

LIGHTNING WARNING STATION
OPERATIONAL SYSTEM FOR ADVANCED LIGHTNING WARNING

P.Richard, DIMENSIONS,
91194 Saint Aubin Cedex, France

I INTRODUCTION

Efficiency and Safety are determinant factors in many different activity domains such as industry, military or aerospace. Among all dangerous or perturbing factors, lightning has been until recently often considered as an unavoidable and unpredictable phenomena though it can be the cause of important hazards and damages in human activities. Operational systems however exist for the monitoring of severe weather: radars can locate heavy precipitation and convective areas, but they are unable to distinguish electrified and non electrified clouds; lightning location systems can be used either to locate cloud-to-ground flashes, but in this case they are limited to mapping functions without possibility of early detection of thunderstorms, or they can be used to locate the total lightning activity (SAFIR system) and thus give early warning informations before cloud-to-ground flashes. All these systems have their own interest and applications, but they can often reveal to be either too performant or costly for applications limited to a single site.

Simpler and less expensive solutions for lightning warning on a single site do exist, however this simplicity must not be gained to the detriment of efficiency and safety. For these reasons Dimensions has developped, on the basis of a know-how developed at the French National Agency for Aerospace Research (ONERA), a local "lightning warning station" performing the monitoring of the electrical activity of nearby thunderclouds and giving early warning informations in case of lightning hazards on the site. This equipment is based on a simple principle: the analysis of the electric field produced by thunderstorms. It represents however a new generation of product in the domain of lightning warning since it integrates state of the art measurement techniques and original know-how for the analysis of the electric field and the elaboration of lightning warning informations, thus giving to the user the most reliable and efficient informations for applications to the safety and efficiency of its sensitive operations.

This paper presents the principles and techniques used in the "lightning warning station", its operation and performances are discussed and illustrated through an example of thunderstorm situation.

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II SYSTEM PRINCIPLES

1 Lightning Warning Principles

Before discussing the principles used for the elaboration of warning informations, we will first describe the typical behavior of thunderstorm clouds during their development.

1.1 Typical development of a thunderstorm cell

Thunderstorms are convective clouds created by the thermal instability of a humid air mass. They are made of convective cells. These cells develop very rapidly, they last a few tens of minutes, grow up to altitudes of 10 to 15 km and have a diameter of about 10 km. Thunderstorms are frequently multicellular, and can extend over tens or hundreds of kilometers and last several hours.

During its development a thunderstorm cell presents very strong updrafts (up to 50 m/s) carrying up precipitation particles. The electrification of the thundercloud is due to the charging of graupels and ice crystals by collisions and to their separation by differential vertical motions. These processes result in a tripole electrical structure with a main negative charge around 6 km, a positive charge in the upper part of the cloud and a small positive charge at the cloud base. Winter thunderstorms have a similar structure, but over a smaller vertical extent.

The electrification of the thundercloud creates a strong electric field (Figure 1 [A]). It can exceed 10 kilovolts per meter on the ground in the vicinity of the thunderstorm, and reaches several hundred kilovolts per meter within the cloud. This initial electrification phase last 5 to 20 mn. The active phase starts with the first intra-cloud discharges (figure 1 [B]). During the first part of the active stage, the activity is made uniquely of intra-cloud discharges occurring between the main negative and the upper positive charge regions. Their rate increases until the cell reaches its maximum vertical development (Figure 1 [C]). They induce very rapid changes in the electrostatic field, which can be observed at a distance of several tens of kilometers; they also radiate electromagnetic waves which can be detected and used for lightning location at long range (SAFIR system). Intra-cloud discharges are much more frequent than cloud to ground lightnings, they typically represent 70 to 90% of the total activity of a thunderstorm.

The first Cloud to ground lightning is usually observed 5 to 30 minutes after the first intra-cloud lightnings. The peak cloud to ground lightning activity occurs subsequently typically 5 to 10 min after the maximum of Intra-cloud activity, it is usually associated to the subsequent descent of precipitation particles below the main negative charge layer and can be accompanied in severe thunderstorms by strong downdrafts and intense precipitations at ground level.

1.2 Lightning warning principles and advantages

A thunderstorm is a rapidly evolving phenomena which can be monitored through the analysis of the electric field that it generates in its vicinity. Until now, the most frequently used techniques were based on the measurement of the static value of the electric field and a warning was issued when the field was increasing over a predetermined threshold. This type of principle does not take into account the dynamic behavior of phenomena and usually only provides a rough information about the situation; the warning is subject to fluctuations and depends on the value of the threshold and on the local conditions which can disturb the measurement (such as local space charge layer).

