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A Three Magnetic direction finder Network for a Local Warning Device

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Abstract :

Tahiti is often struck by lightning and local electric field detectors have checked off a mean value of 80 thunder days per year (over 7 years). Because lightning strokes cause troubles a lightning location system called LIFT (Localization of Impacts for Flashes on Tahiti) has been set up to send off warnings about thunderstorm occurrences. LIFT consists of 3 commercial magnetic direction-finders (MDF) connected together via a pre-existing network. The locations provided by LIFT are deduced from the triangle formed by the three direction vectors and are validated with an independent lightning location network, the WWLLN. The lightning locations using MDFs have been widely studied but the present paper deals with a network devised in a very austere environment. The small size of the island, the non-flat terrain and the numerous nearby conducting objects cause a very large systematic and random error in the azimuth measurements. The comparison of the two systems allows a site error correction function to be expressed. There remains however a large discrepancy so a second correction function assuming a non horizontal magnetic component is proposed.

Index Terms

Lightning location, magnetic direction finders, warning system

1 INTRODUCTION

The elaboration of a local lightning location system in Tahiti has been essentially motivated by the need of a warning device because of the frequent damage done by lightning on the Tahitian power transmission network (TPT). Indeed, although it is a small-sized island (1042 km²), Tahiti is often struck by lightning. Local CIGRE counters (2-10kHz, ≈30 km detection in radius) have checked off a mean value of 80 thunder days per year (over 7 years) [1]. Furthermore, a local lightning location system affords the opportunities for scientific studies of atmospheric electricity and convective system over the ocean. In 2003 I became associates with the local public electricity company Electricité De Tahiti (EDT) and set up a lightning location system called LIFT (Localization of Impacts for Flashes on Tahiti), with the aim to warn about thunderstorm occurrences.

The Lightning Location System (LLS) networks using low frequency radio receivers are usually classified into two categories. When the electric field is concerned, the sensors record the time of arrival (TOA) of the signals and the lightning location is deduced from the differences in the times of arrival at the different sensors (hyperbolas techniques). When the magnetic field is detected, the receivers consist in two orthogonal magnetic-loops (Magnetic Direction Finders, MDF) from which the source azimuth can be deduced. The source location is then estimated by a triangulation technique. The network described in this paper concerns this last category. It is made of three MDFs and the flash location is deduced from the intersection of the three detection vectors.

The principle of a single MDF is quite simple in theory but, in practice, the measurement of the azimuth of the lightning location cannot be accurately made and the intersection of three detection vectors is far from being punctual but results in a S surface. The three MDF exhibit systematic azimuth errors, which makes it that the triangulation was not at all accurate. Algorithms proposed to solve the site error problem are difficult to apply because of the proximity of the MDF. In addition, other parameters required, such as the amplitude signals or an accurate time of arrival, are not recorded. Nevertheless, despite this inadequate infrastructure, the site error problem can be partially solved by comparing the MDF bearing with the data provided by another Lightning Location System, the World Wide Lightning Location Network data (WWLLN) [2]. This network composed of about twenty sensors at VLF is distributed all around the world and the lightning strokes are located by using the time of group arrival method (TOGA). Although the site error correction provides more coherent

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triangulations, even outside the network, another kind of correction is necessary to make LIFT into a reliable device.

The paper deals with the description of this new correction method. This correction function assumes the existence of a non horizontal component of the magnetic field and the location is deduced from an iterative calculation minimizing the S surface of the triangle. The validity of the location accuracy has been assessed by checking the data with the LIS data, the satellite images, personal observations and dated damages done on the power transmission network.

2 THE SYSTEMATIC ERROR OF THE MAGNETIC DIRECTION FINDERS

The error in azimuth determination introduced by the MDF sensors has been the subject of a lot of studies from the eighties [,3,4,5,6,7,8,9]. More than a random error, a systematic error has to be determined for each MDF. This so-called "site error" is estimated either by using redundant locations and/or iterative techniques or by determining a correction function for each MDF. The resolution of the problem is based on a least square analysis to determine the parameters of a sinusoidal correction function. The main reason for the site error comes from the presence of large conductive objects in the vicinity of the sensor, which introduces a bias in the lightning flash location [10]. Schulz [9,11] proposes an analysis of the absorption and re-radiation of an incident lightning radiation by a horizontal power line. These objects act as "mirrors" in the LF range and it has been shown [3] that the site error is in the form of a two-cycle sinusoidal function of either the measured or the true azimuth for each MDF.

From all the statistical analysis reported by many authors during the last 20 years, it has been commonly admitted that a large number of MDF is necessary although the location deduced from the two closest MDFs is the most likely to be relied upon [12]. The error in regard to the North alignment and to the baseline problem (the lightning impacts close to the imaginary line connecting two MDFs) has also been taken into account in the global correction function. Lastly, it has been reported that the site error correction is inefficient outside the area occupied by the MDF network [9].

