2014 International Conference on Lightning Protection (ICLP), Shanghai, China

Evaluation of BrasilDAT relative detection efficiency based on LIS observations and a numeric model

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***Abstract*— The BrasilDAT total lightning detection network provides the capability of detecting total lightning on a continental scale. An understanding of the detection efficiency of BrasilDAT is necessary for use of total lightning data in applications such as severe weather detection and derivation of rainfall rates. BrasilDAT relative detection efficiency is studied by comparing lightning flashes seen by the network and by the Lightning Imaging Sensor (LIS) on board of the low earth orbit satellite TRMM. Also projections of BrasilDAT relative detection efficiencies will be computed based on calculations of ELAT's 4th generation relative detection efficiency model.**

Keywords – Lightning; BrasilDAT; LIS; Network; Numerical Model; Detection Efficiency

I. Introduction

BrasilDAT is a lightning detection network based on technology from Earth Networks. BrasilDAT sensors are designed to detect both in cloud (IC) and cloud to ground (CG) discharges using wideband sensors. The sensors measure the radiated electrical field from a lightning discharge and utilize time of arrival techniques to determine the time and location of the electrical discharge. Besides locations, the system also provides a polarity of charge lowered to the ground, peak current estimates and classification of a flash as IC or CG. BrasilDAT produces a time and location for individual pulses of a flash which include in-cloud components and multiple return stroke components for CG flashes.

BrasilDAT currently has 56 sensors deployed throughout Brazil as seen on the map in Figure 1. Additional 5 sensors from Earth Networks Global Network (ENGLN) fill out other areas of South America providing VLF solutions. Sensors were installed starting in October of 2011 and initial installations were completed in May of 2012.

The performance evaluation of a lightning detection network like BrasilDAT is an intricate process that includes several theoretical assumptions, mathematical methods and, lightning data provided by the network. To help understanding the complexity of this kind of analysis, the reader is referred to the CIGRE Task Force C4.404A Report "*Cloud-to-ground lightning parameters derived from lightning detection systems: the effects of system performance*" [3].

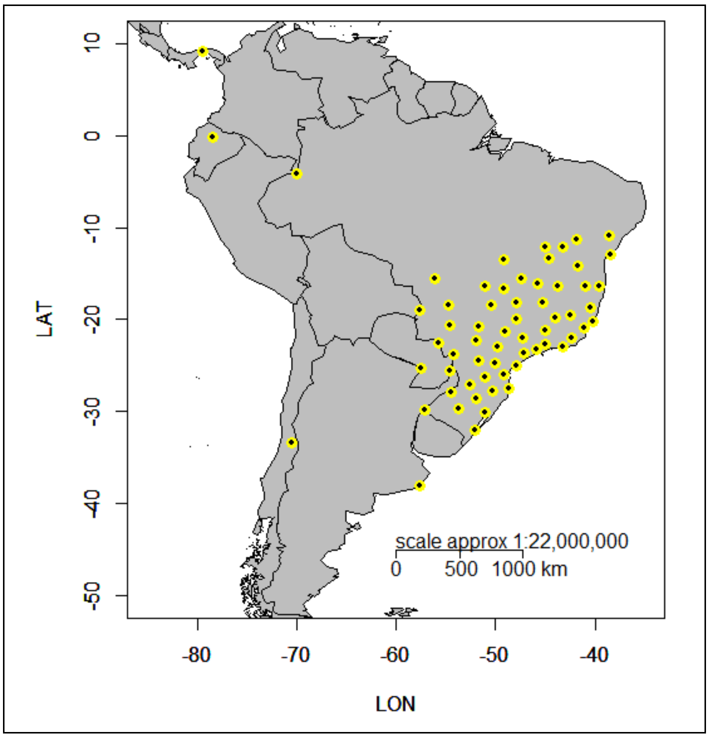

Figure 1. Sensor locations of BrasilDAT within Brazil. Additional 5 sensors outside Brazil provide VLF solutions over South America.

