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Possible evidence of new particle formation and its impact on cloud microphysics from airborne measurements over Bay of Bengal

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ABSTRACT

Airborne measurements conducted under a special mission over Bay of Bengal (BoB) during the CAIPEEX (Cloud Aerosol Interaction and Precipitation Enhancement EXperiment) in 2011 were analyzed in the present study. Research flights were carried out on 19 and 20 October, 2011 (referred as RF1 and RF2), in the region over BoB, which was influenced by a depression to evaluate the aerosol–cloud interactions over marine environment. The increased concentration of aitken/accumulation mode particles was observed at 500 m above sea surface level over the ocean after the passage of the depression. The source of these particles and their subsequent growth during RF1 at about 200 km from coastline has been attributed to (i) increased production of aerosols due to oxidation of dimethyl sulfide (DMS) because of upwelling of the deep ocean water during the depression and (ii) anthropogenic aerosols transported from inland. Moreover, measurements of accumulation and coarse mode particles with diameter ranging from 0.1 to 3 μm and cloud droplets in the range 3 to 47 μm show systematic growth associated with cloud microphysical/rain formation process. On the other hand, no such evidence of increasing particle concentration and growth has been observed at about 60 km from coastline towards southeast during RF2. Evidently, the rain event observed during the night hours of 19 October caused the washout and scavenging of aerosols which contributed towards the decreased aerosol concentration observed near the coast.

1. Introduction

It is well known that the aerosol particles play an important role in many atmospheric processes. They are responsible in altering Earth's energy balance via direct and indirect effects (Hudson and Yum, 2001; Lohmann and Feichter, 2005). Natural sources of atmospheric aerosol particles are gas-to-particle conversion, volcanoes, dust-storms, wave-breaking over the oceans etc. Being the large areal extent of the oceans, marine aerosol constitutes one of the most important natural aerosol systems at the global level. The bursting of white caps, the oxidation of gases emitted by the ocean and the transport of continental air are the main sources of aerosols over a marine region (Blanchard and Woodcock, 1980; O'Dowd et al., 1997, 1998, 1999, 2007; Clarke et al., 1998; Shenoy et al., 2006). The new particle formation, chemical processes leading to the nucleation and their subsequent growth are particularly important for better understanding of these aerosols. The theories proposed to be responsible for the nucleation and growth of newly formed particles include binary water–sulphuric acid nucleation theory (Kulmala and Laaksonen, 1990), ternary water–sulphuric acid–ammonia nucleation theory (Napari et al., 2002; Merikanto et al., 2007), cluster activation theory (e.g. Kulmala et al., 2004b, 2006), ion-mediated nucleation (Yu and Turco, 2000), and the nucleation mechanisms involving organic vapors (O'Dowd et al., 2002a)

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or iodine (O'Dowd et al., 2002b). Moreover, it has been observed that the nucleation rates are highly dependent on the environmental conditions, such as the chemical composition of the atmosphere, water vapor content, and the amount of solar radiation (Kulmala et al., 2004a and references therein, Sogacheva et al., 2008).

Formation of new particles in the low tide conditions in coastal regions due to emission of dimethyl sulfide (DMS), the most abundant volatile sulfur compound, by the marine microbiota has been proposed as a strong source for particles in coastal regions (Pirjola et al., 2000; O'Dowd, 2002; O'Dowd et al., 2007). These particles are <20 nm in size at the time of formation but can grow to Aitken particle size range in few hours through condensational growth by deposition of sulfate derived from the oxidation of DMS (Leck and Bigg, 2005). From long term measurements at Hyytiala, Southern Finland, new aerosol particle formation in different synoptic situations was identified by Sogacheva et al. (2008) suggesting that it tends to occur on days after passage of a cold front and on days without frontal passages. Hussein et al. (2008) have inferred from their long term measurements of fine particle number-size distributions at Helsinki that these events occurred most frequently during spring and autumn. Large increases in concentration of new particles are relatively common over the central Arctic Ocean in summer and have occasionally been observed over lower latitude oceans (Leck and Bigg, 2010). Over the tropical region, occurrence of aitken mode particles has been demonstrated from submicron aerosol size distribution measurements over the tropical and South Pacific by Hoppel and Frick (1990). Similarly, new particle formation due to gas-to-particle conversion processes has been reported over tropical Indian Ocean from submicron aerosol measurements by Deshpande and Kamra (2002).

