São Paulo Lightning Mapping Array (SP-LMA): Network Assessment and Analyses for Intercomparison Studies and GOES-R Proxy Activities

J. C. Bailey[1*], R. J. Blakeslee[2], L.D. Carey[1], S. J. Goodman[3], S.D. Rudlosky[4], R. Albrecht[5], C. A. Morales[6], E.M. Anselmo[6], J.R. Neves[7], D.E. Buechler[1]

1. University of Alabama in Huntsville, Huntsville, Alabama 35899, USA
2. NASA Marshall Space Flight Center, Huntsville, Alabama 35812, USA
3. NOAA/NESDIS/GOES-R Program Office, Greenbelt, MD 20771 USA
4. NOAA/NESDIS/SCSB, College Park, MD 20740 USA
5. Instituto Nacional de Pesquisas Espaciais, Cachoeira Paulista, SP Brazil
6. Universidade de São Paulo, São Paulo, SP Brazil

ABSTRACT: A 12 station Lightning Mapping Array (LMA) network was deployed during October 2011 in the vicinity of São Paulo, Brazil (SP-LMA) to contribute total lightning measurements to an international field campaign [CHUVA - ***C***loud processes of t***H***e main precipitation systems in Brazil: A contrib***U***tion to cloud resol***V***ing modeling and to the GPM (Glob***A***l Precipitation Measurement)]. The SP-LMA was operational from November 2011 through March 2012 during the Vale do Paraíba campaign. Sensor spacing was on the order of 15-30 km, with a network diameter on the order of 40-50km. The SP-LMA provides good 3-D lightning mapping out to 150 km from the network center, with 2-D coverage considerably farther. In addition to supporting CHUVA science/mission objectives, the SP-LMA is supporting the generation of unique proxy data for the Geostationary Lightning Mapper (GLM) and Advanced Baseline Imager (ABI), on NOAA's Geostationary Operational Environmental Satellite-R (GOES-R: scheduled for a 2015 launch). These proxy data will be used to develop and validate operational algorithms so that they will be ready to use on "day1" following the GOES-R launch. As the CHUVA Vale do Paraíba campaign opportunity was formulated, a broad community-based interest developed for a comprehensive Lightning Location System (LLS) intercomparison and assessment study, leading to the participation and/or deployment of eight other ground-based networks and the space-based Lightning Imaging Sensor (LIS). The SP-LMA data is being intercompared with lightning observations from other deployed lightning networks to advance our understanding of the capabilities/contributions of each of these networks toward GLM proxy and validation activities. This paper addresses the network assessment including noise reduction criteria, detection efficiency estimates, and statistical and climatological (both temporal and spatially) analyses for intercomparison studies and GOES-R proxy activities.

∗ Contact information: J.C. Bailey, University of Alabama in Huntsvillle, Alabama, USA, Email: jeffrey.c.bailey@nasa.gov

1. INTRODUCTION

1.1 ***Background***

The next generation NOAA Geostationary Operational Environmental Satellite-R (GOES-R), presently under development and scheduled for a 2015 launch, will offer improved observing capabilities to monitor, track, and predict weather that include the Geostationary Lightning Mapper (GLM) and the Advanced Baseline Imager (ABI) instruments. The GLM, building on the heritage of the NASA Optical Transient Detector (OTD) and the Lightning Imaging Sensor (LIS), will detect *total* lightning (i.e., both ground and cloud flashes) with storm scale resolution (i.e., on the order 8-12 km), high detection efficiency, and millisecond timing [Boccippio et al., 2002; Christian et al, 1992; Christian et al., 2003]. The ABI is a visible and infrared imager that offers significant improvements over the current generation of GOES imager in spectral-band coverage, spatial resolution, and frequency of sampling.

