A Lightning Warning Algorithm Using a EFMs Network and LPS

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Abstract

In this work, an Electric Filed Mills (EFMs) network and Lightning Positioning System (LPS) data during June, July and August of 2013&2014, were chosen and processed for lightning warning. We set a region of 10km radius from the EFM sites as the Area Of Concern (AOC), and a second region extending 20km outward, as the Warning Area (WA). Electric field (EF) was smoothed using a running average of a particular number of samples to lessen the effect of rapid vibration. A warning is triggered if one of the following condition is met:

1) Lightning occurs within the WA and at least one of the field values is above a threshold,

2) Both field values are above threshold,

3) Lightning occurs within the AOC.

The result showed that our algorithms performed better than the method using lightning data alone, and that an EF threshold of 4kV/m and a smoothing window of 30sec turned out to be the best combination in most conditions.

Key Words: Electric Field (EF), Electric Filed Mills (EFM) network, the Lighting Warning Algorithm, data procession and analysis, the Probability Of Detection (POD), and the False Alarm Rate (FAR).

Introduction

Lightning activity is one of the major causes of weather related human injuries, deaths and loss of property. It is a source of 496 disasters and accidents on average in Jiangsu, China, from 2008-2013. Because of the short-life and small-range of many thunderstorms as well as the small-extensibility and low-resolution of the Numerical Weather Prediction (NWP) Model, lightning forecast is rather complex and challenging (Zhenhui 2009, Minxue et al. 2012).

Warnings due to lightning have been eventually developed from the detection of Cloud-to-Ground (CG) flashes (Xiaofeng et al. 2003). With development of automated Electric Field Mills (EFMs), some work has appeared in the literature discussing performance of EFMs in the lightning warning systems. Wilson et al. (2004) put up with a threshold of 2kV/m to trigger a lightning alarm. Aragorn et al. (2009) analyzed thunderstorm episodes in Spain during 2008 and found that EF polarity reversion indicated CG flashes afterward. Nicholson and Mulvehill (2000) discussed the network of EFMs at the NASA Kennedy Space Center (KSC). While they didn't discuss a specific warning algorithm, they did describe the pattern of electric fields observed under typical Florida thunderstorms. Likewise, Montanya et al. (2004) described a principle component analysis method for utilizing multiple variables in addition to EF data for lightning forecast. More recently, Junchi et al. (2013) carried out analysis of EF characteristics during thunderstorms in addition with Lightning Positioning System (LPS) data around Nanjing from June to September 2009. Then, forecasting equations were set up based on the amplitude, fluctuation rate, profiles and polarity reversal. Also, some scholars described lightning warning approaches by combining EF with other data such as radar and precipitation (Taichang et al. 2006, Haihua et al. 2009, Hond et al. 1994, Xiaofeng et al. 2003, Goodman et al. 1988).

Motivation for the Present Study

The foregoing instruction makes it clear that a more systematic study on contribution of EFMs to lightning warning systems, with a larger and continuous sample of data, is needed. First, we will utilize continuously recorded and time-stamped EF data. A large sample of storm data is also required. In

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addition, given that EFMs are frequently used in conjunction with CG lightning detection data in automated warning algorithms, we'll replicate that same set of circumstances with this analysis for comparison. We seek to determine the specific contribution of false detections to the problem, and to assess the effects of varying the parameters by which the EF data are incorporated in the algorithm.

Data and Methods

The EF data comes from stations as Figure 1 settled by Jiangsu lightning protection center during 2013 and 2014. All the EFMs are continuously digitized at a 50 Hz sampling rate. This satisfies one of our major objectives, data continuity. Although all the four EFMs are recorded, we selected two of the sites in particular, the EAGLE MOUNTAIN site and the PUKOU site, which are approximately 4km apart, a geometry that is similar a typical airport lightning warning system(Yuwen et al. 2004). The EF data are broken down into files of 30 minutes duration. Any bad data was removed and calibration was conducted by method proposed by our previous work (Junchi et al. 2011).

