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Self-initiated versus Nearby-lightning-triggered Upward Flashes at the Gaisberg Tower (2005 - 2015)

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Abstract **- Upward lightning initiated from tall objects is classified in two distinct groups. Self-initiated lightning occurs when the slow charge buildup produced by cloud electrification is sufficient to start the upward propagating leader. Nearby-lightning-triggered flashes are initiated by the rapid field changed caused by nearby lightning activity, either to ground or inter-cloud. In this paper we analyzed 307 upward flashes initiated from the Gaisberg Tower in Austria and based on measured electric fields at close distance to the tower 80 % were classified as self-initiated and 20 % as nearby-lightning-triggered. Some storms produced exclusively one type of discharges. In case of self-initiated lightning the median height of the -10°C isotherm was in the range of 3000 m, whereas in case of nearby-lightning-triggered lightning the isotherm was at a height of 4800 m.**

Keywords—upward lightning, self-initiated, nearby-lighting-triggered, lightning current, near field

I. INTRODUCTION

The classification of upward initiated lightning in two different types, called self- and other-triggered, was first introduced by [*Wang et al.*, 2008]. [*Zhou et al.*, 2012] suggested using the terms “self-initiated” flashes and “nearby-lightning-triggered” flashes to classify these same two types of upward flashes from tall towers in order to emphasize more the physical processes, which do not involve any triggering event in the first case of self-initiated flashes. We will also use the terms “self-initiated” and “nearby-lightning-triggered” flashes throughout this paper.

The question of whether initiation of upward lightning is caused by rapid field changes from nearby, preceding flashes or from the slower charge buildup produced by cloud electrification has been raised already by [*Berger*, 1967]. Even though this question was raised five decades ago, the initiation criteria and conditions needed to produce upward lightning are still an issue that has yet to be fully investigated and explained.

[*Wang and Takagi*, 2012] reported on 53 upward flashes from a windmill and its protection tower. 47% of the upward flashes were self-initiated and 53% were nearby-lightning-triggered. They also noted that some storms produced exclusively self-initiated upward lightning while others produced only nearby-lightning-triggered upward flashes.

[*Warner et al.*, 2012] reported on 81 upward flashes from towers in Rapid City, USA, Observations were made during the summer convective seasons 2004–2010, and in all but one case, visible flash activity preceded the development of the upward leaders and majority of the upward lightning flashes were triggered by a preceding flash with the dominant triggering type being the positive cloud-to-ground (+CG) flash.

[*Jiang et al.*, 2014] analyzed upward flashes from a 325 m tall meteorology tower and among eight upward lightning flashes documented during two thunderstorms, four were self-initiated events without nearby lightning activity prior to their initiation, two were triggered by the nearby +CG, and the remaining two were triggered by nearby intra-cloud lightning activities.

Analyses of 172 video recordings of lightning discharges on rotating wind turbines in Japan by [*Vogel et al.*, 2017] resulted in 75 % of upward lightning flashes marked as self-initiated and 25 % as nearby-lightning-triggered. The attachment angle of nearby-lightning-triggered discharges were scattered throughout the circumference from 90° to 270°. Self-initiated discharges were most frequently observed to start at vertical blade alignment.

II. DATA

A first evaluation of the recorded flashes to the Gaisberg Tower (GBT) in terms of self-initiated versus nearby-lightning-triggered discharges was performed by [*Zhou et al.*, 2012] for the period 2005-2009. In [*Zhou et al.*, 2012] we can find a comprehensive description of the current and field recording system installed at the GBT site and the performance of the lightning location system ALDIS.

In this paper we have extended the period of investigation to the period 2005 – 2015, where currents for a total of 508 flashes were recorded at the GBT. For 307 of those flashes fast electric field records from a flat plate antenna (decay time constant 0.5 ms) at close distance (170 m) are available and these field records allow classifying them as either self-initiated or nearby-lightning-triggered discharges.

Examples of a nearby-lightning-triggered and a self-initiated flash are shown in Fig.2 and Fig.3, respectively. Red line in those two figures indicates the current measured at the tower top and blue line indicates the vertical electric fast field at a distance of 170 m. Starting time of the current flow (trigger-time of the current measuring system) is marked by the vertical dashed red line. Fig.2 shows obvious changes in the electric field starting about 40 ms prior to the beginning of the flow of lightning current at the top of the tower. It is assumed that any transient field change observed prior to the beginning of current flow at the tower top is resulting from lightning activity nearby the tower site, either from CG or IC lightning, and hence this is classified as nearby-lightning-triggered. In some of those cases we could find nearby lightning events located by ALDIS, the operated lightning location system (LLS) in Austria.

