S3-1 Indo-Japanese Lidar Studies of Tropical Atmosphere

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1. Introduction

A State-of-the-art Lidar system has recently been established at the National MST Radar Facility (NMRF), Gadanki (13.8°N, 79.2°E), India under an Indo-Japanese collaboration program. The Lidar and the colocated Mesosphere-Stratosphere-Troposphere (MST) radar constitute a unique combination for conducting high resolution studies on the structure and dynamics of the middle atmosphere. It has two independent receiving sub-systems, one to measure Rayleigh molecular backscatter to determine temperature profiles in the height range of 30-80km and the other to measure height profiles of scattering ratio, involving both Rayleigh scattering from molecules and Mie scattering from aerosols, to derive aerosol concentration profiles using a model to account for the Rayleigh scattering. The Mie backscatter signals, often showing sharp spiky enhancements, could also be used for detection and characterisation of clouds. The dual polarisation capability available with the Mie scatter channel permits to study the anisotropic properties of the aerosols as well as water and ice phase determination of the clouds.

In section 2 of the paper we present a concise description of the Indo-Japanese Lidar (IJL) system, including data acquisition and processing. The methods of analysis for determination of temperature, scattering ratio and extinction profiles are outlined in section 3. The results and discussion on temperature structure, aerosol extinction and cloud characterization from observations made during March-December 1998 are presented in section 4.

2. Lidar System Description

The Indo-Japanese Lidar (IJL) system comprises a Laser Pulse transmitter, two receiving telescopes and data acquisition and processing sub-systems. The Lidar transmitter employs the second harmonic of Nd-YAG pulsed laser at 532nm with pulse energy of about 550mJ. The Lidar operates at a pulse repetition rate of 20Hz and pulse width of 7ns. The transmit beam, having a divergence of 0.1mrad, is directed vertically by a flat mirror oriented at 45° to the beam axis. There are two receiver subsystems, one to measure temperature using Rayleigh backscatter and the other to determine aerosol concentration using Mie component of the backscatter.

The Rayleigh receiver employs a Newtonian telescope with primary mirror having an effective diameter of 75 cm. A narrow band interference filter with full-width at half maximum (FWHM) of 1.07nm is used to reject much of the background light. The signal is then split into two channels in the ratio of 9:1, the high gain channel (R) to cover 50-80km where the signal is weak and the low gain channel (U) to cover 30-50km where the signal is relatively stronger. The signals are directed to photomultiplier tubes (PMTs) which operate in photon count mode for both the channels. The outputs of the PMTs are given to pulse discriminators consisting of a 300MHz pulse amplifier with threshold adjustable comparator and shaper circuit.

The Mie-receiver employs a compact Schmidt-Cassegraine type telescope with an effective diameter of 35 cm. A narrow band interference filter centered at 532 nm with FWHM of 1.13nm is used for cutting down the background light. A polarized beam splitter is employed for splitting the beam into co- and cross-polarized components with the two channels designated as P and S, using identical PMTs and pulse discriminators.

The outputs of the four pulse discriminators of P, S, R and U channels are connected to a PC-based photon counting data acquisition system, employing a multi-channel scalar plug-in card (MCS-Plus). The MCS-Plus works with dwell times ranging from 2μs to 1800s and a maximum memory length of 8192 channels with input counting rates upto 100 MHz. It records 5000 laser-shot averaged photon count profile as one frame with a time resolution of 250s and range resolution of 300m. The photon count profiles thus obtained form the basic database for studies on temperature, aerosol and cloud characteristics as described below.

