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Lightning ground flash patterns over Paris area between 1992 and 2003: Influence of pollution?

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ABSTRACT

12 summers of cloud-to-ground (CG) lightning flashes data over a 200 km × 200 km domain centered on Paris (France) have been analyzed to infer the possible influence of pollution on lightning activity. Lightning flashes densities are calculated on a 5 km × 5 km grid, filtered for discarding extremely high events, and differentiated from weekdays to week-end days, with a specific insight upwind, over, and downwind Paris. Lightning flashes are more numerous in the North-East part of the domain and increasingly large events progressively concentrate over Paris and over some hills around. The former result indicates a possible influence of pollution on lightning activity downwind of Paris; the latter probably illustrates the influence of the urban heat island and of the relief on the convection strengthening. Furthermore, the number of positive CG flashes is rather uniformly distributed on the whole domain, except in the North-East where it appears somewhat relatively lower meanwhile negative CG are relatively more numerous in that region. This corresponds to a reduction in the percentage of positive CG downwind of Paris. Additionally, lightning activity appears weaker downwind of Paris during weekend days. A specific daily analysis of the lightning density in circles distributed along the direction of prevailing wind through Paris shows that the lightning activity appears higher downwind during the days most worked as Tuesday, Wednesday and Thursday. This higher electric activity persists up to about 40 km on Wednesday, and up to about 80 km on Tuesday and Thursday (most days worked). The electrification seems therefore more important downwind of Paris during the more polluted days.

1. Introduction

Among the various influences that anthropogenic emissions may have on local and regional meteorology, the one that involves aerosols and cloud physics via the droplet spectrum appears very complex, especially when thunderclouds and electrification are considered (Mossop and Hallett, 1974; Rosenfeld and Lensky, 1998; Williams et al., 1999; Bell et al., 2008). As a matter of fact, lightning activity is supposed to be affected by several parameters that can reinforce the convection like the sensible heating in response to solar radiation, the relief, the urban heat island (UHI), the wind convergence… However, these parameters can be in competition with the aerosols for lightning enhancement (Williams et al., 2004). The aerosols can even be key parameters according to several observations over cities where an increase in CG density and a decrease in positive CG percentage were detected (Orville et al., 2001; Areitio et al., 2001; Steiger et al., 2002; Naccarato et al., 2003; Pinto et al., 2004; Stallins et al., 2006; Kar et al., 2009), or under the influence of smokes emitted by biomass fires resulting on contrary in an increase in the positive CG percentage (Lyons et al., 1998; Murray et al., 2000; Lang and Rutledge, 2006). Furthermore, the triggering and the propagation of discharges could also be affected by

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pollution, which governs the electric conductivity of hydrometeors that are involved in discharge processes (Boussaton et al., 2005).

As far as the influence of aerosols on microphysics is concerned, the usual hypothesis put forward is that of Rosenfeld and Lensky (1998) and Williams et al. (1999). The so-called aerosol hypothesis is detailed and illustrated in Williams et al. (2002) and Rosenfeld et al. (2008). According to it, the increase in the number of cloud condensation nuclei (CCN) originated from a dirty continental boundary layer induces the multiplication of small droplets that share the available liquid water in the storm updraft. Subsequently, the coalescence process is less efficient because of a lack of mean droplet size. Therefore, more cloud water can reach the mixed phase region where droplets participate on one hand to the strengthening of the convection by the release of latent heat during their freezing, and on the other hand to the growth of graupel by riming and therefore to the charge generation process (see the review by Saunders, 2008). The electrification is thus enhanced by the presence of numerous CCN. However, the conclusion of this hypothesis is inconsistent with the part played by the Hallett-Mossop glaciation process. As described by Mossop and Hallett (1974) and by Mossop (1978), the secondary ice crystal production is sensitive to the drop size distribution and the presence of a high number of large drops is necessary. The release of CCN by anthropogenic activities tends to diminish the number of large drops and thus, to inhibit the Hallet–Mossop process. As this mechanism that provides high ice crystal concentrations is essential to cloud electrification (Hallett and Saunders, 1979), an increase in the number of CCN could produce a diminution in lightning activity. The question remains open.