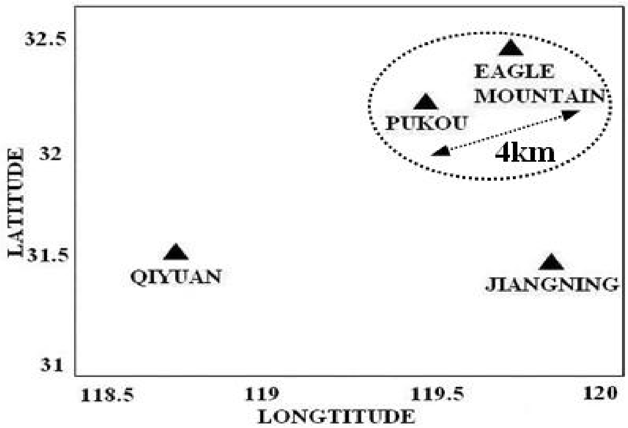

Figure 1: locations of EFMs.

During a thunderstorm, EFMs detect field charges due to the charge separation processes in the cloud as well as the evolution and eventual dissipation of regions of net charges as the storm decays. Lightning induced field changes can make the field either rise above or drop below a threshold level used in a warning algorithm. For this reason, the data have to be smoothed to lessen the effects of the rapid field changes. Figure 2 shows a sample of EF data from the EAGLE MOUNTAIN sensor during a two hour thunderstorm(the light gray solid line) together with 30sec(the dark gray dotted line) and 90sec smoothed(the black dashed line) values of the same period. In our analysis, smoothing is done using a running average of a particular number of samples. In addition, for our present study, the lightning data were provided by the National Lightning Positioning Network (NLPN).

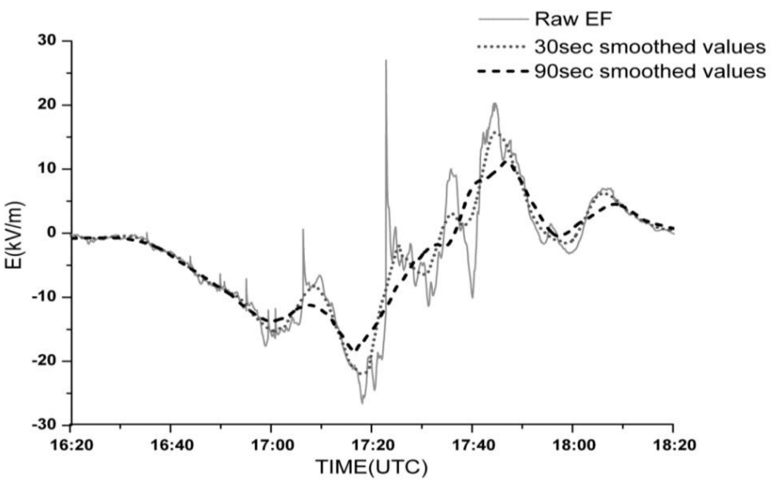

Figure 2: EF data from the EAGLE MOUNTAIN sensor during a two hour thunderstorm together with 30sec and 90sec smoothed values of the same period.

In Figure 3, there is an inner region set as the Area Of Concern (AOC), when a CG flash occurs in the region, it is considered as an immediate threat, and the objective is to use additional information to provide advance notice prior to the first CG in the AOC. A second region, called the Warning Area (WA), surrounds the AOC. The AOC extends 10km outward from the EFMs in each direction, and the WA extends 20km outward. As is seen in Figure 4, a warning is triggered if one of the following condition is met:

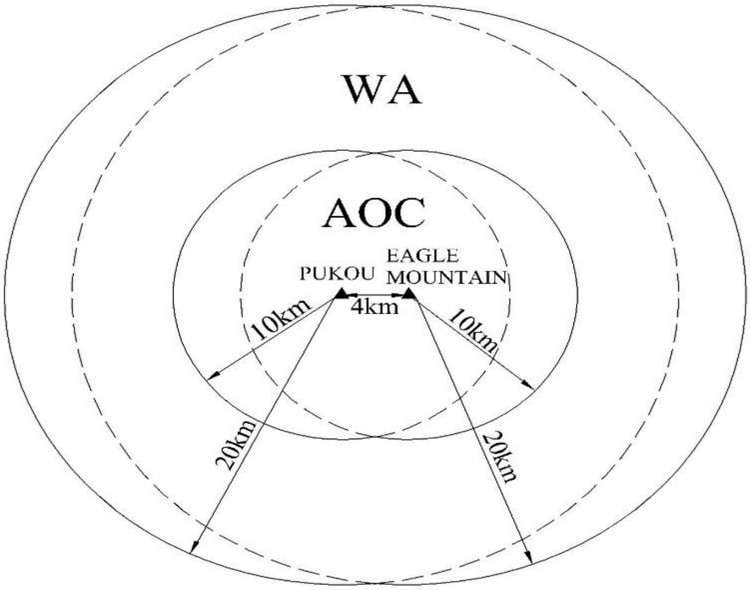

Figure 3: Configuration of AOC and WA.