The principle of the warning processing used in the "lightning warning station" is to take into account the dynamic behavior of thunderstorms in order to better characterize the phenomena and to forecast its short term evolutions. This analysis is performed in real-time, it is a real "intelligent processing" of the electric signal generated by the thundercloud.

This intelligent processing relies on 3 main levels of analysis:

- the standard measurement of the static value of the electric field; it characterizes the electrification level over the site.
- The analysis of the variations in the electric field; it characterizes the intensity of electrification processes within the thundercloud, as well as the movements of electrified clouds in the vicinity of the sensitive site.
- The detection and analysis of lightning flashes (intra-cloud and cloud-to-ground) which enables the early detection of active thunderclouds up to 30 minutes before the first cloud-to-ground flashes, the characterization of thundercloud severity, and the long range detection of approaching active thunderstorms (~30 km).

On a practical stand-point this processing gives four different warning levels:

Level 0 (green)

- no thunderstorm activity.

Level 1 (blue)

- Early detection of electrical activity. Tendency towards thunderstorms in the nearby area;
- Typical delay: 15-45 min.;
- No confirmed short-term risk for the site.

Level 2 (orange)

- Distant thunderstorm activity (>10km), short term thunderstorm hazard on the site
- Typical delay: 5 - 20 min.;
- Possible disturbances on the site.

Level 3 (red)

- High-risk situation. On-site thunderstorm, lightning stroke hazard;
- Typical delay: less than 10 min.;
- Lightning-stroke hazard on this site;
- Possible disturbances on the site.

The same principles are used for lightning warning clearing.

2 sensor principles:

The automatic lightning warning station hardware comprises a measurement system (electric field sensor) and a warning terminal (figure 2).

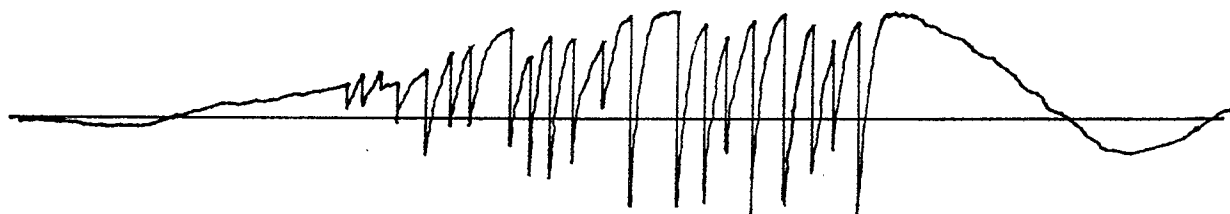
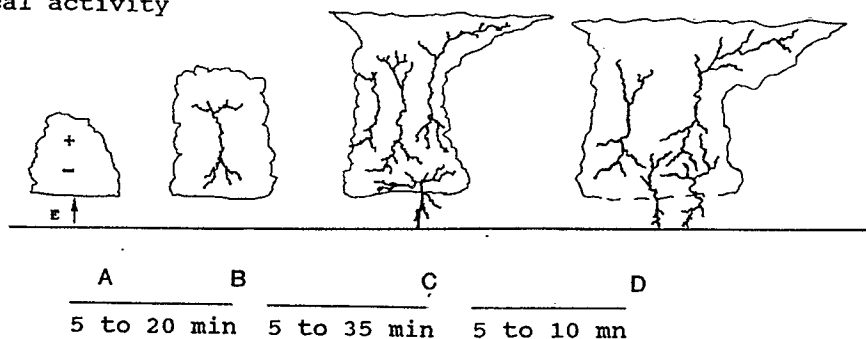
2.1 The Sensor

The electric field sensor includes:

- An atmospheric electric field measurement system based on the field mill principle;
- A micro-processor central processing unit;
- A backed-up power supply.
- A modem for transmitting data to the warning terminal either through the standard telephone network or dedicated transmission lines.

