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Aerosol Optical Depth: A study using Thailand based Brewer Spectrophotometers

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Abstract

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The Aerosol Optical Depth (AOD) was retrieved from the direct-sun Brewer observation by the application of the Beer's law for the years 1997-2011 at two monitoring sites in Thailand (Bangkok and Songkhla). AOD values measured in Bangkok exhibited higher values than Songkhla. In addition, AOD values were higher in the morning and evening in Bangkok. In contrast, the AOD values in Songkhla were slightly lower during the mornings and late afternoons. The variation of AOD was seasonal in Bangkok, with the higher values found in summer (from Mid-February to Mid-May) compared with rainy season (Mid-May to Mid-October), whilst there was no clear seasonal pattern of AOD in Songkhla.

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Keywords: Aerosol; Atmospheric aerosol; Aerosol Optical Depth; Aerosol optical properties 20

1. Introduction 22

This research focuses on total atmospheric column aerosol concentration for locations in central and southern of Thailand. Aerosol concentrations in the environment play an increasingly deleterious role in global climate change, ecosystem processes and human health, as they critically 27 change the balance between the radiation entering and 28 leaving the atmosphere. The measure of Aerosol Optical 29 Depth (AOD) provides a quantitative measure of the 30 extinction of solar radiation in a vertical column of 31 way of scattering and absorption by aerosols 32 (Schmid et al., 1997). The wavelength dependence of the 33 AOD typically decreases with increasing wavelength. 34

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Aerosols can significantly reduce UV radiation and also 35 affect the radiative transfer in the Earth's atmosphere 36 (Sellitto et al., 2006). It has been observed that desert dust 37 and aerosols from biomass burning can significantly reduce 38 surface UV levels (WHO, 2002). In addition, absorption of 39 solar UV radiation by anthropogenic aerosol particles in 40 highly polluted urban areas reduces surface UV radiation, 41 resulting in less ozone generation (Sellitto et al., 2006). 42 43 There is increasing concern that the recent rise in high concentration of aerosol particles in the atmosphere in 44 northern and southern Thailand during summer will cause 45 air pollution and health problems (Sukitpaneenit and Kim 46 47 Oanh, 2013).

Aerosols attenuate UV radiation at the earth's surface 48 and AOD data can be used to measure the effects of 49 aerosols on UV levels. Recently, there has been increased 50 51 interest in AOD retrieval in the UV range, visible to infrared (IR) regions of the spectrum, due to the complex prop-52 erties of aerosols on climate change. Throughout the

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reviewed literature on the AOD, the principal instruments 54 used for measuring AOD are in visible and near IR radia-55 tion. One criticism of some of this literature (Janjai et al., 56 2009: Jantarach et al., 2012) is that aerosol impacts on 57 UV have never been measured by using Brewer Spec-58 trophotometers in Thailand. Interestingly, this is the only 59 instrument that can measure direct solar radiation, ozone, 60 and sulphur dioxide levels at the same time. Therefore, 61 uncertainty in aerosol optical thickness retrieval will be 62 reduced due to ozone and sulphur dioxide dada obtained 63 from the same sources. Measurement in the UV range from 64 space is a useful method for detecting absorbing aerosols 65 (smoke and dust) (Li et al., 2012), which cannot be effec-66 tively discriminated in the visible range. Moreover, it is 67 being able to detect aerosols above backgrounds, which 68 are bright in the visible range, such as clouds and snow 69 (Li et al., 2012). So this study has focused on the Brewer 70 AOD retrieval at UV wavelengths by using the direct-sun 71 measurement based on Beer's law, which provides a better 72 nderstanding of AOD climatology and its impact on glo-73 oal climate changes in tropical regions. Our results encour-74 age the widespread use of the Brewer Spectrophotometer 75 provide greater spatial availability of AOD data. 76

