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AN ASSESSMENT OF CLOUD-TO-GROUND LIGHTNING WARNING AT U.S. ARMY DUGWAY PROVING GROUND USING KENNEDY SPACE CENTER ALGORITHMS

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1.INTRODUCTION

Predicting cloud-to-ground lightning onset and cessation is one of the most crucial and challenging jobs of forecasters at U.S. Army Dugway Proving Ground (DPG). Test safety plans require that all test operations cease and participants seek shelter when cloud-to-ground lightning is within 15 km (9.3 miles). In addition to the required shutdown at 15 km, many tests desire to know well in advance of this criterion that lightning is approaching. Similarly, Meteorology Division Internal Operating Procedure states that a 1-hr lead time is desired for thunderstorm warnings.

Currently forecasters utilize radar, satellite, and surface-based observations, including electric field measurements, to subjectively issue warnings. Prior studies have utilized Electric Field Meters (EFM) and National Lightning Detection Network (NLDN) data to develop a warning algorithm for cloud-to-ground lightning around the Florida Spaceport at Cape Canaveral, FL. (Murphy et al. 2008, herein after M08). This study seeks to 1) asses the accuracy of this warning algorithm at DPG and 2) provide a basis of comparison between DPG and Florida for further comparisons and studies.

1.1. EFM Network.

A network of 28 Campbell Scientific CS110 EFMs have been installed across DPG. The CS110 is capable of measuring electric field from 0 to ±22,300 V/m (Campbell, 2006). The EFMs have been site-calibrated and are installed facing the ground at a height of 2 m (see Fig. 1). The EFMs record values of the vertical component of the electric field every second. These values are transmitted via 900 MHz radios back to the meteorology office once a minute. Most EFMs lie at a similar elevation (approximately 4300 ft); however, there is at least one notable exception: station 9 which is situated on a hill to enable it to act as a radio relay for other stations. The average 'nearest neighbor' distance is 7.2 km with relatively even spacing of all stations.

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Fig 1.1 EFM

2. MOTIVATION

While the DPG EFM network has been used by forecasters as an indicator of the potential for lightning strikes, no objective criterion has been established. A more in-depth study of the magnitude of the electric field during lightning strikes, presented in Kimball and Gallagher (2008), demonstrated that elevated values of the electric field at the location of the lightning strike was a potentially necessary but insufficient criterion to forecast future lightning.

Thus, currently the probability for lightning is still determined subjectively by the Meteorologist in Charge based upon the local radars, satellite, NLDN, and direct observation or reports from the field. Rules of thumb for predicting lightning onset abound; however, none of these may be used to extend the current safety regulation. Current regulations require test operations to shut down for cloud-to-ground lightning within 15 km. but make no mention of in-cloud lightning, or the probability of cloud-to-ground lightning within 15 km. Due to the serious hazards posed by lightning to personnel, especially in light of the common use of explosives across DPG's range, there is a tendency to over warn by forecasters, resulting in a high false-alarm rate. By providing a methodology for objective forecaster guidance based on EFMs, this study seeks to decrease the frequency of false alarms.

3. BACKGROUND

Since the DPG network is so new, there is a limited dataset for electric field at DPG; this gives reason to seek out other locations with similar capabilities. One such location is Kennedy Space Center (KSC) at Cape Canaveral, FL. KSC has a network of 31 EFMs. Like DPG, KSC has ongoing operations which may undergo costly delays in the event of lightning. Unlike DPG, much of the concern for lightning at KSC is focused on triggered lightning where a rocket, space shuttle, or other projectile is struck by lightning when passing through a high electric field region in the cloud. Thus many airborne EFM campaigns have focused on improving the lightning launch-commit criteria which define the weather requirements for a vehicle launch from KSC.

M08, the study selected for comparison at DPG, was chosen for three key reasons. First, it focuses on an *automated objective* prediction algorithm for cloud-to-ground lightning which is the desirable outcome for DPG. Second, it integrates the NLDN and EFM data, which are both available for DPG. Finally by using the same methods as at KSC it will provide a point of comparison between the two facilities which have similar lightning prediction capabilities but very different climates.

3. METHODOLOGY

The goal in constructing this study was to use identical methods to those presented by M08. To asses the algorithm at DPG, first an identical test region was chosen. This test region consisted of an inner “Area of Concern” (AOC) of 10 km by 10 km and an outer “Warning Area” (WA) of 20 km by 20 km. The goal of the lightning detection algorithm as presented by M08 is to predict sloud-to-ground lightning strikes in the AOC using two data sources: the NLDN recorded CG lightning strikes in the WA, and the value of the electric field measured by two EFMs within the AOC. The details of the warning criteria and algorithm are shown in section 3.1.

To begin assessment of the algorithm, a geographic AOC was selected at DPG. The AOC is a 10 km region centered on the main testing region. Surrounding this AOC is a WA consisting of a 20-km box centered on the same region. Figure 3.1 shows the WA and AOC for this study. Two EFMs were used to match the M08 study; however, eight were within the AOC.The utility of including additional EFMs will be examined at a later date.

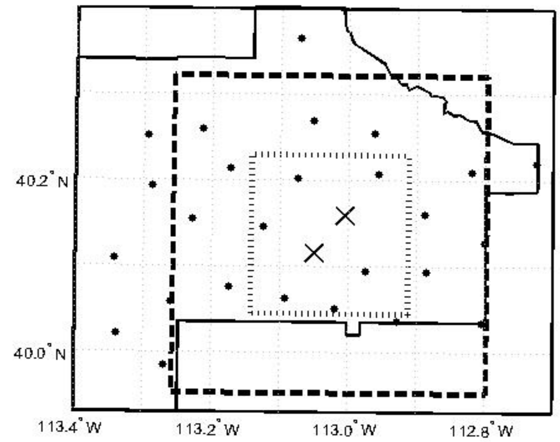

Figure 3.1 Study area map indicating DPG boundary (solid line), WA boundary (heavy dashed), AOC boundary (light dotted), EFM locations (dots), and EFM used in this study (x).

