Proceedings of the Technical Sessions, 16 (2000) 34-41
Institute of Physics – Sri Lanka

A Study of LLP Systems and their Performance in Locating Lightning Ground Flashes in Sri Lanka (1998 – 1999)

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A study of the performance of wideband magnetic direction finding systems used in locating lightning ground flashes in Sri Lanka is presented. The studies carried out with these systems show that they are highly sensitive to the geometric placement with respect to each other as well as to the induced magnetic fields produce by the external objects in the vicinity of the antennas (site errors). The results of two studies carried out by placing two of these stations in the same vicinity of each other and also in two remote locations (Colombo 6.90° N, 79.86° E and Ratnapura 6.68° N, 80.40° E) are presented.

1. INTRODUCTION

In February 1998, four Magnetic Direction Finding (DF) stations were donated to the Department of Physics, University of Colombo, Sri Lanka by the International Programs for Physical Sciences (IPPS), Uppsala University, Sweden. The objective of the program was to set up a lightning detection network in order to locate lightning ground flashes in any part of Sri Lanka and in the surrounding area of the Indian Ocean.

The DF stations donated by Sweden were manufactured by Lightning Location and Protection (LLP) Inc., Tucson, Arizona, USA and are formally known as LLP systems. The description and working principals of the LLP systems can be found elsewhere [1,2] and hence only the necessary technical details are given in this paper.

A DF station is capable of providing the time of occurrence, angle with respect to North, strength of the first return stroke, multiplicity, and the polarity of lightning ground flashes. Normally, the information on lightning flashes detected by the DF stations are sent to a central position-analyser (PA) via a dedicated asynchronous communication link for further processing. During these two years no PA unit was available and hence personal computers were coupled to DF stations to store the

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lightning data. The analysis of the lightning data and the reconstruction of the strike position were done offline.

This paper discusses the summary of the two studies carried out in 1998 and in 1999 by placing two of the LLP direction finding stations in close vicinity of each other and in two remote locations respectively [3,4].

2. RANDOM & SYSTEMATIC ERRORS

The wideband magnetic direction finding systems with cross loop antennas, which depends on the angular information to locate lightning ground flashes, have significant random and systematic errors [5]. The random errors associated with these instruments can be studied by keeping two stations in close vicinity of each other and comparing the recordings of the same measurement. The systematic errors are more or less coupled to the site where the stations are installed as well as the topology of the detection network.

During 1998, tests were carried out with two DF stations in order to investigate the instrumental errors associated with the angular measurement and the signal strength measurement. The sensing antennas were mounted on top of the Department of Physics building (height 14.5 m) at the University of Colombo. Approximately, 15 m long signal cables were used to connect the electronic units, which were kept inside the building, and the sensing antennas. The data were transferred at a rate of 1,200 bps (which corresponds approximately to 250 ms between recordings) from the electronic units to two personal computers via the built in serial ports.

Every attempt has been made to operate the DF stations round the clock. However, power failures often interrupted data collection specially when thunderstorms were in close vicinity. No UPS units were available during these tests.

Time of occurrence was used as the main criterion in identifying the recordings belonging to the same flash. DF stations are accurate in providing time of occurrence to within 1 ms. However, it was observed that the internal clocks of the DF units have a time drift of approximately 3 ms per hour with respect to each other. Hence it was necessary to correct for these drifts in selecting coincidence records. A time window of 20 ms was used during these tests. After rejecting the weak signals and overflows, roughly, 60% coincidences between the two DF stations were observed.

In principal, the instrumental error in measuring the azimuth angle can be obtained by operating the two antennas under identical conditions and calculating the difference between the measurements. It was found that the instrumental angular error associated with the DF station is ±0.5 degrees.

If the antennas are not in identical conditions, which will be the case when implementing stations at remote locations, the site errors can introduce large systematic errors in the angular measurement. This effect is shown in Figure 1 where the average azimuth angle measured from the two DF stations is plotted against the difference in the measured angle. The two curves A and B are for two different placements of the antennas.

