Validation of Cloud-to-Ground (CG) Lightning Flash Discriminations Obtained from Two Different Lightning Data Processing Programs by the Reference E-Field Recordings

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ABSTRACT: We present a comparison between lightning data from Polish lightning detection system, called PERUN, and a reference station E-field measurements in low frequency (LF) range. PERUN data were obtained in parallel from two different central processor's versions. In 2012 the Institute of Meteorology and Water Management (IMGW), which is the Polish Meteorological and Hydrological Service, upgraded a lightning detection's core processing program called 'SAFIR Central Module' (SCM) [Loboda et al. 2009] to the newest technology called 'Total Lightning Processor' (TLP) [Vaisala]. Vaisala company was a producer of the two program's versions. During the modification of PERUN system the SCM version was added in parallel to TLP so the system is generating two separate lightning datasets, i.e. the former and the current one. To compare two datasets we used E-field recordings in LF range archived by one measuring station of the Local Lightning Detection Network (LLDN) [Baranski et al., 2011]. These recordings served as an additional reference data source of independent cloud-to-ground (CG) stroke identifications. We analyzed a random set of data derived from 2013. SCM and TLP detected only 28% and 12% of reference records respectively. The results showed that CG stroke discrimination criteria applied in the PERUN system by the SCM and TLP central processor give 92% and 60% confirmation by reference independent identifications, respectively. The polarity of detected CG strokes by both central processors in the PERUN system was in perfect accordance with the reference E-field recordings. The reference measurements have shown 16 multiple CG flash incidents with multiplicity ranging from 2 to 5, while the SCM has partially distinguished only 6 of them.

INTRODUCTION

In 2013 a validation procedure was performed in order to compare randomly chosen data and to check reliability of two data processing programs implemented in the Polish lightning location system called PERUN. We present some results on detection of lightning events and discrimination of lightning type from two different measurement datasets validated by reference single-station electric field recordings in low frequency (LF) range. Six random thunderstorm days were chosen to collect data. Differences in return stroke (RS) discrimination attributions for single and multiple CG flashes have been observed for PERUN lightning data in comparison to 89 E-field RS signatures collected by the reference measuring

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station. Some earlier results were published by Baranski and Bodzak [2006].

The data processing programs (called "central processors") were connected to the same lightning detection network consisted of lightning sensors SAFIR3000 type produced by Vaisala company. SCM is more than 10 year older than TLP. Our motivation was to investigate improvement and reliability of discrimination mechanisms applied in SCM and TLP basing on a few reference measurements.

Description of the SAFIR3000 network and PERUN system

A national lightning detection network called "PERUN system" operates in Poland since 2002. It was installed by the Institute of Meteorology and Water Management (IMGW). The network consists of 9 SAFIR3000 sensors operating in LF and very high frequency (VHF) bands. Sensors are located homogenously with baseline of 200 km over territory of Poland. Until 2005 sensors were connected to SCM central processor unit using satellite connection, later the connection was changed to Wide area Network (WAN). From 2002 the system is collecting total lightning data (cloud-to-ground flash data and cloud-to-cloud lightning data).

Until 2011 SCM was working operationally as a primary central processor unit. When in 2009 Vaisala (SCM's manufacturer) expressed its decision to stop supporting this type of technology, IMGW decided to upgrade central processor to the Total Lightning Processor (TLP) version. Upgrade process was finalized in 2012.