3 THE LOCAL LIGHTNING LOCATION SYSTEM : LIFT

A local LLS has been devised by installing and connecting together around Tahiti island three MDFs through a local pre-existing communication network (Figure 1). The MDFs come from a relatively cheap commercial product using a MDF antenna (Boltek Storm Tracker®) which has been adapted to work within a network. The system is designed to work with only one Magnetic Direction Finder. The MDF consists of a 'black' box housing the two coils oriented North-Southward and West-Eastward. It is connected to an acquisition card in which the induced voltages at the two coils are stored. From those measurements, the azimuth is computed and the distance estimated. An associated software points out the moving of surrounding thunderstorms on a screen. The data are displayed with a minimum period of 20ms. The MDF has an average 300km radius detection and the bandwidth of the whole system is meant to be 40-100kHz. The efficacy of the system has been tested in Tahiti over one rainy season and, globally, the directions of the storms detected are coherent with visual observations and satellite images but the distances provided by the Storm Tracker sensor are not at all accurate. Therefore, the system with a single sensor cannot be used to efficiently supervise the TPT network.

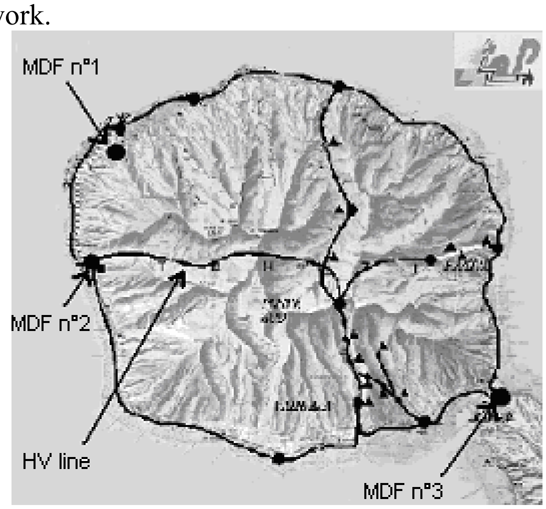

Figure 1 : Tahiti relief and location of the 3 MDFs. Location of the sensible HV line (provided by TEP : Transport Electrique de Polynésie)

Since the local power distribution company (EDT) has put at our disposal its own communication network, three Boltek MDFs have been installed all around the island and connected together through this network. More than their low cost and easy installation, the Boltek MDFs have also been chosen because the Linux drivers of the PC card are available on the Boltek website. The global LIFT architecture is shown in Figure 1. The location of the three detectors is not optimal from a geometric point of view: the triangle formed by the three sensors is not isosceles and they are not at a great distance from one another (≈20–50 km). Likewise, according to the fact that a MDF network becomes inaccurate outside the area limited by the MDF locations, the use of LIFT as a warning device may prove to be too optimistic. It must be also noted that the relief is quite rugged since Tahiti is a 15km radius circular island culminating at 2200m.

Lastly, the way the sensors are located around the buildings housing the MDF controllers prevents a good LF reception. As indicated above, the presence of metallic objects in neighbouring buildings could not be avoided. The n°1 detector is mounted on the roof of a 10m high building located on the hillside. The roof is a 40m² plate supporting various small metallic objects. The only means to protect the MDFs from these objects was to mount it at the top of a 4m high wooden mast. The n°2 detector is mounted on a 25m x 40m surface metallic roof, inclined at about 15°, at the top of a 18m high building located in a narrow corridor valley. The antenna is mounted at the top of a 4m high wooden mast. The building neighbours a large power station. The n°3 detector is mounted at the top of a 7m high wooden mast set in a field about 15m from the main building. N°1 and n°2 detectors stand next to the sea on one side and to the mountain on the other side (Figure 1). N°3 detector is located on an isthmus, oriented North-West and South East.

The transfer function of the Boltek detection system remains unchanged and the raw data consist of the tanθ, θ being the lightning flash azimuth. The estimated distances provided by the software will not be used in the present study. Momentarily stored on the buffer acquisition board the data can be read and transferred to a PC every 10ms thanks to the Linux drivers provided by the Boltek company. The mean interstroke interval is about 60ms [13] and it is quite unlikely to be smaller than 10ms. We can thus assume that not more than one event (first stroke or subsequent stroke) is recorded at a time. The three MDFs are connected together through the local communication network in a master-slave configuration. The time synchronisation is carried out by means of a GPS clock. The data are transferred and compared in order to proceed to the triangulation calculation.

Due to the network geometry, the distances between the flash locations and the three MDFs are of the same order. That explains why the location problem is always solved by taking the three detections vectors into account. An event is only recorded if 3 azimuths are recorded in a 10ms window. When the draw of the three detection vectors produces a triangle, i.e. a coherent triangulation, the S area of its surface is recorded as a parameter. The detection area concerned by the LLS is about 250km in radius. Planar coordinates have been used for the calculations.

Among the very large amount of data recorded from February to December 2004, very few have led to a coherent triangulation. Furthermore, when the triangulation is obtained with an acceptable triangle area, the localisation may disagree with the WWLL data, the meteorological satellite photographs or the LIS data. The LLS network design is likely to lead to this failure to operate. In order to determine the three site errors, each measured azimuth is compared to the three "true" azimuths provided by another independent LLS.

