Analysis of the Altitude of the Isotherms and the Electrical Charge for Flashes that Struck the Gaisberg Tower

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ABSTRACT: The features of lightning flashes occurring on tall structures can give some valuable information about their initiation, especially the cases of upward flashes for lightning protection of tall structures such as wind-turbines. More than 300 flashes which struck the Gaisberg tower (Austria) have been analyzed in order to investigate differences in occurrence conditions between winter and summer. More flashes struck the tower in winter unlike the Austrian lightning activity is much lower during this season. These winter flashes deposit to ground more electrical charge than summer ones. The median values of the -10 ºC isotherm altitudes during winter are 2-km lower than during summer. This difference would produce stronger electric fields at ground level which could favor the triggering of upward flashes.

1. INTRODUCTION

Tall instrumented structures at the ground have been employed during years for gathering information about lightning currents [Diendorfer et al., 2006; Miki et al., 2005]. The results denote that most of the lightning flashes on tall structures are upward type.

For the thunderstorm electrification, several ground and in-situ observations reported dipole structures with negative and positive charges at lower part and upper part in the cloud, respectively [Wilson, 1956; Rust and Marshall, 1996]. Tripole structures were firstly proposed by Simpson and Scrase [1937] then, confirmed by many other studies [Williams, 1989]. This electrical feature was also put forward from the analysis of the charge structure of lightning discharges to ground [Krehbiel et al. 1979; Koshak and Krider 1989]. Other recent measurements by Rust and Marshall [1996] showed the presence of more than three charge regions. A common feature of these previous works is that the negative charge seems to reside between altitudes defined by the -10 ºC and the -20 ºC isotherms in non severe thunderstorms. Few studies have investigated the electrical structure of winter storms [Brook et al. 1982] but the previous feature of the negative charge region seems to be similar.

The Gaisberg tower was instrumented for measuring lightning currents [Diendorfer et al., 2006]. It is located on a 1250 m hill near the city of Salzburg (Austria) and has a height of 100 m. Recently Diendorfer et al. [2006] analyzed the lightning events at the Gaisberg tower during a winter thunderstorm. This winter thunderstorm exhibited some features similar to those of winter storms in the coastal area of Japan [Brook et al. 1982].

This paper presents the analysis of the lightning activity at the Gaisberg tower with the aim to study the possible relation between lightning activity and isotherms altitudes in summer and winter thunderstorms. The analysis is focused on the improvement of knowledge about the favourable conditions for lightning triggering by tall towers. Applications in understanding of lightning inception and lightning protection are discussed.

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2. DATA

The Gaisberg tower is instrumented with a current shunt located at the top of the tower which provides the entire current waveform of each flash. Several papers presented the statistics of the lightning currents recorded on this tower [Diendorfer et al., 2006]. For the present study a total of 309 flashes recorded from January 2000 to April 2006 are analyzed. In other hand, the altitudes of the isotherms of each thunderstorm day are obtained from soundings made twice a day. Cloud-to-ground (CG) lightning activity over Austria is obtained from the Austrian Lightning Detection and Information System (ALDIS) [i.e. Schulz et al., 2005].

3. ANALYSIS

The average annual CG lightning activity in Austria for the period 2000-2006 is displayed in Figure 1. This activity is very low during the winter season (December to February) while it reaches a maximum of 34 % in July. On the contrary, the tower is more often struck by flashes during winter since February and March display the highest percentages (Figure 1).

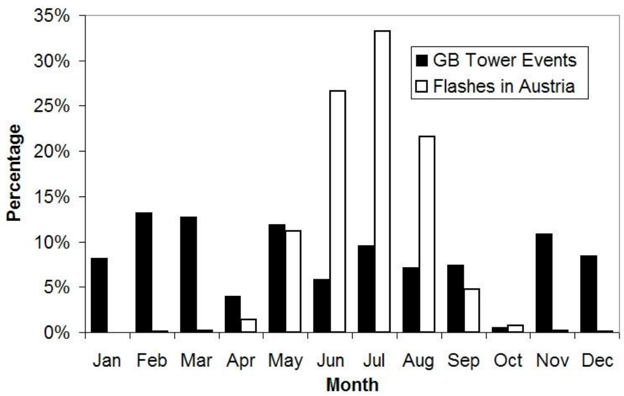

Figure 1. Average percentage of CG lightning activity per month in Austria and in the Gaisberg (GB) Tower.

