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EFFECT OF TOWER INITIATED LIGHTNING ON THE GROUND STROKE DENSITY IN THE VICINITY OF THE TOWER

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Abstract:

Detailed comparison of located lightning strokes in a 10 km radius area and directly measured lightning currents to the instrumented Gaisberg Tower (GBT) located in the centre of that area is presented. In 84% of the days, when lightning was measured at the GBT, no thunderstorm (TS) activity was observed in the surrounding area. On the other hand, no lightning events at the GBT were recorded in 77 % of the days, when TS activity was present in the area. Upward initiated lightning from the GBT occurs more or less independent of the general CG activity in the area and we conclude that elevated objects neither reduce nor increase the number of strokes to ground in the objects vicinity significantly. Any additional lightning initiated by the object hits directly the object.

1. Introduction

Grounded vertical objects produce relatively large electric field enhancement near their upper extremities so that upward-moving connecting leaders from these objects start earlier than from the surrounding ground and, therefore, serve to make the object a preferential lightning termination point. A comprehensive review of the interaction of lightning with tall objects is given by Rakov (2003). With increasing height of an object an increase in the number of lightning discharges is observed with an increasing percentage of upward initiated flashes. Objects with heights ranging from 100 to 500 m experience both types of flashes, upward and downward.

To account for the observation of increased lightning activity to towers of moderate height (less than 100 m) on high mountains a so called “effective height” being larger than the physical height of the object is assigned to the structure (e.g. Eriksson, 1978; Zhou et al., 2009). The effective height accounts for the additional field enhancement at the tower top due to the presence of the mountain. The high number of lightning events to elevated towers makes those objects preferential for direct lightning current measurements. Lightning to the GBT in Austria is directly measured since 1998 and the instrumentation is described in more detail in Diendorfer et al. (2009).

2. Seasonal Occurrence of Lightning in the GBT area

During the eight years period 2000 to 2007 a total of 489 flashes were recorded at the instrumented tower. About 50 % of the flashes showed an initial continuing current (ICC) only without any current pulses exceeding 2 kA, referred to as ICC_{Only} in this document. The remaining 50 % of flashes showed either ICC pulses exceeding 2 kA (ICC_P) or the ICC was followed by one or more return strokes (ICC_{RS}) as shown in Fig.1.

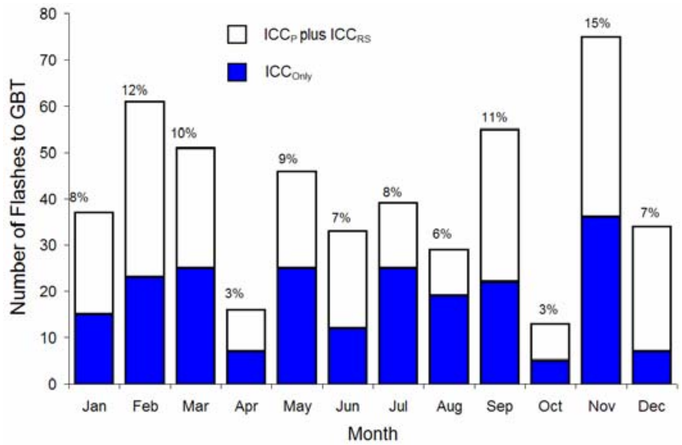


Fig.1: Monthly lightning activity observed to the GBT from 2000 to 2007.
Note: Shaded bar sections represent the fraction of ICC_{Only} events. Percentage numbers on top of bars represent the monthly contribution to the total number of lightning events measured at the GBT

Based on data from the Austrian lightning location system ALDIS we observe a pronounced lightning season in Austria (Fig.2), where most of the lightning activity (81%) occurs during summer. Interestingly from Fig.1, lightning to the GBT is more or less uniformly distributed over the year and independent of the overall lightning activity. Slightly more (56%) negative upward lightning from the GBT was recorded during the cold season (fall and winter) compared to 44% recorded during the warm season (spring and summer).