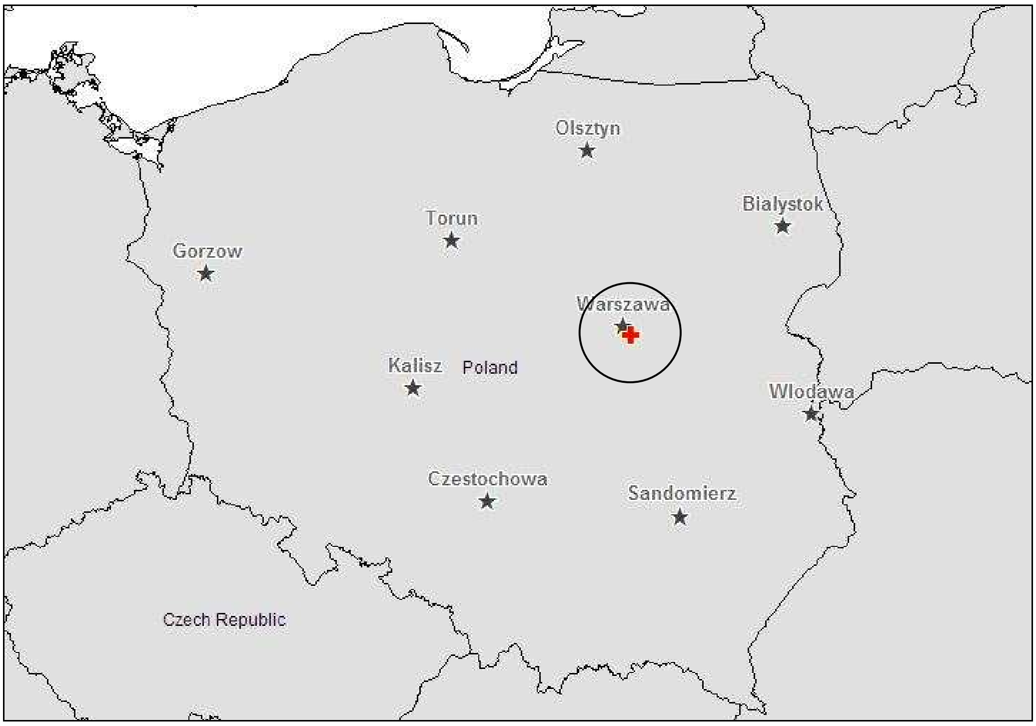

Figure 1. Configuration of the Polish lightning detection stations (marked as black stars) of SAFIR3000 network. The reference LLDN station is marked as red cross. Circle shows approximate area of validation

A need of verification of the new system

After the upgrade we learned from a few weather forecasters' reports that TLP could be underperforming. There was a possibility to check data quality improvement (between SCM and TLP versions) because a special process on TLP computer has been running since an upgrade. The process allows doubling each of nine received source data-steams. The doubled data is transmitted in a parallel mode to two central processors TLP and SCM. Both central processors were performing lightning data parameters calculations in independent way, using different algorithms.

In order to document differences in lightning data produced by two central processors we decided to choose an independent dataset that can serve as a reference measurement.

Reference sensor

As a validation data we chose a single-station E-field antenna detecting in LF range. Earlier the antenna was used in Local Lightning Detection Network (LLDN) [Baranski et al. 2012] The antenna is placed in a faraway place in Warsaw. Location of the antenna corresponds to the center of PERUN network. Hence we assumed homogeneous network performance of the PERUN network over the validation area. Figure 1 shows a configuration of PERUN network in the period of performing validation measurements with the Polish lightning detection stations marked as black stars and the reference LLDN station marked as a red cross. Similar measurements were conducted by Sonnadara et al. [2006a] and Richard et al. [1986].

DATA ANALYSIS

Measurements

The comparison area was limited to a circle of 55 km radius with its center in Warsaw (Lat. = 52°12'52" N Lon. = 21°04'03" E), in location where the reference antenna was placed. The area is about 3% of PERUN network coverage.

The reference antenna was recording electric field changes with 1 µs time resolution, whereas for the TLP and the SCM return stroke data it was 100 µs. Output data of the reference measurements set allowed to register field changes and to make interpretation of detected events such as polarity and multiplicity of the detected events. Recorded lightning activity data from reference measurements was interpreted basing on commonly known masks. Examples of lightning signal records from the measurement set are shown in figures 2 and 3.

