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A lidar study of atmospheric aerosols during two contrasting monsoon seasons

P. C. S. DEVARA and P. E. RAJ
Indian Institute of Tropical Meteorology, Dr. Homi Bhabha Road, Pune 411 008, India

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RESUMEN

Los perfiles verticales de los aerosoles de la capa fronteriza obtenidos mediante un sistema de Lidar biestático de iones de argón en el Instituto de Meteorología Tropical (IITM) de Pune, India, durante dos estaciones contrastantes y suscesivas del monzón del SW (verano) de 1987 (año de monzón débil) y 1988 (año activo de monzón) han sido estudiados. Los parámetros meteorológicos concurrentes tales como temperatura, humedad relativa y lluvia en Pune, han sido también estudiados. Se observa que el contenido columnar de aerosoles (integración del perfil vertical en toda la gama de alturas) es mayor durante los meses del monzón activo y menor en los meses del monzón débil. De manera que, el total de la lluvia monzónica durante 1987 y 1988, aparte de otros parámetros meteorológicos, muestran una correspondencia íntima con el contenido columnar de aerosoles sobre la estación experimental.

Se da una breve descripción del arreglo experimental del Lidar y de la base de datos. La asociación observada entre el contenido columnar de los aerosoles y la actividad monzónica se explica en función de las condiciones ambientales y meteorológicas predominantes sobre Pune.

ABSTRACT

The vertical profiles of the boundary-layer aerosols obtained with a bistatic Argon ion lidar system at the Indian Institute of Tropical Meteorology (IITM), Pune, India, during two contrasting, successive south-west (summer) monsoon seasons of 1987 (weak monsoon year) and 1988 (active monsoon year) have been examined. The concurrent meteorological parameters such as temperature, relative humidity and rainfall over Pune have also been studied. It is noticed that the aerosol columnar content (integration of vertical profile throughout the height range) is greater during the active monsoon months and less during the weak monsoon months. Thus the monsoon season total rainfall during 1987 and 1988, apart from other meteorological parameters, shows close correspondence with the aerosol columnar content over the experimental station.

A brief description of the lidar experimental setup and the database is given. The observed association between the aerosol columnar content and the monsoon activity is explained in terms of the environmental and meteorological conditions prevailing over Pune.

1. Introduction

It is an established fact that atmospheric aerosols play the most crucial role in cloud processes (Zuev, 1982), and cloud cycling is the major mechanism responsible for the modification of aerosols in the troposphere. Twomey (1977) described the aerosols that act as cloud condensation nuclei (CCN) and the processes by which these CCN alter the cloud droplet size distribution, which influence the amount and distribution of precipitation. Connections between the aerosol (natural and human-induced) conversion / removal processes and precipitation have been studied by numerous investigators (for example, Changnon, 1980). Although the main component of atmospheric aerosol that is responsible for the generation and maintenance of the hydrological cycle is not yet clear, it is evident that aerosols are effective agents. Hence, systematic and long-term data of aerosol vertical distributions could be used to infer relationships with variations in monsoon behaviour, weather and climate under certain meteorological and/or environmental conditions.

In recent years, powerful and versatile experimental methods have been developed for better understanding of the aerosol-cloud-precipitation interaction mechanisms. Laser radar or lidar is one such techniques that can be used for studying the aerosols and clouds with excellent spatio-temporal resolution and it has been demonstrated by ground-based, airborne, shipborne, and space-borne experiments (WCRP, 1988; Devara, 1992; McCormick *et al.*, 1993). An attempt has been made in this paper to study the relationship between the atmospheric aerosol content and precipitation over an urban region during two contrasting and consecutive south-west (SW) Indian monsoon seasons. For this purpose, the lidar aerosol observations in the lower troposphere (50-2700 m AGL) and surface data of selected meteorological parameters collected at Pune during the years of weak (1987) and active (1988) monsoon seasons have been analyzed. A brief description of the lidar system and the results of the study are presented.

2. Lidar System and Data

The lidar system at the Indian Institute of Tropical Meteorology (IITM), Pune, India, which was used for the present study has been described by Devara and Raj (1987). The Argon ion laser, which serves as transmitter has a CW (continuous wave) power of about 1.7 W at wavelength of 514.5 nm. The receiver is a 250 mm Newtonian telescope tailored with detection and on-line data acquisition systems. The transmitter and receiver were coaxially separated by a distance of 60.2 m in order to operate the system in bistatic mode. This unique arrangement provides angular distribution of scattered intensity for obtaining aerosol size distribution. The detector was an RCA C31034A photomultiplier tube housed in a PFR TE-306TSRF cooler which can cool the tube up to -5°C. An interference filter having FWHM (full width at half maximum) of 1 nm was used to reject side-band laser return radiation onto the photomultiplier. Further amplification of the output of the photomultiplier was achieved by means of a gain switching amplifier comprising of AD 515J ICs. The complete lidar system was installed on the terrace of the Institute building in order to minimize the background noise due to city lights and also to avoid obstructions due to nearby tall topographic objects.

