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Key Points:
- The overall pulse detection efficiency for upward flashes was found to be 73%
- The detection efficiency for upward flashes with pulses larger than 2 kA was estimated to be 97%
- The median of the absolute distance location error for upward flashes was found to be 186 m

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Evaluation of the performance characteristics of the European Lightning Detection Network EUCLID in the Alps region for upward negative flashes using direct measurements at the instrumented Säntis Tower

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Abstract In this paper, we present a performance analysis of the European Cooperation for Lightning Detection (EUCLID) lightning detection network using data obtained on lightning currents measured at the Säntis Tower (located in northeastern of Switzerland) from June 2010 to December 2013. In the considered period of analysis, a total number of 269 upward negative flashes were recorded at the Säntis Tower. The performance of the EUCLID lightning detection network is evaluated in terms of detection efficiency, location accuracy, and peak current estimates for upward flashes. Excluding flashes containing only an initial continuous current with no superimposed pulses exceeding 2 kA, the flash detection efficiency for upward flashes is estimated to be 97%. The recorded flashes contained a total of 2795 pulses (including return strokes and International Conference on Communications pulses characterized by risetimes lower than 8 μs and peaks greater than 2 kA). The overall pulse detection efficiency was found to be 73%. For pulses with peak values higher than 5 kA, the pulse detection efficiency was found to be about 83%. Peak current estimates provided by the EUCLID network were found to be significantly larger than their directly measured counterparts. This overestimation might be attributed to the enhancement of the radiated electromagnetic fields associated with the presence of the tower and the mountain. The median of the absolute distance error, defined as the median distance between the Säntis Tower location and the EUCLID's stroke locations, was found to be 186 m, the majority of large location errors being associated with measured current peaks lower than 10 kA. The analysis revealed also that the location accuracy of the EUCLID network improved significantly in 2013 as a result of an upgrade in the location algorithms to take into account propagation effects.

1. Introduction

Instrumented towers and rocket-triggered lightning are two effective means to investigate the performance of lightning location systems (LLS) [*Nag et al.*, 2015]. Both of these methods can provide valuable data on different characteristics of LLS like detection efficiency (DE), location accuracy (LA), and peak current estimation accuracy. A discussion on the differences between the DE and the LA obtained from direct tower measurements and other methods, such as video and continuous electric field recordings, is in order. The salient differences are as follows:

1. The DE and LA from tower data are valid for the tower position and they may be different for other parts of the region around the tower. The performance parameters obtained from video recordings, on the other hand, are valid for the region where a sufficiently unobstructed view can be guaranteed, preferably from more than one recording site. On the other hand, direct measurements using towers or triggered lightning provide exact locations, which are not the case for video or electric field recordings.
2. Tower data are essentially based on upward lightning, which are characterized by the absence of the first return stroke, and the presence of an initial continuous current (ICC) with or without superimposed pulses. It is important to note that an appreciable number of upward flashes from towers might contain only an initial continuous current with neither superimposed pulses nor return strokes [*Smorgonskiy et al.*, 2013]

and, therefore, cannot be detected by LLS. For example, the percentage of upward flashes containing only an ICC was 64% at Mount San Salvatore [*Berger*, 1967] and 48% at Gaisberg [*Diendorfer et al*., 2009].

The presence of the tower might affect the location accuracy of LLS in different ways. On the one hand, the presence of a straight, tall strike object results in “clean” electromagnetic field waveforms with enhanced amplitudes [*Rachidi et al*., 2001]. This effect is expected to have a beneficial impact on the location accuracy of LLS. On the other hand, the transient process along a tall strike object can cause distortions of the field waveforms that might negatively affect the performance of LLS. For example, the waveforms of the electric and magnetic fields associated with lightning strikes to the CN Tower in Toronto exhibit a first zero crossing about 5 μs after the onset of the return stroke [*Pavanello et al*., 2007], which is due to the reflection of the current at the base of the tower. In general, the flash DE of a LLS is also affected by the number of strokes per flash. The more strokes occur in a given flash, the higher is the probability to detect this flash because a flash is reported (detected) if at least one stroke (first or subsequent) is detected. Therefore, the flash DE can be much higher than any form of stroke DE. A more detailed description of the differences in the ground truth data evaluation methods can be found in *Nag et al*. [2015].

The performance of the Austrian Lightning Detection and Information System (ALDIS), which is an integral part of the European network European Cooperation for Lightning Detection (EUCLID), has been investigated using direct measurements at the 100 m tall Gaisberg Tower in Austria [*Diendorfer et al*., 2002; *Schulz and Diendorfer*, 2004; *Schulz et al*., 2014a] and using video and *E* field recordings [*Schulz et al*., 2005; *Schulz and Diendorfer*, 2006; *Schulz and Saba*, 2009; *Schulz et al*., 2010]. In the latest performance analysis presented in *Schulz et al*. [2014a], the obtained detection efficiency for negative flashes was found to be 98% (flash detection efficiency) and 84% (stroke detection efficiency), based on video and *E* field recordings, and 96% (flash detection efficiency) and 71% (stroke detection efficiency) based on Gaisberg Tower measurements (evaluation of negative return strokes only). The median location accuracy was found to be improved from ~300 to ~100 m during the period of investigation [*Schulz et al*., 2014a, 2014b]. In addition, a very good agreement was reported [*Diendorfer et al*., 2002; *Schulz et al*., 2014a] between peak currents measured at the Gaisberg Tower and correlated peak currents estimated by EUCLID.