4 THE WORLD WIDE LIGHTNING LOCATION NETWORK

In the present study, the data provided by the World Wide Lightning Location Network (WWLLN) are taken as a reference for evaluate the systematic errors that are recorded in the three MDFs. Any terms related to this network will be indexed as W. This network, operated by LF*EM in New Zealand partnering with the University of Washington in Seattle, is a network of lightning location sensors at VLF (3-30kHz) [2,14]. The sensors (24 stations in number today, one of which in Tahiti) are arranged all around the world and may be several thousand kilometres distant from the stroke. Figure 2 shows eleven sensors distributed in the Pacific Ocean area. The lightning stroke location requires the times of group arrival (TOGA) from at least 4 WWLL sensors. The number of N_W stations used for the localisation and a time accuracy Δt (up to 200µs) are associated to each lightning location. It is suggested that only the data determined from at least $N_W=5$ and a $\Delta t<30$ µs are considered as high quality data. Comparing the system with another detection array (LASA), Jacobson et al [15] have led to the conclusion that the WWLL network does not offer a level of detail even of the satellite based optical imagers but is accurate enough (≈15-20km) for synoptic locations. It is shown that the detection efficiency approaches a few percent for high current amplitudes. Therefore, the current magnitude of IC flashes being lower than for CG flashes, the WWLL is statistically more sensitive to the CG flashes. All stroke locations over the whole world are available monthly on a CD support.

Figure 2 : Location of the closest eleven WWLL sensors around Tahiti

Though the number of flashes was underestimated, the WWLLN provided a large quantity of data all around the island throughout the year 2004. About 4000 flashes have been simultaneously (20ms range) detected by both LIFT and WWLLN in a 350km perimeter. Conserving a high quality data ($N_W \geq 5$ and $\Delta t \leq 30 \mu s$), 1019 CG flash locations can be dealt with.

Among the 1019 CG flashes selected, only a small proportion are located inside the LIFT network, i.e. over the island. It is obvious that an accurate location at a distance greater than 100km is not reasonable but all the data will be examined and the distance will be treated as an adjustable parameter for the discussion. Figure 3 shows the D_W distance distribution of the 1019 CG flashes from the centre of the island. Distances smaller than 15km can be said to lie within the LIFT network. The area including the selected flashes is about 100 times larger than the area delimited by the LIFT network.

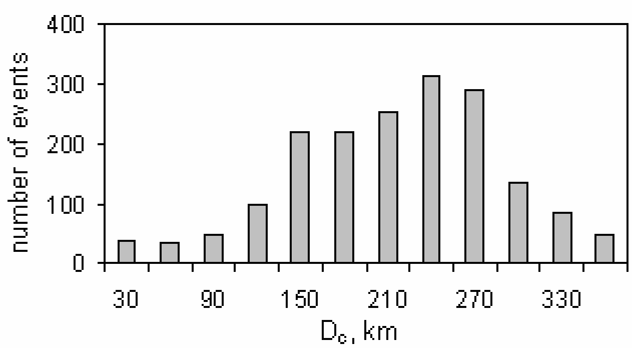

Figure 3 : Distribution of the distances of the WWLLN CG flash locations

5 SITE ERROR ANALYSIS

The events are selected when both WWLLN and LIFT systems localize one flash in a 20ms window. For each event, the WWLLN location is considered as the "true" location and a "true" azimuth $\theta_{W,i}$ (i =1, 2, 3) can be deduced for each MDF and compared to the measured azimuth $\theta_{B,i}$ (i =1, 2, 3). Thus, the error $\Delta\theta_i = \theta_{W,i} - \theta_{B,i}$ can be drawn as a function of $\theta_{B,i}$. The $\Delta\theta_i$ distributions versus the $\theta_{B,i}$ azimuths of the three 3 detectors are plotted in Figure 4. It can be seen that : a) the $\Delta\theta_i$ distribution are $\theta_{B,i}$ dependent; b) the amplitude of the $\Delta\theta_i$ distributions is about 30°, which is a very high value; c) the $\Delta\theta_i$ distribution exhibit a large difference in shape from one detector to another.

The influence of different parameters has been checked to reduce the strong discrepancy between the two systems. The D_c distance of the CG flash locations to the centre island does not have any influence upon the large amplitude of the $\Delta\theta_i$ distributions. On the contrary, the $\Delta\theta_i$ distributions seem to be more "aleatory" as regards the closest flash locations. Neither does the number of sensors involved in the W lightning locations, N_W, and the residual fit errors, Δt, have any influence upon the $\Delta\theta_i$ distribution. It must be noted that when locations deduced from the same number of stations are gathered together, the shapes of the $\Delta\theta_i$ distributions remain unchanged. Therefore, the large amplitude of the $\Delta\theta_i$ distributions is more likely to result from the LIFT configuration.

