JP1.29 FORECASTING C−G LIGHTNING POTENTIAL AT WSMR

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1. INTRODUCTION

The primary goal of this study is to show that the use of storm and boundary layer characteristics can be used to decrease the false alarm rate (FAR) while maintaining similar probability of detections (POD) and lead times for forecasting cloud to ground (C−G) lightning potential. During the summer months, one of the primary roles of forecasters at White Sands Missile Range (WSMR) is to monitor convective activity and warn personnel working on the range of any associated danger, including that from C−G lightning. From an operational standpoint, the onset and dissipation of lightning activity are important for ensuring the safety of personnel working on the range.

As part of the U.S. Army Test and Evaluation Command (ATEC) 4DWX program, the NCAR Auto−Nowcast (AN) system for forecasting thunderstorm life−cycle (Mueller et al. 2000) has been running at WSMR since 1997. The AN system provides forecasts of storm locations for a 30 minute forecast period. In the spring of 2001, a procedure for forecasting lightning potential was added to the system (Saxen and Mueller, 2001). The aim of this study is to explore the effects of including storm characteristics in lightning potential forecasting methodologies and also point out some of the limitations of this and similar methods.

2. METHODOLOGY

Most previous work in the area of lightning forecasting has focused primarily on predicting lightning onset using reflectivity thresholds above the freezing level as an indicator (Dye et al. 1989, Hondl and Eilts 1994, Gremillion and Orville 1999). These previous results suggest that if one desires higher PODs and longer lead times, either a lower threshold and/or a lower level needs to be utilized. However, this will also lead to a higher FAR.

For this study, two sets of Auto−nowcast runs will be presented, a base run which utilizes a 30 dBZ reflectivity threshold above the −10 C level and an enhanced run which includes storm and boundary layer characteristics.

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The base run consists of using a 30 dBZ threshold above about the −10 C level as an indicator of lightning potential, which is very similar to previous studies that used this type of methodology. This is a somewhat lower reflectivity threshold than the 40 dBZ threshold suggested by Gremillion and Orville (1999), but using a 40 dBZ threshold at WSMR led to significantly lower PODs and short lead times. Hondl and Eilts (1994) used a 10 dBZ threshold at the 0 C level as an indicator of lighting onset are Kennedy Space Center in Florida, but this low of threshold resulted in significant false alarms for the WSMR area. Michimoto (1991) showed that lightning production occurred after 30 dBZ reached the −20 C height, but using the −20 C level at WSMR led to significantly lower PODs and shorter lead time. So for this study, a 30 dBZ threshold at the −10 C level was utilized as the baseline predictor of lightning potential.

The enhanced runs consist of using a 30 dBZ threshold above about the −10 C level to calculate various storm characteristics and this information was combined with boundary relative steering flow information. The storm characteristics are derived using a centroid based cell tracker called TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting; Dixon and Weiner 1993). The boundary relative steering flow is the vector difference between the steering level (2−5 km height) mean winds and the motion of any detected boundary layer convergence lines (gust fronts).

The methodology employed uses fuzzy logic to combine these various interest fields (or feature detectors). The five fields that were used are described below and the membership functions and weights used by the fuzzy logic engine are depicted in Figure 1.

a. Storm Volume

This field provides the storm volume greater than 30 dBZ above about the −10 C level. Large storm volumes above the −10 C level indicate more mass in the mixed phase regions and hence more change generation within the storm based on noninductive charging theory (Takahashi 1978, Carey and Rutledge 2000).

b. Storm Volume Growth Rate

This field provides the volume growth rate for a specific storm cell (i.e. volume rate of change). Positive grow rates indicate the storm is in the developing stage and thus suggest a higher potential for producing lightning in the future. Negative growth rates indicate the storm may be dissipating and thus suggest a lower potential for producing lightning.

