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Negative Cloud-to-Ground Lightning in the Alpine Region

A new Approach

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Abstract*— Cloud-to-ground (CG) flashes in the Alpine Region show some specific characteristics not being observed in other regions of the world. One of them is the observation of a 10% to 15% higher percentage of negative single stroke flashes during warm-season thunderstorms. Such a high percentage of single stroke negative CG flashes is a unique observation and deserves a scientific investigation. Besides that, a lack of information to confirm or refute a geographical dependence of the majority of lightning parameters is currently present and most of the lightning parameters for lightning protection were determined more than 35 years ago. As the design of lightning protection systems is based on lightning parameters, further research on their regional suitability is of interest for the society. In the course of this research project, root causes for the high percentage of negative single stroke flashes in the Alpine Region are closely investigated and a detailed study on flash and stroke parameters is performed. On-site time correlated high-speed-videos in conjunction with E-field measurements during different storms are conducted and sites with orographically exposed areas such as mountain tops and mountain crests are the main observation areas. Additionally wind turbines, antennas and transmission line towers under alpine conditions are in the focus. Lightning location data and meteorological data are used as supplementary data in order to base the analysis on comprehensive flash and storm information. The captured high resolution video and E-field data in conjunction with lightning location data and meteorological data will allow to identify the reasons for the deviating CG flash conditions as well as to extract properties and behavior of natural lightning in general. Investigations within the context of the research will provide comprehensive flash and stroke parameters considering alpine orography and exposed infrastructure. Results of this project will give an elaborated data set to estimate the hazard potential due to negative CG lightning and will contribute to a better understanding of the discharge behavior of lightning in general.

Keywords*— *Cloud-to-Ground Flash; Single Stroke Flash; Alpine Region; Lightning Parameters; High-Speed-Video; E-Field Measurement

I. INTRODUCTION

This paper deals with the description of a research project, which is carried out in the Alpine Region. The main goal of this project is the investigation of cloud-to-ground (CG) flashes and strokes with respect to their behavior and properties. At present time there is no evidence on the geographical dependence of negative CG flash parameters and recent studies recommend further investigations to confirm or refute a link between them [1]. Previous studies in the Alpine Region showed some lightning characteristics that remarkably deviate from internationally published values such as a percentage of negative single stroke flashes of about 30 %. Within the context of this research project we try to find reasons for unusual flash behavior and identify causes for what makes the Alpine Region more attractive for negative single stroke flashes in general. Additionally we will investigate flashes and strokes in detail in order to estimate regionally valid values for CG lightning parameters.

To illustrate the cloud-to-ground lightning situation in the Alpine Region, a flash density map of a period of 7 years is shown in Fig. 1.

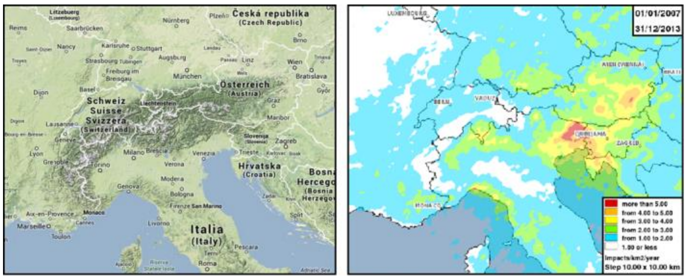

Fig. 1. Left: Orographic map of central Europe including the Alpine Region. Right: Corresponding CG flash density map of central Europe based on EUCLID (European Cooperation for Lightning Detection) data

It can be seen that the south-eastern part of the Alps exhibit the highest lightning activity in central Europe (partially more than 5 flashes per km^2 and year). High lightning density areas as shown in Fig. 1., imply a raised risk due to lightning. Consequently there is a particular need for scientific based knowledge on the CG flash characteristics in order to develop and provide locally valid lightning parameters for engineering applications as well as for proper lightning protection.

II. Properties of Negative CG Flashes

A. *Negative Single Stroke Flashes in the Alpine Region*

Previous studies showed that regions in the Alps exhibits a remarkable higher percentage of negative single stroke flashes (~10% to 15% higher) compared to other regions in the world. About 30% negative single stroke flashes were determined in eastern Alpine Region based on combined electric field and video observations [3] whereas 14% to 20% is typically observed ([4], [5], [6], [7], [8]). Fig. 2. shows the observed differences in the percentage of single stroke flashes in the eastern Alps compared to Arizona (USA) and Sao Paulo (Brazil) as reported by Saraiva et al. [2].