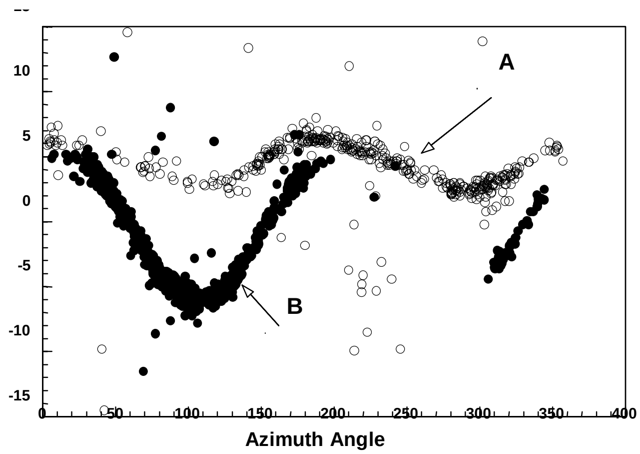

Figure 1: Average azimuth angle vs. the difference in the measured angle by the two DF stations. The curves A and B represent measurements taken with two different placements of antennas.

Both measurements show the well-known two cycle sinusoidal variation, which can be observed for Radio waves, picked up by crossed loop antennas in the presence of induced magnetic fields generated by nearby objects. Curve A, which was taken with antennas kept in somewhat similar conditions, , shows much smaller deviation (except for an asymmetry caused by a nearby building) than curve B which was taken by deliberately shifting one antenna towards the building by approximately 2 metres. The width of the band, which is the actual instrumental error in the system, can be achieved only by keeping the antennas in ideal conditions.

In Figure 2, the correlation of flash strengths measured by the two DF stations is shown. In general, a good agreement is seen. The plot shows a slight spread in the data for higher signal strengths (i.e., for nearby flashes). However, the calculated percentage resolution is nearly a constant (roughly 1.5%) for all signal strengths. By using the amplitude correlation as a criterion, the validity of the selection criteria based on the time window can be tested. Once it is done it is seen that about 90% of the selected strikes are in good agreement.

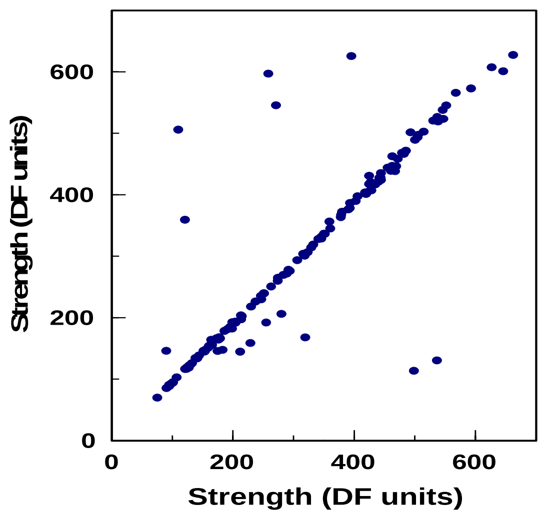

Figure 2: Correlation of flash strength measured by the two DF stations.

3. REMOTE MEASUREMENTS

During 1999, two DF stations were installed in observation sites maintained by the Department of Meteorology in Colombo (6.90N, 79.86E) and in Ratnapura (6.68N, 80.40E), located at 7.3 m and 86.3 m from sea level respectively. Both electric and magnetic field antennas were fixed at a height of 1.5 m from ground level. The cables connecting the antennas and the electronic units were shielded and laid underground to reduce the interference effects due to induced magnetic fields.

Again, the time of occurrence was used as the selection criterion, since the distance between the stations can only contribute to a time jitter of not more than 0.2 ms. First, the recorded data were filtered by rejecting signals with very low amplitudes or signals that overflowed the DF units. Then the events that recorded simultaneous hits (coincidences) in both stations were selected by applying a time window of 100 ms. The pairs of hits that satisfied this selection criteria were marked and identified as events produced by true lightning strikes. Approximately 55% of the filtered data from the Colombo station and 70% of the filtered data from Ratnapura contributed to the coincidences.

