LIDAR OVERLAP FUNCTION DETERMINATION USING THE RAMAN LIDAR SIGNALS

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ABSTRACT

The determination of vertical distribution of optical properties of clouds and aerosols using the lidar system is affected by the incomplete overlap between the field of view of transmitter i.e. laser beam & the receiver in the near-field range. Thus, the study of vertical profiles of aerosol optical properties in the lower atmosphere is erroneous without the correction of lidar overlap function. Here we have analysed the effect of overlap using a simple technique proposed by Ansmann and Wandinger to determine overlap function. We have determined the overlap factor for 5 different days of June 2016 and then calculated the mean overlap profile and determined the relative deviation of each day with respect to mean overlap factor. Results reveal that the complete overlap was achieved beyond 300 meters.

1. INTRODUCTION

In recent years, the lidar system has drawn greater attention for the measurement of optical aerosol properties at near altitudes due to increasing air pollution episodes. The lidar system can provide the range resolved measurements of optical properties of aerosols and clouds. However, the lidar observation is affected by the incomplete overlap between the transmitter and receiver field of view (FOV) in particularly at lower heights. This incomplete overlap makes a significant impact on the vertical profiles up to a few kilometres in the systems having a FOV as narrow as 0.5 mrad or below. Without correcting the lidar backscattered signal for the overlap effects, it is not possible to study the boundary layer pollution and its sources using the lidar system.

There are several methods to analytically determine the overlap factor [2], by applying raytracing model [1], and also experimentally [3]. However, there are several limitations to these techniques since it requires us to know the technical parameters and we have to make an assumption of homogeneous aerosol environments. In this work we are using a simple technique proposed by Ansmann and Wandinger to determine the overlap function [4]. This method relies on the combination of elastic and Raman backscattered signals under clear atmospheric conditions.

2. METHODOLOGY

A Raman Lidar system has been deployed at the CSIR-Institute of Himalayan Bioresource Technology (IHBT), Palampur, Himachal Pradesh, India. The station is situated at an altitude of 1347 m (amsl). This lidar system is currently being used to obtain the vertical distribution of clouds and aerosol over Palampur.

2.1 Experimental Setup

Table 1 specifies the technical specifications of the Raman lidar system installed at Palampur. This lidar system has a space resolution of 7.5m and operated at 355nm (elastic channel) with Raman channel at 387 nm. The return signal is detected in the binary format after which it is converted to ASCII format using the software provided by the manufacturer for further processing. The co-polarized and cross polarized Mie channels of the lidar system provides the linear depolarization ratio which is an indicator of the shape of the aerosol/cloud particle. The nitrogen Raman channel at 387 nm of the lidar system can be used to derive the lidar ratio, which is an important parameter for the identification of different types of aerosols in the troposphere.

Table 1 Lidar System Details

Emitter	
Laser Source	Nd:YAG (Quantel

	ULTRA100 Series)
Wavelength	355 nm (frequency tripled)
Pulse Energy	32.8 mJ
Repetition Rate	20 Hz
Near Field Beam Diameter	3.59 mm
Laser beam divergence	<0.8 mrad
Receiver	
Telescope type	Cassegrain
Primary Diameter	200 mm
Secondary Diameter	48 mm
Field of View	2.3 mrad (adjustable from 0.5 to 3mrad)
Detection Unit	
Transient Recorder	Licel (20-12bit) with 7.5m Raw Spatial Resolution
Detectors	3 PMTs

2.2 Sampling Site

The sampling site is in Palampur located at the southern region of Western Himalayas and lies within the latitude 32.093° N and longitude 76.543° E. Figure 1 shows the topographic map of Palampur. The experimental site is situated at Chandpur village which is at the altitude of 1347 m (amsl).
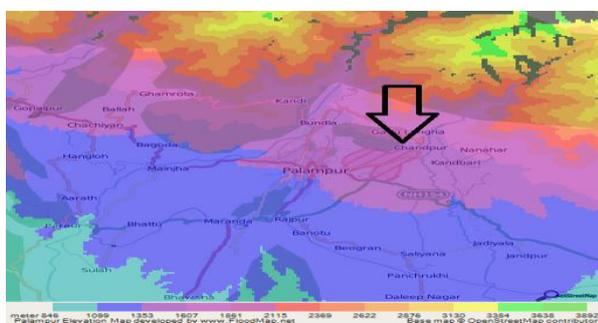
Figure 1: Topographic map of Palampur

2.3 The Overlap Correction

The lidar equations for both elastic and Raman channel are given as follows:

$$P_o(z) = C_o O_o(z) z^{-2} [\beta_{o,P}(z) + \beta_{o,M}(z)] T_o^2(z) \quad (1)$$

$$P_R(z) = C_R O_R(z) z^{-2} \beta_R(z) T_o(z) T_R(z) \quad (2)$$

Here *P* denotes received power and *0 & R* denote the wavelength of the laser at λ_0 and λ_R is the Raman wavelength; system constants are denoted by C_0 and C_R for both the elastic and Raman channels respectively; and $O(z)$ represents the overlap factor. The $O(z)$ reaches to zero near the lidar system (without overlap) and reaches to 1 in the time of complete overlap at large distances. The basic assumption made here in this approach is that $O_0(z) = O_R(z)$ [1].