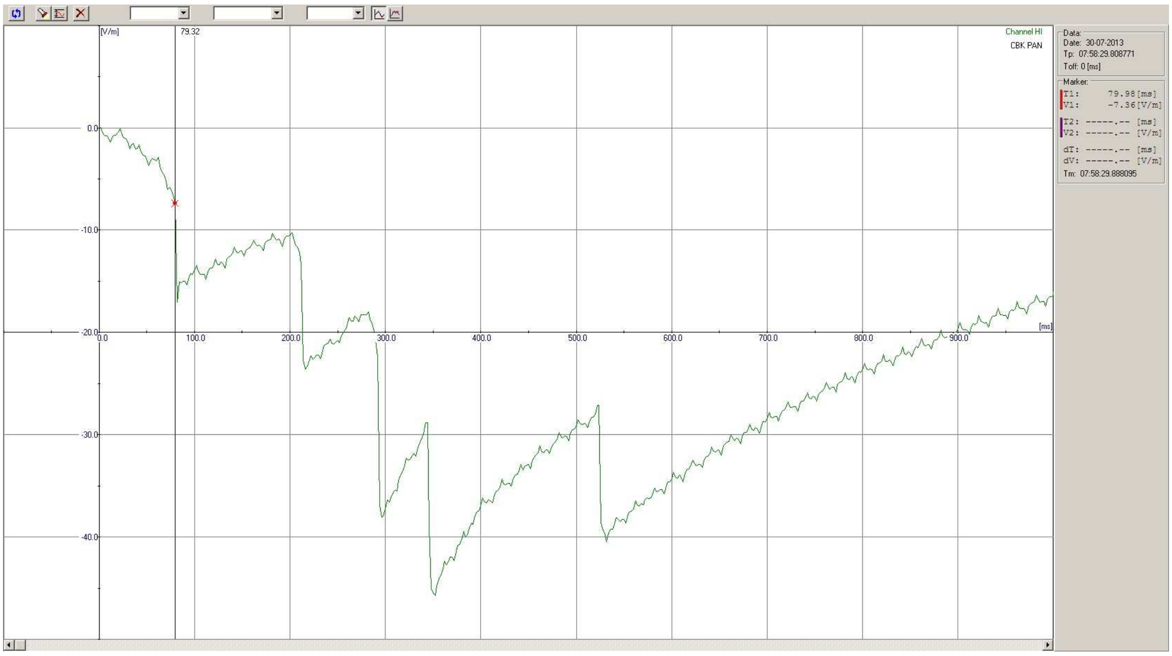

Figure 2. Multiple CG flash consisting of 5 negative polarity return strokes recorded from reference measurement sensor in Warsaw. A vertical line with a red “x” mark shows a starting point of lightning event.

Personal investigation of records allowed to create a list of detected signals. The collected reference dataset consisted of diversified content:

- Date and time (with 1 μs resolution) of a lightning stroke timestamp. The timestamp was determined by personal inspection of graphs. It allowed registering the precise time of a lightning starting point. See a vertical line with a red “x” mark in figure 2 and 3.
- Number of subsequent stroke in multiple flash (“0” value in this column means identification of a bipolar flash)
- Polarity of a detected event (“+” – positive, “–“ – negative)
- Cloud-to-ground type identification (“RS” for cloud-to-ground return stroke or “RS/CC” for cloud-to-ground return stroke with continuing current phase)