Proxy data, which play an important role in the mission preparation phase, are employed to develop and validate operational algorithms so that they will be ready for use on "Day 1" following the launch of GOES-R. In developing proxy data products for GLM, several existing lightning measurement systems are being used, ranging from the space-based LIS to a variety of ground-based detection networks. Lightning Mapping Array (LMA) network data are of particular interest since these networks also detect *total* lightning, which the GLM will detect. LMA is a regional lightning detection system [Goodman et al., 2005] that deploys 9 to 12 VHF receivers to provide 3-D mapping of lightning channels (i.e., 3-D mapping out to about 150 km from center of the LMA network, 2-D detection out to 250+ km, with diminishing detection efficiency with distance). Since LMA detects different processes in a flash than GLM (i.e., LMA detects optically weak breakdown processes, GLM will detect energetic, optically bright return strokes and recoil streamers), LIS data, which is similar to what GLM will detect, is used to tune LMA observations to produce a total lightning GLM proxy data set.

1.2 ***Target-of-Opportunity***

A target-of-opportunity to acquire unique proxy data for GLM and ABI presented itself in Brazil during the period November 2011 through March 2012 in association with the international CHUVA field campaign. The focus of CHUVA is revealed in the campaign title: "***C***loud processes of t***H***e main precipitation systems in Brazil: A contrib***U***tion to cloud resol***V***ing modeling and to the GPM (Glob***A***l Precipitation Measurement)." The new understanding of cloud processes and precipitating systems gained from this experiment will contribute to improved precipitation retrievals for tropical storm systems, which has direct applicability to the GOES project. To take advantage of this opportunity, a São Paulo LMA (SP-LMA) network was deployed in October 2011 and operated for 5 months in support of CHUVA and GOES-R objectives. Thunderstorms occur regularly at this location and season, associated with the South Atlantic Convergence Zone (SACZ), local convection, and orographic enhancement of precipitation. The measurements obtained from the SP-LMA will provide for the first time total lightning measurements in conjunction with SEVIRI (Spinning Enhanced Visible and Infrared Imager on the Meteosat Second Generation or MSG satellite) observations. As the CHUVA opportunity was formulated, a broad community-based interest developed among lightning providers for a comprehensive lightning location system (LLS) intercomparison and assessments study. Other LLSs included Earth Networks (ENTLN or BrazilDat), LINET, World Wide Lightning Location Network (WWLLN), Vaisala (TLS200 and GLD360), and RINDAT (INPE), STARNET (USP), ATDnet (Met Office). In addition, electric field mills, field change sensors, high speed cameras and other lightning sensors were deployed at selected locations.

2. PROJECT DESCRIPTION

2.1 Instrumentation and Technical Approach

We deployed 12 portable LMA (2nd generation) sites for SP-LMA as shown in Figure 1. As described in Goodman et al. [2005], a LMA system locates the peak source of impulsive VHF radio signals from lightning in an unused television channel (channel 8 for eleven stations, channel 10 for one) by measuring the time-of-arrival of these signals at different receiving stations in successive 80 μs intervals. As these signals are located, an accurate three dimensional channel image is mapped out. Figure 2 schematically illustrates the time-of arrival approaches used with LMA. Global Positions System (GPS) receivers at each station provide both accurate signal timing and station location knowledge required to apply this approach.

Figure 1. Portable LMA detection station

2.2 Network Configuration and Operations

The SP-LMA network configuration is depicted in Figure 3. The CHUVA dual polarization X-band radar was located near São Jose dos Campos. Since a LMA provides good 3-D coverage out to 150 km, this coverage overlapped nicely with the areal coverage of the CHUVA dual polarization radar (especially toward the west). As noted previously, the LMA provides 2-D detections out to 250+ km (and often sees lightning even farther away). The “modus operandi” for SP-LMA was similar to that used by the DC Metro Area LMA in the United States, in which all the stations are connected to the internet for real-time processing and display of decimated data, and post processing of the full data sets. For the latter processing, the full data were either downloaded during low storm activity periods or picked up at the site. During this project, collaborating scientists in the United States monitored, managed and processed the data remotely from the National Space Science and Technology Center (NSSTC) in Huntsville, Alabama, while the Brazilian collaborators provided local maintenance/operation support. We operated parallel servers in the U.S. and Brazil to provide both redundancy and improve local Web access. The SP-LMA was operated from late October 2011 until April

