Spatio-temporal assessment of Aerosol Optical Depth from Himawari-8 satellite data over Malaysia

Nurul Amalin Fatihah Kamarul Zaman[1] and Kasturi Devi Kanniah[1, 2, *]
[1]Tropical Map Research Group, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor

[2]Centre for Environmental Sustainability and Water Security (IPASA), Research Institute for Sustainable Environment (RISE), Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor

*Email: kasturi@utm.my

Abstract. Aerosols, particulate matters and air pollution are significant atmospheric issues in the Southeast Asia (SEA) countries particularly Malaysia. Despite their importance, data to investigate their spatio-temporal variation, estimating their abundance and modelling the trend are not widely available due to financial constraints and technical expertise. Remote sensing data are alternative solution to the limited data available from ground stations. One of the latest remotely sensed Aerosol Optical depth (AOD) data available is from Himawari-8 satellite that provides high temporal resolution data (every 10 minutes) at moderate spatial resolution of 5 km. Nevertheless, the robustness of these data for the tropical region has not yet been validated yet. This study aimed at assessing the performance of Himawari-8 AOD L2 product by (i) comparing its absolute AOD values against AOD retrieved from AERONET stations and (ii) analysing the spatial and temporal patterns of the AOD data. The AERONET data were averaged for ±5 min of the Himawari-8 overpass and matched to each other using statistical measures i.e. Correlation, Root mean square error (RMSE), Relative bias (RB) and Mean Absolute Error (MAE). Preliminary results of the analysis provided a coefficient of determination (R^2) value =0.31, RMSE =0.16, and MAE = 0.15. The Himawari-8 AOD product is found to be overestimated the AOD values by 24.19%. Nevertheless, Himawari-8 AOD L2 product is able to exhibit similar spatial and temporal patterns compared to other remotely sensed AOD data such as that of MODIS. The high temporal resolution of Himawari data will facilitate frequent monitoring of air pollution in this region.

1. Introduction

Air pollution is not a new problem for developing countries like Malaysia where the urbanization rate has increased rapidly since 1970 [1]. Malaysia experiences haze episodes almost every year since 1997 [2]. It happens not only due to local sources like motor vehicles and industries [3] but also due to trans-boundary pollutant [4]. This is sources such as transportation, industrialisation and burning activities, but Malaysia also lies in the main pathway of Southeast Asian (SEA) pollution outflow [5] which increases the pollutant concentration. Despite air pollution is a serious environmental and health

hazard data to investigate their spatio-temporal variation, estimating their abundance and modelling the trend are not widely available in Malaysia due to limited established stations to measure aerosol concentration. Recently, Malaysia has 65 air quality monitoring stations across Malaysia and obviously it is insufficient to cover the whole country (330,290 km2). Establishing more stations is a costly process (installing one monitoring station will incur cost about one million ringgit and onestation only represent the pollutant level within 15km radius) [6] and therefore, remote sensing is the best option to monitor air quality over large areas.

Aerosol optical depth (AOD) is a measure of the disappearance of the solar light caused by absorption and scattering by dust, smoke, and other pollutants in the atmosphere [7]. It is an indicator of the concentration of pollutants where high AOD values indicate large amount of pollutants in the atmosphere. AOD is widely been used to determine the air pollution level. AOD has been retrieved from various remote sensing satellites like MODerate resolution Imaging Spectroradiometer (MODIS) [8-11], Multi-angle Imaging SpectroRadiometer (MISR) [12], Advanced Very High Resolution Radiometer (AVHRR), Medium Resolution Imaging Spectrometer (MERIS) [13, 14], and Visible Infrared Imaging Radiometer Suite (VIIRS) [15, 16]. The polar orbiting satellites especially MODIS is popular in air quality studies since early 2000 where it provides daily observation at 10km and 3km worldwide. However, SEA countries is very challenging when comes to the application of remote sensing data because of the extensive cloud cover that causes missing data [17, 18]. The geostationary orbit satellite like Himawari-8 is highly needed in this area because it can monitor the earth with a fixed view and provide high temporal observation [19]. The Himawari-8 is a new generation of geostationary meteorological satellite which was launched on 7 October 2014 by the Japan Meteorological Agency (JMA). It has a great potential in air quality studies where it has relatively moderate spatial resolution of 5km and provide hourly or even 10 minutes AOD data. This capability of Himawari allows better observation of atmospheric variation and spatial distribution characteristics [20]. Therefore, in this study AOD level 2 products at 500nm retrieved from Himawari-8 is validated with ground-based AOD from AERONET over Malaysia. Besides that, spatial and temporal pattern of the Himawari-8 AOD product was evaluated by plotting the data over different stations and time period. This is the first evaluation of Himawari-8 AOD product in Malaysia and it will provide new understanding on the potential of Himawari-8 AOD in air quality studies.

