Sferics Timing And Ranging NETwork – STARNET: 8 years of measurements in South America

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ABSTRACT: This study presents a short summary of 8 years of STARNET measurements since its deployment in 2006. Nowadays, STARNET is working with 11 VLF antennas over Brazil, Argentina, Gaudeloupe and Cape Verde. With the current configuration, STARNET is able to measure lightning over South America with a location accuracy that varies from 2-10km in South America and around 20 km in the ITCZ. By analyzing the sferics distribution in South America it is possible to identify the hot spots that are localized at Maracaibo, northern Argentina, Paraguay, Bolivia and Brazil. In Brazil, the hot spots are found at regions bounded by the Amazon basin, i.e., Manicoré and Tapau in Amazonas, Altamira in Pará, Parque Nacional do Araguaia at Tocantins and Paranatinga at Mato Grosso.

INTRODUCTION

STARNET (Sferics Timing and Ranging Network) is a Very Low Frequency (VLF) long range lightning detection network that measures the radio noise emitted by atmospheric discharges, known as sferics. The sferics waveforms bounce in the waveguide bounded by the ionosphere and the earth surface and create sky waves that can be detected at several thousands of kilometers at VLF (Lee, 1986; Morales, 2001).

In early 1990´s Resolution Display Inc. was awarded a NASA Small Business Innovative Research (SBIR) grant (***NAS5-32825***) to develop a long range VLF lightning detection network based on the previous work of Lee (1986) and incorporate the recent technological advances of that time, i.e., internet, GPS and personal computers (PC). These advancements, aloud the possibility to transmit all sferics measurements, get a better time precision (90 ns) and make a simple and reliable system to be deployed. In 1997, the experimental STARNET prototype was deployed in the east coast of US (Rhode Island, Virginia, Alabama, Florida) and Puerto Rico for a proof of concept (Morales, 2001) and operated until 1998.

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STARNET measures continuously the vertical electric field in the range of 7-15 kHz and the system is designed to detect up to 130 sferics per second. Through a series of filters and compression schemes at the PC, the sferics waveforms contained on 4.4 ms window are compressed and stored on 16 seconds files which represents files of 40-60 kbytes that are transmitted to a central computer. To determine the sferics position, STARNET uses the arrival time difference (ATD) technique (Lee, 1986) that requires at least 4 VLF antennas to not have an unbiguous solution. To compute the ATDs, sferics waveforms measured by a pair of VLF antennas are time cross-correlated in a 1024 millisecond time window and only the the ATD that have a r^2 greater than 0.99 are accepted. Later in 2007, a polarity algorithm based on ELF components of the VLF signal (Morales et al., 2007) has been implement. Therefore, besides sferics position, polarity measurements are also available at STARNET.

STARNET locating algorithm is set as continent/network configurations that requires a minimum of 4 antennas and a maximum of 9. The present algorithm can hold up to 30 different network configurations, thus providing a integration possibility for different networks, such as the done with STARNET and ZEUS during the AMMA project in 2006 (www.eol.ucar.edu/**projects**/**amma**.../**ZEUS**_popular_summary_2006.pdf). If one sferics has been detected by different continental solutions, the sferics that has the lowest ATD errors is selected as a final solution.

STARNET was initially deployed in August of 2006 with 2 sensors in Brazil (Fortaleza and São Paulo), 1 in Guadeloupe (Caribbean) and integrated with the 4 antennas installed in African continent (Nigeria, Ethiopia, Tanzania and South Africa). The Brazilian sensors were acquired by R&D COELCE project, while at Guadeloupe by University of Nevada at Las Vegas and the African sensors through a NSF grant. In 2007 the Nigerian sensor was moved to Campo Grande, Brazil. In 2008 an antenna was installed in São Martinho da Serra (Rio Grande do Sul, Brazil) due to a CNPq grante, while in 2009 two more sensors were installed in Brasilia and Manaus (Distrito Federal and Amazon, Brazil) by SIMEPAR and FINESP/UFAM/SIPAM. In 2012 a VLF antenna was deployed at Belém (Pará, Brazil) (FINEP/UFPA/SIPAM), in 2013 at Ilhéus (Bahia-Brazil), Cape Verde (COELCE) and Trellew (Argentina) (STORM-T/USP). Based on this configuration STARNET is currently working with 11 VLF antennas that cover South America and part of the Atlantic ocean, Gulf of Mexico and Caribbean, Figure 1.

