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Preliminary Comparison of Data from the Säntis Tower and the EUCLID Lightning Location System

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***Abstract*—In this paper, direct lightning current measurements obtained on the Säntis Tower from June 1st, 2010 to May 31st, 2011 are used to evaluate the ability of the EUCLID lightning detection network to detect this type of lightning triggered by a tall tower in terms of detection efficiency, location accuracy and peak current estimates. The Säntis Tower is a 124-meter tall tower sitting on the top of the Säntis Mountain (2500 m) in Switzerland. The tower has been instrumented to measure waveforms of the lightning current and of its time derivative. In the considered period, 57 flashes were recorded at the Säntis Tower out of which 15 were of positive polarity. The data have been correlated to EUCLID data by comparing the time-stamps provided by the GPS time references. The flash detection efficiency for negative flashes is estimated to be 93%. The median value of the location error is 126 m. The EUCLID peak current estimates were on average significantly larger than the measured current. The measurements include four typical positive flashes, which were successfully detected by EUCLID. The location errors for the positive events ranged from 1 to 3 km, with a median of 959 m.**

Keywords- lightning detection, lightning location, tall tower, negative flashes, positive flashes.

I. INTRODUCTION

The assessment of the performance of lightning location systems can be evaluated by means of directly measured events provided by either instrumented towers (e.g. [1, 2]) or rocket-triggered lightning [3].

Diendorfer et al. [1, 4] compared lightning peak currents measured at the Gaisberg tower (100-m tall) to correlated lightning peak currents reported by the Austrian Lightning Detection and Information System (ALDIS). They reported very good agreement, the differences between the directly-measured and ALDIS-estimates being in the range of measurement errors of both systems. Rachidi et al. [5] derived equations to infer the mean value of the return stroke current from the mean values of the peak remote field and the return stroke speed. The derived equations were validated using simultaneous measurements of return stroke current, electric fields at 5 km, and return stroke speeds associated with triggered lightning and reported by Willett et al. in [6]. Jerauld et al. [3] evaluated the performance characteristics of the U.S. National Lightning Detection Network (NLDN) [7] using rocket-triggered lightning data acquired during the summers 2001-2003 at Camp Blanding, Florida, reporting a tendency of NLDN to underestimate peak currents with a median peak current estimation error of about -18 %. This underestimation has been shown to result from propagation model parameters that were not well-suited to the NLDN sensor baseline distances [8]. More recently, Nag et al. [9] presented a similar analysis using the Camp Blanding data acquired during 2004-2009. The reported flash and stroke detection efficiencies were 92% and 76%, respectively, while the median absolute location error was 308 m. The median NLDN-estimated peak current error was −6.1 %. Pavanello et al. [10] used directly-measured lightning currents at the top of the CN Tower (553 m) to evaluate the performance of the North American Lightning Detection Network (NALDN) in terms of current peak estimates. They showed that the NALDN inferred values overestimate the actual current peaks for strikes to very tall towers by a factor of about 3 to 4 because the presence of the tall struck object is not included in the NALDN current peak estimation algorithm. However, correcting the NALDN estimates by using the tower correction factors proposed either by [11] or [12] results in an excellent estimation of the lightning current peaks.

The Säntis telecommunications tower was instrumented in May 2010 to measure lightning currents. In this paper, we use the data obtained from June 1st, 2010 to May 31st, 2011 to evaluate the performance of the EUCLID lightning detection network in terms of detection efficiency, location accuracy and peak current estimates. We also discuss some limitations in detecting strokes in upward-initiated lightning flashes.

The paper is organized as follows. Section II presents briefly the instrumentation at the Säntis tower. A brief description of the EUCLID network is given in Section III. The analysis results and discussion are presented in Section IV. General conclusions are given in Section V.

II. SÄNTIS TOWER INSTRUMENTATION AND OBTAINED DATA

A. *Tower Instrumentation*

The Säntis Tower is a 124-meter tall tower sitting on the top of the Säntis Mountain (2500 m). The tower has been instrumented to measure waveforms of the lightning current and of its time derivative. To measure the current, a total of three Rogowski coils were installed, two (from different manufacturers) at a height of 24 m and one at 82 m. The current derivative is measured making use of a suitably developed B-dot sensor at 82 m [13]. The analog outputs of the sensors are relayed to a digitizing system by means of an A/D – D/A 12-bit optical link characterized by an overall -3 dB bandwidth of DC to 25 MHz and a signal-to-noise ratio SNR_{max} = 74 dB. Two National Instruments PCI-5122 high-speed digitizers are connected to the fiber optic digital-to-analog converters. They are characterized by a sampling frequency of 100 MSa/s, a 14-bits A/D conversion and a 100 MHz bandwidth achieved by anti-aliasing filters.