The normalized scattered signal strength profiles obtained by operating the lidar system with its vertically transmitted laser beam and angular scanning of the receiver in vertical plane have been converted into aerosol number density profiles by following the inversion technique described elsewhere (Devara and Raj, 1987; Devara *et al.*, 1995). The lidar has been operated during the early night period. A total of 20 nocturnal aerosol profiles in 1987 and 13 profiles in 1988 were available during SW monsoon season. The rainfall, and surface temperature and relative humidity data recorded in the Pune region during these seasons for the above two years have been collected from the published data of India Meteorological Department, Pune.

3. Results and Discussion

Although the results presented here also include the pre-monsoon (March-May) and post-monsoon (October-November) seasons, much of our discussion in this paper is concentrated on the comparison between the variations of atmospheric aerosols and meteorological parameters during SW monsoon (June-September) months because most parts of India receive rainfall during this season.

3.1 Atmospheric aerosols

The environment prevailing over the observation site is semi-urban and the possible aerosol type present over the station is a mixture of water-soluble, dust-like and soot-like aerosols. The aerosol loading over Pune exhibits minimum levels during the SW monsoon, and gradually builds-up during the post-monsoon and winter seasons. Thus it shows a dominant annual cycle due to cloud-scavenging, rain- and wash-out processes during the monsoon season, and dust-storm /

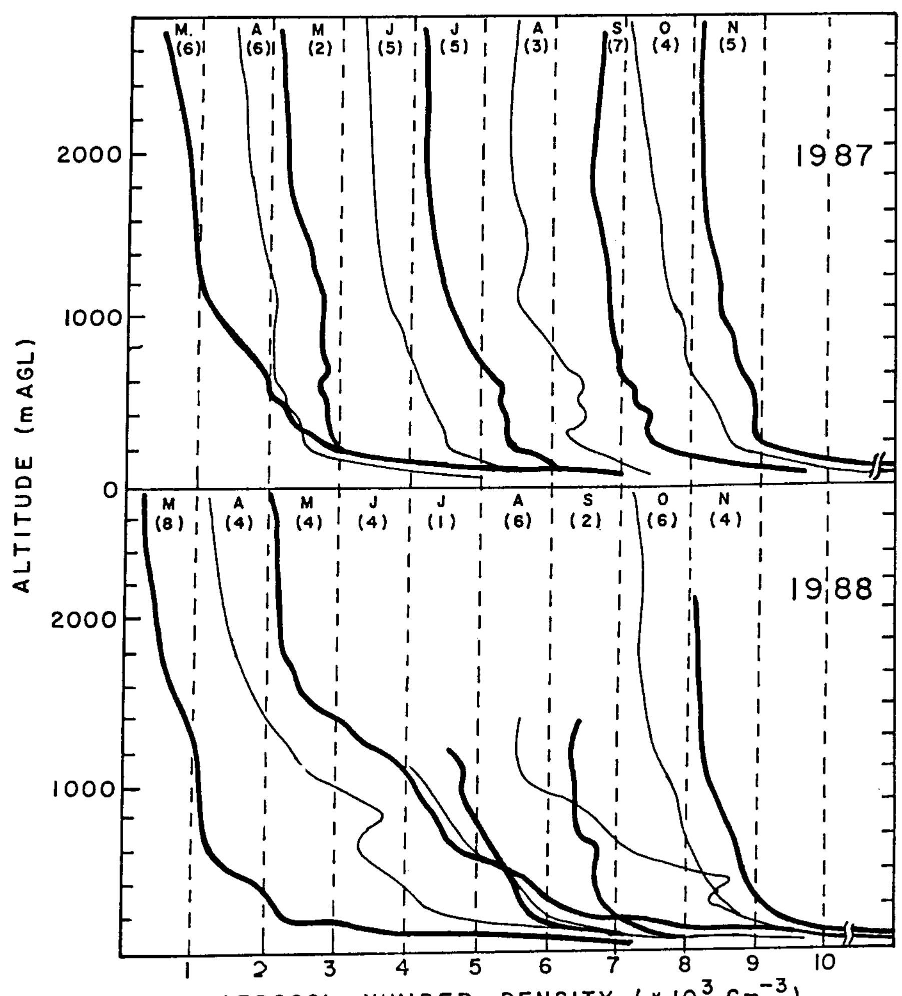

Fig. 1. Lidar-measured aerosol vertical distributions during contrasting monsoon years, 1987 and 1988. Profiles are represented alternately by thick and thin lines for the consecutive months.

