News on Streamer Modeling in Air

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Streamers and leaders are essential elements of electric breakdown in lightning physics and high voltage engineering. I will review new insights into their properties and modeling.

1. Verification and validation: Streamer modeling is getting quantitative: fluid and particle models for the electron dynamics in propagating streamers agree quantitatively, and they agree with experiments within 20% error. The discrepancy might be attributed to streamer heating.

2. Streamer properties are not purely determined by the background electric field. Rather in the same field, thick streamers might accelerate and thin streamers decelerate. The range of velocities and diameters of streamers covers at least 2 or 3 orders of magnitude.

3. Both positive and negative streamers can keep propagating when the streamer channel loses conductivity. In a homogeneous electric field they can reach a mode of uniform propagation for both polarities. This observation relates to the concept(s) of the stability field, that requires a critical revision.

4. 3D simulations of streamer branching agree well with experiments. This lays the ground for more quantitative reduced models of multi-streamer processes, including the transition to leaders.

5. The plasma chemistry in the streamer channel as well as the deposited heat play a role both in the dynamics of repetitive streamer pulses and in the transition to leaders. Discharge dynamics and chemical impact are discussed.

Source Mapping and Quantitative Measurements with Broadband VHF Lightning Interferometry

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Lightning is a powerful broadband radio emitter.Low frequency emissions (below approximately 100 kHz) are produced mainly by powerful lightning processes, such as cloud-to-ground strokes, and can be measured from hundreds to many thousands of km distant from the lightning itself.These signals form the basis for many lightning detection and geolocation networks.But some lightning processes also emit strongly at much higher frequencies, to at least several hundred MHz, and these processes are much smaller in spatial scale.This enables fast detailed imaging of lightning channel and flash development through interferometric imaging of the VHF radio emissions, a concept that has been developed and implemented by numerous research groups.Over the past 5 years, we have developed and improved a broadband VHF interferometer by adding long baselines, expanding the range of frequencies and bandwidth, and integrating those measurements with simultaneous VLF, LF, and ultrabroadband VHF-UHF (1–750 MHz) recordings.These additional capabilities enable us to achieve higher space and time resolution imaging, compute 3D source locations, explore the relationship between streamer activity (VHF) and current flow (LF), and also quantitatively measure the electric field in VHF-radiating streamer zones.We will describe and summarize our recent and new findings in these areas and thus provide new insight into the spatial structure and temporal development of lightning flashes.

Close View of Downward Negative and Upward Positive Leader Connection in Two Cloud-to-ground Lightning Flashes

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The attachment process of a lightning flash to a structure on the ground is one of the most important and difficult topics in the research of lightning physics. Any progress in its understanding contributes to the understanding and improvement of lightning protection. On the other hand, as the attachment process occurs only in the last millisecond before the return stroke, its observation is extremely difficult.
This work describes the attachment process of two cloud-to-ground flashes that occurred close to a high-speed camera working at 40,000 frames per second. The proximity of the attachment allowed the observation of details of the negative downward leader and of the positive upward connecting and positive unconnected leaders.
We will present some characteristics such as length and speed of the leaders, the transition from corona brush to streamers in upward positive leaders, as well as the shape and dimensions of these discharges and their relation to space stem leaders.

Asymmetric Behavior of Positive and Negative Upward Lightning Leaders in Triggered Lightning