The difference observed from the distributions in Figure 1 suggests investigating the specific characteristics of summer and winter thunderstorms. The average number of CG flashes on the tower per thunderstorm is 2.7 and 3.7 during summer and winter, respectively. Regarding the electrical parameters, the majority of the CG flashes derive negative charge to ground. Considering only negative flashes, the average total charge per flash is 48.6 C and 67.6 C in summer and in winter, respectively. Thus, the total electrical charge per CG flash is approximately 1.4 times greater in winter than in summer.

By analyzing the available data of radio soundings, the mean altitude of the -10 ºC isotherm is 4.6 km and 2.8 km for summer and winter season, respectively. In the same way, the mean altitude for the -20 ºC isotherm is 6 km and 4.2 km for summer and winter, respectively. As the negative charge is assumed to reside between -10 ºC and -20 ºC isotherms, the difference of both isotherm altitudes has been computed and found equal to 1.5 km. Table 1 gives the summary of the described results.

Table 1. Differences between summer and winter characteristics of CG lightning flashes and isotherms. Values in parenthesis correspond to median values

	Summer	**Winter**
Total number of CG flashes	97	212
Mean number of flashes per thunderstorm	2.7	3.7
Mean value of charge transferred to ground per flash (C)	48.6 (32.4)	67.6 (42.5)
Mean altitude of the -10ºC isotherm (km)	4.6 (4.9)	2.8 (2.9)
Mean altitude of the -20ºC isotherm (km)	6.0 (6.4)	4.2 (4.4)
Mean thickness -20 ºC / -10 ºC layer (km)	1.4 (1.5)	1.5 (1.4)

4. DISCUSSION

According to high voltage tests in laboratory, such as plate-point breakdown, it seems evident that during winter, the distance between the charged region of the cloud (plate) and the tower (point) is much lower than in summer. It could suggest that in winter a positive leader forms more easily from the tip of the tower. The propagation of positive streamers and leaders in high-voltage test for air gap breakdown requires lower electric field than negative ones [Les Renardières Group, 1977].

Based on laboratory and on field experiences, Lalande [1996] proposed the concept of stabilization field E_s which is the 'background' electrostatic field that is required for the upward leader propagation:

$$E_S = \frac{210}{\left(1+\frac{h}{10}\right)} + 10.7 \qquad (1)$$

where E_s is the stabilization field in kV m^{-1} and h is the tower altitude in m. In the case of the Gaisberg tower (100 m) the stabilization field E_s at an altitude of approximately 1250 m corresponds to 29.8 kV/m.

In order to analyze the background electric field and the electric field enhancement at the tower's tip region, electrostatic field simulations have been done. The electric field distribution between cloud and ground is obtained by the finite element method [i.e. Jackson, 1999] according to the cloud charge geometry displayed in Figure 2. The positive and negative charge regions are represented by ellipsoids (Figure 3) centred at the altitudes of Table 1. Simulations are performed for several charge densities ranging form 0.2 to 3 nC m^{-3}. These values agree with those estimated by Marshall and Stolzenburg [1998]. The model does not take into account the space charge between the cloud and the ground. The tower is represented by a vertical line of 100 m over the mount Gaisberg modelled as a semi-ellipsoid shape (Figure 3), both at ground potential.

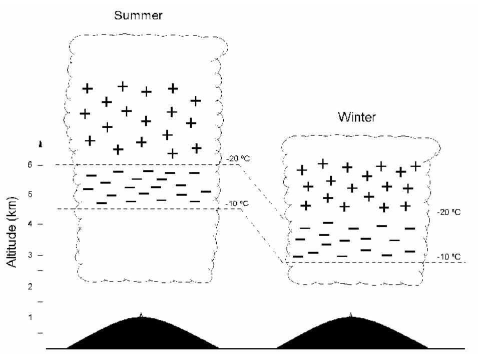

Figure 2. Summer and winter representations of the cloud charge distribution over the Gaisberg tower.

