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DETERMINATION OF BACKSCATTER-EXTINCTION COEFFICIENT RATIO FOR LIDAR-RETRIEVED AEROSOL OPTICAL DEPTH BASED ON SUNPHOTOMETER DATA

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ABSTRACT

Backscattered power data from the Doppler LIght Detection And Ranging (LIDAR) systems at the Hong Kong International Airport (HKIA) could be used to obtain the extinction coefficient of the troposphere by combining with the meteorological optical range (MOR) data from the nearby forward scatter sensor. The Range-height Indicator (RHI) scan of the LIDAR is then utilized to derive the vertical profile of extinction coefficient, which is integrated with height to obtain the aerosol optical depth (AOD). In the retrieval of extinction coefficient profile, there is a power exponent of unknown value relating the backscattered power and the extinction coefficient. This exponent (called the backscatter-extinction coefficient ratio) depends on the optical properties of the aerosol in the air, and is normally assumed to be 1. In the present study, the value of this ratio is established by comparing the AOD measurements by a hand-held sunphotometer and the LIDAR-based AOD estimate in one winter (October 2008 to January 2009) at HKIA, which is the season with the largest number of haze episodes. It is found to be about 1.4. The sensitivity of extinction coefficient profile to the value of the ratio is also examined for two cases in the study period, one good visibility day and one hazy day.

1. INTRODUCTION

AOD data are useful in the monitoring of hazy weather. They could be obtained from meteorological satellite observations (e.g. Moderate Resolution Imaging Spectroradiometer, MODIS) and ground-based LIDAR data [1]. At the Hong Kong International Airport (HKIA), two Doppler LIDAR systems of the Hong Kong Observatory (HKO) have been in operation for windshear alerting. At the same time, the backscattered power data from the LIDAR, coupled with the MOR readings from the nearby forward scatter sensors, could be used to retrieve the vertical profile of extinction coefficient, which is integrated with height to give the AOD.

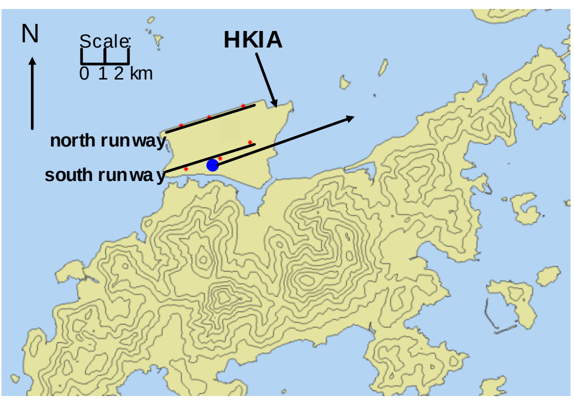

Figure 1 Location of the LIDAR and the direction of the LIDAR RHI scans considered in the present study. The red dots indicate the locations of the forward scatter sensors along the two runways.

In retrieving the extinction coefficient profile using Klett's method (as in [1]), it is assumed that the backscatter coefficient β is related to the extinction coefficient σ through a power law, namely, $\beta = \sigma^k$. The power index k, which is called backscatter-extinction coefficient logarithmic ratio or backscatter-extinction coefficient ratio in short in this paper, is unknown theoretically and dependent on the optical properties of the aerosol in the air. It is common to assume that $k = 1$. However, there are many studies based on LIDAR measurements that k may not be equal to 1. For instance, in a study at Lanzhou, China, k is found to be 0.8 – 0.9 (see [2]).

The value of k is established in this paper using AOD measurements of a hand-held sunphotometer (Microtops II) as ground truth. As the sunphotometer has not been used at HKIA for a long time, only the data of one winter (October 2008 to January 2009) is considered in this paper, which is the season with the highest number of hazy days. Only the data from the south runway LIDAR (location in Figure 1) are considered in the present study. The backscattered profiles are taken from Range-height Indicator (RHI) scans at an azimuth angle of 70 degrees from the north, as shown by the arrow in Figure 1. The LIDAR data are combined with the MOR readings from the forward scatter sensor near the centre of the south runway (location in Figure 1) in retrieving the extinction coefficient profile.