The Toronto CN Tower (533 m) has been used to evaluate the performance of the North American Lightning Detection Network (NALDN) [*Lafkovici et al*., 2008]. The authors of that study reported a flash detection efficiency of 100%, a pulse detection efficiency of 55%, and a mean absolute location error of 395 m. That study did not discriminate between return strokes and ICC pulses. *Pavanello et al*. [2009] used directly measured lightning currents at the top of the CN Tower to evaluate the performance of the NALDN in terms of peak current estimates. They showed that the NALDN peak current estimates are about 3 to 4 times larger than directly measured values. This overestimation is due to the presence of the tower itself which is not included in the NALDN peak current estimation algorithm. *Pavanello et al*. [2009] showed in addition that NALDN estimates can be corrected by applying a so-called tower correction factor [*Bermudez et al*., 2005; *Baba and Rakov*, 2007].

A preliminary analysis of the performance of the EUCLID network in Switzerland has been presented using the 124 m tall Säntis Tower in the period of June 2010 to May 2011 [*Romero et al*., 2011]. In the period of analysis considered in *Romero et al*. [2011], 42 negative flashes containing ICC pulses and/or return strokes were recorded at the Säntis Tower. The flash detection efficiency was estimated to be 93% and the median value of the location error 126 m. The EUCLID peak current estimates were found to be larger than the measured currents. A total number of 42 flashes with 600 strokes were used to evaluate detection efficiency, peak current, and location accuracy of the EUCLID network.

Rocket-triggered lightning has also been used to evaluate the performance of the U.S. National Lightning Detection Network using data provided from 2001 to 2012 at Camp Blanding, Florida [*Jerauld et al*., 2005; *Nag et al*., 2011; *Mallick et al*., 2014].

In this paper, we use current waveforms associated with upward negative flashes measured at the Säntis Tower from June 2010 to December 2013 to evaluate the performance characteristics of the EUCLID network. Note that the majority of the recorded flashes at Säntis are of upward type and only a few downward negative flashes were recorded in the period of analysis which were excluded from this study. It is worth noting that LLSs do not distinguish between upward and downward flashes. Most of the flashes occurring in nature are of downward type. Upward flashes occur only from tall structures or moderate structures located on the top of mountains [e.g., *Rakov and Uman*, 2003]. In the context of renewable electrical energy generation, the number of upward

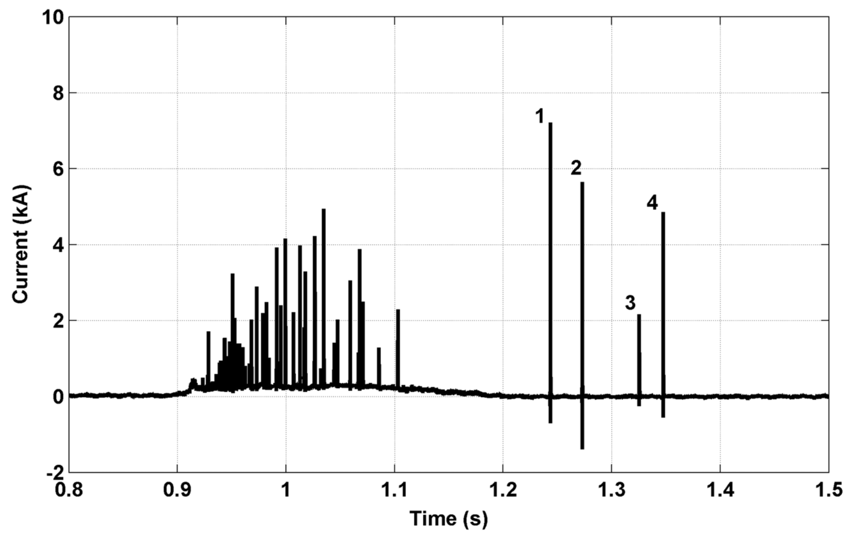

Figure 1. The current waveform associated with an upward negative flash recorded on 14:52:22, 6 August 2012. The initial continuous current (ICC), ICC pulses and 4 return strokes (labeled 1 to 4) can be identified in the waveform.

flashes is significantly increasing with the construction of tall wind turbines. As a result, the evaluation of the performance of LLSs for locating and detecting upward flashes is becoming more and more important.

The presented study is significant for at least three reasons, which are as follows:

1. As mentioned earlier, among different methods used to evaluate the performance of LLS's, direct measurements using towers or triggered lightning provide exact locations, which is not the case, for example, using video or electric field recordings.
2. The Säntis Tower is located in a mountainous area (Alps) and the obtained data are indicative of the general performance of LLS's in mountainous areas. It is worth noting that the propagation of lightning electromagnetic fields over mountainous terrain is considered as one of the main factors affecting the location error associated with the time-of-arrival method [*Cummins et al*., 2010].
3. The presented study concerns upward flashes for which little information is available in the literature as far as the performance characteristics of the LLS are concerned. Upward flashes are generally initiated from tall structures and their initiation mechanism is not fully understood and is a subject of ongoing research. They are therefore of special interest for wind turbines or other tall structures.