Communications and siting issues are a problem when a lightning network is first installed and improvements can only be made once data is gathered and analyzed. The BrasilDAT lightning network has been steadily improving as communications issues are fixed and sensor siting issues are resolved. The detection efficiency of the network is also increased by improvements in the lightning locating system and sensor firmware. Figure 2 shows a graph with the total number of data packets sent (blue), the aggregate up time percentage of the network (red) and the percentage of packets with no lightning data (green). After initial setup of the network, it took several months for the up time percentage of the sensors to reach 85% or higher. The average up time percentage for 2012 is 74% and the average up time percentage for 2013 is 82%. Many improvements were made in the siting of the sensors in 2013, which resulted in a decrease in packets with no lightning (green). This equates to an improvement in the signal to noise ratio at the sensors. Even if lightning is far away, a good sensor location will see some lightning signal in most seconds. The rate of packets that see no lightning decreased from 40% in August of 2012 to less than 1% in November of 2013.

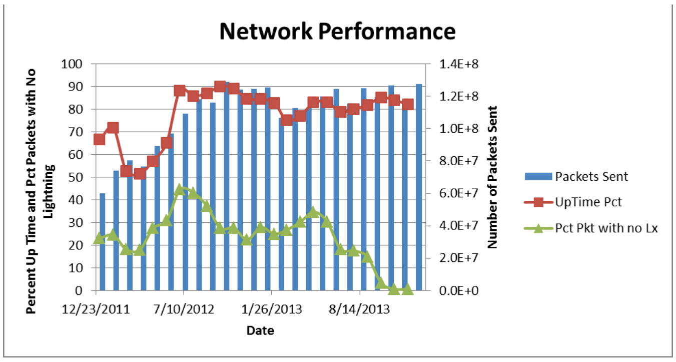

Figure 2. Network performance: the up time percentage (red) is a good measure of network availability. The percent of packets with no lightning (green) is a measure of signal to noise ratio and siting.

II. METHODOLOGY

A. Comparing BrasilDAT to LIS

The Lightning Imaging Sensor (LIS) is a lightning event detector on board of the Tropical Rainfall Measuring Mission (TRMM) satellite. LIS was launched in late 1997 and is still acquiring total (cloud-to-ground and intracloud) lightning with a 35º-inclination orbit [1][2], which covers Brazil entirely.

To determine the relative detection efficiency of BrasilDAT as compared to LIS, we start with a list of all LIS flashes in the region from 50 degrees south to 10 degrees north latitude and from 85 degrees west to 35 degrees west longitude. We then search for a corresponding stroke from the BrasilDAT network that is within 20 km radius of the center of the LIS flash and within 100 milliseconds prior to the start of the LIS flash through to 100 milliseconds after the duration of the LIS flash. The relative detection efficiency is defined as the ratio of the number of LIS flashes that had a coincident BrasilDAT flash to the total number of LIS flashes.

The analysis of BrasilDAT relative detection efficiency versus LIS is compared to the sensor baseline and integrates sensor up-time and siting metrics to provide a normalized detection efficiency of the network.

B. The Theoretical Detection Efficiency

The density of sensors impacts the detection efficiency of lightning location networks. Analyzing the relationship between sensor density and detection efficiency in other deployed networks gives us an idea of what we could expect in other geographies. A theoretical model of the detection efficiency of the BrasilDAT network can be assessed based on data from ENTLN network deployed in Guinea, Africa. The network in Guinea, Africa is a network of 12 sensors installed on cell towers.

An analysis of the detection efficiency of the Guinea ENTLN network relative to LIS was performed for the time period of August 2013, through May of 2014. The detection efficiency is calculated for each 1x1 degree grid in the network and compared to the sensor baseline, which is defined as the average distance from the center of each 1x1 degree grid to the closest 5 sensors in the network.

Figure 3 shows the results of comparing the detection efficiency of the Guinea network versus sensor baseline. A fit to the data is shown by the red line and given by the equation **$y = -0.261 \ln(x) + 1.9525$**. By using this equation as a theoretical relationship between sensor baseline and detection efficiency, we can apply this relationship to any other network by calculating a sensor baseline for the given network geometry.