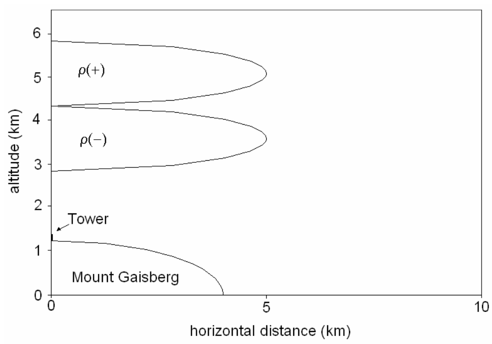

Figure 3. Geometry used for electrostatic simulations (case of winter).

The electric field distribution along the vertical axis of the tower is obtained in order to compare with E_s (equation (1)). The electric field from 10 m above the tower tip to an altitude of 2800 m is displayed in Figure 4: curves *a* and *b* correspond to winter cloud structures with 3 and 0.2 nC m^{-3} charge densities, respectively, and curves *c*, *d* and *e* correspond to summer cloud structures with 3, 2 and 0.2 nC m^{-3} charge densities, respectively. The results clearly indicate that the electric fields are stronger in winter than in summer. According to case *d*, 2 nC m^{-3} is the minimum value that produces electric fields larger than E_s for a positive upward leader propagation. In the case of a winter cloud structure, this minimum value is 0.94 nC m^{-3}. Marshall and Stolzenburg [1998] found that the cloud charge densities were typically less than 2 nC m^{-3}. Our calculations show that this value is the minimum required for upward lightning triggering in summer thunderstorms.

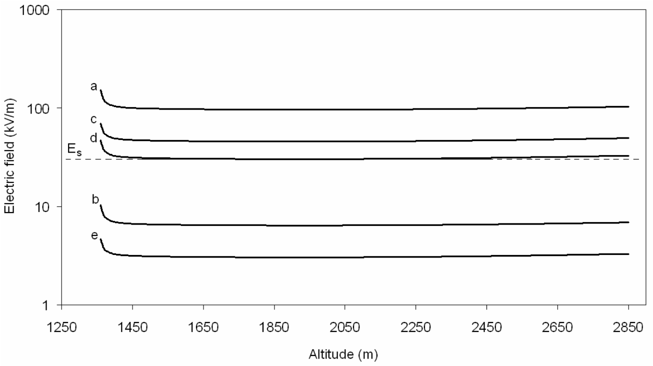

Figure 4. Electric field along the vertical axis of the tower. *a* and *b* correspond to winter cloud structure with 3 and 0.2 nC m^{-3} cloud charge densities, respectively. *c, d* and *e* correspond to summer cloud structure with 3, 2 and 0.2 nC m^{-3} cloud charge densities, respectively. E_s is the stabilization electric field.

4. CONCLUSION

The paper presents the characteristics of lightning activity and striking frequency at the Gaisberg tower in winter and summer. The lightning activity is low in Austria during winter however, the tower is more often struck than in summer. Furthermore the average charge carried to the tower by a CG flash is larger in winter. Most of winter CG flashes on the tower are upward-leader type while summer ones are most of time downward-leader type. It suggests that winter thunderstorms produce electric fields more favorable for upward lightning triggering. This assumption has been investigated by calculations of electrostatic field produced by charge structures at altitudes determined from isotherms observations in winter and summer. The field values obtained close to the tip of the tower can confirm better conditions for upward leader triggering. The weak occurrence of downward CG flashes in winter could be explained with the reduction of the Low Positive Charge Center (LPCC) in the winter thunderclouds because of colder temperatures at the cloud base. As a matter of fact, the LPCC, produced by the non inductive charging mechanism at temperature higher than -10°C, could play an important role in the triggering of negative CG downward lightning [Simpson and Scrase, 1937; Williams, 1989; Murphy et al., 1996].

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