Atmospheric Pollution Research 6 (2015) 682-695

Atmospheric Pollution Research

www.atmospolres.com

AERONET data–based determination of aerosol types

Fuyi Tan [1], Hwee San Lim [1], Khiruddin Abdullah [1], Tiem Leong Yoon [1], Brent Holben [2]

[1] *School of Physics, Universiti Sains Malaysia, Malaysia*
[2] *NASA Goddard Space Flight Center, USA*

ABSTRACT

Aerosols are among the most interesting topics investigated by researchers because of their complicated characteristics and poor quantification. Moreover, significant uncertainties are associated with changes in the Earth's radiation budget. Previous studies have shown numerous difficulties and challenges in quantifying aerosol influences. In addition, the heterogeneity from aerosol loading and properties, including spatial, temporal, size, and composition features, presents a challenge. In this study, we investigated aerosol characteristics over two regions with different environmental conditions and aerosol sources. The study sites are Penang and Kuching in Malaysia, where a ground–based AErosol RObotic NETwork (AERONET) sun–photometer was deployed. The types of aerosol, such as biomass burning, urban/industrial, marine, and dust aerosols, for both study sites were identified by analyzing aerosol optical depth and angstrom exponent. Seasonal monsoon variation results in different aerosol optical properties, characteristics, and types of aerosols that are dominant in Penang and Kuching. Seasonal monsoon flow trend patterns from a seven–day back–trajectory frequency plotted by the Hybrid Single–Particle Lagrangian Integrated Trajectory model illustrated the distinct origins of trans–boundary aerosol sources. Finally, we improved our findings in Malaysian sites using the AERONET data from Singapore and Indonesia. Similarities in the optical properties of aerosols and the distribution types (referred to as homogeneous aerosol) were observed in the Penang–Singapore and the Kuching–Pontianak sites. The dominant aerosol distribution types were completely different for locations in the western (Penang–Singapore) and eastern (Kuching–Pontianak) parts of the South China Sea. This is a result of spatial and temporal heterogeneity. The spatial and temporal heterogeneities for the western and eastern portions of South China Sea provide information on the natural or anthropogenic processes that take place.

Corresponding Author:
Fuyi Tan
☎ : *+60-194721521*
🖷 : *+60-46579150*
✉ : *fuyitan@yahoo.com*
tf09_phy061@student.usm.my

Article History:
Received: 21 June 2014
Revised: 28 January 2015
Accepted: 29 January 2015

Keywords: *Seasonal monsoon, aerosol, aerosol optical depth (AOD), angstrom exponent, precipitable water (PW)*

doi: 10.5094/APR.2015.077

1. Introduction

Understanding atmospheric aerosols is crucial for climate change dynamics. Owing to the presence of large uncertainty on aerosol reports by the Intergovernmental Panel for Climate Change (IPCC) 2007 on radiative forcing of climate between 1750 and 2005, the influence of the anthropogenic and natural forcing agents of aerosol on climate dynamics remains unclear and is an active area of scientific research (IPCC, 2007). Even the most recent report by IPCC working group I in the fifth assessment report (IPCC, 2013) also cited the same problems, that is, aerosol interaction with radiation and the existence of clouds, which result in significant uncertainty because of the complex mixing of aerosols and their variation in large volumes of the atmosphere.

Aerosols remain poorly characterized because of the spatial and temporal variations of aerosols and of the existence of different aerosol types, which have different properties. As a result, the global impact of aerosols on the Earth's climate is difficult to quantify because of the lack of extensive and reliable measurements in most regions of the world (Hansen et al., 1997; Tripathi et al., 2005; Kaskaoutis et al., 2007; Kaskaoutis and Kambezidis, 2008; Russell et al., 2010). Many scientists believe that the origins of aerosol sources and their distribution in the atmosphere should be determined to understand why different locations have different aerosol types and are affected by environmental development, monsoon and southern oscillation variation, and seasonal change. The trans–boundary long–range transport of aerosols may interact with local aerosols, especially with cloud droplets, thus further enhancing the modification of their microphysical properties, such that precipitation processes and their radiative properties are influenced (Ichoku et al., 2004; Rosenfeld, 2007; Andreae and Rosenfeld, 2008; Lin et al., 2013).