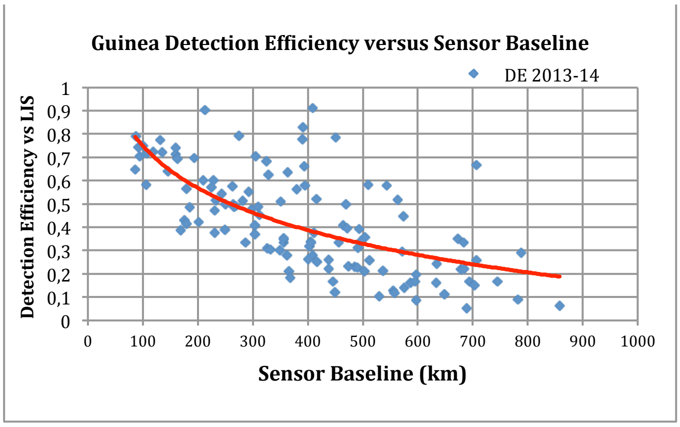

Figure 3. A scatter plot of the detection efficiency of the Guinea network versus the sensor baseline. A curve fit of the detection efficiency versus sensor baseline is plotted in red and given by **$y = -0.261\ln(x) + 1.9525$**.

C. Computations of a Relative Detection Efficiency Model

According to the CIGRE Report [3], there are a numerous factors that affect the detection efficiency of a network:

- Missed events – Very low peak current events (few kA) may not be detected by any sensors and somewhat larger events will be seen by a small number of sensors, but insufficient to obtain an accurate location;
- Variable detection of events – Depending on network geometry, base line and status of the sensors, intermediate-size events (several kA) can be seen by a sufficient number of sensors to obtain a location for some positions in the network, but not all;
- Consistent detection – Normally large events (tens of kA) radiate electromagnetic signals that are large enough to cross threshold at all sensors within several hundreds of kilometers. Thus, 4 or more sensors can always see those events. It is also important to consider the effect of very high peak current events on the network detection efficiency. These large events may saturate one or more nearby sensors, or may produce a complex waveform that is not properly detected by nearby sensors. This can lead to poor detection of large events when the network is small (has only a few

sensors). Although the numerical effect in detection efficiency resulting from missing such large events is small due to the low probability of occurrence, these large events can be the most important to detect because of their potential for severe damage.

In conclusion, variations in the network detection efficiency can be highly significant due to sensors faults, communication issues or unfavorable network geometry. Thus, one practical way to evaluate variations in BrasilDAT detection efficiency is the use of a numerical model [4].

The most recent version of the BrasilDAT model (RMED4) has the ability to better reproduce the network dynamics, particular for a spatially non-homogenous network sensor configuration [5]. The RMED4 takes into account the propagation effects to simulate the electromagnetic radiation attenuation from the source to the sensor by using detection efficiency distributions for each individual sensor as a function of the distance and the azimuth. Also, closer to the network boundaries, most of the sensors are required to provide a lightning solution, which causes an artificial increase of the relative detection efficiency over these outermost areas. The new RDEM4 neglects these types of solutions in a more consistent way compared to the previous versions. This consistency is achieved not only checking the minimum number of required sensors but also the peak current range and the distance from the sensors, which provides much more realist results, particularly in the outermost areas.

Thus, the new RDEM4 will be applied to the BrasilDAT lightning dataset in order to evaluate its relative detection efficiency over the whole coverage area.

III. Results

A. *Comparing BrasilDAT to LIS*

The comparison of BrasilDAT to LIS was performed for the years 2011 through 2013 and various analyses were performed. Figure 4 shows the average detection efficiency of BrasilDAT for all land areas of Brazil by year. The average detection efficiency over all land areas will be relatively low because the network is concentrated in the eastern part of Brazil. Detection efficiencies are higher in the states of São Paulo, Minas Gerais, Esperito Santo and Rio De Janeiro because these are the states contain the largest number of sensors. Detection efficiencies are lower in Amazonas, Acre and Amapa because these states contain no sensors.

Figure 5 shows the BrasilDAT detection efficiency broken down by state. States in the east, such as São Paulo, Minas Gerais, Esperito Santo and Rio de Janeiro have detection efficiencies on the order of 30 to 40%, while western states such as Amazonas, Acre and Amapa have detection efficiencies on the order of 10%. The Brazilian states with their abbreviations are shown in Figure 6.

