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Airborne and ground based CCN spectral characteristics: Inferences from CAIPEEX – 2011

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HIGHLIGHTS

- Co-located CCN spectral characteristics at the cloud base and at the ground level.
- Surface CCN concentration decreases as liquid water path increases.
- New particle formed are below the critical activation diameter of ≈60 nm.
- Mechanical mixing during wet days and convective mixing during dry days.
- Short time variations in dynamics and cloud characteristics impact surface CCN.

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ABSTRACT

A first time comprehensive study of Cloud Condensation Nuclei (CCN) and associated spectra from both airborne and ground campaigns of the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) conducted over the rain shadow region of Western Ghats during September and October 2011 is illustrated. Observations of CCN spectra during clean, polluted and highly polluted conditions indicated significant differences between airborne and ground observations. Vertical variation of CCN concentration is illustrated from airborne observations in the clean, polluted and highly polluted conditions with different air mass characteristics. The cloud base CCN number concentrations are three times less than that of the surface measurements at different supersaturations. Diurnal variations of the ground based CCN number concentration and activation diameter showed bimodality. Atmospheric mixing in the wet conditions is mainly through mechanical mixing. The dry conditions favored convective mixing and were dominated by more CCN than the wet conditions. New particle formation and growth events have been observed and were found more often on days with convective mixing. The average critical activation diameter (at 0.6% SS) observed at the ground is approximately 60 nm and availability of a large number of particles below this limit was due to the new particle formation. Observations give convincing evidence that the precipitable water and liquid water path is inversely proportional to surface CCN number concentration, and this relationship is largely dictated by the meteorological conditions.

1. Introduction

Aerosols affect the climate directly through the phenomena of absorption and scattering of solar radiation. Aerosols also act as condensation nuclei for cloud droplet formation, interact with clouds and alter the droplet size distribution, and modulate the incoming shortwave radiation, thereby indirectly regulate climate (Twomey, 1991, 1977). Under constant cloud water content, increased aerosol number concentrations can decrease/delay

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precipitation by increasing cloud droplet number concentration while simultaneously reducing the droplet size resulting in increased cloud life time (Albrecht, 1989; Rosenfeld, 1999), and thus collision coalescence is suppressed. Impact of aerosols on the monsoon system has been under investigation for a few years now. On one hand, studies indicate that the increase in aerosol loading over the monsoon region has weakened the monsoon (Bollasina et al., 2011; Manoj et al., 2012; Sajani et al., 2012; Bhawar and Rahul, 2013). On the other hand, some studies indicate that the increase in aerosols might have intensified the monsoon and/or resulted in earlier rains in summer (Lau et al., 2006; Bollasina et al., 2008; Koren et al., 2012). In situ aerosol measurements over the Indian subcontinent can give a better perspective on the cloud–aerosol interactions during monsoon than the Aerosol Optical Depth (AOD) which is used in most of the studies. The three major field campaigns that performed aerosol measurements over the Indian region were the Indian Ocean Experiment (INDOEX), the Integrated Campaign for Aerosols, gases and Radiation Budget (ICARB) and the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX). INDOEX conducted during 1998–1999 was a multinational, multi-platform campaign which concentrated on measuring the green house gases and aerosols over the Indian Ocean (Mitra, 2004). ICARB (Moorthy et al., 2008), again a multi-platform field experiment headed by the Indian Space Research Organization (ISRO) conducted during March to May 2006 over peninsular India focused on the vertical distribution of aerosols (Satheesh et al., 2009) and Black Carbon (BC) (Babu et al., 2008). CAIPEEX program started in 2009, concentrated mainly on understanding the interaction of aerosols on cloud microphysics, precipitation in different parts of India and also to understand the efficacy of cloud seeding in the rain shadow region of the Western Ghats. In situ observations of aerosols and CCN were made in both the boundary layer and the cloud layer during CAIPEEX (Prabha et al., 2012). Kulkarni et al. (2012) gives information on the phase I of the program.

