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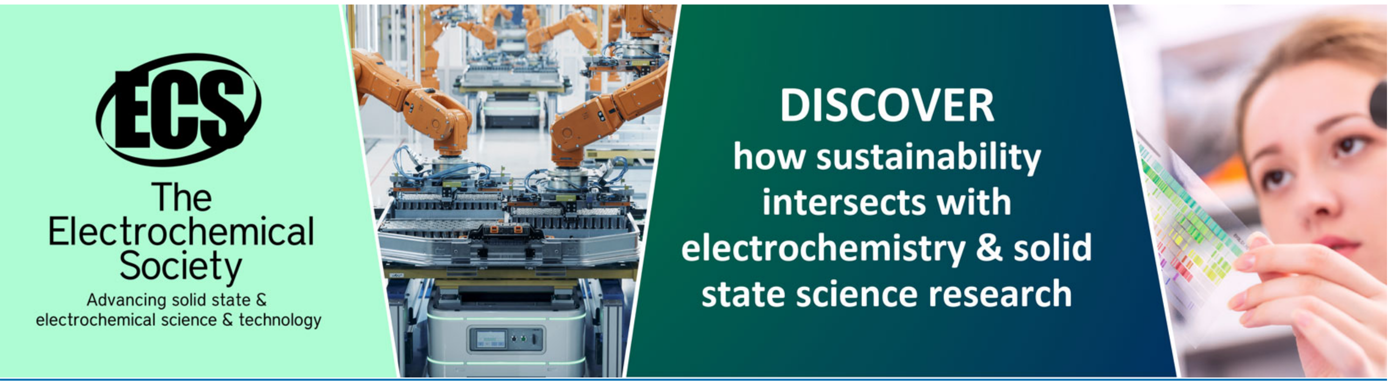

Preliminary results of the aerosol optical depth retrieval in Johor, Malaysia

H Q Lim, K D Kanniah[1], A M S Lau
Department of Remote Sensing, Faculty of Geoinformation and Real Estate, Universiti Teknologi Malaysia

E-mail: kasturi@utm.my

Abstract. Monitoring of atmospheric aerosols over the urban area is important as tremendous amounts of pollutants are released by industrial activities and heavy traffic flow. Air quality monitoring by satellite observation provides better spatial coverage, however, detailed aerosol properties retrieval remains a challenge. This is due to the limitation of aerosol retrieval algorithm on high reflectance (bright surface) areas. The aim of this study is to retrieve aerosol optical depth over urban areas of Iskandar Malaysia; the main southern development zone in Johor state, using Moderate Resolution Imaging Spectroradiometer (MODIS) 500m resolution data. One of the important steps is the aerosol optical depth retrieval is to characterise different types of aerosols in the study area. This information will be used to construct a Look Up Table containing the simulated aerosol reflectance and corresponding aerosol optical depth. Thus, in this study we have characterised different aerosol types in the study area using Aerosol Robotic Network (AERONET) data. These data were processed using cluster analysis and the preliminary results show that the area is consisting of coastal urban (65%), polluted urban (27.5%), dust particles (6%) and heavy pollution (1.5%) aerosols.

1. Introduction

Atmospheric aerosols have become an important element in climate change due to their tremendous impacts on radiative forcing and air quality [1]. They also affect the public health. The high spatial and temporal variation in aerosol distribution and their optical properties cause large uncertainties in the earth's climate system [2].Thus, the understanding of aerosol concentration and distribution especially over urban surfaces is very important and useful in the mitigation of aerosol's impacts and in air quality management.

For regional or global (large scale) studies, satellite remote sensing is one of the suitable approaches for aerosol measurements, but the retrieval of aerosol optical depth (AOD- defined as a measure of the amount of incident light either scattered or absorbed by particles in the atmosphere [3]) over urban region is complicated due to the confusion between surface reflectance and aerosol reflectance in passive solar reflectance measurement [4]. Currently, the aerosol retrieval is usually applied over dense dark vegetated surface where the surface reflectance is small [5]. This method is used by Moderate Resolution Imaging Spectrometer (MODIS) sensor on board Terra and Aqua satellites to routinely estimate AOD over the land surface of the Earth. This algorithm was developed to produce MODIS AOD collection 4, which was then modified by [6] to provide AOD collection 5. Various satellites and algorithms have been employed to provide aerosol information [7,8] and their uncertainties have been studied [9,10,11,12]. Nevertheless, AOD retrieval over the urban surface at sufficient accuracy and spatial resolution is needed for air quality management in urban areas [13].

[1] To whom any correspondence should be addressed.