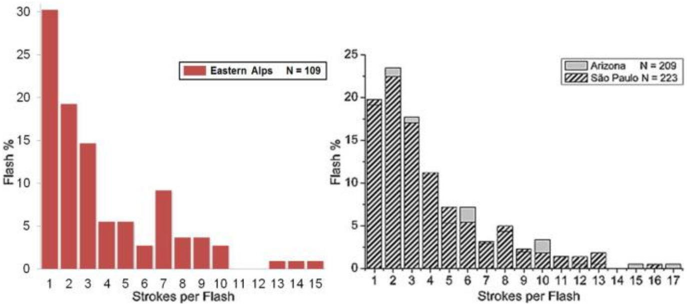

Fig. 2. Remarkable higher percentage of flashes versus number of strokes. Left: Eastern Alps in 2010 [3]. Right: Arizona in 2007 and Sao Paulo in 2003 and 2004 [2]

To our best knowledge 30% negative single stroke flashes have not been observed anywhere else in the world. This observation needs to be investigated in detail because there is currently no explanation for this regional phenomenon [1].

B. *Parameters of CG Lightning*

Regarding lightning stress to an object the values for peak currents, current derivate, charge and specific energy of a stroke as well as the number of strokes per flash that strike the same point (multiplicity) can be seen as most important. The basic parameters for lightning protection are to a high extend based on tower measurements or rocket triggered lightning at given location. Lightning to towers or triggered lightning are mainly of the upward type and represent a minor percentage of the over-all CG lightning activity. Consequently there is a need for research on alternative methods to obtain lightning parameters from natural CG flashes (e.g. negative downward or positive downward flashes) as these types of discharges mostly occur during conventional storms.

Especially continuing currents (CC) are of particular interest because most serious thermal lightning damages are caused by strokes followed by CC. Current knowledge of occurrence of very short CC is relatively poor from the scientific point of view. At present, not even a clear definition for CC with time durations of less than 10 ms is available and published values for such currents are to a certain extent still estimates [9].

III. Instrumentation

Our investigation of CG lightning is mainly based on observational data. Observational data are data from on-site measurements and data from the Austrian Lightning Detection and Information System (ALDIS). Meteorological data (e.g. radar, soundings) are also included, but not discussed in this paper.

A. *Mobile Video and Field Recording System (VFRS)*

The used on-site observation system is a mobile Video and Field Recording System (VFRS) which records the optical and electromagnetic properties of CG lightning flashes. Data of VFRS are so called ground truth data. Collecting VFRS data is currently the only method to determine type and properties of CG lightning flashes independent of the location and with a video evaluation at high time resolution. A mobile VFRS allows the observation of all CG flashes in different thunderstorms and at different locations.

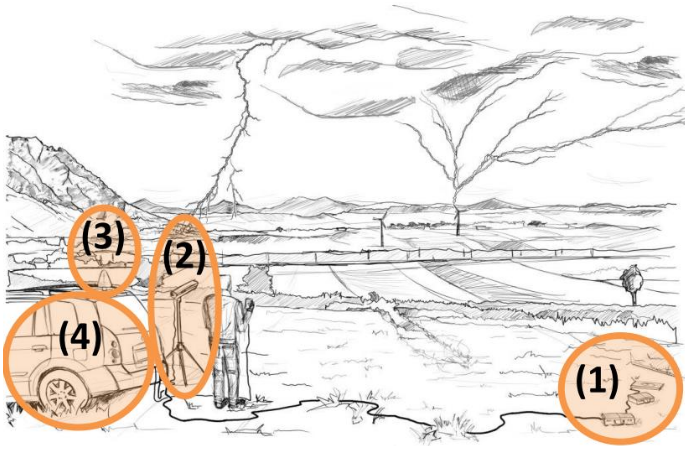

Fig. 3. Schematic setup of the VFRS operated in the field: (1) Electric field sensor, (2) Camera, (3) GPS antenna, (4) Car with inside components (e.g. data acquisition)

This is a major advantage compared to other common methods to collect ground truth data, like instrumented towers or rocked triggering lightning, which are locally restricted and cover mainly special types of CG flashes (upward initiated). VFRS data represent the typical CG lightning activity during the observed thunderstorm and is therefore most appropriate to gather reliable information on typical CG flash characteristics.

