Analysis of Lightning Events Preceding Upward Flashes from Gaisberg and Säntis Towers

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***Abstract*—In this paper, we present an analysis of the initiation of upward lightning flashes for the Gaisberg and the Säntis Towers. The results are compared with previous studies. 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.**

Keywords-upward lightning; downward lightning; self-initiated lightning; other-triggered lightning; Gaisberg Tower; Säntis Tower

I. Introduction

Understanding the mechanisms of initiation of upward lightning flashes is an important issue in lightning research. Previous observations show that in some cases upward lightning discharges from tall structures are initiated without any preceding lightning activity [1], while in other cases [2] preceding events seem to play a significant role in their initiation.

In this paper, we present further analysis and comparisons aiming at better understanding the underlying mechanisms of the initiation of upward flashes from tall structures.

II. Previous Studies

Three recent studies have analyzed upward flashes from tall structures and their correlation with lightning events preceding them [1-3]. The classifications of the flashes in these studies, along with the classifications of the present study, are summarized in Table 1. Some details about each of the previous studies are presented in the following subsections.

A. Uchinada-chou, Japan [3]

Lightning strikes to a wind turbine and its lightning 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.

Half of the upward flashes were self-initiated, while 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.

B. Rapid City, USA [1]

Upward lightning discharges from ten towers (91–191 m) were recorded during seven convective seasons. US National Lightning Detection Network (NLDN) data within a range of 200 km radius centered around the towers were combined with GPS-time-stamped optical observations. Only lightning strokes detected by the NLDN in a time window of 5 seconds starting from 2 s prior to the initiation of upward flashes were considered in their analysis.

Optical observations revealed that in 99% of the cases, nearby lightning activity preceded the initiation of the upward lightning. Some of the preceding events were also detected by the NLDN. Positive cloud-to-ground (+CG) lightning was found to be a major triggering event for upward flash initiation.

C. Gaisberg, Austria [2]

The 100-m tall Gaisberg tower is equipped at its top with a shunt for the measurement of lightning currents. Electric fields are also measured using a flat plate antenna at a distance of 170 m from the tower. Lightning return strokes detected by the EUCLID lightning detection network within a range of 20 km from the tower 5 s prior to the initiation of upward flashes were used in the study.

In contrast with the Rapid City study, most upward flashes from the Gaisberg tower (87%) were not preceded by any nearby lightning activity. Among the nearby-lightning-triggering events, +CG was the most frequent triggering event, similarly to the previous study.

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TABLE 1. COMPARISON OF THE SELF-INITIATED AND OTHER-TRIGGERED FLASHES OBSERVED AT DIFFERENT LOCATIONS

Location	Uchinada-chou (JP)	Rapid City (USA)		Gaisberg (AT)	Gaisberg (AT)	Säntis (CH)
Reference	[3]	[1]		[2]	This study	
Study period	2005-2010 (winter)	2004-2010 (Apr-Sept)	2004-2010 (Apr-Sept)	2005-2009 (all year)	2000-2013 (all year)	2011-2012 (all year)
Method of study		NLDN	Optic	Electric field	EUCLID	EUCLID
Radius of observation circle		200 km	200 km	20 km	50 km	50 km
Duration of observation interval		2 s	2 s	5 s	2 s	2 s
Total upward flashes (100%)	**53**	**81**	**81**	**205**	**759**	**326**
Other-triggered upward flashes	**25** (47%)	**67** (83%)	**80** (99%)	**26** (13%)	**121** (16%)	**48** (15%)
triggered by a + CG		46	54	15	72	1
triggered by a – CG		0	0	1	29	17
triggered by a + IC		19	11	10	12	3
triggered by a – IC		2	2		3	25
unknown			13		5	2
Self-initiated upward flashes	**28** (53%)	**14** (17%)	**1** (1%)	**179** (87%)	**638** (84%)	**278** (85%)

III. DATA AND PROCEDURE USED IN THIS STUDY

In this study, we focus on upward flashes from two towers: the Säntis Tower in Switzerland [4] and the Gaisberg Tower in Austria [2]. The analysis method (identical for both towers) is as follows:

1. A list of lightning flashes directly measured at the tower and an extract from the 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 (CG or IC) of the preceding lightning event.

The results of our study for the Gaisberg and the Säntis towers are presented in the last two columns (highlighted) in Table 1. Unlike Rapid City, it can be seen that the majority of upward lightning discharges from the Gaisberg and the Säntis Towers (84% and 85%, respectively) are initiated without any preceding lightning activity. Interestingly, while upward flashes from the Gaisberg Tower were mostly triggered[1] by positive lightning events, flashes from the Säntis Tower were mostly preceded by negative lightning events.

TABLE 2. COMPARISON OF THE POLARITIES OF TRIGGERING EVENTS AND ASSOCIATED TRIGGERED UPWARD FLASHES AT THE SÄNTIS AND GAISBERG TOWERS.