After its initial formation due to nucleation, an aerosol particle may grow to several hundreds of nanometers in diameter and can act as a cloud condensation nucleus. In the last decade, several airborne experiments such as Indian Ocean Experiment (INDOEX) (Hudson and Yum, 2002; de Reus et al., 2001), Integrated Campaign for Aerosols, Gases and Radiation Budget (ICARB) (Murugavel et al., 2008), Pacific Dust Experiment (PACDEX) (Lee et al., 2010), African Monsoon Multidisciplinary Analysis (AMMA) (Chen et al., 2011), Suppression of Precipitation (SUPRECIP) (Rosenfeld et al., 2008a,b), and Gulf of Mexico Atmospheric Composition and Climate Study (GoMACCS) (Lance et al., 2009) were conducted worldwide to address the extent of the aerosols and pollutant transport over the ocean, aerosol–cloud interaction and role of increased pollution on precipitation. Airborne measurements of the aerosol number concentration and the size distribution conducted over the northern Indian Ocean during INDOEX in February–March 1999 reported that the aerosol in the marine boundary layer can be characterized by high number concentrations of submicron and accumulation mode particles, which gradually decreases with distance from the Indian subcontinent (Hudson and Yum, 2002; de Reus et al., 2001). Airborne measurements of sub-micron aerosols made at four vertical levels over the Bay of Bengal (BoB) across the coastline at Bhubaneswar (20.3°N, 85.8°E), India during ICARB campaign show that the land-to-ocean dispersion of aerosols in stable atmosphere may extend up to 500 m altitude. Further, these results demonstrate that the newly-formed particles in coastal zones may be convected up to 1000 m in altitude even in stable meteorological conditions in the lower atmosphere (Murugavel et al., 2008). This confirms the earlier results reported by O'Dowd (2002) around the coastline at Mace Head. The CCN concentrations and the activation characteristics of atmospheric aerosols in a diversity of air masses sampled at Finokalia Island over Eastern Mediterranean Sea during the Finokalia Aerosol Measurement Experiment-2007 (FAME-07) campaign by Bougiatioti et al. (2009) show dependency on air mass origin.

A major Indian national experiment, 'Cloud Aerosol Interaction and Precipitation Enhancement EXperiment' (CAIPEEX) was conducted during the period of 2009–2011 to explore the variability of thermodynamic properties, aerosol, clouds and precipitation through airborne measurements over the Indian region. In-situ observations of clouds and aerosol at several locations in India were carried out during Phase-I and Phase-II of this experiment with an instrumented aircraft. More details of this experiment were given in Kulkarni et al. (2012). The aircraft observations during CAIPEEX-2009 were utilized to understand the elevated pollution layers, cloud microphysical properties over Indian monsoon regions and role of aerosols in controlling the depth of warm rain in convective clouds (Padmakumari et al., 2012; Morwal et al., 2012; Konwar et al., 2012).

The objective of this work is to present the airborne measurements over the Bay of Bengal (BoB) from Bhubaneswar (20.3°N, 85.8°E), India during 19–20 October, 2011 to highlight the possible evidence of new particle formation and the evolution of associated growth of the primary marine aerosols to cloud droplets. Also, the role of prevailing synoptic forcing due to cyclonic conditions and transport of aerosols in modifying the local aerosol distributions and its effect on cloud microphysics have been examined.

2. Data and methodology

2.1. Sampling platform and instrumentation

Large variations in size, concentrations and composition of aerosols and cloud parameters coexist in convective clouds. The ability to analyze the microphysical properties of all these types of particles requires in-situ measurements with appropriate airborne instrumentation. During the CAIPEEX program, a twin-engine turboprop 'Aero-Commander', a pressurized research aircraft was used during the intensive observational period in 2011. For aerosol measurements the instruments used onboard are high-flow automated Differential Mobility Analyzer (DMA) system (Collins et al., 2000), a Droplet Measurement Technologies (DMT) Passive Cavity Aerosol Spectrometer Probe (PCASP) and a DMT continuous flow cloud condensation nuclei (CCN) Counter. The DMA system, operated over the size range of 0.02 to 0.49 μm, covers accumulation mode of aerosols and the PCASP operated in the size range from 0.1 to 3 μm, covers the accumulation and part of the coarse mode of aerosols. The forward scattering spectrometer probe (FSSP) is used to measure the cloud droplet size distribution in the size range from 3 to 47 μm.