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Microphysical characteristics of convective clouds over ocean and land from aircraft observations

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ABSTRACT

The Cloud Aerosol Interaction and Precipitation Enhancement EXperiment (CAIPEEX) is a field campaign conducted in India with an instrumented research aircraft. On 29 October 2010, a cyclonic circulation over the Bay of Bengal persisted throughout the day. A special mission was conducted over the Bay of Bengal on this day with the objective of characterizing marine and continental clouds on the same day and finding contrasting/similar signatures of their microphysical properties. The research aircraft sampled growing convective clouds over the ocean and over land. High concentrations of aerosol and cloud condensation nuclei (CCN) were observed over land compared to ocean. Over ocean, higher liquid water content (LWC) and lower cloud droplet number concentrations (N_c) were observed, and droplets reached the threshold of precipitation initiation at lower cloud depths. Over land, clouds contained lower LWC and higher N_c, hence droplets did not reach the threshold of precipitation initiation at a warm temperature as in ocean clouds. Over the ocean larger droplets or drizzle were observed at lower cloud depth than over land. The maximum LWC was found to be very similar at higher altitudes. The convective clouds over land were modified by pollution aerosol with contrasting microphysical properties to those over the ocean.

1. Introduction

Clouds play an important role in the Earth's climate system. Atmospheric aerosols serve as cloud condensation nuclei (CCN) and modify cloud micro as well as macro physical properties such as droplet size distribution (Twomey, 1977) and cloud lifetime (Albrecht, 1989). The important parameters that determine cloud microphysical processes that lead to the formation of rain are liquid water content (LWC), cloud droplet number concentration (N_c), and effective radius (R_e). Important cloud macro physical parameters are cloud thickness and liquid water path (LWP). Using satellite data many researchers have studied cloud macro and microphysical properties and precipitation characteristics of low level water clouds over the tropics, mid latitudes and oceanic regions (Kubar et al., 2009; Sorooshian et al., 2009; Suzuki et al., 2010; Nakajima et al., 2010; Kawamoto and Suzuki, 2012; Noble and Hudson, 2015). Studies also showed differences in cloud characteristics and drizzle formation over land and ocean in the mid latitudes based on satellite data (Kawamoto and Suzuki, 2013; Michibata et al., 2014). More drizzle is observed in maritime clouds, whereas in continental clouds heavy smoke and urban pollution often suppress drizzle (Rosenfeld, 1999, 2000).

Cloud microphysical properties over land and ocean have also been studied with aircraft observations (Warner, 1955; Squires, 1956; Martin et al., 1994; Kaufman and Fraser, 1997; Baumgardner et al., 2005; Deshpande et al., 2014; Rosenfeld et al., 2014). Significant N_c difference in maritime and continental clouds were first noted by Squires (1956). This difference was attributed to contrast in CCN concentrations at cloud base (Squires, 1958). The relationship between N_c and aerosols below cloud base have been studied for maritime and continental clouds over the eastern Pacific Ocean (Martin et al., 1994; Hudson et al., 2010, 2015; Hudson and Noble, 2014). Aircraft measurements in eastern Florida showed that over the continent drizzle was suppressed due to high CCN concentrations compared to more maritime clouds (Hudson and Yum, 2001). Observations also showed significant changes in cloud droplet size distributions and differences in the height of precipitation initiation in maritime and polluted clouds (Andreae and Rosenfeld, 2008). Based on aircraft observations, satellite data and models, increases in polluted aerosols are found to affect the microphysics and the precipitation of the convective clouds through aerosol-cloud interaction (Alizadeh-Choobari and Gharaylou, 2017; Fan et al., 2016; Rosenfeld et al., 2014; Altaratz et al., 2014; Thompson and Eidhammer, 2014; Chen et al., 2011; Yum and Hudson, 2004).

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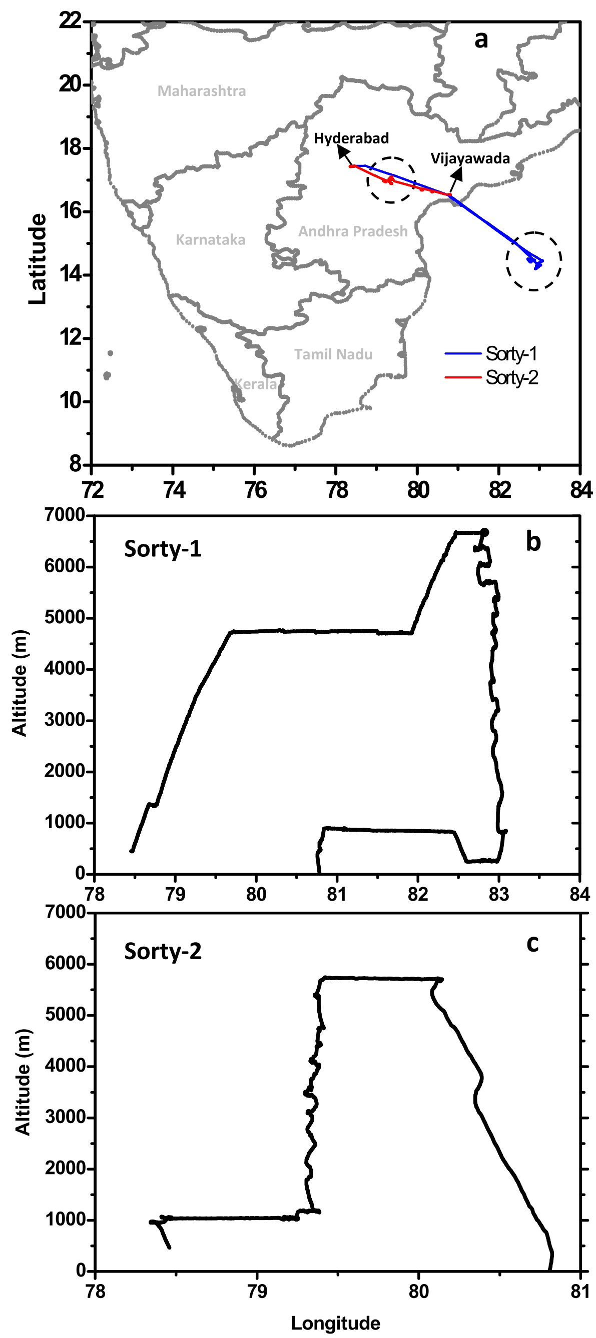

