Multiangle Imaging Spectroradiometer (MISR) and Moderate Resolution Imaging Spectrometer (MODIS) Aerosol Optical Depth (AOD) spatial variations in Peninsular Malaysia

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Abstract. Aerosol Optical Depth of Moderate Resolution Imaging Spectroradiometer (MODIS) and the Multiangle Imaging Spectroradiometer (MISR) over peninsular Malaysia for the year 2015 were analysed. The AOD_{MODIS} retrieved using a retrieval algorithm which utilizes robust cloud screening and on-board calibration techniques with 10 x 10 km spatial resolution. Meanwhile, the AOD_{MISR} from AOD daily of Level-3 at spectral bands (446, 558, 672, and 866 nm) with a cross-track ground spatial resolution of 0.5° x 0.5° was used. The preliminary results showed a trend of high reading from AOD_{MODIS} which concentrated at the Eastern region and Southern West of Peninsular Malaysia. The initial pattern of AOD distributions had shown the highly concentrated was located at rapid urbanized and industrial cities. Low reading from AOD_{MISR} has been retrieved over Peninsular Malaysia which further analyzed is needed, but the initial pattern of AOD shows the distribution was concentrated at urban areas.

1. Introduction
Malaysia has resulted in high aerosol concentrations due to the increase in population growth and rapid urbanization associated with economic development [1, 2]. According to a report titled East Asia’s Changing Urban Landscape: Measuring a Decade of Spatial Growth, Malaysia is among the more urbanized countries of East Asia, and its urban population continues to increase rapidly [3]. A study from [4] stated increasing of urbanization transformation, vehicle emission and industrial development have contributed to high amounts of atmospheric pollutants. Urban or industrial areas with a lot of transportation and industrial activities that found emitted various pollutants and prone to air quality degradation [5]. Studies by [6, 7] stated in Malaysia, the major cause of land-use changes in agricultural land use. Kuala Lumpur experiencing dramatic changes in land use for the past few decades due to the pressure from new development in the urban area and the green area in Kuala Lumpur are seen rapidly declining in term of space and quality [8]. A complex process involving significant demographic change, intensified economies activity and induced variation in extensive land cover and traffic pattern, urbanization plays a significant role in relation to air quality, especially in developing regions [9].
[10] Classified the sources of aerosol are from sea-salt aerosol, terrestrial aerosol (soil dust, biological emissions) and anthropogenic sources (industry, agriculture, burning of vegetation and fossil fuels, fertilizers). These natural and artificial sources of aerosols pollution in the air can heavily impact human health and also the surrounding environment. [11] Study has reported the major source of aerosol pollution is vehicle, industry and domestic fossil fuel. According to [12], the atmospheric aerosol has influenced many atmospheric processes including cloud formation, visibility variation and solar radiation transfer. Visibility degradation in most urban area has become major environmental topic of community concern because low visibility range will lead to worsening of air quality [12]. Studying and monitoring of aerosol distribution is very important to assess the AOD over a large spatial and temporal analysis because AOD is the main parameter to determine the distribution of aerosol and impact on climate [13].

According to [14], main sources of air pollution in Malaysia comes from local production or activities from aerosol which contributes to the high-level concentration of aerosol and atmospheric air quality degradation. Moreover, the decreasing air quality may due to increasing concentration of aerosol from automobile, factories or burning activities including fossil fuel power plant and open burning activities [15] as bad as from industrial activities. The emission of smoke and fog from the factories also is one of major factors poor air quality and can alter the climate of the earth. Previous studies [16] stated aerosol from biomass burning and industrial emissions observed in Indonesia and Indo-China give a considerable amount of pollutant to Malaysia because of it lies in the main pathway of Southern Asia (SEA) pollutant outflow. The concentration of aerosol can be determined by using Aerosol Optical Depth (AOD) as a good indicator due to strong correlation between the small particle concentration and light extinction coefficient [16]. AOD value range is from 0 to 5 and the values exceed 1 usually indicate as heavy pollution [17].

Remote sensing data is increasingly used in particulate matter pollution studies, the ability to characterize the aerosol over regional and global scale make the technology is widely used. It’s potential to measure the highly variable aerosol field on global scales during longer periods and can provide information over a relatively large spatial scale [18]. Generally, aerosol optical properties have been derived from satellite sensors. According to [5], a different sensor is installed in each different satellite-based on wide range of spatiotemporal, radiometric and spectral resolutions where made the remote sensing be the good source for large scale application. Detailed knowledge of spatially and temporally aerosol variations in understanding the dynamics of aerosol for global and regional climatic conditions [19]. It acts as an input to determine an anthropogenic climate change as well as for climate modelling [20]. In this paper, AOD$_{MISR}$ and AOD$_{MODIS}$ were analysed spatially.

