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In situ measurements of aerosol vertical and spatial distributions over continental India during the major drought year 2009

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HIGHLIGHTS

- Aerosol vertical and spatial distribution in monsoon environment over Indian sub continent.
- Dominance of fine and coarse mode aerosol and strong vertical gradient during monsoon.
- Surface level concentration and height of ABL influence the aerosol optical depth.

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ABSTRACT

The variability in aerosol vertical and spatial distribution over the continental Indian region is studied using the airborne observations during the Cloud Aerosol Interactions and Precipitation Enhancement EXperiment (CAIPEEX) from May to September, 2009. The fine mode (0.1–3.0 μm) aerosol vertical profiles up to 6 km at different regions showed different vertical structures mostly influenced by the atmospheric boundary layer (ABL) depth as well as the origin of air mass trajectories and the presence of clouds. Elevated aerosol layers are observed during pre-monsoon and during monsoon at some locations but comparatively lower than the one observed in the boundary layer. During monsoon, aerosol number concentration showed strong vertical gradient and a transition is observed between the boundary layer and the free troposphere. The coarse mode (>3 μm) aerosol vertical profiles also showed elevated layers at higher altitudes due to the incursion of dry air laddened with dust. The spatial distribution shows significant variation at the elevated layers as compared to that in the boundary layer during pre-monsoon, while high variability is observed in the boundary layer during monsoon. The frequency distribution of different aerosol types from Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) showed dominating contributions from dust, polluted dust and smoke during pre-monsoon. During monsoon also traces of these pollutants were found to be high as the year 2009 is a drought year with rainfall deficiency of 22%. The surface level number concentration and the height of ABL are found to influence the aerosol optical depths significantly.

1. Introduction

Atmospheric aerosols play a major role in climate change by directly scattering and absorbing the incoming and outgoing radiation and through modifying cloud properties, such as droplet size distribution (Twomey, 1974) and cloud lifetime and extent (Albrecht, 1989; Ackerman et al., 2000). Indian sub continent has anthropogenically generated pollutants and dust from local sources as well as from long range transport (Ramanathan et al., 2001; Dey et al., 2004; Moorthy et al., 2008; Kaskaoutis et al., 2012). Fine mode aerosol dominance is observed during winter and coarse mode aerosol dominance during pre-monsoon (Gautam et al., 2007). As compared to aerosol optical depths, aerosol vertical profile retrievals give more insight on the aerosol impacts on climate change such as aerosol warming on the thermal structure and stability of the atmosphere, because of the presence of distinct aerosol layers aloft called elevated layers that are consistently observed with various observational techniques (Ramana et al., 2004; Raj et al., 2008; Babu et al., 2011; Prabha et al., 2012; Padmakumari et al.,

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2013). Also the vertical distribution of aerosol determines the degree with which it would interact with clouds, influence air quality and the atmospheric heating profiles. The aerosol in the ABL is often local in origin, while aerosol in elevated layers is usually transported from large distances. Hence, the physical, chemical and optical properties of aerosol in the ABL may be different from those of the free troposphere. Apart from aerosol spatial distribution, understanding of their vertical distribution is very important for the quantitative determination of their radiative effects (Heitzenberg et al., 1997). However, aerosol measurements, particularly their vertical distribution, are less and unevenly distributed in India.

Apart from ground based and satellites measurements, aircraft is proven to be an effective platform for in-situ measurements of atmospheric aerosol over a reasonably large spatial domain. Moreover, aerosol measurements during monsoon are very sparse over India to understand aerosol–cloud interactions. Especially, aerosols in the neighbourhood of clouds are seldom observed by other traditional approaches. CAIPEEX conducted over India with an instrumented aircraft led a pathway to understand the aerosol vertical distribution and their interaction with monsoon clouds. More details about CAIPEEX are presented in an overview of the experiment (Kulkarni et al., 2012). CAIPEEX phase-I was carried out for the first time over different parts of Indian sub continent during May to September 2009, which was a major drought year. In this paper, the vertical and spatial distribution of aerosol over different locations under different synoptic conditions is discussed. For the same year, earlier studies based on satellite data showed the presence of elevated aerosol layer upto 4 km (Rahul et al., 2011) and aerosol indirect effects during the long breaks in Indian summer monsoon (Manoj et al., 2012). On one hand aerosols are found to inhibit the cloud growth (Albrecht, 1989) and on the other hand they are found to enhance the deep convection (Koren et al., 2005) under suitable conditions. However, the influence of aerosol effects on monsoon under drought conditions is yet to be unravelled.