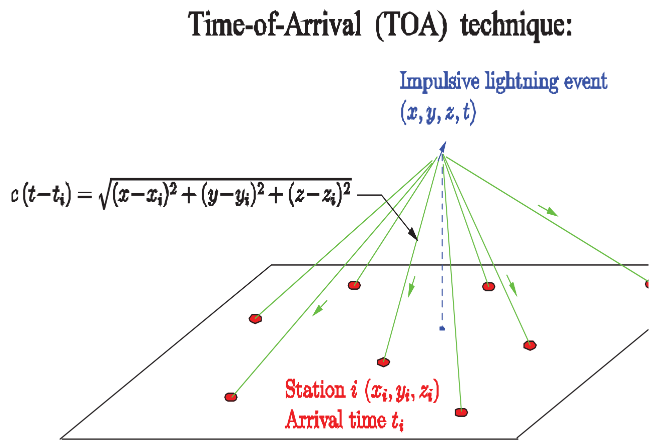


Figure 2. *Illustration of the time-of-arrival method used by the LMA. The times, t_i, when a signal is detected at N≥4 stations are used to solve for the 3-D source location (x, y, z, t) of the impulsive breakdown processes associated with a discharge.*

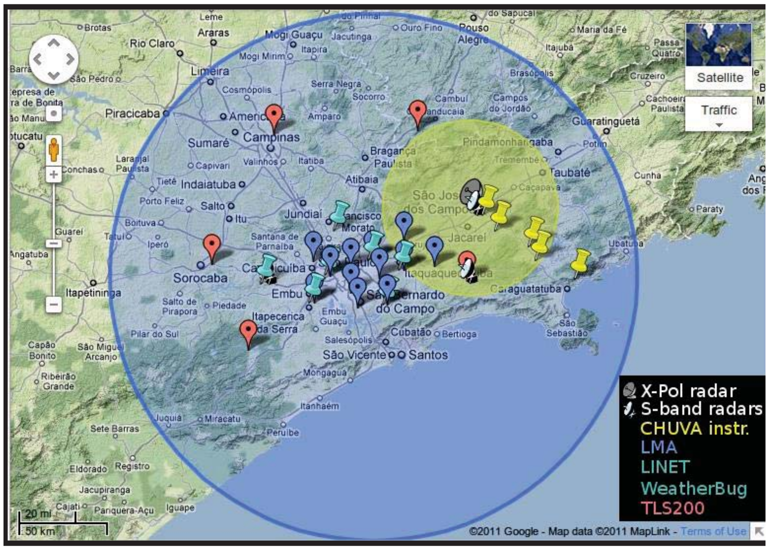


Figure 3. *Location of the SP-LMA stations and some other CHUVA systems. The blue circle represents area of 3-D lightning mapping and the yellow circle shows region of optimum radar. Red flags and yellow "stick pin" are instrument sites. Other S-band radars are shown on either side of the SP-LMA.*

2012 (see Table 1 for start and end dates for each site), when the system was shut down, packed up and shipped back to the United States. There were 11 or 12 active sites (Figure 4) for most of the intensive operation period. The PQC and ARJ (the most eastern site) sites became active in early December. The archived data sets (level 2 was recently submitted) are available from the CHUVA archive for follow-on investigations supporting CHUVA, GOES-R, or other precipitation studies.

3. SCIENCE OBJECTIVES

The primary science objective from a GOES-R perspective is to combine and leverage the observing assets associated with the international CHUVA field campaign (and in particular with the Vale do Paraiba campaign component) with the U.S. supplied portable LMA network to generate and evaluate proxy data sets for GLM and ABI that include simultaneous total lightning and SEVIRI observations. The SEVIRI

Table 1: Dates when sites were activate.