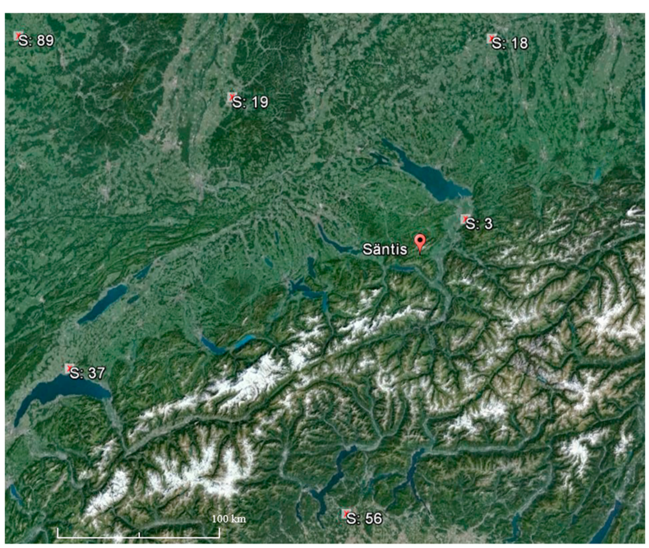

Figure 2. Location of EUCLID sensors around Säntis Tower (located in the Appenzell region in Northeastern Switzerland).

The paper is organized as follows. Section 2 briefly reviews the instrumentation installed at the Säntis Tower and the obtained direct current data. A brief description of the EUCLID network is presented in section 3. The analysis and discussion of the results are given in section 4. Finally, conclusions are presented in section 5.

2. Säntis Tower Instrumentation and Obtained Data

The Säntis Tower is a 124 m tall tower sitting on the top of the 2502 m tall Mount Säntis located at 47°14′57″N and 9°20′32″E in the Appenzell region

Table 1. Flash Detection Efficiency of the EUCLID Network Associated with Negative Lightning Flashes to the Säntis Tower

Events	Number
Number of recorded upward negative flashes with available corrected time stamp at the Säntis Tower	269
Number of recorded ICC_{Only} flashes (ICC and minor ICC pulses (peak current < 2 kA)) at the Säntis Tower	7
Number of detected flashes by the EUCLID Network	253
Flash detection efficiency of the EUCLID Network excluding ICC_{Only} flashes	97%

in the northeast of Switzerland. The Säntis Tower was instrumented in May 2010 for measurement of lightning current parameters [*Romero et al.*, 2012a]. The lightning current waveforms and their time derivatives are measured at tower heights of 24 m and at 82 m. A Rogowski coil and a multigap B-Dot sensor are currently installed at each height. The whole measurement system is triggered by the d*i*/d*t* signal measured by the B-dot sensor located at 82 m. Note that the B-Dot sensor at the lower height was not present prior to 29 June 2013 (see *Romero et al*. [2012b] for detailed information on the instrumentation and *Azadifar et al*. [2014] for recent upgrades made in 2013–2014). The analog outputs of the sensors are relayed to a digitizing system by means of 12 bit fiber optic links (Terahertz LTX5515) characterized by an overall bandwidth from DC to 25 MHz. Using National Instruments Compact-RIO modules linked via fiber optic links, the system allows over-the-Internet control and monitoring of the instrumentation. The initial data acquisition system which used an industrial PC (described in *Romero et al*. [2012a]) was replaced with a system based on PCI eXtensions for Instrumentation platform of National Instruments, that is, particularly efficient in terms of synchronization, timing, and triggering. Indeed, the system is equipped with the GPS-synchronized board PXI-6682 characterized by an onboard 10 MHz clock with skew of 1 ppm and a synchronization accuracy of ±100 ns with 13 ns standard deviation. Also, in order to have a wider time window to record initial continuous current of upward flashes, the sampling rate of the system was reduced from 100 MS/s to 50 MS/s starting from June 2012, resulting in a 2.4 s time window and a pretrigger delay of 960 ms (instead of 1.2 s time window and a pretrigger delay of 240 ms for flashes recorded between May 2010 and June 2012).

In the period from June 2010 to December 2013, a total number of 327 flashes were recorded, out of which 273 flashes were classified as negative, 46 flashes as positive and 8 as bipolar. The great majority of the measured waveforms are associated with upward flashes. Among the 327 recorded flashes, based on the measured current waveforms, only 4 were identified as downward (3 negative and 1 positive).

It is worth noting that GPS time stamps were not available for some of the events due to a defective GPS card (138 out of 327 flashes). In those cases, the Säntis data and EUCLID events were time correlated by analyzing the interstroke interval patterns which were used to calculate time offsets of Säntis events due to a drift of the internal clock. Events from the Säntis Tower and from EUCLID were considered synchronized if the two following criteria were satisfied after time drift correction: (i) the time stamps of events (EUCLID and Säntis) were within a time difference of 1 ms and (ii) the location of events proposed by EUCLID were within a 5 km circle centered at the Säntis Tower. Sometimes upward lightning is preceded and possibly initiated (note that the causality has not been established at this time) by a nearby downward lightning to ground and the applied 1 ms time difference should be sufficient to avoid an erroneous correlation of the preceding lightning located by EUCLID and the discharge measured at the tower. Out of the considered 273 upward negative flashes, one was discarded because it was not possible to accurately correct time drift.

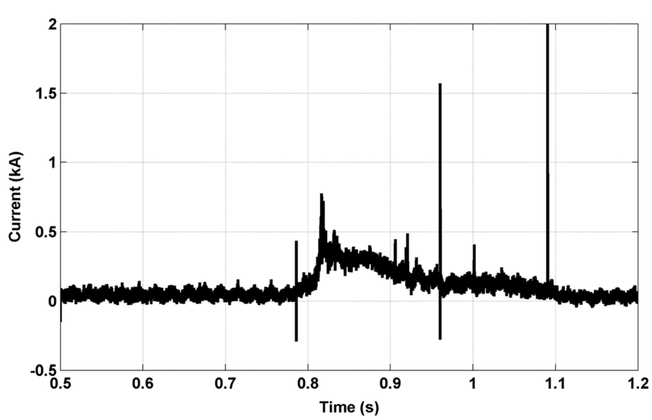

Figure 3. Measured current waveform associated with an upward negative flash recorded on 18:40:15, 25 August 2012. The current is characterized by a low amplitude ICC and ICC pulses with no return strokes.

