Proceedings of the Technical Sessions, 17 (2001) 30-36
Institute of Physics – Sri Lanka

Performance Comparison between the Magnetic Direction Finding Technique and the Time of Arrival Technique

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ABSTRACT

A study was carried out in order to understand the strengths and weaknesses of two popular lightning locating systems namely, the wide band magnetic direction finding category (sometimes referred to as IMPACT sensors) and the time of arrival category (TOA sensors) which are used world-wide today. For IMPACT sensors, it has been shown that with three stations having angular accuracy limited to 2° to 3°, strike location can be reconstructed up to a few km's near the centre of the network. The accuracy roll off gradually when one moves away from the antennas extending up to few tens of km's over 400 km distance. The estimates of the location accuracy in TOA systems show that they are accurate up to 300m near the network centre which degrade up to a few km's for large distances (over 400 km).

1. INTRODUCTION

Remote sensing of lightning detection is based on the principal that the electromagnetic fields are generated by the moving charges in the lightning channel and propagated outwards from point of strike. Antennas placed at strategic location's sense these fields and the strike location is computed. The ability of detecting a lightning flash from a remote station depends on the peak current of its first return stroke. The higher the peak current, the more likely the flash will be detected even at larger distances. Lightning flashes can vary in magnitude (peak current) and type (positive or negative). Lightning detection systems are normally tuned to detect the cloud-to-ground lightning flashes and filter other type of flashes.

In the past lightning ground flash densities were determined by using 'flash counters'. They had limitations in their range and had difficulties in discriminating intra-cloud flashes and cloud-to-cloud flashes from those of cloud-to-ground flashes.

Today, there are many different types of systems are used in lightning detection. They are flash counters, spherics monitors, VHF interferometric techniques, time-of-arrival and wide band magnetic direction finding. Lightning can also be observed using radar, satellites, aircraft's and shuttles.

From these systems, to locate a point of strike of lightning ground flashes up to few hundred kilometre's, the two most popular methods used today are the wide band magnetic direction finding (IMPACT) technique and the time-of-arrival (TOA) technique.

The implementation of a national level lightning locating network for Sri Lanka was initiated in late 1998 when IPPS, Sweden, Uppsala University donated 4 IMPACT sensors. The Department of Physics, University of Colombo with the support from Industrial Technology Institute and Department of Meteorology began installing these systems in strategic locations to locate lightning ground flashes that strike in and around Sri Lanka. Currently the lightning network consists of 3 IMPACT sensors installed in Colombo, Kandy and Hambanthota.

The present study is carried out to understand the change in the performance when adding TOA sensors to the existing network consist of IMPACT sensors.

2. MAGNETIC DIRECTION FINDING TECHNIQUE

2.1 Principle of Operation

The wideband magnetic direction finding systems measures the EM fields radiated by a lightning flash using two vertical, orthogonal (oriented north-south and east-west) wire loop antennas and a horizontal flat plate antenna which determines the polarity and the change in the vertical electric fields of the CG flashes [1]. The radiated magnetic fields of a lightning flash induce a current, which is sensed in the loops. The voltage signal measured in a loop antenna is related to the flash's magnetic field strength by the cosine of the angle between the plane of the loop and the direction to the flash. By comparing the voltage signals from two loops, a direction to the flash can be determined. The flat plate antenna is used to resolve the 180 degree ambiguity associated with the calculations [2].

The IMPACT sensors are capable of discriminating cloud–to-ground flash from other forms of lightning or noise by their electromagnetic signature. When the stepped leader reaches the ground, the return stroke is triggered producing a sharp voltage rise. This information is used to distinguish cloud-to-ground flashes from other EM noise. The processing electronics are designed to respond only to those field shapes that are characteristics of return strokes in CG flashes.

The raw data from all IMPACT sensors record within a time window of 25 milliseconds or less can be assumed to be generated from the same flash and can be used in calculating the location of the lightning strike to ground [2]. The detection efficiency of these systems is about 80% within a range of 400 km.

2.2 Performance

The two main errors contributing to the detection of a strike location are the random and systematic errors, which effect the accurate determination of the azimuth angle from the receivers. The random errors of these systems were verified and found to be within 0.5 degrees [3]. The systematic errors that associated with the environment of the receiving antennas can be corrected using a set of prior data and they can be reduced up to 2 or 3 degrees error on the azimuth [2].