B. *Säntis Data*

In the considered period (June 1st, 2010 to May 31st, 2011), 57 flashes were recorded at the Säntis Tower out of which 15 were of positive polarity. From the 42 negative flashes 37 could be correlated to EUCLID data by comparing the time-stamp provided by the GPS time reference installed on the Säntis and the EUCLID time. Specifically, events from Säntis and EUCLID were considered synchronized if the two following criteria were satisfied: i) the GPS time stamps were within a time window of a few ms and ii) the pattern of strokes/pulses time stamps provided by EUCLID and Säntis data fitted within the µs range. Note that the data provided by the EUCLID network were restricted to a circular area of 5 km radius centered in the location of the Säntis Tower. Concerning the time synchronization, it is worth observing that the trigger of the measurement system of the Säntis tower makes use of a threshold-based logic applied to the time derivative signal of the lightning current that is directly measured by means of a B-Dot sensor. Such logic results in a time delay that, as expected, depends on the waveform of the lightning current time derivative. However, such a time delay is, for typical values of current time derivatives, within 0.1 – 1 µs.

Figure 1 shows an example of a typical current waveform measured by one of the Rogowski coils located at 82 m height. The current waveform is typical of upward negative flashes with an initial continuing current (ICC) of about 500 ms duration and superimposed ICC pulses. The number of recorded ICC pulses is in excess of 30, with peak amplitudes ranging from about 1 kA to 14 kA. After the extinction of the ICC, a return stroke with a peak current of about 22 kA can be distinguished. The maximum steepness of the return stroke is about 56 kA/µs and the total transferred charge of this flash is 21 C.

III. EUCLID NETWORK

EUCLID (European Cooperation for Lightning Detection) is a consortium of 16 European national lightning detecting networks with the aim to identify and detect lightning all over the European area (http://www.euclid.org). Presently, the complete network consists of 138 sensors contributing to the detection of lightning. For cloud to ground (CG) lightning, an overall flash detection efficiency of 98% and a stroke detection efficiency of 84% have been determined for the EUCLID network based on video studies in Austria [14]. Very similar values of detection efficiency are observed for lightning to the Gaisberg Tower [15] for upward flashes including at least one return stroke. For the location of the Säntis Tower, the overall performance of the EUCLID network for CG lightning should be very much the same as that observed in Austria. For upward initiated lightning from a tall tower, the detection efficiency of these kinds of networks is affected by the occurrence of ICC pulses with longer current risetimes, and more generally with waveshapes very different from those associated with downward flashes for which they are calibrated.

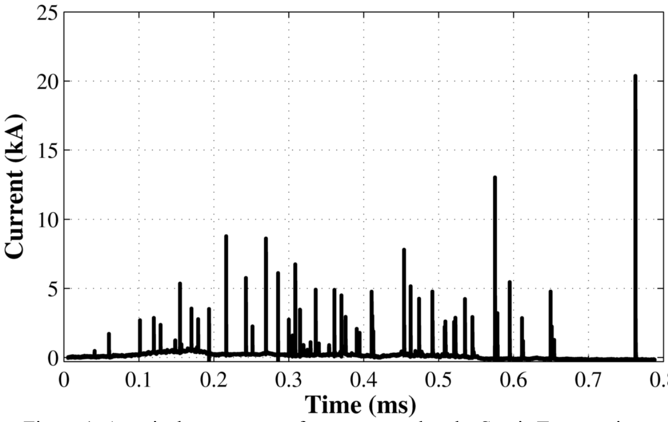

Figure 1. A typical current waveform measured at the Säntis Tower using a Rogowski coil located at 82 m above ground level. The flash occurred on October 12, 2010, at 19h52

IV. RESULTS AND DISCUSSION

A. *Flash Detection Efficiency*

Table 1 presents the flash detection efficiency for the negative flashes to the Säntis Tower observed in the mentioned period during which 42 flashes were recorded at Säntis.