Figure 1 shows an example of a current waveform associated with a flash recorded at the Säntis Tower. The current waveform is typical of upward negative flashes, with an initial continuing current (ICC) of about 260 ms

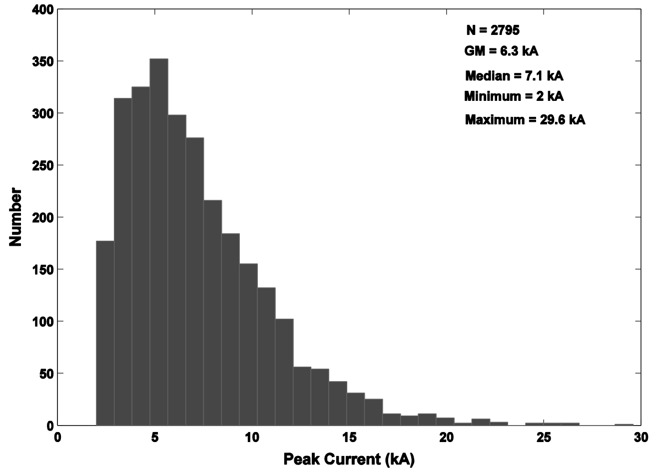

Figure 4. Peak current distribution of pulses associated with upward negative flashes measured at the Säntis Tower.

duration and superimposed ICC pulses, followed by 4 return strokes.

For the analysis of the performance of the EUCLID network, we will consider altogether negative return strokes (pulses occurring after the extinction of the ICC) and ICC pulses (superimposed on the initial continuous current fulfilling two conditions: a risetime lower than 8 μs and an amplitude greater than 2 kA). These pulses are believed to be associated with the leader/return stroke mode of charge transfer, as opposed to slower pulses which are associated with the *M* component charge transfer mode [*Flache et al.*, 2008]. It should be mentioned that the 2 kA current amplitude criteria were applied based on the study by *Cooray and Rakov* [2012] in which the smallest value of the return stroke current amplitude that can exist in nature lies in the range of 1.5 to 3.0 kA. Note, in addition, that ICC pulses with risetimes greater than 8 μs are rarely located by EUCLID as those slow rising currents do not radiate sufficient fields to be detected by several sensors.

Finally, note that throughout the text, both return strokes and ICC pulses fulfilling the above two conditions will be referred to as pulses.

3. EUCLID Network

EUCLID (European Cooperation for Lightning Detection) is a consortium of 19 national lightning detection networks with the aim of identifying and detecting lightning all over the European area (http://www.euclid.org). Figure 2 shows the location of six EUCLID sensors in the vicinity of the Säntis Tower.

In 2014 the complete network consisted of about 150 sensors. As mentioned in the introduction, an overall flash detection efficiency of 98% and stroke detection efficiency of 84% have been reported by *Schulz et al.* [2014b] determined from video and *E* field recordings in southeastern France (Cévennes-Vivarais). It should be noted that, unlike the present study, most of the flashes in *Schulz et al.* [2014b] are of downward type. Direct current measurements at the Gaisberg Tower in Austria provided a flash DE of 98% and a stroke DE of 85% [*Diendorfer*, 2010]. A similar study performed at the Säntis Tower for 42 recorded flashes over the period from June 2010 to May 2011 [*Romero et al.*, 2011] reported a flash detection efficiency of 88%. In the analysis presented in *Romero et al.* [2011], only flashes containing ICC pulses and/or return strokes were considered. The main difference in the reported DE values of these previous studies is most likely a result of the limitations of the used method (video observations versus tower measurements), the used data (only return strokes versus a mix of return strokes and ICC pulses), and regional variations of the DE, as discussed in the introduction of this paper.

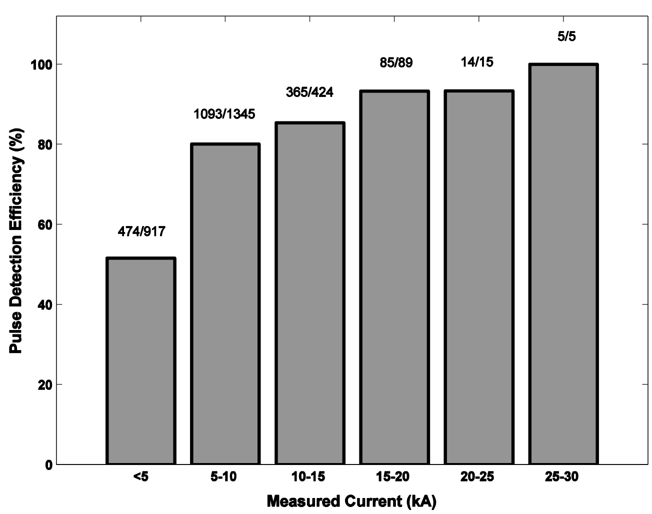

Figure 5. EUCLID detection efficiency as a function of pulse peak current measured at Säntis (the bin size of 5 kA) for upward negative events.