In an ideal situation, both DF stations should report the same values for the polarity and the multiplicity for any given lightning flash. The data shows that on average, in 50% of the events both DF stations provide the same multiplicity. In about 25% of the events it differs by ±1, and in 25% of the cases the difference in multiplicity was more than ±1. The numbers obtained by keeping the two DF stations in the same location for the same are 70%, 20% and 10%. For the case where the two stations were operated from the same location, only instrumental errors such as the difference in the hardware settings in identifying the multiple strokes in a single flash can contribute. The additional reduction in the coincidence measured when stations are at remote locations can be attributed to the difference in attenuation of the signal strength received by the two DF stations. Our measurements indicate that multiplicity is a poor parameter to be used in the filtering criteria to select coincidence strikes. However, polarity can be used as an additional criteria to select lightning ground flashes.

The strike position of the lightning can be reconstructed by using the crossing point of the two direction vectors. If the strike position is correct, then the normalised signal strengths measured by the two distant stations should show a tight correlation since it would represent the strength of the source. In figure 3, the correlation of the flash strengths measured by the two DF stations are shown. The signal strengths are normalised to 100 km. Only hits that produce a difference in angles of greater than ±25 degrees are plotted here to avoid errors due to the geometrical placement of the stations [2]. Although the data show some correlation, it is not as tight as expected and show a large scatter which is well beyond the instrumental resolution of DF stations. The reason for observing a large dispersion can be attributed to the site errors.

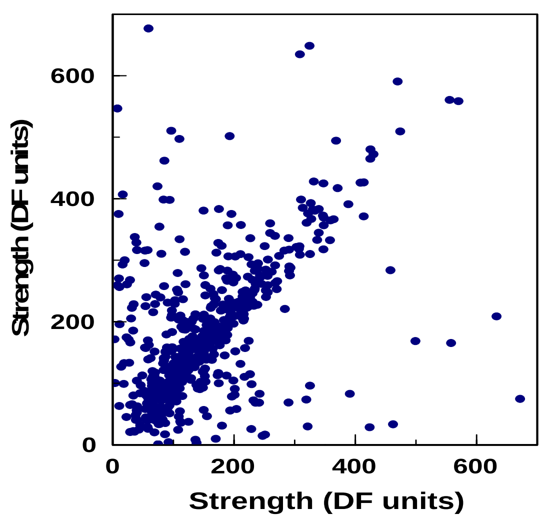

Figure 3: Correlation of normalised (100 km) flash strength measured by the two DF stations for hits that produce a difference of greater than ±25 degrees by the two stations

4. LOCATING GROUND FLASHES

To test a methodology of using signal strengths to improve the position reconstruction in two station measurements when site errors and geometrical errors are present, a Monte-Carlo program was utilised [2]. It generates the angle to the point of strike and the signal strength at each DF station convoluted with the measured instrumental uncertainties of ±0.5 degrees for the angle and ±1.5% for the signal strength. The position of the lightning strike was varied randomly. The locations of the DF stations were defined using the corresponding longitudes and latitudes.

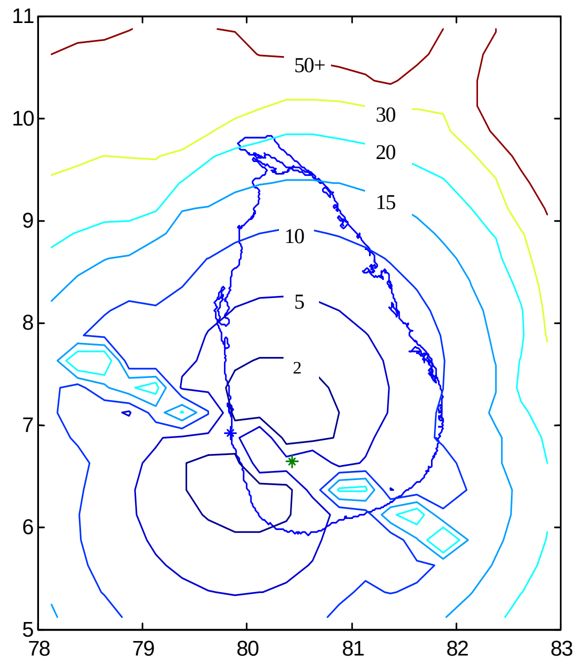

Figure 4: Position error distribution for the region where Sri Lanka is located. The two stations are placed at Colombo and Ratnapura.

