Airborne particles washout: A case study investigated using Laser Radar

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Abstract—**A portable laser radar system was installed at Manora Peak, Nainital (29° 22' N, 79°27' E, 1960 m MSL) under a scientific collaborative programme between National Atmospheric Research Laboratory (NARL), Gadanki and Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital. The laser radar system provides the extinction of vertical distribution of airborne particles in the atmosphere. In this paper, we show the laser radar observations obtained on two consecutive days. A drastic reduction in the height distribution of airborne particles due to heavy rain scavenging processes in the atmosphere was seen in the laser radar observations obtained on 17 May 2006. The airborne particle optical depth (AOD) obtained on 16 May 2006 was about 0.21 at λ=0.532 µm, which is typical for the month of May at this high altitude site. However, on 17 May 2006 this value reduced to 0.08 due to the rain washout effect in the height range of 0.2 to 3.0 km AGL.**

Keyword-laser radar, remote sensing, airborne particles, extinction, washout

I. Introduction

Laser radar systems have shown great potential for monitoring the atmosphere and various cloud parameters as they define the position and spatial resolution of airborne particles and clouds better than any other kind of remote sensing techniques [1]. According to Intergovernmental panel for climate change [IPCC] report [2001], the airborne particles suspended in the atmosphere have a direct radiative forcing as they scatter and absorb solar and infrared radiation in the atmosphere [2] and indirectly affect the size distribution of cloud droplets. In addition to these, airborne particles also play a vital role in providing the information on the development of cloud micro physics, climate variability, atmospheric pollution and atmospheric boundary layer evaluation [3-6]. Technological advancements in the field of solid state laser, optical detectors and data acquisition systems have enabled the development of the new generation laser radar systems, known as micro pulse lidar [7,8] for airborne particles and cloud studies. The laser radar also referred commonly as lidar.

A detailed knowledge of airborne particle optical properties such as the extinction and optical depth as well as their temporal and vertical distribution is essential for understanding their effects on the atmosphere and its processes. To achieve these objectives National Atmospheric Research Laboratory (NARL), Gadanki developed a portable and cost effective laser radar system [9], first of its kind in the country, which provides time dependent vertical structure with high spatial and temporal resolution of airborne particles and clouds in the troposphere. Although the portable lidar system employs micropulse radar technique, but it uses different configuration as compared to other commercially available micropulse systems. The received signal (represents backscatter from air molecules and particles) can then be analyzed to extract the airborne particle altitude profile, the boundary layer ranging, cloud base height and its vertical extent [10,11].

In the present study, the portable laser radar system measurements on 16 and 17 May 2006 have been conducted to investigate the airborne particle extinction and AOD (at 532 nm wavelength) at a high altitude station Nainital, located in the Shivalik Ranges of central Himalayas in India. A case study examined using the laser radar remote sensing technique on particle distribution before and after thundershowers that occurred at 0800 LT on 17th May 2006 during a prevailing sunny day at this high altitude station in India.

II. Instrument details and data analysis

As a part of boundary layer laser radar (BLL) network, a portable laser radar system was installed in 2006 at Manora Peak, Nainital, a high altitude station located in the Shivalik ranges of the central Himalayas (latitude = 29°22′ N, longitude = 79°27′ E), which is at an altitude of ~ 2 km MSL. This site is located geographically in free troposphere (above local boundary layer) and is reasonably away from major pollution sites, making the site conducive for evaluating the background airborne particle loading of atmosphere. The laser radar system was installed at ARIES-Nainital in mid of May 2006 in a temperature controlled room (see Figure 1).

Figure 1. Portable laser radar system installed at ARIES-Nainital, a high altitude station, located in the central Himalayas. The laser radar system was installed at this location as a part of scientific collaboration between NARL, Department of Space (DOS) and ARIES, Department of Science and Technology (DST).

The laser radar uses a diode pumped Nd:YAG laser with built-in second harmonic output at 532 nm and operated at 2500 pulses per second. The emitter beam is coaxial to receiver field of view (FOV) and operated in zenith direction. The lidar receiver employs a 150 mm Cassegrain telescope as collecting optics and a high gain PMT as detector that operating in photon counting mode. The complete overlap between the laser beam and the telescope FOV is expected at about 150 m above ground level. This value represents the lower limit of our vertical laser radar profiles. A PC based multichannel analyzer (MCA) has been employed for recording the backscattered photon returns. The vertical and temporal resolutions of the laser radar system were set at 30 m and 2 min, respectively. The basic laser radar data collected at the high altitude location during the installation time is shown in Figure 2.

