# 25A4 AN OVERVIEW OF LIDAR STUDIES OF THE ATMOSPHERE AT PUNE, INDIA

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## INTRODUCTION

Lidar is a powerful tool to study atmospheric structure, composition and dynamics with high degree of spatial and temporal resolutions (Proc. IEEE, 1989; Opt. Engg., 1991). A programme of tropospheric aerosols, trace gases, turbulence and winds using the lidar techniques have been in progress since December 1985 at the Indian Institute of Tropical Meteorology, Pune (18°32'N, 73°51'E, 559 m AMSL), India. We have continued the aerosol vertical profile measurements using the Argon ion lidar as part of a long-term effort to develop an aerosol climatology over a tropical station, Pune. Such tropospheric aerosol climatologies are sparse over the globe, more so over tropics and almost non-exist in India.

The Argon ion lidar has also been used for determining the path-averaged and range-resolved atmospheric $NO_2$ concentration in the surface layer by following the DIAL approach. In addition, path-integrated atmospheric turbulence and crosswinds over line-of-sight paths in the surface layer have been measured using an He-Ne laser scintillometer developed at the Institute. Further, the morphology of stratospheric aerosol layers and associated circulation features have been studied using the published ground-based lidar and satellite data relating to the Pinatubo volcanic eruption. The results of the above studies together with a brief description of the lidar systems employed are presented in the following sections.

## EXPERIMENTAL SITE AND LIDAR SYSTEMS

The environmental conditions at Pune vary markedly from continental (winter) to maritime (summer) and possible aerosol type present over the station is a mixture of water-soluble, dust-like and soot-like aerosols. The complete lidar setup has been installed on the terrace of the Institute's building which is about 13 m high above ground level. The positions of the lidar site and other surrounding activities in the experimental area are shown in Fig. 1. The experimental site is surrounded by hillocks (valley-like) of average elevation of about 610 m AMSL. The transport and dispersion of pollutants are believed to be affected by the circulation processes evolved due to typical terrain. Also, the stone quarries and brick kilns which are situated at about 1 km distance on either side of the lidar are considered to be the major local anthropogenic sources contributing to aerosol and trace gas observations at the experimental site.

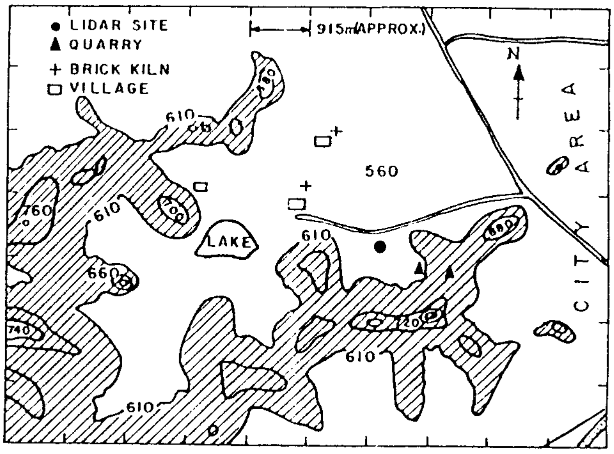

Fig. 1 Schematic of lidar experimental site. Hatched areas indicate elevations ≯ 610 m.

In the case of aerosol measurements, the lidars are operated in bistatic mode with a separation of about 60 m between the transmitter and receiver. This experimental arrangement also provides information on angular scattering of aerosols of different sizes present in the atmosphere for determining their size distributions.

The equipment essentially consists of a Lexel Model 95-4, tunable, Argon ion or Spectra-Physics Model 159 Helium-Neon laser as transmitter and a 25-cm dia., f/7.6 Newtonian telescope as the receiver. Light at wavelength of 514.5 or 632.8 nm is emitted vertically up into the atmosphere and scattered light is collected at different elevation angles of the receiver which is equipped with narrowband interference filter and cooled PMT. The electrical signals of the PMT, after necessary corrections, used as input data for the inversion routine programmes to estimate the aerosol vertical profiles. A detailed description of the equipment, and experimental and data retrieval procedures have been published elsewhere (Devara and Raj, 1987). The Argon ion laser lines at wavelengths of 469.5 and 501.7 nm have also been used as ON and OFF lines for the measurement of atmospheric $NO_2$ concentration by following both path-averaged and range-resolved DIAL approaches. The He-Ne laser has also been used for scintillometer measurements of turbulence and crosswinds in the surface layer.

