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Microphysical characteristics of clouds and precipitation during pre-monsoon and monsoon period over a tropical Indian station

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ABSTRACT

Characteristics of clouds and precipitation during the pre-monsoon (PM) and monsoon months (MM) have been examined in the present study over the tropical station Kolkata (22.65°N, 88.45°E), which is located in the eastern part of India. Satellite data of clouds for the years 2005–2007 and raindrop size distributions (DSD) derived from ground-based Disdrometer for the years 2005 and 2006 for PM and MM has been considered here. Results shows that lower and middle level clouds dominate in the pre-monsoon season and the higher-level clouds are predominant in the monsoon season over the mentioned region. Correspondingly the cloud effective radius value also increases from the pre-monsoon to the monsoon months. The impact of aerosols and moisture plays a vital role in such changes. The characteristics of raindrop size distribution for the two seasons also showed that larger drops are more prevalent during pre-monsoon season whereas the smaller drops are present in larger number in the monsoon months. This is mainly due to the convective nature of rainfall in the pre-monsoon months, where intense convection, accompanied by strong updrafts modifies the raindrops. Thus pre-monsoon (monsoon) season over Kolkata region is characterized by lower/middle level (higher level) clouds, smaller (larger) cloud drop size and larger (smaller) raindrop size at the surface.

1. Introduction

Cloud feedback problem is one of the important issues that remains still unresolved in the present ongoing climate change studies. Due to the profound influence of clouds on both the water balance of the atmosphere and the earth's radiation budget, small variations in cloud properties can alter the climatic response associated with changes in greenhouse gases, anthropogenic aerosols or other factors associated with global change (Stephens, 2005). Several studies could be found in the open literature related to the role of aerosols in altering the microphysics of clouds (Rosenfeld et al., 2008; Albrecht, 1989; Chakravarty et al., 2011). These studies portray that increase in aerosols in the form of cloud condensation nuclei (CCN) increases the number of droplets in the clouds which tends to decrease the mean droplet size (or cloud effective radius, CER), and may increase the cloud albedo, depending on the aerosol absorption and cloud optical thickness (Breon et al., 2002; Twomey, 1977; Kaufman and Nakajima, 1993). The process, known as "Twomey effect" or the "first indirect" aerosol radiative forcing has a significant effect on climate in respect of cooling.

The optical thickness of a warm cloud on the other hand is dependent on both the cloud liquid water path (LWP) and cloud effective radius (CER), in the way that it is proportional to cloud liquid water path (LWP) and inversely related to the cloud droplet effective radius (Kubar et al., 2009). The microphysical variable of cloud, i.e. the CER at the same time is the ratio of the third to second moment of the droplet size distribution (Wood, 2006). Thus, by assuming that the lognormal size distribution does not vary vertically, the LWP is fundamentally related to both CER and droplet concentration (N_d) as follows (Matrosov et al., 2004).

$$\mathrm{LWP} = (4/3)\pi\rho N_d r_e^3 \exp(-3\sigma^2)\Delta h \quad (1)$$

where σ is the distribution width, Δh is the cloud thickness, r_e is the cloud droplet effective radius. As such, for a given LWP, small changes in r_e are associated with substantial increase in N_d. Liu and Daum (2000, 2002) showed that the increase in r_e is connected with broadening of size distribution of cloud droplets that reduces the indirect effect of aerosols. The shape of cloud droplet spectrum on the other hand is linked to the change of number of cloud droplets and cloud condensation nuclei (Takeda and Kuba, 1982) and affects the indirect effect of aerosols significantly (Lohmann and Feichter, 2005). At the same time, it is known that the decrease in cloud drop size also

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suppresses precipitation, which is known as "second indirect effect" (Albrecht, 1989; Rosenfeld, 2000). Under such circumstances, it becomes essential to know how the size of cloud droplets is related to precipitation. Although several studies on cloud-precipitation interaction have been undertaken, the understanding could not grow largely due to the complex nature of clouds, especially in the tropical monsoon region.