2. CALCULATION OF AOD

The calculation methodology is the same as that in [1] and only a summary of the major equations is given here. The distance-corrected backscattered power S of the LIDAR could be used to retrieve the extinction coefficient profile of the troposphere using Klett's method based on the following equation:

$$\sigma(r) = \frac{\exp[(S(r) - S_m)/k]}{\left\{\sigma_m^{-1} + \frac{2}{k}\int_r^{r_m} \exp[(S(r') - S_m)/k]dr'\right\}} \quad (1),$$

where those quantities with subscript m are the corresponding values at a reference distance. The extinction coefficient σ for the LIDAR's wavelength (2022 nm) is adjusted to that at the visible range (500 nm), indicated as σ'. The latter quantity is then integrated with height to give AOD:

$$AOD = \int_0^{z_{\max}} \sigma'(z)dz \quad (2).$$

Following [1], the maximum height z_{max} is taken to be 4 km.

3. SELECTION OF K

The AOD values calculated from the LIDAR are compared with the actual measurements from the sunphotometer. In the LIDAR retrieval, the ratio k is varied between 0.5 and 2.0 at a step of 0.1. For each value of k, the LIDAR AOD is plotted against the sunphotometer AOD for the whole study period and the data points are fitted with a straight line using total least square technique (as in [1]). Three quantities of the best-fit straight line are considered, namely, the slope, y-intercept and correlation coefficient (R^2). Moreover, the root-mean-square (r.m.s.) difference between the two AOD datasets is considered.

The variations of the above-mentioned quantities with k are shown in Figures 2(a) to (d). The slope of the best fit straight line is closest to 1 and the corresponding y-intercept is closest to 0 for k = 1.4. The R^2 and r.m.s. difference also flat out with k for $k \geq 1.2$. As such, it seems that the optimum value of k for the airport area is about 1.4, at least based on the data in the study period (October 2008 to January 2009).

The AOD data points and the best fit straight line at k = 1.4 are shown in Figure 3(a). As a comparison, the corresponding scatter plot for MODIS AOD vs. sunphotometer AOD is given in Figure 3(b) (note: study period is the same but the actual observation times may be different because Figure 3(b) only includes those data points when MODIS AOD data are available). The slopes and the y-intercepts of the best fit straight lines in Figures 3(a) and (b) are of similar magnitude. The R^2 for MODIS is higher, but of a magnitude comparable with that for LIDAR.

4. SENSITIVITY OF EXTINCTION COEFFICIENT PROFILE TO K

To demonstrate the sensitivity of extinction coefficient profile to the choice of k, two case studies have been conducted. The first occurs in the morning of 20 October 2008. At that time, visibility was good at HKIA and the human-observed visibility value was about 15 km. MODIS data show that AOD is relatively low along the coast of south China (Figure 4(a)). RHI scan of the LIDAR indicates that the backscattered power (and thus aerosol loading of the air) is higher from the ground up to around 1.1 km above (Figure 4(b)). The corresponding extinction coefficient profiles based on different values of k are given in Figure 4(c). It could be seen that the profiles for different k values have generally similar appearance. In particular, the extinction coefficient is higher below 1 km or so. However, the fluctuations of σ' with altitude are more "exaggerated" for smaller value of k. As such, the AOD based on a smaller value of k (such as 0.5, with an AOD value of about 0.23) deviates more significantly from the sunphotometer measurement (about 0.28).

Similar behaviour is also observed on a hazy day. During the daytime of 15 December 2008, it remained hazy at HKIA with the visibility hovering around 4000 m due to the aerosols brought about by the northwesterly sea breeze. MODIS data show that AOD is higher around the Pearl River Estuary (Figure 4(d)). RHI scan of the LIDAR (Figure 4(e)) indicates that, apart from the higher backscattered power values below 1.1 km or so, there are two elevated bands of higher values as well at about 2 km and 2.5 km above the sea level. As such, the retrieved σ' does not drop significantly with altitude until at about 3 km. Once again, the σ' profile (Figure 4(f)) shows more exaggerated fluctuations with height for a smaller value of k, particularly between 2 and 3.3 km (for k = 0.5). Thus, the resulting AOD value (1.37 for k = 0.5) deviates more from the sunphotometer measurement (1.25).