## OBSERVATIONS

The observational programme consisted of the measurement of a minimum of two and a maximum of seven vertical profiles of tropospheric aerosols during night clear-sky conditions in each month. The lidar has been operated on every Wednesday (Regular Geophysical Day) and also on alternate Thursdays, the latter to synchronize with the radiometersonde temperature and humidity experiment of the India Meteorological Department, Pune. More than 360 weekly-spaced vertical (covering heights between 50 and 1380 m) profiles were collected from October 1986 through September 1993. The pibal wind and selected surface-level meteorological data on the days of lidar observations were also collected. Apart from these profile measurements, many other (NBL, multi-spectral and multi-scattering angle) experiments relating to atmospheric aerosols have been performed. The DIAL $NO_2$ experiments have been conducted during some selected nights. Observations of turbulence in the surface layer during different atmospheric conditions have been carried out for more than one-year period using the He-Ne laser scintillometer. This scintillometer, with minor modifications, has also been used for simultaneous measurements of atmospheric turbulence and crosswinds on some selected days. Both satellite and ground-based lidar (15 stations) published aerosol data relating to Pinatubo volcanic eruption have been analyzed to study the stratospheric aerosol layer structures and associated circulation features.

## RESULTS AND DISCUSSION

We briefly present and discuss the results of the lidar studies of the atmosphere undertaken at our Institute in this section.

Aerosol vertical distributions. The vertical profiles of aerosol number density studied up to 300 m using the He-Ne lidar, and up to 7 km using $Ar^+$ lidar were found to be in good agreement with those of the model predicted profiles. The results indicate an appreciable increase in the lowest layers which is considered to be due to the combined effect of source regions and meteorological conditions at the experimental site (Devara and Raj, 1989). The time-height variations in aerosol concentration show marked differences between the post-sunset and pre-sunrise periods. The seasonal variation in aerosol vertical profiles indicates maximum aerosol concentration in pre-monsoon (March-May) and minimum in South-West monsoon (June-Sept.), which is attributed to the meteorological conditions over the observing station during those months (Raj and Devara, 1989). Spectral analysis of vertical distribution of aerosol concentration data suggests shorter periodicities in the lower altitudes, up to about 300 m, contribute significantly, whereas the longer periodicities, around 45 weeks contribute most to the total variance at higher altitudes. These features reveal damping of high frequency oscillations at higher altitudes and the propagation of low-frequency oscillations from lower to upper levels of the atmosphere at Pune (Devara et al., 1994).

Aerosol columnar content. The aerosol loading at Pune, computed by integrating each profile of aerosol concentration throughout the height range, shows pronounced peak during pre-monsoon and broad minimum during monsoon seasons. The loading was observed to be decreased by about 33% during monsoon season as compared to its maximum during pre-monsoon, and aerosols present up to 200 m were found to contribute about 40% to the overall aerosol loading (Devara and Raj, 1990). The time series of lidar-derived aerosol column content at Pune during Oct. 1986-Sept. 1993 is shown in Fig. 2. The spectral analysis of aerosol content and concurrent meteorological parameters reveals the presence of significant common periodicities indicating correspondence between them.