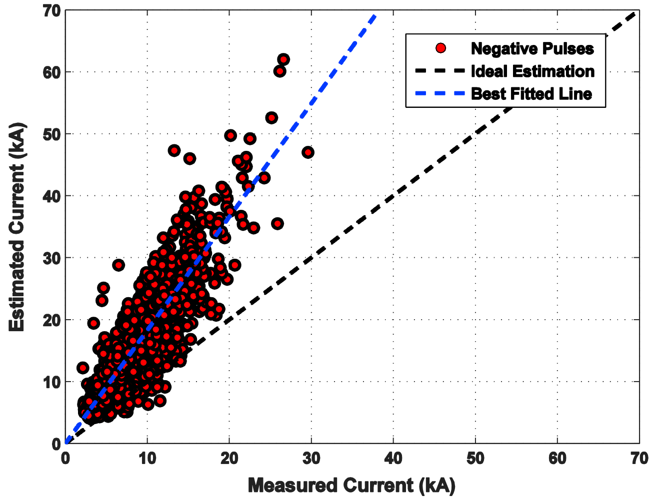

Figure 6. EUCLID peak current estimates versus peak currents directly measured at the Säntis Tower.

4. Results and Discussion

As mentioned in section 2, among 273 negative flashes recorded during the considered period of this study, three of them were classified as downward flashes and one was discarded because it was not possible to accurately correct its associated time drift. Excluding these four flashes, 269 upward negative flashes were analyzed in this study. It is important to note that upward flashes containing only an initial continuous current ICC (with neither superimposed pulses with peaks higher than 2 kA nor return strokes) were not considered in the present analysis. These flashes (labeled "ICC_{Only}" in *Diendorfer et al*. [2009]) were excluded for two reasons. First, LLS's are not able to detect ICC_{Only} flashes. Second, the lightning measurement system currently installed at the Säntis Tower is triggered by the d*i*/d*t* signal measured by the B-dot sensor and, therefore, it is likely that the system misses most of the flashes containing ICC_{Only}.

4.1. Flash Detection Efficiency (Excluding Upward Flashes Containing Only ICC)

Table 1 presents the flash detection efficiency for negative flashes to the Säntis Tower observed in the mentioned period, during which 269 upward flashes were recorded by the current measurement system with available timestamps. Out of these 269 flashes, 7 (2.6%) were characterized by an ICC with no pulses satisfying the higher than 2 kA peak current and were not considered in the analysis. Figure 3 shows an example of a

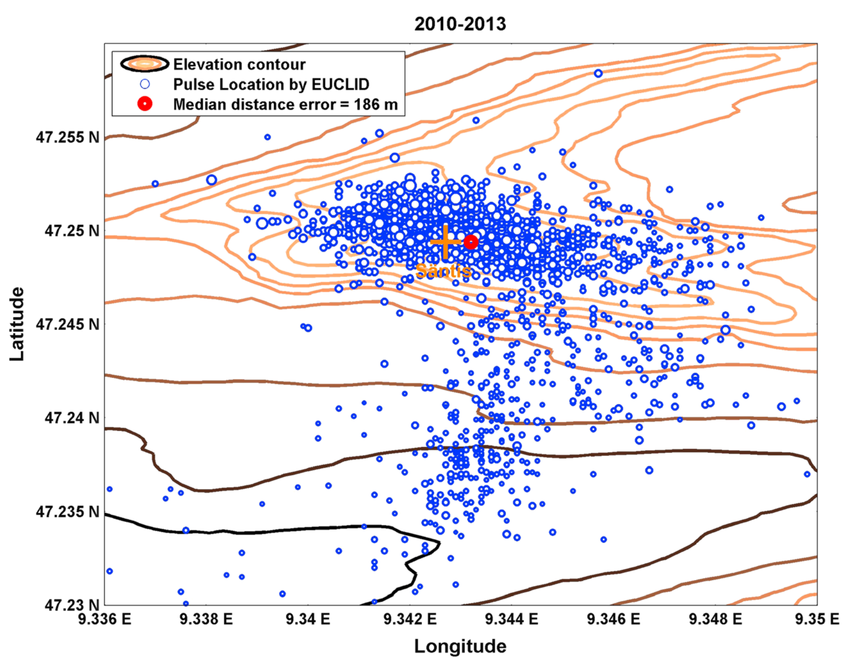

Figure 7. Plot of EUCLID pulse locations for upward negative flashes recorded in the period of analysis. The size of the circles is proportional to the current peak measured at Säntis. The length and width of the shown area are, respectively, 3.34 and 1.06 km.

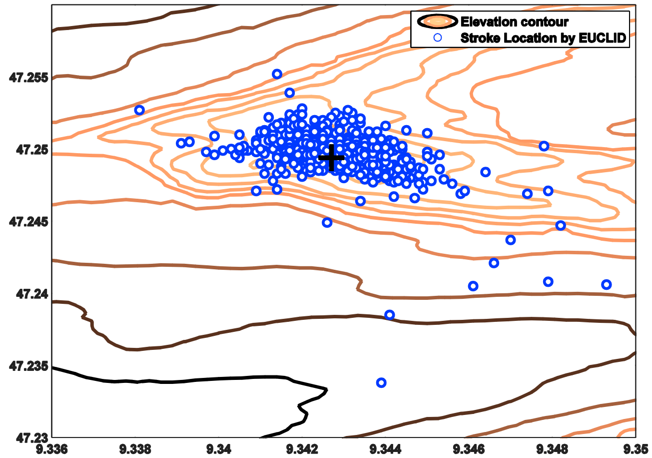

Figure 8. Plot of pulse locations estimated by EUCLID excluding pulses with peak values lower than 10 kA.

negative flash with just an ICC and low amplitude ICC pulses. Out of the considered flashes, 253 were detected by the EUCLID network, resulting in a flash detection efficiency of 97%.