For this study, we initially present a summary STARNET evaluation (Morales et al. (2014) and later we show some of the lightning signatures observed by STARNET along these 8 years of measurements.

Figure 1. Location of STARNET VLF receivers in 2013

STARNET SUMMARY

STARNET was evaluated against Brazilian lightning detection network (RINDAT) (Naccarato et al., 2006), World Wide Lightning Location Network (WWLLN) (Holzworth et al., 2004), Lightning Imaging Sensor (LIS) (Boccippio et al., 2002) on board the Tropical Rainfall Measuring Mission (TRMM) satellite and Vaisala GLD360 network (Demetriades et al., 2010), according to Morales et al. (2014). In this study it was possible to find that the theoretical simulations for location accuracy agreed are within the intercomparisons, Table 1, i.e., STARNET location accuracy is between 5 and 10 km over most of South America and above 20 km in the Atlantic Ocean and Caribbean, since RINDAT has an expected location accuracy of 0.5-2 km (Naccarato et al., 2003), WWLLN around 10 km (Holzworth et al., 2004), GLD360 around 2 km over the United States (Demetriades et al., 2010) while LIS should be arund 10 km (Boccippio et al., 2002).

For detection efficiency (DE) thought, with 2013 data, STARNET measures mainly more than 70% of the RINDAT strokes in their best coverage area, and it presents a day (***85%***) and night (***45%***) detection efficiency oscillation. When compared with GLD360, it was observed that STARNET detects more than 10% of GLD360 at the ITCZ, 70% over the Amazon, 90% at Tocantins and 75% over Bolivia, Morales et al. (2014). Nonetheless, the DE varies according to the number of sensors available during the location, Figure 2. For instance, when 9 stations are available for lightning location STARNET is measuring more than RINDAT in 90% of the time, but when it uses only 7 it drops to 70%, with 6 at 50% and with 5 at 40%. Thus the number of available sensor is key parameter in the determination of a lightning location, because the

location algorithm rejects solutions that high ATD errors, so when more sensors are available and observe the same event it does not reject an initial solution because several antennas are measuring the same event.

TABLE 1. MEAN LOCATION DIFFERENCE AND NUMBER OF COINCIDENT MATCHES BETWEEN STARNET AND RINDAT, LIS, WWLLN AND GLD360.

Systems-Domain	Location Difference (km)	Number of Matches
RINDAT	**8.43**	**306,875**
LIS – ALL Domain	**22.08**	**22,956**
LIS – Brazil	**19.23**	**6,538**
WWLLLN	**12,1**	**6,260,900**
GLD360		
01S-09N and 27-17W	**26.66**	**87,597**
08S-02N and 65-55W	**11.13**	**728,870**
15S-05S and 53-43W	**7.58**	**1,345,711**
21S-11S and 70-60W	**12.15**	**1,752,731**

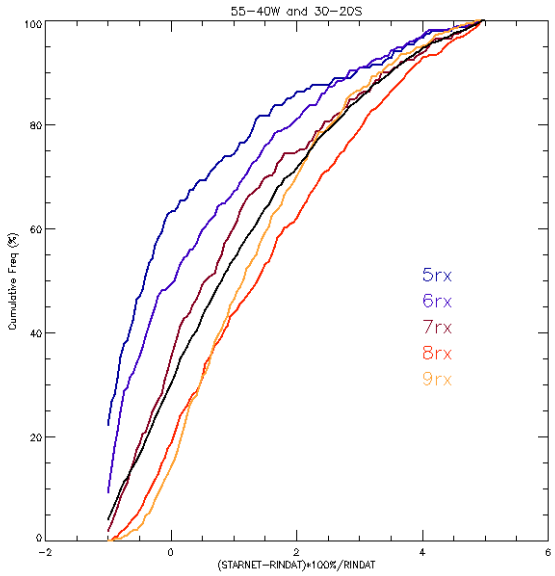


Figure 2. STARNET detection efficiency as compared against RINDAT during 2013 as a function of the number of available sensors.

