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Thunderstorm warning alarms methodology using electric field mills and lightning location networks in mountainous regions

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Abstract— This paper presents a methodology for thunderstorm warning alarming using electric field measurements and lightning location data under mountainous conditions in Medellín – Colombia. The methodology is used to set warning criteria for preventing human and sensitive systems risks and damages.

Keywords- Electric field mill, lightning location system, two area method, forecast verification, non flat terrain.

I. INTRODUCTION

Colombia, due to its inter-tropical location, has a high cloud to ground lightning activity [1]. Several authors have found a ground flash density higher than 40 flash/km^2 into the territory. The high lightning activity represents a countless Compatibility Electromagnetic problems, as well as lot of human injuries and fatalities. For example, the last year more than 50 injuries and fatalities were reported by Colombian news networks. Daily, the aviation systems, oil transporting and storage systems, electrical systems, outdoors sports activities and others have to hol on this inclement natural phenomenon.

Despite a lightning strike is impossible to be avoided, several strategies could be designed to deal with it and to generate warning alarms to prevent fatalities and human injuries, failures, material damages, economic losses and others problems related with the lightning activity.

Nowadays, lightning data are becoming more available and cheaper; however this information requires processing efforts to be useful.Tthe lightning warning systems are between the main applications of this data..Several studies worldwide have been developed about this subject; some authors use the cloud to ground information [2]-[4], others the total lightning activity from lightning location networks [5], and recently electric field measurement have been included into warning methodologies [6], weather information such as radar reflectivity and satellite images [7]-[8] have been used jointly implemented or separated.

This work presents a preliminary methodology for triggering thunderstorm warning alarms in mountainous regions based on the measurement of the environmental electric field variations obtained from an electric field mill, and cloud to ground lightning information obtained from the Colombian Lightning Location Network (SID). The spatial and temporal characterization of thunderstorm's activity over Medellín, with previous measurement systems, summarized in [9]-[10], allowed designing several criteria for triggering lightning alarms.

The obtained results from this previous methodology showed that the traditional method, used in generating this kind of alarms known as the "two area method" [2]-[11], is not completely optimal when it is applied to regions with high altitude variations, as it is presented in the Colombian territory. Nevertheless, the criteria developed in this study improve the the efficiency and effectiveness indicators in order to obtain a more optimal TWS over non flat terrain..

II. THUNDERSTORM WARNING AND PREDICTION METHODOLOGY

A. Owerview about international standars over TWS

Nowadays, few international standards have been developed around the thunderstorm warning systems. For example, the European Committee for Electrotechnical Standardization – CENELEC published the standard EN50536 [12] – Protection Against Lightning - Thunderstorm Warning Systems. The goal of this standard is to provide information on the characteristics of thunderstorm warning systems and information for the evaluation of the usefulness of lightning real time data and/or storm electrification data in order to implement lightning hazard preventive measures..

Similarly, the Federal Aviation Administration – FAA, in the ACRP report 8 [13] – Lightning Warning System for Use by Airports, summarized the impact of the total cessation of activities in airports, the safety and operational ramp, when outdoors activities should be halted, the cost of suspending ramp operation, the aircraft delay, labor delay, passenger time delay, and in the worst case the remuneration cost by human fatalities.

B. Prediction methodology – " Two area method"

The Two area method was introduced by Muypy et al [3]-[4]. This method defines two concentric areas at a geographical point called Point of Interest – PI. The first area that surrounds the PI is called Area of Concern – AOC. This region includes zones highly vulnerable by any stroke without notice. The second area or Warning Area – WA surrounds the AOC. When the atmospheric activity is reported over the second region, the thunderstorm warning should be triggered, and the preventive actions must be started. Figure 1 shows the two areas method analyzed in this work.

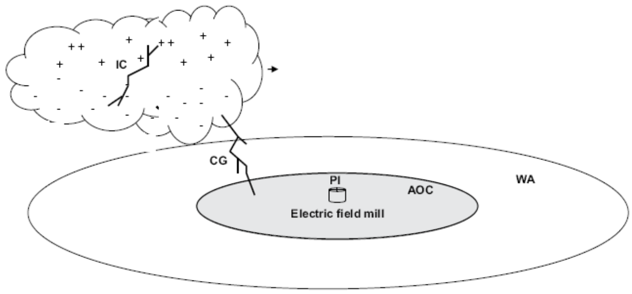

Figure 1. The two area method

The size and shape of the regions should be adjusted according to the detection efficiency and localization accuracy of the detection system and the target shape. This work employed Electric Field Mill – EFM records and data from the Colombian Lightning Location Network – SID, allowing designing multiple criteria for triggering warning alarms.