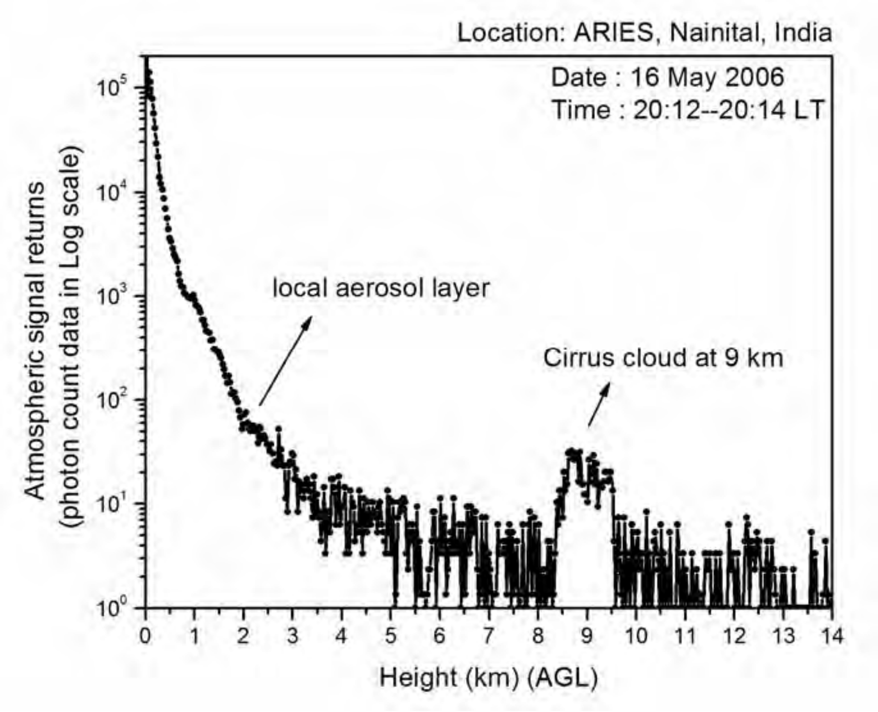

Figure 2. Basic laser radar data obtained at the ARIES, Nainital on the installation day of portable laser radar system during 16 May 2006.

The backscatter signal intensity measured by the portable lidar system is given in term of photon counts. It is shown in figure 2 for the observations made on 16^{th} May 2006. The plotted photon counts are proportional to the laser light returns due to atmospheric backscatters and sky background. The interesting feature that is observed in the range resolved backscatter photon counts profile of 16^{th} May 2006 is the presence of cirrus clouds at an altitude ranging between 8 and 10 km AGL. Whereas on 17^{th} May, the observed photon counts profile (not shown) shows a moderate backscattered signal enhancement perhaps due to a thin cloud layer superimposed on the elevated aerosols at a height ranging from 2 to 3 km AGL. The evaluation of rangesquared signal employs the range loss correction to the photon output data, whereas the backscatter coefficient is the primary atmospheric parameter that determines the strength of the lidar signal. It describes how much light is scattered into the backward direction i.e. towards the lidar receiver [10].

The backscattered signal intensity measured by laser radar is proportional to the backscattering by particles and air molecules present in the atmosphere [11].The basic data shown in figure 2 indicates the altitude distribution of photon count generated by particle and molecular distribution in the atmosphere. The number of photon returns collected at the laser radar receiver is governed by an equation [11].