In this work, the performance of the network of IMPACT sensors were tested by using Monte-Carlo technique. Lightning strikes were assumed to be randomly distributed in an area of 672×896 km^2 (corresponding to Longitude 78-84 and Latitude 4-12 to cover Sri Lanka and the surrounding area of the Indian Ocean). Sensors were assumed to be fixed at Colombo (6.93N, 79.84E), Kandy (7.31N, 80.64E) and Hambanthota (6.12N, 81.12E) corresponding to baselines of 99 km, 144 km and 170 km respectively. These are the actual locations of the IMPACT sensors installed so far. The error associated with the azimuth due to random and systematic errors was introduced using a gaussian random number generator. Total area was divided into 28×28 km^2 cells and errors associated with each cell was calculated by reconstructing the strike location and comparing with the actual location.

Figure 1 shows the results from this study. The white band is corresponds to strike position reconstruction errors of 10 km. The next level of gray corresponds to 20 km and so on. A map of Sri Lanka is superimposed on the same figure to mark the boundaries. Figure 1a shows the accuracy only with random errors. Figure 1b shows the accuracy with random and systematic errors. It can be seen that if only random errors are present, most of Sri Lanka and the surrounding area of the Indian Ocean can be covered within 10 km accuracy. However, once the systematic errors are introduced the errors have increased to 30 km. As expected, large errors are seen in the northern part of

Sri Lanka due to the geometrical placement of the sensors. The best accuracy of 5 km is seen at the center of the sensor network.

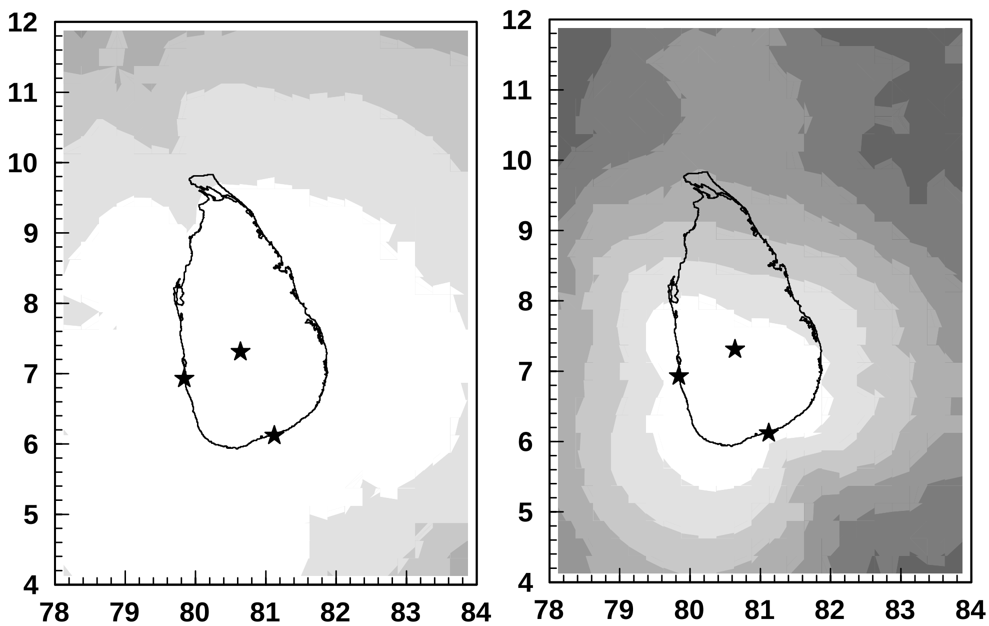

Figure 1: Strike position reconstruction accuracy of IMPACT technique (a) with random error (b) with random and systematic errors

3. TIME OF ARRIVAL TECHNIQUE

3.1 Principle of Operation

The TOA sensors use the time difference between sensing the arrival of the electric pulse emitted by a lightning discharge at three stations to construct intersecting hyperbolas that uniquely locate the lightning flash. The TOA sensors detect and report virtually all CG strikes within a flash. Because TOA sensors are also more sensitive than the IMPACT sensors, some intra-cloud strikes may also reported.

At each antennas site, there are two antennas, one to detect the lightning generated electric fields and other to receive the timing signals generated by geo-stationary satellites (LORAN C or if more accurate timing is desired then through GPS systems). A minimum of 3 stations is required to detect a CG strike in order to calculate the location. Each station generates information on lightning generated electric fields and arrival time of the peak amplitude. The antennas have no sitting requirements (can be even placed on a top of a building).

3.2 Performance

The main error in the TOA system arises due to the deformation of the signal as it propagates between the point of impact and the receiver. Since it depends on the ground conductivity over which it travels, it is difficult to correct even at offline. Errors in the order of few tenths of μs are possible over a distance of few hundred kilometers if the ground conductivity is poor. Also synchronisation errors due to the movement of the telecommunication satellites which generate the clock signals can lead to error in the order of 2 μs.

