008; Kaskaoutis et al., 2006; Pedrós et al., 1999; Smirnov et al., 2002; Volz, 1974).

Angstrom parameters(α,β) are typically considered as independent parameters. The β parameter is associated with the particle concentration and is equal to the AOD at 1 μm, whilst the α parameter is related to the size of particles (Cachorro et al., 1993, 2001; Kambezidis et al., 2001; Kaskaoutis et al., 2007; Kumharn, 2010; Shifrin, 1995;

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Toledano et al., 2007). Values of $\alpha \leq 1$ indicate size distributions dominated by coarse mode aerosols (radii ≥0.5 µm) typically associated with dust and sea salt, whilst values of $\alpha \geq 2$ indicate size distributions dominated by fine mode aerosols (radii ≤0.5 µm) usually associated with urban pollution and biomass burning (Angstrom, 1929). In addition, Angstrom exponent ranges in the interval of 1.0–1.55 characterized by aerosol size contained fine mode sub-micron (radius <1 µm) and coarse mode super-micron (radius >1 µm) (Eck et al., 1999, 2001; Holben et al., 2001).β parameter is associated with atmospheric cleanliness low values describe clean sky whereas high values describe very turbid sky as can be seen from the data in Table 2 (Iqbal, 1983). Although most AOD research to date has focused on the visible (400–700 nm) and infrared (700–1000 nm), this study will explore the UV part of the spectrum. Previous research in this field has looked at wavelengths larger than 340 nm part of UV, especially that AERONET that provide 340 and 308 nm. Throughout the literature review the AOD, particularly in visible and near IR, is often used for determining aerosol size distribution.

Recently, there has been an increased interest in AOD retrieval in the UV, visible and near IR regions of the spectrum, due to the ill-defined impacts of aerosol on radiative forcing and climate change. Throughout the reviewed literature the AOD, particularly in visible and near IR, is often used for determining aerosol size distribution according to Angstrom's equation. These data have been further used to calculate the Angstrom parameters which provide us with further information about the aerosol, resulting in an improved understanding of the aerosol climatology at UV wavelengths. In this study α, β were investigated at seven sites (Chiang Mai, Chulalongkorn, Mukdahan, Phi mai, Silpakorn Nakhon Pathom, Ubonratchathani, Songkhla) in Thailand, which would increase a better understanding of α and β climatology and its impact on global climate changes in tropical regions. Our results encourage the widespread uptake of AERONET data.

2. Data collection

The AERONET is a network of ground-based aerosol properties measurement. Sun photometer (AERONET, 2009) which is widely used in the AERONET network measured at the nominal wavelengths of 340, 380, 440, 500, 675, 870, and 1020 nm. Sunphotometers are used for measurement of direct spectral solar radiance and then AODs are determined. The AODs are retrieved via an inversion algorithm developed by Holben et al. (1998, 2001). However, AERONET is not always perfect for all purposes of analysis. The errors, especially, for interpolation, can be very large in some cases such as low AOD, large sun zenith angle and so on. Validation of the AOD at 320 nm obtained from AERONET was addressed through a comparison with the Brewer AOD (Brewer Aerosol Optical Depth) at 320 nm (Kumharn and Sudhibrabha, 2015). Brewer was designed for direct UV measurements which is a useful method for detecting absorbing aerosols (smoke and dust), which cannot be effectively discriminated in the visible range.

AERONET AOD data at 320–380 nm were applied on LM and VM at seven sites in Thailand to determine Angstrom parameters from 2003 to 2013. Thailand is usually divided into 4 regions (North, Central, North-east, and South). The Northern part of Thailand is surrounded by highest mountains and forests. The Central region is where Bangkok is situated, covering the broad alluvial plain of the Chao Phraya River. The Northeast is situated on the Khorat Plateau, with the Mekhong River forming its northern border. Southern Thailand extends from Bangkok all the way down the Malay Peninsula to west Malaysia's northern border. The west lays the Andaman Sea, while Gulf of Thailand is located along the east side. As Table 1 shows, there are seven sites of Sun Photometer operated under the AERONET in Thailand.