In the present paper, an attempt is made to examine the characteristics of clouds during the pre-monsoon months (PM), i.e the months of April–May and monsoon months (MM) i.e months from June–September, over the tropical station Kolkata (22.65°N, 88.65°E), which is located at the eastern part of India. In order to find the microphysical parameters of the clouds, three years satellite data from 2005–2007 has been considered for the study. Correspondingly, the nature of raindrop size distribution (DSD) at ground level for PM and MM has also been considered in the present study. One of the most complete description of a rainfall event is given by its dropsize distribution (DSD) and its space-time variability (Rosenfeld and Ulbrich, 2003). Various factors affecting the raindrop size distribution are available in the open literature. Kozu et al. (2005) and Marzuki et al. (2010) have reported on the rainfall rate dependence of DSD and also precipitation type dependence in the equatorial region using 2D-Video Disdrometer observations. On analyzing some stations over southern and south-eastern Asia, Kozu et al. (2006) pointed out that DSDs are affected by diurnal convective cycles and seasonal variations in precipitation characteristics. The drop size distributions of rain characterized by high temporal and spatial variability affect both microwave measurements and ground-based validation. The knowledge related to raindrop size distribution (DSD) not only gives the information about rainfall but also the complex microphysical process occurring within the precipitation system. It has been found that the microphysical and dynamical processes occurring in the evolution of raindrops during their descent to ground, plays a vital role in the observed seasonal or spatial differences in DSD (Radhakrishna et al., 2009). Several studies have been done across the world related to the variation of DSD from storm to storm, within the storm and from one season to the other (Tokay et al., 2002; Bringi et al., 2003; Ulbrich and Atlas, 2007). In the Indian region, a distinct difference of DSD has been noticed between the southwest monsoon (SWM; June–September) and northeast monsoon (NEM; October–December) rainfall (Narayana Rao et al., 2009) over Gadanki (13.5°N, 79.2°E) a tropical Indian station over southern India. Raindrops with smaller diameter are found to be dominating in the northeast monsoon (NEM) compared to that in the southwest monsoon (SWM) and at the same time larger mass-weighted mean diameter (D_m) values are evident in the SWM. As such, the variation of DSD for the PM and MM for two years (2005–2006) over the Kolkata region has been described in the present paper. The difference in the largest drop diameter for the two seasons has also been portrayed here. Possible causative mechanisms for these variations are also been discussed with the help of Moderate Resolution Imaging Spectroradiometer (MODIS) data.

2. Data

The region under consideration is Kolkata and its suburban areas, which is located in the eastern part of India (Fig. 1). Since it is located very near to the Bay of Bengal, the region experiences both the continental and maritime type of climate. Kolkata receives heavy monsoon rainfall during July–September period, the highest being in the month of August (i.e around 306 mm) and the annual rainfall being 1582 mm. The monsoon rains are basically due to the Bay-of-Bengal branch of south-west monsoon trough, as most of the cyclones/depressions during monsoon originate at the head of Bay-of-Bengal and move north-west to form the quasi-permanent monsoon trough. Often during early summer i.e in the months of April–May, dusty squalls followed by spells of thunderstorm and heavy rains lash the city, bringing relief from the humid heat. These thunderstorms (or the pre-monsoon rain) are basically convective in nature and are locally known as "Kalbaisakhi".

Fig. 1. Map of India showing the region of interest for the present study.

For understanding the characteristics of clouds in the mentioned region, MODIS data for three years (2005–2007) has been utilized for the current study. MODIS is a 36-band scanning spectroradiometer aboard Aqua, which is part of A-train constellation (Stephens et al., 2002). Four of the MODIS bands are used for the daytime shortwave cloud retrieval algorithm, including the visible band of 0.86 μm over the oceans and 0.65 μm over the land, and 1.64, 2.13 and 3.75 μm in the near IR (King et al., 1997). The combination of one of the three absorbing near-IR bands is used to retrieve cloud optical depth (COD) and cloud effective radius (CER). The CER and COD of level-3 MODIS data (1° × 1°) during 2005–2007 have been taken into consideration here. Information about different types of clouds over Kolkata region is derived from the MODIS data by taking the concept of International Satellite Cloud Climatology Project's (ISCCP) cloud classification (Hahn et al., 2001) technique.

The validation of the DSD over the surface has been done by using Disdrometer (Joss and Waldvogel, 1969) data. The Disdrometer (Joss and Waldvogel, 1969) is the impact type of Disdrometer that records the number of raindrops hitting 50 cm^2 surface of the sensor enabling the direct estimation of rain integral parameters like rain rate, radar reflectivity and liquid water content. The range of drop diameters that can be measured with this system spans from 0.3 to 5.3 mm. The diameters are distributed in 20 different channels with the sampling interval of 30 s. The rain-rate (in mm/h) is estimated by employing the following standard formula

$$\text{Rain rate} = \frac{\Pi}{6} \times \frac{3.6}{10^3} \times \frac{1}{F \times t} \times \sum_{i=1}^{20} \left(n_i \times D_i^3 \right) \qquad (2)$$

where n_i is the number of drops measured in drop size class i during time interval t, D_i is the average diameter of drops in class i, F is the size of sensitive surface of the sensor of Disdrometer (0.005 m^2) and