With the large uncertainty in characterizing aerosols, a local study for every region is essential for verifying satellite imagery because the extraction of aerosol optical properties from remote sensing data has limited accuracy despite its capability to provide global–scale coverage of aerosol properties (Kaufman et al., 2002; Levy et al., 2005; Tripathi et al., 2005; Gupta et al., 2013). Local studies on aerosol optical properties can be conducted by using reliable equipment, such as sun–photometers or sky radiometers (Holben et al., 1998; Remer et al., 2008; Salinas et al., 2009). However, these methods are limited to space coverage, unlike satellite imagery. Therefore, ground– and space–based measurements are complementary in performing reliable and comprehensive studies on atmospheric aerosols.

Characterization of aerosol properties is important because of the rapid growth of both population and economic activities, which cause the anthropogenic aerosol emission rates to increase as a result of the increases in fossil–fuel combustion and biomass burning. These pollutants directly affect the climate and, at the same time, increasing the haze, fog, and cloudy conditions (Mukai et al., 2006), which decrease visibility, particularly under high turbidity. According to Salinas et al. (2009), Asian sources are known to differ from those in Europe or North America. More absorbing soot and organic components are added to the Asia Pacific atmosphere because of substantially greater coal and biomass burning emissions and long–range transport by wind

(Lelieveld et al., 2001; Huebert et al., 2003; Seinfeld et al., 2004). In Singapore, industrial and fossil fuel combustion from energy stations and mobile vehicles are the major anthropogenic aerosols, as well as the biomass burning aerosol from neighboring countries at a certain period of the year (Salinas et al., 2009).

According to an environmental quality report for Malaysia in 2010, power plants (main pollutants emitted are nitrogen dioxide and sulfur dioxide), motor vehicles (main pollutant emitted is carbon monoxide), and industries (main pollutant emitted is particulate matter) are the major air pollutants in Malaysia (DOE, 2010). The major pollutants of concern in Malaysia are ground–level ozone and particulate matter that is less than 10 µm (PM_{10}), with PM_{10} being dominant most of the time. Moreover, PM_{10} value will increase abruptly during trans–boundary haze pollution from Central Sumatra, Indonesia, especially during the southwest monsoon period (June to September).

In this study, we intend to determine the sources and origin of the aerosol types distributed in the Penang and Kuching regions, which have different environmental conditions. In additional, the aerosols for both regions are investigated with respect to seasonal change, and the major dominant aerosol type is determined according to ground–based sun–photometer measurement from the AErosol RObotic NETwork (AERONET) database.

2. Methodology

The study sites are located in Penang, Peninsular Malaysia and Kuching, East Malaysia; a ground–based AERONET sun photometer was available for each site [Figure S1, see the Supporting Material (SM)]. The northern and southern parts of Southeast Asia respectively span from 8 °N to 28 °N and 10 °S to 8 °N for longitudes between 90 and 130 °E. Level 2 AERONET data were used in this study because they were cloud–screened and verified. Sun–photometer made direct sun measurements every 15 min at 340, 380, 440, 500, 675, 870, 940 and 1 020 nm (includes the 1 640 nm channel in Cimel version 5). These solar extinction measurements are used to compute aerosol optical depth (AOD). Typically the estimated uncertainty in computed AOD from a newly calibrated field instrument under cloud–free conditions is approximately ±0.010 to ±0.021, which is spectrally dependent with higher errors in the UV (<440 nm) (Holben et al., 1998; Eck et al., 1999). Angstrom exponent can be retrieved from AODs. Rather than calculating angstrom exponent on two wavelengths, as is traditionally done, 4 or more were used to plot for the AOD vs. wavelength in log space and making a linear fit of the data to retrieve the angstrom exponent. Thus if one channel is miscalibrated by 0.02 but the others are spot on, the angstrom exponent is less affected by the one bad channel. Normally very low AOD values may cause significant errors in AE. To minimize these errors, only AOD values larger than 0.05 at 500 nm were adopted. In our dataset, approximately 95% data recorded are AOD values larger than 0.1 at 500 nm. The remaining are AOD values in between 0.05 and 0.10.