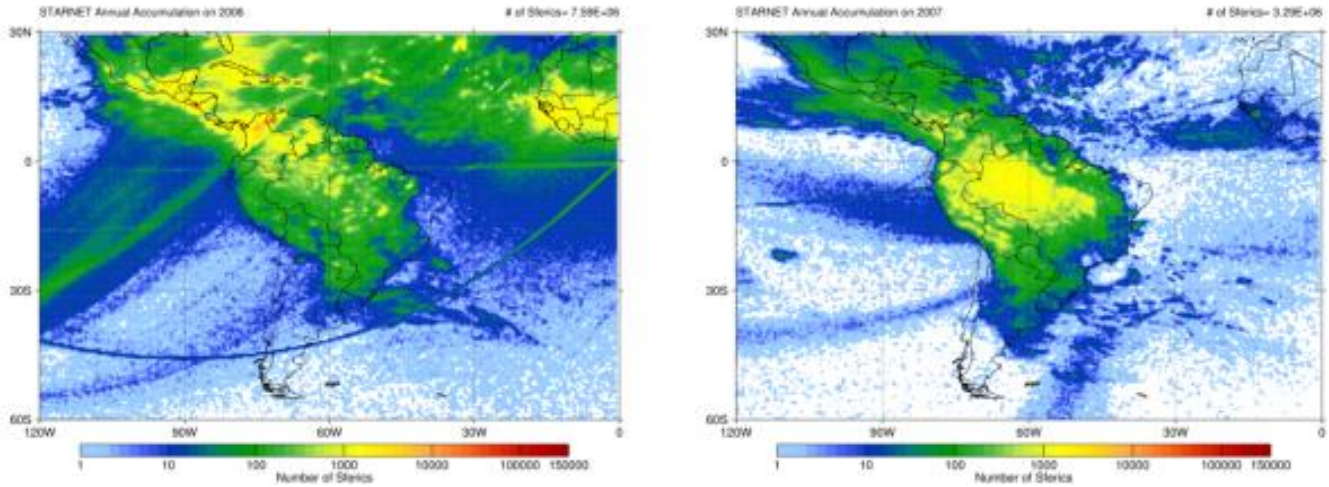
CLIMATOLOGY

During this 8 years of operation, STARNET was able to detect lightning over South and Central America, Caribbean and the Atlantic ocean, Figure 3. By combining with Table 2, we can

see that by increasing the number of sensors the DE and coverage area increases In 2006, the network was in the northeast of Brazil, Caribbean and in Africa and it was able to monitor the lightning activity of the second semester in Africa. With the upgrades that initiated in 2007, STARNET focused only in South America with special attention to Brazil. As a consequence, most of the lightning activity of STARNET concentrated at the Amazon basin and central part of Brazil. After 2009, it was possible to the detect more sferics at south of South America and in 2013 with the Argentinan sensor, it was possible to observe the intense lightning activity in northern Argentina, Paraguay, and Bolivia. In looking the map of 2013, it is possible to identify the hot spots as Lake of Marcaibo at Venezuela, Amazon basin, including Amazonia, Pará, Tocantins and Mato Grosso.

TABLE 2. NUMBER OF SFERICS MEASURED BY STARNET SINCE 2006.