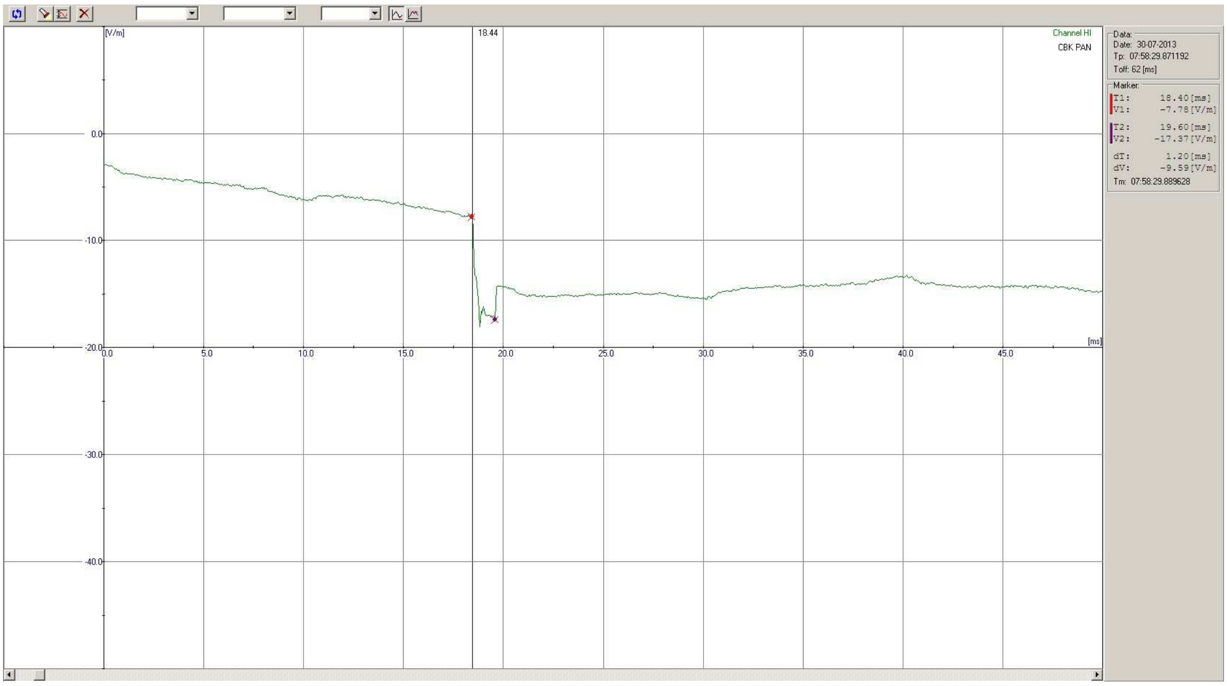

Figure 3. Single stroke, negative CG flash recorded from reference measurement sensor in Warsaw. A vertical line with a red "x" mark shows a starting point of lightning event.

Data comparison procedure

GPS time precision was truncated to 0.1 ms in SCM and TLP (GPS antenna precision was nanosecond, but it is not used in secondary data format on which we made the comparison). A use of raw data with better time quality was not possible from technical reasons. We applied the following criteria for validation:

- Distance reported by PERUN system between detected events and reference measurement antenna location had to be less than 56 km
- Time criteria for detected events was limited according to the following inequalities

$$\begin{cases} T_{D1} = t_{SCM} - (t_R - t_P) \leq 300\mu s \\ T_{D2} = t_{TLP} - (t_R - t_P) \leq 300\mu s \end{cases} \qquad (1)$$

where:

T_{D1} – time difference between SCM and corrected reference antenna measurement
T_{D2} – time difference between TLP and corrected reference antenna measurement
t_R – lightning event time reported by reference antenna
t_P – propagation correction (assuming speed of light signal propagation)
t_{TLP} – lightning event time reported by TLP
t_{SCM} – lightning event time reported by SCM

Basing only on signal propagation correction the T_{D1} and T_{D2} values should be less than 180μs to be considered as corresponding events in various systems. Use of such value resulted in rejecting a few RS from multiple flashes. To allow these RS from multiple flashes we assumed that there were other time errors sources that were rising this value to 300µs. Doing so we gave priority to multiple RS recognition by SCM.

For each reference measurement, databases of SCM and TLP were browsed in order to find corresponding events that fulfill (1) criteria. Results are showed in Table A and B in the Appendix. The mean time difference (T_{D1} and T_{D2}) between reference measurements was 121 µs for SCM and 132 µs for TLP.

Results

Analysis of thunderstorm days selected for validation resulted in 89 recognized events. RS and 37 continuing current (CC) stroke events with both polarities were detected by the reference LLDN station. Due to small dataset we decided to include in the comparison a few cloud-to-cloud data from SCM (2 events) and TLP (4 events), understanding them as a misidentification caused by improper functioning of discrimination algorithms.