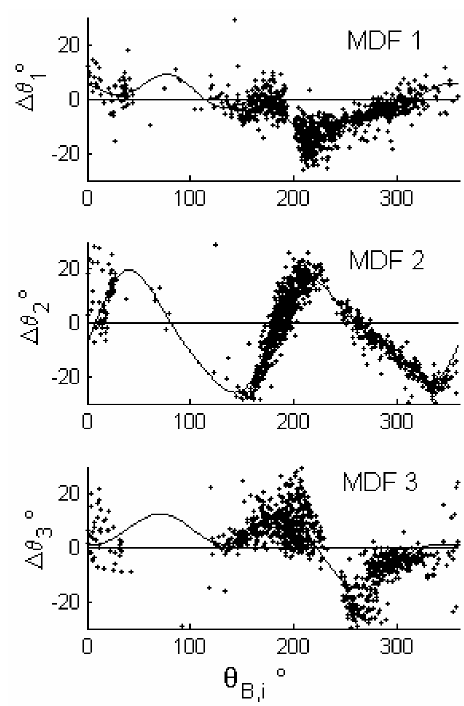

Figure 4 : $\Delta\theta = \theta_W - \theta_B$ as a function of the measured azimuth for the 3 MDFs and site error function (Eq.1) with 4 harmonics

It is a well known fact that the MDFs at LF range are sensitive to systematic errors, usually called site errors and caused by non-flat terrains and by the presence of metallic objects in the vicinity of the antenna. For each antenna, the resulting site error distribution of one object is a two-cycle sinusoid function or the addition of several two-cycle sinusoidal functions with different amplitudes and phases according to the amount of metallic objects surrounding the MDF. On the other hand, a calculation has been made [16] to express the perturbation on the azimuth measurement due to an arbitrary inclination of the antenna in regard to the verticality. Also, for a given mast inclination, the correction function is a two-cycle sinusoid function. In any case, the result remains a two-cycle sinusoidal function.

Therefore, a classical trigonometric polynomial K_i including large orders has been used for each MDF (i index) as a correction function:

$$K_i = a_{0,i} + \sum_{n=1}^{N_i}[a_{n,i}\cos(n.\theta_{w,i}) + b_{n,i}\sin(n.\theta_{w,i})] \qquad (1)$$

TABLE 1 : Percentage of successful triangulations. "all" means locations without restriction in regard to the accuracy. D_{WL} is the distance between the W and LIFT flash locations. R is the radius of the area of interest. A = all flashes, B = D_{WL}<20km

		All data	R <150km	R <100km	R <50km
simultaneous W and LIFT data		1019	205	51	13
Triangulation without correction	A	5%	2%	8%	31%
	B	0,4%	2%	8%	31%
Triangulation with site error correction	A	43%	55%	90%	77%
	B	5%	17%	31%	69%
Triangulation with site error + Eq.6 correction	A	93%	92%	61%	100%
	B	15%	20%	31%	85%

The $a_{k,j}$ coefficients are determined by a linear regression using Eq.1 to fit the $\Delta\theta_i$ distribution. First, and according to the site error theory, even values for the n coefficients have been imposed. The results were satisfying but the best fittings were obtained without any restriction, that is to say that both even and odd harmonics have been conserved. The existence of odd harmonics in the site error function has already been noticed by Schultz [9]. Figure 5 displays the harmonic amplitudes for N_i = 6. No general behaviour can be sorted out since odd harmonics are dominant for MDF n°3, even harmonics for MDF n° 2. It must be noted that despite particular attention paid to the northern alignment when mounting the MDFs, the continuous component is not negligible. It is quite difficult to determine the N_i number of harmonic. N_i must be determined for each sensor and different criteria can help make a decision such as the regression coefficient of the linear regression, the significance of the $a_{k,j}$ coefficients, the standard deviation of the residue distributions and the visual aspect of the fitting and of the residue distributions. The first three criteria do not vary significantly enough to clearly define the limit of the series. The last two criteria are not objective. As a conclusion the best achievement only comes down to a range of N_i values. Similar criteria were obtained for N_i values ranging from 3 to 8. Lastly, the three N_i values have been determined by choosing the triplet (N_1, N_2, N_3) leading to the highest number of coherent localisations (small S surface and acceptable D_{LW} distance between the locations provided by the two systems). The combination N_1=N_2=N_3=4 is selected for the three MDFs. Figure 6 shows the residues of the three regressions. It can be observed that, if the shape of the correction function is correct, the error remains very large since the standard deviation of the residues is about 6°. This value is not significantly improved if only flash locations within a 200 or 100km radius are considered. Nevertheless, this first correction involves a substantial improvement in the triangulation process. Let us assume that an acceptable location is defined by a S<10km² triangle surface and a D_{LW}<20km distance. Without any correction, out of the 1019 data, only 178 have led to a triangulation only 10 of which were acceptable. The application of the site-error correction function, Eq.1, has increased the number of triangulations up to 442 (43%) with 53 acceptable locations (see Table 1).

6 ASSUMPTION OF A NON HORIZONTAL MAGNETIC FIELD COMPONENT

Once the site error correction has been applied to each azimuth measured, the residual error should have decreased to less than one degree. But Figure 6 shows that the standard deviation of the residues is about 6°. Another reason for the remaining errors may come from the quality of the acquisition system. The measurement of the NS and EW components from which the azimuth is deduced generally bears on the initial peak magnetic fields which are radiated by the bottom hundred meters of the lightning channel [13].