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2. Instrumentations 77

Brewer Spectrophotometer measures the direct solar 78 radiation that passes through the atmosphere at five differ-79 ent wavelengths; 306, 310, 313, 316, and 320 nm. It was 80 designed for direct UV measurements to determine column 81 ozone by using the ground-based direct solar radiation mon-82 itoring taken at four different wavelengths in the UV range 83 (Gröbner, 2003; Silva and Kirchhoff, 2005; Savastiouk, 84 2006) and three of them are used to produce the total 85 amount of sulphur dioxide in a vertical column. The World 86 Ozone Network has incorporated more than 200 Brewers in 87 over forty different countries throughout the world since 88 1982. They are mostly deployed to measure ozone and sul-89 phur dioxide with currently only a small number researching 90 OD. In this study, two Brewers make the direct sun 91 measurements for AOD calculations. One Brewer#121 has 92 been installed on the rooftop laboratory of the meteorolog-93 ical department that has been located in the city centre area 94 of Bangkok (13.7°N, 100.6°E) since 1997. The other 95 Brewer#120 has been operational on the rooftop of the 96 meteorological building of Southeastern Meteorological 97 Center in Songkhla (7.2°N, 100.6°E) since 1997 and, while 98 on peninsula light industry will influence the environment 99 of the region. Both the instruments have been well main-100 tained and are regularly calibrated against a world standard 101 instrument, meaning that they are operating to WMO GAW 102 standards (Kumharn and Sudhibrabha, 2014). 103

3. Methodology 104

The UV attenuation is mainly due to the strong ozone 105 absorption and a small amount of sulphur dioxide and 106

107 nitrogen dioxide absorption. It is also due to Rayleigh and aerosol scattering, so therefore Beer's law in the UV 108 range can be rewritten as: $109 \\ 110$

$$I_{n\lambda} = I_{n\lambda}^{0} E_{0} \exp(-m\tau)$$
(1.1) 112

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here	•		113
$I_{n\lambda}$ is irradiance at wa	avelength λ a	t the earth's atmo-	114
sphere (W/m^2)			116
I_{μ}^{0} is the extraterrestri	al irradiance	of the sun (W/m^2) .	177
E_0 is the eccentricity c	orrection fact	or	118
m is the air mass			129
τ is the extinction opti	ical depth		120
	- 		123 124

(1.2) $\tau = \tau_a + \tau_{O_3} + \tau_r + \tau_{SO_2} + \tau_{NO_2}$

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(1 4)

127 where a is aerosol, O₃ is ozone, SO₂ is sulphur dioxide, NO_2 is nitrogen dioxide, r is Rayleigh scattering. 128

Brewer AOD calculations in this study are performed on 129 a clear sky day, as cloud cover has been observed to falsely 130 increase apparent aerosol concentration by as much as 5% 131 (Kaufman and Koren, 2006). In general, the most common 132 method of monitoring a clear sky day is derived from cloud 133 cover observations, measured in Okta. When the sky is fully 134 covered by clouds, cloud cover is defined as eight Okta, 135 whereas a sky with no cloud cover is recorded as zero Okta. 136 Unfortunately, this study does not have a record of clear 137 sky data. Nonetheless, because of the variation in the inten-138 sity of the sun's radiation during the day, the direct sun 139 measurements (individual DS measurement), taken 5 times 140 in about 3 min every 30 min from the Brewer on a clear sky. 141

Beer's law requires measurement of the direct beam solar 142 radiation, and then a method of distinguishing the different 143 extinction parameters, which become more or less relevant 144 145 depending on wavelength. A considerable amount of literature has been published on AOD, sulphur dioxide and 146 nitrogen dioxide, which is often considered negligible; how-147 ever, in some studies account was taken of sulphur dioxide, 148 allowing a more accurate determination of the AOD to be 149 achieved (Arola and Koskela, 2004; Cheymol et al., 2009). 150

Rayleigh scattering is used to describe light scattering by 151 molecules which are much smaller than the wavelength of 152 light. It was calculated for each wavelength using the 153 approximated expression of Bucholtz (1995) by the follow-154 155 ing equation:

$$\tau_{r\lambda} = 0.008659\lambda^{-(3.6772 + 0.389\lambda + 0.09426/\lambda^2)}$$
(1.3)

when λ is wavelength (μ m).