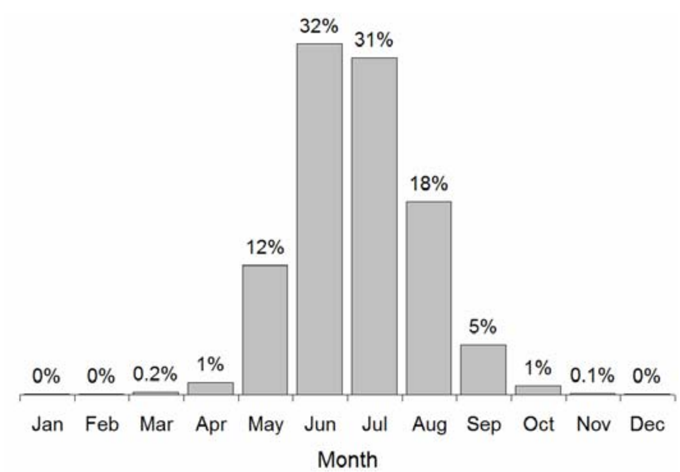


Fig.2: Monthly lightning activity observed all over Austria from 2000 to 2007. Shaded diagram bars represent the convective season (April – August) and unshaded bars represent the cold (non-convective) season (September – March); (Diendorfer et al., 2009)

Many of the GBT events occurred, when no or only very low lightning activity was observed by the lightning location system (LLS) in a region with a radius of 10 km around the GBT site, a region that is used for all the evaluations in this paper. When at a given day only a very few flashes were located in the region, those flashes are possibly the result of upward flashes from other elevated objects located within the region and not necessarily an indication of typical TS activity with CG lightning. In order to evaluate the conditions more quantitatively, when GBT events occurred, we have determined the number of LLS located flashes per day in a ring area around the GBT site, with an inner radius of 1 km and an outer radius of 10 km. Correlation of these data with the GBT records allows us to classify each day with lightning activity in the 10km region as follows:

(A) Lightning was measured at the GBT only and no TS activity was observed in the area,
(B) TS activity was observed in the area by the LLS and one or more events were recorded at the GBT, and
(C) TS activity was observed in the area by the LLS but NO events were recorded at the GBT.

A day with TS activity in the area is assumed, when more than 10 flashes were located within the 10 km ring area. This procedure allows avoiding misclassification of days due to single flashes in the ring area either as a result of large location errors of GBT events (exceeding inner ring radius of 1 km) or as a result of individual flashes from storms nearby the ring area.

In Fig.3 we show the percental distribution of the first two categories (A) and (B), covering all the days when a GBT event occurred. Obviously the fast majority (mean is 84% over 10 years) of GBT events occurred, when no TS activity (less than 10 flashes) was observed in the ring area. On the other hand, general TS activity in the ring area was only present in 16% of the days when GBT events were recorded.

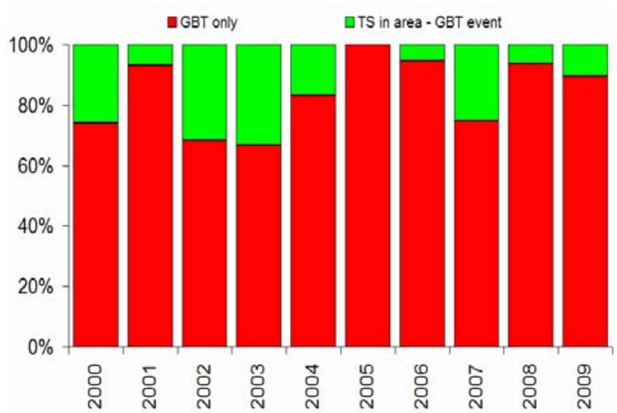
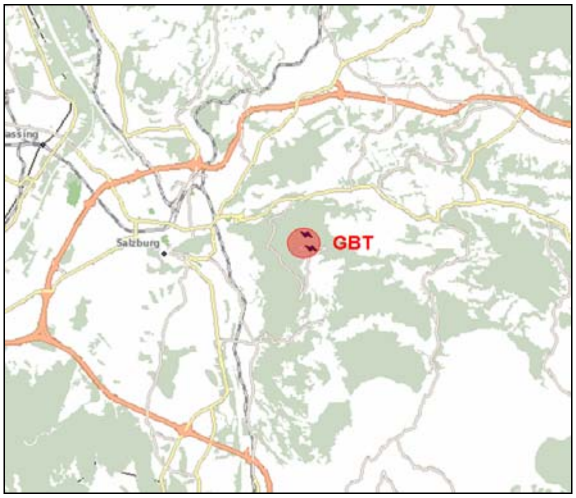