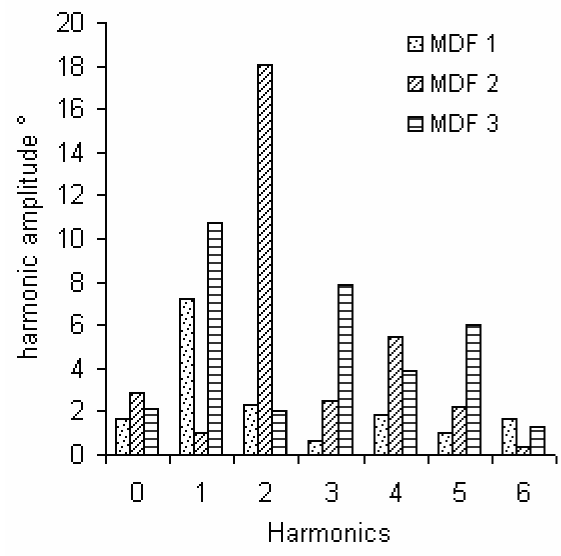

Figure 5 : Harmonic amplitudes of Eq.1 for N = 6

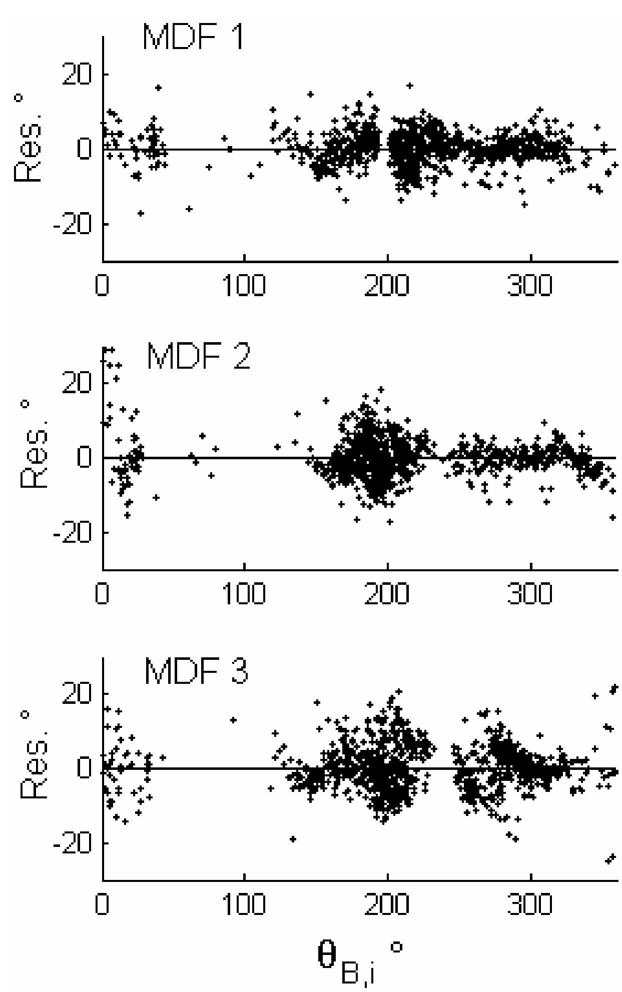

Figure 6 : Residue of the regression of the $\Delta\theta_i$ distribution by Eq.1 for the three MDF (N_i=4)

The bottom section is assumed to be straight and vertical. Nevertheless, due to the relative narrow bandwidth (a frequency of interest of about 50kHz of the Boltek devices is mentioned by the manufacturer), the initial peak of the magnetic field may be not correctly recorded. The Boltek MDF behave like the narrow band MDFs which are known to exhibit large inherent azimuth errors due to non vertical channel sections, branchings or reflections from the ionosphere (sky waves). The MDFs could be sensitive to non-horizontal magnetic components radiated from non-vertical lightning channel sections. This additional error is called polarization errors. Furthermore, Le Vine et al [17] suggest that over a finitely conducting earth, the channel geometry is important to determine the detailed structure of the radiated fields.

6.1 Correction due to the canal inclination

Considering the source as a straight line from the ground that comes at a β angle from the vertical, [18] have derived a general equation for the magnetic field and deduced its time derivative. With such equations, the R_M ratio of the NS and EW components of the return-stroke magnetic field are not dependent upon the β inclination. The geometry of the present problem is illustrated in Figure 7. The source is limited to a straight part of a tortuous channel above the ground, inclined at a β angle to the vertical toward a direction having a α angle in regard to the North, located at an h altitude and seen from the detector at a γ angle from the ground. The source image (not displayed in Figure 7) is taken into account assuming a perfectly conductive ground. In a large proportion, the ground proves to be the ocean surface which has a high conductivity. The four vectors $\overrightarrow{OA}$, $\overrightarrow{OA}*$, $\overrightarrow{\delta\ell}$ and $\overrightarrow{\delta\ell}*$, A* and $\delta\overrightarrow{\delta\ell}*$ being the A and $\overrightarrow{\delta\ell}$ images respectively, can be expressed as a function of the three angles, α, β and γ in the Oxyz coordinate system:

$$\overrightarrow{OA} = D\left[\cos\gamma\cos\theta\vec{e}_x + \cos\gamma\sin\theta\vec{e}_y + \sin\gamma\vec{e}_z\right] \quad (2)$$

$$\overrightarrow{OA}* = D\left[\cos\gamma\cos\theta\vec{e}_x + \cos\gamma\sin\theta\vec{e}_y - \sin\gamma\vec{e}_z\right] \quad (3)$$

$$\overrightarrow{\delta\ell} = \delta\ell\left[\sin\beta\cos\alpha\vec{e}_x + \sin\beta\sin\alpha\vec{e}_y + \cos\beta\vec{e}_z\right] \quad (4)$$

$$\overrightarrow{\delta\ell}* = \delta\ell\left[-\sin\beta\cos\alpha\vec{e}_x - \sin\beta\sin\alpha\vec{e}_y + \cos\beta\vec{e}_z\right] \quad (5)$$