Ozone absorption has been investigated by a number of researchers. In the UV and visible ranges, Vigroux presents attenuation coefficient in Bouguer's law form for ozone (Iqbal, 1983):

$$\tau_{a\lambda} = \exp(-\kappa_{0\lambda}l) \tag{1.4}$$

when

- λ is wavelength (μ m) l is the total vertical ozone (cm)
- $\kappa_{o\lambda}$ is the spectral ozone absorption coefficient

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Fig. 1. Scatter-plots of the simultaneous AOD measurements between AERONET AOD at 320 nm in Chulalongkorn University, Bangkok (13.7°N, 100.5°E) and Brewer#121 at 320 nm on the rooftop of the meteorological department, Bangkok (13.6°N, 100.6°E) in 2004.

sulphur dioxide and nitrogen dioxide were calculated using 172 a similar formula to ozone with sulphur dioxide absorption 173 coefficients $(k_{so_2\lambda})$ and nitrogen dioxide absorption coeffi-174 cients $(k_{Nor\lambda})$. 175

4. Validations and results 176

Validation of the AOD using the Brewer was addressed 177 through a comparison with independent measurements of 178 the AOD obtained from AERONET Sun photometer data 179 by a second-order polynomial fit to the AERONET data in 180 order to extrapolate to 320 nm. The time difference 181 between AOD measurements from AERONET versus 182 Brewer instruments were allowed to apply in 0-20 min. 18 AODs obtained from both instruments were retrieved 18 under the following conditions: clear sky and an air-mass 185 of less than 4. Fig. 1 shows there is a linear relation 186 between the values of Brewer#121 AOD at 320 nm on 187 the rooftop of the meteorological department, Bangkok 188 (13.7°N, 100.6°E) and those of the AERONET AOD 189 (320 nm) at Chulalongkorn University, Bangkok (13.7°N, 190 100.5°E) with correlation coefficients of 0.89. Both sites 191 are located in the city centre area of Bangkok. Note that 192 the AERONET data in Bangkok are available in 193 2003-2004. Unfortunately, Brewer AODs data in Bangkok 194 are only available in 2004. Therefore the data in 2004 were 195 only applied for validation. 196

From the data in Fig. 2, there was a significant positive 197 correlation between Brewer#121 and AERONET AOD at 198 320 nm on the rooftop of the meteorological building of 199 Southeastern Meteorological Center in Songkhla, with a 200 correlation coefficient of 0.89. However, systematic error 201



Fig. 2. Scatter-plots of the simultaneous AOD measurements between AERONET AOD at 320 nm and Brewer#120 at 320 nm in Southeastern Meteorological Centre, Songkhla (7.2°N, 100.6°E) in 2010.

in Brewer#121 is due to calibration uncertainty in either the AERONET or Brewer instruments. The AERONET measurements of AOD are accurate to ~0.01 in the visible and near infrared and ~0.02 in the UV wavelength (Eck et al., 1999).

At longer wavelengths, the AOD generally decreases 207 rapidly as wavelength increases, and one might expect this 208 to continue into the UV. The wavelength dependence of the 209 AOD varies depending on the aerosol type and its physical 210 and chemical characteristics. It is described by the wave-211 length exponent (Eck et al., 1999), which is closely corre-212 lated to the size distribution of the scattering aerosol 213 particles. Higher values of the AOD at 320 nm obtained 214 from Brewer in Bangkok were found a small increase in 215 the in the afternoon hours (Fig. 3). This result may be 216 217 due to aerosol emission from transportation during afternoon rush hours. This finding is in agreement with Leong 218 and Laortanakul (2003) which demonstrated a gradual 219 increase in traffic noise level reaching a peak during morning and evening hours.

Fig. 4 shows the mean AOD diurnal data in Songkhla from 1997 to 2011 on the clear sky day, and an air-mass of 4. Higher values are found during the afternoon hours: this pattern is quite different to that of Bangkok (Fig. 4). The afternoon was warm with low humidity and moderate wind speed, all of which would contribute to continued suspension of aerosols. As illustrated in Fig. 5, the monthly variation in Bangkok (923 days) was found that higher values of AOD were found in summer, reaching the peak in March, whereas AODs in June were lower.