5. CONCLUSIONS

Based on the limited dataset in the present study, the backscatter-extinction coefficient ratio is found to have an optimum value of 1.4, at least for the winter of 2008-2009. More sunphotometer data would be collected to study the seasonal and possibly the year-to-year variation of *k*.

REFERENCES

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[2] Zhang, W.Y., Y.Q. Wang, J.Y. Song, L. Zhang, L. Sun, 2008: Research on logarithmic ratio k of aerosol backscatter extinction using Lidar, *Plateau Meteorology*, **27**, pp. 1083-1078.

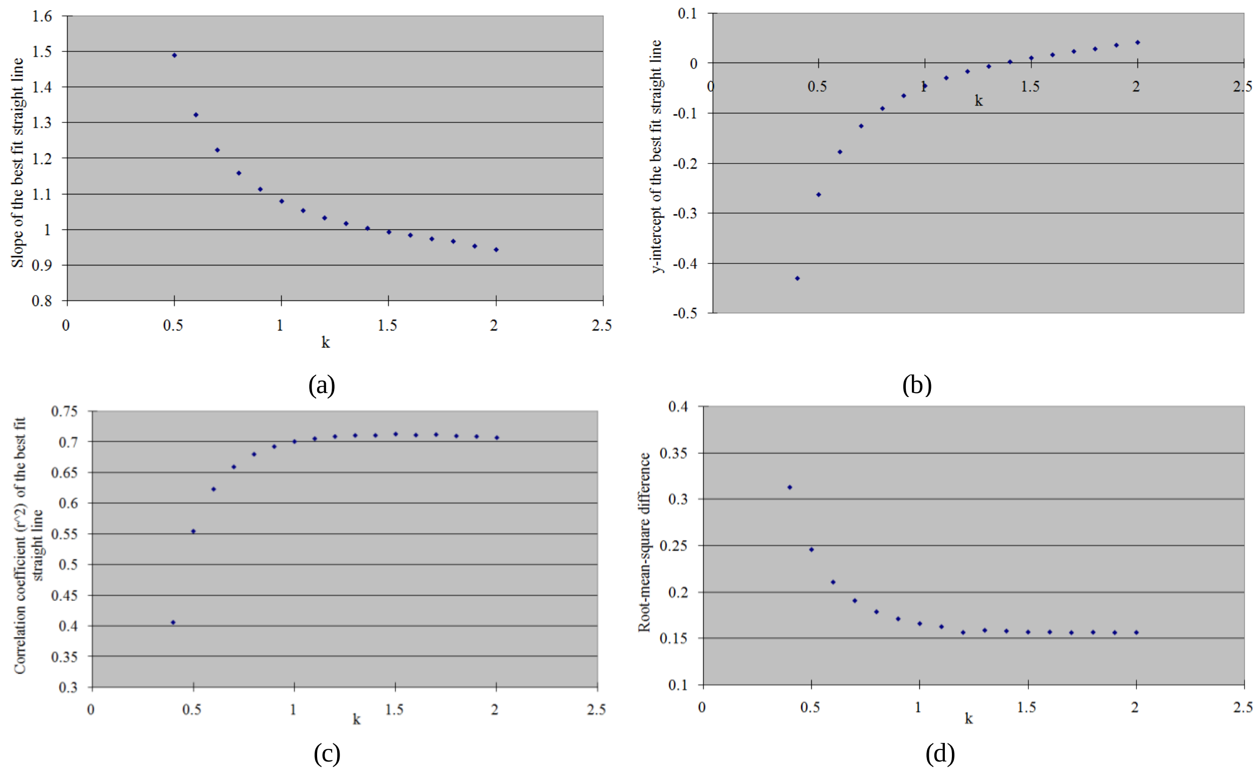


Figure 2 Variation of the following quantities with k: (a) slope, (b) y-intercept, and (c) correlation coefficient of the best fit straight line, and (d) root-mean-square difference, between AOD from LIDAR and AOD from sun photometer during the period October 2008 to January 2009..