The magnetic field components at the detector location being proportional to the product $\overrightarrow{OA} \wedge \overrightarrow{\delta\ell} + \overrightarrow{OA}* \wedge \overrightarrow{\delta\ell}*$, it can also be expressed as a function of the three angles. With the surface coil vectors oriented as follows : $\vec{S}_1 = -S\vec{e}_y$ and $\vec{S}_2 = -S\vec{e}_x$, S being the common area of the coils, the two magnetic fluxes are α, β and γ dependent. The ratio of the two fluxes provides the tangent of the θ_m measured azimuth. The tangent of the actual θ azimuth can be expressed as a function of the measured one as follows:

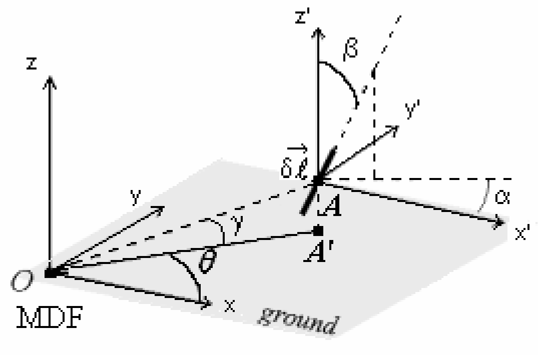

Figure 7: Geometry used in assuming a non-vertical source of the magnetic radiated field

$$tg(\theta) = tg(\theta_m)\frac{1 - tg(\beta).tg(\gamma).\dfrac{\cos(\alpha)}{\cos(\theta_m)}}{1 + tg(\beta).tg(\gamma).\dfrac{\sin(\alpha)}{\sin(\theta_m)}} \qquad (6)$$

The flux ratio is thus affected by the inclination of the source. This influence disappears at γ=0, i.e. when the source is on the ground. Note also that β=0 or γ=0 leads to no correction : $\theta = \theta_m$.

Practically speaking, θ_m in Eq.6 will be the azimuth $\theta_{i,K}$ which is the azimuth measured by the i detector θ_i and corrected by the site error function K_i (Eq.1): $\theta_{i,K} = \theta_i - K_i$. The definitive corrected θ azimuth will be named $\theta_{i,C}$. A set of values is associated to the three angles (α, β, γ). Three column matrices are created with values incremented from 0° to a determined L_i limit with a given δL_i step. For each combination of the 3 angles, $\theta_{i,C}$ is calculated from Eq.6 regarding the 3 detectors. The three direction vectors thus corrected produce a triangle (if they cross one another) the S surface of which can be expressed as a function of α, β, γ. The triplet of angles (α_0, β_0, γ_0) leading to the smallest triangle area, S, is assumed to be the right triplet. The choices of the range L_i and the step δL_i given to the three angles is guided by the comparison between the LIFT and W locations. However, the step is limited by the time of calculation which is important when working on real time mode. It must be noted that the γ_0 angle should not be the same for the three detectors since it is defined for one detector. When the location is far from the island, a common γ_0 value is acceptable. When the location is close to or inside the island, the γ_0 value must be taken as a mean value of the three "actual" angles.

This second correction significantly increases the number of CG flash locations. The table 1 summarises the effect of the corrections upon the number of triangulations. From the 1019 data, 945 (93%) have led to a triangulation among which about 142 (15%) with a D_{LW}<20km. The performance increases when the area of study is limited within a given R radius. For R=150km, 92% of the calculations give a flash location, 20% of which with D_{LW}<20km. For R=50km, 100% of the triangulations are calculable, 85% of which with D_{LW}<20km. In any case, the S surface is always smaller than 0.01km². Since the method is based upon the S minimization, it has been ascertained that the solution is unique and unambiguous. Figure 8 shows an example of the effect of the corrections upon the triangulation. This case corresponds to a lightning stroke which has released the HV line (see also Figure 1). The dotted lines correspond to the azimuths not corrected and the straight lines to the azimuths corrected with Eq.1 and Eq.6. It can be noticed that with an identical correction function, the azimuths from the detectors 1 and 2 have been reduced while the third one has been increased.

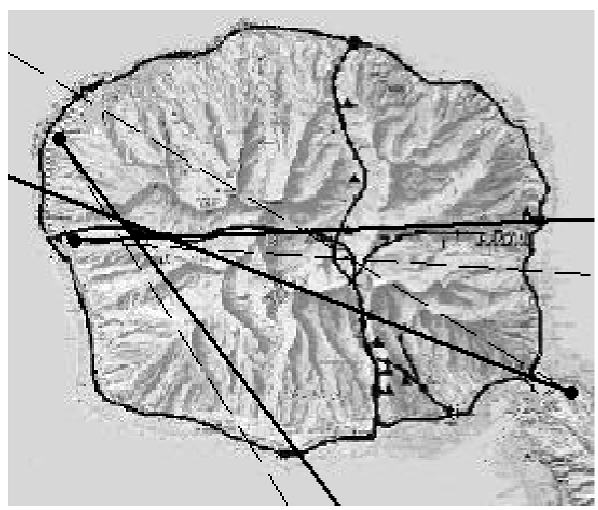

Figure 8 : Effect of the correction functions Eq.1 and 2. dotted line : measured azimuth; straight line : corrected azimuth