$$P(\lambda, z) = E_S A \frac{O(z)}{z^2} \beta_T(\lambda, z) \eta_L T^2(z) + P_b \quad \text{---(1)}$$

where P(z), is the laser radar signal received from a range z at a wavelength λ , E_S is the emitted laser energy per pulse , A is the collecting telescope receiving area, η_L is the laser radar total efficiency factor, $\beta(\lambda, z)$ is the atmospheric volume backscattering coefficient, O(z) is the overlap factor between the field of view of the telescope and the laser beam, T(z) is the atmospheric transmission due to presence of air molecules and particles, Pb is the background noise caused by external light and z is the range. The laser radar data have been processed with the algorithm described by [12], and the molecular (or Rayleigh) contribution to the signal is taken from the CIRA 1986 standard Atmosphere. According to the Klett [12] formulation, the solution of the lidar equation is given as

$$\beta_T(z) = \left[\beta_m(z) + \beta_p(z)\right] = \frac{X(z).\exp\left[-2\int_0^z \beta_m(z)[L_p(z) - L_m].dz\right]}{\frac{X(z_0)}{\beta_t(z_0)} - 2\int_0^z X(z).L_p(z)\exp\left[-2\int_0^z \beta_m(z)[L_p(z) - L_m].dz\right].dz} \quad \text{---- (2)}$$

where, the total backscattering coefficient is the sum of Rayleigh and particulate contribution. The term $\beta_T(z_o)$ is the boundary condition set on $\beta_T(z)$ at the reference far-end range. The solution to the equation (2) was solved numerically and was explained in detail by Sudharshan Reddy and Bhavani Kumar [13]. A Matlab code was generated for inverting the laser radar signal. The inversion methodology provides backscattering coefficient of particles distribution in the atmosphere. The inversion procedure employs a lidar ratio (Lp) equal to 35, which is an average value for rural, urban and maritime particles [14]. The application of inversion starts at reference height (Z-ref) where the laser radar profile follows the molecular atmosphere (generally between 4 and 6 km). The derived attenuated backscatter profile using the above algorithm is shown in Figure 3.

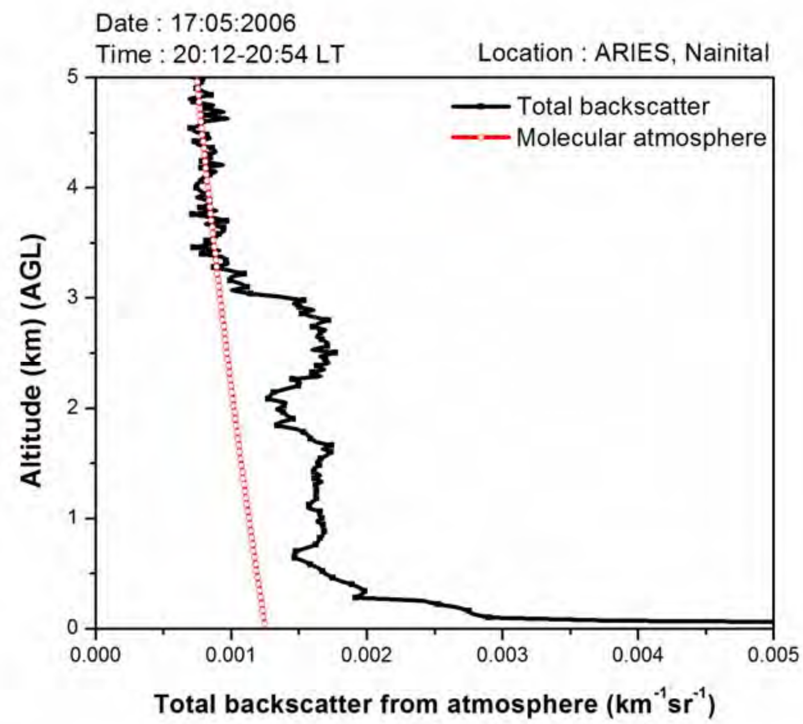

Figure 3 The attenuated backscatter profile derived using the developed algorithm is presented along with the air molecular profile to illustrate the particles distribution in the atmosphere.

The computation of particle extinction coefficient is usually made by multiplying the particle backscattering coefficient with lidar ratio (Lp) and is represented empirically as

$$\alpha_p(z) = L_p(z).\beta_p(z)$$

The summation of atmospheric particle extinction profile provides the particle load in the atmosphere and its distribution gives the vertical extent of particle presence in the atmosphere. The atmospheric particle extinction profiles were computed using the above relation for the two consecutive days of observation i.e for 16th and 17th May 2006. The evaluated atmospheric particle extinction profiles were shown in Figures 4 and 5. A heavy rain downpour associated with pelting hail stones occurred at the high altitude station, Nainital on the early hours of 17th May 2006. These are thunder storm rains and generally occur during May/June periods at this high altitude location.