Fig.3: Classification of days, when at least one GBT event was recorded in two categories:
(A) Lightning was measured at the GBT only (red) and no TS activity in the area and
(B) TS activity was registered in the area by the LLS and one or more events were recorded at the GBT (green)

On the other hand, no lightning events at the GBT were recorded in 77 % of the days, when TS activity was present in the area.

A typical example of a category (A) day is shown in Fig.4 with no lightning activity in the area except two single discharges located by the LLS at the GBT site. Fig.5 shows the corresponding slow electric field record from a field mill installed at a distance of 170 m from the GBT. Electrostatic field at ground level was in the range of 2 to 3 kV/m when three discharges were triggered by the tower. We have to note, that the absolute field values shown in Fig.5 are probably affected by an incomplete calibration of the field mill including enhancement effects due to the platform construction, where the field mill is installed. Initial calibration resulted in an overall enhancement factor of 6, which is applied to the data shown in Fig.5 and Fig.7, respectively. A more detailed recalibration of the field mill measurements is planned for summer 2010, but nevertheless a relative comparison with Fig.7 is possible.

Each discharge to the GBT shows up as a rapid field change in Fig.5. One of the discharges was an ICC_{Only} type and hence only two discharges were located by the LLS as shown in Fig.4.



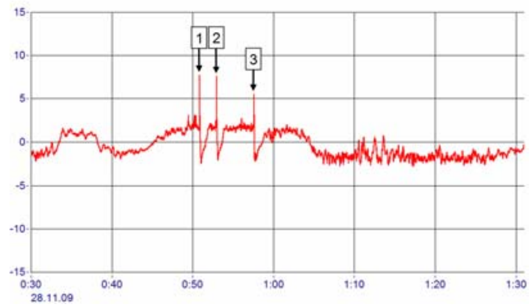
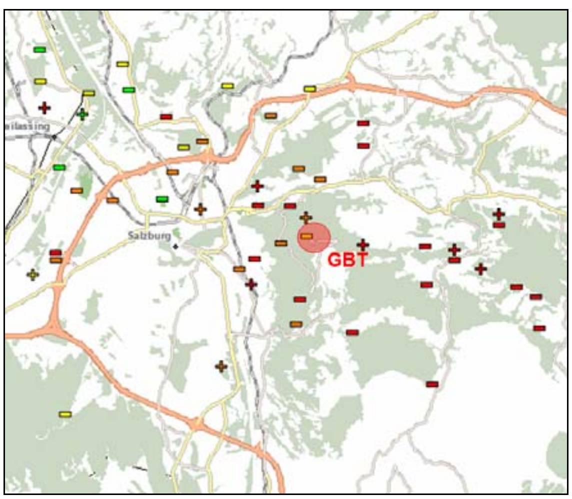


Fig.4: 28-11-2009, 00:00 – 24:00: Lightning events occurred at the GBT, whereas no lightning activity was observed in the 10 km area around the GBT

Fig.5: Electric field mill record for 60 minutes period, when lightning activity shown in Fig.4 occurred. Field mill is located at a distance of about 170 m from the GBT. Three lightning events are marked by arrows.