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Polarity asymmetry in the development of positive and negative lightning leaders is a central question in atmospheric electricity. It is also the likely root cause of all other asymmetries between positive and negative lightning flashes, including the ones regarding: occurrence rates, stroke multiplicity, presence of continuing current, recoil activity, VHF power spectrum, leader velocities, and emission of energetic radiation. In the present work, we highlight the contrasting differences between two rocket-triggered lightning flashes, one of each polarity. The two flashes were recorded at the Langmuir Lab mountain-top facility in central New Mexico, USA, in the Summers of 2012 and 2014. These two flashes were handpicked for potentially being the two simplest triggered flashes (of each polarity) that have ever been recorded with a high-precision 3D VHF lightning mapping array (LMA). In these two flashes the VHF sources were simultaneously located by up to 23 different LMA stations around Langmuir Lab. By "simplest flash" we mean with the simplest spatial structure. Each of the two flashes developed vertically upwards from the rocket-wire system and branched predominantly in only two directions, with leaders propagating horizontally in opposite directions. Each horizontal leader also developed smaller lateral branches, but the dominant LMA source activity formed a simple spatial structure, resembling a capital letter T. Despite the similar qualitative shape, the corresponding temporal dynamics of current transferred to ground is completely different. The upward positive leader exhibits the typical initial continuous current stage followed by multiple return strokes (the latter stage resembling a natural negative cloud-to-ground flash), while the negative upward lightning leader development is by itself the entire flash. The measured current waveforms serve as input in a computer model that simulates the lightning channel plasma, allowing us to correlate key channel properties, such as resistance, luminosity, and dissipated energy, to the overall growth of the lightning-leader network [see da Silva et al., JGRA, 2019, doi: 10.1029/2019JD030693]. In future studies, these two flashes are ideal candidates to serve as ground truth for the validation of lightning-leader models that can capture their asymmetric behavior.

Analysis of GLM Detections of Lightning Flashes to Tall Towers

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Nowadays, optical lightning detections from space are available from different sources (e.g., ISS-LIS, GLM, FY-4A, and ASIM). In the majority of the cases, these imagers provide optical detections of the light escaping from the clouds emitted by lightning channels. Considering the total lightning nature of these detections is interesting to investigate the particular case of lightning flashestotall structures. This work investigates several detections of lightning flashes from space that occurred to tall towers.

Space-based data is provided by the Geostationary Lightning Mapper (GLM) In 2017, GLM was the first operational lightning imager in a geostationary orbit observing the Americas (e.g. Goodman et al. 2013). Currently, GLM has two instruments, one onboard the GOES 16 satellite (GOES-East at 75.2° W) and one on the GOES 17 satellite (GOES-West at 137.2° W), extending the coverage to include a large portion of the Atlantic and the Pacific oceans. GLM provides continuous observations with a time resolution of 2 ms with ~8 km spatial resolution at nadir (GOES-R Algorithm Working Group and GOES-R Series Program, 2018)

The first group of flashes involves the Morro do Cachimbo's instrumented tower (Visacro et al. 2004, 2012, 2017). Four return strokes were measured in one of the flashes with peak currents of -28 kA, -21 kA, -28 kA, and -14 kA, respectively. In that case, GLM detected the three subsequent strokes of the flash. The first stroke was not reported in the L2 data, probably because the flash initiated lower in the cloud. After the first stroke, lightning leaders mighthave had reachedhigher altitudes. No relation between the amplitudes of the peak currents and optical energy is found.

The second group of flashes occurred at the Pico do Jaraguá towers (Schumann et al., 2019) in Sao Paulo (Brazil). For these towers, high-speed video recordings are available. The cases discussed in this work present similar features where upward flashes are initiated from one or two towers as a response to a nearby positive cloud-to-ground (+CG) stroke. Upward leaders from the towers initiate just after the +CG strokes or during the following continuing currents. The results of this investigation can be helpful to identify the situations of lightning to tall towers such as wind turbines.

A Self-consistent Lightning Return Stroke Model Capable of Predicting the Effect of the Ground Conductivity and the Current Reflection at the Strike Point on the Lightning Currents and Electromagnetic Fields

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Abstract: Several ideas that could be implemented in return stroke models to investigate the effect of the ground conductivity at the strike point on the return stroke current characteristics and the effects of current reflection at ground level on return stroke electromagnetic fields had been proposed by Cooray and Rakov [1]. In this paper, these theories are extended and implemented to create a full-fledged lightning return stroke model to investigate both the effect of the ground conductivity at the strike point and the current reflection on the source electromagnetic fields generated by return strokes. The source electromagnetic fields are the electromagnetic fields generated by lightning flashes measured in such a way that they are not distorted by propagation effects. In addition to providing electromagnetic fields generated by the dart leader-return stroke process, the model can be used to investigate how the source electromagnetic fields are influenced by the ground conductivity at the strike point. The possibility to include the current reflection at ground level is also included in the model.