2. Data and Methodology

2.1 AERONET data

The AERONET (Aerosol Robotic NETwork) is a global ground-based aerosol monitoring using CIMEL sun photometer [21]. AERONET provide AOD data at 340nm, 380nm, 440nm, 500nm, 675nm, 870nm, and 1020nm with temporal resolution 15 minutes [21]. Since, AERONET data has low uncertainty many study used it to validate the AOD retrieved from satellite [4, 19, 22, 23]. In this study, level 2 (quality assured) data were used from 2 stations from Malaysia (USM, Penang and Kuching) and 1 from Singapore (Figure 1). The AERONET data was downloaded from https://aeronet.gsfc.nasa.gov/ for January to December 2018.

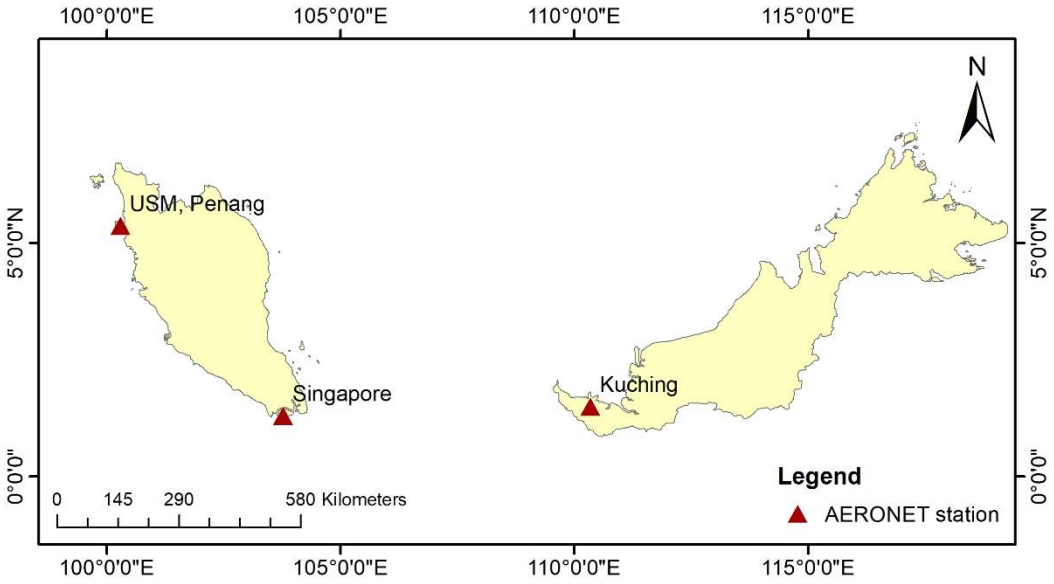

Figure 1. Map of AERONET stations in Malaysia that were used for validating Himawari-8 AOD product.

2.2 Himawari-8 AOD product

Himawari-8 was launched on 7 October 2014 and carried Advanced Himawari Imager (AHI) which equipped with 16 bands from visible to infrared [24]. Himawari-8 provide two AOD product which is Level 2 (L2) and Level 3 (L3) where derived every 10 minutes and 1 hour respectively. Both product has same spatial resolution which is 5km. In this study, the performance of AOD L2 product will be validated over Malaysia. The AOD L2 product has quality assurance (QA) flag with various confidence test [25]. Besides that, AOD L2 product is derived from algorithm developed [26] using three visible bands and two near infrared bands. The Himawari AOD L2 product from January to December 2018 was downloaded from http://www.eorc.jaxa.jp/ptree/index.html website.