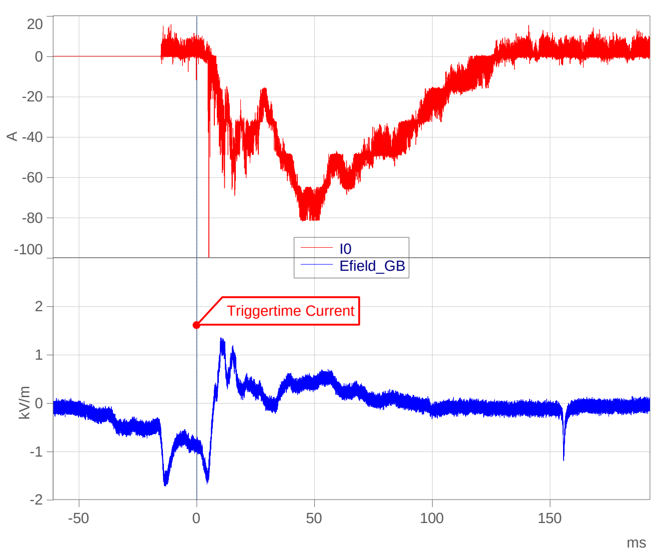

Fig. 1. Example of a nearby-lightning-triggered upward flash from Gaisberg Tower (#862).

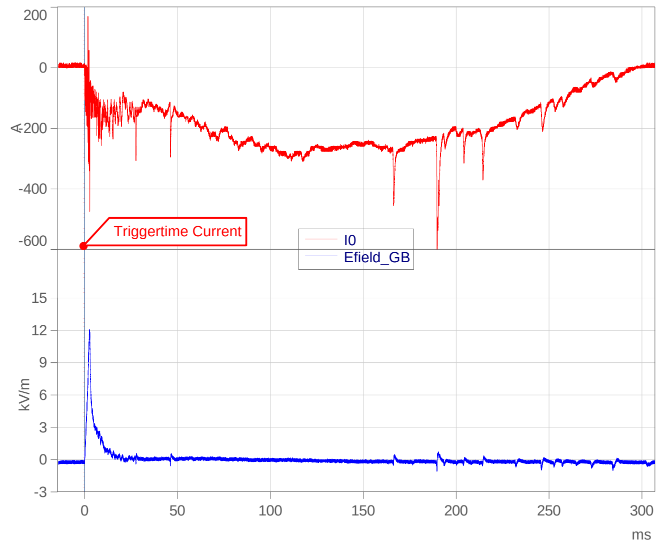

Fig. 2. Example of a self-initiated upward flash from Gaisberg Tower (#875)

III. RESULTS

Overall 80 % (N=247) of the 307 flashes were classified as self-initiated and 20 % (N=60) were classified as nearby-lightning-triggered. Seasonal occurrence of the two types of discharges is given in TABLE I. Non-convective season in the Salzburg area lasts from about September to March.

TABLE I. SEASONAL OCCURRENCE OF SELF-INITIATED AND NEARBY-LIGHTNING-TRIGGERED UPWARD FLASHES

	Non-convective Season (Sep-Mar)	**Convective Season (Apr-Aug)**	**Total**
Self-initiated	180 (58 %)	67 (22 %)	**247 (80 %)**
Nearby-lightning-triggered	7 (3 %)	53 (17 %)	**60 (20 %)**
Total	**187 (61 %)**	**120 (39%)**	**307 (100 %)**

A. Self-initiated flashes

The main characteristics of a self-initiated upward flash is that lightning current and electric near field, measured at a distance of 170 m from the tower, exhibit a simultaneous opposite polarity change, no measured field change is observed in the field record, and no nearby stroke is detected by the LLS prior to the initiation of current flow at the tower top. 180 out of the 247 (73%) self-initiated flashes occurred during non-convective season.

Regarding the polarity of the lightning current measured at the GBT, these 247 flashes consisted of 227 (92 %) negative, 10 (4 %) positive, and 10 (4%) bipolar upward flashes. Seasonal occurrence of the different polarities is summarized in TABLE II.

TABLE II. SEASONAL OCCURRENCE OF DIFFERENT TYPE OF POLARITIES FOR TOTAL OF 247 SELF-INITIATED UPWARD FLASHES

Polarity	*Non-convective Season*	*Convective Season*	*Total*
Negative	168 (68 %)	59 (24 %)	227 (92 %)
Positive	5 (2 %)	5 (2 %)	10 (4 %)
Bipolar	7 (3 %)	3 (1 %)	10 (4 %)
Total	**180 (73 %)**	**67 (27 %)**	**247 (100 %)**

B. Nearby-lightning-triggered flashes

In case of the 60 nearby-lightning-triggered flashes (out of the total of 307 or 20%), an electric field change is observed just prior to the initiation of the leader current at the top of the GBT. 53/60 (88%) of nearby-lightning-triggered flashes occurred during convective season and 7/60 (12 %) during non-convective season.