Year	Sferics Measured
2006	7,585,405
2007	3,290,597
2008	17,204,274
2009	123,394,328
2010	45,015,908
2011	36,768,128
2012	62,397,672
2013	180,928,944



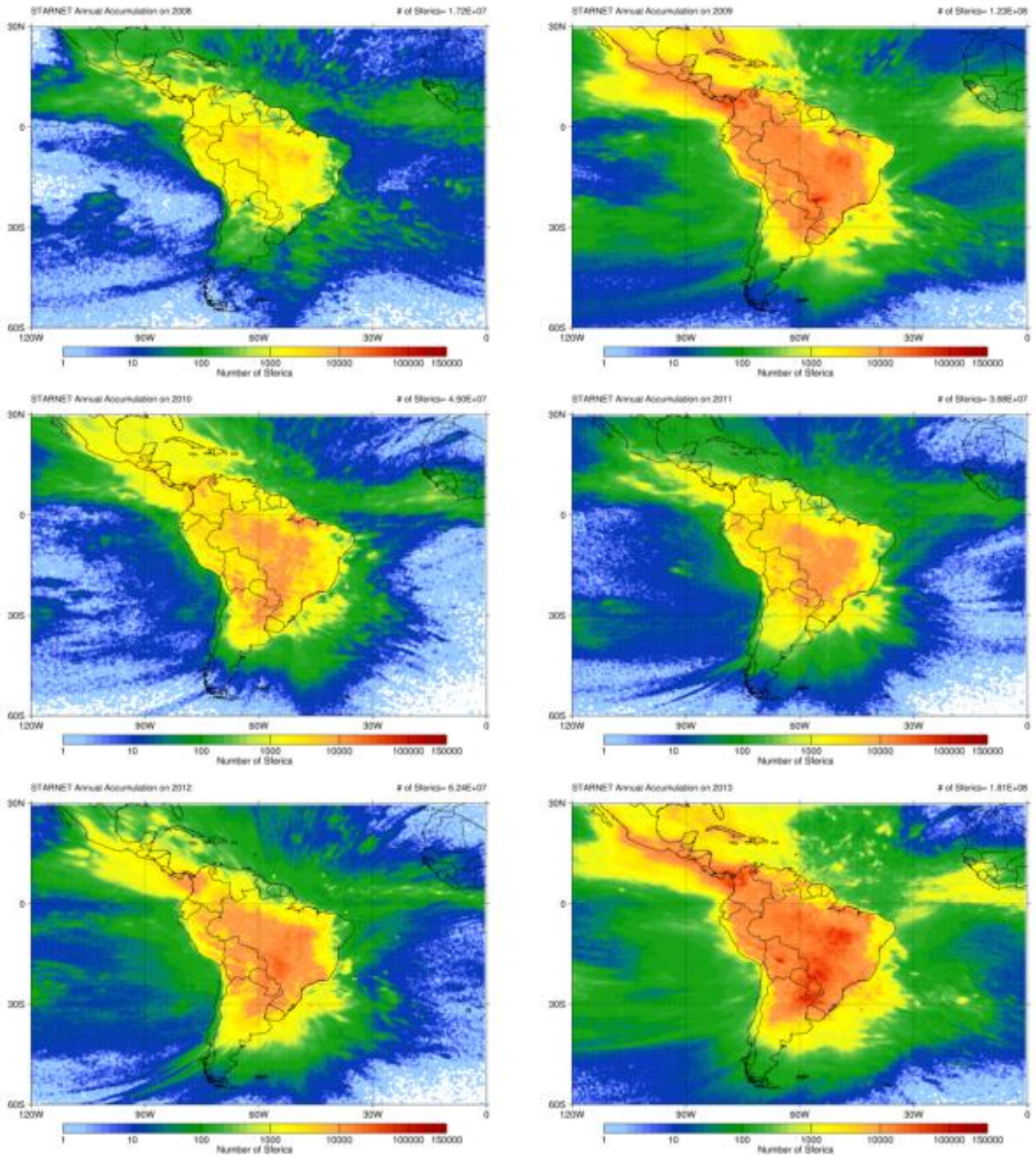


Figure 3. Annual sferics distribution from 2006 through 2013 as observed by STARNET.