TABLE 1. FLASH DETECTION EFFICIENCY (FDE) OF THE EUCLID NETWORK ASSOCIATED WITH NEGATIVE LIGHTNING FLASHES TO THE SÄNTIS TOWER, JUNE 2010-MAY 2011.

Number of Säntis Tower measured neg. flashes	42
Number of EUCLID detected flashes	37
Flash Detection Efficiency	88%
Flash Detection Efficiency, excluding flashes containing ICC pulses only	93%

Out of the 42 flashes, 37 were detected by the EUCLID network.

However, it should be noted that among the 5 flashes missed by EUCLID, two were characterized by only an ICC without return strokes (these flashes are referred to as ICC_p [14, 15]). As mentioned before, ICC pulses often feature longer risetimes (small di/dt) and are not associated with sufficient radiation to be detected by lightning location systems. These two flashes are shown in Figures 2a and 2b.

Figure 3 presents the EUCLID pulse detection efficiency as a function of pulse peak current measured at Säntis (the minimum considered current peak in the analysis was 2 kA for the Säntis data). Even though the number of data points is insufficient, especially for high peak currents (see Figure 4), the data suggest a clear increase of the pulse detection efficiency as a function of peak current.

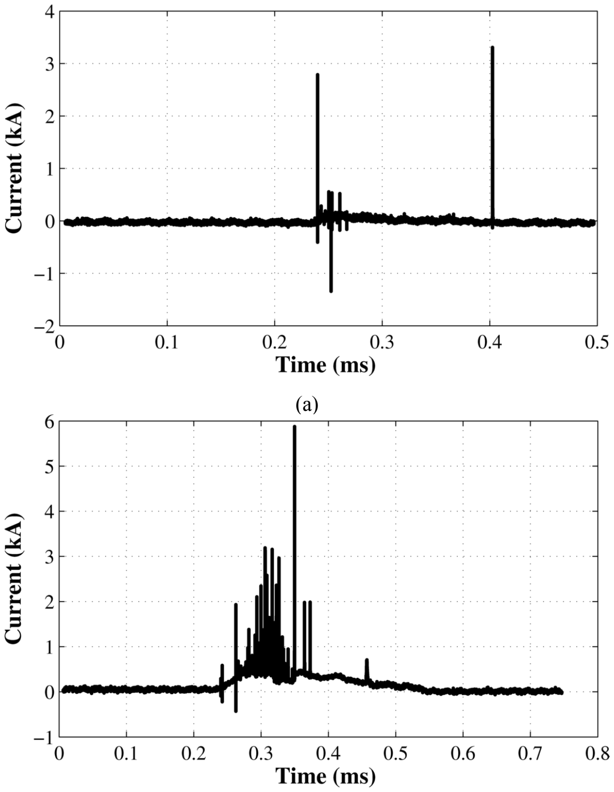

Figure 2. The two ICC_p type flashes missed by EUCLID. None of them contained any return strokes. (a) April 12, 2011 at 17:34, (b) April 28, 2011 at 16:25.

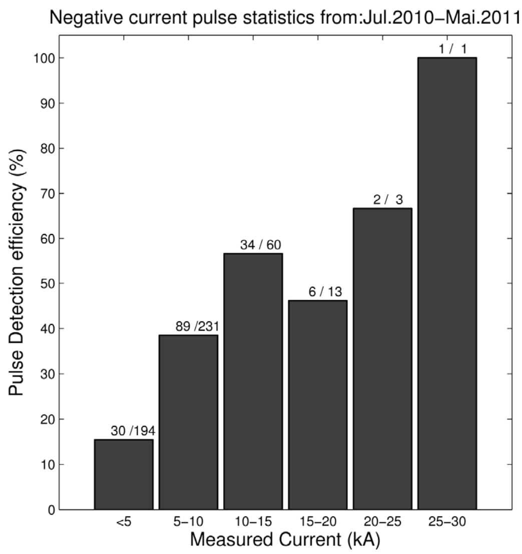

Figure 3. EUCLID detection efficiency as a function of pulse peak current measured at Säntis (bin size of 5 kA).