3.1 Warning Criteria

There are three criteria for initiating a lightning warning for the AOC:

1. A strike occurs in the WA and at least one EFM meets the criterion.
2. Both EFMs meet criteria.
3. A strike occurs in the AOC.

Once a warning has been activated it remains in effect for 15 min following the last time at which ANY of the above three warning criteria were met. Using the above-established criteria as predictors for CG lightning in the AOC, it is evident that the criteria selected for the EFMs are the dependent variables to be optimized.

3.2 EFM Criteria

M08 selected four total criteria dependent upon averaging time period and the absolute value of the electric field. They looked at the 10-second and 1-minute average exceeding 1000 V/m or 2000 V/m.

For DPG there were three criteria selected for voltages exceeding 1000, 2000 and 3000 V/m for an average of 1 minute. Due to the relatively high elevation and thus closer proximity to cloud base, electric fields at DPG are typically much higher than those seen in Florida, thus two thresholds (1000 V/m and 2000 V/m) were chosen to compare with KSC while another higher threshold (3000 V/m) was chosen to see if varying the threshold criterion resulted in more accurate warnings.

Objective Voltage Criteria		CG AOC	SUC	FA	LEAD-TIME	FAR	FTW	POD
1000 V/m	2007	11	6	15	12.3	71%	45%	55%
	2008	1	1	15	*	94%	0%	100%
	Average	12	7	30	*	81%	42%	58%
2000 V/m	2007	11	6	16	9.7	73%	45%	55%
	2008	1	1	12	*	92%	0%	100%
	Average	12	7	28	*	80%	42%	58%
3000 V/m	2007	11	5	15	8.6	75%	55%	45%
	2008	1	1	10	*	91%	0%	100%
	Average	12	6	25	*	81%	50%	50%

Table 4.1 Warning metrics for each of the three objective voltage criteria
*** indicates too few data points for calculation**

4. RESULTS

There are three key ideas used in defining the metrics by which the algorithm will be evaluated. (1) CGAOC is the number of incidents having at least one cloud-to-ground flash within the AOC. (2)Success (SUC) is an incident of a cloud-to-ground strike in the AOC, which was proceeded by warning criteria 1 or 2 being met. (3) False Alarm (FA) is an event for which no cloud-to-ground lightning is ever recorded in the AOC. Using these three definitions, the following metrics are defined:

(1) Probability of Detection (POD):

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

(2) Failure to Warn (FTW):

$$FTW = 1 - POD$$

(3) False Alarm ratio (FAR):

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

In an ideal algorithm, the POD would approach 1 while the FTW and FAR approach 0. As a final measure of the effectiveness of the algorithm, the lead-time, in minutes, is calculated for each successful warning. The lead-time is defined as the time elapsed between the first point the warning criteria are met and the first CG AOC. The results of the three EFM criteria applied at DPG are presented in Table 4.1 above.

4.1 Evaluation of warning metrics at DPG

Overall the M08 warning algorithm does an unsatisfactory job of providing automated lightning warning at DPG. The POD is low, the FTW rate is high, and the FAR rate is alarming. There is an increase in lead time with the varying criterion; however, in all cases it is far below the 60 minutes desired. While there are some differences between the three criteria, because of the small sample size in each case, it is not reasonable to infer that any of the three criteria rank better than the others.

One positive note comes with comparison to the algorithm's effectiveness at KSC. In table 4.2, data from Table 2 of M08 is compared with DPG data both taken from cases where the EFM criterion was 2000 V/m averaged over 1 minute. When DPG and KSC warning metrics are compared, the algorithm appears to provide a higher POD and lower FTW at DPG than it does at KSC. However at both locations the FAR is still quite high.

	KSC	DPG
POD	15%	55%
FTW	84%	46%
FAR	78%	73%

Table 4.2 Comparison of KSC and DPG warning metrics.

4.2 *Comparison with current forecast metrics*

In order to compare the accuracy of the objective EFM-based algorithm presented above with the current subjective-based warnings, the same warning metrics were computed for subjective forecaster issued warnings in the same time period. The forecaster's area of responsibility includes a much larger region than the 10 km by 10-km AOC use for the objective criteria; hence a strike anywhere within DPG (an area slightly larger than the WA and depicted as the outer boundary line in figure 3.1) was considered for the “CG AOC” column in this comparison. Table 4.3 shows the resulting statistics for subjective criteria. Overall, the subjective forecaster-issued warnings produced better results than the automated algorithm, as expected. While the subjective and objective algorithms have similar FAR, there is considerable gain in the FTW and POD for subjective warnings. Forecasters failed to warn just once in 2 years, whereas the objective algorithms had an average FTW of 29 percent.

	CG AOC	SUC	FA	FAR (%)	FTW (%)	POD (%)
2007	8	7	8	53	13	87
2008	2	2	9	82	0	100

Table 4.3 Warning metrics for subjective forecaster issued warnings

5. Conclusions

Overall, the lightning prediction algorithm using EFM and NLDN data presented in M08 is found to be too inaccurate to use operationally at DPG based on the low POD and high FAR. The study does demonstrate that significant differences are seen between KSC and DPG implying that future attempts to develop lightning prediction algorithms for DPG should not be limited based upon prior examples in the very different climate regime of KSC. Furthermore, the objective algorithms do not appear to offer lower FAR than the current subjective systems.

6. REFERENCES

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