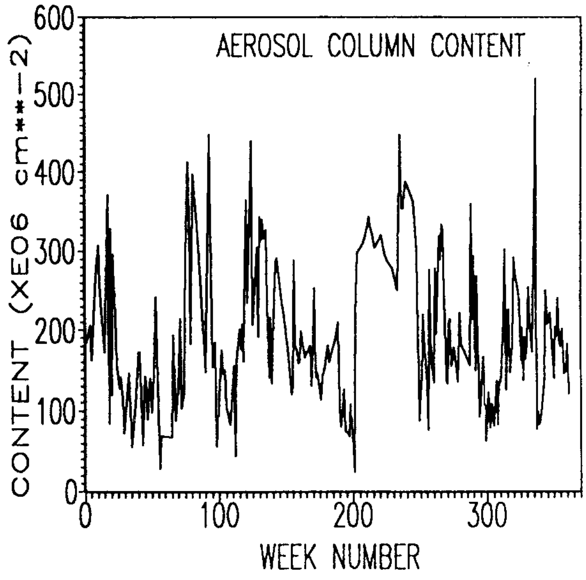

Fig. 2 Lidar-derived aerosol column content at Pune during Oct. 1986 - Sept., 1993.

Aerosol layer structure. The structure of the vertical distribution of aerosol concentration was studied by computing Normalized Concentration Gradients (NCG) from the vertical profiles as suggested by Sasano et al (1982). The aerosol layers formed in different height regions in the lower atmosphere were found to drift downward between post-sunset and midnight hours, and upward between midnight and pre-sunrise hours. A comparison of the profiles of NCG with those of atmospheric stability parameters showed good correspondence (Devara et al., 1994).

Nocturnal atmospheric boundary layer (NBL) and air quality studies. The stratified layer structure in a terrain-induced NBL has been studied. A comprehensive study made by utilizing about 130 lidar-derived nighttime aerosol profiles collected during Oct. 1986-Sept. 1989 showed that the mixing depth over Pune ranges between 160 and 500 m, and stably stratified aerosol layers, present above the mixing depth, with their maximum frequency of occurrence at around 750 m (Raj and Devara, 1993a). The nighttime mixing depth deduced from lidar observations showed good agreement with the height of ground-based shear layer observed by simultaneously operated sodar at the lidar site (Devara et al., 1992). The ventilation coefficients, evaluated as products of nighttime mixing depths and average wind velocity (from pibal data) in the mixed layer, show that winter late evenings at Pune tend to have higher pollution potential (Raj and Devara, 1992).

DIAL $NO_2$ estimations. Atmospheric $NO_2$ concentration measurements using the DIAL technique have been made. The tunable Argon ion lidar was used for these measurements by following both the path-averaged and range-resolved approaches. A topographic target (hill) is used for determining path-averaged surface concentrations and spectral properties of atmospheric attenuation is used for making range-resolved measurements in the surface-layer. The average surface $NO_2$ concentration was found to be around 0.01 ppm under certain atmospheric conditions and the range-resolved measurements exhibited higher values suggesting treatment of lidar data for atmospheric extinction and turbulence effects (Devara and Raj, 1992).

Atmospheric turbulence and crosswinds. Path-integrated atmospheric turbulence from estimations of $C_n^2$ have been made during March 1990-Dec. 1991 using an He-Ne laser scintillometer. The optical turbulence was found to be high during the periods of strong inversion (nighttime) and lapse rate (daytime), and also over longer pathlengths. The results also indicated high turbulence on the days with clear-sky conditions as compared to cloudy-sky days (Raj et al., 1993). Further, the time evolution of scintillation spectra was found to be associated closely with those of wind and temperature spectra. The optical turbulence and crosswinds derived from scintillation patterns were found to be in good agreement with those obtained from thermal techniques and conventional anemometers, respectively.

Eruption-induced stratospheric aerosol studies. The transport and dynamical processes, and aerosol loading in the stratosphere due to the Pinatubo volcanic eruption have been studied using the published data of ground-based lidars and satellite (Raj and Devara, 1993b). The study revealed the presence of multiple aerosol layers around 25 km over Mauna Loa. The results also point out that the layers were initially narrow on formation, widened on descent and took nearly one month to reach steady state conditions. The satellite data revealed mean easterly wind velocity of 20-22 m/sec.

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