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Association of thunderstorm frequency with rainfall occurrences over an Indian urban metropolis

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ABSTRACT

Thunderstorm, associated with strong convective activity in the tropics, is one of the most prominent weather phenomena in the atmosphere. A critical analysis is done on the nature of variation of the thunderstorm frequencies over an urban metropolitan location Kolkata (22°32′N, 88°20′E), India with the pre-monsoon and monsoon rainfall amounts during the period 1997–2008. The occurrences of severe thunderstorms are decreasing during the last decade, although the number of ordinary thunderstorms occurring in this period has an increasing trend. A decrease in Convective Available Potential Energy (CAPE), Vertical Wind Shear (VWSH), Deep Layer Shear (0–6 km AGL) and an increase in Lifted Index (LI) may be an indicator for the suppression of the severity of thunderstorms over the urban location. There is also a decreasing trend for the pre-monsoon rainfall and an increasing trend in the monsoon rainfall amounts over the region. A further study indicated a significant positive correlation for all the types of thunderstorm (severe, ordinary and total) events with the pre-monsoon rainfall amount which are mainly associated with the vigorous convective phenomenon. On the other hand, a significant anti-correlation is observed between the severe thunderstorm frequencies with the monsoon rainfall amount for the same period. The decrease in the severity of the thunderstorm events is accompanied by an increase of pre-monsoon cloud Liquid Water Content (LWC) with Integrated Water Vapor (IWV). Hence, there is an expected strong association of the thunderstorm frequency with the pre-monsoon and monsoon rainfall amounts at this tropical location. Possible explanations are presented.

1. Introduction

Thunderstorms are one of the most vigorous convective activities that Indo-Gangetic plain including Kolkata (22°32′N, 88°20′E) and Northeast India (20°N–24°N latitude, 85°E–93°E longitude) encounter every year during the pre-monsoon season (March–May). It is a mesoscale weather phenomenon with space scale varying from a few kilometers to a couple of 100 km and time scale varying from less than an hour to several hours. The wind in these severe thunderstorms comes generally from some north-westerly direction and hence is commonly known as "Nor'westers" or "Kal-baishakhi" (Midya et al, 2011b). The phenomenon is important to meteorologists and a serious hazard to aviation (Awadesh, 1992; Litta et al., 2012a). Severe thunderstorms as a function of large-scale environmental conditions have also a strong impact on climate change (Brooks, 2013). The prediction of this weather event has continued to be a serious challenge to meteorologists within the framework of mesoscale meteorology (Chaudhuri, 2008a). The mesoscale convective systems can develop under the large-scale envelope of the seasonal and low-level trough over the West Bengal–Bihar–Jharkhand belt with a possible embedded low pressure area. The common feature of the weather phenomenon is the outburst of severe local convective storms,

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which may reach tornadic violence associated with thunder, squall lines, lightning, torrential rain and hail, causing considerable loss in agriculture, damage to property and sometimes even loss of life. The casualties reported due to lightning associated with thunderstorms in this region are among the highest in the world. Depending on the conditions present in the atmosphere, the three stages of thunderstorm formation — the cumulus stage, the mature stage and the dissipation stage, can take anywhere from 20 min to several hours to occur. The thunderstorm occurrences are generally divided into two categories — severe (horizontal wind speed > 64 km/h) and ordinary (horizontal wind speed ≤ 64 km/h). Determination of these two types of thunderstorms comes primarily from the wind profile in conjunction with the instability condition of the atmosphere.

The phenomenon of monsoon is global in character, affecting a large portion of Asia, parts of Africa (Sahel) and northern Australia, which cover more than 50% of the world population. Asian Monsoon is a spectacular phenomenon due to the huge landmass of Asia collocated with the huge water mass of the Indian Ocean (Mooley and Shukla, 1987). Indian summer monsoon rainfall is the rainfall carried by the southwest monsoon during June to September every year in India and accounts for approximately 80% of the annual Indian rainfall. Monsoon occurs mainly due to the differential heating of land and ocean and deflection of wind due to rotation of earth. India being a tropical country, the south-west monsoon winds have great importance in Indian agriculture. The regions which receive the largest rainfall are along the west coast of India and the states of Assam and West Bengal in northeast India. In these regions orographic features play an important role, because the moisture laden monsoon winds strike against physical barriers by way of mountains. Apart from orographic features, atmospheric convection plays an important role during the monsoon and the period just preceding it. In the pre-monsoon months, parts of northeast India, especially West Bengal, Bihar and Assam experience severe pre-monsoon thunderstorms or Nor'westers. The rainfall associated with these thunderstorms is of a transient nature. The intensity of precipitation is high but the rainfall is of short duration. Monsoon rain is of a different genre. It has continuous spread over days, and the intensity of precipitation is not as high as that of convective rain. Ganda and Midya (2012) reported that rainfall trend of most of the urban areas is gradually increasing with respect to non-urban regions of Indian landmass. It is concluded that AVOC (Anthropogenic Volatile Organic Compounds) which is related to tropospheric ozone may play an important role to form CCN (Cloud Condensation Nuclei) of proper dimension of raindrop formation.