From Eq. (1), $\beta_{0,P}$ and $\beta_{0,M}$ denote the backscatter coefficients for elastic channel at λ_0 for particles and molecules respectively. The nitrogen Raman backscatter coefficient at the wavelength λ_R is denoted by β_R in Eq.(2). Atmospheric transmission at λ_0 is represented by T_0 i.e. two way between the lidar and the backscatter region whereas T_R at λ_R is atmospheric transmission after the Raman scattering process along the way back to the lidar.

The iterative approach used here is based on the fact that the deviation between the Klett solution [5], [6] for the backscatter coefficient i.e. $\beta_{Klett}(z)$, determined from the elastically backscattered signal and the Raman solution [7] $\beta_{Raman}(z)$, contains the important information about the incomplete overlap [5].

This iterative approach makes use of the fact that the aerosol backscatter signal, after overlap and range corrections is directly proportional to the total backscatter coefficient (see Eq. (1)).

This iterative procedure to reduce the overlap effect on elastically backscattered signal is based on the aforementioned principle. As a first step (*i*=1), we apply the Klett inversion method to the elastically backscattered uncorrected signal. The solution thus obtained is used to solve the expression:

$$\Delta O_i(z) = \frac{\beta_{Raman}(z) - \beta_{Klett,i}(z)}{\beta_{Raman}(z) + \beta_{O,M}(z)} \quad (3)$$

The overlap correction to elastically backscattered signals is applied as follows:

$$P_{o,i+1}(z) = P_{o,i}(z)[1 + \Delta O_i(z)] \qquad (4)$$

This signal profile $P_{0,2}(z)$ is used as an input (step i=2) in the Klett method to derive backscatter coefficient $\beta_{Klett,2}(z)$ and complete the next iteration. By repeating the same procedure again and putting $\beta_{Klett,2}(z)$ into Eq. (3) we can derive a new $\Delta O_2(z)$ which can be used in Eq. 4 again to correct the signal for overlap effect. This procedure is repeated till 10-12 iterations so as to completely remove overlap effect. In each step, the new difference between $\beta_{Klett}(z)$ and $\beta_{Raman}(z)$ decrease. The final overlap profile is derived by comparing the improved signal with the measured signal.

3. RESULTS

We have used here the iterative method to successfully determine the overlap function at Palampur station. The results are shown in Figure 2(a) and 2(b) obtained on five days of June 2016 with the help of Raymetrics Raman lidar system. The Palampur has pristine environment and rainy conditions during this time of the year so a lidar ratio of 35sr at 355nm is assumed for Klett inversion.
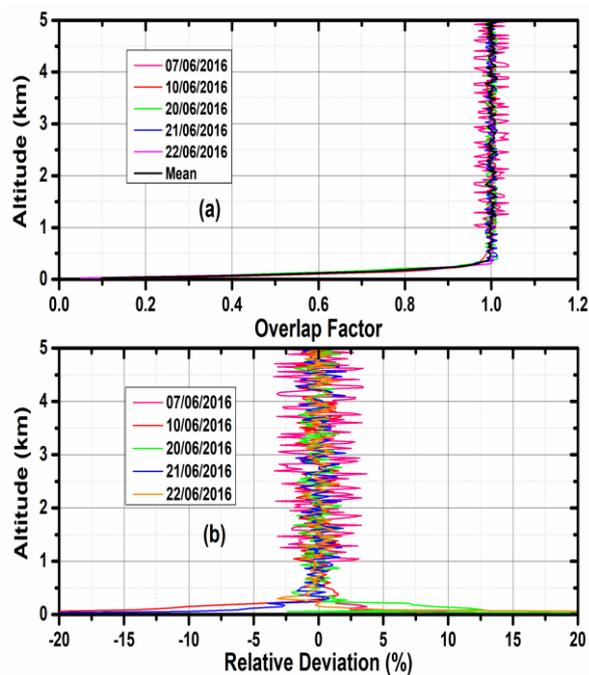
Figure 2(a) shows the overlap function calculated for the five days in the month of June 2016 with the mean overlap factor (black line) calculated using iterative method. Figure 2(b) shows the relative deviation of the overlap factor for 5 days with respect to mean overlap factor.

The results of Klett inversion and Raman inversion were derived and the solutions for several different iterations were derived using the method discussed in section 2.3. Here we have performed 12 iterations to determine the complete overlap height for each day. We have taken 5 different days of June 2016 and determined the overlap factor for each day and then computed the mean overlap profile with the relative deviation of each day with respect to mean. The results are shown in Figure 2(a) and 2(b). We can see from figure 2(a) that there was incomplete overlap below 300 meters and the complete overlap was achieved beyond 300 meters. Below 300 meters, the value of overlap function was less than 1 and after 300 meters, the value was close to 1. Figure 2(b) shows the relative deviation of overlap factor calculated for each day with respect to mean overlap factor. The deviation above 300 meters was less than 5%, however for lower heights i.e. below 300 meters the deviation was high.

4. CONCLUSIONS

It is important for the lidar users to have a proper knowledge about the geometrical form factor to remove or correct the lidar backscattered signals for the overlap effect which occurs at lower altitude due to the incomplete overlap between laser and telescope field of view. Here we have used an iterative approach to determine the overlap function. Results reveal that the lidar system was in complete overlap above 300m and the lidar data has been applied with this correction. The overlap correction has helped us to determine the optical properties with improved results especially in planetary boundary layer.

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