Upward Positive Lightning Flashes Observed from the Gaisberg Tower from 2000 to 2009

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Abstract: In this paper, we report the measured current characteristics of positive lightning discharges observed from the Gaisberg Tower (GBT) in Austria from 2000 to 2009. Based on the recorded current waveforms, a total of 26 flashes were identified as upward positive discharges initiated by an upward negative leader from the top of the GBT, consisting of initial stage current only, without any leader-return-stroke sequences. No downward positive flashes containing microsecond-scale current waveforms of return strokes were observed. The occurrence of upward positive flashes accounts for 4% (26/652) of the total number of recorded flashes at the GBT during the 10-year observation period. Nineteen (73%) out of the 26 flashes occurred during non-convective or cold season (September- March). Median values of flash peak current, flash duration, flash charge transfer, and flash action integral were determined as 5.2 kA, 82 ms, 58 C and 0.16×10^3 A^2s, respectively. Narrow current pulses of high repetition rate, different from normal initial continueous current (ICC) pulses typical for upward negative flashes, were found during the initial portion of the ICC for these upward positive flashes. Based on simultaneous current and electric field measurements at a distance of 170 m from the GBT these pulses are inferred to be associated with the stepping process of the upward propagating negative leaders initiated from the tower top.

Keywords: upward positive lightning, current parameters, measurement, tower

1. INTRODUCTION

Positive lightning discharges are thought to be associated with high peak current values (up to hundreds of kilo-Amperes) and large charge transfers (up to hundreds of coulombs) [1]. Depending on the propagation direction of the leader, positive lightning can be divided into upward positive lightning and downward positive lightning. Upward positive lightning involves upward negative leaders initiated from the top of tall structures, sometimes followed by positive downward-leader-return-stroke sequences, which are similar to subsequent return strokes in natural downward lightning. Berger and co-workers based on measured lightning current waveforms at two towers on Monte San Salvatore in Switzerland [2]-[3] were the researchers who first presented a comprehensive study of positive discharges including both upward positive and downward positive flashes. Even today, these data are still adopted as the main reference for the lightning protection standards. In this paper, we examine the measured current characteristics of positive lightning discharges observed from the Gaisberg Tower (GBT) in Austria from 2000 to 2009. Based on the recorded current waveforms, a total of 26 flashes were identified as upward positive discharges initiated by an upward negative leader from the top of the GBT. Median values of current parameters, such as flash peak current, flash duration, flash charge transfer for upward positive flashes are compared with Berger's data.

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2. INSTRUMENTATION

The lightning current waveforms were measured by a shunt resistor of 0.25 mΩ having a bandwidth of 0 Hz to 3.2 MHz installed at the base of the air terminal on the 100-m tall Gaisberg Tower (GBT), which is located on the top of the Gaisberg Mountain, Salzburg, Austria. Two separate fiber optic links (Nicolet ISOBE 3000, from DC to 15 MHz) associated with different sensitivities (±2 kA and ±40 kA) are used to transmit the electrical signal from the shunt resistor to our measuring system in the nearby house. The sampling rate is 20 MS/s, and the total record length is 800 ms with a 15 ms pre-trigger time.

A digital filter with an upper cut-off frequency of 250 kHz (Butterworth, 2nd order) and appropriate offset correction is applied to the current records before the lightning parameters (peak current, charge transfer, action integral, etc.) are determined. More details of the lightning measurement program at the GBT and the deployed instrumentation can be found in [4].

3. ANALYSIS AND DISCUSSION

3.1 OCCURRENCE CHARACTERISTICS OF UPWARD POSITIVE LIGHTNING TO THE GAISBERG TOWER

We examine the recorded current waveforms measured at the GBT in Austria from 2000 to 2009. Out of the 652 flashes in our database, a total of 26 flashes were identified as upward positive discharges, which are summarized in TABLE 1. The occurrence of upward positive flashes accounts for 4% (26/652) of the total recorded flashes at the GBT during the 10-year observation period. Interestingly, all the flashes consist of initial stage current only, no leader-return-stroke sequences followed. Three similar upward positive flashes were also observed at the Peissenberg tower in Germany [5]. No downward positive flashes containing microsecond-scale current waveforms were found. From TABLE 1 we can see that no positive flashes were observed in the years 2003 and 2008, and on the other hand several positive flashes occurred during a short period during one thunderstorm (e.g. 4 pos. flashes were recorded within 10 minutes on 2004-05-02). Nineteen (19/26 or 73%) out of the 26 flashes occurred during non-convective or cold season (September-March) in Austria.

