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An analysis of the initiation of upward flashes from tall towers with particular reference to Gaisberg and Säntis Towers

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ABSTRACT

In this paper, we present an analysis of the lightning events preceding initiation of upward lightning flashes from the Gaisberg and the Säntis Towers. It is found that the majority of upward lightning discharges from both towers are initiated without any preceding lightning activity. We show also that the results of the presented studies on the initiation of upward flashes from tall structures might be affected by the selected parameters of the study, namely the time and distance intervals used to identify the triggering events. Preceding events had the same polarity as triggered flashes in the case of the Säntis Tower and had opposite polarities in the case of the Gaisberg Tower. The effect of seasonal and temperature variations have been also analyzed.

1. Introduction

Understanding the mechanisms of initiation of upward lightning flashes is an important issue in lightning research. It has been suggested in early studies (e.g., Berger et al., 1975; McEachron, 1939) that upward flashes originated from tall towers could be actually initiated by preceding lightning activity in the surrounding area. Recently, the interest in understanding the mechanism of the initiation of upward flashes has increased, essentially because of the continuous growth in the number of tall structures, such as wind turbines. On the other hand, the dramatic improvement of the lightning research equipment, including instrumented towers for direct lightning current measurements, video observations, and large-scale availability of data from lightning location systems (LLS) has made it possible to gather valuable experimental data.

Several studies on this topic have been performed at various locations around the world (Heidler et al., 2014; Manhardt et al., 2012; Smorgonskiy et al., 2014; Wang and Takagi, 2012; Warner et al., 2012; Zhou et al., 2012), with sometimes contradictory conclusions. In some cases, upward lightning discharges from tall structures were found to be initiated without any preceding lightning activity, while in other cases, preceding events seem to play a significant role in their initiation. In the literature, the latter are referred to as 'other-triggered' or 'nearby-lightning-triggered' flashes, while the former are called 'self-triggered' or 'self-initiated' flashes. In other words, the word triggered (or initiated) is used in the literature and in this paper to refer to the relation between flashes initiated on tall objects and other lightning activity that precedes them within given spatial and temporal limits. It is important to note, however, that the causality implied by the word triggered has not been established at this time. Very recently, (Rubinstein et al., 2015) used a probabilistic model to show that it is possible to explain at least some of the lightning activity prior to tower flashes as being the result of chance.

In this paper, which is an extended version of (Smorgonskiy et al., 2014), we present further analyses and comparisons aiming at better understanding the underlying mechanisms of the initiation of upward flashes from tall structures, with particular reference to the data obtained at two instrumented towers: the Gaisberg Tower in Austria (Diendorfer et al., 2009) and the Säntis Tower in Switzerland (Romero et al., 2012).

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2. Previous studies

2.1. Uchinada, Japan

The objects of this study were a wind turbine and its lightning protection tower with heights of 100 and 105 m, respectively, and separated by a distance of 45 m. Both of them are located on a hill of 40 m above the sea level. Lightning strikes to the wind turbine and the protection tower were recorded during 6 winter seasons. Lightning currents were measured at the bottom of both structures using Rogowski coils. Electric fields were measured using a field mill as well as slow and fast capacitive antennas. This research was initially focused on studying the reduction of lightning incidence to the wind turbine due to the protection tower, but further analysis of the data allowed observing different mechanisms of upward lightning initiation (Wang and Takagi, 2012). Half of the upward flashes (actually, initiated from both the wind turbine and the tower) were self-initiated, whereas the other half were preceded by lightning activity ('other-triggered' or 'nearby-lightning-triggered'). No classification of the triggering events was given in the published study.

2.2. Rapid City, USA

Observations made at Rapid City were focused on upward lightning discharges from ten towers with heights varying from 91 to 191 m, located on a ridge of 180 m above the surrounding terrain. The towers are distributed over a distance of 8 km on a line stretched from North to South. The presence of so many towers within a relatively small area and the fact that multiple simultaneous upward flashes from different towers were observed, makes this location unique among the other studies and should be taken into consideration when comparing the observed results.