strong convective activities during the pre-monsoon season. Monthly mean vertical distribution of aerosol number density during the monsoon seasons of 1987 and 1988 are shown in Figure 1. The numbers shown with parentheses at each mean profile represent the total number of aerosol profiles available for averaging in the month. The sky conditions allowed us to obtain aerosol profiles up to 2700 m AGL during the SW monsoon season of 1987 whereas the profiles could be obtained up to an altitude of 1200 m AGL during 1988. The wash-out of aerosols due to monsoon precipitation can be clearly seen. The profiles during the active monsoon season appear to be associated with higher negative aerosol gradients as compared to those during the weak monsoon season. In this context, it may be noted that higher aerosol concentrations in the lowest layers of the atmosphere and the steep negative aerosol gradients up to around 200 m in all the profiles are mainly due to the human activities and terrain characteristics of the lidar site (Devara and Raj, 1991).

In order to study the variations in aerosol loading during two contrasting monsoon seasons of 1987 and 1988, aerosol columnar content was estimated by integrating each profile throughout the height range, and Figure 2 shows this monthly mean aerosol content or loading over Pune. Aerosols present in the air layers close to the ground contribute greatly to the total loading. The aerosol content in the air layer between 50 and 200 m is also shown in the Figure 2. It is clear from the figure that the aerosol content is greater during the active monsoon year and less during the weak monsoon year.

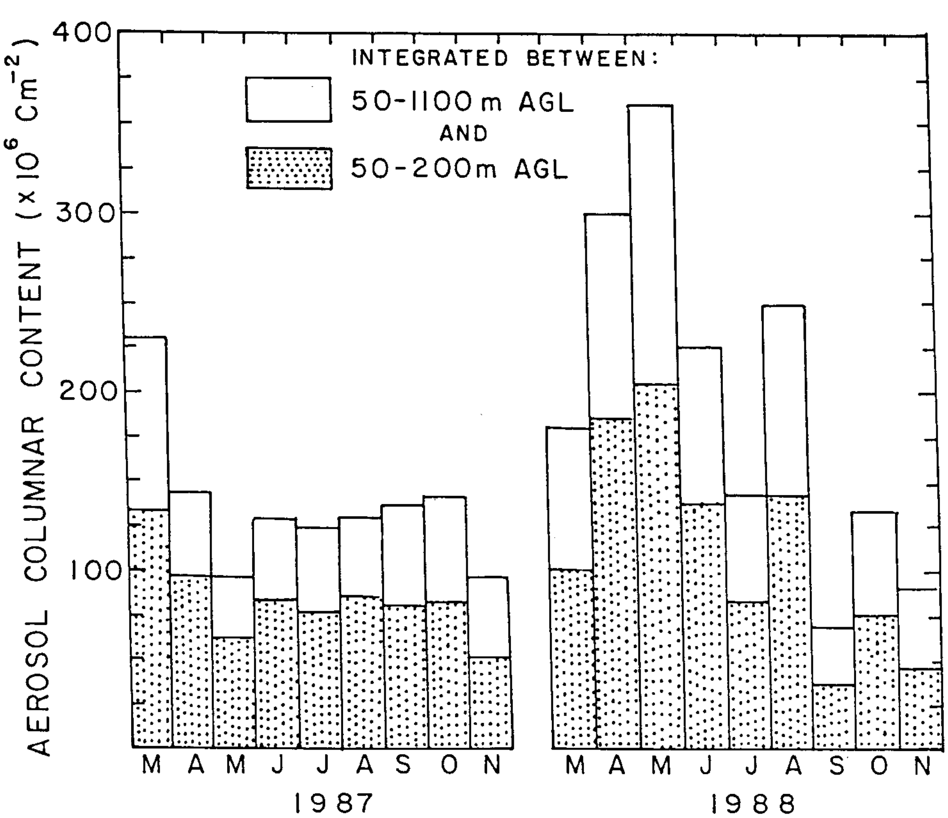

Fig. 2. Lidar-derived aerosol columnar content during pre-monsoon, SW monsoon and post-monsoon months of 1987 and 1988.