Site	Start Date	End Date
UAB	10/23/2011	04/03/2012
PCT	10/23/2011	04/03/2012
FEI	10/23/2011	04/03/2012
IFP	10/23/2011	04/03/2012
CSP	10/23/2011	04/02/2012
RBP	10/23/2011	03/27/2012
ULE	10/23/2011	03/26/2012
MKZ	11/01/2011	04/03/2012
MGC	11/06/2011	04/03/2012
CSZ	11/07/2011	04/03/2012
PQC	12/05/2011	03/02/2012
ARJ	12/06/2011	03/24/2012

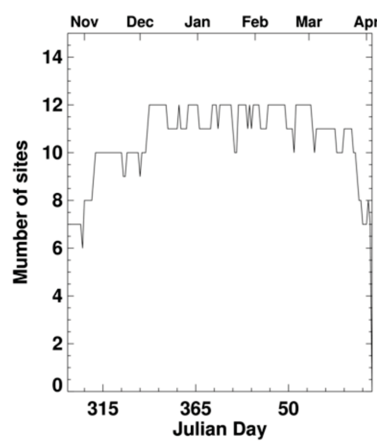


Figure 4: *Number of active sites for each julian day. The months are also given on the top axis. The data starts on October 23rd, 2011 and ends on April 3rd, 2012.*

instrument, with its 12 spectral channels (4 visible, 8 infrared), provides an excellent proxy source for the GOES-R ABI, while the ground-based LMA provides total lightning observations that, when adjusted appropriately, serve as an excellent proxy of what GLM would detect. Research topics being investigated include “Day 1” Algorithm testing/validation, and new products associated with Cell Tracking, Lightning Jump, Quantitative Precipitation Estimation (QPE), Aviation Weather, Lightning Forecast and Warning, as well as combined sensor products. In support of this core objective, and the main focus of the rest of this paper, we provide an assessment, including noise removal, of the SP-LMA network and analyses that can be used to support the intercomparison studies and the GOES-R proxy activities.

From the CHUVA point-of-view, the participation/contribution of the regional SP LMA is to provide total lightning, lightning channel mapping and detailed information on the locations of cloud charge regions for the thunderstorms investigated during the Vale do Paraiba field campaign. Science questions that the LMA data is helping to address in CHUVA include: 1) *How do cloud microphysics and electrification processes evolve during the cloud life cycle?*, 2) *How to improve precipitation estimates and cloud microphysics descriptions by using conventional and polarimetric radar?*, 3) *What is the contribution of aerosol in the process of cloud microphysical development and precipitation formation?*, *and* 4) *What are the average characteristics (3D cloud processes) of the main regimes of precipitation in Brazil?* .

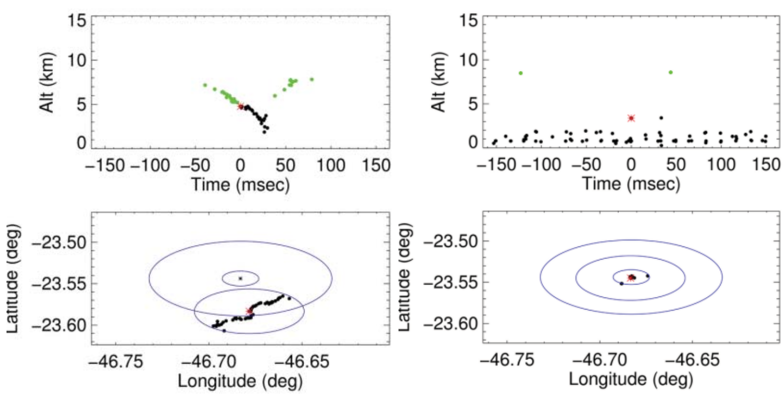
4. ANALYSIS AND DISCUSSION

*4.1 **Network Assessment and Noise Reduction***

After installation of the LMA stations, one strong noise source (designated N1: a TV station on channel 9 located at -46.6830, -23.5438) and one weaker noise source (designated N2: a radio station located at -46.8245, -23.608) were discovered which were not identified during the site survey. N1 was by far the strongest noise source and the majority of its noise tended to be concentrated within 1 km radius from the center of N1 and at altitudes below 2 km. There were several other weaker noise sources but they did not contribute appreciably to the total noise. For the N1 source, we found that the one LMA station operating on channel 10 (closest to the N1 noise source) was less affected by this noise signal than our other LMA stations operating on channel 8. This may be due to the fact that the video carrier, located at a lower frequency in the allotted pass band, has stronger signal than the audio carrier. The N1 noise also contains 60 Hz and higher harmonics that likely come from the TV sync pulse for the horizontal scans.

