NEWLY DEVELOPED PORTABLE LIDAR SYSTEM FOR ATMOSPHERIC AEROSOL AND CLOUD STUDIES

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ABSTRACT

Recently a low cost portable lidar system has been developed at the National Atmospheric Research Laboratory (NARL), Gadanki (13.5°N, 79.2°E), India for profiling the atmospheric aerosol and clouds. The lidar system utilizes state-of-the-art technology with a high repetition rate, low pulse energy diode pumped Nd:YAG laser and photon-counting detection, which considered to be first of its kind in India. The lidar system measures the laser backscattered radiation from aerosols and molecules at 532 nm that provide information on the height profiles of aerosols, boundary layer mixing height, cloud base height and cloud vertical extent. The system is capable of continuous, autonomous data acquisition in both daytime and nighttime. The lidar range go up to about 3 km during daytime, where as its visibility extends to the end of troposphere during nighttimes.

1. INTRODUCTION

Aerosols are tiny particles suspended in the atmosphere. They are produced by a variety of natural and anthropogenic processes near the Earth's surface. Since there are several sources of aerosols on the Earth's surface, the atmospheric boundary layer (ABL) often contains high concentration of aerosols. These near surface aerosols are the important part of atmospheric aerosol system that confined to ABL plays an important role on the air quality and chemical composition of the atmosphere. They produce direct effect on human health, visibility, and environment and also lead to formation of mist and fog. Aerosols can scatter and absorb the solar and infrared radiation and also capable to alter the cloud properties. Atmospheric aerosols exhibit large temporal and spatial variability due to a variety of production, removal and transport processes. Therefore, it is important to study the optical properties and dynamics of aerosols so that particle transport and local atmospheric variation can be explained. The systematic way to investigate the time variation of aerosol height profile is to have a continuous monitoring of aerosol distribution in short time intervals. A micropulse lidar is a suitable instrument for this type of work. Recently a low cost portable micropulse lidar system, designed specifically for profiling the boundary layer aerosol, has been developed at the National Atmospheric Research Laboratory (NARL), Gadanki (13.5°N, 79.2°E), India. By using the commercially available components, the cost of the lidar has been reduced considerably. The prototype lidar system that presently in operation at Gadanki site is developed at a cost of about 30000 US dollars. Due to its low cost, a network of this type of lidar systems was planned. Under this program, two more lidar systems have been developed for installation at other locations in India.

2. INSTRUMENT SETUP

The newly developed portable lidar system has been in operation at a fixed location in a temperature controlled cubical. The lidar transmitter system is the second harmonic output of a microchip (all-in-one laser cavity) Nd:YAG laser. It is laser diode pumped and acoustic switched. The output pulse energy is 2 - 20 µJ depending on the repetition rate.

The output pulse energy is set at 10µJ at 2500 Hz repetition rate. The laser beam diameter is 0.4 mm and its divergence is less than 1.5 mrad. The laser beam was expanded to 3 mm in diameter and collimated to have the beam divergence of about 200 µrad. The light output was linearly polarized with the degree of polarization being greater than 99%. The laser beam is sent into the atmosphere using two mirrors kept at 45 °angles.

Table-I: The portable lidar specifications

Transmitter
Laser: Diode Pumped Nd:YAG laser
Wavelength: 532 nm
Output Pulse Energy: 10 micro-Joule
Pulse Repetition Frequency: 2500 Hz
Pulse Duration: 10 ns
Polarization: >100:1
Transmitter Field of View: 200 µrd
Receiver
Telescope: 15 cm diameter
Cassegrain
Field of View: 400 µrad
Detector
Type: Photon counting -high gain PMT
Data Acquisition
Pc based MCS card
Bin width: Settable from 15 m
(in multiples of integer)

A monoaxial configuration was employed in the lidar system. The laser backscattered light was received by a Cassegrainian telescope, whose diameter and F-value were 15 cm and 9, respectively. The geometrical form factor for a coaxial lidar having no apertures (other than the objective lens or mirror of the telescope) or obstructions is unity, provided the divergence angle of the laser beam is less than the opening angle of the telescope. Hence an iris diameter (pin-hole) of 0.5 mm was used to obtain a receive FOV of about 400 µrad. A narrowband interference (IF) filter was positioned in front of the photomultiplier tube (PMT). A narrowband IF filter, with center-wavelength of 532 nm, was used to reduce background light. A high gain PMT was used as the photon detector. The pulse signals from PMT were passed through a discriminator and fed to a PC based multichannel analyzer (EG&G Ortec model MCS-pci). The instrumental bin width was normally set at 200 ns, corresponding to an height resolution of 30 m. Usually 300000 shot integrated photon count profile constitutes a raw data profile that corresponds to a time resolution of 120 sec. The transmit and receive optics are housed in a closed box to maintain a clean, thermally stable, and dry environment. Brief specifications of the system are given in Table –I.