It is worth noting that the number of pulses per flash (multiplicity) for upward flashes measured at Säntis has a median value of about 8 [*Romero et al.*, 2013], which is about twice as high as the multiplicity of downward flashes [CIGRE WG C4.407 Report 549, 2013]. This might explain the obtained high value for the EUCLID efficiency in detecting Säntis flashes, despite the fact that upward flashes do not have first strokes.

4.2. Pulse Detection Efficiency

A total of 2795 pulses classified either as return strokes or as ICC pulses satisfying the risetime and amplitude criteria presented in section 2 were identified in this study. Figure 4 shows the peak current distribution of these pulses, featuring a maximum value of 29.6 kA, a median of 7.1 kA, and a geometrical mean value of 6.3 kA. Figure 5 presents the pulse detection efficiency as a function of measured peak current at the Säntis Tower. As expected, the detection efficiency of the EUCLID network increases with the peak current value. The overall pulse detection efficiency is 73%. For pulses with peak values higher than 5 kA, the pulse detection efficiency is about 83%. It is interesting to note that, among the total number of 2036 detected pulses, 73% of the time-correlated pulses were classified as cloud pulses by EUCLID. This can be explained by the fact that ICC pulses with short current risetimes are believed to be associated with leader/return stroke mode discharges to an existing channel branch at some height above the tower top [*Flache et al.*, 2008; *Zhou et al.*, 2015]. Another reason for misclassification is that electric fields radiated from return strokes to a tall tower might feature a shorter peak-to-zero time [*Pichler et al.*, 2010] or an undershoot (for very tall structure) [*Pavanello et al.*, 2009].

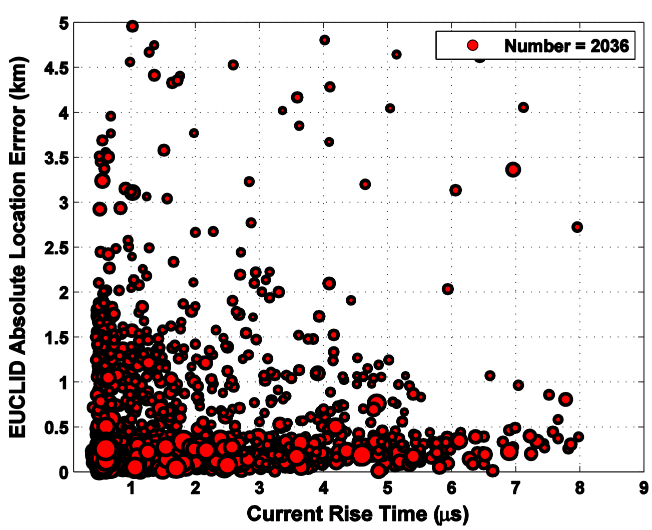

Figure 9. EUCLID absolute location error versus measured 10–90% current rise time for upward negative pulses. The radius of each circle is proportional to the current peak value.

4.3. Peak Current Estimates

The problem of indirect estimation of lightning return stroke currents from remote electromagnetic field measurements has been thoroughly discussed in the literature (see, e.g., [*Rachidi and Thottappillil*, 1993]. From a theoretical point of view, it has been shown [*Rachidi et al.*, 2004] that a statistical estimation (e.g., in terms of mean values and standard deviations) of the current peak is possible from remote field measurements. However, due to the high variability of key parameters such as the return stroke speed, it is impossible to determine the lightning current accurately from the remotely measured electric or magnetic field for a given event. On the other hand, triggered lightning was used to test peak current

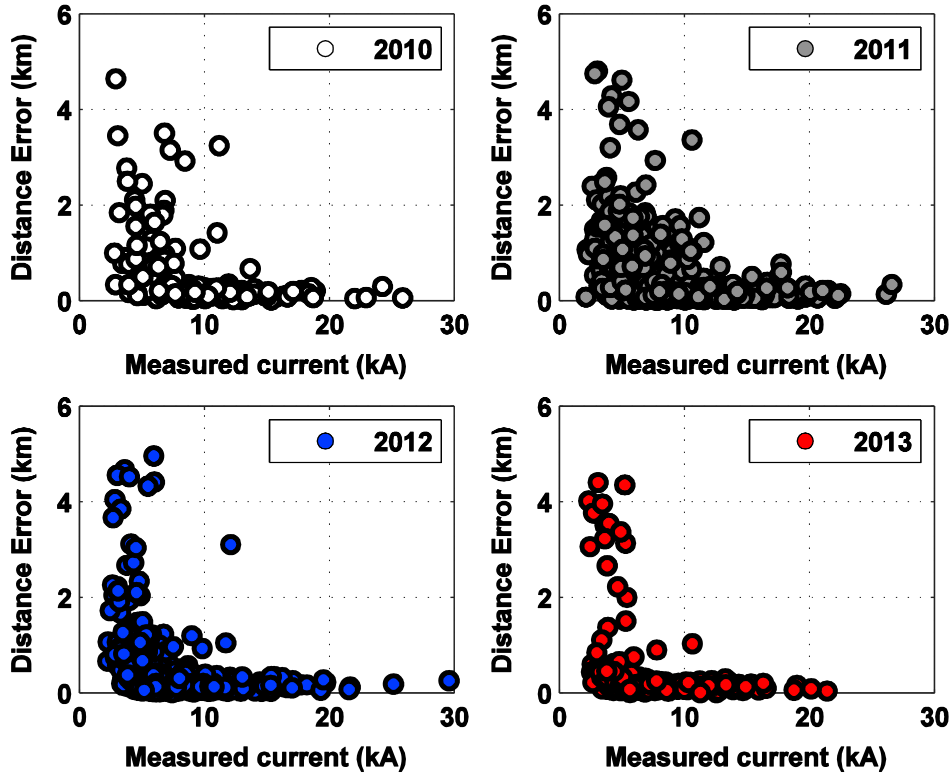

Figure 10. EUCLID absolute location error versus Säntis Tower measured peak current for pulses of upward negative events. Data are presented in different plots and different colors are associated with each of the four years of considered in this study.

