Estimation of lidar ratios during haze events in Penang, Malaysia

W Y Khor*, M Z Mat Jafri and H S Lim
School of Physics, Universiti Sains Malaysia, Penang, Malaysia

*Email: kwy13_phy071@student.usm.my

Abstract. Three haze events occurred in Malaysia during the years of 2014 and 2015. Humidity and visibility parameters are obtained and used to estimate the Lidar ratio (LR) values during these three haze events using the algorithm generated. The possible aerosol types during the haze were also evaluated. The haze event that happened from August to October 2015 was the worst among the three cases with a maximum LR value of 177 sr. The LR values also range from 50 sr to 145 sr. The possible aerosol type during the haze events are highly light absorbing particles such as biomass burning aerosols. The LR values are much larger compared to other literature which may be due to overestimation. The assessed LR values are consistent with the changes of the number of hotspots in neighbouring countries during the haze events.

1. Introduction
Haze is a seasonal issue every year in Malaysia. This is caused by the monsoon seasons and seasonal burning in neighbouring countries of Malaysia, such as Vietnam, Indonesia and many more. In year 2014 and 2015, Malaysia was struck with three separate events of haze during different time periods. A moderate haze episode occurred between February and March 2014 whereas transboundary haze pollution occurred during the Southwest monsoon from June to October 2014. Year 2015 had only one occurrence of haze from August to September 2015 which was more devastating than the previous two haze events [1].

The API levels for these three haze events were very high which preached the unhealthy level of more than 200. The visible atmospheric condition was also very hazy with very low visibility. To further learn about the atmospheric conditions during these three time periods, the lidar ratios (LR) values can be assessed to further invert lidar signals and extract information. The possible aerosol types can be known based on the values of the LR [2]. Therefore, the LR values during these three time periods are estimated and presented in this paper.

2. Study Area
The island of Penang is located in the northwestern region of Peninsular Malaysia and lies within latitudes 5.2ºN to 5.5ºN and longitudes 100.15º E to 100.43ºE (Figure 1). The lidar used is the Raymetrics LB100-ESS-D200 Eye-Safe Scanning Lidar system. It is placed on the rooftop of the School of Physics, USM, Penang at a latitude of 5.40ºN and a longitude of 100.30ºE.
3. Data Acquisition and Processing

An algorithm for estimating the LR values is generated based on multiple regressions. The final algorithm is as shown in Eq (1):

\[ LR = a_0 + a_1 \log_{10} H + a_2 (H \times V) \]  

The parameters required for implementing in the equation for estimating LR are humidity (H) and visibility (V). These two parameters are average values obtained daily. Once the H and V values for the three time periods of haze is obtained, the LR values during the haze events in year 2014 and year 2015 was generated based on the algorithm. Graphs are plotted to display the values of the LR. The LR values are plotted according to the 3 haze event that has occurred separately in the years 2014 and 2015.

4. Results and Discussion

Table 1 shows the maximum, minimum, mean and median values of LR during the three haze events respectively. The maximum LR value is highest for the Aug – Oct haze event in 2015 with 177 sr while the lowest was in Feb – Mar 2014 with 123 sr. The average LR was highest for the haze in 2015 with 97 sr while the other two haze events had 79 sr and 73 sr respectively. It can be implemented that the haze event was the worst from August to October 2015 compared to the previous two cases in year 2014.

It should be noted that although the haze event in year 2015 was reported to be from August to September, the haze event in Penang seemed to occur for a longer period which is from August to October 2015. This may be due to the fact that the pollution particles have lingered in the atmosphere during the inter-monsoon season of October. Lack of wind and rain this month has prolonged the lifetime of aerosols in the atmosphere from deposition and removal from the atmosphere through rain and other natural atmospheric processes.
Table 1. Maximum, minimum, mean and median values of lidar ratios during three haze events (Feb – Mar 2014, June – Oct 2014, Aug – Oct 2015)

| Lidar ratios, sr | Feb-Mar14 | June-Oct14 | Aug-Oct15 |
|-----------------|-----------|------------|-----------|
| Max             | 123       | 141        | 177       |
| Min             | 58        | 46         | 48        |
| Mean            | 79        | 73         | 97        |
| Median          | 77        | 69         | 88        |

Figure 2 shows the LR values for these three haze events during the respective period of occurrence. February to March 2014 haze displays LR values in the general range of 60 to 95 sr. Only two extreme values of LR values are found. On the other hand, the second haze event from June to October 2014 contains LR values within the range from 50 sr to 100 sr. 9% of the values are greater than 105 sr. The third haze event from August to October 2015 showed LR values which are more scattered over a very large range of LR values from 50 sr to 145 sr. 11% of the LR values during this period were larger than 160 sr.

Among these three haze events, the most serious case is no other than the one that happened in year 2015. It contains the highest values of LR and the LR value range is very large. The other two haze events were less serious compared to this haze event.

