Remote sensing assessment of absorbing aerosol over Peninsular Malaysia from OMI onboard Aura satellite

K C Tan*, H S Lim and M Z Mat Jafri

School of Physics, Universiti Sains Malaysia, 11800 Penang, Malaysia

*E-mail: kctan@usm.my

Abstract. The observation of aerosol index derived from the Ozone Monitoring Instrument (OMI) on board the Dutch-Finnish Aura satellite with spatial resolution 1° x 1° have been analyzed over Peninsular Malaysia for 2013-2015, from June to September, respectively. The results show significant spatial and temporal variabilities in aerosol index with higher values during June 2013 and September 2015. On the other hand, the aerosol index does not show significant differences between the Peninsular Malaysia for the remaining study duration. The high positive aerosol index values over Southern Peninsular Malaysia clearly reveal the ultraviolet absorbing nature of smoke particles affecting the area during Indonesia forest fire, associated with the Southwest monsoon season. The spatial distribution of aerosol index has been analyzed using monthly OMI/Aura data obtained from the NASA-operated Giovanni. The result shows that the satellite measurements can measure and observe the increase of the aerosol index over different regions.

1. Introduction

The report by the Intergovernmental Panel on Climate Change had recognized that atmospheric aerosols affect the climate, energy balance and hydrological cycle [1]. Besides, the atmosphere consists of many aerosols which affect the atmospheric process such as chemical processes, visibility, air quality, precipitation, and cloud formation. Aerosol particles interact with solar radiation by absorbing and scattering it, resulting from direct effect of aerosols on solar radiation and subsequent climate change [2]. The indirect effect is that they can influence on formation and properties of clouds by acting as cloud condensation nuclei (CCN) and affect the microphysical properties and formation of clouds [3]. Hence, the studies of aerosol processes and properties can give an obvious view on the factors that involved in local and global climate change.

Recently, there is growing of researches have reporting the use of satellite measurements to investigate the indirect effects of temporal and spatial patterns of aerosols, at both regional and global scales [4]. Meanwhile, satellite remote sensing is an important tool for examine the radiative effects and global aerosol budget that aerosols have on climate [5]. In theory, satellite remote sensing allow users to assess the spatial distribution and properties, and it also provide major benefit by allowing synoptic and complete mapping of a large area in a single snapshot [6]. Satellite remote sensing has been successfully applied in deducing the origin, spatial and temporal distribution of absorbing aerosols [7], and in constraining biomass-burning emissions [8].

In particular, the ultraviolet aerosol index provides a useful tool in satellite remote sensing that indicates the presence of elevated absorbing aerosols in the troposphere [7]. The absorbing aerosol index has an advantage that capable to detect aerosols over land due to the low surface albedo of land within ultraviolet wavelength. The spectral comparison between two ultraviolet wavelengths is used to
calculate aerosol index. The existing of spectral contrast is caused by the difference in the characteristic of absorbing aerosols and other phenomena such as Rayleigh scattering, surface reflectance, gaseous absorption and cloud and aerosol scattering [9].

The magnitude of aerosol index depends on the height of aerosol layer, viewing geometry, aerosol type (single scattering albedo), and aerosol optical depth [10]. Negative values of aerosol index are assigned by pure scatterers while positive values of aerosol index are assigned by desert dust and smoke [7]. Nevertheless, the other features such as spectral slopes in the surface reflectance among the reference wavelengths and high altitude clouds also bring the negative value of aerosol index [11]. In addition, the presence of clouds will give the near zero values of aerosol index [12]. Whilst aerosol index values greater than 1.0 represent the absorbing aerosols such as dust or soot particles [13].

2. Ozone Monitoring Instrument (OMI)

The Ozone Monitoring Instrument (OMI), a contribution of the Netherlands and Finland to the National Aeronautics and Space Administration’ (NASA) Aura mission, is flown on the Aura spacecraft. Aura is part of NASA’s long term Earth Observation System (EOS) mission and was launched on 15 July 2004, from Vandenberg Air Force base in California. The OMI is the first of a new generation of space-borne spectrometers that combine a high spatial resolution (13 × 24 km² at nadir) with daily global coverage [14]. Measuring the trend in stratospheric O₃ as well as detecting tropospheric O₃ on regional scales is top priorities among the science objectives for Aura satellite [15].

OMI is used to measure the reflected solar radiation in the ultraviolet and visible part in the spectral range between 270 nm to 500 nm, by using two channels with a spectral resolution of about 0.5 nm. The light entering the telescope is pseudodepolarized using the scrambler and then split into two channels, which are ultraviolet channel and the visible channel.

3. Study Area

Peninsular Malaysia is located in Southeast Asia within the latitudes of 1° to 7° N and the longitudes of 99° to 105° E (south of Thailand, north of Singapore, and east of Sumatra). Peninsular Malaysia has an area of approximately 131,587 km² (Figure 1) and an estimated population of 23 million.

Peninsular Malaysia enjoys a humid tropical climate throughout the year; the weather is warm and humid, and the temperature ranges from 20 °C to 32 °C [16]. Mountainous topography and complex land-sea interactions significantly influence the tropical climate. Intra-seasonal and inter-decadal fluctuations, such as the El Niño Southern Oscillation, the Indian Ocean Dipole, and the Madden Julian Oscillation, significantly influence Malaysia’s inter-annual climate variability. April to May and July to August are the months with the highest average temperatures, and the lowest average temperatures occur from November to January.