2.3 Methodology

This study used Himawari-8 AOD product at 500nm therefore it can be directly compared with the AOD from AERONET. In order to match the Himawari AOD L2 product the AERONET data were averaged for ±5 min of the Himawari-8 overpass [25, 27]. Statistical techniques such as like root mean square error (RMSE), relative bias (RB) and mean absolute error (MAE) were used to quantify the accuracy of the Himawari-8 AOD L2 product against AOD from AERONET.

3. Results and Discussion

3.1 Validation of Himawari-8 AOD product

The Himawari-8 AOD retrievals at 500nm were validated against AERONET AOD measured at 500nm retrieved from 3 stations (USM Penang, Kuching and Singapore). The validation results are shown in Figure 2.

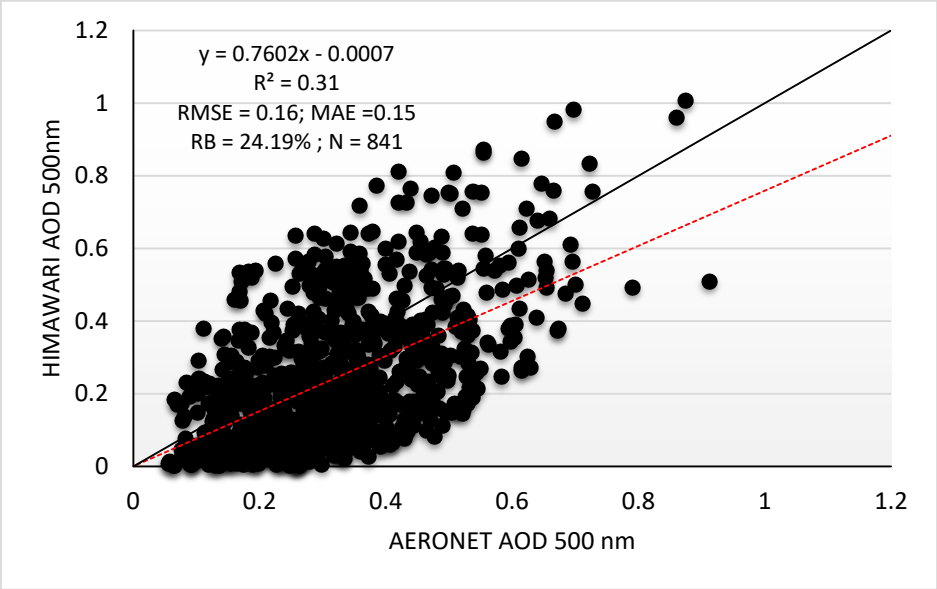

Figure 2. Validation of Himawari-8 AOD product with AOD retrieved from AERONET. The black line represent the one to one line; the red dash-line indicates the linear fit

The Himawari-8 AOD L2 product has moderate correlation with AOD from AERONET with R^2 =0.31, RMSE =0.16, MAE = 0.15. Figure 2 shows that Himawari-8 AOD L2 product is over estimated by about 24.19%. The correlation between AOD from Himawari-8 and ground based data is lower in this study compared to other studies. [27] validated Himawari-8 AOD L2 product against AERONET over Asian region. The study obtained promising accuracy about R^2 = 0.45, RMSE = 0.29 and Himawari-8 AOD L2 product showed overestimation with relative mean bias (RMB) > 1.0 for every season. The overestimation of Himawari-8 AOD L2 product is possibly due to sub pixel cloud contamination [28], furthermore Malaysia has heavy cloud cover thus it is difficult to obtain clear aerosol reflectance.

