# Measure lightning

2015

Lightning detection provides always higher performance in R&D context. But the applications of lightning data in Meteorology and industrial safety requires a better understanding of the quality of the measures provided by detection networks. We will highlight the key drivers for this quality and how they can be assessed.

## What is lightning ?

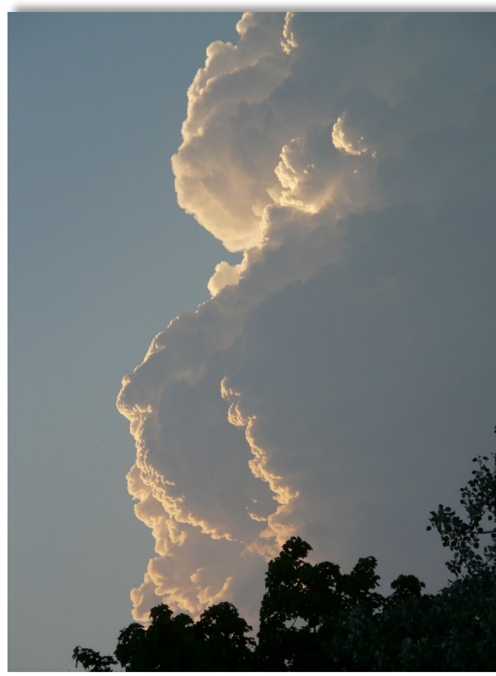
Lightning is a complex natural phenomenon that is dangerous although rare, known by everyone but not always understood, random and easy to detect. There is actually no single physical event called lightning, it is rather a collection of different events that we group under this denomination.

Lightning is the consequence of an electrical discharge process; it occurs mainly in thunder clouds (Cumulo Nimbus or CBs) but also happens during volcanic eruptions and sand storms. We will focus on lightning events produced by CBs because they represent the highest threat to human activities and are the most frequent. The other types of lightning events correspond to the same physical processes and can be described by similar explanations. Different electrical discharges exist in the upper atmosphere, producing different phenomenon known as Sprites, Elves and Blue Jets; we will not cover them is this paper.

## The CB, cloud and process

The Cumulo Nimbus is both a type of cloud and a highly dynamic process.

The CB is the only cloud that reaches the lower limit of the troposphere, extending vertically from 0-2 km to 10-12 km depending on the Latitude. This vertical extension is due to the availability of warm air and moisture concentrated at ground level, the warm air being lighter than the surrounding cool air starts rising and as it gains altitude it loses temperatures. At lower temperatures the water contained in the air starts to condensates, this process will consume energy and thus further reduce the temperature. As the air is now cooler that the surrounding area, it will start to descend to lower altitude. This whole process is a thermodynamic engine that is fed by warm air and moisture and produces a movement of the air along a vertical column of 10 km. The process will last as long as there is heat and moisture available at ground level, this can be from 30 minutes for an isolated cloud to 48 hours for a large frontal phenomenon that regenerates itself.



The vertical updraft within the cloud can reach a speed of 100 km/h, with similar values for the downdraft. Depending on their relative weight, the elements caught in this huge "washing machine" will reach different speeds and rub one against the other. The friction between particles of water, dust and sand will induce a charge separation that results in a polarization process. Negative and positive electrical areas are created and get separated, resulting in areas of opposed polarities. The thermodynamic engine has become an electrostatic generator.

As the convection continues the electrical charge of each area increases, and at some point the isolating capability of the air is not sufficient to maintain the charges separated. A discharge process will start between areas of different polarities. This process has been observed to be a stepped phenomenon where darts emerge from one charged area and propagate as successive steps until they reach an area of opposed charge. At this moment a connection is established between two charged areas allowing electrical current to flow between them. The intense current passing through the path build up by the stepped darts transform this area in plasma, an excellent conductor of electricity. This current is the first component of a flash. As the resistivity of the media is low, and the charge important, the current along the path joining the two areas will be very high. The heat generated by this current will cause the explosion of the plasma channel, the thunder is the noise of this explosion. This process generally occurs firstly inside the cloud and later between the cloud and ground, causing electrical discharges to earth or to the tall objects that attract lightning.

## A brief history of lightning measurement.

Thunderstorms have been observed probably since an observer has been available, by animals and later human beings. The first known representation of lightning is found an ancient Mesopotamia, on a seal found in Babylon, and the personification of thunder as Zeus in Greek mythology show the high impact of this phenomenon on the human psyche.

The first known measure of thunder is the famous Keraunic level, defined as "the number of days thunder was heard" and named after the Greek god Keraunos. This measure is heavily dependent on the presence and reliability of a human observer, it provides information for reduced areas only but it had been used by meteorologist to describe the climate and in electrical engineering guidebooks to help design surge protection schemes.