Tower	Triggering events		Triggered upward flashes	
Säntis, 2011-2012	1	+ CG	1	positive
	17	– CG	16	negative
			1	positive
	3	+ IC	1	positive
			2	bipolar
	25	– IC	25	negative
Gaisberg, 2005-2009	15	+ CG	15	negative
	1	– CG	1	positive
	10	IC	8	negative
			1	positive
			1	bipolar

Another major difference between the towers was observed when the polarities of the preceding lightning events and the

[1] The word triggered is generally used in the literature and in this paper to refer to the relation between flashes and other lightning activity that precedes them within given spatial and temporal limits. Note, however, that the causality implied by the word triggered has not been established at this time.

triggered upward flashes were analyzed. As can be seen from Table 2, negative upward flashes from the Säntis Tower were triggered by negative CG or negative IC flashes, while positive and bipolar flashes were triggered by preceding positive flashes. Conversely, upward flashes from the Gaisberg Tower were triggered by preceding events of opposite polarity.

The reasons for these differences are currently unknown. A more detailed analysis over a more extended time period should be carried out to clarify this issue.

IV. Practical Issues

Some practical issues can arise when applying the general procedure used in this study or similar methodologies used in previous studies for the analysis of initiation of upward flashes from tall structures. Some of these issues can be handled by applying common rules. They are briefly described in what follows.

A. Time window and distance to the tower

When correlating the occurrence of upward lightning flashes on a tower with preceding lightning strokes or flashes from a lightning location system database, the time window and distance to the tower should be limited. As it was mentioned in Section II.B, the study in Rapid City used a circle of 200 km radius while, in the Gaisberg study, the circle's radius was 10 times smaller. On the other hand, the time interval was smaller in the Gaisberg study.

Clearly, by increasing the time and distance intervals, it is more likely to find a preceding lightning event. The resulting ratio of self-initiated to other-triggered upward flashes will therefore be affected by the choice of these two parameters. We have illustrated this effect for the Gaisberg Tower in Table 3, in which the variation of the percentage of other-triggered upward flashes is calculated based on the choice of different time intervals and circle radii.

Table 3. Percentage of other-triggered upward flashes for the Gaisberg Tower as a function of time window and distance (circle radius)

Circle radius, km	Maximum time interval between preceding lightning event and triggered upward flash				
	1 ms	10 ms	0.1 s	1 s	2 s
1	0%	0%	0%	0%	0%
5	1%	1%	1%	1%	1%
10	1%	2%	4%	4%	4%
20	2%	4%	8%	10%	11%
50	3%	5%	12%	16%	16%
100	3%	5%	12%	17%	17%
200	3%	6%	12%	18%	19%
500	3%	6%	13%	21%	24%
1000	3%	6%	15%	25%	29%

From Table 3, it can be seen that the rate of growth of the percentage of upward flashes reduces significantly when considering circles greater than 50 km and time intervals longer than 1 s.

The result shown in Table 1 for the Gaisberg Tower represents the case when the values were 50 km for the circle radius and 2 s for the time interval.

B. Sequence of preceding lightning events

Some rare upward flashes from the towers were preceded by a series of lightning events, where it was not evident which preceding stroke to consider as a triggering event. When it was not possible to differentiate the sequence of lightning events, the unknown category was assigned to such cases reported in Table 1.

C. Limited Detection Efficiency of LLS for IC discharges

LLS have limited capabilities to detect IC discharges of small peak fields and detection efficiency may depend on the orientation of the IC (mostly vertical similar to CG, or mostly horizontal).

V. Conclusions

We presented an analysis of the initiation of upward lightning flashes for the Gaisberg and the Säntis Towers solely based on the data from the EUCLID lightning location system. We have updated the study for the Gaisberg Tower, with an increased observation period of 14 years. The proportion of self-initiated and other-triggered flashes for the Gaisberg Tower remained almost unchanged with respect to the previous study, which was carried out over an observation period of 5 years. We presented a similar study for the Säntis Tower, for which we obtained a behavior analogous to that of the Gaisberg Tower, namely that the majority of upward lightning discharges from both towers are initiated without any preceding lightning activity. The observations at the Gaisberg and the Säntis Towers differ greatly from the Rapid City study in which most of the flashes were preceded by nearby lightning activity.

The study revealed two major differences between the data obtained at the Gaisberg and the Säntis Towers concerning flashes with preceding lightning activity: (1) Upward flashes from the Gaisberg Tower were mostly triggered by positive lightning events, while flashes from the Säntis Tower were mostly preceded by negative flashes, (2) 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.

We showed 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 and the performance of the LLS to detect IC discharges. Although our results do not enable us to propose optimum values for the radius and the time interval, we recommended to use a time interval of at least 1 s and an area around the tower of at least 50 km radius.

References

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