Studies of urban aerosols in Macao using a horizontal Mie Lidar

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ABSTRACT

A horizontal Mie Lidar has been constructed for studying urban aerosols in Macao since 2005. Since the Lidar system is used for monitoring in urban city, it was designed to be eye-safe. The Lidar system is placed in a house which locates on the roof of Meteorological and Geophysical Bureau (SMG) building and at the top of a hill. The system is mainly used for studying the aerosol distribution over the densely urbanized districts as well as monitoring particles concentration emitted from the power station. In this paper, some representative results from the Lidar system will be presented. In addition, correlation between the mean values calculated from the RSP profiles and PM_{10} and $PM_{2.5}$ values measured by the samplers in SMG are examined.

1. INTRODUCTION

Macao is a highly developed and urbanized city locates in the west of the Pearl River Delta (PRD) Region in China. Because of the rapid economic development and population growth, pollution becomes a great concern in the recent years. Air quality in Macao is not only affected by local sources of pollution such as power stations and exhaust emissions of vehicles but also influenced by the regional transport of air pollutant in PRD region. Macao is located in the East Asian Monsoon zone. In winter, the northerly wind brings dirt and high polluted air from the continent and cause low air quality and visibility. Besides, Macao is one of the most popular touring cities in the world. The number of vehicles has also increased rapidly in the past few years and becomes one of the sources of air pollutants in Macao.

For long-term monitoring of aerosol distribution, a horizontal Mie Lidar has been developed in Macao since 2005 [1]. Lidar is an advanced remote sensing technique which provides high temporal resolution data for studying the atmospheric aerosols [2-3]. Because in the lidar site two types of aerosol mass concentration measurement systems are in routine operation, the aerosol concentration data can be readily used to calibration and correlate lidar inversion. In this paper, the design of the Mie Lidar is described. The methods of data acquisition and inversion used to obtain extinction coefficients are discussed. Some recent results measured in high pollution days are presented. Finally, the mean values calculated from the respirable suspended particulates (RSP) profiles are correlated with the respirable particulate matter (PM_{10} and $PM_{2.5}$) values taken by the samplers in SMG.

2. LIDAR DESIGN

The Lidar system is located on the roof of SMG building and at the top of the hill in Taipa as shown in Fig. 1. The system is based on a Nd:YAG laser operating in 532nm wavelength. Receiver telescope is a Schmidt-Newtonian f/4 telescope with 254mm diameter and 1016mm focal length. The laser and telescope are in biaxial configuration. Since the Lidar is operated continuously in urban and near the airport, the system is designed to be eye safe. To achieve eye safe operation, the laser beam is expanded to 90mm diameter by using a Maksutov-Cassegrain telescope. The pulse repetition rate is set to 1 kHz. A narrow bandwidth interference filter with 0.3nm FWHM is employed to suppress the daytime background light. Additionally, a variable iris is used to obtain better near-field performance at daytime. Signals are detected by the photomultiplier tube (PMT).

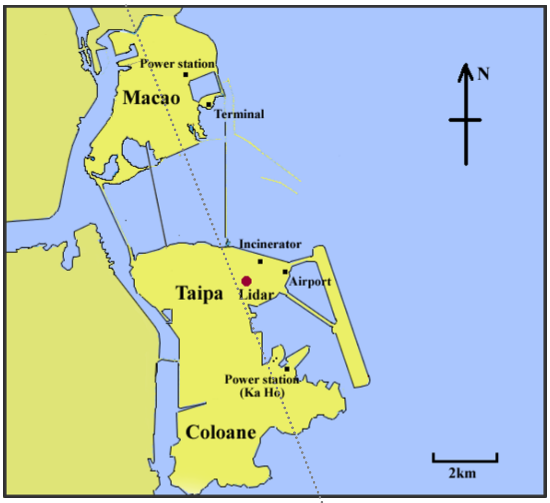

Fig. 1 Location of the observation site and the dotted line indicates the Lidar line of sight

To perform data logging, a transient recorder operating at 20 MHz with 1k memory bins is used. This gives the system a maximum range of about 7.6 km with a 7.5m resolution. The recorder comprises both analogue and photon counting channels. Analogue channel has better performance in daytime. Conversely, photon counting channel gives a better range at night when the background signal is small. Near-range correction is also applied to correct the diminished signal due to the light being out of focus at the field stop. Thus, the Lidar is able to be operated in a near range of about 100m. The system is designed to work automatically. Data acquisition process is computer-controlled under the LabVIEW platform. Retrieved data are transferred to SMG through network. The schematic diagram and specification of the Lidar is shown in Fig. 2 and table 1.