The results show that the ground conductivity at the strike point does not influence the peak of the current or the peak of the radiation field significantly for ground conductivities higher than about 0.001 S/m. However, with decreasing conductivity, the peak electric field starts to decrease. On the other hand, the application of the same theory but dimensioned for small sparks shows that even the variations in the conductivity of sea water (i.e., from 1 S/m to 10 S/m) can influence the peak current.

In contrast to the lightning current, the time derivative of the lightning current and the electric field of lightning flashes striking a poorly conducting ground are much smaller than the ones striking a good conducting ground. The results agree with the inference made by German scientists that the lightning flashes striking poorly conducting ground could not generate source electromagnetic fields with derivatives as large as the lightning flashes in maritime conditions in Florida [2].

The inclusion of the current reflection at ground level influences significantly the saturation of the close electric fields. The current reflection gives rise also to residual electric fields, a difference in the field levels generated by the dart leader and the return stroke. The residual field decreases as the fraction of the reflected current decreases.

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X-rays Associated With Stepping of the Dart Leader in Upward Negative Lightning Discharges at the Säntis Tower: Preliminary Results

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X-rays have been observed in downward could-to-ground lightning and in rocket-triggered lightning [1-3]. Relatively low energy X-rays associated with upward lightning were observed for the first time at the Gaisberg Tower in Austria [4], where only three out of 155 dart leader processes were accompanied by X-rays. Since then, X-rays with much higher energies and incidence have been observed at the Säntis Tower in 2020 [5]. Here, we report new X-ray data from the Säntis Tower dating from the Summer of 2021. For the first time, we report simultaneous observations of subsets of the following measurement quantities: X-rays, channel-base currents, electric fields, high-speed camera images, and interferometer VHF source location data in upward lightning.
The observations were made on eight negative flashes. We observed that all eight flashes had at least one X-ray emission associated with the dart leader phase. Only one of the flashes included data from a high-speed camera.
The dataset contains observations of X-rays prior to return strokes. These typically consist of lower energy X-rays of some tens and hundreds of keV, followed by a rapid increase to values exceeding 1 MeV during the final jump phase. We observed in some of the events that electric field stepping occurs at the moment of X-ray detection, suggesting that the X-rays are generated during the stepping of the dart leader.

This is the first observation of high energy X-rays associated with upward lightning that includes simultaneous observations of electric fields, currents, interferometer source mapping data, and high-speed camera images. For the first time in the case of upward lightning, these X-rays are shown to be associated with stepping in the dart leader by means of electric field observations, similar to previous observations in downward cloud to ground lightning [6].

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Lightning Initiation Scenario: From Electron Avalanches to a Self-propagating Hot Channel Segment

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Maximum electric fields typically measured in thunderclouds is notably lower than the expected conventional breakdown field. Here, we report scenario [1,2] that represented the lightning initiation as a sequence of two transitions of discharge activity to progressively larger spatial scales: the first one is from small scale avalanches to intermediate-scale streamers; and the second one is from streamers to the lightning seed. We postulate the existence of ion production centers in the cloud, whose occurrence is caused by electric field bursts accompanying hydrometeor collisions (or near collisions) in the turbulent thundercloud environment. When a new ion production center is created inside (fully or partially) the residual ion spot left behind by a previously established center, there is a cumulative effect in the increasing of ion concentration. As a result, the essentially non-conducting thundercloud becomes seeded by elevated ion-conductivity regions (EICRs) with spatial extent of 0.1–1 m and a lifetime of 1–10 s. The electric field on the surface of an EICR (due to its conductivity being at least 4 orders of magnitude higher than ambient) is a factor of ≥3 higher than ambient. For a maximum ambient electric field of 100 kV/m typically measured in thunderclouds, such field enhancement is sufficient for initiation of positive streamers and their propagation over distances of the order of decimeters, and this will be happening naturally, without any external agents (e.g., super energetic cosmic ray particles) or extraordinary in-cloud conditions, such as very high potential differences or very large hydrometeors. Provided that each EICR generates at least one streamer during its lifetime, the streamers will form a 3D network, some parts of which will contain hot channel segments created via the cumulative heating and/or thermal-ionizational instability. These hot channel segments will polarize, interact with each other, and cluster, forming longer conducting structures in the cloud. When the ambient potential difference bridged by such a conducting structure exceeds 3 MV or so, it is assumed that the lightning seed, capable of self-sustained bidirectional extension, is formed.