3.2 Spatial variations of Himawari-8 AOD product

The spatial distribution of seasonal-mean AOD L2 over Malaysia for dry and wet seasons is shown in Figure 3. During the dry season, the Himawari-8 AOD L2 product shows higher AOD concentration over the central southern region of Sabah and Sarawak (East Malaysia). The region experienced high pollutant concentration due to the forest fire in Kalimantan [8]. Besides that, the high AOD (~1.0 -1.4) value generally concentrated in dense populated and developed areas like Kuala Lumpur and Penang Island as shown in red box in Figure 3a.

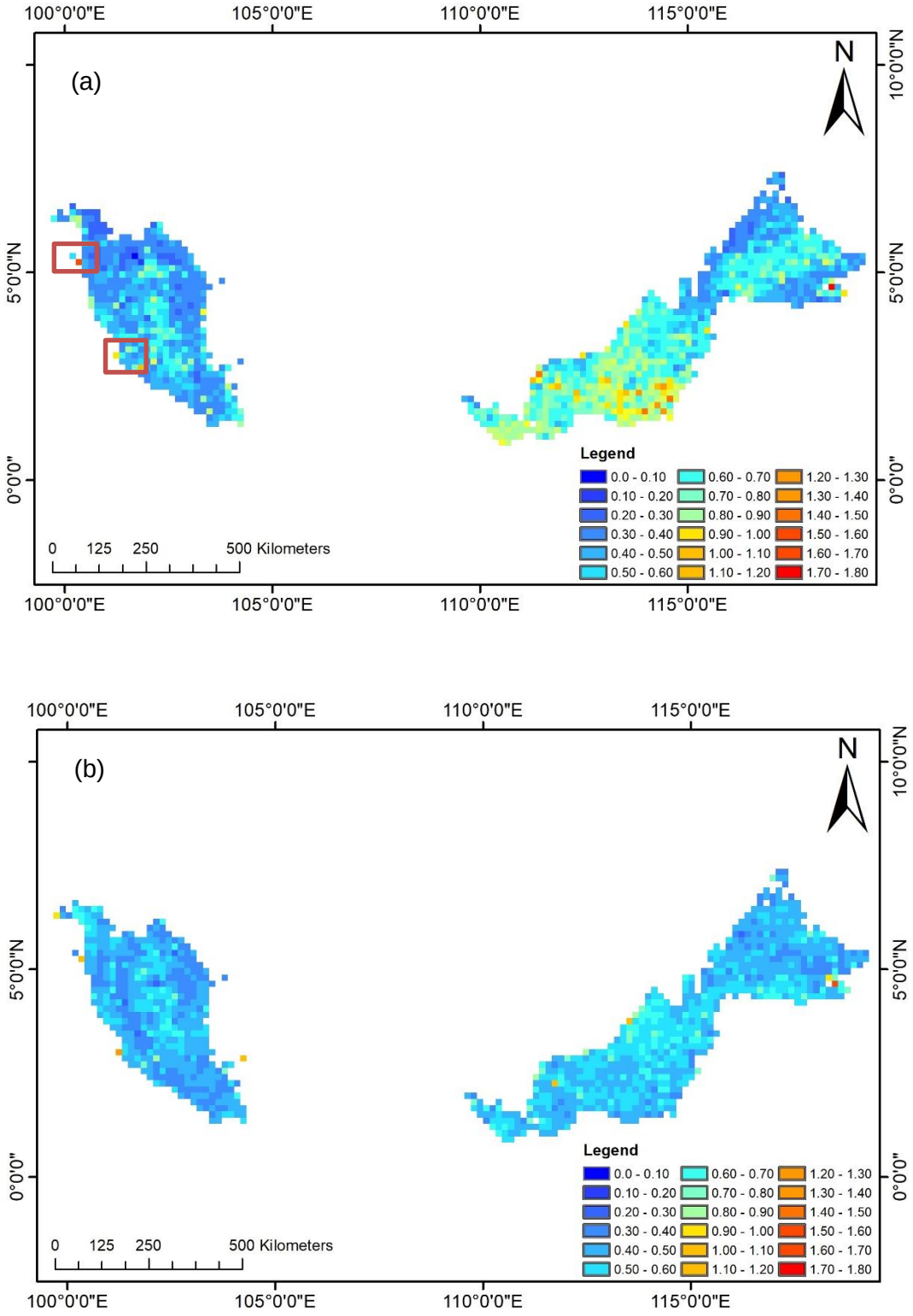

Figure 3. Seasonal-mean spatial distribution of Himawari-8 AOD L2 (5km x 5km) over Malaysia in the (a) dry season (June- Sept) and (b) wet season (Nov-March) for year 2018.