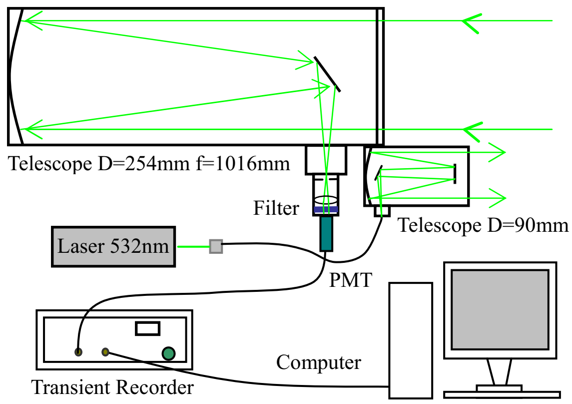

Fig 2 Schematic diagram of the Lidar

Table 1 Lidar specifications

Transmitter	
Laser	Nd:YAG 532 nm
Repetition rate	1 kHz
Maximum pulse energy	50µJ
Beam diameter	Expanded to 90m by a Maksutov- Cassegrain telescope
Receiver	
Telescope	254mm Schmidt-Newtonian telescope f/4
Bandpass filter	0.3 nm FWHM
Data acquisition	20 MHz transient recorder with analogue and photon-counting
Detector	Photomultiplier tube (PMT)
Range resolution	7.5m

3. DATA INVERSION

Fernald's method [4] is applied to derive the extinction coefficient of aerosols:

$$\sigma_P(x)=\frac{\frac{P(x)x^2T_R(x)^{\left(3S/4\pi\right)-2}S}{CE}}{1-\frac{2S}{CE}\int_0^x P(x)x^2T_R(x)^{\left(3S/4\pi\right)-2}dx}-S_1\beta_R(x) \tag{1}$$

where $P(x)$ is the signal received at range *x*, $T_R(x)$ and $T_P(x)$ are the transmission for Rayleigh scattering and atmospheric aerosols at range *x* respectively. β_R is the Mie backscattering coefficient. S_1 is the lidar ratio. In here, we assumed this ratio to be 50 [5]. The system constants, *S/CE* can be obtained by imposing some boundary conditions. In our measurements, the visual range measured by a forward scattering visibility sensor (Vaisala model FD12) in SMG is used for calculating the boundary value. By putting the relative humidity and assuming the atmosphere to be horizontally homogeneous, RSP concentration can be calculated from the extinction profiles using [1]:

$$\frac{\sigma}{RSP}=a+b\times\left(\frac{RH}{100}\right)^c \tag{2}$$

where *a* = 0.0047, *b* = 0.036 and *c* = 12.92. This relation was established by correlating some local visibility and PM_{10} data. This method is similar to Hänel [6] where the dependence of extinction on the relative humidity is developed from Mie theory for different air mass models. Since the correlation in this paper was only performed as far as a relative humidity of 92% and hence the RSP calculation may involved some uncertainties for humidity higher than this. Besides, fogs and precipitations may also induce uncertainties in the RSP calculation.

4. RESULTS AND DISCUSSION

Currently, the Lidar is either pointing horizontally to the north or the south during observation for detecting the aerosol distribution over the densely urbanized districts in Macao peninsular or monitoring particles concentration emitted from the chimneys of the power station in Ka Ho. Each measurement is integrated for about ten minutes to improve the signal to noise ratio in far range. Some recent results are shown in Fig. 3 to 5.

Fig 3 shows the RSP profiles measured on 11th January, 2006. Lidar was pointed towards the power station in the south. During the measurement period, Macao was influenced by winter monsoon. Northerly winds were prevailing. Temperature at SMG was approximately 16°C. From the RSP profiles, homogeneous distribution of the aerosols can be observed in near range. However, once the Lidar pulse reached the proximity of the power station at about 2.5km, a sharp peak can be recognized. The sharp peak varied between 200µg/m^3 and 600µg/m^3 from 9pm to 11pm. The particle concentration became stable again it passes 3km. The RSP derived by Lidar in near range was about 40µg/m^3, which compares well with the value measured by the PM_{10} sampler in the SMG building.