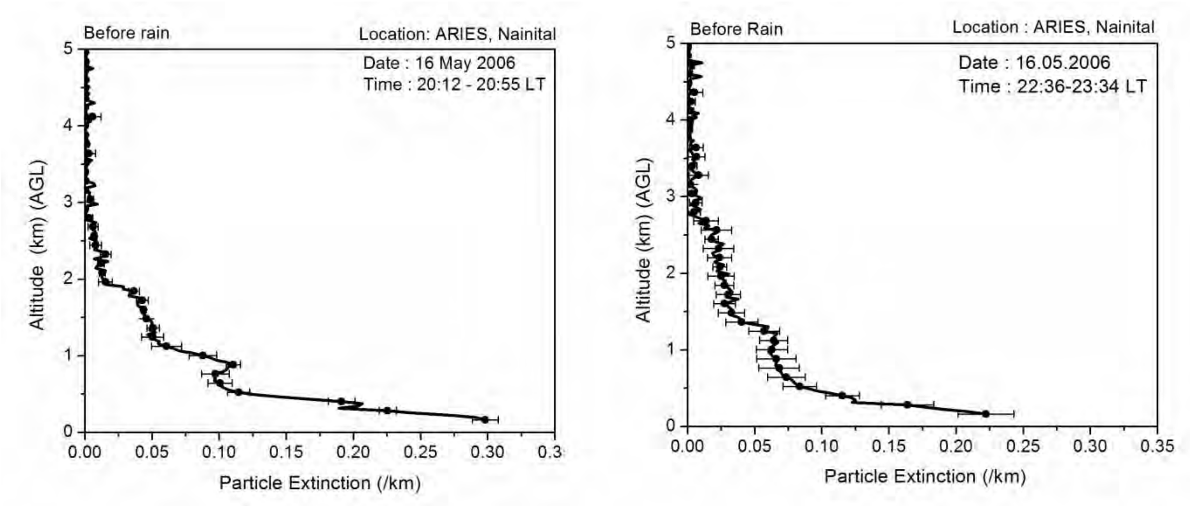

Figure 4. Altitude distribution of atmospheric particles extinction derived from laser radar data collected on 16th May 2006 at the high altitude station in the central Himalayas before heavy rain event.

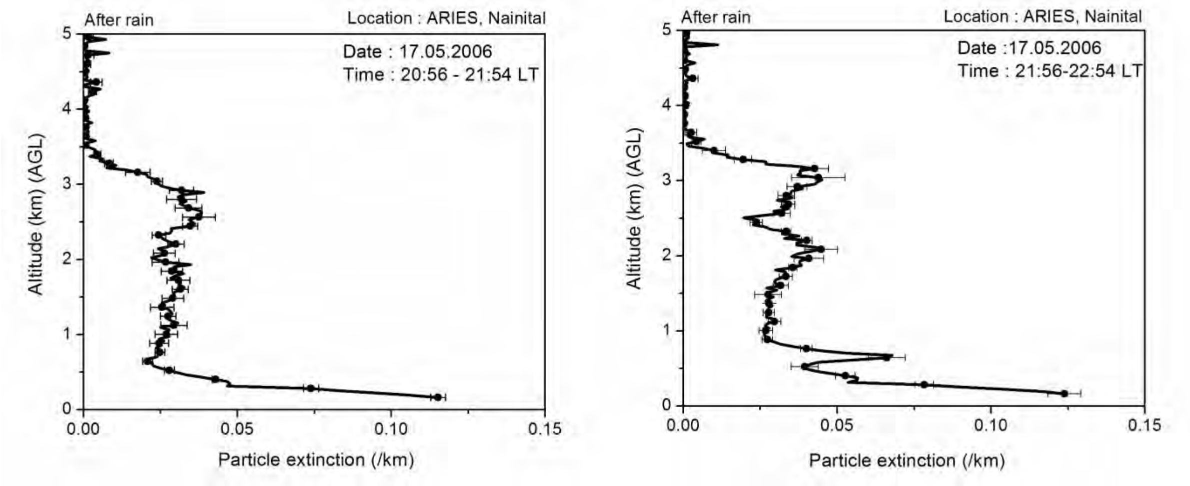

Figure 5 Altitude distribution of atmospheric particles extinction derived from laser radar data collected on 17th May 2006 at night hours after the episode of heavy rain at the high altitude station in the central Himalayas.