In recent years, atmospheric scientists have shown much concern about the pronounced differences in the precipitation yield and dynamical and electrical properties of the tropical mesoscale cumulonimbus regimes embedded in the monsoonal convection during the monsoon season and the more vigorous but sparsely distributed thunderstorms of the pre-monsoon season (Rutledge et al., 1992; Williams et al., 1992; Jayaratne, 1993). Considerable amount of literature is available on thunderstorm studies over the Indian region as well as in the other region (Sohoni, 1931; Rao and Raman, 1961; Raman and Raghavan, 1961; Williams, 1961; Chaudhury, 1961; Balogun, 1981; Sivaramkrishnan, 1990; Awadesh, 1992; Moid, 1995; Chaudhuri, 2008b; Midya et al., 2010, 2011b) during several decades to reveal the related climatology, frequency, diurnal variation, month wise and season wise distribution of thunderstorms. Saha et al. (2011) mentioned that the pre-monsoon thunderstorm frequency over Kolkata attains its maximum during solar peak phase of the 23rd solar cycle and it is due to the increase of solar activity. The pre-monsoon thunderstorm frequencies increase after the solar maximum due to the depletion of O_3 concentration and increase of greenhouse gases over Kolkata. The rate of depletion of total column ozone (TCO) is also related to wind speed of tropical cyclone and surface temperature (Midya et al., 2011a; Midya et al., 2012; Midya and Goswami, 2013). Again, humidity and rainfall are reported to be correlated to ozone concentration (Midya and Saha, 2011a,b; Midya et al, 2011c). Williams et al. (1992) have pointed out that although the above mentioned differences usually common in the tropical monsoonal storms, there is a need for an assessment of similar information from the Indian region where land and warm waters are juxtaposed for monsoon development. Since the convective phenomena play an important role in the generation of thunderstorm activities in the tropical region, and at the present location, as both pre-monsoon and monsoon rainfalls are associated with convection, it is intended to study the association of rainfall with thunderstorm activities (Manohar et al., 1999) which affect the lives of people, particularly at urban locations. The purpose of this paper is to present the study of thunderstorm frequency over Kolkata (22°32′N, 88°20′E) and summer monsoon rainfall over the same in Gangetic West Bengal.

2. Data and methodology

The data for the thunderstorm over Kolkata (22°32′N, 88°20′E) during pre-monsoon and monsoon seasons for the period 1997–2008, used in the present study, are collected from Regional Meteorological Centre, Kolkata. We have used the ISMR (Indian Summer Monsoon Rainfall) dataset of the Indian Institute of Tropical Meteorology (IITM), Pune (ftp://www.tropmet.res.in). The sub-divisional rainfall data from Gangetic West Bengal, which includes the location of Kolkata (Fig. 1), are utilized for the present study. The dataset covers pre-monsoon (March to May) and monsoon (June to September) months.

The thunderstorm occurrences are divided into three categories in our study — severe (horizontal wind speed > 64 km/h), ordinary (horizontal wind speed ≤ 64 km/h) and total (severe and ordinary) thunderstorm. The yearly variations of the severe, ordinary and total thunderstorm frequencies over Kolkata against pre-monsoon and monsoonal rainfall amounts over Gangetic West Bengal (Kolkata) are also plotted.

Radiosonde measurements obtained by the University of Wyoming from the website http://www.uwyo.edu at Kolkata, India (22°32′N, 88°20′E), a tropical location, during the period 1997–2008 for the months March to May (pre-monsoon) and June–September (monsoon), have been used in the present study. Usually, radiosonde observations are made twice a day, at around 00 and 12 GMT (0530 and 1730 IST). The stability indices, namely, Convective Available Potential Energy (CAPE) and Lifted Index (LI) data were also extracted from the Radiosonde measurements for the same