3. APPLICATION OF LIDAR SYSTEM FOR ATMOSPHERIC STUDIES

The lidar system has been in use for monitoring the atmosphere on routine basis at NARL, Gadanki since its development. Usually the lidar is operated between 17:00 LT and 06:00 LT on every day, except on maintenance or rainy days. So far, the lidar system was operated for about 350 days with more than 5000 hrs of observation. The lidar system has been successfully applied to study the evolution of atmospheric boundary layer (ABL), profiling of atmospheric aerosols and real-time detection and ranging of low and high-level cloud occurrences in the atmosphere.

3.1 APPLICATION TO ABL STUDIES

To demonstrate the performance of the lidar system for ABL evolution, a continuous 15-day observation was conducted at Gadanki site in January 2005 (dry season) during clear sky period. The variation of range corrected signal *S(r)* over a diurnal period (24-hour) is shown in Fig. 1. Fig 1 provides the time evolution of lidar range squared signal *S(r)* from 0:00 LT on 6 January to 0:00 LT on 7 January 2005.

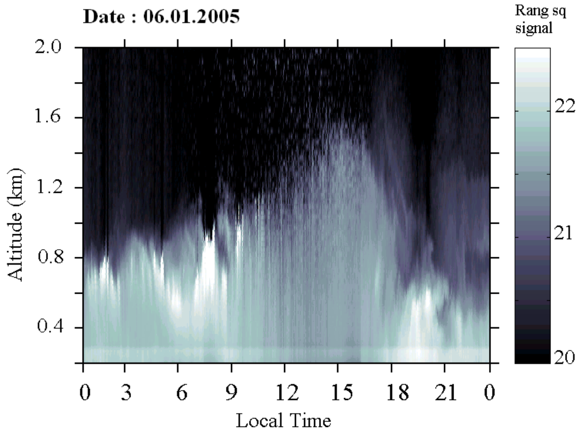

Fig 1. Diurnal variation of range-squared signal shows the typical ABL evolution

Over land surfaces, the boundary layer has a well-defined structure that evolves with the diurnal cycle [Stull, 1988]. From Fig. 1, one can observe the mixed layer (ML) development from the lidar signal enhancement during 06:00 to 15:00 LT. The mixed layer (ML) or Convective Boundary Layer (CBL) is formed by the convection that arises from solar heating of the earth's surface and is associated with organized thermal transport due to highly developed vertical motion. Soon after the sunset buoyant (eddy) production ceases and the atmosphere changes to a near neutral condition. A weak residual layer containing the remnants of the daytime mixed layer is observed in the background after 18:00 LT. In the late night hours, as the surface gets cooled the elevated eddies are directed downwards. This causes formation of a stable boundary layer (SBL) near to the surface. This is seen at late evening hours over land surfaces. The intensified signal returns in late evening hours is clearly show the formation of SBL. The SBL has been observed to form in the height range of 200 to 600 m during dry season due to low night temperatures. Thus, the portable lidar system has been successfully used to study the structure, dynamics and the evolution of Atmospheric Boundary Layer using aerosols as atmospheric tracers. Using the portable lidar system, the internal sub-layers of ABL such as Mixed Layer (ML), Residual Layer (RL) and Stable Boundary Layer (SBL) or Nocturnal Boundary Layer (NBL) have been identified clearly over the tropical rural site Gadanki. This result shows the feasibility of the low-pulse energy lidar system application in atmospheric boundary layer measurements.

3.2 STUDY OF HEIGHT PROFILES OF ATMOSPHERIC AEROSOL

The lidar system detects the laser-backscattered radiation from air molecules and aerosols up to about 3 km during daytime and up to about 17 km during night. The portable lidar operation is in regular operation at Gadanki site since January 2005. Using the system, temporal variation in the vertical profiles of aerosols over Gadanki is being studied. Fig. 2 shows the average monthly aerosol extinction profiles measured over Gadanki during the period from January to April 2005. During winter months the aerosol height profiles are limited to 2 km altitude region where as one can observe an increase in aerosol amount during summer months, pre-monsoon period, in the 2 to 4 km altitude region.