2. Data and methodology

2.1. Aircraft instrumentation and data

A twin engine Piper Cheyenne-II research aircraft was used during the intensive observation period. It was equipped with standard instrumentation for state parameters (such as temperature, pressure, relative humidity, and wind speed). More details of all the equipped instruments namely, the list of instruments, their range, accuracy, resolution, frequency and measured parameters were given elsewhere (Kulkarni et al., 2012) and at website http://www.tropmet.res.in/~caipeex/. The instrumentation used onboard for aerosol measurements was a Passive Cavity Aerosol Spectrometer Probe (PCASP-100X), with diameter ranging from 0.1 to 3 μm. This instrument is used mainly for the detection of fine and accumulation mode particles. Aerosol total number concentration is obtained by normalizing the total bin counts with the sample flow rate. While data processing the first bin data is discarded, as the data in the first bin is usually very high and treated as noise data. Cloud Droplet Probe (CDP) is used to measure the drop size distribution in the size range of 2–50 μm. In this study, the CDP number concentration outside the cloud (with a threshold of <15 μm) is used to represent the coarse mode particles. In clear sky conditions, CDP is mainly considered to detect large aerosol particles such as mineral dust and sea salt aerosols (Zhang et al., 2006; Padmakumari et al., 2013). The sizing calibration was done regularly by using glass beads of known sizes through a sampling volume. The optics of the instruments were cleaned regularly for removal of dirt and also were purged with nitrogen gas for removal of moisture content in the probes. Data is collected at an interval of 1 s (~100 m) and is quality controlled. Radiosonde (RSRW) flights were carried out at each base before the time of aircraft flight.

2.2. Area of flight operations

CAIPEEX phase-I was conducted from six different locations in India representing different environmental conditions from May to September 2009. The locations are Pune (18.52 °N; 73.85 °E) in the west, Pathankot (32.23 °N; 75.63 °E) in the north near the foot hills of the Himalayas, Hyderabad (17.45 °N; 78.38 °E) in the south central, Bareilly (28.42 °N; 79.45 °E) in the north of Indo Gangetic Plain, Bengaluru (13.14 °N; 77.62 °E) in the south and Guwahati (26.09 °N; 91.58 °E) in the north-eastern part of India. Fig. 1 shows the map of India with different bases from where the aircraft was operated and corresponding flight tracks.

The entire flight is segregated as ascent and descent flights i.e. from the surface to a maximum altitude and from maximum altitude to the surface, respectively. Thus, we have two profiles for each flight separated by a distance of ≈300 km–400 km. Data is averaged for every 200 m in vertical. The profiles are shown above the mean sea level. Standard deviations at every 200 m are also used in the study to represent the spatial variation in aerosol number concentration. ABL height above mean sea level is obtained from the vertical profiles of virtual potential temperature derived from radiosonde profiles. Surface level aerosol concentration and ABL mean concentration are obtained by averaging the lowest 200 m layer and concentrations up to the ABL height, respectively.

2.3. Other data sets

CALIPSO 5 km Aerosol Layer Product (Version 3.01) is used to categorize different aerosol sub types over the flight operational areas. The aerosols are categorized into six different types, based on their integrated attenuated backscatter and volume depolarization ratio along with ancillary information on surface type and altitude

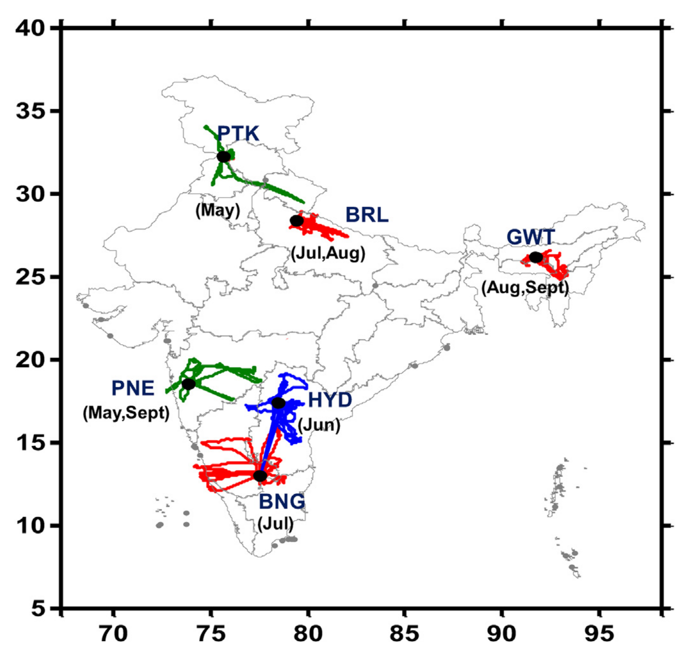

Fig. 1. Map of India showing the aircraft flight tracks from different bases.