estimates provided by LLSs. It was shown that the ratio of directly measured and estimated current peaks was characterized by an arithmetic mean of 1.1 [*Nag et al.*, 2011].

Figure 6 presents peak current estimates provided by the EUCLID network as a function of the peak currents directly measured at Säntis. It can be seen that EUCLID tends, in general, to overestimate the peak current. The best fit linear regression, forced to go through the origin, is also shown in Figure 6 which shows that the current estimates provided by EUCLID are typically about 1.8 times higher than those from direct measurements. Note that this difference is well above the uncertainty associated with the current measurement system (Rogowski coil), which has been estimated to be less than 3% [*Azadifar*, 2015].

The overestimation of the peak current can be attributed to the enhancement of the radiated electromagnetic fields due to the presence of the tower and the mountain [e.g., *Baba and Rakov*, 2005, 2007; *Bermudez et al.*, 2005; *Pavanello et al.*, 2009]. A recent full wave finite difference time domain analysis [*Li et al.*, 2015] supported by experimental observations consisting of simultaneous records of lightning currents and electric fields revealed that the combined effect of tower and mountainous terrain topography around Säntis Tower results in an enhancement of radiated electric field, which is consistent with the overestimation of the EUCLID Network.

Table 2. Evolution of the Median and the Mean Values of Absolute Distance Error for Pulses Detected by the EUCLID Network

Year	2010	2011	2012	2013
Number of Pulses	167	1104	494	271
Median (m)	219	191	186	160
Arithmetic Mean (m)	587	487	449	386

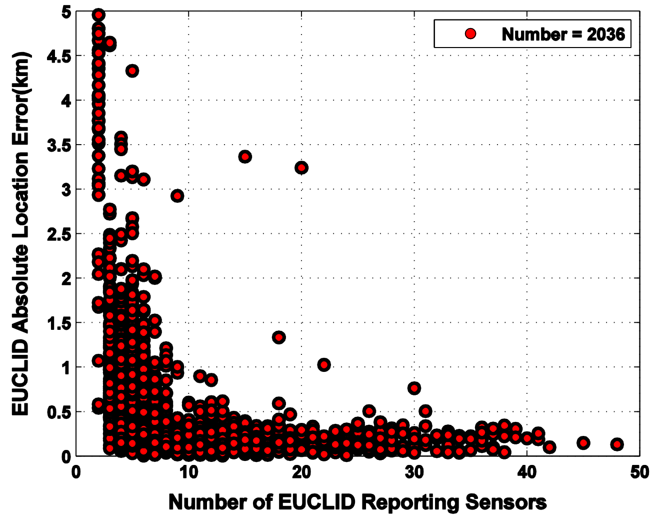

Figure 11. EUCLID absolute location error versus the number of EUCLID reporting sensors.

4.5. Location Accuracy

Figure 7 presents a plot of pulse locations estimated by the EUCLID network for the Säntis Tower pulses. In that figure, the location of each pulse is marked with a circle whose radius is proportional to the peak current value measured at the Säntis Tower. It can be seen that most of the pulse locations are around the tower. However, a secondary cluster is located in the south of the tower. As shown in Figure 8, these larger location errors are related to low peak pulses (lower than 10 kA or so), most of which are associated with ICC pulses. As discussed in *Diendorfer et al*. [2014], ICC pulses with short risetimes are due to return strokes attaching to an existing channel and often involve strongly tilted channel branches at low altitudes. As a result, larger location errors are associated with them.

On the other hand, the location accuracy seems not to be appreciably affected by the current risetime, as can be seen in Figure 9 in which the absolute location errors of the EUCLID network are presented as a function of the 10–90% current risetime. In this figure, the radius of each circle is proportional to the current peak value. It can be seen that no clear correlation can be found between current rise time and the absolute location error. It is worth noting that, for pulses with much larger risetimes (8 μs and larger), it is expected that the probability of detection decreases considerably. Data at the Gaisberg Tower have revealed that only 3% of the pulses with current risetimes greater than 8 μs were detected by EUCLID.

The median of the absolute distance error, defined as the median distance between the Säntis Tower location and EUCLID's stroke locations, is 186 m. The absolute location error as a function of the peak current measured at the Säntis Tower is presented in Figure 10 in separate plots, one for each study period year. It can be seen that large location errors are associated with pulses whose measured current peaks are lower than 10 kA. It can also be seen from Figure 10 that the location accuracy of the EUCLID network improved considerably in 2013 following an upgrade in the used location algorithms to account for propagation effects [*Schulz et al*., 2015]. Table 2 presents the evolution of the median and the mean values for the absolute distance error.