Fig. 1. (a) Map showing flight track from the base at Hyderabad toward the Bay of Bengal (sorty-1) and from Vijayawada to the Hyderabad base (sorty-2). Cloud profiling during (b) sorty-1 and (c) sorty-2.

From aircraft observations, most of the earlier studies focused on marine clouds. In this study, we focus on growing convective clouds over ocean and land. In India, the Cloud-Aerosol Interaction and Precipitation Enhancement EXperiment (CAIPEEX) was conducted with an instrumented research aircraft to study the variability of aerosols and their interaction with convective monsoon clouds (Kulkarni et al., 2012). CAIPEEX started in 2009, see http://www.tropmet.res.in/~caipeex/index.php for more details. Using these CAIPEEX data, various studies of aerosols, cloud microphysics and precipitation processes have been carried out during pre-monsoon, monsoon and post monsoon seasons over different parts of India (Padmakumari et al., 2013a, 2013b; Konwar et al., 2012; Pandithurai et al., 2012; Morwal et al., 2012, 2015; Maheskumar et al., 2014). On 29 October 2010, a special CAIPEEX mission was conducted over the Bay of Bengal. On this day, persistent synoptic features were observed throughout the measurement period due to cyclonic circulation over the Bay of Bengal. In the present paper, convective clouds profiled over ocean and land on the same day were studied to document the contrasting/similar signatures of clouds and their microphysical properties.

2. Data and methodology

Hyderabad (17.45° N, 78.38° E) in southern India was the base of operations for CAIPEEX during 2010. The research aircraft was equipped to make measurements of aerosol size and concentration, cloud hydrometeor size and concentration and thermodynamic parameters such as temperature, pressure, relative humidity and winds. The instrument used to measure aerosol size distribution was the Droplet Measurement Technologies (DMT) Passive Cavity Aerosol Spectrometer Probe (PCASP-SPP200) with aerosol diameter range 0.1 to 3 μm. A DMT CCN counter was used to measure cloud condensation nuclei (CCN) at supersaturations (S) of 0.2%, 0.4% and 0.6%. A DMT hot-wire liquid water content (LWC) probe was used to measure cloud LWC in the range of 0.01 –3 gm^{-3}. A Forward Scattering Spectrometer Probe (FSSP-SPP100) was used to measure droplet size distributions in the range of 2–50 μm (Baumgardner et al., 2011). The DMT Cloud Imaging Probe (CIP) and Precipitation Imaging Probe (PIP) were used to measure larger droplets and hydrometeors in the diameter (D) range of 25–1550 μm and 100–6200 μm, respectively. Software filters that make use of particle aspect ratio and inter-arrival time were used to eliminate the effects of hydrometeor breakup or splashing when colliding with probe tips (see Korolev et al., 2011 for more details). The resolution of all the data collected was 1 Hz (~100 m). For more details about the instrumentation, see Kulkarni et al. (2012).

Droplet size distributions measured by the FSSP probe were used to compute cloud droplet effective radius (R_e) as the ratio of the third moment of the cloud droplet size distribution to the second moment (Hansen and Travis, 1974; Reid et al., 1999). R_e is a key variable in climate models because it represents radiative properties of clouds (Reid et al., 1999). It is affected by CCN concentration at cloud base, LWC and width of the droplet spectra (Martin et al., 1994; Wood and Field, 2000).

On 29 October 2010, a special mission was carried out in southeast India and over the Bay of Bengal. The research aircraft took off from Hyderabad toward the Bay of Bengal and conducted cloud measurements 275 km off the eastern coast at 12:00 IST (Indian Standard Time). The clouds over the Bay of Bengal had the appearance of small cumulonimbus. Non-precipitating clouds generated from new convection that were selected for penetration and cloud sampling was done from 6300 m to cloud base at 1300 m. From cloud base the aircraft descended to 360 m and measured CCN concentrations at various supersaturations. At this altitude, some white caps were observed on the water surface indicating the occurrence of wave breaking, which releases salt particles (Colon-Robles et al., 2006; Hudson et al., 2011a, 2011b), giant CCN. Once CCN measurements were completed the aircraft climbed to 900 m, flew inland, and landed in Vijayawada on the east coast. The flight track and location of the cloud profiling over the ocean (sorty-1) is shown in Fig. 1.

After a 42 minute refuelling stop at the Vijayawada airport, the aircraft took off and headed west and inland toward Hyderabad at 5700 m altitude. A growing convective cloud cluster was observed inland with cloud tops at 4700 m. These clouds were profiled from 4700 m to cloud base at 1200 m. After cloud base measurements the aircraft descended to 1080 m for CCN measurements. The flight plan that was executed inland was similar to that over the ocean. The flight track and location of cloud profiling over land (sorty-2) are also shown in Fig. 1.

Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) transport and dispersion model (Draxler and Hess, 1998) is used for computing air parcel trajectories. Using this model the airmass back