The mean seasonal distribution of AOD during the wet season of 2018 (Figure 3b) is lower due to rain washout [29]. Based on the seasonal distribution of Himawari-8 AOD for year 2018 shows the AOD values are reasonable compared to our earlier studies using MODIS data (cite all our previous papers on AOD) and no missing data is recorded. Himawari-8 AOD product is obviously able to provide a better understanding of aerosol distribution compared to other AOD products. For instance, our previous study [23] was unable to provide overall mean PM_{10} distribution map even we are using 5 years data due to limited AOD retrievals as a result of cloud cover. However, Himawari-8 AOD L2 product demonstrates the same spatial distribution as MODIS AOD product.

3.3 Temporal variation of Himawari-8 AOD product

The monthly mean AOD from Himawari-8 was averaged over five classification sites (background, industrial, rural, sub urban and urban). Background station is located in Jerantut, Pahang (in the middle of Peninsular Malaysia) is expected to receive low pollutants from sources such as transportation, soil dust, open burning and natural forest [30]. The AOD values in the industrial sites slightly increase after August especially from 0.50±0.11 to 0.73±0.39. At the urban sites the values changed between 0.42± and 0.68±0.29. In October (inter-monsoon season) AOD at industrial areas increased to 0.93±0.6 and starting from Nov the mean AOD for all areas decreased. The higher AOD value during the late dry season (October) is coincides with biomass burning in Indonesia [4]. Rural areas display lower AOD values almost for all months because of low level of pollutants released by anthropogenic sources. Based on the temporal pattern analysis Himawari-8 AOD product is reliable and can be used for air pollution studies in Malaysia.