An important factor that might affect location accuracy of the system is the number of reporting sensors for each pulse. Figure 11 shows EUCLID absolute location error versus the number of its reporting sensors for each pulse. As expected, the absolute distance error decreases with an increase of the number of reporting sensors.

Figure 12a shows a scatterplot of EUCLID's semimajor axis length of the 50% confidence ellipse for each pulse versus measured peak current. It can be seen that the majority of large semi-axis values are associated with low peak current values. A plot of EUCLID's semimajor axis length of the 50% confidence ellipse versus location error is presented in Figure 12b. In this figure, pulses characterized by peak currents lower than 10 kA are shown in red, while those associated with peak currents greater than 10 kA are shown in blue. It can be seen that the peak current is the critical parameter determining the location accuracy. It is worth noting that using the median confidence ellipse as a measure of the median location error of LLS's is widely accepted and its accuracy was validated based on lightning to the Gaisberg Tower [*Diendorfer et al*., 2014].

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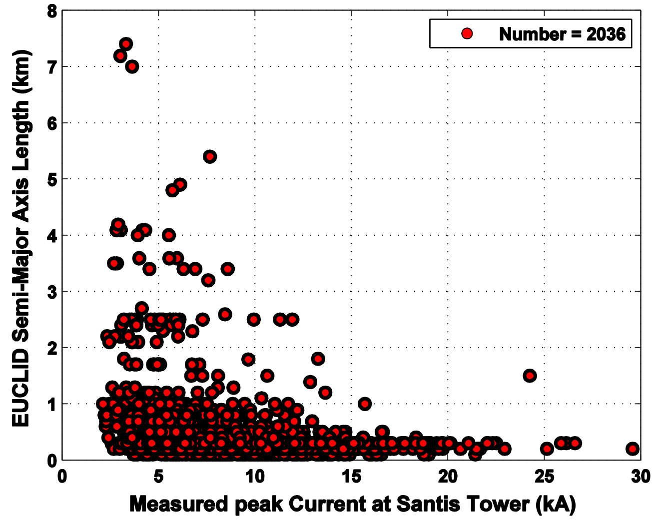
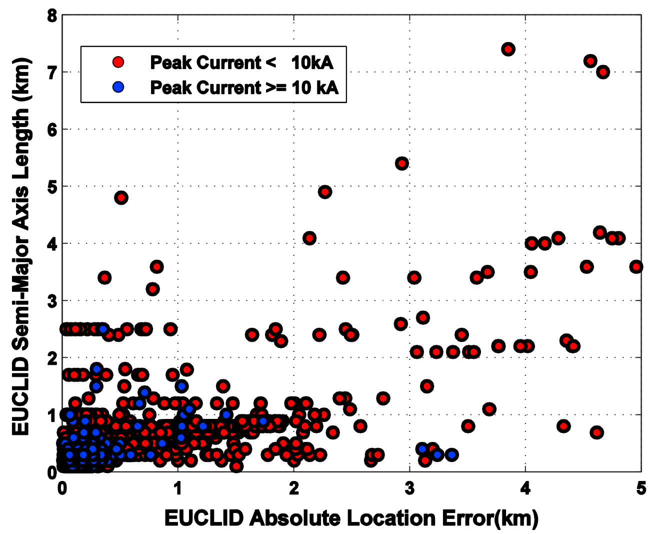


(a)



(b)

Figure 12. (a) EUCLID semimajor axis length of the 50% confidence ellipse versus peak current value of upward negative pulses measured at the Säntis Tower and (b) EUCLID semimajor axis length of the 50% confidence ellipse versus absolute location error of upward negative pulses.

5. Summary and Conclusions

We presented a performance analysis of the EUCLID lightning detection network using the obtained data on lightning currents measured at the Säntis Tower from June 2010 to December 2013. In the considered period of analysis, a total of 269 upward negative flashes were recorded at the tower. The performance of the EUCLID lightning detection network was evaluated for negative upward flashes (excluding ICC_{Only} flashes) in terms of detection efficiency, location accuracy, and peak current estimates. The overall flash detection efficiency was estimated to be 97%.

The recorded flashes contained a total number of 2795 pulses (including return strokes and ICC pulses with risetimes lower than 8 µs and peaks greater than 2 kA). It should be noted that in a number of the measured flashes, the level of the initial continuous current was too low to allow the unequivocal classification into ICC pulses and return strokes. The overall pulse detection efficiency for upward flashes was found to be 73%. For pulses with measured peak currents higher than 5 kA, the pulse detection efficiency for upward flashes was about 83%. Note that the pulse detection efficiency given in this paper is obtained for a combination of return strokes and ICC pulses of short risetimes (<8 μs), and therefore, it is not directly comparable to DE values obtained in other experiments, where a clear distinction is made between return strokes and ICC pulses (e.g., triggered lightning or Gaisberg Tower).

Peak current estimates provided by the EUCLID network were found to be significantly larger than their directly measured counterparts. This overestimation might be attributed to the enhancement of the radiated electromagnetic fields associated with the presence of the tower and the mountain.

The median of the absolute distance error defined as the median distance between the Säntis Tower location and EUCLID's stroke locations was found to be 186 m. It was observed that most of the large location errors are associated with measured current peaks lower than 10 kA. The analysis revealed also that the location accuracy of the EUCLID network improved significantly in 2013, after the location algorithms were upgraded to take into account propagation effects.

The analysis presented in the paper can be considered as indicative of the general performance of lightning location systems in mountainous areas. However, the location accuracies and detection efficiencies inferred in this paper can certainly not be generalized to all the Alps region. More research is definitely needed to generalize the presented results in wider areas.

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