1) Lightning occurs within the WA and at least one of the field values is above threshold,

2) Both field values are above threshold,

3) Lightning occurs within the AOC. We consider it a failure to warn in condition if lightning occurs within the AOC without any of the three situation above being satisfied previously. If one of the conditions is satisfied prior to the first flash in the AOC, we consider it a successful warning and compute the lead time between the start of the warning and occurrence of first flash in the AOC. A false alarm is any event for which a warning is triggered by condition 1) or 2) or both, but no flashes detected in the AOC. When the three conditions above are no longer satisfied, the warning is still continued for 15 minutes (the dwell time) before it is terminated, we used two different values, 2kV/m and 4kV/m.

We measure the performance of the automated warning algorithm with the three principles, which depends on three quantities:(1)the number of warning episodes having at least one CG flash in the AOC, (2) the number of episodes in (1) that were successful,(3)the number of false alarm warning episodes. In this article, we give the three quantities the names “CGAOC”, “SUC”, and “FA”. Then, we can define the following three performance metrics for the warning algorithm:

$$POD = \frac{SUC}{CGAOC}$$

$$FTW = 1 - POD$$

$$FAR = \frac{FA}{FA + SUC}$$

The probability of detection (POD) is simply the ratio of the number of successful warnings to the total number of episodes with a CG in the AOC, and the Failure-To-Warn rate (FTW) gives the fraction of unsuccessful warnings, which mean no advance notice prior to first CG in the AOC. The false alarm ratio (FAR) is measured by on using the warning episodes triggered by two EFMs above threshold or by a combination of an EFM above threshold and lightning detected in the WA. Thus, of all warning episodes having CG lightning in the AOC, only the successful ones can appear in the denominator of

FAR. This implies an interesting relationship between POD and FAR. In fact, if a change in either the field threshold or the smoothing window results in a significant drop in the number of SUC, it is possible for FAR to rise even if the total number of False Alarm episodes , FA, also decreases.