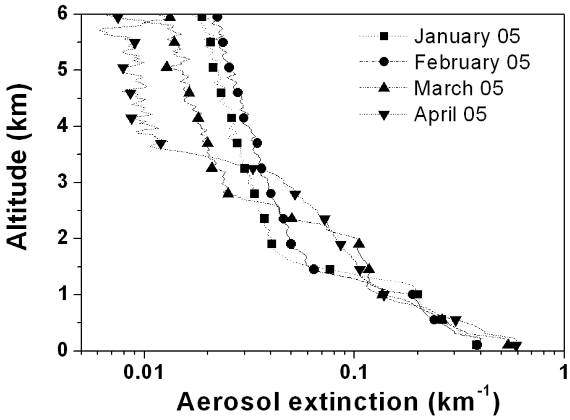

Fig 2. Lidar derived mean height profiles of aerosol extinction observed over Gadanki site

This shows a rise in local boundary layer during summer months. This increase could be probably due to increased hygroscopic growth of aerosol particles in the 2 to 4 km altitude region. Thus, the lidar study of aerosols in the lower atmosphere is useful in the altitude distribution of the particles, which are significant in the estimation of the altitude variation of aerosol radiative forcing.

3.3 CLOUD BASE DETECTION AND VERTICAL EXTENT

One of the potential applications of lidar is in the studies of characterization of clouds. Usually strong backscattering arises from clouds due to relatively large scattering cross-sections of cloud particles and huge number density of scatterers. Though lidar systems have been employed to measure the cloud height in scientific investigations, the studies of precipitation structure were not the primary objective of the lidar experiments. However, it was realised during the work on cloud layers that the system was potentially capable of providing useful data on the instantaneous, small-scale variation in cloud base during rainfall. Fig. 3 shows the results obtained with the lidar during a light rain period. The rainfall from cloud base is seen as streaks of strong signal intensity in Fig shown.

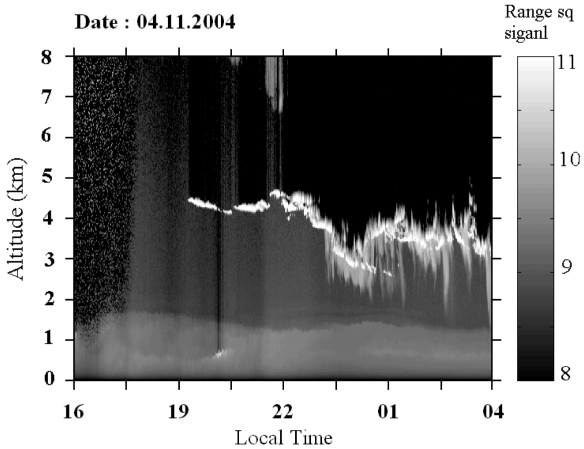

Fig 3. The portable lidar observation of low-level cloud during a light rain time. The lidar beam was directed at an elevation angle of 18° from zenith.

It is well established that lidar has the capability to delineate the position and spatial structure of clouds in the atmosphere. Because of its high spatial resolution, it can be used to locate cloud base and its top with a good precision that is not possible with any other remote sensing technique. This feature of lidar has attracted more researchers recently in investigations of clouds at various height regions as clouds play a critical role in the radiation budget of the earth atmosphere.

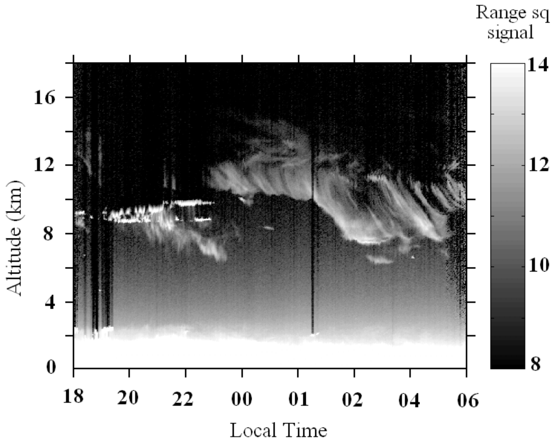

Fig. 4. Portable lidar observation of high altitude clouds

The appearance of deep cumulus clouds during convective periods is a common phenomenon at tropical latitudes. Usually the upper portion of convective cumulous clouds constitutes ice that extends in the fibrous anvil, which at a later stage takes the form of cirrus. The formation of high altitude clouds such as cirrus in the tropics plays a particularly important role in the Earth-atmosphere radiation budget. Tropical cirrus develops in a variety of forms, ranging from optically thick anvil cirrus that is closely associated with deep convection to optically thin cirrus layers frequently observed near the tropopause. A typical lidar observation of cirrus system in the night of 11-12 September 2005 is shown in Fig. 4. Fig. 4 represents the temporal variation of range-squared signal as a function of altitude for the night observation made on 11-12 September 2005.

Reference:

Stull, R.B., Introduction to Boundary Layer Meteorology, Kluwer Academic Publishers, Netherlands, 1988.