P1.15

DETERMINATION OF A LIMITED SCOPE NETWORK'S LIGHTNING DETECTION EFFICIENCY

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1. INTRODUCTION

A ground based lightning detection system employs an array of sensors which record and evaluate the electromagnetic signal arriving from by a lightning strike. Detectors register the signal's time of arrival, azimuth and emf signature. By coordinating the data from several detectors an event 'solution' is generated giving the signal's point of origin, strength, peak current, and polarity.

The signal from an event undergoes geometric dispersion and environmental attenuation. As a result some signals will not be above the detection threshold at a sufficient number of the network detectors to produce a solution. This is especially true for a large expanse serviced by a sparse grid of detectors.

The detection efficiency (DE) varies over the service area and limits the network's utility in gathering information on regional lightning strike density and related meteorological features.

The process described in this presentation permits the determination of a reliable DE contour for an expanded service area for limited scope networks.

2. PEAK CURRENT DISTRIBUTION

In an ideal network with a 100% DE, complete information on all lightning strikes is gathered using tested algorithms. The range of peak currents, I_o, varies from less than a single kiloamp to a few hundred kiloamps (+/-).

The peak current distribution represents the fractional event density as a function of peak current. The fractional event density is the fraction peak current within the range Io +/- ΔI. The area of all observed events within the distribution is one.

The process is illustrated using data from a grid of four detectors in Brazil's Rondonian region. The service area exceeds a million square kilometers, much of it rain forest.

The data set depicted in Figure 1 represents a nearly 100% DE since it was restricted to a record of strikes within a relatively small region central to these four detector sites.

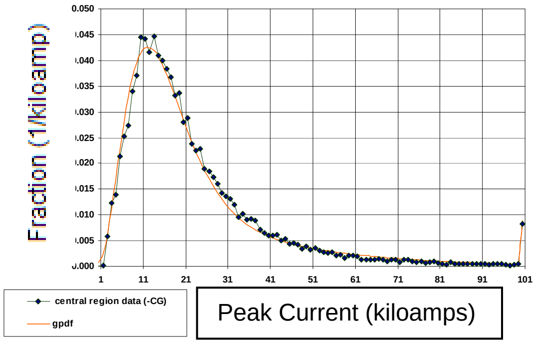

Figure 1

The shape of the distribution is that of a gamma probability distribution function (GPDF). Figure 1 contains such a distribution fitted to the empirical data. It is assumed that this profile is characteristic of events occurring over the entire region. Though the area density of lightning strikes may vary over the region, the distribution spectrum remains constant.

3. DETECTOR MINIMUM PEAK CURRENT DETECTION THRESHOLD

The electromagnetic signal approximates signal produced by a current is a long straight wire and follows a range, r, dependence of (1/r). The signal also experiences environment attenuation which is taken as an exponential decay.

These range factors together with a detector's threshold establish a minimum peak current required of events occurring at a given point in the service area. In order for a detector to register an event originating from specific location, that event peak current, I_o, must be above this minimum.

The mapping of these detection thresholds over the full region results in a minimum peak current detection threshold (MPCDT) for that sensor.

By correlating the MPCDT contours for the entire grid with the number of detections needed for particular solution algorithm, one arrives at a minimum peak

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current solution threshold (MPCST) contour for the full region.

4. DETECTION EFFICIENCY CONTOUR

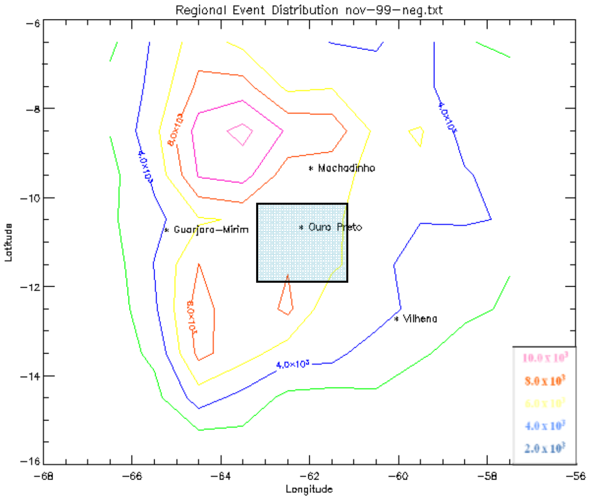
The MPCDT contour is then translated into a detection efficiency contour using the region's peak current distribution profile.

The fraction of the distribution's area with peak current above a location's MPCDT is the fraction of all lightning strikes which result in a solution. This area is representative of the network's detection efficiency for events at that location. A detection efficiency contour is produced by applying this technique to the full service region.

DE contours can be formulated for various combinations of: signal dispersion/attenuation models, network configuration, and detection parameters.

5. SAMPLE APPLICATION TO THE RONDONIAN GRID

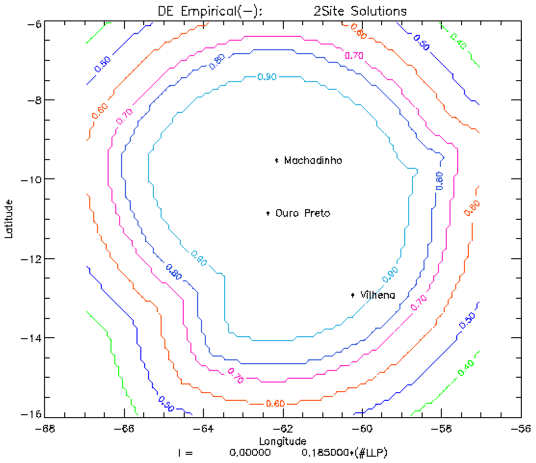
The sample data set referred to earlier was accumulated using the Rondonian grid in November, 1999. The distribution of negative strokes is illustrated in Figure 2 along with the central region (shaded area) used in formulating the peak current distribution represented in Figure 1 (100% DE assumed).