Previous study [14] shows that MODIS AOD over Peninsular Malaysia (2000-2009) has large gaps especially in the urban areas due to the failure of the MODIS AOD algorithm over urban/highly reflective regions. Thus, a more extensive study examining the reflectance of heterogeneous materials (i.e. soil, water, buildings, vegetation etc.) in urban surface is needed to accurately estimate the AOD. Thus, the objective of this study is to characterize different aerosol types in the study region (south of Johor- figure 1). The information generated in this study will be used to construct a Look Up Table (LUT) containing the simulated aerosol reflectance and corresponding aerosol optical depth. The LUT will be used to derive AOD over urban areas in Iskandar Malaysia (Johor state, Malaysia).

2. Study area and data set

2.1. Study area

Iskandar Malaysia (IM) (figure 1) is the main southern development corridor in Johor, Malaysia encompassing an area of 2,216.3km^2. IM was established in 2006 and focusing on the development of five flagship zones covering the city of Johor Bahru and towns of Pontian, Senai, Pasir Gudang and Nusajaya. [15].

The economic development of IM is contributing to the high urbanization rate of Johor Bahru. A total of 70% of Johor's manufacturing establishments are located in this region. The current developed and undeveloped areas of IM are 15.35% and 84.65% of the total area respectively. Although the residential, commercial and industrial areas cover only a small portion of the total land area, but due to the sustainability development plan of IM in the future, the percentage of developed area and urbanization rate will be increased. Thus, the contribution of traffic and industrial emission to air pollution is expected to increase as well.

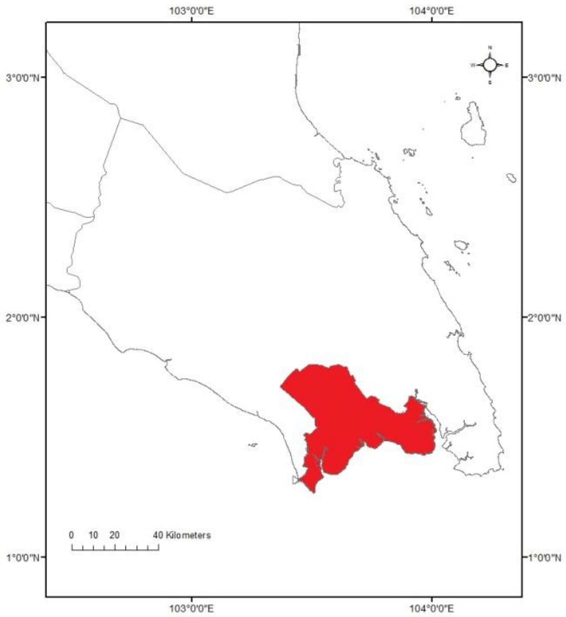

Figure 1: Location of Iskandar Malaysia in south of Johor, Malaysia.

2.2. Data sets

The Aerosol Robotic Network (AERONET) level 2 aerosol and inversion products were used to classify various aerosol types in the study area. A total of 24 parameters(AOD at 500 nm, angstrom exponent value, 4 single scattering albedo values, 8 real and imaginary refractive index values, 4 asymmetry factor values, 2 mean radius values, 2 standard deviation values, and 2 mode total volume values) from the AERONET station located in Singapore were used. These parameters are important to identify the types of aerosols as they describe the optical, size and absorption properties of aerosols.

The AERONET data were obtained from Singapore (1N, 103E) station as it is nearer to the study area and has a long term observational (6 years) data compared to other AERONET stations in Malaysia such as Kuching, Penang and Tahir that has only about less than a year data. Meanwhile, Singapore has similar geographic characteristics with IM such as having urban area surrounded by water surface and also similar weather conditions in terms of temperature, rainfall and relative humidity. Similar methodology has also been applied in [16].

3. Methodology

The AERONET aerosol and inversion products from Singapore station were acquired (total data are 108, from year 2006 to 2011). Cluster analysis was then applied to AERONET data to classify different aerosol types (urban, maritime, dust etc.) using the aerosol parameters mentioned in section 2.2. Cluster analysis is the process for grouping objects that are similar to each other in certain predefined variables [17]. Two types of procedures are available for cluster analysis: hierarchical procedure (agglomerative and divisive) and non hierarchical procedure (k-mean clustering).

The k-means clustering technique was used in this study. SPSS statistical software was used for the analysis. For this technique, the data are assigned to cluster (or centre of the groups) which is nearest in distance and the number of clusters needed to be specified first. Thus, the number of clusters was defined using Ward's automated hierarchical method [18] and found as four. Then, the k-mean clustering method was applied to calculate the centres of each cluster as shown in table 1.