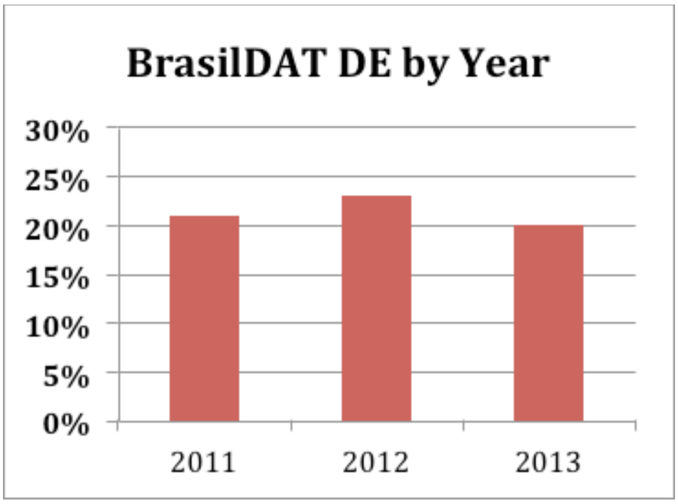

Figure 4. BrasilDAT detection efficiency (DE) versus LIS by year.

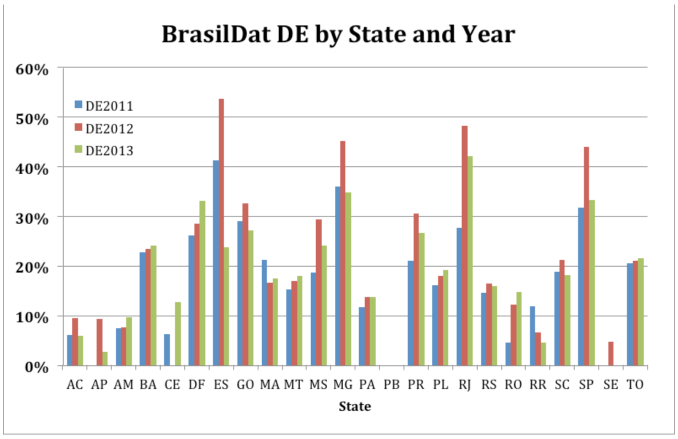

Figure 5. BrasilDAT detection efficiency versus LIS by State / year.

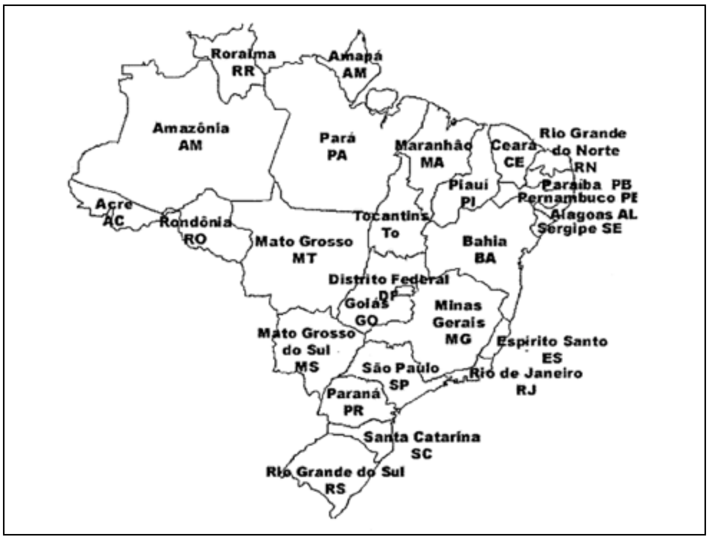

Figure 6. Map of Brazil with states labeled along with their abbreviations.

The spatial distribution of the BrasilDAT detection efficiency versus LIS for the year 2013 can be seen in Figure 7. Detection efficiencies are greater in the east where the sensor baselines are shorter. In the east, detection efficiencies are approaching 50 percent, and falling off to less than 10% as you extend out from the center of the network. The northwest portion of South America has higher detection efficiencies due to the influence of other ENTLN sensors deployed in northwest South America and southern Central America. The detection efficiency shown on the map in Figure 7 does not include flashes detected, by the Earth Networks Global Lightning Network (ENGLN) data. ENGLN is a combination of data from regional total lightning networks (ENTLN) and the World Wide Lightning Location Network (WWLLN). The WWLLN is a VLF network operating in the range 3-30kHz that uses the time of group arrival (TOGA) method to locate lightning.