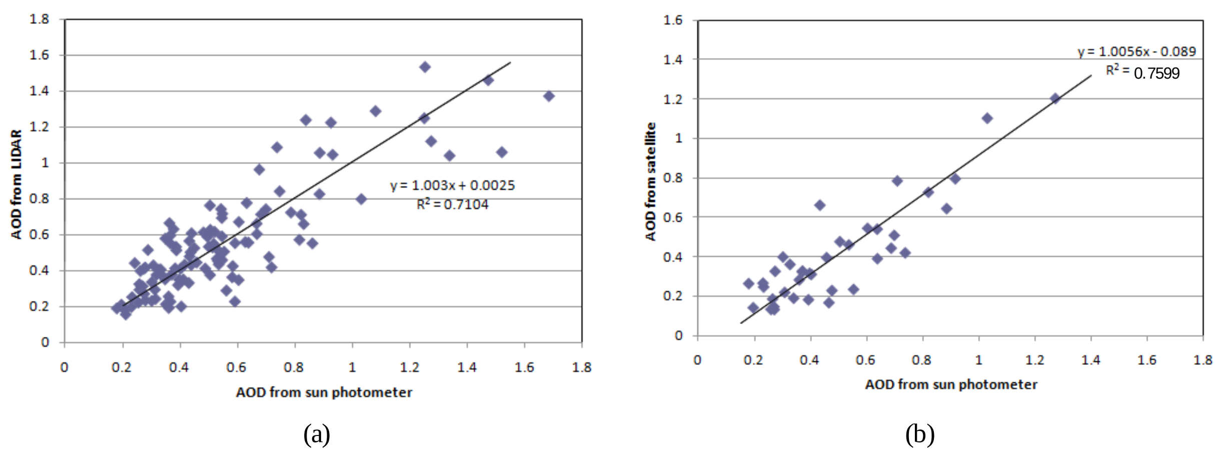
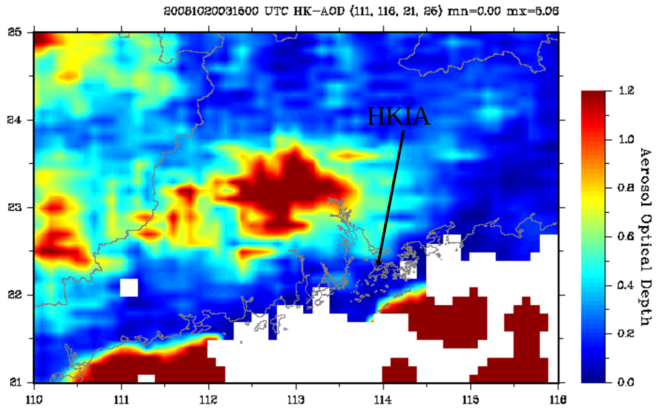
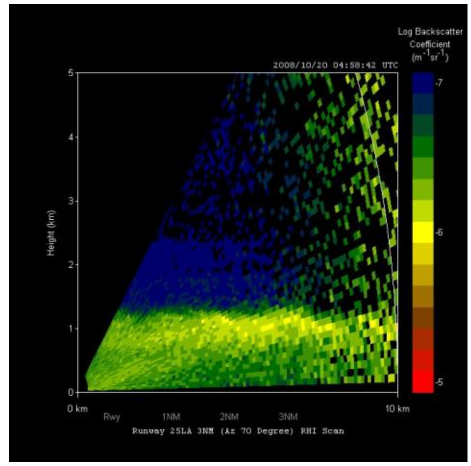