TABLE 1 SUMMARY OF THE 26 UPWARD POSITIVE LIGHTNING FLASHES OBSERVED AT THE GAISBERG TOWER FROM 2000 TO 2009

Flash ID	Date	Time (UT)
98	2000-01-21	16:17:55.4574729
112	2000-01-21	16:25:28[a]
139	2000-03-04	23:00:15.2480720
161	2000-04-12	10:42:19.0715054
210	2000-11-08	02:50:03.9671365
214	2001-02-23	10:22:54.9612212
270	2001-12-06	07:05:25.1695024
288	2002-03-22	16:36:53.5718253
298	2002-03-23	14:46:08.6169805
329	2002-09-09	20:47:40.2342732
330	2002-09-09	20:50:50.3437178
380	2004-05-02	17:16:57.8878403
381	2004-05-02	17:19:47.5042114
382	2004-05-02	17:21:57.5650167
383	2004-05-02	17:25:08.6902511
446	2005-12-16	16:59:29.1319064
449	2005-12-16	23:10:19.6217119
450	2005-12-16	23:14:52.5009259
453	2006-01-18	14:38:09.6431093
468	2006-05-30	23:00:48.2231094
482	2006-08-04	15:32:30.4544864
499	2006-11-03	01:06:09.5324886
507	2006-11-04	02:13:47.7926678
540	2007-08-19	16:41:08.5856558
707	2009-01-18	19:43:18.6137976
770	2009-12-10	17:18:14.9598430

[a] GPS failure.

3.2 DEFINITION OF PARAMETERS

Fig. 1 shows the measured lightning current waveform of flash GBT #380 on low amplitude scale (± 2kA) to define the various current parameters used in this paper and described as follows: (1) The pulse peak current of the upward positive flash is the difference between the maximum current value of this flash and the no-current zero level. (2) The flash peak current of the upward positive flash is the difference between the maximum underlying slowly varying current value of this flash and the no-current zero level. (3) The flash duration of the upward positive flash is the time duration in which the flash current is essentially non-zero. (4) The charge transfer of the upward positive flash is the integral of current over the flash duration as seen in Fig. 1. (5) The action integral is the integral of the square of current over the flash duration as indicated in Fig. 1. It represents the specific energy dissipated by the lightning current in a 1 ohm resistor. If the peak current saturates at 2 kA, then the high amplitude current record is employed to determine the above parameters except the flash duration. For flash duration, we determine the end time of the flash by checking the low amplitude current record which has better resolution than that of high amplitude current record.

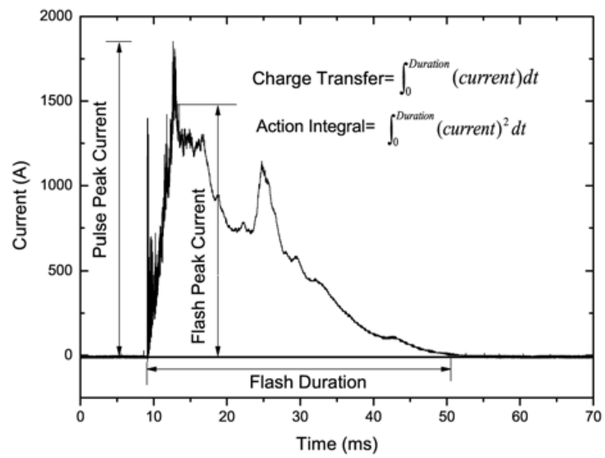

Fig. 1. Measured lightning current waveform (GBT # 380) illustrating the definitions of current parameters (pulse peak current, flash peak current, flash duration, charge transfer, and action integral) for upward positive lightning flashes.