An example of a category (C) day is shown in Fig.6. Significant lightning activity occurs in the area but no discharge was located at the GBT site although the slow E-field record from the field mill in Fig.7 shows much higher static fields in the range from 5 - 10 kV/m compared to Fig.5.



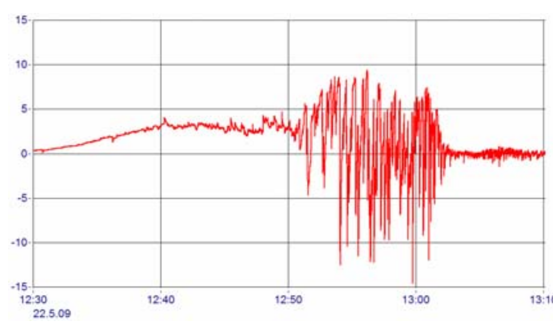


Fig.6: Thunderstorm activity in the GBT area on 22-05-2009 12:30 – 13:10 with more than 40 flashes located within a distance of 10 km. No lightning activity was recorded on the GBT (Tower position is marked by red arrow).

Fig.7: Electric field mill record for the period of lightning activity shown in Fig.6. Field mill is located at a distance of about 170 m from the GBT

From the observations above we can conclude, that there exists no or only little correlation between the occurrences of upward initiated lightning and the overall lightning activity in the area. In view of this results it seems questionable to estimate the number of lightning to an elevated object based on the number of CG lightning in the area by Eq.(1). This equation was derived by Eriksson (1987) to estimate the annual lightning incidence N (in yr^{-1}) to ground-based objects, including both downward and upward (if any) flashes:

$$N = 24\ x\ 10^{-6}.\, H_S^{2.5}.\, N_g \qquad (1)$$

where H_S is the object height in meters and N_g is the ground flash density in $km^{-2}\ yr^{-1}$.

3. Ground stroke density (GSD) in the vicinity of the GBT

Ground stroke densities (GSD) are derived from LLS data providing information about the striking position of CG lightning strokes. In case of upward initiated lightning a fraction of ICC pulses is also detected by the LLS. ICC pulses are only located, when they have sufficiently short current risetimes and consequently radiate a field pulse strong enough to be detected by several remote LLS sensors. Some of the ICC pulses have current rise times similar to return strokes (Miki et al., 2005; Flache et al., 2008). For the eight year period from 2000 – 2007 we have LLS locations for 853 strokes, which were also recorded by the GBT instrumentation.

For the following analysis of the local GSD in the vicinity of the GBT we are using the 2000 – 2007 lightning locations provided by the Austrian lightning detection system ALDIS and EUCLID, respectively. For more details about the setup and performance of the EUCLID network see Schulz et al. (2005). A grid cell size of 500 m x 500 m is used for the area of 20 km x 20 km with the GBT located in the centre. Practically all of the return strokes to the GBT occurred in upward initiated lightning. The LLS located strokes to the tower result in a pronounced peak of the local GSD plot in Fig.8. The location error of the LLS results in a widening of the column at the base level. In Fig.9 we have plotted with equal scaling the GSD of the same area, when all the events resulting from GBT flashes were removed from the basic data set supposedly showing the “background” GSD that would exist without the presence of the tower. The pronounced peak reduced significantly, although there is still an increase of GSD at the tower site. We found, that the remaining increase of GSD is a result of GBT events missed by the tower instrumentation over the years for different reasons, as e.g.:

- male function of current measuring system,
- male function of GPS synchronization of current recording system,
- a few current records were incomplete, when the duration of lightning current exceeded the maximum recording time of 800 ms of the tower instrumentation,
- temporary outage of the entire tower instrumentation, when the top section of the GBT was refurbished in 2003,
- etc.

Unfortunately we do not have any possibility to identify all the missed GBT strokes that remain in the dataset and hence we are unable to produce a plot of GSD excluding all strokes to the GBT.