Table 1. Classification of detected signals.

Type of discrimination and polarity	Number of strokes identified by reference station	Number (and %) of strokes detected by SCM	Number (and %) of strokes detected by TLP
RS-	42	20 (48)	9 (21)
RS+	6	0 (0)	1 (16)
RS/CC+	28	2 (7)	1 (4)
RS/CC-	9	1 (11)	0 (0)
Bipolar (RS- and RC+ afterwards)	4	2 (50)	0 (0)

We did an approach to test multiplicity, but as in TLP configuration the multiple strokes recognition was not set [Sonnadara et al. 2006b] we were examining only if multiple strokes reported by reference antenna were detected by TLP as return strokes (RS).

Table 2. Multiple flash detection

Type of flash	Number of flashes/strokes identified by reference station	Number of flashes*/strokes detected by SCM	Number of flashes**/strokes detected by TLP
Single stroke flashes	46/46	6/6	4/4
Two stroke flashes	8/16	3/6	1/3
Three stroke flashes	3/9	1/3	0/2
Four stroke flashes	0/0	0/0	0/0
Five stroke flashes	2/10	2/8	0/2
Bipolar flashes	4/8	2/2	0/0

Total	63/89	14/25	5/11

*As SCM did not report every RS in flash event we assumed that the flash is detected if at least two strokes in one multiple flash (identified by reference measurement) were detected by SCM.

**As TLP did not report flash event at all we assumed that the flash is detected if at least two strokes in one multiple flash (identified by reference measurement) were detected by TLP.

As the SCM dataset has an information about flash multiplicity ("Discr." column in Table A and B in the Appendix) it was possible to take it into consideration [Sonnadara 2014]. A total number of proper assignment of multiplicity information by SCM was only 4 flashes, so we decided to ignore this information. Only RS stroke information was compared to the reference measurements. SCM recognized 21% of flashes and 28% of RS information from multiple flashes detected by the reference measurements.

Polarities fit perfectly for CG discriminations in PERUN data, it means that if the event was recognized as cloud-to-ground, the system properly determined its polarity in every case.

Table 3. Polarity

Polarity of return stroke	SCM results	TLP results
Consistent	23	7
Opposite	0	0
Recognized as cloud-to-cloud	2	4

DISCUSSION AND CONCLUSIONS

Number of collected by the reference antenna events and a relatively small amount of correlated lightning data from both central processors do not allow to perform reliable validation due to large errors. However they are important clue about performance of two installed systems.

The final result of 7 cloud-to-ground return strokes detected by the TLP consistent with 89 incidents indicated by the reference measurements is a strong signal that some changes in TLP should be done. SCM result shows that better performance with the same source data is possible.

It is important to note that personal investigation of reference measurement signals is very time consuming. Future analysis should have more automated procedure of finding and preparing the reference dataset. Better time resolution for PERUN data should be used and a source of large time difference in (1) should be investigated. It is important also to mark that SCM reported some of bipolar flashes only by its first RS while TLP did not report any.

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APPENDIX

Tables show data used for validation. On the left side we present reference measurements. On the right side SCM data (Table A) and TLP data (Table B) are presented. The data are filtered using (1) and (2) inequalities, respectively for SCM and TLP. Table A contains all reference measurements. In Table B only events correlated with TLP data are collected.