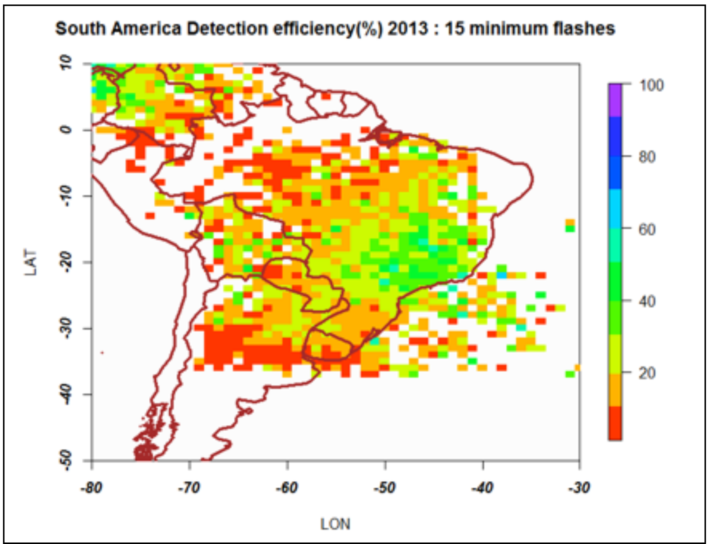

Figure 7. BrasilDAT detection efficiency spatial distribution for 2013.

Figure 8 shows the detection efficiency in Brazil based on a combination of the BrasilDAT and GLN networks. Data from BrasilDAT and GLN are combined by removing solutions from GLN which are considered to be duplicate in time and space. As can be seen from the maps, the detection efficiency in eastern Brazil is dominated by the influence of the BrasilDAT network and is improved in the west of Brazil where there are no sensors installed and the detection efficiency of BrasilDAT falls off. By including solutions from the GLN network, detection efficiencies are seen to be on the order of 10 to 20% in the Amazon region.

B. *The Theoretical Detection Efficiency*

As discussed in Section IIB, the average sensor baseline (a measurement of the sensor density) impacts the detection efficiency of the network. Figure 9 shows a map of sensor baseline for the BrasilDAT network in 2013 based on installed and reporting sensors.

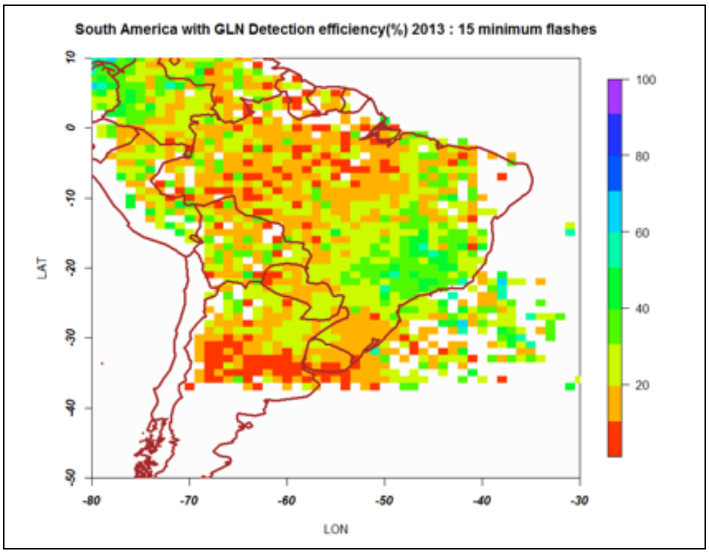

Figure 8. GLN detection efficiency spatial distribution for 2013.