Information on the vertical profile of aerosols in the atmosphere can help in quantifying the effects of cloud–aerosol interactions. Aerosols not only change the optical, chemical and physical characteristics of the air column but also can change the vertical heating distributions by forming haze and cloud particles (Dumka et al., 2014). The vertical profiling studies of aerosols were primarily carried out using Lidars, which could be ground based (Devara et al., 1995), airborne (Gadhavi and Jayaraman, 2006; Satheesh et al., 2009) or spaceborne (Kumar et al., 2012). Use of Unmanned Aerial Vehicles (UAV) for airborne measurements of aerosols and BC is also not uncommon (Corrigan et al., 2008). Since only a fraction of aerosol particles act as CCN, information on the latter is much more desirable in cloud microphysical studies. One such study made over the Pacific Ocean showed that the CCN particles found above the oceans are not entirely sea-salt particles (Hobbs, 1971). The First Aerosol Characterization Experiment (ACE 1) conducted over the Southern Ocean in 1995 showed that air masses coming from land carried more CCN than those traversing over oceans (Hudson et al., 1998). The cloud base CCN concentrations increased from south to north of the Indian Tropical Convergence Zone (ITCZ) and satisfactory predictions of CCN using the Köhler theory was possible only when the aerosol soluble fraction was reduced from south to north of the ITCZ (Cantrell et al., 2000). VanReken et al. (2003), Bougiatioti et al. (2009) and Asa-Awuku et al. (2011) have also used the Köhler theory for attaining closure with the aircraft CCN measurements. Srivastava et al. (2013) found great variability in the CCN closure over Khajurao at different altitudes owing to the difference in air mass characteristics at these altitudes. In situ observations of aerosols and CCN made during CAIPEEX (Phase I) showed significant differences in the cloud microphysical properties (Prabha et al., 2011) and the level of raindrop formation (Konwar et al., 2012) in the premonsoon and monsoon conditions.

In this paper, characteristics of atmospheric CCN over the rain shadow region of the southern peninsula are examined using the CAIPEEX 2011 airborne observations (Fig. 1). The ground level CCN measured during the associated Integrated Ground Observational Campaign (IGOC) is also illustrated along with the collocated observations of clouds, thermodynamics and dynamics. The IGOC location (Mahabubnagar; 17 °N, 78 °E) is a semi arid region and mainly used as a crop land. Hence the major source of pollution is primarily biomass burning, but cannot disregard the local vehicular exhausts and advected pollution.

2. Instrumentation and data

Airborne measurements were made during the transition from southwest monsoon to northeast monsoon (15 Sept–31 Oct 2011) using an aircraft (Aero Commander 690A). The research flight was equipped with PMS Forward Scatter Spectrometer Probe (FSSP), a PMS Passive Cavity Aerosol Spectrometer Probe (PCASP), a continuous flow DMT CCN Counter (CCNC), a high flow Differential Mobility Analyzer (DMA) developed by Texas A&M University researchers along with other cloud, aerosol, radiation and state variable measuring instruments. All instruments were calibrated prior to the commencement of the experiment. Details of the instruments and parameters used for this study can be found in Table 1.

FSSPs are single particle counting instruments which detect light scattered by droplets when they traverse through a focused laser beam. Attention was required to avoid particle rejection due to attenuated laser beams caused by dusty prisms. FSSP data was rejected whenever the ratio of rejected counts to total counts was above 0.85. In the present study FSSP data was used only to screen the outside cloud data. Like FSSP, PCASP also measures the optical size of the particle. Differences in the collected scattering angles of the instruments give rise to differences in the sizing sensitivity of the two instruments. The DMA was installed inside the aircraft cabin. The air is sampled through an aerosol inlet and dried in a bundle of Nafion tubes. DMA measures the electrical mobility size which is approximately the physical size of the particle. DMA separates particles of roughly one diameter from a sample polydisperse aerosol. To measure an aerosol size distribution, the applied voltage is exponentially ramped over a wide range over a period of one minute and the separated particles are continuously counted with a Condensation Particle Counter (CPC). A matrix inversion algorithm is used to relate the array of particle counts to a size distribution (particles in the diameter range of 0.02–0.49 μm) which is then subjected to a number of automated quality checks and any questionable data are removed.

In the CCNC, the air sample is subjected to set supersaturations in a vertical column where the water vapor condenses onto aerosols particles which are counted using an Optical Particle Counter (OPC). At a flow rate of 50 vccm, 6000 particles per cm^{-3} could be counted with a 10% confidence (DMT, 2012). Detailed description on the working of the CCNC can be found in Lance et al. (2006). Supersaturation (SS) drifts are common in CCNCs which have to be checked by regular calibrations as calculating the thermal efficiency and correcting the supersaturations cannot always bring measurements to theoretical values (Rose et al., 2008). The CCNC was calibrated by operating in parallel with a CPC downstream of the DMA that size classified $(NH_4)_2SO_4$ aerosols generated using a collision atomizer. The aerosols were dried using a Nafion tube bundle and brought to a steady state charge distribution inside an aerosol neutralizer before being introduced into the DMA for size classification. The high voltage applied to the DMA for particle size separation was slowly scanned over a period of about 30 min for different CCNC supersaturations.