Starting in the 1950s the CIGRE counters were installed in isolated locations to provide a more automated measurement. Those counters detect the electromagnetic waveform produced by a flash and allow to count the number of occurrence of those flashes. CIGRE counters were patronized by the Conférence Internationale des Grands Réseaux Electriques, a research entity for the operators of high voltage grids. They have been mostly used in the electrical sector, but some MET institutes deployed such counters in order to produce regional lightning density maps and follow the evolution of the lightning activity during the year.

The use of networked sensors in the VLF frequency range was introduced circa World War II by Russian radio engineers, they allowed the detection of the Sferics produced by remote lightning events. In the early 70's the NASA funded a research program for lightning detection after Apollo 12 was hit by lightning just after launching.

Since the 1980's the development of LF sensors by commercial companies has led to the deployment of many ground based lightning detection network covering large areas. The first networks appeared in the US (Arizona and Florida) close to the research labs that created the original sensors. They were able to locate lightning events in real time and provide an estimate of the peak current for each flash.

The VHF detection technology fostered by French space research institute ONERA brings the detection and localization of the electrical breakdowns that initiate the discharge process. A VHF interferometer allows to map this process in 2D instead of the "single point information" given by LF detection. Lately, the use of VHF time of arrival networks with very short baselines such as the LMA allows to produce a 3D map of the discharge process that shows the evolution of the discharge process with very high timing resolution.

The Electromagnetic Detection technologies mentioned above allow for the remote detection of lightning events at ranges of hundreds of thousands of kilometers. Other instruments can provide different kind of information, although on a more limited range:

- **High speed video cameras** can record a complete flash process with very high timing resolution. They can be used to understand the discharge process and to provide reference information for the calibration of LDNs
- **Electric field antennas** can measure the time variation of the E field when a flash occur. They provide an indirect measure of the polarity, peak current, rise and decay time for the flash and its subsequent strokes.
- **Lightning imagers** on board of satellites can measure the luminescence at the top of the clouds, providing a different view of the phenomenon.

Finally, direct measurement of lightning is also possible (with the use of ad-hoc security precautions) in two practical situations:

- **Instrumenting a tower** with current measurement devices on the grounding wire of their lightning rod
- **Sending rocket** with a pulled wire under a cloud to induce the discharge

But in both cases, the type of lightning event that is captured is not a "standard one": high tower tend to generate upward positive flashes (when the vast majority of natural lightning is downward negative) and triggered lightning is in fact a subsequent return strokes rather than a flash.

Producing lightning in a Lab can be achieved using high voltage generators, and such equipment are routinely used to test protection devices. But the scale of the induced flash is not comparable to the natural event in terms of length, current and variability.

# Use of lightning data

Nowadays Lightning Detection Networks (LDN) of various kind and brands are installed in different countries. They have been providing data over large areas and for many years, with some specific characteristics such as real time capacity, long range capability and the absence of artifacts, that led to the development of a number of applications.

Lightning data is used for research purposes in order to gain a better understanding of the global electric circuit, in order to better understand the electrical discharge process or as part of meteorological campaigns on severe weather.

Lightning data is also used as a proxy in many applications such as climate change studies, NOx emission, hail or wind-shear hazard warning.

Lightning is still one of the major cause of outages on the power distribution networks, driving the need for decision support tools for the management of the assets

Lightning is finally a threat for any outdoor activity, from farming to golfing, from flying to mining, and early threat warning to end users is now part of the risk mitigation approach.

# The need for a better evaluation of the measure

All those applications benefit from the available lightning information but they push the requirements beyond the mere delivery of a data point representing the existence of a flash.

For climatological applications, when mid to long term trends are analyzed, the enhancement of the measurement device introduces a bias. Today's technology can detect probably 3 times as many ground events as its ancestor 30 years ago.

Researchers in atmospheric physics want to know the electrical charge transferred by a flash, and electrical engineers are interested in the rise time of the current discharge because steeper discharges induce more dangerous surges with higher frequency harmonics in their networks. The capability to properly measure those parameters is the next milestone for lightning sensors.