3. Methodology

Angstrom parameters will be determined by using Linear fitting method (LM) (Cachorro et al., 1987; Volz and Sheehan, 1971) and Volz method (VM), which are given below.

Linear fitting method (LM) is based on a linearisation of Angstrom's Equation (1) which plots a log-log of the AOD versus the wavelength:

$$\ln\,\tau_{\mathrm{a}}(\lambda) = -\alpha\,\ln\,\lambda + \ln\,\beta \tag{2}$$

We found that the slope of strength line yields α while the intercept providesβ.

3.1. Volz method (VM)

The α and β parameters can be obtained using VM and are calculated by the following system of equations for each *i* and *j*:

$$\tau_{\mathrm{a}}\left(\lambda_{\mathrm{i}}\right) = \beta\lambda_{\mathrm{i}}^{-\alpha} \tag{3}$$

$$\tau_{\mathrm{a}}\left(\lambda_{\mathrm{j}}\right) = \beta\lambda_{\mathrm{j}}^{-\alpha} \tag{4}$$

Using a natural logarithm a linear system is achieved from which α and β can be retrieved at each wavelength λ:

$$\alpha(\lambda) = \ln\left[\tau_{\mathrm{a}}\left(\lambda_{\mathrm{i}}\right)/\tau_{\mathrm{a}}\left(\lambda_{\mathrm{j}}\right)\right]/\mathrm{In}\left(\lambda_{\mathrm{j}}/\lambda_{\mathrm{i}}\right) \tag{5}$$

$\alpha(\lambda)$ is constant for λ_i and. λ_j

The α parameter is determined from Equation (5) and is then used in the following equation to calculateβ.

$$\beta = \frac{\tau\left(\lambda_{\mathrm{i}}\right)}{\lambda_{\mathrm{i}}^{-\alpha}} \quad \text{or} \quad \beta = \frac{\tau\left(\lambda_{\mathrm{j}}\right)}{\lambda_{\mathrm{j}}^{-\alpha}} \tag{6}$$

The LM is required for a wider range of wavelength, whist the VM can be applied for a narrow wavelengths range. In this study, LM (320–380 nm) and VM (320–380 nm) will be applied for α and β retrieval at 7 AERONET sites in Thailand during 2003–2013.

4. Validations

A strong relationship between the values of Brewer#121 AOD at 320 nm on the rooftop of the meteorological department, Bangkok (13.7°N, 100.6°E) and those of the AERONET AOD (320 nm) at Chulalongkorn University, Bangkok (13.7°N, 100.5°E) has been reported (Kumharn et al., 2015). In addition, Kumharn et al. (2015) was found good agreement between Brewer#121 and AERONET AOD at 320 nm on the rooftop of the meteorological building of Southeastern Meteorological Center in Songkhla.

Table 1
List of Sun Photometer sites operated under the AERONET in Thailand.

Station	λ (nm)	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Chiang Mai Meteorological Station Chiang Mai 18.78°N, 98.98°E	340				✓	✓	✓	✓	✓	✓	✓	✓
	380				✓	✓	✓	✓	✓	✓	✓	✓
	440				✓	✓	✓	✓	✓	✓	✓	✓
	500				✓	✓	✓	✓	✓	✓	✓	✓
	675				✓	✓	✓	✓	✓	✓	✓	✓
	870						✓	✓	✓	✓	✓	✓
	1020				✓	✓	✓	✓	✓	✓	✓	✓
Chulalongkorn Bangkok 13.40°N,100.37°E	340	✓	✓									
	380	✓	✓									
	440	✓	✓									
	500	✓	✓									
	675	✓	✓									
	870	✓	✓									
	1020	✓	✓									
Mukdahan 16.49°N, 104.56°E	340	✓	✓	✓	✓	✓	✓	✓	✓			
	380	✓	✓	✓	✓	✓	✓	✓	✓			
	440	✓	✓	✓	✓	✓	✓	✓	✓			
	500	✓	✓	✓	✓	✓	✓	✓	✓			
	675	✓	✓	✓	✓	✓	✓	✓	✓			
	870	✓	✓	✓	✓	✓	✓	✓	✓			
	1020	✓	✓	✓	✓	✓	✓	✓	✓			
Phi mai Nakhon Ratchasrima 15.10°N,102.33°E	340	✓	✓	✓	✓	✓	✓					
	380	✓	✓	✓	✓	✓	✓					
	440	✓	✓	✓	✓	✓	✓					
	500	✓	✓	✓	✓	✓	✓					
	675	✓	✓	✓	✓	✓	✓					
	870	✓	✓	✓	✓	✓	✓					
	1020	✓	✓	✓	✓	✓	✓					