Note that the data shown in Figure 3 are a combination of return strokes and ICC-pulses and, therefore, the reduced detection efficiency for lower amplitudes in this preliminary comparison is most likely caused by the high number of ICC-pulses with long risetimes in this low amplitude range.

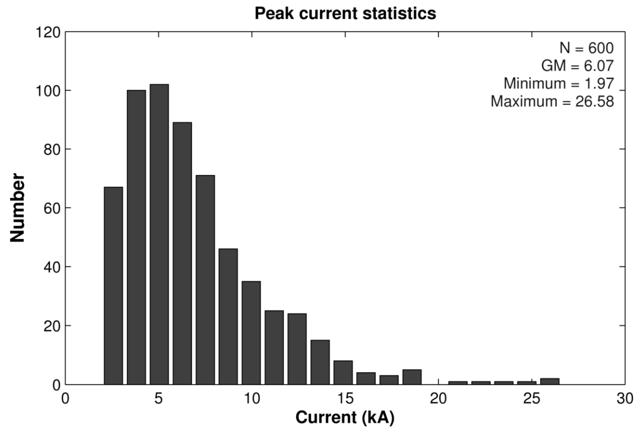

Figure 4. Distribution of peak current (Säntis measurements)

Regarding the positive flashes, out of the 15 recorded events, only four were characterized by typical positive current waveshapes [16]. The current peaks associated with these four single-stroke flashes were 43, 18, 16 and 31 kA. For all of these flashes, we can find time correlated EUCLID detected strokes. At this time, it is unclear whether EUCLID located the main channel attached to the tower top or located some recoil streamers within the cloud above the tower. The 43-kA event is plotted in Figure 5. It is worth noting that the M-component-like pulse that occurred at about 170 ms was detected by EUCLID and classified as a second stroke.

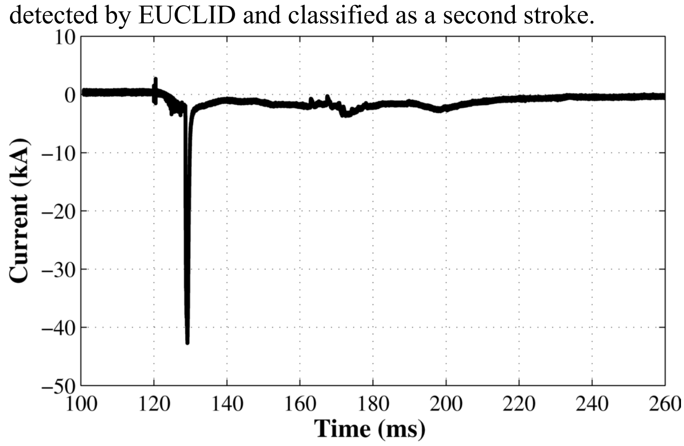

Figure 5. Current waveform associated with a positive flash recorded on July 21, 2010, 19:05. The M-component-like pulse that occurred at about 170 ms was detected by EUCLID and classified as a second stroke.

It is also worth noting that some of the upward flashes from the tower can be triggered by nearby cloud-to-ground or intracloud discharges some tens of ms prior to the start of the upward leader from the tower [17]. The uncertainty in the time correlation being in the order of ms, it is therefore possible that, in some cases, the located events at some km distance from the Säntis are the triggering events and not the discharges to the tower. Although we expect these events to be rare, they might have some influence on the estimated detection efficiency, location accuracy and peak current estimations of the system.

B. Location Accuracy

Figure 6 presents a plot of pulse locations estimated by EUCLID. The median of the absolute error for the location (defined as the distance between the Säntis Tower location and the median of EUCLID's stroke locations) of negative flashes is 126 m.