29/60 (48%) of the nearby-lightning-triggered flashes were triggered by nearby CG discharges, when a maximum distance of 20 km was allowed in the LLS database request. Assuming a CG flash detection efficiency (DE) of the LLS close to 100 %, we conclude that the remaining 52 % of nearby-lightning-triggered flashes were triggered by intra-cloud lightning activity. Especially in the years before 2010 the LLS did not detect any significant fraction of IC discharges and therefore we cannot confirm occurrence of any IC by time and spatial correlated LLS detections when a field change is observed prior to the beginning of current flow.

For time correlated LLS located CG events a histogram of the obtained distances between the GBT and the LLS located triggering CG events is given in Fig. 3.

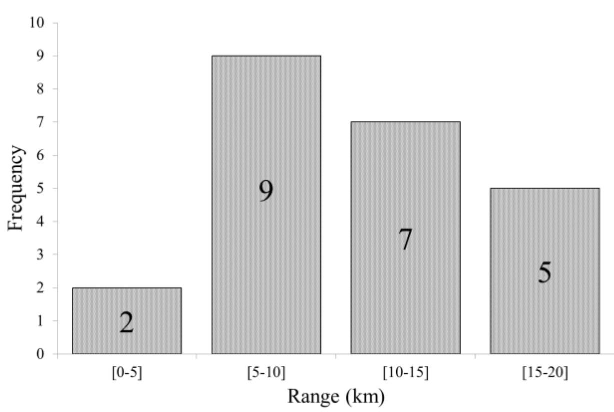

Fig. 3. Histogram of distance of LLS located triggering CG flashes from the Gaisberg Tower

Finding a time correlated event within a distance of 20 km does not necessarily proof the triggering effect of this event. [*Rubinstein et al.*, 2016] have used a simple probability model to estimate the percentage of lightning flashes that would be classified as nearby-lightning-triggered if they occurred by chance in the vicinity of a tower and within a specified time interval before the upward flash to the tower.

It is interesting to note that often the same type of discharge (self-initiated or nearby-lightning-triggered) is observed when more than one flash is recorded at the GBT during a single storm situation (during one day). The 307 flashes analyzed in this paper occurred on 98 different days. On 38 days only one flash was available for the self-initiated versus nearby-lightning-triggered classification. On 6 out of these 38 days more than one flash were recorded at the GBT, but missing E-field records did not allow performing the classification. On 51 out of the 61 (84%) days with more than one flash available for classification all flashes on those days were of the same type. Only on 17% (10/61) of the days with more than one flash a mix of self-initiated and nearby-lightning-triggered flashes was observed. This is in agreement with the observation by [*Wang and Takagi*, 2012] that some storms produced exclusively self-initiated upward lightning while others produced only nearby-lightning-triggered upward flashes.

We have also looked at the height of -10°C isotherm in case of self-initiated and nearby-lightning-triggered flashes. Isotherm heights at the days, when flashes were recorded at the GBT were obtained from radio soundings data from the station in Munich, the closest station to the GBT, where a balloon with a radiosonde is launched every day at 00:00 UTC and 12:00 UTC. The altitude of the -10° C isotherm was determined from the last sounding available before (pre-flash isotherm) and the first sounding available after the event (post-flash isotherm), respectively [*Schulz and Diendorfer*, 2016].

Results of the median height of -10°C isotherm before and after the discharges to the GBT for the two classes of discharges are summarized in TABLE III.

TABLE III. MEDIAN HEIGHT OF -10°C ISOTHERM

	Self-initiated	**Nearby-lightning-triggered**
Pre-flash isotherm	3000 m (N=216)	4800 (N=71)
Post-flash isotherm	2700 m (N=208)	4300 (N=69)

IV. DISCUSSION

The results of the analysis presented in this paper indicate a significant seasonal dependency of the occurrence rate of self-initiated and nearby-lightning-triggered discharges with 73% (180/247) of self-initiated flashes occurring during non-convective season. On the other hand only 12 % (7/60) of the nearby-lightning-trigged flashes have been recorded during non-convective season. There is also a difference in the median height of -10° isotherm for self-initiated (3000 m) and nearby-lightning-triggered flashes (4800 m). This might explain why observed occurrence rate of self-initiated upward lightning is quite different at different sites around the globe.

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