Table 1 (*Continued*)

Station	λ (nm)	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Silpakorn Nakhon Pathom 13.82°N,100.04°E	340						✓	✓	✓	✓	✓	✓
	380						✓	✓	✓	✓	✓	✓
	440						✓	✓	✓	✓	✓	✓
	500						✓	✓	✓	✓	✓	✓
	675						✓	✓	✓	✓	✓	✓
	870						✓	✓	✓	✓	✓	✓
	1020						✓	✓	✓	✓	✓	✓
Ubonratchathani 15.25°N,104.87°E	340							✓	✓	✓	✓	
	380							✓	✓	✓	✓	
	440							✓	✓	✓	✓	
	500							✓	✓	✓	✓	
	675							✓	✓	✓	✓	
	870									✓	✓	
	1020							✓	✓	✓	✓	
Songkhla 7.2°N, 100.60°E	340						✓		✓	✓	✓	✓
	380						✓	✓	✓	✓	✓	✓
	440						✓	✓	✓	✓	✓	✓
	500						✓	✓	✓	✓	✓	✓
	675						✓	✓	✓	✓	✓	✓
	870						✓	✓	✓	✓	✓	✓
	1020						✓	✓	✓	✓	✓	✓

Table 2
Parameter of various degrees of atmospheric cleanness.

Atmosphere	β	α	Visibility (Km)
Clean	0.00	1.30	340
Clear	0.10	1.30	28
Turbid	0.20	1.30	11
Very turbid	0.40	1.30	<5

Reproduced from Iqbal (1983).

5. Results and discussion

5.1. Angstrom parameters

The results of this investigation show that Angstrom parameters obtained from LM are consistent with Angstrom parameters obtained from VM (Figs. 1 and 2). However, the comparison between the two methods in some spectral bands had significant differences, especially at short wavelengths due to a poor signal-to-noise ratio and low turbidity conditions (Kaskaoutis and Kambezidis, 2008). In addition, theses parameters varied depending on the method used and the spectral resolution of the instrument. The strong absorption of UV radiation by ozone, the LM appears to be the best method in the strong absorption brands (Kaskaoutis and Kambezidis, 2008). Therefore, Angstrom parameters obtained from LM are illustrated. As illustrated in Fig. 3 (Chaing Mai), the frequency distribution of α is much higher for the interval of 0.81–1.0 at 28.94%. On the question of α, this region found that aerosol particles in Chaing Mai show a clear domination by coarse mode which is associated with biomass burning and forest fires (Gautam et al.,2013). The frequency distribution of α is much higher for the interval of 1.01–1.20 at 22.42% in Chulalongkorn and the interval of 0.81–1.00 at 32.20% in Silpakorn (Fig. 2). Aerosol particles contained by both fine and coarse modes in Bangkok and coarse mode in Silpakorn (Janjai et al., 2009). This is probably caused by urban pollution, mainly from road traffic, industrial and anthropogenic activities as the major sources of aerosol emission. The frequency distribution of α is much higher for the in-