Table legend, columns:

#	– number of subsequent stroke ('0' means a bipolar stroke)
Discr.	– Discrimination given by SCM or TLP system, it can have values ranging from 0 to 5. • 0 for isolated point • 1 for beginning of Cloud-to-cloud event • 2 for midpoint of Cloud-to-cloud event • 3 for end of Cloud-to-cloud event • 4 for first RS of Cloud-to-ground event • 5 for subsequent RS of Cloud-to-ground event
Dist. to ref. antenna	– a distance form lightning event to the reference antenna.
T_{D1}	– time difference between SCM and corrected reference antenna measurement
T_{D2}	– time difference between TLP and corrected reference antenna measurement

Table A. Data selected for SCM

Reference measurements							SCM lightning data						
Date 2013 dd/mm	hh	mm	ss.ssssss	#	Identification	Polarity	hh	mm	ss.ssss	Discr.	I [kA]	Dist. to ref. antenna [km]	T_{D1} [μs]
21/06	11	51	0.532515	0	RS	-	11	51	0.5324	4	-10.57	50	51
21/06	11	51	0.533645	0	RS	+							
25/06	14	3	34.737784	0	RS	-							
25/06	14	3	34.73891	0	RS	+							
25/06	14	3	34.773609	1	RS	-							
26/07	19	10	38.777118	1	RS	-							
26/07	19	10	38.826099	2	RS	-							
26/07	19	10	38.880001	3	RS	-							
26/07	19	11	13.517419	1	RS	-							
26/07	19	11	13.588478	2	RS	-							
26/07	19	11	13.655936	3	RS	-							
26/07	19	12	50.685519	1	RS/CC	+							
26/07	19	12	50.903811	1	RS/CC	+	19	12	50.904	1	0	29	284
26/07	19	12	51.031836	1	RS/CC	+							
26/07	19	13	18.541983	1	RS	-							
26/07	19	14	16.537711	1	RS	-	19	14	16.5377	4	-12.50	27	78
26/07	19	14	16.778311	1	RS	-							
26/07	19	14	16.793327	2	RS/CC	-							
26/07	19	14	16.897336	1	RS	-							
26/07	19	14	53.426359	1	RS	-	19	14	53.4264	4	-10.79	25	124
26/07	19	14	53.6417	1	RS	-	19	14	53.6417	5	-13.96	25	82
26/07	20	45	52.760768	1	RS	-							
30/07	7	58	29.889628	1	RS	-	7	58	29.8897	4	-13.42	42	211

30/07	7	58	30.02156	2	RS	-	7	58	30.0215	4	-17.31	39	70
30/07	7	58	30.102096	3	RS	-							
30/07	7	58	30.154073	4	RS/CC	-	7	58	30.1541	5	-15.31	43	170
30/07	7	58	30.332681	5	RS	-	7	58	30.3326	5	-21.06	43	62
30/07	8	2	54.658674	1	RS/CC	+							
30/07	8	4	0.6086	1	RS/CC	+							
30/07	8	4	0.81301	1	RS	-	8	4	0.813	4	-14.27	47	145
30/07	8	4	22.193096	1	RS/CC	+							
30/07	8	4	22.369481	1	RS	-							
30/07	8	7	14.754419	1	RS	+							
30/07	8	7	14.781714	1	RS	-	8	7	14.7816	4	-9.04	51	54
30/07	8	7	14.866593	2	RS	-	8	7	14.8665	5	-11.29	54	85
30/07	8	9	37.097342	1	RS/CC	+							
30/07	8	9	37.390783	1	RS/CC	+							
30/07	8	10	20.089024	1	RS/CC	+							
30/07	8	10	20.258757	1	RS/CC	+							
30/07	8	11	36.872414	1	RS	-	8	11	36.8724	5	-25.42	40	119
30/07	8	11	36.904523	2	RS	-							
30/07	8	11	36.92814	3	RS	-	8	11	36.9282	5	-13.43	42	199
30/07	8	11	36.975882	4	RS	-	8	11	36.9758	4	-30.87	40	50
30/07	8	11	37.025049	5	RS	-	8	11	37.025	4	-23.31	42	91
30/07	8	12	44.502928	1	RS/CC	+							
30/07	8	12	44.599427	1	RS/CC	+							
30/07	8	13	14.62839	1	RS/CC	+							
30/07	8	13	14.785517	1	RS/CC	+							
30/07	8	14	6.598153	1	RS/CC	+							
30/07	8	14	36.514638	1	RS	-							
30/07	8	16	22.202394	1	RS	-	8	16	22.2023	4	-45.96	55	88
30/07	8	16	22.259175	2	RS	-	8	16	22.259	5	-8.63	53	3
13/10	13	51	42.723629	1	RS	-	13	51	42.7236	4	-12.55	46	124
13/10	13	51	42.748882	2	RS	-	13	51	42.7488	5	-22.92	47	74
13/10	13	51	42.803796	3	RS	-	13	51	42.8039	5	-18.68	45	255
13/10	13	53	52.205967	1	RS	-	13	53	52.2059	4	-18.35	45	82
13/10	13	53	52.28771	2	RS	-	13	53	52.2877	5	-12.80	41	126
13/10	13	53	52.48268	1	RS	-							
13/10	14	33	10.551388	1	RS/CC	-							
13/10	14	41	32.934775	1	RS	-							
06/12	1	8	29.640964	1	RS/CC	+							
06/12	1	11	14.481226	1	RS/CC	+							
06/12	1	11	14.493808	1	RS/CC	+							
06/12	1	12	57.628567	0	RS	-							
06/12	1	12	57.629631	0	RS	+							
06/12	1	15	41.236958	1	RS	+							
06/12	1	15	41.294872	1	RS	+							
06/12	1	15	41.311567	1	RS/CC	+	1	15	41.3117	4	15.51	36	254