C. Forecast Verification

Independently of the lightning data source, the effectiveness and efficiency of any Thunderstorm Warning System – TWS should be assessed. For example, the Forecast Verification is employed to validate the forecast methodologies for several natural phenomena [14]. In this case, the forecast verification is applied by using a simple dichotomous method, summarized by the contingency table showed in the Table 1.

TABLE I. CONTINGENCY TABLE

		Observed		
		YES	NO	Total
Forecast	YES	EA	FA	Forecast yes
	NO	FTW	----	Forescast no
	Total	Observed yes	Observed no	Total

Table above allows evaluating the following parameters:

- Effective Alarm – EA: Observed lighting that was correctly predicted. Occurred when a thunderstorm warning is triggered prior any stroke into AOC.
- The False Alarm – FA: Lightning warning triggered, but none lightning stroke observed into the AOC.
- The Failure to Warn – FTW: Lightning observed within the AOC without a previous triggered warning.

The Lead Time – LT is other important parameter into the methodology. This is the time for preventive actions to be taken, such as looking for safe places, activation of auxiliary power systems, disconnection of sensitive equipment, cessation and evacuation of exposed zones and others. Technically this time is the difference between the triggering alarm time and the time when this alarm is effective.

In addition, when a thunderstorm warning is triggered, a time limit must be established for the extinction. This temporal window is called Dwell Time – DT and represents the time under electrical activity conditions with the highest risk level for human injuries and dead. The DT is reset by any stroke on WA or AOC. In many cases, this time is adopted as a function of the cost by each cessation activity, for example: oil fields, aviation, airports and other. In this work, 30 min of DT was adopted.

On the other hand, several authors, Muprhy et al [4], Aranguren et al [6], the European Standard EN50536 [13] employed two categorical statistical for assessing the effectiveness and efficiency of the prediction methodology: the probability of detection – POD and the false alarm ratio - FAR. In this study the same categorical statistics given by Eq. (1) and Eq. (2) are used.

$$POD = \frac{EA}{EA + FTW} \qquad (1)$$

$$FAR = \frac{FA}{FA + EA} \qquad (2)$$

III. DATA AND METHODOLOGY

A. Data

The lightning detection and localization information was provided by the Colombian Lightning Location Network - SID operated by Interconexión Eléctrica S.A – ISA. The network is composed by six low-frequency sensors TS7000 (Thunder Storm 7000). These sensors combine the Time of Arrival (TOA) and Direction Magnetic Finding (DMF) techniques. SID provides only information about cloud to ground (CG) lightning activity. Some CG lightning parameters are: time, peak current, polarity and location. Currently the SID network is not used for thunderstorms warning systems or forecasting, it is only used for technical purposes. On the other hand, the change in the atmospheric electric field was measured by using an Electric Field Mill – EFM located in Medellín city. The EFM was designed by the Research Group of Analysis and Acquisition Signal PAAS –UN; it is described by Aranguren [15]. Due to the EFM was installed over non flat terrain and in the top of a building, the electric field measurements contain some shielding effects, amplification or distortions generated by neighboring elements. Some authors as Aranguren [15] and López [9] have studied the behavior the electric field in tropical regions; they performed several computational simulations and correlations between lightning location data and electric field measurements for suggesting some methodologies about correction factors. Figure 2 shows the EFM station used in this work.