In this study, we divided our dataset into four groups based on the seasonal monsoon (Awang et al., 2000; Babu et al., 2007; Moorthy et al., 2007; Kumar and Devara, 2012; Xian et al., 2013) as follows: (i) December to March (northeast monsoon), (ii) April to May (pre–monsoon), (iii) June to September (southwest monsoon), and (iv) October to November (post–monsoon). Meanwhile, the "overall" data were also analyzed for the entire study period. In this study, data obtained for Penang (Kuching) site is for the year 2012 (2011). The post–monsoon (pre–monsoon) period is not discussed for Penang (Kuching) because no data are available for that period. The aerosol optical properties of aerosols for the study sites on each monsoon season were identified by analyzing the AOD_500 and $angstrom_{440–870}$ based on their frequency distribution patterns. The frequency distribution patterns of PW (in cm) shows the amount of water content in the atmospheric column. Additionally, the aerosol distribution patterns over Penang in each monsoonal period were quantitatively identified according to the scattering plots of the angstrom exponent against aerosol optical depth (AOD). Therefore, the variations in aerosol characteristics could be inter–annually investigated to determine the aerosol types for different periods or those that were sustained throughout the year. However, the sites in Penang and Kuching lack a complete dataset of Level 2 AERONET data; hence, only four groups were considered for these sites. We could generally and subjectively compare the data. The seven–day back–trajectory frequency seasonal plot by the Hybrid Single–Particle Lagrangian Integrated Trajectory (HYSPLIT_4) model (Draxler and Hess, 1998) was used to describe the aerosol sources because of its suitability to simulate air–mass movement. The results obtained for Penang were compared against that of Singapore, while that of Kuching against Pontianak. Singapore and Pontianak were chosen due to (i) they have a complete annual Level 2 AERONET data, (ii) their proximity to the sites of comparison, (iii) similar environmental factors between the sites being compared.

3. Results and Discussion

3.1. Climatology of Penang and Kuching

The climatology data for Penang and Kuching is obtained from the website, e.g. (GSFC, 2014) for year 2012 and 2011 respectively. As shown in Figure S2 (see the SM) the AOD value at shorter wavelengths between 500 nm and 340 nm (visible in the ultraviolet wavelength portion) is obviously higher than that at longer wavelengths from 670 nm to 1 020 nm (visible in the near–infrared wavelength portion). This condition can be attributed to the fact that fine mode particles dominate the atmosphere because small particles are more efficiently scattered at shorter wavelengths than at longer wavelengths (Kaskaoutis et al., 2007). In Figure S2a (see the SM), the AOD value in Penang increases significantly during the southwest monsoon period, two peaks were found in June and August. Another peak is found in March during the northeast monsoon. During the inter–annual southwest monsoon period, smoke (biomass burning aerosol) is transported from Sumatra, Indonesia, to the study sites. Therefore, the fine biomass burning aerosols have a greater effect on the AOD in the ultraviolet than in the near–infrared wavelengths (Schuster et al., 2006). This phenomenon is obviously observed at AOD_340, which increases by a factor of ~2.7 from April to June in comparison with an increase by ~1.9 for AOD_1020. Meanwhile, Penang seldom has a very good air quality because the AOD_440 value is almost always higher than 0.1 in the study site records. Under clean background conditions, AOD value should be less than 0.05 at AOD_440 nm (Toledano et al., 2007) or pure atmospheric conditions should be between 0.04 and 0.06 (Smirnov et al., 1995). Kuching is also affected by the open burning activities from Kalimantan, Indonesia, during the inter–annual southwest monsoon period (refer to Figure S2b in the SM). The AOD value achieved the peak in August. Meanwhile, this site is also dominated by fine mode aerosol (smoke) because the AOD value at wavelengths shorter than 500 nm are significantly higher than that at longer than 500 nm, and AOD_340 increases by a factor of ~3.8 from April to August in comparison with ~3.5 for AOD_1020.

3.2. Temporal evolution for AOD, angstrom exponent, and PW

Penang. Figure 1a shows the spectral variation of AOD values at certain times in Penang. High, medium, and low fluctuations are observed during the southwest, northeast, and pre–monsoon periods. The high fluctuation of AOD during the southwest monsoon period (between June and September) is attributed to the intermittent open burning activities committed locally and from neighboring country, i.e., Indonesia. The Malaysia Meteorological Department (MMD) reported that rainfall amount in this period is the lowest of the year (MOSTI, 2012). Independently, recorded PW (the water content in the