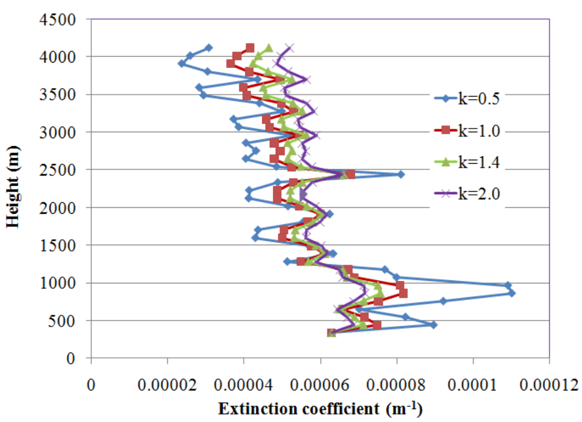
Figure 3 Scatter plot of AOD: (a) between LIDAR and sun photometer, and (b) between MODIS and sun photometer.



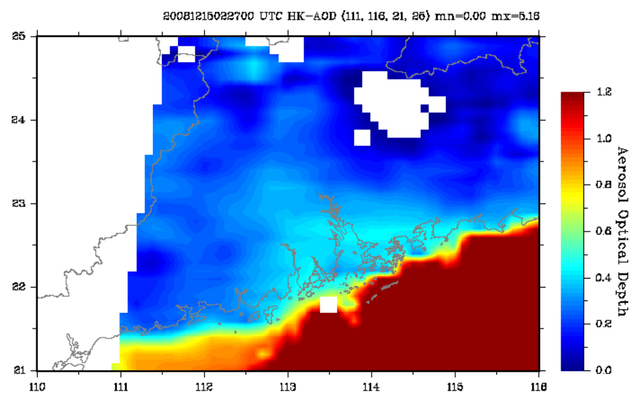
(a) MODIS AOD map at 03:16 UTC, 20 Oct 2008



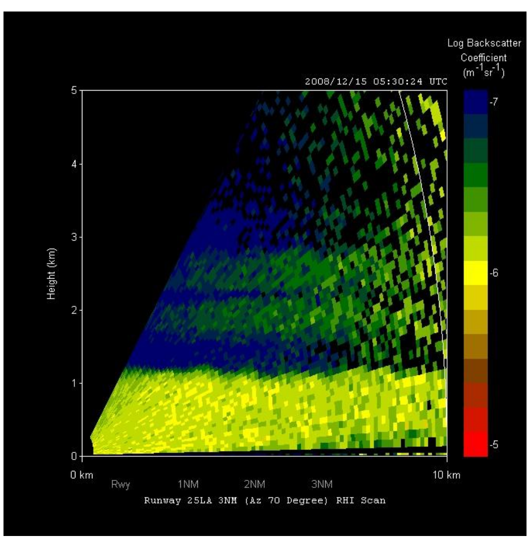
(b) LIDAR RHI plot of backscattered power



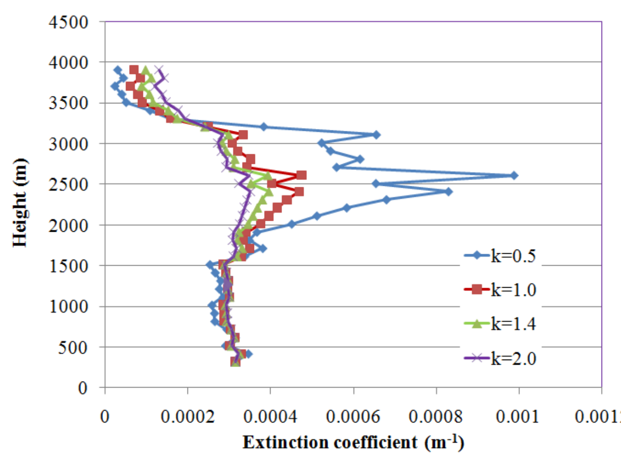
(c) LIDAR-derived extinction coefficient profiles



(d) MODIS AOD map at 02:27 UTC, 15 Dec 2008



(e) LIDAR RHI plot of backscattered power



(f) LIDAR-derived extinction coefficient profiles

Figure 4 Data plots for the two events under study in this paper, namely, 20 October 2008 (a) to (c), and 15 December 2008 (d) to (f).