The VFRS consists of two main components. One component is an E-field system to measure transient electric fields and the other component is a camera system to record high-speed videos. Both components, E-Field and Camera, provide GPS time synchronized measurements. This allows the correlation of VFRS data with any other GPS time synchronized data (e.g. data from lightning location systems). Additionally, the VFRS is portable with a regular car (compact), operable from a car (safety issues for the operator during thunderstorm activity), operable independent of any external power supply (free choice of observation sites) and protected against weather influences (protection for sensitive outdoor components). Fig. 3. shows the schematic of the VFRS with its outdoor components while operated in the field.

E-Field Measurement

For transient E-field observations during the project, an improved version of the system developed by Schulz et al. [10] will be used (see Fig. 4.).

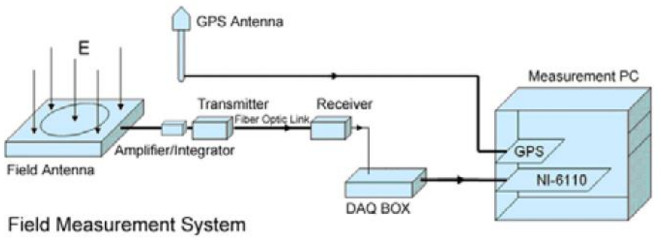

Fig. 4. Schematic representation of the system to measure the transient electric fields of lightning discharges [10]

The improvements mainly affect the data acquisition parts (digitizer and chassis with integrated controller) in order to record E-field data with sufficient resolution.

The design of the components "Field Antenna" to "Receiver", shown in Fig. 4., is based on the example of [10]. These components, except the receiver, remain outside during the measurements. The flat plate field antenna is deployed at ground level at each site to avoid field enhancement and calibration issues. The flat plate field antenna does not need a weather protection. The remaining outdoor parts are weather protected with self-made protective housings. The digitizer with a sampling rate of 10 MS/s and a resolution of 16 bit provides twice the sampling rate and a 4 bit increased resolution compared to the system used in Schulz et al. [10] and will be used for sampling the received analogue integrator output signal. For time synchronization, a GPS time synchronization module is used. Both modules are integrated in an appropriate and compact chassis including a controller unit to operate the system. Power supply for the E-field system is provided by a gasoline operated generator.

Camera System

High-speed camera observations are one of the key elements of this project. To improve our knowledge of high-speed camera requirements we used a Vision Research Phantom v9.1 high-speed camera. Besides a 6 GB internal memory, the camera provides up to:

- 153,846 frames per second (fps)
- 1,632 x 1,200 pixel
- 14 bit image bit depth

The maximum recording time depends on the camera settings (e.g. recording speed, resolution, image bit depth) and should not be smaller than 1.7 s, including a pre-trigger time of ~0.2 s. A conventional lightning flash sequence including all flash related strokes typically does not exceed time durations of 1.5 s, but lightning flashes with remarkably longer time durations have already been observed. Due to limitations of the camera we have to take into account that some lightning flashes will exceed the recording time and therefore cannot be covered with this system. An additional limitation is the huge amount of data per video sequence and its transfer to an external storage in order to clear the internal camera memory. The time duration of the data transfer of one video can take several minutes. Additionally, the camera is not able to record simultaneously at full speed, full optical resolution and full image bit depth. Hence, goal-oriented settings had to be determined and applied to the camera to ensure sufficient data quality and camera availability during the observations. For determining the most efficient camera use we compared following settings:

(1) 3,200 fps at 8 bit with reduced resolution

(2) 3,200 fps at 14 bit with reduced resolution

(3) 2,000 fps at 14 bit with reduced resolution

Note: Reduced resolution represents the highest possible resolution at the given frame rates, image bit depths and required recording time. For observation efficiency reasons, a widescreen picture format is used. (e.g. 1200 x 400)

We found setting (3) to be most appropriate because:

- 2000 fps allow the distinction between upward and downward leader propagation for typical stepped leader propagation speeds of $2*10^5$ m/s
- 14 bit image bit depth provides 16,384 grayscale steps for each pixel for the investigation of lightning channel luminosity.

A speed of 3,200 fps slightly increases the time information, but doesn`t justify the associated loss of resolution and furthermore the reduced field of view.