The weather in central, northern, and northeastern Thai-232 land is determined by three seasons. The weather is mostly 233 234 dry in the winter (from Mid-October to Mid-February) and

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Fig. 3. The mean AOD diurnal data in Bangkok from 1997 to 2011.



Fig. 4. The mean AOD diurnal data in Songkhla from 1997 to 2011.



Fig. 5. The monthly variation of mean AOD at 320 nm obtained from Brewer during clear sky days and an air mass of less than 4 in Bangkok and Songkhla from 1997 to 2011. The error bars represent standard deviation for Brewer AOD.

summer (from Mid-February to Mid-May) whereas the 235 rainy season is from Mid-May to Mid-October. AOD might 236 be related to an increase of heat convection that uplifts dust 237 particles from road traffic to the atmosphere. Another pos-238 sible explanation for this is that high pressure governed 239 through those months, with dry weather and plenty of sun-240 shine, which keeps aerosol particles in the atmosphere for 241 longer periods as there is no wet deposition in summer. 242 The seasonality of Biomass Burning as a major aerosol 243



Fig. 6. The yearly average of AOD at 320 nm obtained from Brewer during clear sky days and an air mass of less than 4 in Bangkok and Songkhla from 1997 to 2011. The error bars represent standard deviation for Brewer AOD.

source in Thailand and neighboring countries during the dry season months (especially, February through April) (Gautam et al., 2013). This finding is in agreement with Janjai et al. (2003), which demonstrated, by using the Multi-Filter Rotating Shadowband Radiometer, that the AODs in Nakhon Phathom are higher in summer months.

Songkhla reiterates the fact that the AODs were no clear 250 seasonal pattern (1274 days); however, the highest AOD 251 was observed in June. These findings are consistent with 252 Kumharn et al. (2012) who used Brewer direct sun mea-253 surement so that weight is added to the method as well 254 as the result. The highest AOD was found in June in 255 Malaysia, which has a similar climate with south of Thai-256 land. In addition, it was found that less rainfall in the 257 Southern Thailand East Coast from February to Mid-258 September would contribute to aerosol particles suspended 259 in the atmosphere (Serm Janjai et al., 2012). The southern, 260 coastal region of Thailand really has only two seasons: 261 rainy season (from Mid-September to December) and dry 262 season (January to August).

Fig. 6, Bangkok data shows the yearly average of AOD 264 from 1997 to 2011. It is likely to drop slightly from 1997 to 265 2010. However, the years that do show increases (2000, 266 2005 and 2011) are the 3 years, reaching the maximum at 267 1.34 ± 0.02 . On a longer time scale the data in Songkhla 268 show that AOD had fluctuations from 1997 to 2011, reach-269 ing the peak in 2007. It seems likely that the result is due 270 eruptions of Kelut volcano in 2007 with volcanic and 271 smoke from wildfires on Sumatra, Indonesia ash being 272 the main source of emission (Overpeck and Cole, 2007; 273 Jeffery et al., 2013). However, in this study it was no 274 appreciable data from Brewer AOD calculation in some 275 years due to the poor weather conditions and serious storm 276 277 damage.

5. Conclusions

Ground based measurements of AOD are limited, and 279 mainly available at visible wavelengths. Thus identifying 280

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the possibility of a further routine source of ground based aerosol data is a major benefit for a better understand of aerosol properties in the UV wavelengths. For groundbased observing instrument in the UV is widely used Brewer Spectrophotometer. AOD has been retrieved from Brewer direct sun UV measurement using Beer's law. The diurnal variation in AOD demonstrated that the AOD values in Bangkok were higher in the morning and afternoon due to rush hour traffic. The variation of AOD values was seasonal, with the higher values found in summer compared with rainy. The mean AOD diurnal, on the other hand, was a slight drop during morning and late afternoon hours in Songkhla. There is no clear seasonal pattern in AOD for the whole year.

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