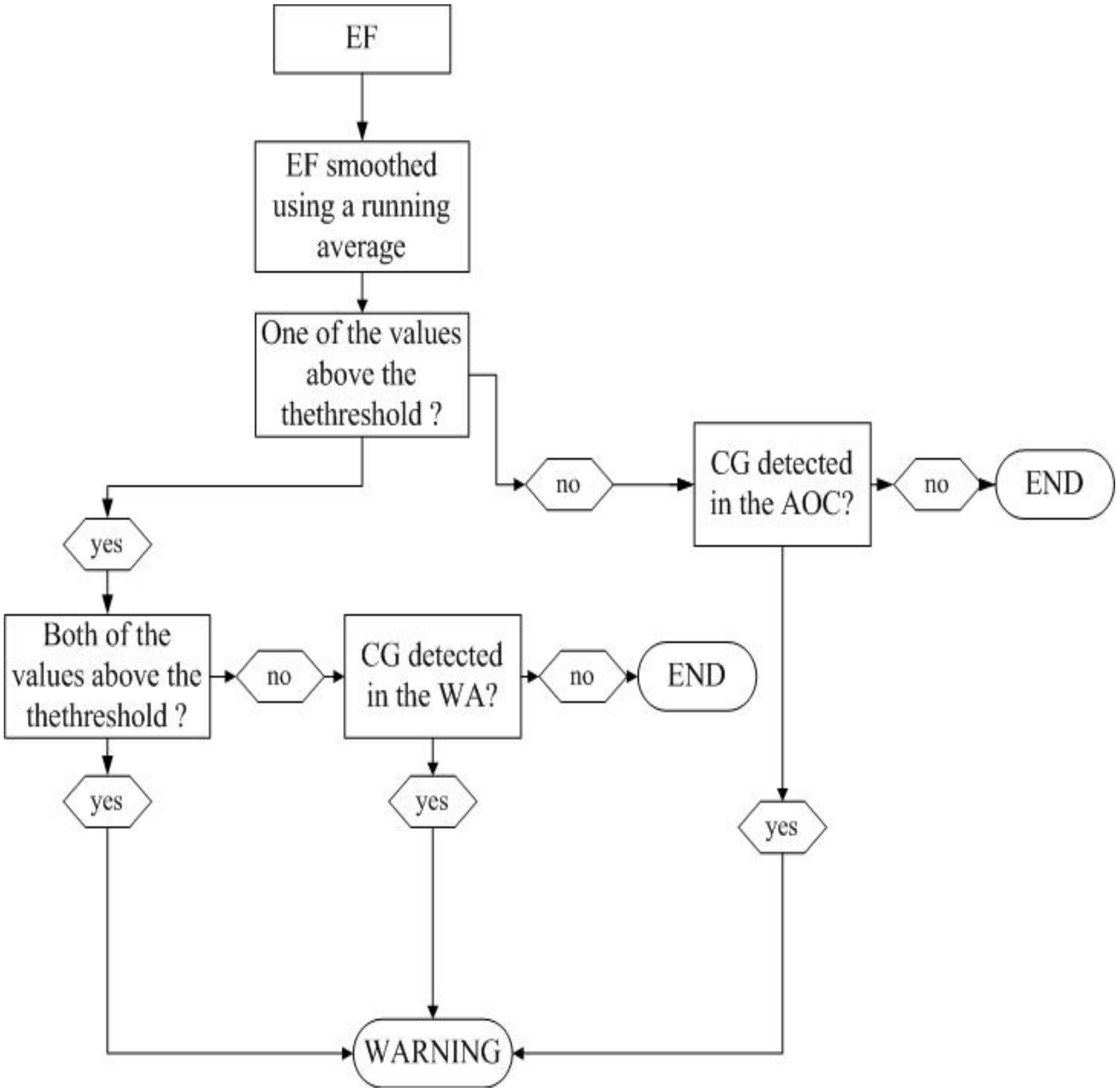

Figure 4: Warning algorithm.

For comparison, we also use a CG lightning-only warning technique, as discussed in the former study. In this method, a successful warning occurs when CG lightning in the WA preceded CG lighting in the AOC, and a false alarm occurs when CG lightning occurs in the WA only, but not in the AOC during the episode.

Results and Analysis

In the section above, we mentioned that we used two different smoothing windows for the electric field data, 30 seconds and 90seconds, and two different EF value threshold, 2kV/m and 4kV/m. Thus, we have four combinations of parameters related to the EF data. Obviously, the CG lightning data do not change, and we do not alter anything about the configuration of the AOC and WA or the dwell time. Table 1 to 4 give the statistics for three months of (June, July, August) analyzed for each of the two years data (2013 and 2014), and the summary of all months taken together. Each table correspond to one of the four combinations of EF-related parameters just discussed. Finally, Figure 5 provides an overall summary of the results.

Table 1: Summary of warning episodes using an EF smoothing window of 90 sec and a threshold of 4kV/m.

Month	Warnings	CGAOC	SUC	FA
Jun 2013	33	21	9	3
Jul 2013	32	22	7	3
Aug 2013	60	42	11	7
Jun 2014	31	19	8	4
Jul 2014	47	27	14	6
Aug 2014	52	35	12	5
Total	255	166	61	28
POD=0.367 FTW= 0.633 FAR=0.315				

Table 2: Summary of warning episodes using an EF smoothing window of 30 sec and a threshold of 2kV/m.

Month	Warnings	CGAOC	SUC	FA
Jun 2013	33	21	9	3
Jul 2013	32	22	7	3
Aug 2013	60	42	11	7
Jun 2014	31	19	8	4
Jul 2014	47	27	14	6
Aug 2014	52	35	12	5
Total	255	166	61	28
POD=0.783 FTW= 0.217 FAR=0.617				

Table 3: Summary of warning episodes using an EF smoothing window of 30 sec and a threshold of 4kV/m.

Month	Warnings	CGAOC	SUC	FA
Jun 2013	38	19	10	9
Jul 2013	65	34	24	7
Aug 2013	48	27	14	7
Jun 2014	39	18	10	11
Jul 2014	66	31	23	12
Aug 2014	42	19	11	12
Total	206	148	102	58
POD=0.689 FTW= 0.311 FAR=0.362				

Table 4: Summary of warning episodes using an EF smoothing window of 90 sec and a threshold of 2kV/m.