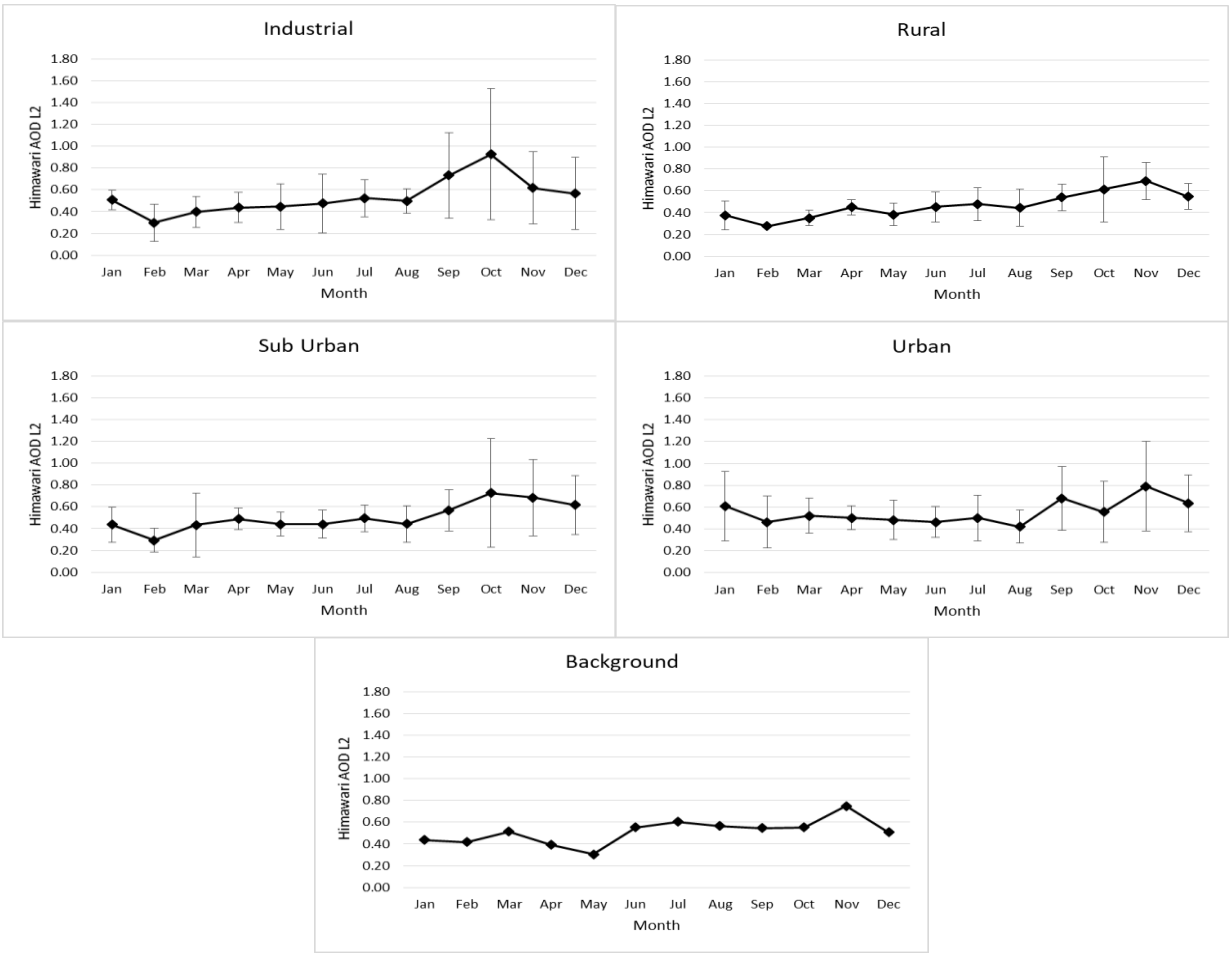

Figure 4. Mean (± standard deviation) of Himawari-8 AOD for January- December 2018 by region.

4. Conclusion

In this study, we validated the Himawari-8 AOD L2 product with AOD from AERONET and the correlation is moderate with R^2 =0.31, RMSE =0.16, MAE = 0.15. Himawari-8 AOD values are found to be overestimated by 24.19%. However, we found that Himawari-8 AOD L2 product is reliable to study the spatio-temporal pattern of aerosol because of their frequent revisit time. It can be concluded that Himawari-8 AOD L2 product is able to exhibit similar spatial and temporal patterns as compared to MODIS AOD product. Therefore, Himawari-8 AOD product can be considered for air quality studies by considering their overestimation and revised product like Himawari-8 AOD L3 should be validated to access their performance in the future.

Acknowledgments

The authors extend their thanks to WNI WXBUNKA Foundation via research grant (R.J130000.7352.4B406) and the Ministry of Education, Malaysia via the Fundamental Research Grant (R.J130000.7852.5F216) for providing research funding. We would like to thank the Japan Aerospace Exploration Agency (JAXA) for making Himawari-8 data available to users. The authors also would like to thank the AERONET team for maintaining and making the data publicly available.

References

[1] U. Yaakob, T. Masron, and F. Masami, "Ninety years of urbanization in Malaysia: a geographical investigation of its trends and characteristics," *J Ritsumeikan Soc Sci Humanit,* vol. 4, no. 3, pp. 79-101, 2010.

[2] M. T. Latif *et al.*, "Impact of regional haze towards air quality in Malaysia: A review," *Atmospheric Environment,* vol. 177, pp. 28-44, 2018/03/01/ 2018, doi: https://doi.org/10.1016/j.atmosenv.2018.01.002.

[3] A. Alias, M. Mat Jafri, H. Lim, N. Saleh, S. Chumiran, and A. Mohamad, "Inferring Angstrom exponent and aerosol optical depth from AERONET," *J. Environ. Sci. Technol,* vol. 7, pp. 166-175, 2014.