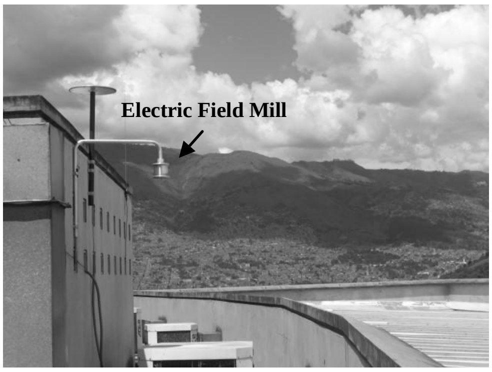

Figure 2. Electric Field Mill. (background: Non flat terrain and the City of Medellín)

B. Methodology

For a given region, in this case the city of Medellín located at Lat 6° 14′ 9.33 N and Long 75° 34′ 30.49″ W and 1600 meters above sea level, it was analyzed the lightning activity of 21 thunderstorms recorded from 2010 to 2011 using the EFM and lighting data. The analysis of categorical statistical was performed over a region of 2800 km^2. Figure 3 shows the geographical configuration of the two area method around Medellín.

In Figure 3, the PI is located over the Minas School building at the National University of Colombia. In this work, the AOC radius was established in 10 km. Similarly, the WA radius was established in 20 km.

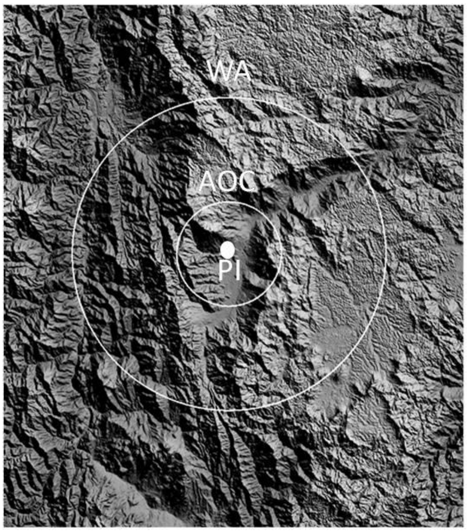

Figure 3. Geograhical configuration of the two area method in Medellín.

IV. ANALISYS AND RESULTS

A. Two area method – common criteria

Initially, the two area method was implemented using the more common criteria. The alarms were triggered by one cloud to ground flash reported in the WA or OAC regions. The number of false alarms and fails to warn was computed by counting the number of these events associated to each storm day on the region. The Probability of Detection - POD and False Alarms Ratio – FAR are summarized in Table II.

TABLE II. STATISTICAL SUMMARY TWO AREA METHOD CRITERIA CLASSIC

Criteria	POD [%]	FAR [%]	Total A	Total EA	Total FA	Total FTW
Classic	64	69	93	24	54	13

Total Alarms – Total A; Total Effective Alarms – Total EA; Total False Alarms – Total FA; Total Failure to Warn – Total FTW.

Table above shows that 93 alarms were triggered; 24 were effective, 54 were false alarms, and 13 were failures. Under the last results, the effectiveness and efficiency reached 64% and 31% respectively. Moreover, the high value of the FAR (close to 70%) indicates that the methodology present a high uncertainty. On the other hand, Figure 4 shows the Lead Time – LT distribution. In general, the LT moves from few second to several minutes.

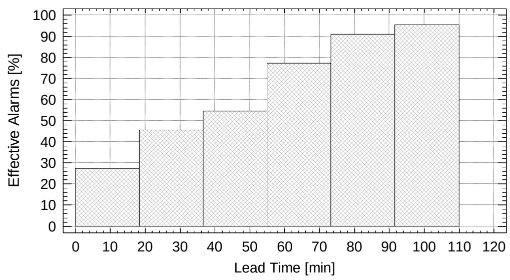

Figure 4. Lead Time – LT in the two area method using common criteria

In Figure 4, 50% of the Effective Alarms - EA had 50 minutes of Lead Time - LT, the others reached up to 60 and 110 minutes. This temporal window represents a reliable time for taking preventive actions. However, despite a short LT be validated as an Effective Alarm, it should be taken as a Failure to Warn, due to it could not be enough time for preventive actions. Preventive actions with short times could increase the risks. The POD and FAR values found in this work are similar to those given by Murphy et al [16] using cloud to ground lightning data and the common used criteria.