It is imperative that these noise sources (within 5 km radius of N1 or N2) in the SP-LMA dataset be drastically reduced or eliminated before using this data to calculate general network statistics or intercompare with other systems. If one is only comparing individual flashes, then one may or may not need to reduce the noise, as lightning signals will typically dominate noise in the 80 μs sample window. The noise signals are typically at a lower signal strength than lighting sources, which reduces the impact of noise when thunderstorms are underway in the region. We have found that eliminating data within 1 km of the noise center typically gets rid of more than 90% of the data on an “all noise” (i.e., non thunderstorm) day. On days when there is lots of lightning this procedure only removes about 2% of the data. However, this is understandable as lightning signals dominate the noise (meaning noise makes up a smaller percentage of the total data on active lightning days). When the lightning is located at further distances (approximately ≥ 150 km) from the SP-LMA center, then the above noise sources can cause the site threshold to be larger than the arriving lightning signal (now at a lower amplitude due to propagation effects) and thus start missing some of the weaker lightning sources.

A method was developed for eliminating most of the noise around the N1 and N2 noise locations. For each hour, if there were storms within 15 km of N1 or N2, then for an individual source within 5 km of N1 or N2 and below an altitude of 5 km, the source to be tested is then compared to sources above 5 km as given in Table 2. All sources within 1 km of N1 and below 2 km altitude are removed. Otherwise, if there are 5 or more sources above 5 km that are within ± 165 msec and 3.0 km radius of the source being tested, then the source is kept. If there are 4 or less sources above 5 km then the source is removed. Note that LIS uses a timing window of approximately 330 msec (Mach et. Al., 2007) and McCaul's flash grouping algorithm (McCaul et. al., 2005) uses a range of approximately 3 km for sources close to the network center. This method allows most 'good' flashes (Figure 5a) to be kept while removing most of the noise (Figure 5b).



5a **5b**

Figure 5: *Example of the noise removal procedure for a good flash (left - 02/10/2012 (1841.2667Z)) and all noise (right - 2012-02-14 (1823.1492Z)). Top: Time versus altitude. Time window is ±165 msec centered on the source being tested (red star). Black/green stars are sources below/above 5 km. Bottom: Longitude versus latitude. Range rings of 1 and 5 km are centered on the N1 noise location (black star). A 3 km range ring is centered on the source being tested. For the good flash (left), all of the sources would be kept. For the all noise case (right), all sources below 2.0 km are removed. Additionally, the sources between 2 and 5 km would also be removed because there are only 2 sources above 5 km. The actual noise sources tend to be centered around N1 or N2.*

Table 2: Noise removal constraints for storms within 15 km of N1 or N2

			Compare with sources at altitudes > 5 km		
	Range limit (km)	Altitude limit (km)	Time limit from current point (msec)	Distance from current point (km)	Constraint (applied to data with alt ≤ 5 km)
N1	r ≤ 1.0	alt ≤ 2.0 km	None	None	Remove all data
	r ≤ 1.0	2.0 < alt ≤ 5.0	-165 ≤ t ≤ +165	d ≤ 3.0, alt > 5.0	$N_{>5km}$ ≥ 5 : keep $N_{>5km}$ < 5 : remove
	1.0 < r ≤ 5.0	alt ≤ 5.0			
N2	r ≤ 5.0	alt ≤ 5.0			

If there are no storms within 15 km of one or both noise sources then remove all data within 15 km at all altitudes but do not interfere with the more stringent constraint. For example at 1900 UTC on January

6, 2012 (Figure 6), there are no storms within 15 km of N1 but there are storms within 15 km of N2. N2 has a more stringent constraint, so use the results in Table 2 for N2 and remove all data at all altitudes within 15 km of N1 except do not take out data that is within 5 km of N2.