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Unusual Plasma Formations Produced by Positive Streamers Entering the Cloud of Negatively Charged Water Droplets

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Kostinskiy et al. (2015), using a high-speed infrared (2.5-5.5 µm) camera, discovered the so-called unusual plasma formations (UPFs) in artificial clouds of charged water droplets. UPFs had complex morphology including both streamer-like regions and hot channel segments. They were observed both in the presence and in the absence of hot leader channels developing from the grounded plane toward the cloud. In this report, which is aimed at revealing the genesis of UPFs, we present two UPFs that occurred inside the initial corona streamer burst of positive polarity emitted from the grounded plane, prior to the formation (or in the absence) of associated hot leader channel. These streamer bursts developed at speeds of 5 to 7 x 10^5 m/s over 1 to 1.5 m in apparently clear air before entering the negatively-charged cloud and producing UPFs at its periphery. Hot channel segments within UPFs were formed in very short times of the order of 1 µs or less. It is not clear if the UPFs were caused solely by the enhanced electric field near the charged cloud boundary or other factors also played a role. Occurrence of UPFs may be a necessary component of any lightning initiation mechanism (Kostinskiy et al., 2020; Iudin et al., 2021).
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Characteristic of Lightning Discharge With Extremely Long Channel in Winter Thunderstorm Season

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Lightning discharge in Hokuriku region during winter thunderstorm season are remarkable phenomena in the world. It is known that the number of lightning strokes in winter is small, however they often causes damages the electric power facilities. It might mean that a large amount of charge is lowered to the ground by one lightning stroke.

We have installed LF band receivers around Toyama Bay to observe lightning discharges in winter thunderstorm season. The LF observation network consisted of 9 LF band receivers with the separation of tens kilometers can locate the radiation sources of the impulsive electric field change using the time-of-arrival method. The discharges with the channels of over 100 km were recognized in the observations by the LF network. These lightning flash have different characteristic from usual ones in winter thunderstorm season. Although, it is said that the number of lightning stroke in winter thunderstorm season is small, 3-22 strokes were detected by Lightning Location System (LLS) in these flashes having extremely long channels. The percentage of positive stroke in these discharge is about 60 %. The peak current value estimated by LLS of some strokes with the long channel exceeded 100 kA, though most of them were under 100 kA. The discharge with the long channels occur in the linear clouds developed parallel to the coast line of the coast line of the Sea of Japan. It is considered that discharge with the long channel was brought by large amount of charge distributed over a wide area in linear loud.

We considered on the charge distribution inside thundercloud from very long lightning channel development and the polarity of the stroke. Variety of LF pulses were observed associated with bidirectional leader, upward leader, and so on. In focusing on the channel development after stroke, the propagation speed of them were consistent with negative and positive leaders. It can be concluded that the charge region of positive and negative are alternately distributed in the horizontal direction in the thundercloud, and connected in succession with the lightning channel after return stroke. These process last for up to 700 ms, and large amount charge flow into the stroke point. From this result, it seems that lightning discharge with the long channel is related to lightning discharge that causes damages the electric power facilities in winter thunderstorm season.