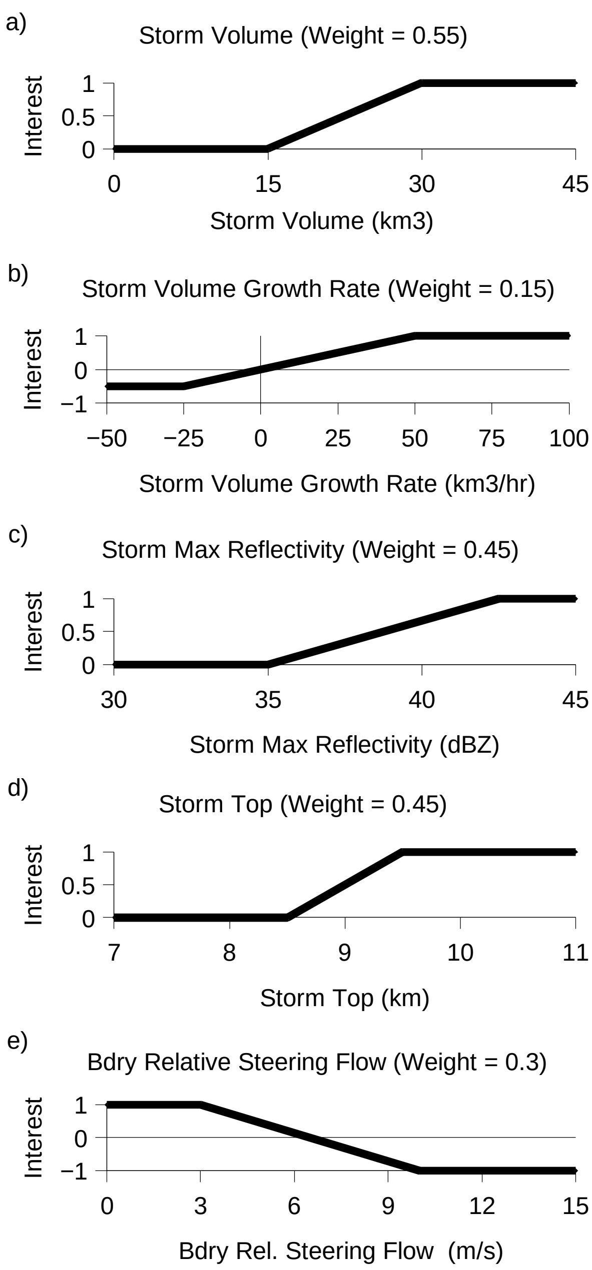

Figure 1. Membership functions and weights utilized by fuzzy logic algorithm to produce the lightning potential forecast.

c. Storm Maximum Reflectivity

This field provides the maximum reflectivity observed above about the −10 C level within the storm. Large storm maximum reflectivities indicate intense storms with stronger updrafts and more hail being lifted into the mixed phase region and hence suggest a higher potential of producing lightning (Carey and Rutledge 2000).

d. Storm Top

This field provides the top height of the 30 dBZ storm volume. Large storm top values indicate deeper storms and hence suggest a higher potential of producing lightning. The membership function reaches a value of one for a top of 9.5 km. This value was suggested by Dye et al. (1989) who showed that for small storms in central New Mexico that the storm tops had to exceed 9.5 km.

e. Boundary Relative Steering Flow

In order to help increase lead time for rapidly developing cells associated was boundary layer convergence zones (gust fronts), boundary relative steering flow was utilized. Wilson and Meganhardt (1997) have shown that developing cells tend to move with the steering level (2−5 km) winds in weak synoptically forced situations as are often observed at WSMR. If the boundary is moving similarly to these winds, the cell will tend to stay with the boundary and have a better chance of intensifying.

3. RESULTS

Three cases where put through the base and enhanced runs. A total of 64 new lightning producing convective elements were identified in these cases. The case days, event duration's, and number of new lightning producing elements are provided in Table 1.

Table 1. Summary of three cases for this study, including duration (in hours) and the number of new lightning producing events.

Event	*Duration (hours)*	*# of New Lightning Producing Events*
2000/07/12	9	23
2001/07/18	5	18
2001/07/27	7	23
Total	21	64

A histogram showing the number of successes at 6 minute lead time intervals was constructed for new C−G lightning producing convective elements. The number of false alarms was also monitored. In order to determine these numbers, the radar reflectivity was examined in conjunction with the C−G lightning activity and the lightning producing convective elements were identified on an object (or storm) oriented basis. The lead times for successful forecasts were assigned to bins 6 minutes in length. These results are presented in Figure 2.

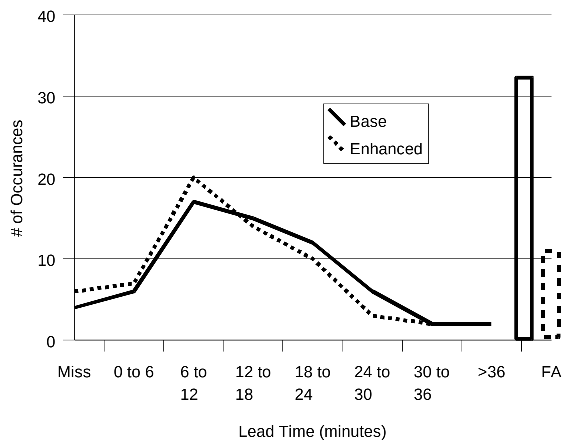

Figure 2. Histogram of number of misses (Miss, plotted at the far left) and successes for various lead time bins (in minutes). Also included on the right as bars are number of false alarms (FA) .