Event Distribution
Figure 2

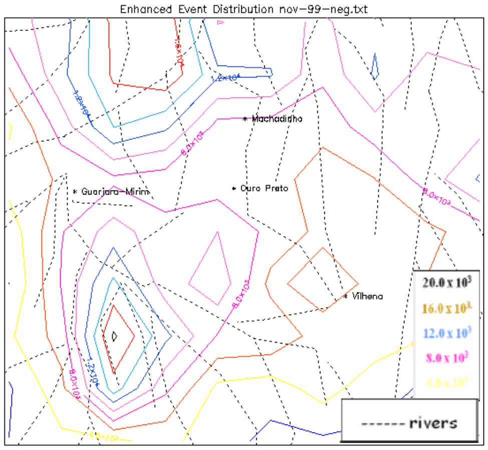
The gammas, Weibull, lognormal probability distribution functions (pdf), as well as the empirical distribution, have been explored to represent the peak current distribution.

This modeled peak current distribution expression was used to generate the DE contour for solutions based on detection of a signal by any two sites (fig. 3).



Detection Efficiency, Two Site Solutions
Figure 3

One application of the DE contour is to estimate a complete distribution of events over the region. That process was applied to the data presented in Figure 2 and results in the regional event density illustrated in Figure 4.



Estimated Event Distribution
Figure 4

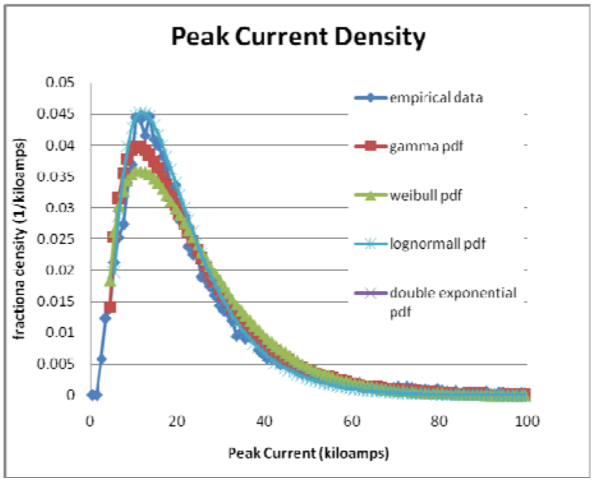
The river traces have been added to the contour to suggest possible applications of this process to regional meteorological studies.

5. MODELING OF THE PEAK CURRENT DISTRIBUTION

The analytical representation of the empirical peak current data is a critical feature of this process. An appropriate representation not only facilitates a reliable estimates of the regional detection efficiency it also provides a bases for investigating the physics prompting the distribution.

In the illustration above, the representation used was a linear combination of gamma probability distributions. The resulting set of shape, scaling and amplitude factors provided more than enough flexibility to model the data and serve as a prototype pdf. A more direct pdf, however, would seem to be a more appropriate representation of the stroke process.

Other pdf's examined are the single term gamma, Weibull, and lognormal. All of these pdf's prove to be viable candidates for modeling the data. The initial fit using these pdf's with scaling and shape parameters alone proved to be adequate. Fit was improved dramatically with the inclusion of a threshold parameter. For all these pdf's when applied to the data used in the illustration above, this offset parameter was about +4.0 kiloamps. Figure 5 compares these pdf's to the empirical distribution from the high efficiency central region.



Peak Current Probability Distribution
Figure 5

Figure 5 also includes variation of the gamma pdf referred to as the double exponential pdf. It represents the statistics of two exponential probability events each with a separate 'shape' or beta parameter. The pdf for such a construct is given by

$$\text{double exponential pdf} = \frac{1}{(\beta_1 - \beta_2)}\left(e^{-x/\beta_1} - e^{-x/\beta_2}\right) \quad \text{Eq. 1}$$

As with the other pdf's in figure 5, an offset of about +4.0 kiloamps is required for best fit.

6. CONCLUSION

The process outlined here is a viable and consistent means of determining a lightning detection network's detection efficiency, especially for networks of limited scope as illustrated here. It relies heavily upon accurately estimating a region's peak current distribution and the applicability of that distribution to the full region. This first constraint demands that the physics and associated algorithms used to determine a strike's peak current be reliable. The last constraint could be relaxed by segmenting the service area into sub regions having uniform peak current distributions or by applying the process in an iterative manner.

The process allows for determination of the impact on detection efficiency of: network design, detector characteristics, and signal dispersion/attenuation parameters. As such, it is a valuable operational and research tool when using observation from small, limited networks such as the four station Rondonia network described in this analysis.

The modeling of the peak current distribution is a potential tool in better understanding the occurrence and timing of lightning strikes within thunderstorms.

By providing a mechanism for determining a more complete profile of strikes within the service region the process becomes a valuable tool in better correlating lightning activity to the region's meteorology.