3.3 CURRENT PARAMTERS FOR UPWARD POSITIVE LIGHTNING FLASHES MEASURED AT THE GAISBERG TOWER

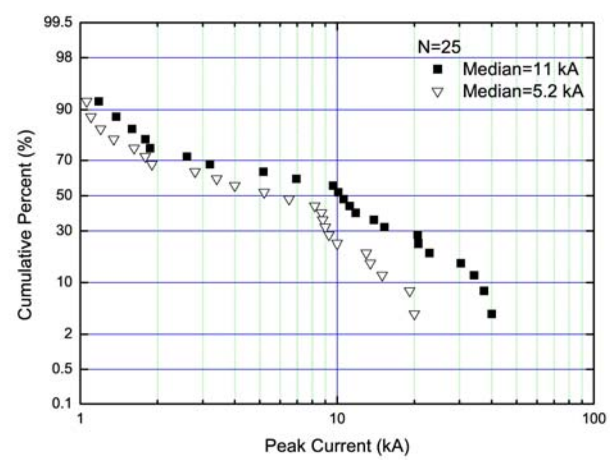

Fig. 2. Cumulative frequency distributions of pulse peak current (with squares) and flash peak current (with triangles) for upward positive flashes. The sample sizes (N) and median value (Median) are indicated in the figure.

Fig. 2 shows the cumulative frequency distributions of pulse peak current (with squares) and flash peak current (with triangles) for 25 upward positive flashes measured at the GBT. The flash GBT #540 with a large impulsive current pulse superimposed on the initial stage current saturated at 40 kA and is not included in Fig. 2 and later, because we will not compare our results to the positive flashes with return-stroke-like impulsive currents in Berger's data [3]. Even more, Berger described his uncertainty to identify those positive flashes with large impulsive components as either downward or upward positive flashes [6]. We have to note that two more flashes, GBT #210 and GBT #770, without large impulsive current components saturated at 40 kA during the initial portion of initial stage current, were included in Fig. 2 and later. This will have little effect on the median values presented in this study, possibly it will cause an underestimation of charge transfer and action integral in the following paragraphs. A median value of 11 kA and 5.2 kA for pulse peak current and flash peak current was obtained, respectively. Berger did not report any high repetition rate current pulses superimposed on the initial stage current, which are essentially upward negative stepped current pulses, as shown in section 3.4. Hence it seems reasonable to compare in this study the flash peak current given by the peak value of the underlying slowly varying current to Berger's data. Berger [3] reported a median peak current of 1.5 kA for 132 upward positive flashes without large impulsive components having magnitudes in the return-stroke range. This is about 3 times smaller than the 5.2 kA median value of the flash peak currents of the GBT events.

Fig. 3 shows the cumulative frequency distribution of flash duration for 26 upward positive flashes measured at the GBT. We determined a median flash duration of 82 ms, which is comparable to 72 ms for 138 upward positive flashes without large impulsive components measured at Berger's towers [3].

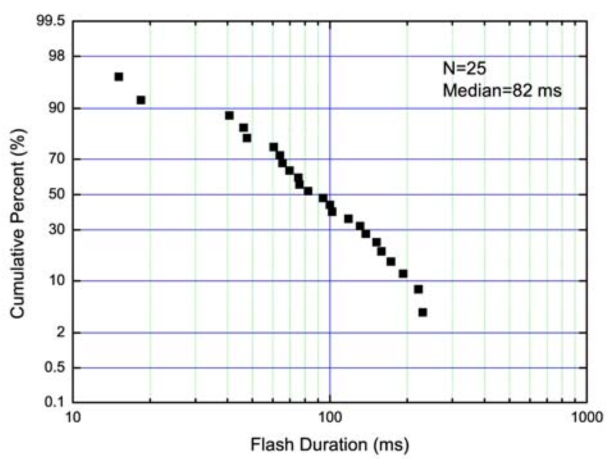

Fig. 3. Cumulative frequency distribution of flash duration for upward positive flashes. The sample sizes (N) and median value (Median) are indicated in the figure.

Fig. 4 shows the cumulative frequency distribution of charge transfer for 26 upward positive flashes measured at the GBT. We obtained a median charge transfer of 58 C, which is 2.2 times larger than the median value of 26 C for 137 upward positive flashes without large impulsive components measured at Berger's towers [3].

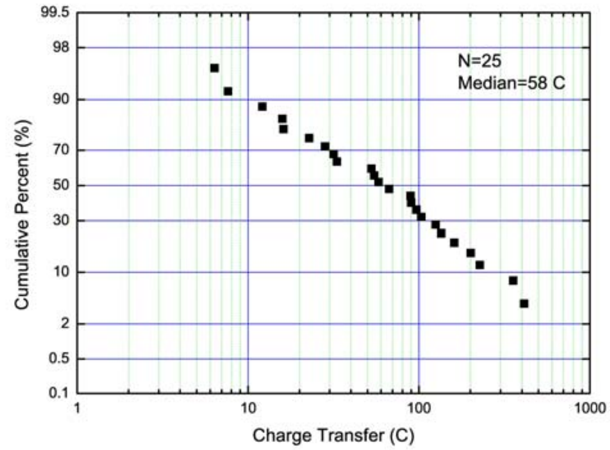

Fig. 4. Cumulative frequency distribution of charge transfer for upward positive flashes. The sample sizes (N) and median value (Median) are indicated in the figure.