It has been shown that [5], the average propagation errors can be calculated by using the expression,

$$\tau = 2.15\times10^{-4}\exp\left(0.529\times\ln\frac{d}{\sigma}\right)$$

where τ is the delay in μs, d is the distance between the point of impact and the receiver in km and σ is the ground conductivity. In this work due to the absence of the precise information, the ground conductivity was taken as 0.001 ohm.m^{-1}. The sycronization errors were assumed to be uniform distribution with maximum error of 2 μs.

To obtain the solution of the intersection point of the two hyperbolas due to the signal arrival times at different antennas (two stations generate one hyperbola and any of these and a third generates another hyperbola), Mathematica was utilized. The solution generated through Mathematica was used in Maple to generate software subroutines, which were called in the main simulation program to obtain the reconstructed strike location.

Figure 2 shows the results from this study. In this plot, the white area corresponds to 1 km accuracy. Hence it can be seen that most part of Sri Lanka can be covered within 1 km accuracy except for the northern part. Some places accuracy in the order of few tenths of meters is seen. When the systematic shift in the mean strike positions were calculated, it was seen that mean shift is also around 1 km (see figure 2b). This error is associated propagation errors cause by the signal attenuation.

With the same sensor locations, the strike position reconstruction accuracy of TOA sensors are far superior to that of IMPACT sensors.

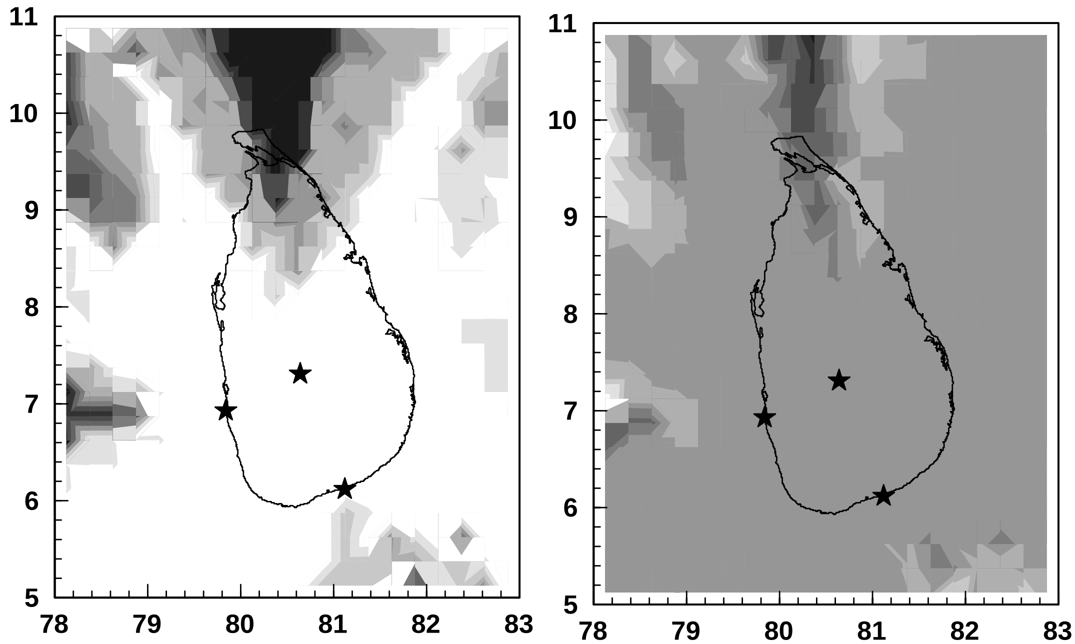

Figure 2: Strike position accuracy of TOA technique (a) position error of the distribution (b) systematic shift in the mean due to propagation errors

4. CONCLUSIONS

The accuracy of the strike position given by TOA sensors are far better than the IMPACT sensors if they were to placed at the same physical locations currently used by the lightning detection network in Sri Lanka. This study shows that even if the overall error (including the random and systematic errors) limited to 2-3 degrees, the accuracy of the strike position given by IMPACT sensors are not accurate enough for most scientific studies such as studying lightning propagation effects etc. Since the TOA sensors report extremely good accuracy's, the existing network should be upgraded to support set of TOA sensors. However, in TOA sensors it is necessary the same lightning strikes be present in a minimum of three stations.

ACKNOWLEDGEMENTS

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

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