[4] K. D. Kanniah, H. Q. Lim, D. G. Kaskaoutis, and A. P. Cracknell, "Investigating aerosol properties in Peninsular Malaysia via the synergy of satellite remote sensing and ground-based measurements," *Atmospheric Research,* vol. 138, pp. 223-239, 2014a.

[5] J. S. Reid *et al.*, "Observing and understanding the Southeast Asian aerosol system by remote sensing: An initial review and analysis for the Seven Southeast Asian Studies (7SEAS) program," *Atmospheric Research,* vol. 122, pp. 403-468, 2013.

[6] M. Z. Ibrahim, M. Ismail, and K. H. Yong, "Mapping the Spatial Distribution of Criteria Air Pollutants in Peninsular Malaysia Using Geographical Information System (GIS)," 2012.

[7] L. Olsen *et al.*, "Nasa/global change master directory (gcmd) earth science keywords," *Version,* vol. 6, no. 0.0, p. 0, 2007.

[8] N. A. F. K. Zaman, K. D. Kanniah, and D. G. Kaskaoutis, "Estimating Particulate Matter using satellite based aerosol optical depth and meteorological variables in Malaysia," *Atmospheric Research,* vol. 193, pp. 142-162, 2017.

[9] H. Lee, Y. Liu, B. Coull, J. Schwartz, and P. Koutrakis, "A novel calibration approach of MODIS AOD data to predict PM 2.5 concentrations," *Atmospheric Chemistry & Physics Discussions,* vol. 11, no. 3, 2011.

[10] S. Chitranshi, S. P. Sharma, and S. Dey, "Satellite-based estimates of outdoor particulate pollution (PM10) for Agra City in northern India," *Air Quality, Atmosphere & Health,* vol. 8, no. 1, pp. 55-65, 2015.

[11] B. Zou, J. Chen, L. Zhai, X. Fang, and Z. Zheng, "Satellite based mapping of ground PM2. 5 concentration using generalized additive modeling," *Remote Sensing,* vol. 9, no. 1, p. 1, 2016.

[12] S. Sotoudeheian and M. Arhami, "Estimating ground-level PM 10 using satellite remote sensing and ground-based meteorological measurements over Tehran," *Journal of Environmental Health Science and Engineering,* vol. 12, no. 1, p. 122, 2014.

[13] K. Kanniah, N. A. F. K. Zaman, H. Lim, and M. N. M. Reba, "Monitoring particulate matters in urban areas in Malaysia using remote sensing and ground-based measurements," in *Remote Sensing of Clouds and the Atmosphere XIX; and Optics in Atmospheric Propagation and Adaptive Systems XVII*, 2014b, vol. 9242: International Society for Optics and Photonics, p. 92420J.

[14] A. Beloconi, Y. Kamarianakis, and N. Chrysoulakis, "Estimating urban PM10 and PM2. 5 concentrations, based on synergistic MERIS/AATSR aerosol observations, land cover and morphology data," *Remote Sensing of Environment,* vol. 172, pp. 148-164, 2016.

[15] J. Wu, F. Yao, W. Li, and M. Si, "VIIRS-based remote sensing estimation of ground-level PM2. 5 concentrations in Beijing–Tianjin–Hebei: A spatiotemporal statistical model," *Remote Sensing of Environment,* vol. 184, pp. 316-328, 2016.

[16] F. Yao, M. Si, W. Li, and J. Wu, "A multidimensional comparison between MODIS and VIIRS AOD in estimating ground-level PM2.5 concentrations over a heavily polluted region in China," *The Science of the total environment,* vol. 618, 11/10 2017, doi: 10.1016/j.scitotenv.2017.08.209.

[17] K. D. Kanniah and N. A. F. K. Zaman, "Remote sensing for studying atmospheric aerosols in Malaysia," in *Remote Sensing of Clouds and the Atmosphere XX*, 2015, vol. 9640: International Society for Optics and Photonics, p. 96400T.