3. Methods of Analysis

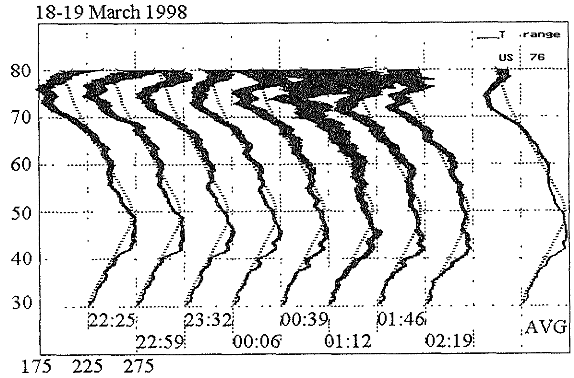
Temperature Determination: The method of analysis adopted for determination of temperature profile from the Rayleigh channel data of the Lidar follows closely that given by Chanin and Hauchecorne (1984). In the height range where Mie contribution is negligible (35-80 km), the recorded signal intensity, corrected for the range and atmospheric transmission, is proportional to the molecular number density. Using the number density taken from an appropriate model (US-76) for the height of 50km where the signal-to-noise ratio is fairly high, the constant of proportionality is evaluated and thereby the density profile is derived. Taking the pressure at the top of the height range (80km) from the atmospheric model, the pressure profile is computed using the measured density profile, assuming the atmosphere to be in hydrostatic equilibrium. Adopting the perfect gas law, the temperature profile is computed using the derived density and pressure profiles. Any uncertainty in the pressure at the top of the profile would contribute to temperature uncertainty that falls rapidly with decreasing altitude. For 15% uncertainty in the pressure at the top of the height range, the temperature uncertainty would be less than 2% at 15km below the top.

Aerosol and Cloud Measurements: The backscatter coefficient β in the Lidar equation given by Fiocco (1984) can be expressed as the sum of two components β_m and β_a representing the molecular and aerosolic components of the air respectively. In the same manner, the extinction coefficient α, involved in the Lidar equation, also takes into account both the gaseous and particulate constituents and can be represented as the sum of α_m and α_a. The molecular contributions to backscattering and extinction can be estimated using a reference model atmosphere (US-76). The scattering and extinction properties of aerosols, however, are more involved. The results of lidar aerosol and cloud measurements are presented generally in terms of the scattering ratio R given by $(\beta_m + \beta_a)/\beta_m$. The scattering ratio computation involves separating the aerosol and molecular contributions to the backscattered signal. It is accomplished by the normalisation of the photon count with molecular density at a specified height (12km) taken from a model (US-76) and then applying the extinction correction to the scattering ratio profile using iterative analysis of the Lidar inversion equation. The scattering ratio profiles as computed above are employed for the purpose of studying the cloud characteristics. For studying the aerosol concentrations, however, extinction profiles are computed for cloud-free nights following the lidar inversion method given by Fernold (1984).

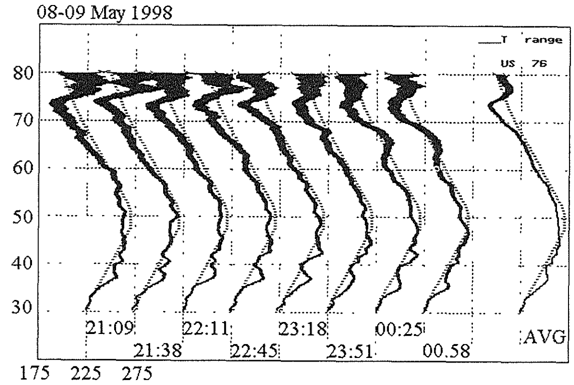
4. Results and Discussion

The temperature, scattering ratio and extinction profiles were derived from the lidar data collected over 40 nights during March-December 1998. The basic Lidar data is in the form of photon count profiles with a height resolution of 300m and a time resolution of 250 s. Figure 1. Presents sequences of half-hour integrated temperature profiles and their average profiles for the nights of 18-19 March, 08-09 May and 28-29 December 1998.

18-19 March 1998



08-09 May 1998



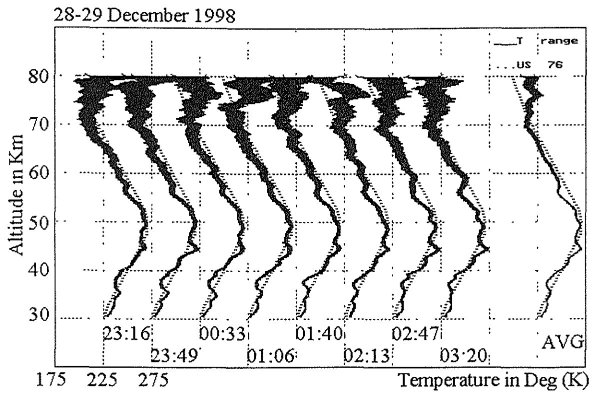


Figure 1. Sequences of 30 minute integrated temperature profiles and the corresponding average profiles observed on the nights of 18-19 March, 08-09 May and 28-29 December 1998.