4. Result and discussion

AERONET level 2 products (a total of 108 data) were processed using cluster analysis and the results are presented in table 1. Cluster analysis found 4 types of aerosols: coastal urban, heavy pollution, polluted urban and dust (table 1).

Table 1. Properties of classified aerosol types.

	Coastal Urban	**Heavy Pollution**	**Polluted urban**	**Dust**
Aerosol optical depth (500 nm)	0.4242	1.3406	0.6658	0.6190
Single scattering albedo (441 nm)	0.9322	0.9650	0.9550	0.9448
Single scattering albedo (674 nm)	0.9181	0.9647	0.9468	0.9218
Single scattering albedo (871 nm)	0.9029	0.9618	0.9360	0.8981
Single scattering albedo (1020 nm)	0.8952	0.9616	0.9288	0.8891
Real refractive index (674 nm)	1.4033	1.5861	1.4127	1.4089
Imaginary refractive index (674 nm)	0.0081	0.0030	0.0056	0.0082
Angstrom coefficient (870/440 nm)	1.2087	1.1655	0.7547	1.2917
Asymmetry factor (674 nm)	0.6579	0.6297	0.6520	0.6858
Fine mode total volume ($\mu m^3/\mu m^2$)	0.0707	0.1170	0.1194	0.1023
Fine mode mean radius (µm)	0.1877	0.1810	0.2008	0.2203
Geometric standard deviation (fine)	0.4608	0.5250	0.5203	0.5528
Coarse mode total volume ($\mu m^3/\mu m^2$)	0.0575	0.0360	0.0427	0.0890
Coarse mode mean radius (µm)	2.4878	1.7860	3.0551	3.8163
Geometric standard deviation (coarse)	0.6660	0.6300	0.6332	0.5705
Number of records	70(65%)	2(1.5%)	30(27.5%)	6(6%)

The clustering result shows that coastal urban type of aerosols dominated the study area (65% of total), followed by polluted urban type (27.5%), dust (6%) and heavy pollution (1.5%). The coastal urban type aerosols are having lowest AOD value and formed by coarse mode (originates from marine type) and fine mode aerosols (from urban type). But the amount of fine mode particles constitutes the lowest portion in this type of aerosols compared to other types of aerosols. Meanwhile, the second largest aerosol type (polluted urban) has the second highest AOD (0.6658) value. This polluted urban aerosols are mostly formed by fine mode particles (fine mode total volume = $0.1194 \mu m^3/\mu m^2$; the highest among all types of aerosol). Other than that, the dust type aerosols are found to have large amount of coarse mode particles (coarse mode total volume = 0.0890) with high AOD value. The least dominated aerosol type is heavy pollution aerosol. They are mostly formed by fine mode particles (fine mode total volume = 0.1170) with highest AOD value (1.3406) and highest single scattering albino (0.9650).

The aerosol type classification result has similarity and also differences when compared to a previous study [16]. Both study areas, Hong Kong from [16] and this study, are commercial and developed region and located near the coast. Therefore, coastal urban type aerosols dominated both these area (45% for Hong Kong). Meanwhile, the dust type aerosol is not the dominant aerosol in both studies (3% only for Hong Kong). Other the other hand, polluted urban and heavy pollution type aerosols constitute the highest proportion [16] which is 30% and 22% respectively. However, heavy pollution type aerosol only contributes 1.5% in our study area (as shown in table 1). This may due to the level of air pollution is different between our study area and Hong Kong.

5. Conclusion

As the first step of aerosol optical depth retrieval, cluster analysis was applied to classify the aerosol types within the study area. Four types of aerosols have been classified: coastal urban, heavy pollution, polluted urban and dust. These different aerosol models coupled with different viewing geometries (solar zenith angles, view zenith angles, relative sun/satellite azimuth angles) are important as they will be inputs into the radiative transfer model to build a Look up Table (LUT) which will have simulated aerosol reflectance and Top-of-Atmosphere reflectance as a function of AOD in the future work. Current aerosol retrieval techniques (aerosol products) over land perform well on lower reflectance area (e.g. vegetation) but not on high reflectance areas like over the urban areas. Therefore, the minimum reflectance technique is suggested in this study, which is one of the approaches to calculate surface reflectance on high reflectance area [16]. For the future work, the surface reflectance will be calculated and in the same time SBDART radiative transfer model will be used to build up the LUT. Finally, the calculated aerosol reflectance from the MODIS level 1b data will be compared with the simulated aerosol reflectance from SBDART for each LUT. The aerosol model with the minimum residual will be selected and located for each pixel. We will validate the results with AOD measured using Microtops II sunphotometer.

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