The relationship between the lightning activity and all the parameters mentioned above is not clearly understood since it is most often difficult to isolate the influence of only one of them. Numerical models are not yet capable of analyzing real cases by taking into account kinematics, microphysics, aerosols, and electrical effects, together at high resolution. At the present time the French non hydrostatic mesoscale model Méso-NH (Lafore et al., 1998) can resolve convection at kilometer scale with an electrical scheme of electrification and lightning production (Barthe et al., 2005; Molinié et al., 2009). Beside, we dispose of the aerosol scheme of Tulet et al. (2005) but it does not apply to cloud interaction. CCN and ice condensation nuclei (ICN) are taken into account in a new scheme that is only currently under development. The other way is to perform long-term climatologic studies of CG lightning flashes that are expected to provide significant information on their average behavior. In order to assess the part played by pollution and UHI over a great urban center, we focused on the Paris area for which we dispose of 12 years of CG lightning data. We performed a progressive filtering of the CG density in order to identify the different zones where lightning flash activity is more and more intense. Moreover, following the approach of Dessens et al. (2001), who pointed out the day-of-the-week size variability of hail supposed to be due to the day-of-the-week variability of the aerosols distribution, we separated the CG distributions between week and weekend days.

After a presentation of the studied domain and of the CG data set, we present hereafter the overall results in terms of number of CG per day and per pixel and in terms of number of lightning days per pixel, for both polarities. Next, we describe the data filtering that appears to be a good tool for determining the location of the increasingly hot spots. We then discriminate the results between weekdays and weekend days and perform a daily analysis of the lightning activity distributed along the direction of prevailing winds through Paris. We finally discuss the influence of the various factors (relief, UHI, pollution) that could be at the origin of the observed CG features on the domain.

2. Domain and data descriptions

The studied domain is defined as a square area of 200 km × 200 km centered on Paris, the latitude and longitude of which are respectively 48.86° and 2.35° (see Fig. 1). The relief of the domain is displayed in Fig. 2, in which the boundaries of Paris city and of its surrounding built-up area are drawn in black lines and several main cities are mentioned with black circles. Located in the Seine valley, Paris is surrounded by several hills that are located close to the borders of the domain in the South-West, North-West, East, and South-East. One ridge North-West to South-East directed between Rouen and Beauvais appears closer to Paris. The maximum altitude on the domain does not exceed 325 m.

The region is usually submitted to a degraded oceanic climate characterized by frequent and generally weak precipitations. During the whole period considered in the present study, which extends from May to September (extended summer period) of 12 years from 1992 to 2003, the average monthly minimum and maximum temperatures in Paris city raised to about 13.9 °C and 23.0 °C, respectively (see Fig. 3). During the same period and in the same location, the number of days with a temperature greater or equal to 25 °C is about 53 on average but varies from 36 in 2002 to 82 in 2003. The latter year corresponds to a well known episode of heat wave. The wind is most often from West/South-West. For example, among the 26 high radar reflectivity storms that occurred during summer 2000 (see Boussaton et al., 2007) about 73% of them moved from the South-West to the North-East of the domain, meanwhile about 23% were involved in a South-East to North-West motion. In order to give a better idea of the wind characteristics during the studied period, the frequency distribution of the wind direction and speed at the 500 hPa level over Paris is plotted in Fig. 4 for the days when lightning were observed from May to September during only 8 years from 1996 to 2003 (data from Météo France – the French National Meteorological Service – were available since 1996), that is to say 66% of the lightning days considered in the whole study. Most of the speeds ranged from 5 to 25 m/s with a main direction from West/South-West.

The domain is also characterized by a strong urban activity, especially Paris and its suburbs that are source of anthropogenic pollution, with a strong industrialization and an intense traffic. An average temperature difference of several degrees is frequently detected between the center and the exterior of the city, which denotes the presence of an important urban heat island effect.