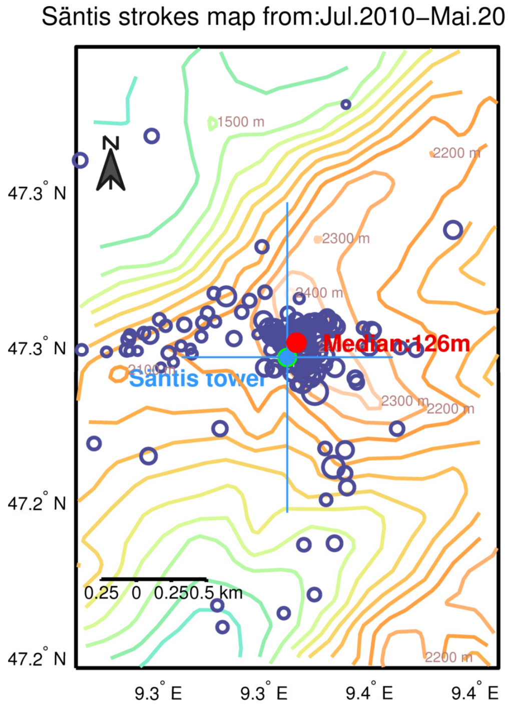

Figure 6. Plot of EUCLID stroke locations for flashes recorded from June 2010 to June 2011. The size of the circles is proportional to the current peak estimated by EUCLID.

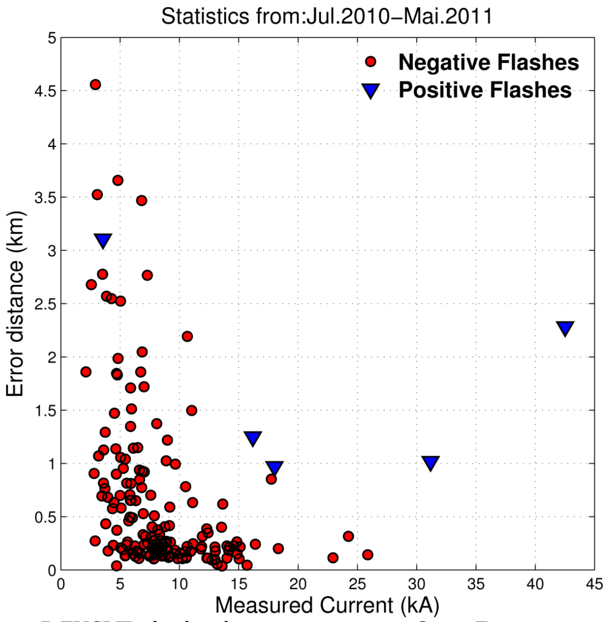

Figure 7. EUCLID absolute location error versus Säntis Tower measured peak current.

Figure 7 shows EUCLID's absolute location error versus the peak current measured on the Säntis tower. The majority of large location errors are for current peaks lower than 10 kA. For negative current peaks larger than 15 kA, the location errors do not exceed 1 km. For positive flashes, the dataset is limited to 5 events. The location errors for these positive events range from 1 to 3 km, with a median of 959 m.

Figure 8 shows the arithmetic mean of the absolute location error as a function of current peak ranges. It can be seen that the error's mean value remains below 500 m for current peaks larger than 10 kA.

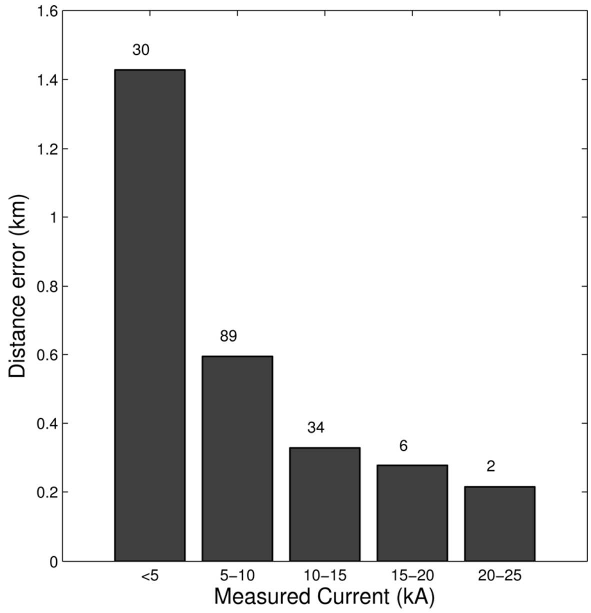

Figure 8. Arithmetic mean of EUCLID absolute location error versus Säntis peak current. Only negative flashes are considered here.

C. Peak Current Estimates

Figure 9 presents the EUCLID peak current estimates versus directly measured peak currents at the Säntis Tower (recorded at the height of 82 m) for both negative and positive events. Note that we obtained nearly identical results using current peaks measured at the lower height. It should be noted that no distinction was made between return strokes and ICC pulses (with rise times smaller than 8 µs). It can be seen that the LLS peak current estimates are on average larger than the measured current.

