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Enhancement of cloud-to-ground lightning activity over Taipei, Taiwan in relation to urbanization

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ABSTRACT

Collecting the cloud-to-ground (CG) lightning flash data from Tai-Power Company of Taiwan, a long term study has been performed to investigate the enhancement of lightning activity in and around Taipei City, the largest metropolitan city of Taiwan, in relation to urbanization, for the period of 2005–2010. Results reveal that negative flash density is enhanced by approximately 64% while the positive flash density is enhanced by 48%, over and downwind of the city compared with other neighboring areas. On the other hand a decrease of nearly 24% in the percentage of positive flashes occurs over and downwind of Taipei compared to upwind values. We have also investigated the effect of urbanization on peak current of both polarities but no significant effect is noticed. Possible influence of urban particulate matter on the enhancement of CG lightning activity has been analyzed utilizing the annual averages of PM10 (particulate matter with aerodynamic diameter smaller than 10 μm) and SO_2 (sulfur dioxide) concentrations data. Interesting results are found, indicating the higher concentrations of PM10 and SO_2 contributes to the CG lightning enhancement. Both the concentrations exhibit a positive linear correlation with the percent change in CG flashes from the upwind to the urban area and from the upwind to the downwind area. However, the correlation coefficient for PM10 concentrations is comparatively much lower than SO_2 concentrations. Positive correlations of 0.55 and 0.68 are found for the PM10 and SO_2 concentrations, respectively, when compared separately with the percent change in CG flashes from the upwind to the downwind area, indicating the influence of aerosols on urban CG lightning enhancement. Hourly variation of lightning flashes show that the urban effects on CG lightning is prominent in the afternoon and early evening hours. The results obtained from the present analysis corroborate the results reported in the literature by other researchers.

1. Introduction

The first indication of the effect of urban area on the enhancement of the cloud-to-ground (CG) lightning activity over and downwind of cities has come through the literature published by Westcott (1995). Thereafter several studies have been conducted to study the effect of an urban area on the initiation and enhancement of CG lightning (e.g. Orville et al., 2001; Steiger et al., 2002; Soriano and Pablo, 2002; Naccarato et al., 2003; Pinto et al., 2004; Farias et al., 2009; Lal and Pawar, 2011; Farias et al., 2014). In general, the urban heat island circulation and the possible role for air pollution have been indicated as the prime influencing factor behind such enhancement in most of these studies. Apparently the urban effect is a combination of an increased pollution concentration in the local air caused primarily by human activities and a thermodynamic effect due to differential heating of the city surface (Farias et al., 2009). Steiger et al. (2002) first conducted a 12-year climatological analysis over Houston, Texas on the percentage of positive flashes and peak current to investigate the urban effect on

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lightning characteristics in these categories. A decrease of (−12%) in the percentage of positive flashes and no significant effect on the peak current of negative and positive CG flashes are reported in their study. Because of the existence of a physical relationship between lightning activity and convective precipitation (Petersen and Rutledge, 1998; Soriano et al., 2001; Kar and Ha, 2003), urban effects on lightning are expected. The concentration of cloud condensation nuclei (CCN) over urban area can be uplifted by the pollution over the cities, which, in turn, may change the cloud microphysical processes. Such changes in cloud microphysical processes, again in turn, may change the charge separation processes in thunderclouds because of its close association with concentration, phase and the size of cloud particles. Orville et al. (2001) indicated that in the boundary layer, the increased pollution is expected to be effective in suppressing the mean droplet size, and more cloud water would therefore be operative in isolating the electric charge, leading to the production of enhanced CG lightning flashes. Recent study conducted by Farias et al. (2014) suggests that urban pollution tends to saturate the intensification of storms and lightning activity in a specific level. Andreae et al. (2004) suggested that the compositions of the aerosol particles and their concentration variations can invigorate the convection. On the other hand comparing the electrification of convective cloud for polluted and clear conditions Williams et al. (2002) suggested that the aerosols effect on CG lightning activity is not clear. So, there is no consensus on the effect of pollution on the CG lightning activity. The reason is due to the complexity of the phenomena. Hence extensive studies from different regions of the globe can resolve the issue. Most of the studies on lightning and thunderstorm have been carried out in the United States and in tropical areas. But the number of research work on lightning related to the areas like Taiwan is limited (Liou and Kar, 2010). As far as our knowledge is concerned no attempt has yet been made to investigate the urban effect on lightning activity over any region of Taiwan. In this paper, a 6-year climatological analysis of lightning data was conducted over and surrounding places of Taipei (25° 02′ 51″ N; 121° 31′ 54″ E), the capital of Taiwan, which is the 16th most densely populated country in the world with an average population density of 642/km^2 (1664/miles^2). In Taipei 9600 people live in every square kilometer. The urban area of Taipei City is approximately 271.8 km^2 and is similar to Houston in that both are coastal cities. Flash density of both polarities and the percentage of positive flashes have been calculated. The results are presented and compared to those available in the literature.