Based on the LR values, the possible aerosol types during the haze events are highly light absorbing fine particles which are possibly biomass burning aerosols and fine particulate matter particles. LR values within the range from 50 sr to 80 sr are highly light absorbing particles as reported by these authors [3], [4]. It is also reported that Malaysia is one of many Southeast Asian countries that has particulate matter pollution from vehicle and industrial emissions, including Indonesian peatland fire during the southwest monsoon (dry) season from June to October [5]. The LR
values assessed in this study are very high which is not highly likely to occur. An observation which took place in India during haze also showed a maximum LR value of 110 sr only for 355-nm wavelength [6]. The LR values are only estimations and may be over-estimated.

The high values of LR in year 2015 compared to year 2014 can also be proved by the high number of hotspots during the period of August to October 2015 compared to the same period in year 2014. This is shown in figure 3. As shown, during the haze event in February to March 2014, the number of hotspots is much less compared to the other two periods. The second haze event that happened from June to October 2014 is less serious compared to the one in year 2015. This is proven by the number of hotspots that is less saturated compared to that in year 2015. A backward trajectory on the 15th of September 2015 shows that biomass burning aerosols from Indonesia would be advected to Penang.

Figure 3. Fire hotspots during February to March 2014 (Top), August to October 2014 (Middle) and August to October 2015 (Bottom)
The number of hotspots for the same period of time is shown here which is from August to October to show the difference of the number of hotspots in the same months but different year. The LR values of in the months of August to October is much higher in year 2015 than in year 2014 which is the same for the number of hotspots during these three months. With the high number of hotspots, it would also mean that the density of smoke and biomass burning is high which attributes to a high number of biomass burning aerosols. These fine particles of biomass burning would induce the increment of the LR values. This means that the assessed LR values would be quite accurate for each haze event. The assessed LR values would be proportional to the number of hotspots surrounding Penang.

![NOAA HYSPLIT MODEL](image)

**Figure 4.** Backward trajectory on 15 September 2015 with 4 trajectories generated every 72 hours from the same location (Penang)

5. **Conclusion**

The most serious haze event is found to be from August to October 2015 with a large LR value range from 50 sr to 145 sr and a maximum LR value of 177 sr. The other two cases were less serious compared to this haze event. The maximum values of LR for February to March 2014 and for June to October 2014 are 123 sr and 141 sr respectively. Possible aerosol types during the haze events are biomass burning aerosols and fine particulate matter particles. The LR values estimated are very much larger than LR values found in literature which may be overestimated. The LR values for the haze events changes with relation to the number of hotspots surrounding Penang.
Acknowledgments
The authors gratefully acknowledge the financial support under the ERGS grant 203/PFIZIK/6730051, Fundamental Research Grant Scheme (FRGS) 203/PFIZIK/6711352 - Investigation Of Aerosol Characteristics And Distribution In Malaysia By Using Aeronet And Lidar Data, ScienceFund 305/PFIZIK/613615 - Environmental Effects And Its Influence of Increased Green House Gasses In Peninsular Malaysia and RUI grant (Individual) 1001/PFIZIK/811228 - Investigation Of The Impacts Of Summertime Monsoon Circulation To The Aerosols Transportation And Distribution In Southeast Asia Which Can Lead To Global Climate Change.

References
[1] Department of Environment Malaysia (DOE) 2015 Chronology of haze episodes in Malaysia pg 3: https://www.doe.gov.my/portalv1/info-umum/info-kualiti-udara/kronologi-episod-jerebudidi-malaysia/319123
[2] Müller D, Ansmann A, Mattis I, Matthias T, Wandinger U, Althausen D and Pisani G 2007 Aerosol-type-dependent lidar ratios observed with Raman lidar J. Geophys. Res.: Atmospheres 112 D16
[3] Novakov T, Bates T S and Quinn P K 2000 Shipboard measurements of concentrations and properties of carbonaceous aerosols during ACE 2 Tellus Ser. B 52 228
[4] Franke K, Ansmann A, Müller D, Althausen C, Wagner F and Scheele R 2001 One-year observations of particle lidar ratio over the tropical Indian Ocean with Raman lidar Geophys. Res. Lett. 28 4559
[5] Fujii Y, Mahmud M, Tohno T, Okuda T and Mizohata A 2016 A Case Study of PM 2.5 Characterization in Bangi, Selangor, Malaysia during the Southwest Monsoon Season Aerosol Air Qual. Res. 16 2685
[6] Franke K, Ansmann A, Müller F, Althausen D, Venkataraman C, Reddy M S, Wagner F and Scheele R 2003 Optical properties of the Indo-Asian haze layer over the tropical Indian Ocean J. Geophys. Res. 108(D2) 4059, doi:10.1029/2002JD002473.