The sensor has auto-test and functional test capabilities. The sensor condition is periodically transmitted to the terminal,

evolution of
electrical activity



evolution of
electric field
on the ground (E v/m)

Fig 1 Typical development of a thunderstorm cell

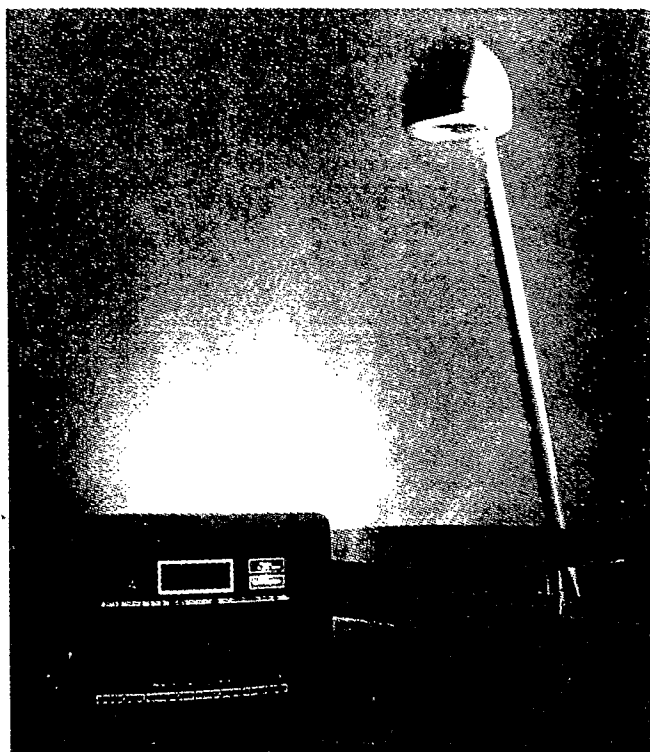


Fig 2: lightning warning station hardware
Electric field sensor and display terminal

it can confirm to the user the quality of system operation and the validity of lightning warning messages. System installation is simple. It only requires a free area with a radius of about ten meters, a power supply and a transmission line (RS-232 or telephone network). The sensor may be installed on a building terrace or in a courtyard; it can take the influence of the site it is installed on into account for the computation of warning data.

2.2 The Terminal

The warning terminal can be either a stand-alone warning display unit or a PC-type micro-computer. It is connected to the sensor through a telephone or a RS-232 line.

The stand alone display unit is adapted to most decision facilities (whether automatic or not) and to applications that do not require later data archiving or processing. It displays warning level as a three-color code and a status of system

operating conditions, shown by means of indicator lights. Included are control lines for remote-controlling of external devices (generators, isolator switches, sirens, etc).

The PC terminal (figure 3) has all of the display unit's functions, but it provides a more user-friendly interface, continuous storage of measurements and a post-processing software package for processing stored data (statistics, afterward justification of an alarm decision, ...). Moreover, it may receive and manage information from several sensors when a wide area is to be covered.

When used through the telephone network, in order to reduce communication costs, the sensor is operated in an automatic call mode, and connects automatically to the terminal (display unit or PC) in case of lightning warning.

III APPLICATIONS

1 Example of thunderstorm situation

Lightning warning stations are already in use on different military and aerospace centers. We present here a typical situation observed at the "Centre Spatial Guyanais" in French Guiana where these sensors are installed in complement to a SAFIR thunderstorm monitoring and lightning warning system (figure 4). We are thus able in this particular case to analyse the behavior of the lightning warning station in comparison with location of lightning flashes.

The thunderstorm cell develops (figure 4) on the ocean about 30km North-East to the launch pads. Thunderstorm lifetime is about 1 hour and it propagates in direction of the space