III. RESULTS AND DISCUSSION

The lower atmospheric particles distributions vary considerably in both time and space and this variation are also subjected to the effective removal mechanism such as scavenging or washout due to rain [15]. The major processes involved in the removal of the particles from the atmosphere are dry deposition or sedimentation and wet removal [16]. In this perspective the short-term studies of the depletion in the atmospheric particles due to preceding rain episode have largely been investigated [17-19]. The reduction of particle distribution due to preceding rain episode was observed on 17th May 2006 in the lidar backscatter signals. The most important features that was quite evident in the derived extinction profiles on 17th May 2006 was the large reduction in the extinction coefficient in comparison to the preceding day's value (see figure 6). Mesoscale weather phenomena, such as thunder showers or land sea breezes, produce changes in the characteristics of atmospheric aerosols over short time scales either by removing them from atmosphere or by spatially redistributing them [18,19]. The reduction in the evaluated extinction coefficient is attributed to the occurrence of heavy rain during the day of 17th May 2006, implying the reduction in the relative abundance of atmospheric particles in the troposphere due to scavenging process. A total of 67.2 mm of rain was observed within a short spell during the daytime of 17th

May 2006. The evaluated aerosol particles optical depth [AOD] on 16 May 2006 was about 0.21 at λ=0.532 µm, which is consistent with the monthly mean columnar AOD (0.32 ± 0.04 at λ=0.500 µm), evaluated with the sun photometer techniques during May [20]. This value was reduced to a value of 0.08 on 17 May 2006 due to the scavenging or washout effect in the height range of 0.2 to 3.0 km.

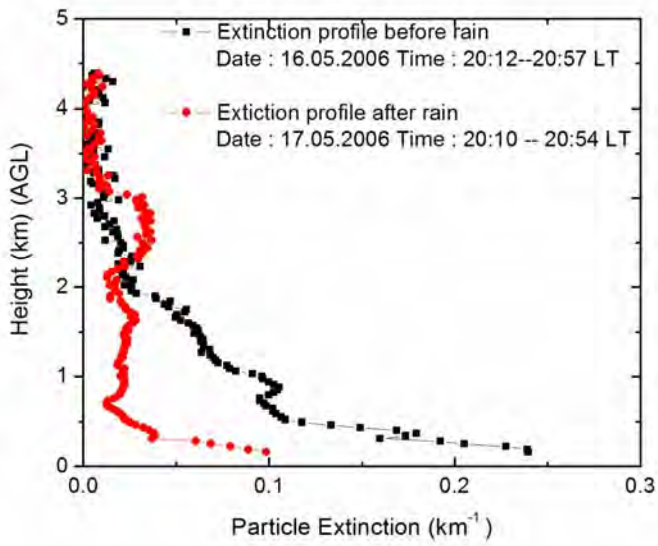

Figure 6. Laser radar derived altitude distribution of atmospheric particle extinction. Black colored trace shows the extinction profile obtained using the laser radar data on 16th May 2006. The red colored trace illustrates the laser radar data derived from the data of 17th May 2006 after the heavy rain event.

IV. CONCLUSION

The NARL-ARIES portable lidar system was successfully installed and tested for the atmospheric study at ARIES, Manora Peak, Nainital. The analysis of the first lidar observations taken from a high altitude location of ~2 km showed the height distribution of airborne particles up to a height of 3 km AGL. The observed range resolved backscatter photon counts profile revealed the presence of cirrus cloud layer at an altitude ranging between 8 and 10 km AGL on 16th May 2006. Whereas on 17th May 2006, the observed photon counts profile showed a moderate backscattered signal enhancement, perhaps due to the presence of a thin clouds superimposed on the elevated particles, at a height ranging between 2 to 3 km AGL. The occurrence of heavy rain (~67 mm) on 17th May 2006 showed a significant reduction in the evaluated particle extinction coefficient. The scavenging process of the particulates that took place in the lower troposphere due to rains on 17th May 2006 also caused ~ 2.5 times reduction in the evaluated AOD and a drastic reduction in the height distribution of airborne particles.

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