For a detailed investigation of continuing currents, especially the very short ones, frame rates of 50,000 fps and more including at least 12 bit image bit depth, sufficient resolution and recording times of more than 4 s would be desirable, but not possible with the available camera.

B. *Austrian Lightning Detection and Information System ALDIS*

The Austrian Lightning Detection and Information System, a lightning location system (LLS) within the European Cooperation for Lightning Detection (EUCLID), is operational since 1992. The ALDIS system consists of 8 Sensors (Vaisala LS 7002) deployed at different sites all over Austria. Each sensor has an average detection range of ~400 km. As ALDIS is integral part of EUCLID, EUCLID sensors contribute to the detection and location of strokes in Austria. Fig 5. gives an overview on the ALDIS and surrounding EUCLID sensor sites. Detailed information about ALDIS and EUCLID can be found in [11], [12], [13], www.aldis.at and www.euclid.org.

ALDIS LLS data provide important additional information to the VFRS records (e.g. stroke location, estimated peak current) that cannot be determined by using just VFRS data. Besides that, ALDIS is one of the most evaluated LLS worldwide and can provide most reliable LLS data under consideration of the system limitations (e.g. [11], [12], [13]).

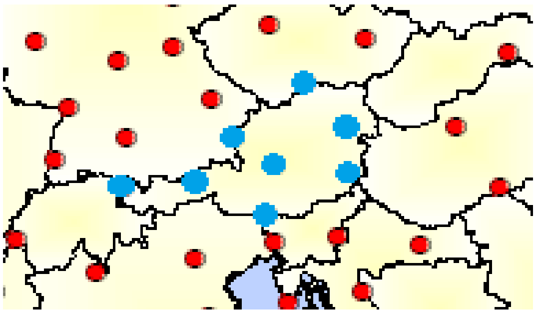

Fig. 5. ALDIS and EUCLID Sensors inside and around Austria, March 2013. The blue dots show ALDIS Sensors, the red dots show the surrounding EUCLID sensors.

IV. Observation Strategy

The key element of this project is the collection of VFRS ground truth data during warm season thunderstorms in the Alpine region.

TABLE I. IDENTIFIED OBSERVATION SITES AND COORDINATES CONSIDERING ALPINE CONDITIONS

Nr.	Site Name	Coordinates		Observations 2015
		Longitude	*Latitude*	
1	Auffenberg	15.933523	47.177146	No
2	Demmerkogel	15.426253	46.788599	Yes
3	Gaisberg	13.110090	47.803095	Yes
4	Gerlitzn	13.910951	46.696364	Yes
5	Haberberg	12.466293	47.538773	Yes
6	Heiligenstadt	14.865627	46.633898	Yes
7	Graz	15.467964	47.111466	No
8	Kalsdorf	15.448693	46.970287	Yes
9	Knittelfeld	14.854336	47.227176	Yes
10	Kulm	15.754363	47.217353	Yes
11	Liezen	14.156294	47.537314	Yes
12	Loosdorf	15.446813	48.194493	Yes
13	Matrei	12.547948	46.995110	Yes
14	Spielberg	14.770880	47.210432	Yes
15	Stuhleck	15.790482	47.573906	No
16	Wiener Neustadt	16.225000	47.775674	Yes
17	Windischgarsten	14.342066	47.721368	No
18	Wörterberg	16.102671	47.228812	Yes
19	Zell am See	12.832124	47.293504	Yes

To be able to investigate the CG flash behavior under alpine conditions, it is important to define criteria for observation sites. One criterion is the visibility of mountainous exposed structures and objects from the observation site. Such objects and structures are:

- Mountain tops
- Mountain crests
- Transmission lines
- Transmission line towers
- Wind turbines
- Towers and Antennas
- Other remarkably exposed structures

As second criterion, the observation sites need to exhibit low electromagnetic noise and should provide a large field of view in order to provide sufficient E-field data quality and to increase the camera observation efficiency.

During a pre-investigation process, 19 sites which fulfill the above defined criteria have been identified. Table I. shows these observation sites including coordinates and Fig. 6. shows the observation site distribution over Austria's eastern Alps where the numbers in Fig. 6. correspond to the ones in Table I. Some areas exhibit a lack of observation sites. This is mainly due to the complex mountainous terrain where adequate observation sites could not be found yet, but the already identified sites provide excellent conditions for alpine CG lightning observation.