Figure 10 shows the median and standard deviation of the EUCLID peak current estimation errors as a percentage of the directly measured Säntis current ranges. For current peaks larger than 10 kA, the absolute percentage error is about 50 to 60%. Note that these errors are significantly larger than those reported by Diendorfer et al. [1, 4] using Gaisberg Tower data.

For the five positive events, the median of the absolute error of EUCLID peak current estimation as a percentage of the directly measured Säntis current is 46%.

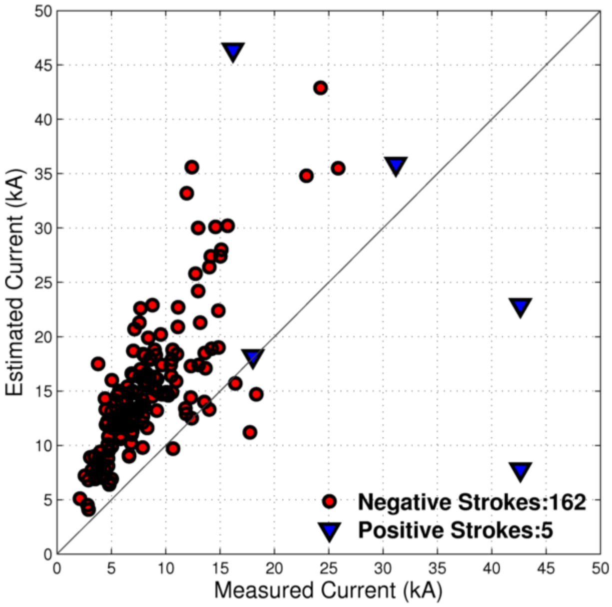

Figure 9. EUCLID peak current estimates versus peak current directly measured at Säntis Tower.

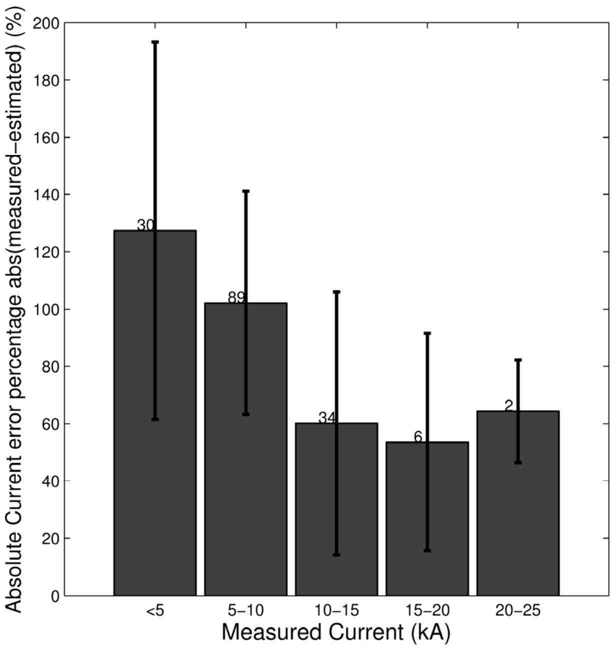

Figure 10. Arithmetic mean and standard deviation of EUCLID peak current estimation errors (magnitude) given as a percentage of the directly measured Säntis current ranges. Only negative flashes are considered here.

V. Conclusions

In this paper, we used the obtained data on lightning current measured on the Säntis Tower from June 1st, 2010 to May 31st, 2011 to do a preliminary evaluation of the performance of the EUCLID lightning detection network in terms of detection efficiency, location accuracy and peak current estimates for these tower initiated lightning events. In the considered period, 57 flashes were recorded on the Säntis Tower out of which 15 were of positive polarity. From them, 37 could be correlated to EUCLID data by comparison of the time-stamp provided by GPS time reference installed on the Säntis and the EUCLID time.

The flash detection efficiency was estimated to be 93% and the median location error was 123 m. The EUCLID peak current estimates were on average larger than the measured current with a median peak current estimation error of about 60% for strokes over 10 kA.

Measurements included four typical positive flashes successfully detected by EUCLID. The location errors for the positive events ranged from 1 to 3 km, with a median of 960 m.

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