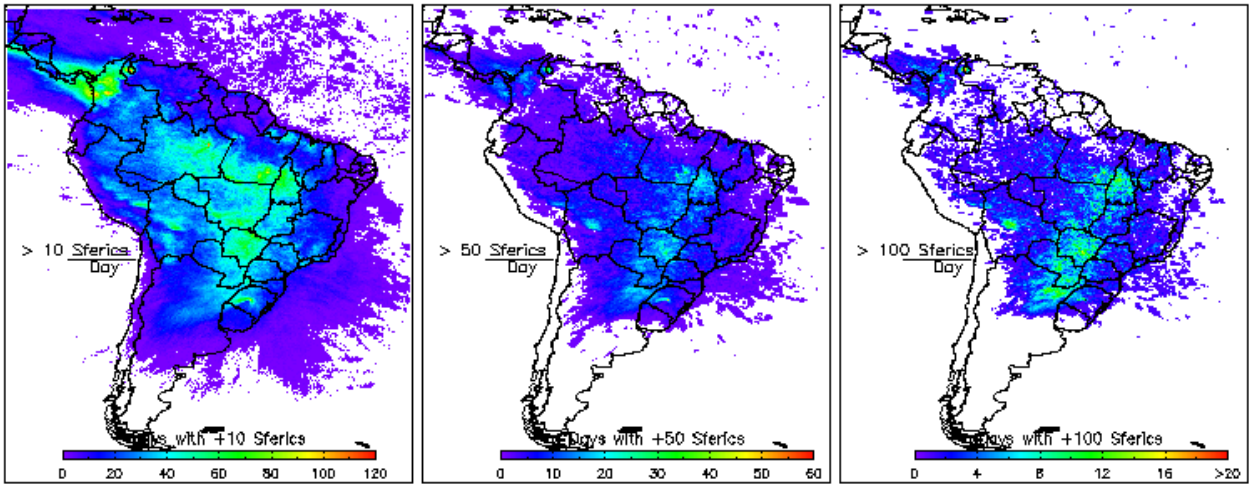


Figure 4. Number of days with more than 10 sferics, 50 and 100 sferics per day over 0.1 ^{o} X 0.1^{o} grid boxes during 2013.

Figure 4 shows the number of days in year that had more than 10, 50 and 100 sferics per day in an area of 0.1^{o} X 0.1^{o} during the year of 2013 and it is possible to observe that Maracaibo, northern Colombia, some areas of Amazonia, Tocantins, Mato Grosso, Bolivia, Paraguay and norther Argentina are the regions that have severe thundertorms along the year. These areas are coincident with LIS climatology and are seasonal dependent. While the center and south of South America are summer dependent, the north region shows two season along the year. The first during summer and the other during the transition from dry to wet season. The later is when we found the more profilic thunderstorms (> 100 sferics/day) that are essentially associated with Mesoscale Convective Systems (MCS) or Mesoscale Convective Complex (MCC).

By looking the hotspots by counties (plot not shown), we found that Manicoré and Tapau in Amazonas, Altamira in Pará, Parque Nacional do Araguaia at Tocantins and Paranatinga at Mato Grosso are the cities that have the highest lightning activity and the number of days of thundetstorms over the year.

CONCLUSIONS

This study showed a review of 8 years of STARNET measurements since its deployment if 2006. Previous location accuracy and detection efficiency analysis revealed that STARNET has a location accuracy that varies from 2 to 10 km in South America and ~20 km over the Atlantic ocean. Taking into account GLD360 and RINDAT DE, STARNET is probably detecting more than 70-80% of the sferics over South America if a minimum of 8-9 VLF antennas are available. Futhermore, it is important to state that *All STARNET sferics measurement are publicly released into our website*, http://www.starnet.iag.usp.br (**link ftp**)

ACKNOWLEDGMENTS

This work is partly funded by CAPES PROEX-PROGRAM, CNPq Grants 306900/2012-2, 307886/2009-3 and 476836/2007-7 and COELCE Research & Development project # PD-0039-0040/2010. The authors wish to thank SIMEPAR, SIPAM, USP, UECE, UESC, INMG/Cape Verde, CIRAD/France, CONICET/Argentina, UN at Las Vegas and UConn for supporting the VLF STARNET. The authors wish to thank the World Wide Lightning Location Network (http://wwlln.net), RINDAT, SIMEPAR, FURNAS, MSFC/NASA and Vaisala for providing a comprehensive lightning validation dataset for STARNET evaluation.

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