Two methods were used in (Warner et al., 2012) to distinguish self-initiated and other-triggered upward flashes. The first one was based on the data from the US National Lightning Detection Network (NLDN) within a circle of 200 km radius centered on the towers. It was found that the majority (83%) of upward flashes were preceded by nearby lightning activity. To overcome the limitations of NLDN in detecting all the flashes (Cummins and Murphy, 2009), optical observations were also used. These revealed that the percentage of the upward flashes preceded by nearby lightning activity was even higher (99%).

2.3. Peissenberg Tower, Germany

The Peissenberg Tower (160-m tall) used in this study is located on the mountain 'Hoher Peissenberg' in the South of Germany. The tower is instrumented for lightning current measurements (Manhardt et al., 2012). The altitude above mean sea level is about 940 m. The electric field was measured at a distance of about 190 m away from the tower. Unlike the observations made in Rapid City, 90% of the 41 analyzed upward flashes were found to be 'self-initiated'.

2.4. Gaisberg Tower, Austria

The 100-m tall Gaisberg Tower is located on a 1287-m high mountain. The tower has been the object of two separate studies on lightning events preceding upward flashes from the tower. The first study (Zhou et al., 2012) was based on a combination of the electric field variations measured at a distance of 170 m from the tower and observations from the EUCLID lightning detection network (Schulz et al., 2005). In contrast with the Rapid City study and in agreement with Peissenberg, most upward flashes from the Gaisberg Tower (87%) were not preceded by any nearby lightning activity. Positive cloud-to-ground (+CG) strokes were the most frequent triggering event, in agreement with the previous study.

3. Procedure used in this study

In this study, we focus on upward flashes from two towers: the Gaisberg Tower in Austria (Diendorfer et al., 2009) and the Säntis Tower in Switzerland (Romero et al., 2012). The Säntis Tower is characterized by a height of 124 m and it is located on the top of Mount Säntis (2502 m high above sea level). Such high altitude is a unique characteristic among other considered tall structures.

The analysis method which was adopted in the present study is as follows:

1. A list of lightning flashes directly measured at the tower (either Gaisberg or Säntis) and an extract from the European Lightning Detection Network EUCLID database with lightning strokes preceding each flash from the tower were merged together.
2. A circle of a given radius around the tower and a maximum time interval between preceding lightning events and observed upward flashes are selected.
3. Upward flashes without preceding lightning events observed within the limits specified in step 2 are categorized as 'self-initiated'. Other upward flashes are labeled as 'other-triggered' and are further classified depending on the polarity and type of the preceding lightning event. Two types of lightning events are reported by EUCLID and are used in this study: cloud-to-ground (CG) and intracloud (IC) lightning discharges.

4. Results and analysis

In Section 2 and Table 1, a brief comparison of the percentage of upward flashes with preceding lightning events was presented. A significant difference was observed between the locations in

Table 1
Comparison of the ratio of self-initiated and other-triggered flashes observed at different locations.

Location	Uchinada, Japan	Rapid City, USA		Peissenberg, Germany	Gaisberg, Austria		Säntis, Switzerland
Tower height, m	100, 105	91 to 191		160	100		124
Location altitude, m	40	1165–1340		940	1287		2502
Study period	2005–2010 (winter)	2004–2010 (Apr–Sept)		1996–1999 (all year)	2005–2009 (all year)	2000–2013 (all year)	2011–2012 (all year)
Method	Electric field	NLDN	Optic	Electric field	Electric field	EUCLID	EUCLID
Total upward flashes	53	81	81	41	205	759	326
Other-triggered	25 (47%)	67 (83%)	80 (99%)	4 (10%)	26 (13%)	121 (16%)	48 (15%)
Self-initiated	28 (53%)	14 (17%)	1 (1%)	37 (90%)	179 (87%)	638 (84%)	278 (85%)
Reference	Wang and Takagi (2012)	Warner et al. (2012)		Heidler et al. (2014) and Manhardt et al. (2012)	Zhou et al. (2012)	Smorgonskiy et al. (2014)	Smorgonskiy et al. (2014)