Lightning Classification Improvements for the Earth Networks Total Lightning Network

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Lightning strokes and pulses can be categorized into one of two very broad groups: those which connect to the ground and those which do not. The ability to distinguish between these categories from the sferic produced by the stroke is important because lightning that connects to the ground is far more likely to cause damage to structures or people than lightning that does not. Most classification algorithms consider various waveform parameters such as rise time and amplitude, and test the algorithm against ground truth data. There are a multitude of different ways to handle algorithm training, each with different strengths and weaknesses, but all of them are fundamentally limited by the breadth of the ground truth set. Ground truth lightning classification data is exceptionally laborious to collect, and frequently done by examining high speed video recordings of lightning flashes to identify strokes which connect to the ground.But there are two major issues with collecting ground truth data in this way. First, it only provides conclusive evidence that a given stroke connects to the ground, and is much less well-suited determining if a stroke does not connect to the ground. In the extreme case where no intra-cloud flashes are identified, the resulting ground truth set is incapable of providing a false alarm rate. Second, the data set is confined to the field of view of the camera, requiring the algorithm to assume lightning sferics are invariant over geography. In this presentation, we will show the results of training a classification algorithm against a vastly expanded ground truth set using manually classified lightning sferics. The manual classification methodology is only able to provide a classification if at least one sensor is close to the lightning flash, but it was also tested against video observations of lightning and found to be over 99% accurate. Importantly, we are also able to classify flashes in many regions of the world and expand our ground truth set from hundreds of strokes to tens of thousands of strokes. The ground truth set allows us to test our existing classification algorithm, as well as develop an improved algorithm which performs significantly better.

LEELA: the Met Offices Next Generation Lightning Location System

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Lightning location information has a broad range of uses from Nowcasting through to aviation safety. Hence, the Met Office, based in the United Kingdom, has operated Lightning location systems since 1935. Here the Met Office’s next generation VLF lightning location system: Lightning Electromagnetic Emission Location using Arrival time differencing LEELA is described. It is set to replace ATDnet, the Met Office’s current operational system in 2022. LEELA features newly designed hardware and processing architecture, with a new novel technique to extract the sferics from the raw VLF data, and new fixing algorithms that improve location accuracy and detection efficiency over that of ATDnet. The night time issues from modal interference that ATDnet suffered from have been mitigated against and the night time performance of LEELA is improved. It will be shown that LEELA can provide lightning information over Europe, Africa, middle east and central America. In addition to this, the new processing architecture means that a near constant stream of VLF data is recorded and archived allowing investigations into sudden Ionospheric disturbances by observing changes in received power from VLF transmitters.

Earth Networks Lightning Processor Update

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Global lightning location data has long been a critical tool for lightning research and safety. The Earth Networks Total Lightning Network (TLN) incorporates advanced lightning location technology delivering competitive lightning detection efficiency, location accuracy, and classification (intracloud vs cloud-to-ground). It consists of over 1800 wideband sensors deployed in 40+ countries to detect lightning and generate real-time localized storm alerts. TLN is constantly evolving through network expansion, as well as hardware and software development. In this presentation, we will cover some of the recent advances to the TLN processor. New upgrades to the lightning location algorithm have increased the detection efficiency, location accuracy, and classification accuracy of the network. Globally, TLN is locating approximately 50% more pulses than it was before. In moderately remote regions of the world, performance gains can be higher. For extremely remote regions including the deep oceans, TLN continues to use WWLLN data which has been further enhanced through the raw sensor signals of approximately 200 TLN sensors. However, how this data is incorporated has been changed, leading to significantly reduced false alarm rates in some regions. Location accuracy was improved by developing a new propagation model for signals produced by lightning, resulting in a reduction in location error by as much as a factor of 2. As a result of the improved location accuracy, as well as enhancements to the false alarms rates, there is improved clustering of lightning, which directly impacts downstream products such as lightning alerting and Dangerous Thunderstorm Alerts.

ACLENet - Leading the Developing World to Lightning Safety

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ACLENet, the African Centres for Lightning and Electromagnetics Network, is dedicated to decreasing deaths, injuries, and property damage from lightning across Africa. Founded in 2014 and incorporated in 2016 as a nonprofit (NGO) in both the United States and Uganda, ACLENet has been working not only in Uganda to save lives, but also with lightning safety advocates on six continents to encourage and mentor lightning safety and injury prevention programs worldwide.