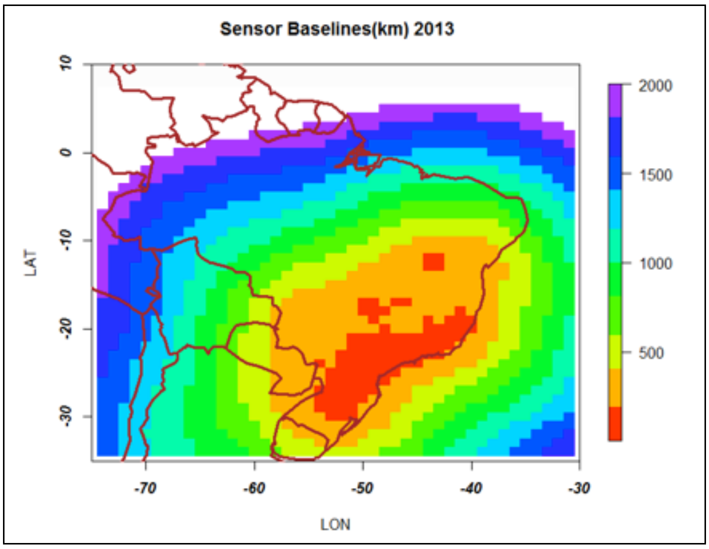

Figure 9. A map of sensor baselines in meters as calculated by finding the average distance to the closest 5 sensors in the network.

By analyzing the spatial distribution of a network's relative detection efficiency versus LIS and the sensor baseline, we can understand the relationship between a network's sensor density and expected detection efficiency. Figure 10 shows a theoretical model (as described in Section IIB) of the detection efficiency of the BrasilDAT network based on data from ENTLN network deployed in Guinea, Africa. Data was analyzed for the timeframe of October 2013 through May 2014.

As can be seen by comparing the theoretical and actual detection efficiency of BrasilDAT, we are seeing lower than expected values of detection efficiency. There can be several reasons for this discrepancy including things outside of our control, such as different vegetation, soil conductivity and land elevation. Poor siting of sensors or background electromagnetic noise can also interfere with optimal sensor operation and decrease the amount of lightning seen by the

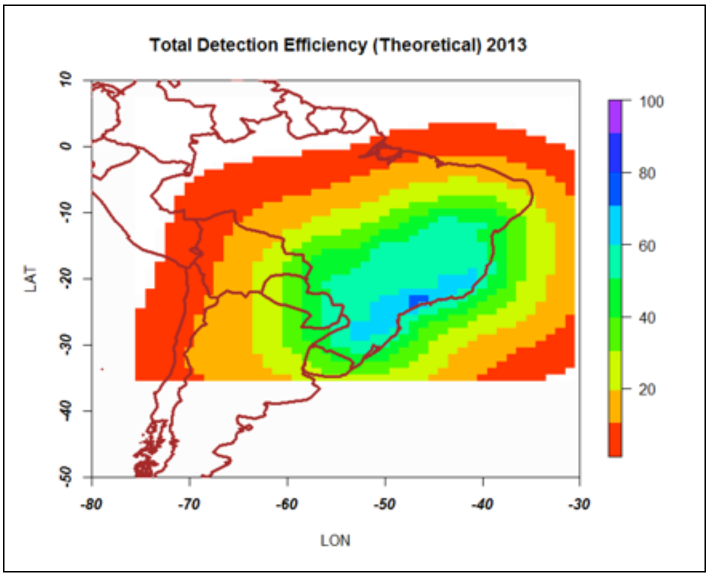

Figure 10. Theoretical detection efficiency of BrasilDAT based on the relationship of detection efficiency versus sensor density for the ENTLN network in Guinea, Africa

sensors. Because the LIS satellite is a low earth orbit satellite, the duration of time that the satellite sees lightning in an area changes rapidly over time. If the satellite is passing over a storm at the same time that the network is having communications issues, the detection efficiency can be lower, but it will be unrelated to the effectiveness of the sensors.

By comparing the measured detection efficiency versus the sensor baseline, we can produce a Sensor Baseline versus Detection Efficiency graph as seen in Figure 11. This Figure shows a scatter plot of the detection efficiency of BrasilDAT versus the sensor baselines for the network for the years 2011 through 2013. The graph also shows a 50 per moving average of the baseline for each year and a line showing the best fit of a similar analysis performed on the ENTLN Guinea, Africa network. Detection efficiencies for BrasilDAT are not following those observed in the Guinea network and are expected to be much higher.

C. *Computations of a Relative Detection Efficiency Model*

As described in Section IIC, the RDEM4 was applied to the BrasilDAT lightning dataset (timeframe of January 2014 through March 2014) in order to evaluate its relative detection efficiency over the whole coverage area.

Figure 12 shows the individual DE distribution for one sensor of BrasilDAT provided by the RMED4 taken into account the hourly reports of the sensor status. The DE curves obtained by RMED4 are computed as a function of three variables: peak current, distance and angle. Different intervals can be applied to each variable, leading to different detail levels. Those features allows the model to better reproduce the dynamics of each sensor and consequently the dynamics of the whole network in terms of signal propagation effects.