If the true source strength is S, the signal strengths measured by the two stations are S_1 and S_2, and, the distance to the point of strike from the two DF stations are r_1 and r_2, then;

$$S = S_1 \times r_1(\theta_1,\theta_2) = S_2 \times r_2(\theta_1,\theta_2)$$

where r_1 and r_2 are functions of the measured angles at the two DF stations, θ_1 and θ_2 respectively. Hence, by varying the angles within their uncertainties one can minimise the function

$$f(\theta_1,\theta_2) = S_1 \times r_1 - S_2 \times r_2$$

to obtain new co-ordinates, which in principle should provide a better estimate of the point of strike of the lightning.

Figure 4 shows the contour plot of position errors after using the above technique. It shows that a position accuracy of ±5 km can be achieved in the region of Colombo where major industries are located, except in the vicinity of the line joining the two stations. Most parts of Sri Lanka can be covered under a ±10 km accuracy except for the extreme north. The errors in the vicinity of the line joining the two stations can be eliminated by installing a third station not in line with the existing stations.

In Figure 5 the reconstructed ground flash distribution for the data is shown. The locations of the Colombo and Ratnapura DF stations are also shown (open circles). It can be seen that, for the recorded data, most of the activities were concentrated between the latitudes 6.4N and 7.2N and longitudes 79.8E and 80.4E where most of the industries are located. This area corresponds to a position accuracy of ±5 km in the worst case except in the vicinity of the line joining the two stations.

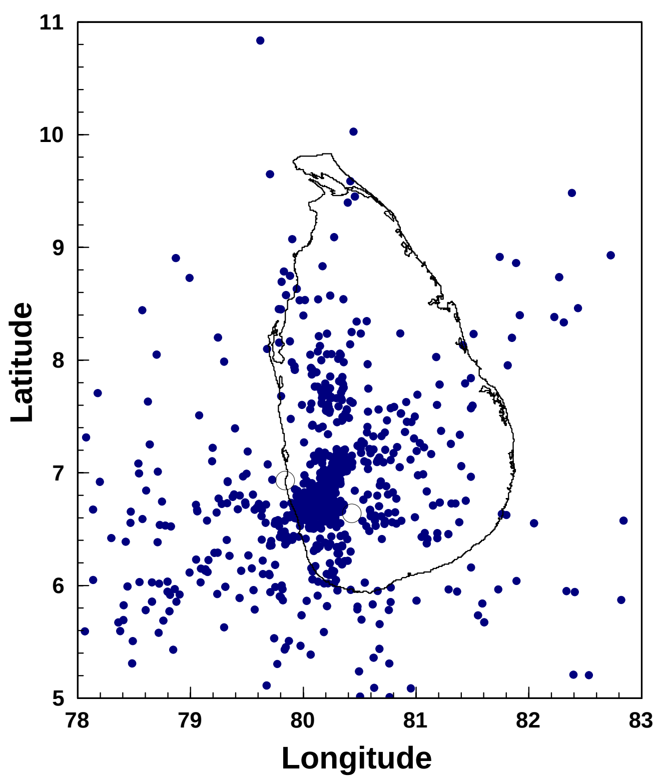

Figure 5: Reconstructed ground flash data for the Northeast monsoon

5. CONCLUSIONS

In selecting coincidence records, a time window of a few tens of ms can be used successfully. This criterion is valid even with remote DF stations as long as the distance between the stations do not contribute to a large time jitter. Further cleaning can be achieved by imposing another selection on the polarity of the flashes. However, multiplicity cannot be used in the selection procedure since DF stations fail to report the correct multiplicity due to the signal attenuation.

The azimuth angles given by DF stations have large systematic errors especially due to the induced magnetic fields generated by the nearby metallic objects (site errors). In addition, two-station position reconstruction is sensitive to the geometrical placement of the stations with respect to each other. Specially, if the strikes are in the vicinity of the line joining two stations, position reconstruction using only angular information cannot be trusted. However, it is shown that by using the signal strength measurement, these errors can be somewhat corrected.

ACKNOWLEDGEMENTS

Financial assistance by IPPS, Uppsala University, Sweden for research grant number SRI:01/1, NSF grant number RG/99/P/02 and University of Colombo grant number 99/S/31 are acknowledged.

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