In order to improve the parameters previously mentioned and their categorical statistical (POD and FAR), a methodology composed by two criteria groups is proposed. The first group analyzes the duration, displacement and proximity of the thunderstorms and thunderstorm tracking parameters based on the SID lightning location data, as described by López et al [10]. The second group includes the spatial and temporal electric filed characterization over Medellín at the same thunderstorm season and described by López [9]. In general, the most relevant criteria developed in this methodology are summarized below:

- Criteria 1: Spatial and temporal lightning data clustering into WA.
- Criteria 2: Geographical overlapping between WA and the thunderstorm active zone.
- Criteria 3: Thunderstorms displacement and direction.
- Criteria 4: Electric field measurements. Threshold, rate of change, sudden or instant variation, among others.

Fig. 5 summarizes schematically the criteria developed in this work.

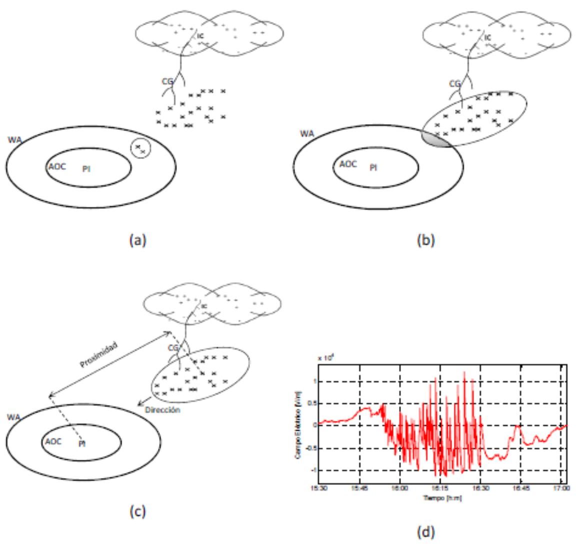

Figure 5. Criteria developed for triggering alarms using two area method: a) spatial and temporal clustering CG, b) Geographical overlapping, c) Thunderstorms displacement and direction of, d) Electric field measurement.

In order to evaluate the previously mentioned criteria, at first the result about lightning data information employing criteria 1 to 3 are shown, then the overall criteria including electric field measurements are presented.

B. Two area method: 1st, 2nd and 3rd criteria. CG lightning only.

In this case, the thunderstorm alarms are triggered **IF** two lightning strokes occurred into WA region within a minute **AND** the WA region and thunderstorm active zone have less than 50% of overlapping **AND** the distance between the thunderstorm “centroid” (mean geographic lightning detection point) and PI is less than 60 km and its displacement is directed toward AOC or WA regions. The previous conditions are adopted by thunderstorm characterization in the non flat terrain case in Medellín. Table III summarizes the predictive parameters and categorical statistics.

TABLE III. STATISTICAL SUMMARY TWO AREA METHOD CRITERIA 1 TO 3. CG LIGHTNING ONLY

Criteria	POD [%]	FAR [%]	Total A	Total EA	Total FA	Total FTW
Classic	51	41	52	19	13	18

In this case 52 alarms were triggered, 19 were Effective Alarms, 13 were False Alarms, and 18 Failures to Warn. The effectiveness and efficiency reached 51% and 41% respectively. Comparing Table II and Table III, it can be noted that the POD decreased 13% due to FTW increased in five. Similarly, the FAR decreased 26% because FA changed from 54 to 19 and the Total Alarms decreased 60%. If each criterion is separately analyzed, the largest amount of EA are provided by the first criterion (clustering), followed by third one (cell tracking) and finalized by second one (overlapping). Figure 6 shows the LT. 47 % of the Effective Alarms - EA had 30 minutes of Lead Time - LT, the others reached up to 30 and 100 minutes; the mean LT was 45 minutes.

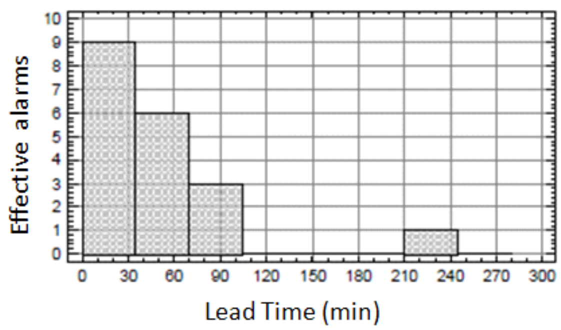

Figure 6. Lead Time – LT the two area method, 1st, 2nd and 3rd criteria

The criteria developed until now, show that add them into two area method, is more efficient than reported the form classic, however, a low value POD indicated that only cloud to ground lighting using data, the methodology does not reach a tolerable level for EA and FTW. The next section shows results add the electric field measurement at the methodology predictive.