In Austria we observe a pronounced lightning season in the convective season (see Fig.2) and we assume that the fast majority of strokes in the non-convective season to the area results from GBT events only. In

Fig.10 we have plotted the GSD for the cold season and obviously a large fraction of GSD is contributed by the tower flashes during the cold season with almost no GSD in the more distant regions from the tower location. In

Fig.11 we have again excluded the identified GBT events and still some strokes are remaining for the same reasons as described before.

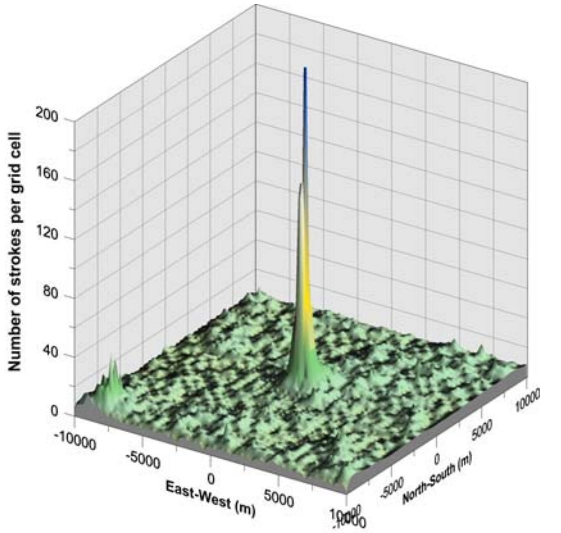


Fig.8: Number of all located strokes 2000 – 2007 in a 20 km x 20 km area, grid cell size is 500 m. GBT is located in the centre of the plot

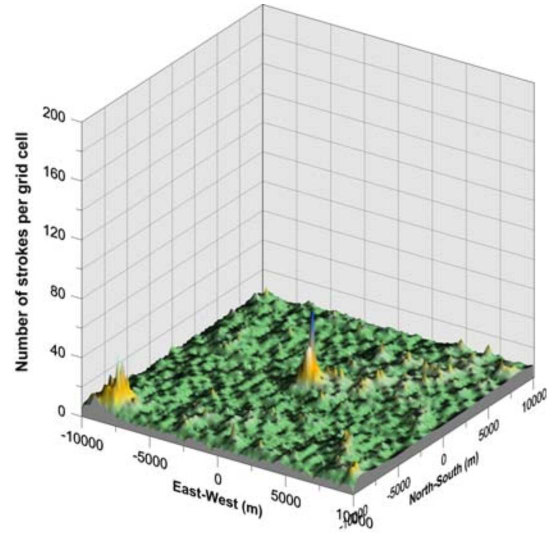


Fig.9: Number of all located strokes 2000 – 2007 in a 20 km x 20 km area, grid cell size is 500 m, when strokes measured at the GBT are removed. GBT is located in the centre of the plot

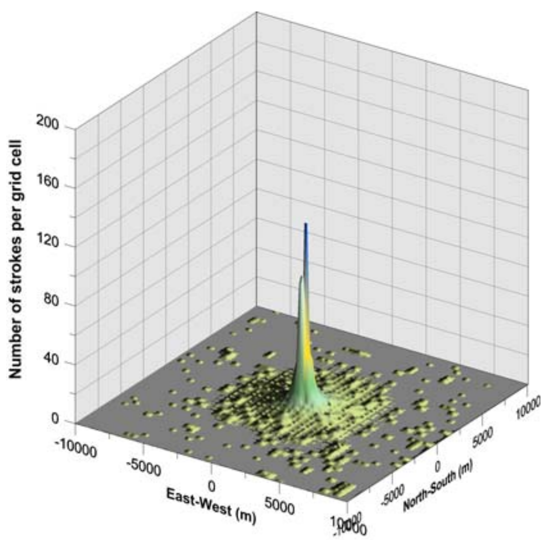


Fig.10: Number of all located strokes during cold season (Nov. – April) in 2000 – 2007 in a 20 km x 20 km area, grid cell size is 500 m. GBT is located in the centre of the plot