06/12	1	15	41.330255	1	RS/CC	+							
06/12	1	17	50.889575	1	RS/CC	+							
06/12	1	17	51.106985	1	RS/CC	+							
06/12	1	19	36.441286	1	RS/CC	+							
06/12	1	19	36.456458	1	RS/CC	+							
06/12	1	19	36.5824	1	RS	+							
06/12	1	22	38.794174	1	RS/CC	+							
06/12	1	22	38.999113	0	RS	-							
06/12	1	22	39.000224	0	RS	+	1	22	39.0002	2	0	49	139
06/12	1	25	53.660516	1	RS	-							
06/12	1	25	53.68568	1	RS	-							
06/12	1	25	54.466718	1	RS	-							
06/12	2	11	50.165268	1	RS/CC	+							
06/12	2	11	50.194503	2	RS/CC	+							
06/12	2	11	50.35645	1	RS/CC	+							
06/12	11	13	1.563615	1	RS/CC	-							
06/12	11	13	1.566298	2	RS/CC	-							
06/12	11	13	2.32931	1	RS/CC	-							
06/12	11	13	2.332825	2	RS/CC	-							
06/12	11	13	3.290379	1	RS/CC	-							
06/12	11	13	3.293201	2	RS/CC	-							

Table B. Data selected for TLP

Reference measurements							**TLP lightning data**						
Date 2013 dd/mm	**hh**	**mm**	**ss.ssssss**	**#**	**Identification**	**Polarity**	**hh**	**mm**	**ss**	**Discr**	**I [kA]**	**Dist. to ref. antenna [km]**	**T_{D2} [μs]**
26/07	19	11	13.655936	3	RS	-	19	11	13.656	4	-13.75	27	155
26/07	19	12	50.903811	1	RS/CC	+	19	12	50.904	0	0	28	283
26/07	19	13	18.541983	1	RS	-	19	13	18.5421	4	-40.68	28	209
26/07	19	14	16.778311	1	RS	-	19	14	16.7784	1	0	18	148
30/07	7	58	30.332681	5	RS	-	7	58	30.3326	4	-22.55	42	60
30/07	8	4	0.81301	1	RS	-	8	4	0.813	4	-14.84	46	142
30/07	8	11	36.92814	3	RS	-	8	11	36.9283	0	0	18	221
30/07	8	16	22.202394	1	RS	-	8	16	22.2023	4	-50.8	55	88
30/07	8	16	22.259175	2	RS	-	8	16	22.259	4	-11.82	53	2
13/10	13	51	42.723629	1	RS	-	13	51	42.7236	4	-13.23	46	124
12/06	1	15	41.236958	1	RS	+	1	15	41.2369	2	0	23	20