In Peninsular Malaysia, the average monthly humidity falls between 70% and 90%, varying by location and month. Peninsular Malaysia experiences two rainy seasons throughout the year due to the effects of the northeast monsoon (NEM) season from November to February and the southwest monsoon (SWM) season from May to August [17]. In most areas, maximum rainfall typically occurs near the end of the year during the early NEM. The lowest monthly rainfall occurs in February, while the highest monthly rainfall occurs in December [18]. These monsoons are associated with the contribution of many regional pollutant sources that affect atmospheric parameters and the amount of pollutants transported to Malaysia [19].
4. Acquisition and Specification

Observations of the earth through remote sensing techniques require a variety of diverse platforms and instruments, ranging from hand-held, close-range spectrometers to images and instruments onboard satellites that orbit many thousands of kilometers above the earth [20]. Various types of sensor data have different advantages and disadvantages. Different types of sensors are suitable for certain studies and/or research purposes. Hence, understanding and updating information on all of these sensors on various types of available satellites is indispensable for remote-sensing applications.

From OMI, ultraviolet aerosol index used to detect the presence of ultraviolet absorbing aerosol such as soot and dust. Ultraviolet aerosol index is calculated based on the contrast method in the ultraviolet region, due to the small absorption of ozone in this region. Thus, it is the difference between model calculations and observations of non-absorbing and absorbing spectral radiance ratios. For OMI, aerosol index (AI) defined as [21]:

$$AI = 100[\log_{10}(I_{360}/I_{331})_{\text{measured}} - \log_{10}(I_{360}/I_{331})_{\text{calculated}}]$$ (1)

5. Methodology

This research has been carried out for twelve months' data from June to September 2013 till 2015. To better access and analyze the impacts of the forest fire over study area, the maps of aerosol index obtained from NASA-operated Giovanni. The daily time averaged maps of ultraviolet aerosol index (OMTO3dv003) were utilized for this purpose. In addition, the mean wind vector also obtained as a supportive data, in order to give an idea on how the transportation of wind can affects the value of aerosol index.

6. Data Analysis and Results

Fig. 2-5 show the time averaged of monthly coverage of ultraviolet aerosol index over study area for June-September, 2013-2015. The OMI/Aura resolution of reanalyses for the region covering Peninsular Malaysia used in this study is (1° log x 1° lat). The ultraviolet aerosol index spatial patterns were almost same for each month, except on June 2013 and September 2015. Average value of ultraviolet aerosol index for every single month is about 0.333-1 (except on June 2013 and September 2015). Whilst for June 2013 and September 2015, the average values for ultraviolet aerosol index range from 0.333-1.667. Aerosol index shows positive values for ultraviolet absorbing particles such as volcanic ash, desert dust, and smoke whereas negative values for non-absorbing particles such as sulphate aerosols and sea-salt particles [21].
Previously, other researcher had shown increasing aerosol index greater than 1.7 in biomass burning plumes during June, 2013 for the Pelalawan District [21]. Biomass burning plumes have carbonaceous aerosols, which exhibit different radiative properties, both absorbing and non-absorbing. Black carbons give the absorbing nature of carbonaceous aerosols [22]. During June 18th-July 1st 2013, an intense haze event occurred in Indonesia that brings significant impacts to other neighbouring countries, such as Singapore, Brunei, Malaysia, and southern Thailand [21].

**Figure 2.** Spatial and temporal variations of monthly averaged aerosol index over Peninsular Malaysia for (June) 2013 to 2015.

**Figure 3.** Spatial and temporal variations of monthly averaged aerosol index over Peninsular Malaysia for (July) 2013 to 2015

**Figure 4.** Spatial and temporal variations of monthly averaged aerosol index over Peninsular Malaysia for (August) 2013 to 2015
Figure 5. Spatial and temporal variations of monthly averaged aerosol index over Peninsular Malaysia for (September) 2013 to 2015

The mean synoptic chart of the wind vector (Fig. 6) was also developed for the region. The results showed that the monthly wind patterns for the June-September (Southwest monsoon) season followed the dominant wind direction as a result of the monsoon wind. When the Intertropical Convergence Zone (ITCZ) moves northward across continental Southeast Asia into the Northern Hemisphere, the Southwest monsoon brings marine air masses from the Indian Ocean to Peninsular Malaysia and experiences the Southwest monsoon season. Figure 6 shows vector components of mean wind systems at 1000 mb for the SWM or summer monsoon (June to September) from 2013 to 2015. The wind vector plots from the analysis data clearly define the ITCZ area.

Figure 6. The mean wind vector at 1000 mb over Peninsular Malaysia region for (June – September) from 2013 to 2015
7. Conclusion
In this study, we present OMI’s monthly observation data of aerosol index from June-September 2013-2015 in Peninsular Malaysia. The detail analyzes over study area successfully identify both the spatial and temporal variations, especially in examining aerosol index. The ultraviolet aerosol index spatial patterns were almost same for each month, except on June 2013 and September 2015. During June 2013 haze event in Indonesia, it released huge amount of aerosols in the region and bring the significant impacts on aerosol index over the study region. The result shows that the satellite measurements are efficiently measure the increase of aerosol index of the absorbing aerosol and transportation over different regions.

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