For March, the maximum temperature is found to be around 275°K and occurs at a height of about 45km. The variation with a deep minimum occurring around 75km shows a wave type perturbation whose characteristics seem to conform to that of a gravity wave. It is interesting to note that this minimum coincides with the discrete scattering layer observed by the colocated 53 MHz MST radar. For May, the temperature maximum is quite broad and occurs in the range of 45-50km with values in the range of 260-270°K. The wave character of the mesospheric minimum could be discerned clearly from the profiles observed at 00:25 and 00:58 IST. The wave perturbations of gravity wave type with vertical wavelength of 5 to 10 km and downward phase progression are also seen in the lower height range of 30-50 km. For December, the maximum temperature occurs around 50 km with a value of about 270°K. The wave associated mesospheric minimum, so conspicuous in March and May, seems almost absent during December. The smaller scale perturbations, however, do remain at Lower heights.

The height profiles of extinction coefficient derived from the co-polarization Mie channel data taken during the nights of 18-19 March, 04-05 June and 28-29 December 1998 are presented in figure 2. The extinction coefficient has a major peak at about 18km, close to tropopause, in all the three months. It has a value of about 5×10^{-4} m^{-1} during the pre-monsoon months and falls by a factor of 2 by winter time. A secondary maximum, as strong as the primary during March but relatively weaker during June and December, is seen in the height range of 10-15km. It thus appears that aerosol concentration in the tropical atmosphere has a major peak close to tropopause and a secondary peak in the height range of 10-15km, which is as prominent as the primary during the pre-monsoon equinoctial period.

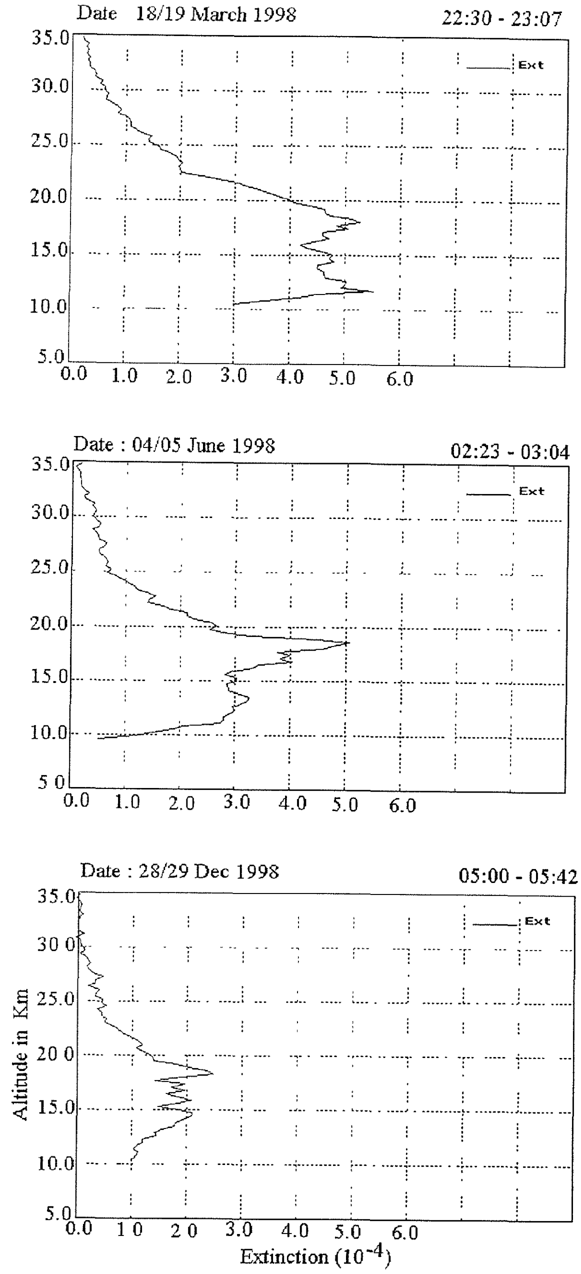


Figure 2. Aerosol extinction profiles observed on the nights of 18-19 March, 04-05 June and 28-29 December 1998.