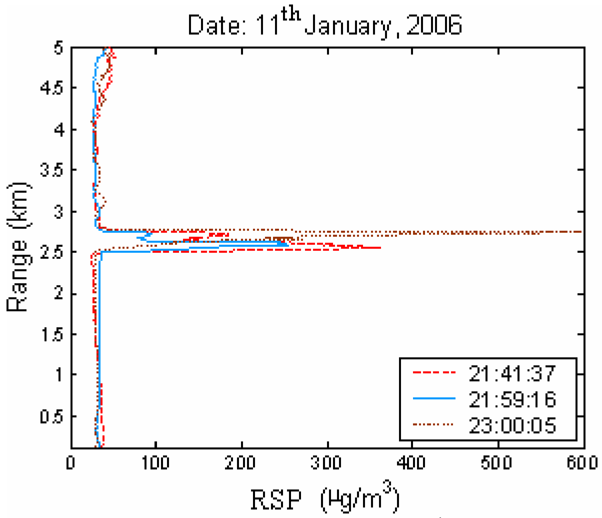

Fig. 3 RSP profiles measured on 11th January, 2006

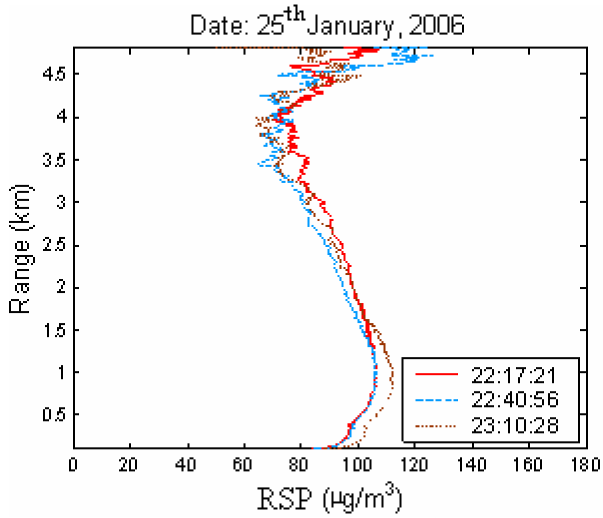

Fig. 4 RSP profiles measured on 25th January, 2006 night

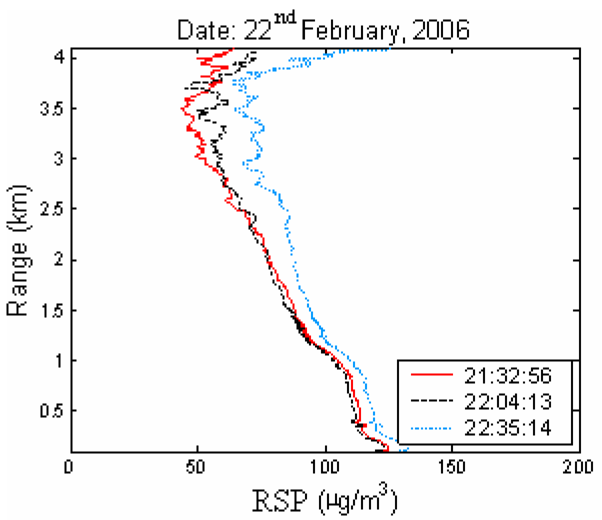

Fig. 5 RSP profiles measured on 22nd February, 2006 night

Examples of the RSP profiles measured in high pollution day are shown in Fig. 4 and 5. The first measurement was made on 25th January 2006. Lidar was pointing towards the Macau peninsular in north direction. PM_{10} concentration recorded in SMG was relatively high throughout the night and ranged between 120 and 130μg/m^3. Aerosol signal was detectable up to about 5km. The RSP profiles show elevated aerosol concentration in near range possibly due to the local pollution from the airport and incinerator. Particle concentration dropped between the ranges 1.5 to 4 km when the laser beam passed over the sea. The RSP concentration elevated again once it reached the densely urbanized districts in Macao peninsular at about 4.5km away from the Lidar site.