C. Two area method: 1st, 2nd, 3rd and 4th criteria. CG lightning and electric field measurement

The measurement of the environmental electric field was added as an additional parameter in order to increase the alarm triggering criteria and finally, improve the number of effective alarms produced for this region. A signal processing algorithm was designed to identify electric field changes associated to the increase of the thundercloud charge, the presence of small lightning discharges, the detection of close lightning activity and the final stage of the storm. In this case, the lightning alarms was triggered **IF**: cloud to ground lightning criteria are satisfied **AND** the electric field threshold exceeds 2kV/m **AND** the rate of electric field change per minute is negative and exceeds -400V/m/min **AND** the electric field abrupt changes "ΔE" exceed 500 V/m. The values or magnitudes above mentioned apply only to Medellin city, under the electric field mill installation conditions and non flat terrain topographic characteristics. Table IV summarizes the predictive parameters and their categorical statistics.

TABLE IV. STATISTICAL SUMMARY TWO AREA METHOD. CG LIGHTNING AND ELECTRIC FIELD MEASUREMENT CRITERIA

Criteria	POD [%]	FAR [%]	Total A	Total EA	Total FA	Total FTW
Classic	76	85	204	28	164	9

The effectiveness in this case was 76% (POD close to 80%). The efficiency was 15 % (FAR close to 90 %). The triggered alarms and false alarms reached 204 and 164 respectively. The failures to warn decreased to 9 events. However, the high values of FA indicate that the methodology is not reliable due to high uncertainty. For this reason, a Boolean filter were developed with the results obtained in each case, so that, the criteria with a best adjustment was taken into account by setting the Total Alarms, EA, FA and FTW using the two criteria groups. By analyzing each criterion, the best adjustments are summarized in the next order:

1. Spatial and temporal lightning clustering into WA region.
2. Thunderstorm active zone direction.
3. Electric field abrupt change "ΔE".
4. Electric field rate of change.

The other criteria were neglected, due to the high values of false alarms. Now, thunderstorms alarms are only triggered, if any of the condition previously summarized are satisfied. In this case, Table V shows the categorical statistics.

TABLE V. STATISTICAL SUMMARY TWO AREA METHOD CRITERIA BEST ADJUSTMENT SETTING

Criteria	POD [%]	FAR [%]	Total A	Total EA	Total FA	Total FTW
Classic	68	46	60	25	22	12

Table V shows that 60 alarms were triggered, of which 25 were effective, 22 were false alarms, and 12 were failures to warn. Under above criteria, the effectiveness and efficiency reached 68% and 54% respectively. On the other hand, Figure 7 shows the Lead Time – LT distribution. In general, LT change from few second to several minutes. 47 % of the effective alarm had 15 minutes of LT, 35% presented LT from 15 to 30 minutes; the others exceeded 30 minutes. The average LT was 32 minutes. In general, for all study case in this paper, 60% of the effective alarm occurred in the first 32 minutes.

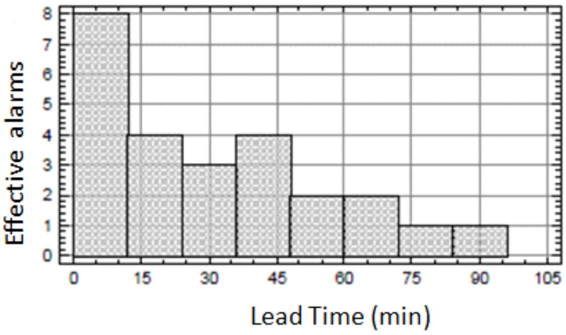

Figure 7. Lead Time – LT the two area method, more common used criteria

Finally, Table VI presents a summary of the warning criteria and categorical statistical found in the non flat terrain conditions in Medellín.