The scattering ratio profiles derived from the Mie receiver data could be used to detect clouds and determine their spatial and temporal characteristics. The presence of a cloud results in a sharp enhancement in the scattering ratio to a high value making the detection quite unambiguous. Figure 3 shows scattering profiles with and without the presence of clouds as observed on the night of 8 May 1998.

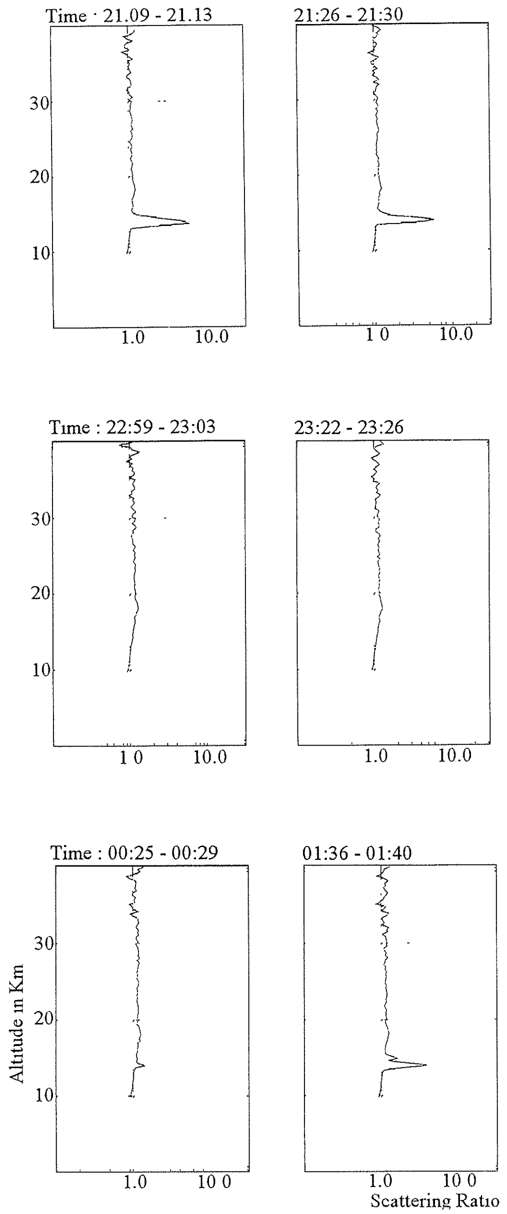


Figure 3. Height profiles of scattering ratio with and without the presence of clouds as observed on the night of 08 May 1998.

During 21:09-21:30, the scattering ratio is found to increase sharply to a value of about 6 at a height around 13km representing a cloud. The thickness of the cloud, represented by full-width at half maximum of the enhancement peak, is of the order of 1km. In the absence of cloud, the peak scattering ratio is only of the order 1.2 representing aerosol concentration peak at about 18 Km as observed during 22:59-23:26. The bottom pair of panels shows the evolution of the cloud during 00:25-01:40 at the same height level as observed earlier. The Mie Channel has capability for dual polarization (Co-and Cross Polarization) measurements of the backscattered signal which could be used to determine the relative concentrations of water and ice in the clouds. For the cloud examples shown here, the maximum depolarization ratio is found to be 0.15, indicating that the cloud is mostly of ice phase. From the observed backscatter to extinction ratio of 0.11 it is inferred, following the classification of Macke(1993), that the ice crystals are of the form of hollow column or bullet rosette.

Acknowledgements

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References

Chanin, M.L. and Hauchecorne, A. (1986). Lidar Studies of temperature and density using Rayleigh Scattering, MAP Handbook, Ed. R.A. Vincent, Vol-13,87.

Fernald, F.G. (1984). Analysis of atmospheric lidar observrations : Some comments, Applied Optics, Vol.23, 652.

Fiocco, G. (1984). Lidar studies of aerosol studies : An outline. MAP Handbook, Ed. R.A. Vincent, Vol-13. 56.

Macke, A. (1993), Scattering of light by polyhedral ice crystals, Applied Optics, Vol-32, 2780.