This correction is supported by a physical interpretation of the large original discrepancy. The angle values must thus coincide with realistic values. The value of the first angle, α, has no physical restriction and the range and the step have no significant influence on the locations. A range from 0 to 330° with a 30° step has been adopted in order not to over-increase the time calculation. On the other hand, the β and γ angles are naturally limited. Figure 9 shows the histogram of the β_0 and γ_0 values obtained for the 189 locations (synchronic to W locations) restricted in a 150km radius area. The number of events localized decreases when β_0 increases from 0 to 45°. That inclination distribution is consistent with a realistic lightning stroke inclination. In return, Figure 9b shows that the γ angle median is about 35°. The γ angle is associated to the height of the source (Figure 7) and to the inclination of the Poynting vector at the detector location. From an overview of the whole results, the γ_0 values are very high and can appear totally incoherent. Since the location coincides with the W data, the events are inevitably CG flashes. It cannot be held that the locations refer to IC flashes. The γ_0 values are only coherent with the recording of sky waves assuming that groundwaves are not registered.

6.2 *Alternative random correction*

Actually, a similar correction without any physical meaning has also been applied and has led to comparable results. Each azimuth θ_i is transformed into a column matrix where the elements vary from $\theta_i - \theta_{i,0}$ to $\theta_i + \theta_{i,0}$ with a given step $\delta\theta_i$. The location is calculated for all the combinations and the principle consisting in the minimization of the S surface has been maintained. The amount of the coherent triangulation is effectively increased in the same percentage as with the previous method. Nevertheless, the locations are very dependent upon the limit of the three angle variations $\theta_{i,0}$. With Eq.6, the limit of the geometric angles, α, β and γ and the step $\delta\theta_i$ have only a weak incidence upon the CG flash locations. However, this second method is compatible with the hypothesis that a non horizontal magnetic field component is actually recorded at the MDFs. In opposition to the previous correction, the non horizontal component is different at the three MDFs and is not physically linked to the source inclination. The error is only deduced from the minimisation of the S surface.

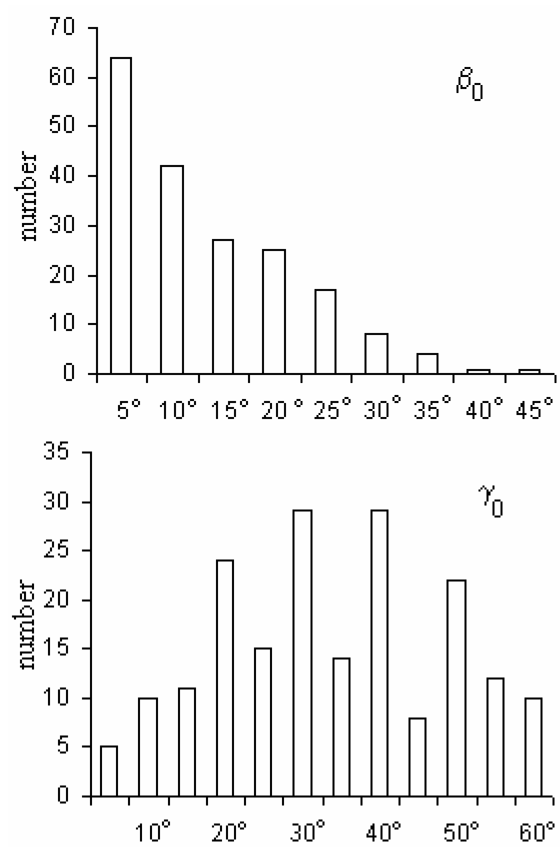

Figure 9 : β_0 and γ_0 distributions for D_c < 150 km

7 COMPARISON WITH THE LIS DATA

The TRMM satellite observes lightning activities for 90 seconds every time it flies over the Tahiti area. According to the data provided by the Nasa website, LIS detected 13 sequences of lightning events close to Tahiti (within a ≈300x300km rectangle) between February and December 2004. During each 90s sequence, the amount of flashes recorded by LIS can vary from 1 to 53 with a mean value close to 9 (53 flashes in 90s was exceptional). Flash detection coincidences between the two systems were observed but with a delay of several hundred of milliseconds. I have plotted the data recorded in a 3 minute sequence including the 90 seconds of the LIS observations. The LIFT locations, after the corrections have been applied, are coherent with the LIS data, at least when the distance does not exceed about 100km from the centre island. Figure 10 shows four examples where flashes are detected in four distinct directions around the island in a 3 minute sequence. Within the sequence the LIFT locations are usually more numerous. When the two systems detect quasi-simultaneous events (within 1 second), the departure is of some kilometres.

Nevertheless, Figure 10d shows that on the North-East/South-West axis only two flashes are located whereas a lot of data were recorded within that sequence. Therefore, the efficiency of the detection regarding that axis is reduced, suggesting that a fourth sensor is needed on the east coast of the Island.