2. Data and methodology

For the present study we have collected lightning data from Tai-Power Company of Taiwan for the years 2005–2010 to determine the urban effect on lightning over Taipei and its surroundings places. The Lightning Location System (LLS) was built in 1989 with one APA (Advanced Position Analyzer), and six Direction Finders (FD) installed at sites covering the entire area of Taiwan. The LLS was upgraded to a Total Lightning Detection System (TLDS) in 2002. The TLDS consist of seven lightning detection sensors (SAFIR 3000), which are located at the top of Ying-Tsu-ling microwave tower, Wu-shih-pi microwave tower, Ji-shan microwave tower, Nan-Ke extra voltage substation, Feng-Lin microwave tower, building roof of Ming-Tan power plant, and building roof of Xiao-liou-chiou. The location of these seven sensors, distributed throughout Taiwan, is shown in Fig. 1. VHF interferometric technique is the main basis for the localization principles of SAFIR network (Richard and Auffray, 1985; Richard et al., 1986). The seven lightning detection sensors, formed a lightning detection network, could detect cloud-to-ground lightning discharges, cloud lightning discharges, and breakdown events. The lightning discharges detection is accomplished through the use of multiple, remote sensors that detect signals emitted by lightning discharges, and by filtering out the signals from non-lightning sources. The Long rang localization of all lightning discharges (CG and CC lightning flashes) is governed by triangulation performed on GPS time synchronized direction of arrival provided by interferometric sensor of two different detection station in a SAFIR network. Each sensor detecting a lightning event sends data about that event to a central processor (SCM) that triangulates the results from each sensor creating an optimal estimate of location of the lightning event. The lightning detection network average efficiency is greater than 90%, and the lightning detection localization accuracy is less than 1 km. However, especially near the edges of the network the assumption of more than 90% uniform flash detection efficiency may not be realistic, but because of comparatively higher average detection efficiency and localization accuracy no attempt was taken to correct the detection efficiency because previous studies (e.g. Naccarato et al., 2003 for a Lightning Position and Tracking System (LPATS); Orville, 1994 for the National Lightning Detection Network in the United States; Finke and Hauf, 1996 for a LPATS in Germany, and Pinto et al., 1999 for a LPATS in Brazil) reported an overall detection efficiency of 90% for several lightning detection networks.

Air pollutant data were collected from a well organized air quality-monitoring network operated by Taiwan Environmental Protection Administration. Taiwan's air quality monitoring network measures PM10 concentrations by the automatic Wedding β-gauge monitors, which is one of the US EPA-designated equivalent methods (no. EQPM-0391-081). For the present study PM10, SO_2 over Taipei County are considered.

For ease in computation we have considered blocks corresponding to upwind, over and downwind areas of Taipei City. A spatial scale of approximately 0.08° latitude × 0.08° longitude has been chosen as grid box. The area enclosed by a grid box is ~8.8 km × 6.6 km–58 km^2. Hence, each block associated with upwind, over and downwind comprises 6 grid boxes. The whole urban area of Taipei is covered by such 6 grid boxes. In the next step the numbers of CG flashes are counted within the blocks assigned for upwind, over and downed area. The computed results are then compared to analyze the urban effect on CG lightning activity. Such procedure was adopted by Westcott (1995). The blocks corresponding to upwind and downwind areas are selected based on the strong prevailing wind motion. Taiwan has a clear southwesterly component of its warm season prevailing wind motion (Chen et al., 1999). Hence, upwind (downwind) areas are located to the southwest (northeast). In calculating the urban CG lightning flash density, we have counted the number of CG flashes in block, which covers the whole urban area of Taipei City. But for the computation of lightning flash density for upwind and downwind areas, we have