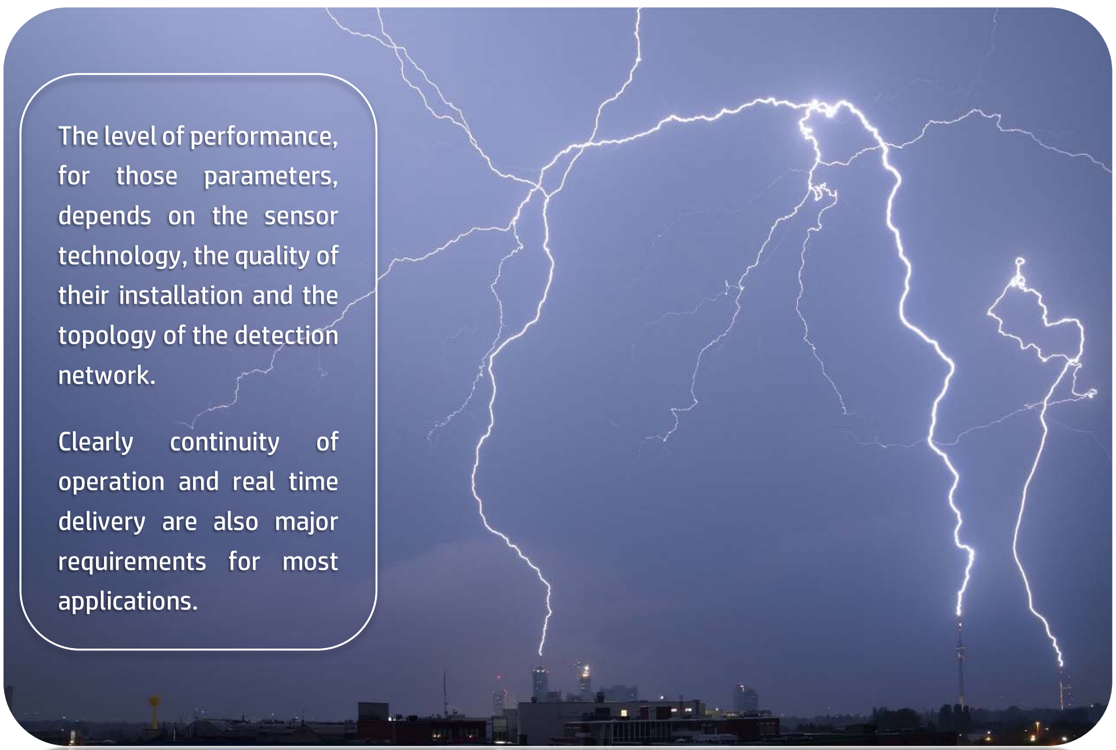
Lightning data is used as a proxy hail and wind-shear, but it is also used for derived products such as precipitation estimate or thunderstorm nowcasting. Knowing the spatial availability for each type of information provided by LDNs is key in producing meaningful value added products.

The assimilation of lightning data in numerical weather forecasts can be developed using sophisticated models combining large amount of meteorological data and running on supercomputers. In this context, the quality of the incoming data is driving the quality of the result, and a precise knowledge of the uncertainty and limitation of the data set is required before any ingestion can be performed.

# Key parameters

When dealing with lightning detection networks, the main parameters that define their delivery are:

- Detection capability of different type of events: Cloud to Ground flashes (CG), Subsequent Strokes, Intra Cloud (IC) discharges
- Capability to classify the different events
- Detection efficiency for a given class of events
- Coverage, the area where detection efficiency is "nominal"
- Location accuracy for CG flashes and strokes
- 2D or 3D localization
- Real time capability and delivery delay

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## The means to evaluate lightning measurement

There is no such thing as a reference flash or a repeatable event that could be used to calibrate a lightning detection network. Although there are different ways to assess the performance of such a system, none of them gives an undisputed truth or "one size fits all" solution. A summary of the methods currently used, their benefits and limitations follows, with practical examples and applications.

**Self-assessment** uses exclusively the data measured by the network. It thus requires that the network be firstly optimized (eventually using an initial self-assessment process) to correct for site installation issues such as sensor rotation, local noise, and to introduce propagation and angle correction factors. Once those steps are realized it becomes possible to figure the coverage and detection efficiency of the network and to estimate the location accuracy. This principle is relatively easy to implement, needing no additional data.

The main limitations of the methods derived from self-assessment is that they do not take in account the limited detection of the network (what is not measured cannot be evaluated) and that they provide no absolute measure of any parameter.

A basic use of self-assessment is the computation of the location accuracy for each flash, this is based on the supplementary information available when many sensor detect the same event. A more advanced example consist in identifying strokes falling within the same channel and using this information to compute the relative localization error. Such a study was done with the French data set in 2013 and 2014; with more than 1.2 million flashes all over the country the mean relative location error was below 100 meters. Interestingly enough the algorithm used to identify those co-located flashes in the data base has been validated using high speed videos as a reference.

**Intercomparisons** can be used for example to check a new network against an existing one or to spot "obvious" discrepancies between a radar image and LDN data when outliers are located far away from the convective area. But obtaining quantitative results when using different systems always assumes the definition of a common model allowing to compare the data from two observation devices. The more different those devices the more difficult it becomes to define such a model and the more difficult it turns to draw practical conclusions. By construction, those methods provide only a relative assessment and not an absolute measure. Unless one system can be trusted as a reference, the results are not easily interpreted. But using a short range 3D-VHF network such as the Lightning Mapping Array allows to evaluate a larger scale LF network, and using a well-known LF network in turn allows to evaluate a long range VLF network. The benefit of this method is that it can use large data sets over wide areas. Météorage has used a LMA network during the last Hymex campaign to benchmark its own network, and participate in the SAETTA project with a similar setup in Corsica.