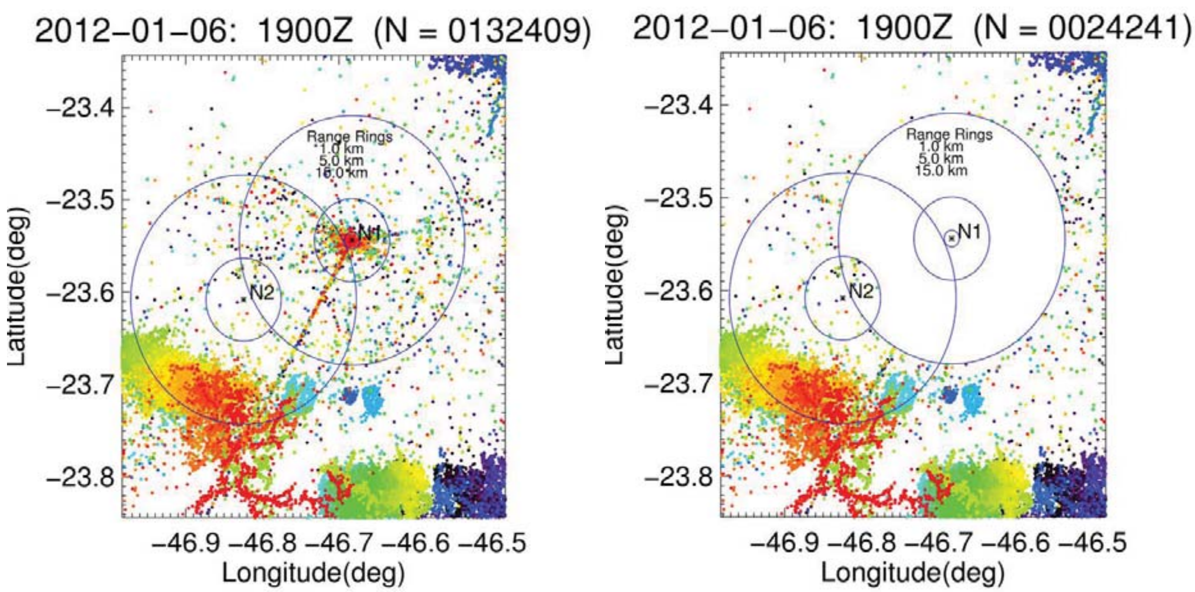


Figure 6: *Example of noise removal algorithm for 1900 to 2000 UTC on January 6, 2012 (left : raw solution data, right : noise removed). Most of the noise that was removed (108,168 sources) was within 1 km of N1. Range rings are 1, 5, and 10 km.*

We believe that the above procedure is best way of reducing the noise in the SP LMA and it is the procedure we have adopted before grouping the data into flashes. In addition, depending on the requirement, we usually also remove flashes that contain 4 or less sources. The great advantage of this approach is that we remove most of the noise without eliminating most of the lower altitude sources from lightning, as these are often useful in identifying cloud-to-ground strokes in a flash. The above criteria are based on histogram plots of the number of sources per flash and plots of the percent noise removed as a function of distance from the noise source (neither one shown in this paper).

Figure 7 provides an example from 27 February 2012 for an hour of SP-LMA observations from 0300 to 0400 UTC, a day with moderate lightning activity and also excessive noise. This presentation format in is referred to as an xlma plot. In this plot format, the top plot corresponds to time (seconds after 1900 UTC) versus altitude. The next "row" has two plots, with the first being altitude versus longitude (left), and the second is activity versus altitude (right), also referred to as the altitude histogram. The final "row" consists of a latitude-longitude plan view map of lightning activity (left) and altitude versus latitude plot (right).This example illustrates how our noise filter procedure described above eliminates noise that would interfere with proper interpretation and intercomparison of the SP-LMA data, while retaining, and not adversely diminishing, the lightning derived events. In this Figure 7, the left panel corresponds to the full data with no noise removed. The right panel is the result with the noise and all flashes with less than 5 sourcess removed. The black/red asterisks in the center of the plan view in the right panel mark the location of N1/N2. N1/N2 are also located by the vertical black/red line in the altitude versus longitude (above the plan view) and the altitude versus latitude (side of plan view) plots in both panels. It is easily observed that the highest percentage of the resulting noise contribution occurs within a short distance from the TV tower (N1). Before applying our "noise filter," the lightning activity histogram with altitude (small square box, second row right in each panel) was dominated by noise events (many at low altitude, close to the TV tower (N1)). Applying the procedure removes the majority of the noise events in the data and results in an altitude histogram in the right panel dominated by lightning events. Removing SP-LMA data