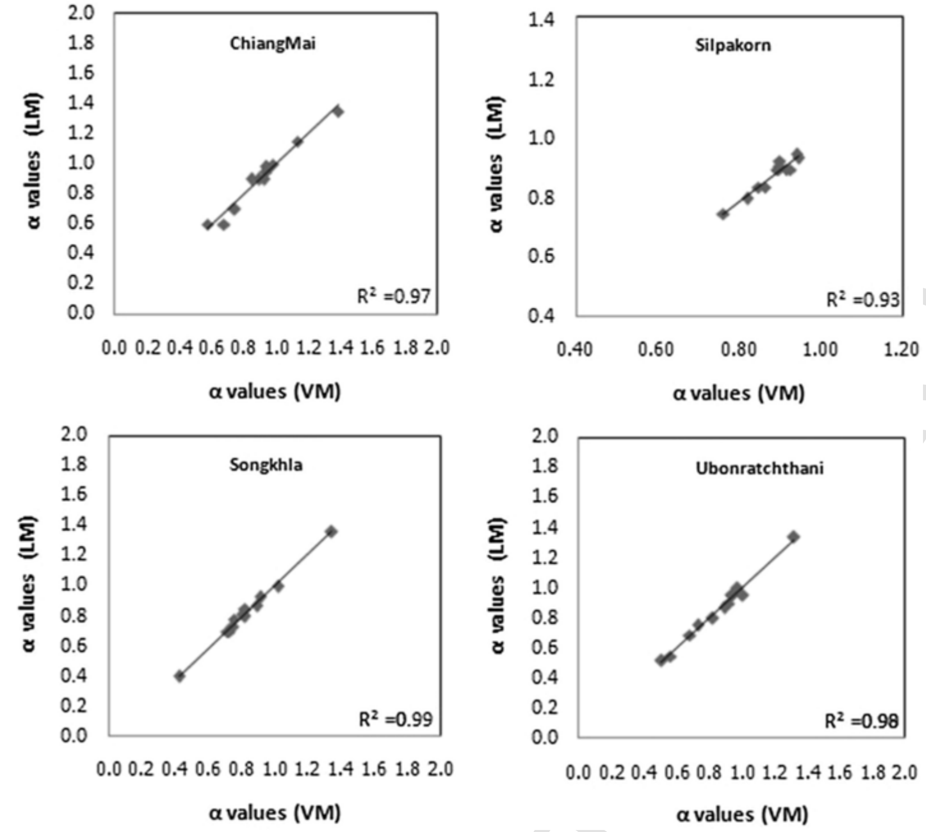

Fig. 1. The mean α values derived via VM and LM for 320–380 nm at 4 regions.

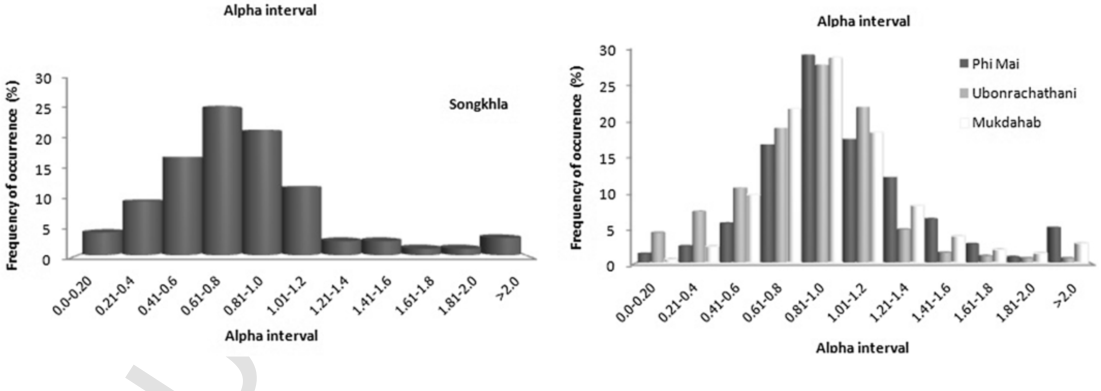

Fig. 3. Frequency of occurrence of used LM between 2003 and 2013 in Chaing Mai (North), Chulalongkorn and Silpakorn (Central), SongKhla (South), and Phi Mai, Ubon Rachathani, and Mukdahan (North east).

terval of 0.81–1.0 in Phi Mai, Ubonrachathani and Mukdahan at 29.59%, 28.16% and 29.24%, respectively. This region indicates size distributions contained by coarse mode aerosols that are typically associated with dust and biomass burning (Eck et al., 2003). The frequency distribution of α is much higher for the interval of 0.61–0.80 at 25.89% in Songkhla. Aerosol particles in SongKhla show a clear domination by coarse mode. This domination is probably caused by sea salt, mainly from sea spray generated by various physical processes.