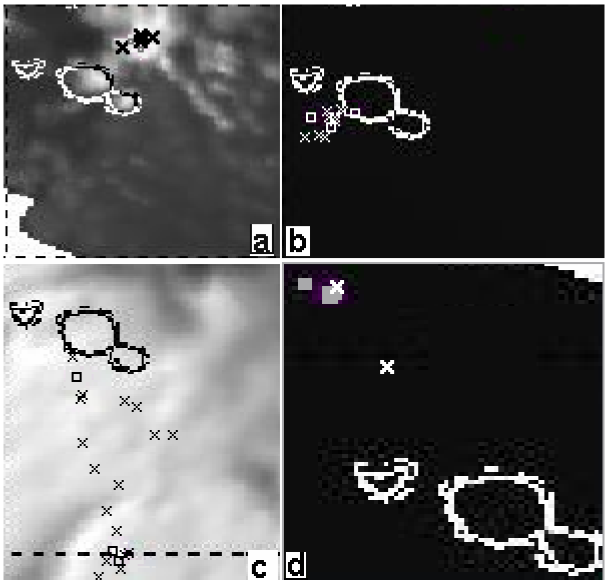

Figure 10 : Four Comparisons between Lift (x) and LIS (squares) locations in a 3 minute sequence

8 LIFT AS A WARNING DEVICE

The first role of the LIFT system is to work as an alarm system in order to send warnings to the dispatchers of the power distribution network about a critical thunderstorm. All the island network must be supervised but the HV line more accurately (see Figure 1). Comparing the W and LIS data has shown that the accuracy of the LIFT data increases when the area under consideration is reduced. One can estimate that within a 75km radius area the locations are accurate enough to build up a warning device. The WWLL network has not provided enough flash locations within the island area to estimate the LIFT accuracy close to the HV line. Local thunderstorms and CG flashes have been visually recorded close to the University. From these observations, the response of the LIFT system proves to be satisfying. Two fatal strokes leading to the circuit breaker operation and to the destruction of the surge arresters have occurred in the year and, upon the LIFT recordings, they were both consecutive to an intense thunderstorm in a very localised place. Figure 11 shows a 20 minute sequence before the fatal stroke of the 13th February when 62 flashes were recorded. CG and IC flashes were definitively recorded and the two histograms of the β_0 and γ_0 distributions are more aleatory in comparison to Figure 9. Unfortunately, the difference between IC and CG flashes cannot be deduced from this distribution.

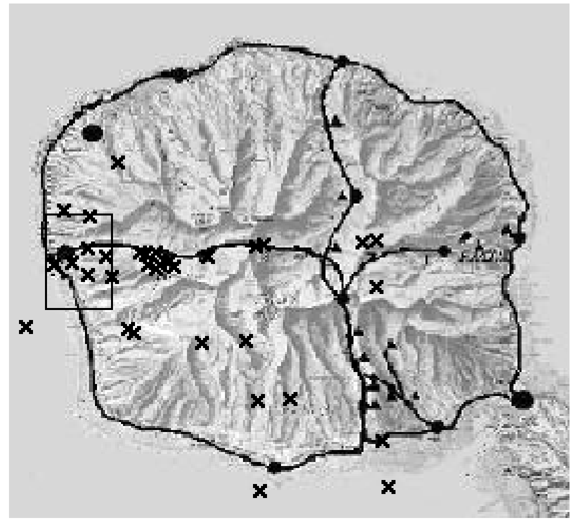

Figure 11 : Recording of a 20 minute sequence of lightning locations

Figure 11 suggests that the HV line has been struck several times before the line tripping. Actually, the HV line area was hit by many thunderstorms in the year 2004, but "only" twice did the strokes lead to a permanent power cut. The analysis of these close thunderstorms has highlighted a critical area. Indeed, the HV line is conventionally protected but it seems that a part of the line is more vulnerable to lightning strokes. Consequently, an alarm is made to trigger off when a critical rate of flashes/sec is recorded in this particular area. This area is shown in Figure 11. It includes one MDF and this could be a problem since close flashes can lead to the saturation of the detection device. For that reason, and also to preclude any accidental or temporary failure of one MDF, a fourth MDF is needed. Its location has been envisaged along the east coast, far from the critical area.

9 CONCLUSION AND PERSPECTIVE

The lightning location system using magnetic direction-finder detectors needs essential corrections especially when the MDF locations cannot be situated far from any nearby conducting objects or on a flat terrain. Two corrections have been proposed. As published by many authors, one correction is inherent to each detector and due to nearby conducting objects. This site error can be estimated with the comparison of the available WWLLN data. The principle of the second correction is based upon the minimization of the azimuth interception triangle surface when varying the three measured azimuths. This variation can be associated to the channel geometry. Although the non-vertical channel model has been extremely simplified, the corrections are effective enough at least to perfect a warning system.

Despite the satisfying results, a lot of improvements can be made to increase the performance of LIFT. For instance, it is obvious that at least one more detector is needed. The alignment of the 3 detectors which makes the localisation on the North-East/South-West axe difficult. Also, it is possible that analysis of the results coupled with other measurements allow the CG flashes from IC flashes to be distinguished assuming that the γ_0 angle is representative of the inclination of the Poynting vector. A measurement of the non-horizontal magnetic component can be envisaged.

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