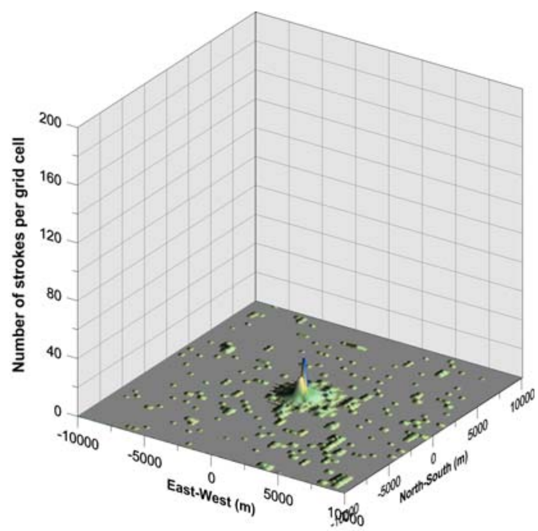


Fig.11: Number of all located strokes during cold season (Nov. – April) in 2000 – 2007 in a 20 km x 20 km area, grid cell size is 500 m when strokes measured at the GBT are removed. GBT is located in the centre of the plot

4. Summary and Discussion

In this contribution we presented the results of a study where we have analyzed in more detail the GSD in the near vicinity (distance range of 10 km) of the GBT location. We have produced different density plots of located strokes in a 20 km x 20 km area when including or excluding the located GBT strokes in order to see, whether the upward initiated lightning from the tower has any effect on the overall stroke density to ground or not.

We conclude that strokes initiated by elevated objects (wind turbines, towers, etc.) do not have any significant effect on the lightning density in the near vicinity of that object. This finding is also supported by the observation, that a high fraction of the flashes initiated by tall objects occurs during the cold season, when there is little or no lightning activity in the area. Occurrence of lightning triggered by tall objects seems to be more or less independent from the general CG flash activity on one hand and does not change the ground flash density in the vicinity of the tall object on the other hand.

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References

Diendorfer, G., H. Pichler, M. Mair (2009), Some Parameters of Negative Upward-Initiated Lightning to the Gaisberg Tower (2000–2007), Electromagnetic Compatibility, IEEE Transactions on, vol.51, no.3, pp.443-452.

Eriksson, A. J. (1987), The Incidence of Lightning Strikes to Power Lines," Power Delivery, IEEE Transactions on , vol.2, no.3, pp.859-870, July 1987

Flache, D., V. A. Rakov, F. Heidler, W. Zischank, and R. Thottappillil (2008), Initial-stage pulses in upward lightning: Leader/return stroke versus M-component mode of charge transfer to ground, Geophys. Res. Lett., 35, L13812, doi:10.1029/2008GL034148.

Miki, M., V. A. Rakov, T. Shindo, G. Diendorfer, M. Mair, F. Heidler, W. Zischank, M. A. Uman, R. Thottappillil, and D. Wang (2005), Initial stage in lightning initiated from tall objects and in rocket-triggered lightning, J. Geophys. Res., 110, D02109, doi:10.1029/2003JD004474.

Rakov, V.A. (2003), A Review of the interaction of lightning with tall objects, Recent Res. Devel. Geophysics, 5, pp. 57-71, Research Signpost, India.

Schulz, W., K. Cummins, G. Diendorfer, and M. Dorninger (2005), Cloud-to-ground lightning in Austria: A 10-year study using data from a lightning location system, J. Geophys. Res., 110, D09101, doi:10.1029/2004JD005332.

Zhou H., N. Theethayi, G. Diendorfer, R. Thottappillil, V. A. Rakov (2009), A new approach to estimation of effective height of towers on mountain tops for lightning incidence studies: sensitivity analysis. X International Symposium on Lightning Protection (SIPDA), Curitiba, Brazil.