It can be seen from the data in Fig. 4 that the most frequently occurring value of β in Chiang Mai is more than 0.4 at 28.47%, associated with very turbid skies. The most frequently occurring value of β

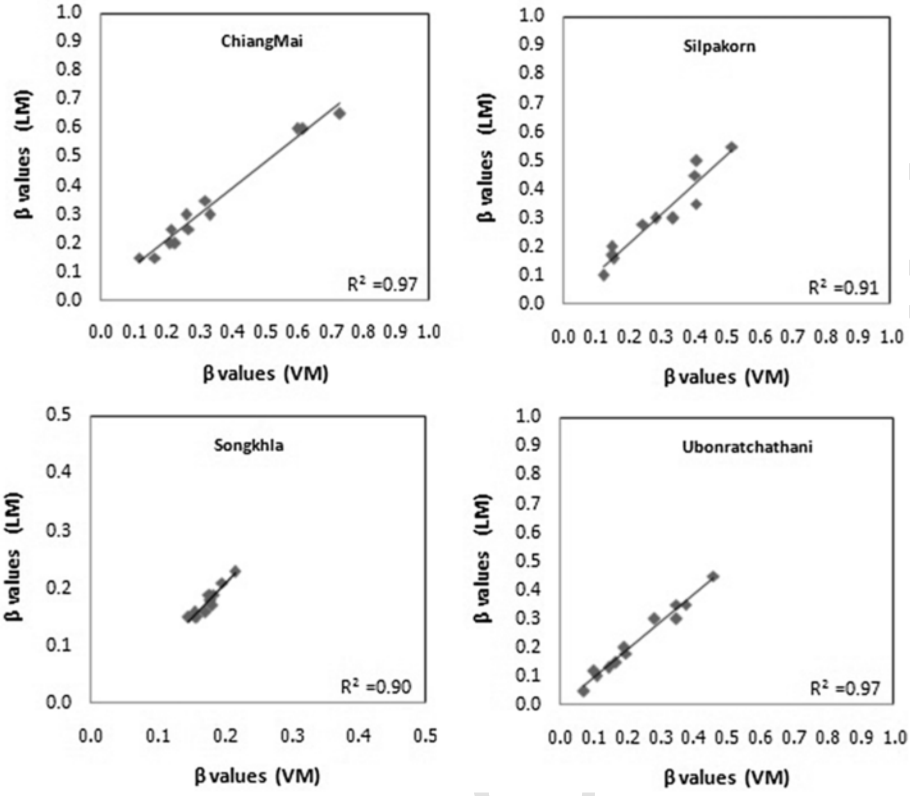

Fig. 2. The mean β values derived via VM and LM for 320–380 nm at 4 regions.