Figure 2 shows that for both the base and enhanced run, the majority of the occurrences fell in the 6 to 24 minute lead time bins (69% for both). The FAR was significantly less for the enhanced run, 35% for the base run compared to 16% for the enhanced run. A false alarm was identified by a convective element that did not produce a C−G lightning strike during it's life (as determined by monitoring radar reflectivity). A cumulative POD diagram is provided in Figure 3. This figure is derived with the information depicted in Figure 2, but directly reports PODs for a given desired lead time. Figure 3 shows that the POD for the two runs are very similar, with slightly longer lead times being realized for the base run. For both runs, the overall POD is > 90%, 94% for the base run and 91% for the enhanced run.

The primary reason for the differences between the two runs was the inclusion of storm volume information. Virtually every false alarm was associated with small storms and thus by including storm volume information in the enhanced runs, the FAR was greatly reduced compared to the base runs which were based solely on the presence of > 30 dBZ above the −10 C level. However, since the new developing storms were also initially small, this also lead to a reduction in lead time in some instances. The inclusion of maximum dBZ, storm volume growth rate, and boundary layer forcing information helped to minimize this reduction in lead time.

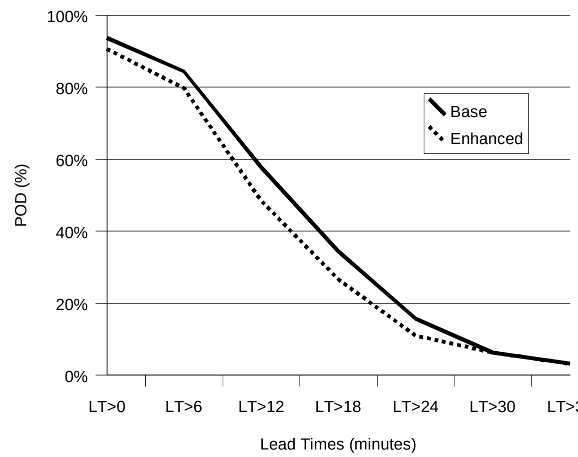

Figure 3. A cumulative POD plot for the base and enhanced run with lead times (LT) provided in minutes.

The results presented here for the WSMR area are very much in line with previous studies from other regions. These previous studies have shown that minimally higher PODs and longer lead times can be realized by using lower reflectivity thresholds and/or lower elevations (Hondl and Eilts 1994, Gremillion and Orville 1999, Michimoto 1991), but storm electrification modeling results suggest that significant improvements over previously found values are not physically realistic (Soloman and Baker 1994). Soloman and Baker's results suggested that an updraft of > 2.5 m/s in the −10 to −25 C layer would produce lightning in 10 to 15 minutes, which is in general agreement with this and other previous observational studies.

4. CONCLUSIONS

The effect of including storm and boundary layer characteristics in a lightning potential forecasting methodology has been explored for three cases from WSMR. The primary findings suggest that while the use of this additional information can help reduce the number of false alarms with minimal changes in the POD and lead time, methods which rely on reflectivity information above the freezing level can only provide a limited lead time (generally 6 to 24 minutes). These methods utilize observations that suggest charging within the storm has begun based on noninductive charging theory.

Modeling results (Solomon and Baker 1994) suggest typical lead times that are very much in line with this and other studies (Dye et al. 1989, Hondl and Eilts 1994, Gremillion and Orville 1999). Therefore, any significant increase in POD and increase in lead time over the typical 6 to 24 minutes will require an approach that does not explicitly rely on existing storm information.

The results of Solomon and Baker (1994) suggest that forcing (either kinetic or thermal) are important for predicting the occurrence of charge generation and hence lightning production. Thermal forcing being related to the CAPE (Convective Available Potential Energy) and kinetic forcing being related to the vertical velocity of air entering cloud base. As they point out, in nature, a combination of these two types of forcing are important. This suggests that longer lead times could potentially be achieved by monitoring the evolution of CAPE and sources of kinetic forcing (such as fronts, outflow boundaries, terrain induced convergent flow features, etc.). CAPE has been shown to be a good indicator of lightning potential (Solomon and Baker 1994, Petersen et al. 1996), but this approach generally does not provide temporally or spatially specific indications of lightning potential since they are typically based on area soundings. However, it may be possible to utilize high resolution mesoscale models to predict the evolution of CAPE and then combine this information with time and space specific observations of boundary layer forcing features to provide forecasts of lighting potential with longer lead times. The NCAR Auto−nowcast system is especially well suited to combining information in this way. However, an approach similar to this would also almost certainly lead to higher FARs.

5. ACKNOWLEDGEMENTS

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