3.2 Meteorological parameters

Pune is about 100 km inland from the west coast of India and is located on the lee-side of the Western Ghats. The air flow in the lower troposphere is predominantly westerly during the SW monsoon season when there is a large influx of moisture from the Arabian sea, and an easterly flow sets in from October, and continental air masses, rich in nuclei of continental origin, pass over the station. Thus the meteorological conditions over Pune vary markedly from maritime (summer) to continental (winter) environments. Figure 3 depicts the monthly mean variations of temperature range (difference between maximum and minimum temperatures), relative humidity and total rainfall during pre-monsoon, SW monsoon and post- monsoon seasons of 1987 and 1988. Though the trends of variations of these parameters are more or less similar, significant differences, particularly in the case of rainfall, are seen between the SW monsoon seasons of 1987 and 1988. A considerable number of studies (for example, Hanel and Lehmann, 1981; Shaw, 1988) suggest that the size distribution of atmospheric aerosols varies significantly with changes in temperature and relative humidity. Apart from the atmospheric circulation systems that favour / suppress the activity of monsoon, the higher relative humidity (lower temperature range) observed during the SW monsoon season of 1988 might have assisted the cloud condensation nuclei to grow and form more cloud droplets which result in higher rainfall in that year.

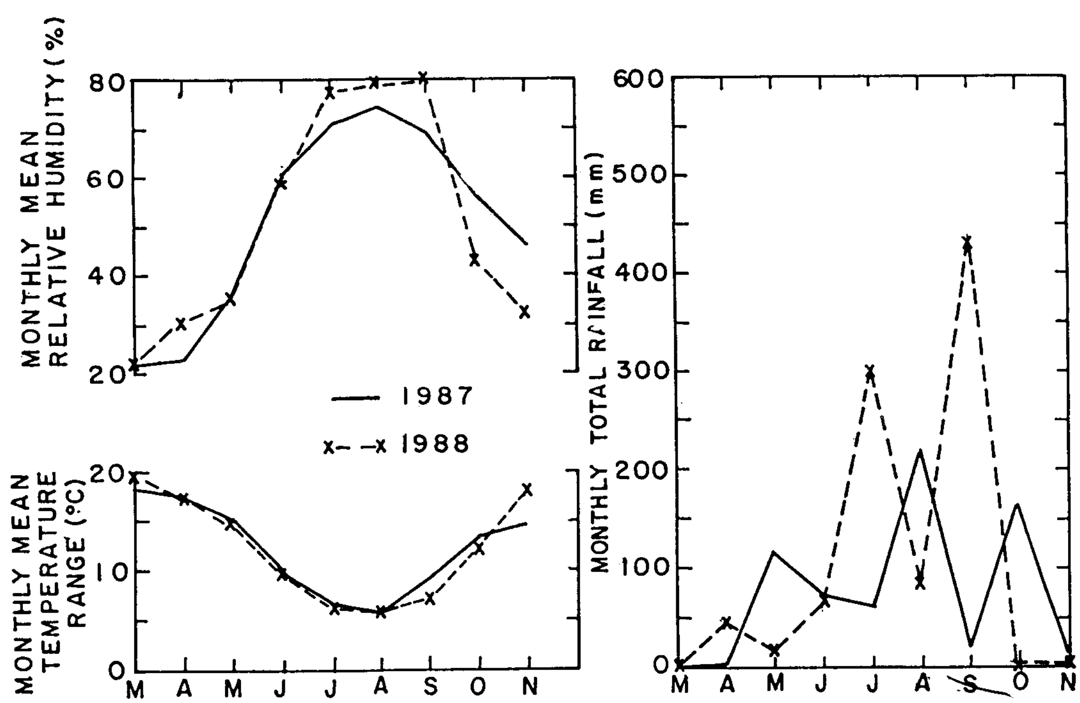

Fig. 3. Monthly mean surface-level relative humidity and temperature range, and total rainfall during the years, 1987 and 1988.

The total rainfall recorded during the SW monsoon season of 1987 was 380 mm whereas during 1988 it was 885 mm. The mean aerosol columnar content observed during the SW monsoon season of 1987 was 129 x 10^6 cm^{-2} whereas during 1988 it was 179 x 10^6 cm^{-2}.

These results suggest a reasonable relationship between the activity of SW monsoon and aerosol loading over the place. This relationship could also be due to the combined effect of the type of aerosols present over Pune and transport of marine air mass from Arabian sea during the SW monsoon season. Such a relationship, if established with a large database, would be valuable to infer the behaviour of monsoon from aerosol observations. Since regular lidar aerosol data are being archived at this site for the past decade, such studies are planned for future research.

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