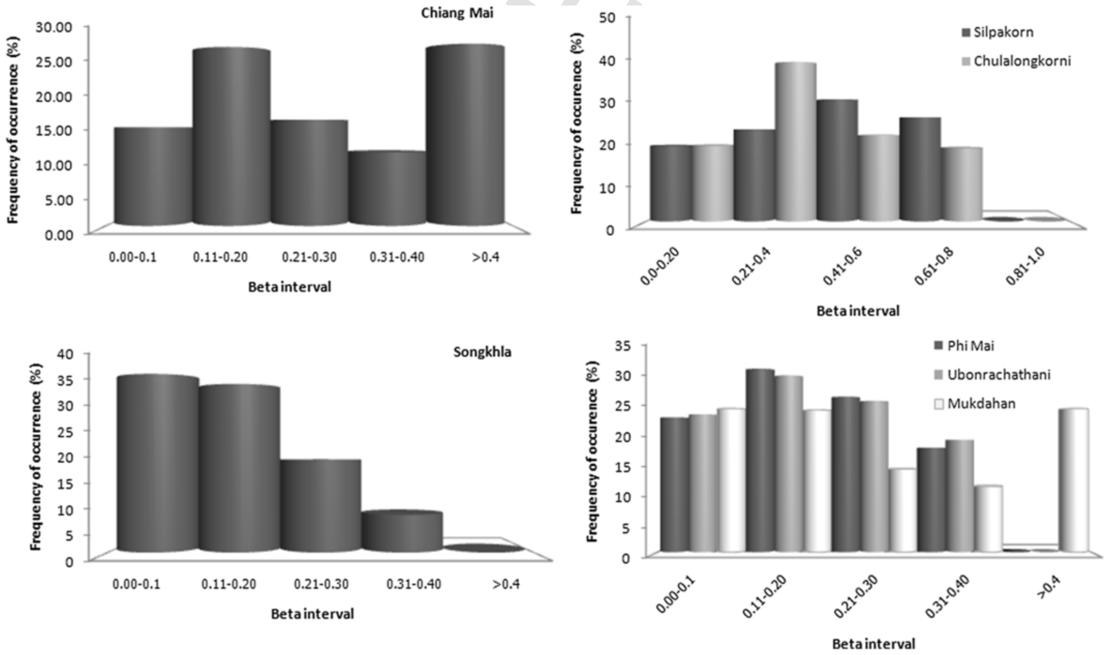

Fig. 4. Frequency of occurrence of β derived from the LM between 2003 and 2013 in Chiang Mai (North), Chulalongkorn and Silpakorn (Central), Songkhla (South), and Phi Mai, Ubonrachathani and Mukdahan (North east).

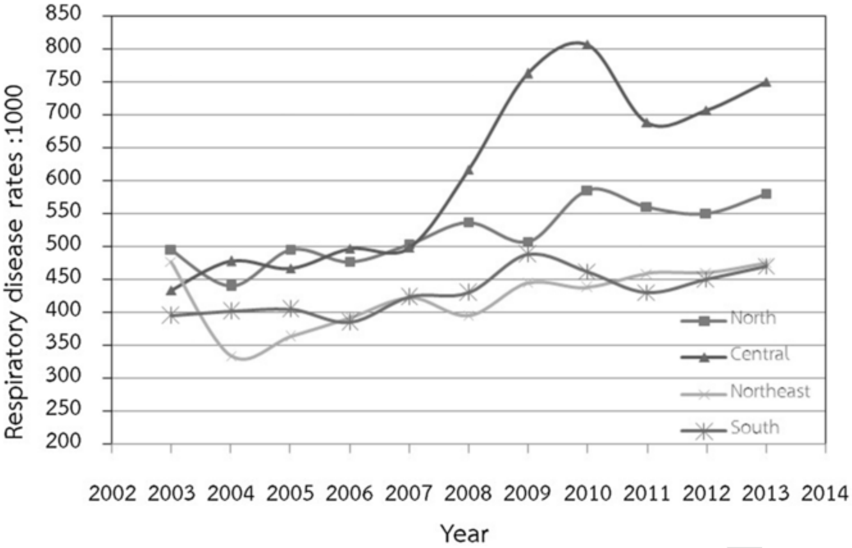

Fig. 5. The numbers of patients with respiratory diseases per thousand in four regions of Thailand from 2003 to 2013.