[18] K. D. Kanniah, D. G. Kaskaoutis, H. San Lim, M. T. Latif, N. A. F. Kamarul Zaman, and J. Liew, "Overview of atmospheric aerosol studies in Malaysia: Known and unknown," *Atmospheric Research,* vol. 182, pp. 302-318, 2016/12/15/ 2016, doi: https://doi.org/10.1016/j.atmosres.2016.08.002.

[19] T. Jiang, B. Chen, K. K. Y. Chan, and B. Xu, "Himawari-8/AHI and MODIS Aerosol Optical Depths in China: Evaluation and Comparison," *Remote Sensing,* vol. 11, no. 9, p. 1011, 2019. [Online]. Available: https://www.mdpi.com/2072-4292/11/9/1011.

[20] H. Wei, W. Wang, F. Xu, and J. Feng, "Evaluation of the Himawari-8 Aerosol Products," in *IGARSS 2019 - 2019 IEEE International Geoscience and Remote Sensing Symposium*, 28 July-2 Aug. 2019 2019, pp. 7825-7828, doi: 10.1109/IGARSS.2019.8898960.

[21] B. N. Holben *et al.*, "AERONET—A federated instrument network and data archive for aerosol characterization," *Remote sensing of environment,* vol. 66, no. 1, pp. 1-16, 1998.

[22] Z. Zhang *et al.*, "Validation of Himawari-8 aerosol optical depth retrievals over China," *Atmospheric Environment,* vol. 199, pp. 32-44, 2019/02/15/ 2019, doi: https://doi.org/10.1016/j.atmosenv.2018.11.024.

[23] N. A. F. K. Zaman, K. D. Kanniah, and D. G. Kaskaoutis, "Satellite data for upscalling urban air pollution in Malaysia," in *IOP Conference Series: Earth and Environmental Science*, 2018, vol. 169, no. 1: IOP Publishing, p. 012036.

[24] K. Bessho *et al.*, "An Introduction to Himawari-8/9— Japan’s New-Generation Geostationary Meteorological Satellites," *Journal of the Meteorological Society of Japan. Ser. II,* vol. 94, no. 2, pp. 151-183, 2016, doi: 10.2151/jmsj.2016-009.

[25] J. Wei *et al.*, "Evaluation and uncertainty estimate of next-generation geostationary meteorological Himawari-8/AHI aerosol products," *Science of The Total Environment,* vol. 692, pp. 879-891, 2019/11/20/ 2019, doi: https://doi.org/10.1016/j.scitotenv.2019.07.326.

[26] M. Yoshida, M. Kikuchi, T. M. Nagao, H. Murakami, T. Nomaki, and A. Higurashi, "Common Retrieval of Aerosol Properties for Imaging Satellite Sensors," *Journal of the Meteorological Society of Japan. Ser. II,* vol. advpub, 2018, doi: 10.2151/jmsj.2018-039.

[27] X. Yang, C. Zhao, N. Luo, W. Zhao, W. Shi, and X. Yan, "Evaluation and Comparison of Himawari-8 L2 V1.0, V2.1 and MODIS C6.1 aerosol products over Asia and the oceania regions," *Atmospheric Environment,* vol. 220, p. 117068, 2020/01/01/ 2020, doi: https://doi.org/10.1016/j.atmosenv.2019.117068.

[28] W. Zhang, H. Xu, and L. Zhang, "Assessment of Himawari-8 AHI Aerosol Optical Depth Over Land," *Remote Sensing,* vol. 11, no. 9, p. 1108, 2019. [Online]. Available: https://www.mdpi.com/2072-4292/11/9/1108.

[29] L. Juneng, M. T. Latif, F. T. Tangang, and H. Mansor, "Spatio-temporal characteristics of PM10 concentration across Malaysia," *Atmospheric Environment,* vol. 43, no. 30, pp. 4584-4594, 2009.
[30] S. Z. Azmi, M. T. Latif, A. S. Ismail, L. Juneng, and A. A. Jemain, "Trend and status of air quality at three different monitoring stations in the Klang Valley, Malaysia," *Air Quality, Atmosphere & Health,* vol. 3, no. 1, pp. 53-64, 2010.