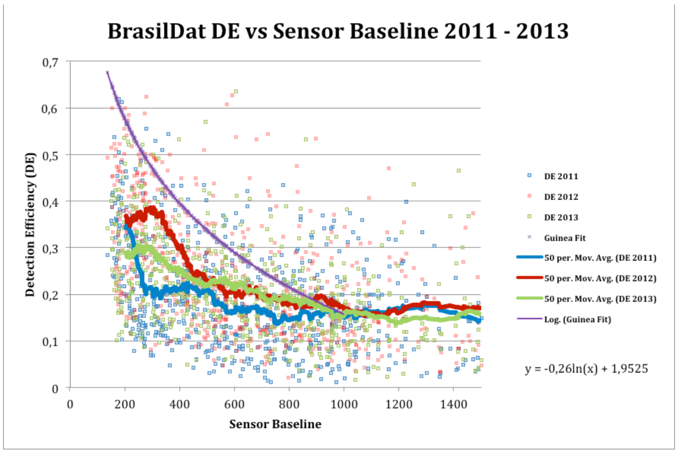

Figure 11. Scatter plot of the BrasilDAT Detection Efficiency versus Sensor Baseline for 2011 to 2013 and the comparison to the Guinea ENTLN.

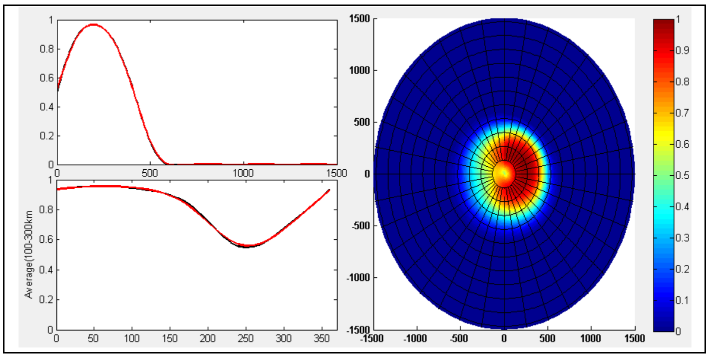

Figure 12. Example of individual DE sensor distribution (as a function of distance, azimuth and peak current) computed by RMED4, which takes into account the hourly reports of the sensor status..

After computing the individual DE distributions for each sensor (shown in Figure 12), the whole network DE is calculated creating a DE spatial map for the whole network. Using those sensor distributions together with the hourly operation status of the sensors, it is possible to daily compute the overall network DE leading to high accurate analysis. The DE distribution map of Figure 13 were created based on the hourly sensor status reports, essential sensors filtering, sensor DE distributions as a function of distance and azimuth integrated to all peak current ranges.

The RDEM4 simulation results for BrasilDAT (Jan/2014 to Mar/2014) agrees very well with the DE computed from LIS comparison. According to each sensor relative detection efficiency curve (which measures the sensor performance as function of distance and bearing), roughly 40% of all BrasilDAT sensors have a low performance that might be caused by background noise or frequent communication issues. Figures 14 and 15 illustrate an example of good and bad sensor performance, respectively.

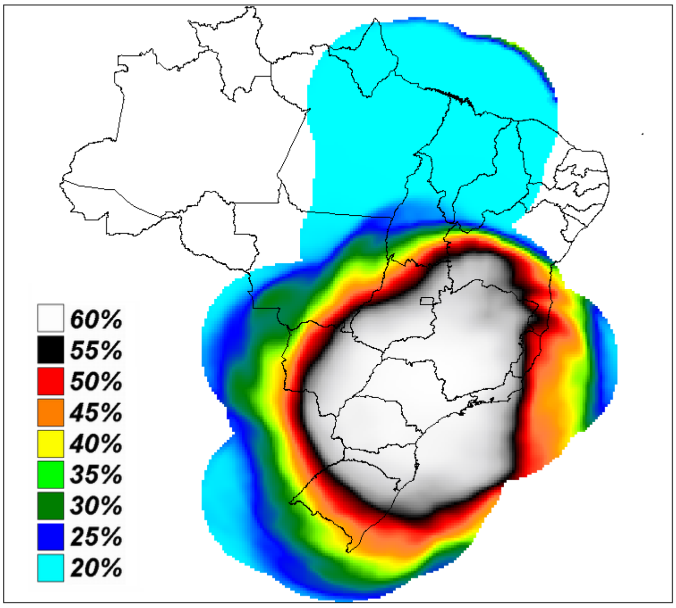

Figure 13. Spatial distribution of BrasilDAT network's detection efficiency computed by the RDEM4.