Another measurement performed on 22nd February, 2006 is shown in Fig. 5. Northerly wind was prevailing at night and brought dirt air from the continent. Particle concentration remained high throughout the night. Similarly, high aerosol concentration can be recognized in near range and over the urban district in Macao. The mean particles concentration was increasing gradually from 9pm to 11pm.

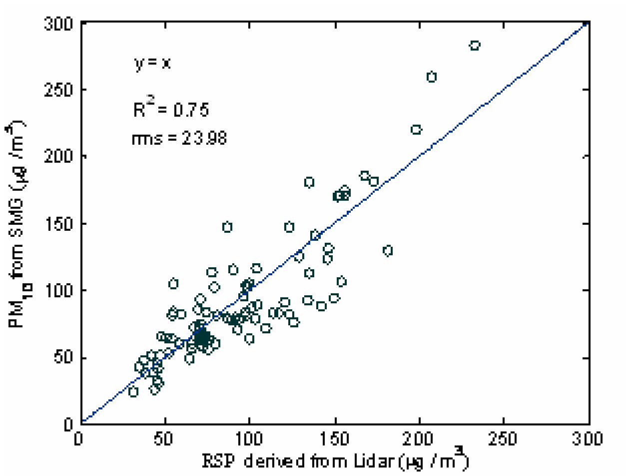

Fig. 6 Correlation between mean RSP from Lidar and PM_{10} value from the sampler in SMG

To verify the Lidar data, the mean value calculated from the RSP profiles are correlated with the PM_{10} and $PM_{2.5}$ values taken by two samplers in SMG. Linear correlations which are shown in to correlate with the estimated aerosol concentrations inferred from the Lidar measurement for PM_{10} (Fig. 6). Similar correlation has been done using the $PM_{2.5}$ data in Fig. 7. Result shows the $PM_{2.5}$ is also directly proportional to the RSP value derived from Lidar. A constant proportional coefficient of 0.51 has been found using least squares fit and this would imply that at the 2.5 microns cut-off the aerosol concentration is about 51% of that at the 10 microns cut-off. Fine particulars can be considered as a significant portion in the total aerosol concentrations in this region of the Pearl River Delta. In Fig. 7 there are some measurements that deviated from this linear relation, and should be considered more carefully in the near future as they will indicate how the meteorological conditions would affect the percentage of the fine particulates. It is suspected that the maritime aerosols would be the points deviated and lies below the linear curve while continental aerosols will be those above.

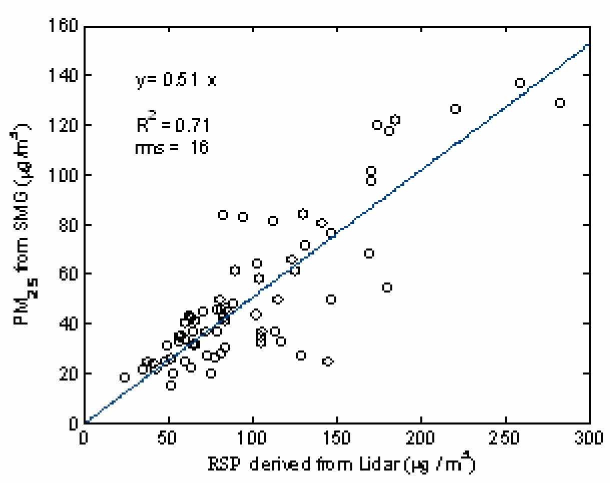

Fig. 7 Correlation between mean RSP from Lidar and $PM_{2.5}$ value from the sampler in SMG

CONCLUSIONS

An eye-safe horizontal Mie Lidar system has been developed for monitoring the urban aerosols in Macao. Designs of the Lidar system and the inversion method used to obtain extinction coefficients are discussed. Some recent results measured in high pollution days are also presented. Higher extinction coefficients were observed over the Lidar pulse reached the proximity of the power station as well as above densely urbanized districts in the Macao peninsular. Correlation between the mean values calculated from the RSP profiles and PM_{10} and $PM_{2.5}$ values measured by the samplers in SMG are examined. Linear relation can be observed from the correlation which shows the Lidar measurement reliable. The fine particulates are found to be correlated well with the Lidar inferred aerosol concentrations.

ACKNOWLEDGEMENTS

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