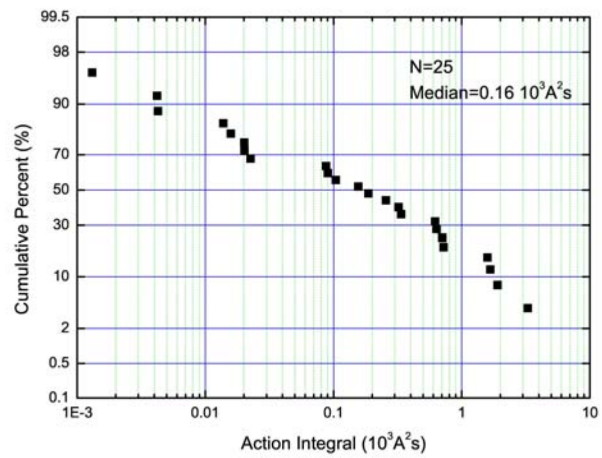

Fig. 5. Cumulative frequency distribution of action integral for upward positive flashes. The sample sizes (N) and median value (Median) are indicated in the figure.

Fig. 5 shows the cumulative frequency distribution of action integral for 26 upward positive flashes measured at the GBT. A median action integral of 0.16×10^3 A^2s (equal to 0.16 kJ/Ω) was determined. This value is relatively small compared to the 9.6×10^3 A^2s (equal to 9.6 kJ/Ω) obtained from upward negative flashes at the GBT [4].

3.4 HIGH REPETITION CHARACTERISTICS

Diendorfer et al. [7] reported significant pulsing structure during the front section of the initial stage current for upward positive flashes. Based on simultaneous current and electric field measurements at a distance of 170 m from the GBT [8], these current pulses of high repetition rate are inferred to be upward stepped negative leader pulses. Fig. 6 shows the high repetition characteristics of these pulses reproduced from Fig. 8 in [8].

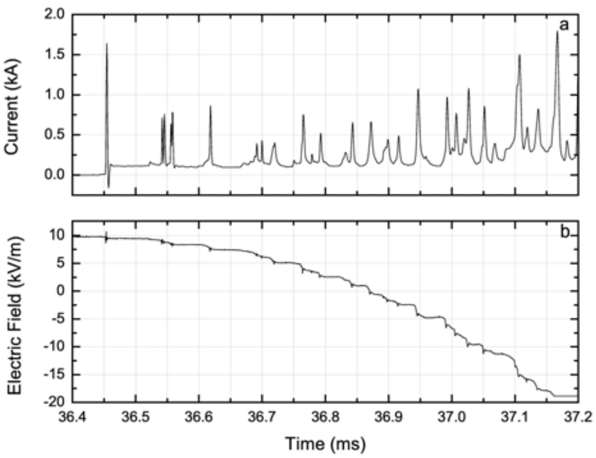

Fig. 6. Simultaneous current and electric field waveforms measured at a distance of 170 m from the GBT for the flash GBT #482, illustrating the high repetition characteristics of current pulses at the initial portion of initial stage current of the upward positive flash.

4. SUMMARY

Based on the measured current waveforms, a total of 26 upward positive lightning flashes were identified. All of them showed an initial stage current only, not followed by any leader-return-stroke sequences, These 26 flashes accounted for 4% (26/652) of the total recorded flashes at the GBT during the 10-year observation period from 2000 to 2009.

No downward positive flashes were observed during this period. Median values of flash peak current, flash duration, flash charge transfer, and flash action integral were determined as 5.2 kA, 82 ms, 58 C and 0.16×10^3 A^2s, respectively.

Based on simultaneous current and electric field measurements at a distance of 170 m from the GBT, high frequency current pulses observed during the front section of the initial stage current in all positive flashes are inferred to be associated with the stepping process of the upward propagating negative leaders initiated from the tower top.

5. ACKNOWLEGDEMENTS

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