TABLE VI. STATISTICAL SUMMARY TWO AREA METHOD CRITERIA BEST ADJUSTMENT SETTING

Criteria	POD [%]	FAR [%]	Total A	Total EA	Total FA	Total FTW
Common	64	69	93	24	54	13
SID	51	41	52	19	13	18
EFM - SID	76	85	205	28	164	9
Best	68	46	60	25	22	12

V. CONCLUSIONS

This paper describes a combination of information sources that leads to the establishment of the necessary criteria and the implementation of a thunderstorm warning methodology for a given region in Medellín - Colombia. This region is located at Andean mountain characterized by complex orography. The latitude in this region varies from 1500m up to 2200m, where an electric field mill was installed and calibrated.

According to the results, a significantly improvement in the efficiency and the effectiveness of thunderstorm alarms is obtained compared to those found from the two area method using only the lightning location system information and without establishing the best criteria for alarms triggering.

As it is shown in the results, for the parameters obtained from the two area method, the POD has low values for the improved methodology having as a maximum 68% and the FAR parameter has high values around 46%. This is probably due to the variability of the formation places and complex movements of thunderstorms in mountainous regions.

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REFERENCES

[1] H. Torres, El Rayo, Mitos, Leyendas, Ciencia y Tecnología, Bogotá: Universidad Nacional de Colombia - Sede Bogotá Facultad de Ingenieria - UNIBIBLOS, 2002.

[2] J. Inampués, D. Aranguren, H. Torres, J. Montanya, I. Santoyo, E. Olarte, and C. Younes, “Analysis of lightning forecasts in Colombia based on the lightning detection detwork data,” X International Symposium on Lightning Protection - X SIPDA, Curitiba, Brazil: SIPDA, 2009.

[3] M.J. Murphy, “Probabilistic early warning of cloud-to-ground lightning at an airport,” 16th Conference on Probability and Statistics in the Atmospheric Sciences, Orlando, Florida: 2002.

[4] N.C. Clements, “The warning time for cloud-to-ground lightning in isolated , ordinary thunderstorms over Houston , Texas,” Master study: Texas A&M University, 2007

[5] M. Murphy and N. Demetriades, “The role of total lightning in thunderstorm nowcasting,” Symposium on Planning, Nowcasting, and Forecasting in the Urban Zone, Tucson, Arizona, USA: VAISALA Inc, 2005.

[6] D. Aranguren, J. Montanya, G. Solá, V. March, D. Romero, and H. Torres, “On the lightning hazard warning using electrostatic field: Analysis of summer thunderstorms in Spain,” Journal of Electrostatics, vol. 67, May. 2009, pp. 507-512.

[7] Montanyà, D. Aranguren, N. Pineda, G. Solà, D. Romero, and V. March, “Total lightning, electrostatic field and meteorological radar applied to lightning hazard warning,” Proceedings of the 20th International Lightning Detection Conference, 2008.

[8] K. Cummins and M. Murphy, “Lightning detection methods and meteorological applications,” IV International Symposium on Military Meteorology, 2000.

[9] J, López. “Metodología para predicción de tormentas eléctricas a partir de mediciones de campo electrostático ambiental y sistemas de localización de rayos en zona montañosa”, Master study: Medellín – Colombia 2011.

[10] J, López.; Perez, E.; Herrera, J.; Porras, L.; , "Methodology for thunderstorm tracking using lightning location systems data in Colombia," Lightning Protection (XI SIPDA), 2011 International Symposium on , vol., no., pp.146-151, 3-7 Oct. 2011.

[11] V. Cooray, “Lightning Protection,” IEEJ Transactions on Power and Energy, The Institution of Engineering and Technology, London, United Kingdom, 2007.

[12] EN50536. “Protection against lightning. Thunderstorm warning systems”. European Committee for Electrotechnical Standardization, 2010.

[13] ACRP Report 8. “Lightning-Warning Systems for Use by Airports”. Airport Cooperative Research Program, Federal Aviation Administration, USA, 2008.

[14] I. Jolliffe and D. Stephenson, “Forecast Verification: A Practitioner’s Guide in Atmospheric Science”, England: British Library, 2003.

[15] D. Aranguren, “Estudio de las tormentas eléctricas a través del campo eléctrico ambiental”, Master study: Universidad Nacional de Colombia - Sede Bogotá, 2006.

[16] M.J. Murphy, R.L. Holle, and N.W.S. Demetriades, “Cloud-to-ground lightning warnings using electric field mill and lightning observations,” International Lightning Detection Conference, Tucson, Arizona, USA: 2008.