2. Methodology

2.1 Study Site
Peninsular Malaysia roughly has 26 million people which is 92% of the total population in Malaysia and also consists of 10 states and 2 federal territories. In term of meteorological and climate factor, the weather is typically quite high but uniform temperature which is around 23°C to 31°C and high humidity level with the lower is 84% and the highest is 89% [21]. Malaysia is located near to the equator with a hot and humid climate throughout the year [22] and experiences four seasonal monsoons; southwest (late May to September), Northeast (October to March), two inter- monsoons is the transition between two monsoons. Malaysia registered an urbanization rate of 75 percent, which is more than 20 percent higher than the global urbanization rate. Industrialization and urbanization have contributed the depleting of air quality especially in large cities [23, 24]. Urbanization and industrialization have found as the main cause of the high concentration of aerosols in the area such as for southern region Johor Bahru, Pahang for east, Penang for north region and Petaling Jaya for west region which is also categorized as high-density population [25]. According to [3] Malaysia has 19 urban areas with more than 100,000 people and the most developed urban area are Kuala Lumpur, George Town and Johor Bahru.
2.2 Data source and Aerosol retrieval

Terra MODIS data level 2 (collection 5) data downloaded at NASA website which is suitable for characterization of aerosol properties. The spatial resolution of the data is 10km x 10km. All the images were undergone atmospheric correction in ENVI Software image processing. As for Terra MISR data Level 3 (Version 4) product with the spectral band (446, 558, 672, and 866 nm) with a cross-track ground spatial resolution of 0.5° x 0.5° covering 15 October 2015 were used. The data were also downloaded from NASA website at Atmospheric Science Data Centre which covering Peninsular Malaysia region. Figure 1 shows the map of Malaysia. Figure 2 shows the overall flowchart of analyses were conducted in the study.

There are seven bands in total to be calculated and undergo atmospheric correction as Equation 1 from [26]:

\[
\text{Reflectance} = 0.00002 \times b1 + (-0.1) \tag{1}
\]

Where;
- \(b1\) = band 1,
- 0.00002 = reflectance multiple band
- -0.1 = reflectance added band from Envi software

The corrected images were then proceed with aerosol optical retrieval values over the study areas as Equation 2:

\[
\text{AOD} = 396R_{\lambda1} + 253R_{\lambda2} - 194R_{\lambda3} \tag{2}
\]

Where;
- \(\lambda1\) = reflectance b1
- \(\lambda2\) = reflectance b2
- \(\lambda3\) = reflectance b3

![Figure 1: Map of Peninsular Malaysia](image-url)
3. Result and Discussion

3.1 Spatial Pattern of AOD

Based on Figure 3, the spatial distribution of AOD based in eastern and the southern region of Peninsular Malaysia recorded highest concentration of aerosol optical depth as compared to west and northern region. The reading scale of AOD divided into three scale; low, medium and high. Orange to red area indicates high reading of AOD, yellow area as medium and last one blue area indicate as low reading area.[4] stated high variation in AOD shows the high level of aerosol loading in atmosphere which contributed by vehicles and transportation and other anthropogenic activities from urbanization development. While west and northern region showed less of AOD distribution in that area which indicating a less polluted area with lower aerosol loading.

Figure 3 (a) shows that Johor as one of state in the southern region of Peninsular Malaysia has recorded the highest reading of AODMIRS at 0.0168, followed by Pulau Pinang and Pahang. [27] stated that rapid development and close to industrial area has caused high reading of AOD. Whilst Pulau Pinang is located in northern region illustrated as second higher at 0.014 shows the population growth which associated with economic development especially new land exploration for residential and cities [28]. The previous studies have shown Pulau Pinang recorded high reading of AOD due to high density of population area and industrial area respectively [29]. However, AOD reading Putrajaya, Negeri Sembilan, Kelantan, Perak and Perlis recorded lower reading due to the location of monitoring station distant from the source of aerosol. According to [30], the presence of aerosol content in the air is closely related to the source of aerosol.

Based on Figure 3 (b), Kedah, Putrajaya, Kuala Lumpur, Pahang, Perlis, and Pulau Pinang recorded high values of AODMODIS. The high concentration can be contributed from human activities that can lead to the high concentration of aerosol which is particularly released of fossil fuels from factories across the area and also emission of vehicles. Moreover, the various pattern of AOD sources in Peninsular Malaysia is from trans-boundary haze fire from neighbouring countries [18]. [31] stated that haze from the forest fire in Sumatra, Indonesia reaches the western part of Peninsular Malaysia more than the east coast especially. According to [22], during southwest monsoon, trans-boundary haze episode across the Malacca Straits to Southwest Peninsular Malaysia can be plausibly caused to contribute the level of pollutant concentration. The forest fire promoted long-range transportation of haze [32] and the lower wind speeds during southwest monsoon may tend to keep pollutants concentrated over urban areas [12].
Distribution of air pollutant in Malaysia is strongly influenced by the monsoon seasons and meteorological conditions; temperature, humidity and wind speed [4].

Figure 3 Inverse Distance Weighting for AOD from (a) MISR and (b) MODIS

Figure 4 AOD\textsubscript{MODIS} and AOD\textsubscript{MISR} average reading in Peninsular Malaysia.

Figure 4 shows the comparison data of AOD\textsubscript{MISR} and AOD\textsubscript{MODIS} in Peninsular Malaysia. From the figure, we can see that Johor was recorded highest AOD reading for both sensors AOD\textsubscript{MISR} reading was 0.0168 and OAD\textsubscript{MODIS} 0.148 respectively. Overall AOD reading still in the permissible level because a
study from [17] stated Aerosol optical depth (AOD) values that exceed 1-values indicates as heavy pollution. The results have indicated that the reading was retrieved from AOD_{MODIS} is higher as compared to AOD_{MISR}.

4. Conclusion
The study demonstrated that remote sensing data is useful to illustrate the distribution pattern of Aerosol Optical Depth (AOD). The initial pattern of AOD distributions had shown the highly concentrated is located at mostly at rapid urbanized and industrial cities. Both sensors are potential to be optimized in air quality studies, whilst low reading of AOD_{MISR} need further improvements especially on the retrieval scaling factor.

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