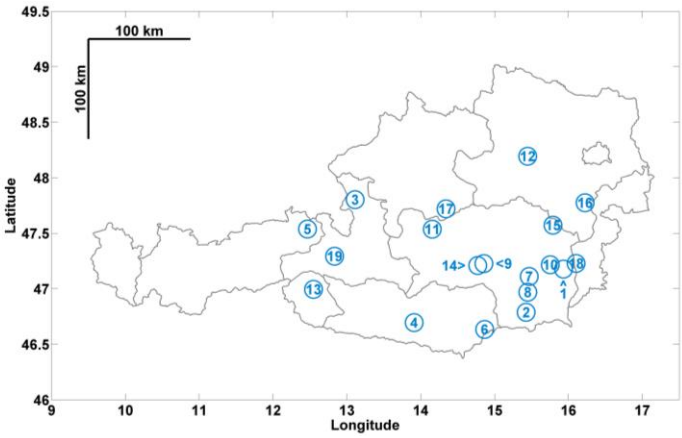

Fig. 6. Distribution of observation sites over Austria`s Eastern Alps. The numbers in this fiugre correspond to the ones in Table I.

V. First Observations and Preliminary Results

Between May and August 2015, observations with the VFRS were conducted. During this period, data from 23 storms and during 20 storm days were recorded. Table I`s right column shows sites where observations have been made. Fig. 7. shows the observation sites (black) and the regions (green) where lightning flashes have been observed in 2015`s warm-season thunderstorms.

The raw observation data have to be examined case by case. This is one of the most time consuming steps due to the huge amount of data that has to be inspected manually. By applying data quality criteria (e.g. visibility conditions, visibility of all strokes, video and E-Field quality) a number of cases will result from this examination process. Based on the current state of the data analysis we expect that a total number of about 165 negative flashes, where the recorded lightning data meet the requirements of the applied quality criteria, will be available for the final analysis. Besides the negative flashes we expect to have about 25 positive and 5 bipolar flashes available from the recent observation period. Note that these values are just estimated values as the examination process is not finished yet.

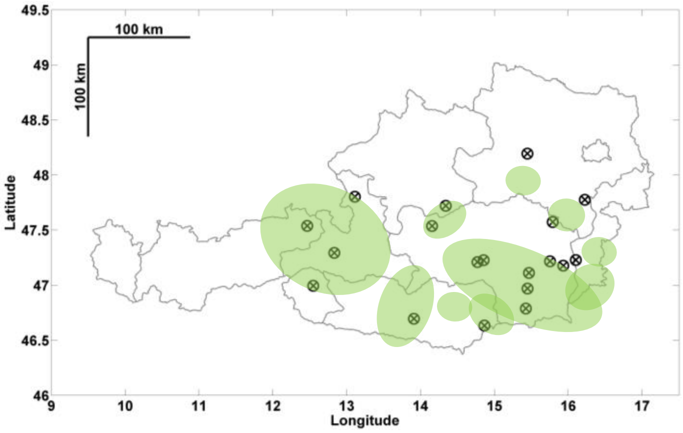

Fig. 7. Observation sites (black) and the regions (green) where lightning flashes have been observed in 2015`s warm-season thunderstorms

VI. Summary and Outlook

During previous years, remarkably deviating CG lightning parameters have been observed in the Alpine Region. Besides that, evidence on the geographical dependence for most of the negative CG parameters is still not given. Based on these issues we started a project that deals with unusual CG flash behavior and CG flash properties in the Alpine Region.

For investigation of CG flash properties, GPS time synchronized E-Field and high-speed video data are recorded at different storms at different sites throughout the Alpine Region. During the first observations in 2015, appropriate settings especially for the high-speed camera were determined. Additionally, suitable observation sites have been identified.

After the preliminary phase, observations were conducted. Out of the collected data we expect to have data from about 165 negative, 25 positive, and 5 bipolar CG flashes.

During winter and spring 2015/16, the examined data will be analyzed and lightning parameters will be extracted. Another observation period is planned from Mai to September 2016 in order to base the complete analysis on a more comprehensive data set.

To optimize the camera data of future observations, a more efficient high-speed camera providing more than 50,000 fps at a reasonable resolution, image bit depth and recording time would be desirable. Additionally, an external memory with fast transfer rates would remarkably increase the number of observations per storm.

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