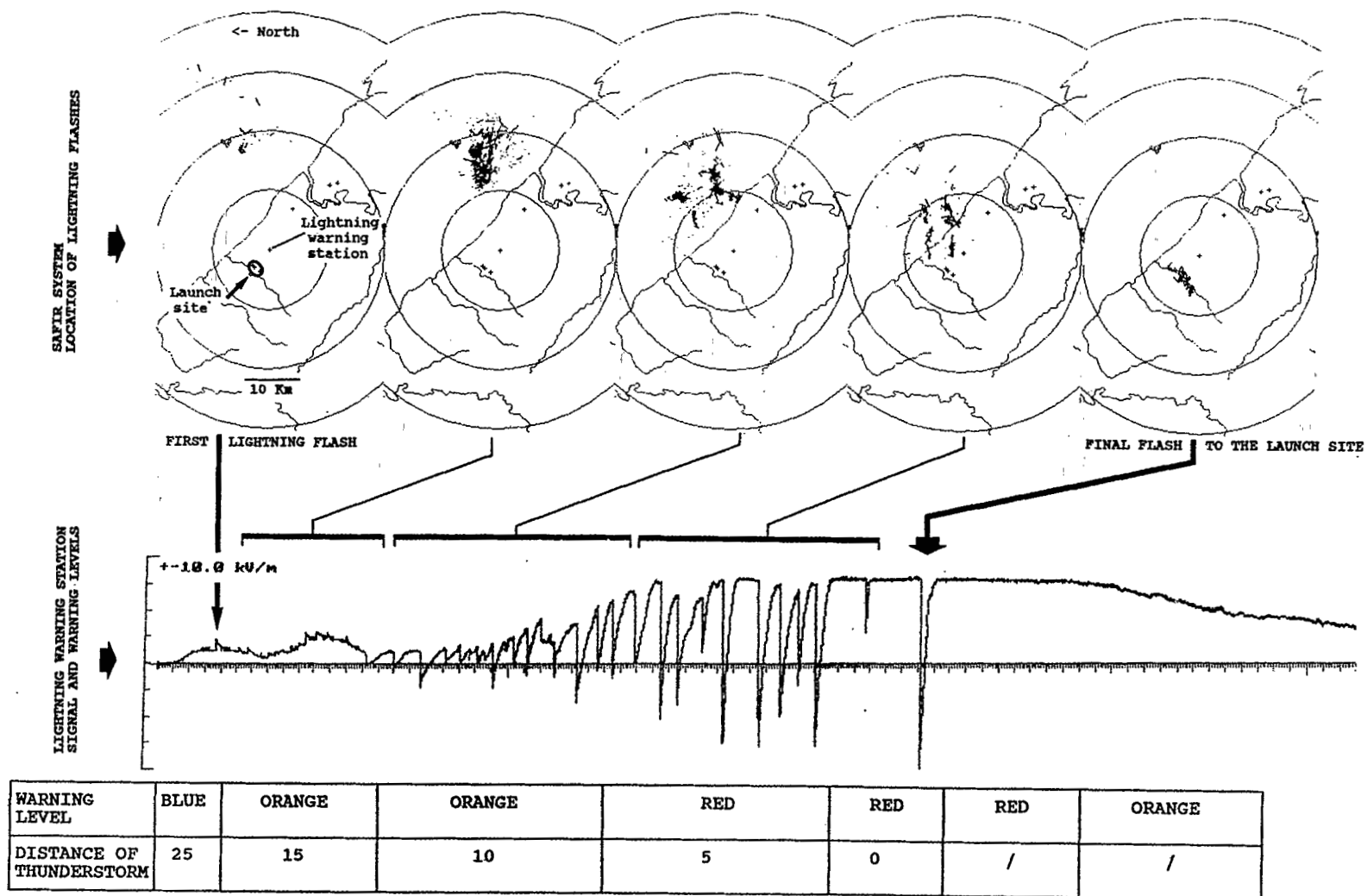


Fig 4

EXAMPLE OF THUNDERSTORM SITUATION
time evolution of warning informations, comparisons with the location of the thunderstorm

center. The last flash, among a total of 48 lightning flashes, strikes the launch area.

The lightning warning station is located a few kilometers away from the launch pads; at the beginning of this situation warning level is 1 (blue) due to earlier detection of fluctuations in the electric field value which reveal unstable conditions.

The station detects its first lightning flashes 43 minutes before the lightning strike on the launch site, at this moment the thundercloud is 25 km away, warning level is set to 2 (orange).

Warning level is then set to 3 (red) more than 20 minutes before flash to the launch site, the thundercloud is still 10 km away. Warning is then maintained to red until final flash and still for ten more minutes.

This situation is a typical example of early warning capability and long range detection of the lightning warning station, a thunderstorm warning is given here more than 40 minutes before lightning strike to the sensitive site when the thunderstorm is still 25 km away, lightning hazard is then confirmed to the user with a 20 min advanced delay.

2 applications

The intelligent processing performed by the lightning warning station enables a fully automatic operation of the equipment, it can provide early warning informations up to several tens of minutes in advanced and can be applied to the manual or automatic implementation of safety procedures and protection systems.

System reliability and warning efficiency will find their main applications and justification for sensitive activities which mainly involve: computer systems, automated production systems, volatile chemicals, explosives, telecommunication equipments, power systems, electronic and radio-systems; it also increases the safety of personnel working under exposed conditions.