The **use of "ground truth" information** relies on gathering third party information that allows verifying the localized data. It comes in different flavors:

Triggered lightning requires the installation of a rocket launcher in a lightning prone area; when a thunderstorm approach a rocket with a metallic wire is launched with the expectation that it will attract the lightning discharge. When this happens, the current flows through the wire and can be measured with a dedicated ammeter.

Collecting data from triggered lightning requires a costly setup and experience shows that each campaign provides a limited amount of data, but this technique allows to assess the peak current amplitude and polarity as well as the location accuracy of a detection network. Campaigns in the US and China show that the technology allows to reach a 15% accuracy for the peak current measurement

## Instrumented towers

High towers such as radio transmitters located on hilltops are known to attract lightning, in fact they produce more upward flashes than they receive downward flashes (natural discharges). Attaching a current measurement device to the lightning rod allows to capture the current waveform. Locating a video camera so that it catches the tower allows recording all the flashes and thus to compute the detection efficiency of a detection network. Although the setup for such project is costly and only provides data for one single location, it can produce enough data so as to measure the random and systematic location errors.

ALDIS, operator of the Austrian lightning detection network has recorded 469 return strokes at the Gaisberg tower since 2005. The median random location accuracy now reaches 90 meters, with no systematic error.

## High speed videos

Cameras have been used for decades in order to capture lightning events; as they record visible light they do not depend on the current or waveform of the electrical discharge, but they are limited to their field of view. Scrutinizing the flashes from the video capture and comparing them to the records from a detection network provides a good measure of the flash detection.

Using high speed cameras (up to 7 000 frames per seconds) that record each subsequent strokes leads to a measure of the stroke detection efficiency. It also brings a validation of the IC/CG classification. Adding an Electric Field antenna to the measurement setup allows to check the polarity the event.

Météorage has been using such a high speed camera in 2013 and 2014, collecting 261 flashes and 724 return strokes in various locations in France, Luxembourg and the UK. The measured detection efficiency reaches 97% for the flashes and 94% for the strokes.

## Forensic files

Using newspaper reports, insurance claims or maintenance logs, it is possible to compare the position of known damages with the nearest lightning. The accurate localization of the damage may be difficult obtain; and the cause of the failure must be clearly identified before any correlation is attempted, thus the analysis is mostly manual and time consuming. But this method provides a simple mean to gather evidences from many different places and thus evaluate the performance of a network over all the covered area. A study performed with 101 reports scattered throughout our network between 2011 and 2014 shows that in all cases a lightning flash had been detected close to the damage; the distance between the nearest flash and the reported place was found to be lower than 200 meters in most cases. Taking in account the fact that not only direct strokes produce damages but also close by flashes induce deleterious effects, those values confirm our estimated accuracy.

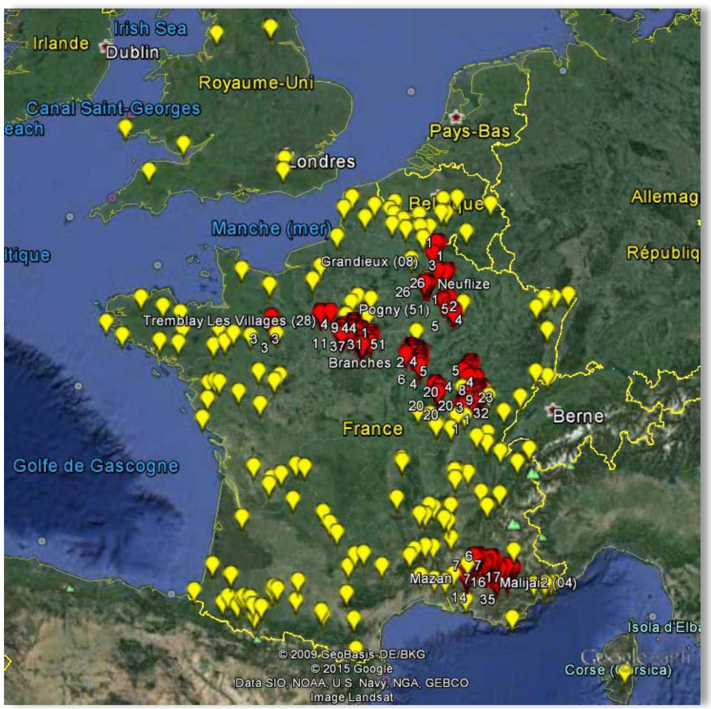


*Fig. 1 locations where Detection Efficiency could be measured (in red) or Location Accuracy could be evaluated (in yellow)*