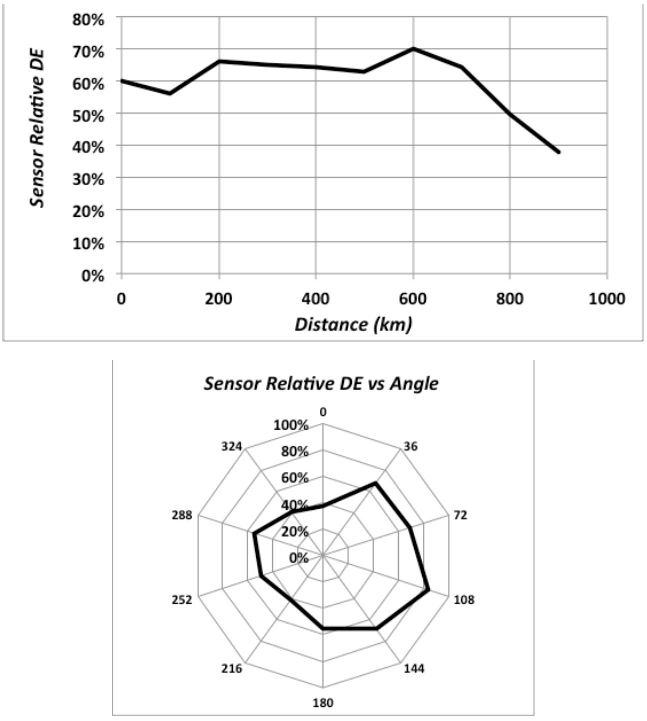

Figure 14. Example of relative detection efficiency curves (as a function of distance and bearing) for a good performancing sensor.

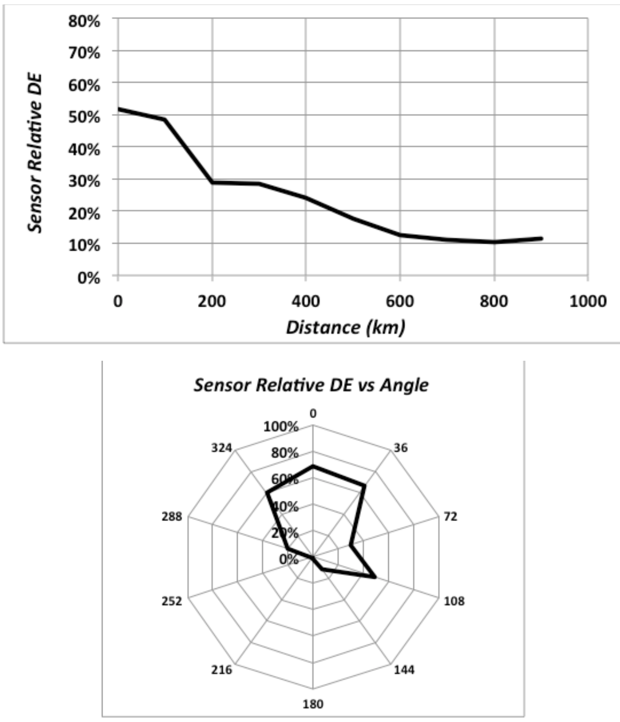

Figure 15. Example of relative detection efficiency curves (as a function of distance and bearing) for a bad performancing sensor.

IV. CONCLUSIONS

Based on our analysis of the detection efficiency of BrasilDAT versus LIS and on the results of the RDEM4 simulations, we can see that the network is still not performing at expected levels as compared to the performance of other isolated networks. From what we can tell, after analyzing each sensor waveforms and its relative DE curves, the biggest issue is with the siting of the sensors or some level of background noise or other problems that are making the signal to noise ratio very poor. This analysis shows that we really need to look at each individual sensor and try to figure out what's causing low detection efficiency at some particular sites.

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