Globally, thousands of people die, are injured, or suffer property damage from lightning ever year, mostly in the developing world where 70% of the world's population live. Lightning is the most common weather threat to life encountered by people worldwide, often on a daily basis and often without the ready availability of safe areas where they can avoid injury or the knowledge of individual behaviors they can use to prevent injury. Thankfully, in 2018 the World Health Organization (WHO) included lightning as a disaster, defined as 'an occurrence disrupting the normal conditions of existence and causing a level of suffering that exceeds the capacity of adjustment of the affected community.' While this is encouraging, the reality is that disaster 'management' in most countries is really disaster 'response' rather than disaster prevention or preparedness. The World Meteorological Organization lags the WHO but is showing more willingness to include lightning as a disaster recently.

Excellent lightning protection (LP) and safety standards have been developed, but they are almost always too expensive for more than 2/3 of the world's population to afford. Unfortunately, the developing world's people are more likely to encounter 'non-standard lightning protection,' either because of ignorance of the standards, false assumptions about lightning's phenomenology, simple greed, convenience, or unavailability and expense of acceptable LP materials locally. Many cultures also have beliefs and folklore that include witches, curses, and gods involved in lightning which discourage reporting of lightning incidents, making it difficult to collect a good database on injuries, deaths, and property damage.

ACLENet and SALNet (South Asia Lightning Network), along with many academics, professional lightning protection experts, researchers, and others are trying to change this by doing public and professional education, sometimes commemorating 28 June, International Lightning Safety Day, a day in 2011 when one lighting strike to a school in Uganda killed 18 children and injured 38, the second highest death toll from lightning ever recorded. Multidisciplinary teams have been formed and most lightning safety advocates willingly share resources, knowledge, and educational materials with colleagues and citizens worldwide. Several virtual conferences have been held over the past year which are readily available online so that all may benefit.

Few lightning safety advocacy programs receive government funding. ACLENet is totally supported by donations and grants and receives no government support at this time. ACLENet's other activities include lightning protection of African schools, public education, working with governments and teachers, and research and investigation of lightning mass casualty incidents as funding allows.

Lightning Detection in the Service of Public Awareness

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The role of lightning locating systems (LLS) in the field of risk prevention is well known, but this study considers their contribution to increasing awareness of individuals and groups to encourage them to practice protective measures for approaching thunderstorms. The study is based on the analysis of 215 remarkable human related lightning incidents in Europe over the last 10 years in order to provide some key lessons for more effective awareness campaigns.
Statistical information on the profile of the victims as well as behavioural lessons are provided and the contribution of LLS is studied under different angles.
The first analysis consists in verifying the predictability of each event, and then determining the possible lead time that could have been provided by LLS.
After having determined that 9 out of 10 of these events were nowcasted, the contribution of LLS is also analysed in its psychological dimensions, in particular the assistance to individuals' decision-making choices.
The detailed analysis of several cases makes it possible to determine the contribution of LLS for three different types of situations.
A first case particularly illustrates the situation of individual and collective failure, which we attribute in the light of the facts, to a lack of awareness. The information delivered by the LLSs confirms a danger predicted with an official meteorological awareness notice ignored by the protagonists, with a lead time of one hour before the incident. By invalidating some statements made after the event, the information provides arguments for campaigns to raise people's awareness.
A second group of cases illustrates the interest of this information when faced with situations of probabilistic approaches to risk that we assume to be at the origin of certain choices. In particular people, even if aware, may hesitate to stop a collective event such as a professional activity or a sporting competition. The information provided by the LLS can then be used to convince people to apply procedures, as shown by the analysis of cases affecting a festival in Germany and a sports competition in Italy.
In the third situation, even in the case of a deterministic approach, when people could systematically apply safety procedures, it turns out that LLS can nevertheless provide more reliable information than decisions based on the sound of thunder. This contribution can sometimes prove to be fundamental as shown by the analysis of several cases seeking to compare 1) the time difference between the alert triggering that would have been sent via an LLS and that of the first lightning flash likely to be visible to the victims, or 2) the analysis of cases showing that a resumption of activity based on the rule consisting of waiting 30 seconds after the last audible lightning flash would not have been a relevant choice.
In conclusion, this study questions the often-stated assumption of the sudden and unpredictable character of thunderstorms causing human lightning related incidents, and underlines the contribution of LLS within the framework of deterministic or probabilistic approaches in the field of risk management.