Month	Warnings	CGAOC	SUC	FA
Jun 2013	58	17	8	33
Jul 2013	78	33	14	31
Aug 2013	87	31	16	40
Jun 2014	58	24	7	27
Jul 2014	71	37	12	22
Aug 2014	65	30	11	24
Total	349	172	68	177
POD=0.395 FTW= 0.605 FAR=0.507				

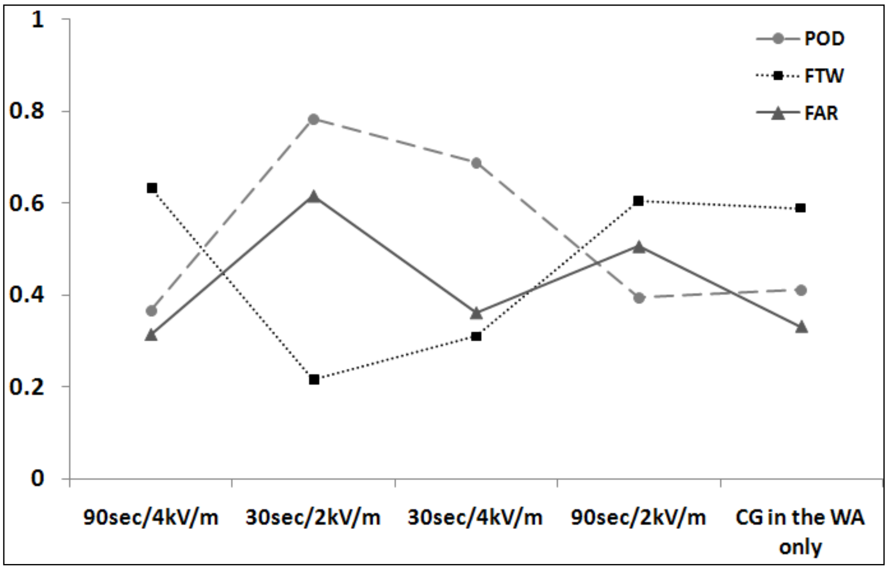

Figure 5: comparison of the three performance metrics for the four combinations as well as the CG in the WA-only algorithm.

As is seen from tables and the figure above, we could come to the result that the combination of 30sec/2kV/m get the best POD but however, its FAR is as high as 0.617, as compared to any other algorithms. The CG in the WA-only method wins the lowest FAR, while its POD is relatively poor. A contradictory relationship is shown between POD and FAR in all of the methods, among which, the combination of 30sec/4kv/m may be the best compromise solution. Its POD is 0.689, ranked the second best, while its FAR is acceptable as 0.311.

Conclusions and Discussion

In this study the data from two EFM sites, during June, July and August of 2013 and 2014 , having approximately 4km apart, a geometry that is similar a typical airport lightning warning system, were chosen and processed for lightning warning. We set a region of 10km radius from the EFM sites as AOC (the Area Of Concern), and also set a second region, the warning area (WA), surrounding the AOC, extending 20km outward in each direction.

A warning is triggered in condition of one of the following is met:

1) Lightning occurs within the WA and at least one of the field values is above a threshold,

2) Both field values are above a threshold,

3) Lightning occurs within the AOC. If one of the conditions is satisfied prior to the first flash in the AOC, we consider it a successful warning. After the three conditions above are no longer satisfied, the warning is continued for 15 minutes (the dwell time) before it is terminated. We used two different threshold values, 2kV/m and 4kV/m and two different smoothing windows as 30sec and 90sec.

The result shows that our algorithms perform relatively better than the method using CG lightning data alone in terms of POD, FTW and FAR. The analysis also tells a contradictory relationship between POD and FAR in all of the algorithms, among which, the combination of 30sec/4kv/m may be the best compromise solution. Its POD is 0.689, ranked the second best, while its FAR is acceptable as 0.311. Thus, in most conditions, following warning strategy could be adopted: First, obtain the EF data smoothed by a 30sec window; Second, A warning is triggered if one of the following condition is met: 1) lightning occurs within the WA and at least one of the field values is above 2kV/m, 2) both field values are above 2kV/m, 3) lightning occurs within the AOC. Alternatively, In a particular condition requiring the best POD and with tolerance of relatively large amount of false alarms, the combination of 30sec/2kV/m could be taken.

In our future work, we will analyze such possible ways for a better warning performance. For instance, we can make the AOC and WA smaller in order to be more consistent. Besides, the EFMs could be more widely distributed in both AOC and WA region. Other alterations to the criteria for initiating a warning may also make it possible to utilize EF information in the most effective way.

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