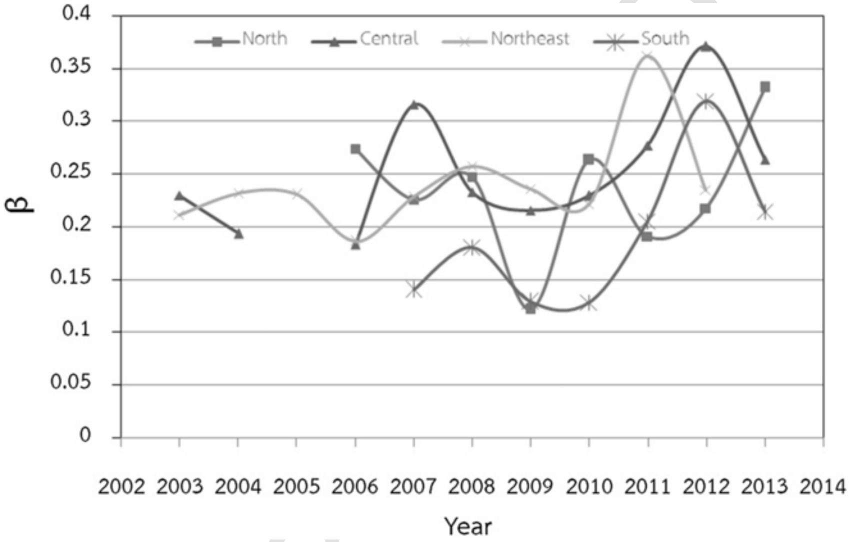

Fig. 6. The year to year variation in β for four regions of Thailand from 2003 to 2013.

in Silpakorn is the interval of 0.21–0.30 at 30.92%, associated with turbid skies. In general, Chulalongkorn has higherβ, attributed to local pollution as Bangkok is regarded as being one of the larger cities in Thailand. However, the most frequently occurring value of β in Chulalongkorn was in the interval of 0.11–0.20 at 40%, associated with clear skies. Note that the instrument in this site only operated in 2003–2004 with a small amount of data.

The most frequently occurring value of β is in the interval of 0.11–0.20 at 30.46% and 30.05% in Phi Mai, and Ubonratchathani respectively. The most frequently occurring value of β in Songkhla and Mukdahan are in the interval of 0.00–0.10 at 41.27% and 24.84% respectively. β results in North east are associated with clear skies, while β results in South are associated with clean skies. Higher values of the β at all sites were found a in the winter (from Mid-October to Mid-Feb) and summer (from Mid-Feb to Mid-May) compared with the rainy season (from Mid-May to Mid-October), in contrast to South (Songkhla) where the highest AOD was observed in June.

5.2. Aerosols and respiratory diseases

Increased levels of aerosol particles in the atmosphere is known to cause both short-term acute symptoms, like asthma and bronchitis, and long-term chronic irritation and inflammation of the respiratory track, leading to cancer (Goudie, 2014). The air pollution in Thailand contributes significantly to respiratory diseases every year (Danpaiboon et al., 2010). In general, forest fires in Thailand occur during the dry season from December to May, reaching a peak in February–March (Forest Fire Control Division National Park, 2015). Respiratory diseases were worst in beginning of the dry season when aerosol loadings were largely due to the burning of agricultural waste and forest fire (Gautam et al., 2013; Ha Trang and Tripathi, 2014; Wang et al., 2015). The numbers of patients with respiratory diseases per thousand in four regions of Thailand are shown in Fig. 5. The graph shows that there has been a slight rise in the number of patients with respiratory diseases since 2003. Similarly, aerosol particles are likely to increase at all sites from 2003 to 2013, as can be seen in Fig. 6. This finding shows that aerosols particles may lead to increased respiratory diseases as a result of a slight increase in the occurrence of atmospheric turbidity has been followed by an increase in respiratory diseases.

6. Conclusions

This study investigated α,β in UV ranges by using AERONET AOD from 2003 to 2013. Extrapolation was applied to AERONET AOD at seven sites in Thailand to estimate AOD at 320 nm. In order to achieveα,β, the LM and VM were applied to the spectral AOD in the UV ranges of 320–380 nm obtained from AERONET in four regions. It was found that aerosol particles were categorized in both coarse and fine modes which are associated with small and large particle sizes, depending on regions. Aerosols loading were related to dry weather, forest fires and most importantly, biomass burning in Northern and Northeastern regions, while aerosols loading were related to transportation, factories and human activities in Central region, and related to sea salt in Southern region. The β values were likely to increase from 2003 to 2013, similarly to an increase in respiratory diseases reviewed by Ministry of Public Health.

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