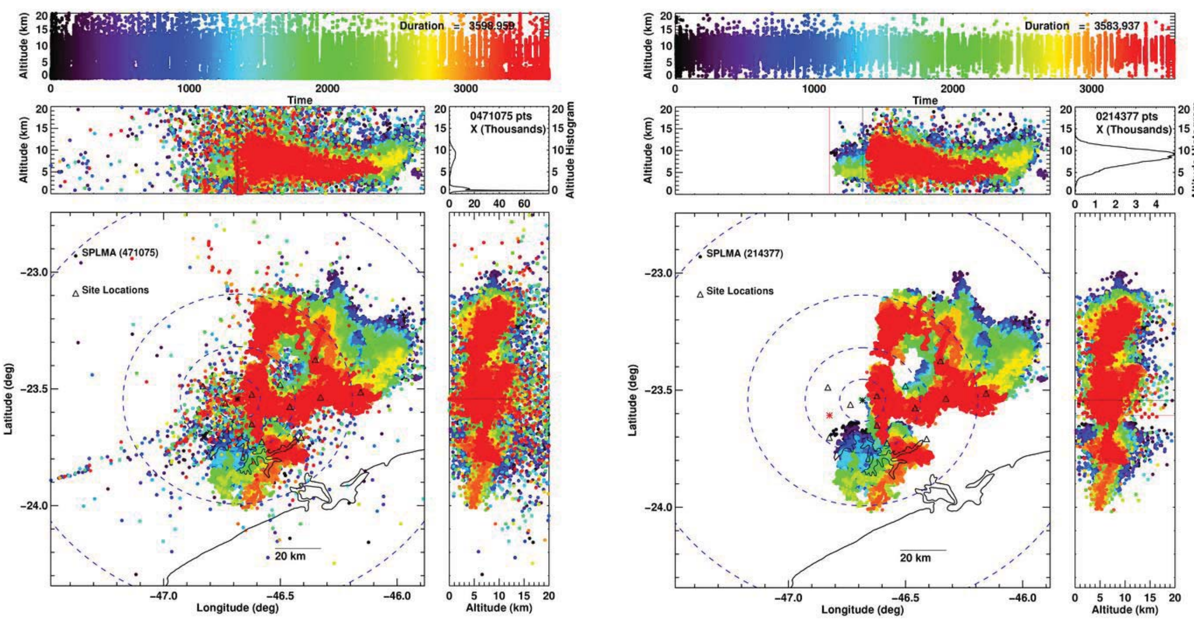


Figure 7: SP-LMA observations on 27 February 2012 from 0300 to 0400 UTC, a day with moderate lightning activity and also excessive noise. Plot on left contains all data, including significant noise events. Plot on right contains mostly lightning events with the noise removed (see text for data that was removed including all flashes containing less than 5 events). Ranges rings are 10, 25, 50, and 100 km centered on N1.

around the N1 and N2 noise sources eliminated 53% (mostly all noise) of the data for this hour. Removing flashes with less than 5 sources eliminated an additional 2% of the remaining data and removed many random scatter flash locations, particularly at higher altitudes.

4.2 ***Analysis and Intercomparisons***

In this section, we provide examples of the SP-LMA data, along with other data sets that will be available to characterize in detail the SP-LMA observations, and support GOES-R proxy activities, LLS network intercomparison studies, and CHUVA precipitation investigations. Figures 8 and 9 show monthly activity plots (all on the same scale) from October 23rd, 2011 to March 31st,, 2012 (The first 3 days of April have some activity but are not shown)). For each panel: we show month versus hour of day (top left), hourly histogram in UTC (top right), day of month histogram (bottom left), and density plot as a function of longitude and latitude (bottom right). The density is the number of sources in a 0.1° x 0.1° grid (~ 10 x 11 km) and has not been corrected for detection efficiency. For the San Paulo area, local standard time = UTC time - 3. The hourly histogram and density are color coded by source count. February and March are the most active months. Local time peak hours are November (1500), December (1500, 1600), January (1500), February (1500, 1700), and March (1600). February and March also have a secondary peak around 2300 local time. There appears to be no significant positional offsets over the 5 month observation period. These activity plots are also very useful for user quick looks (e.g.:

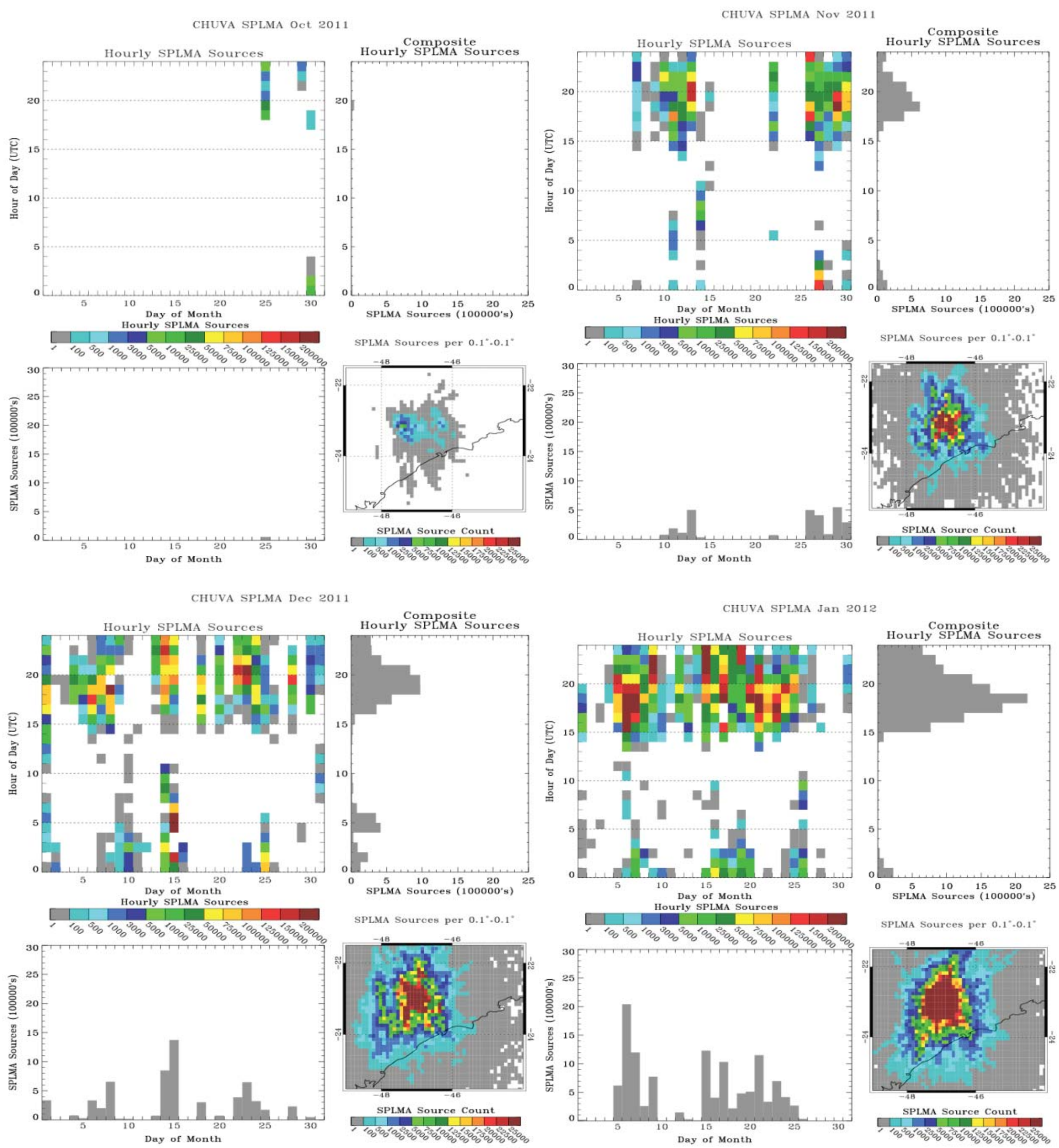


Figure 8: *SPLMA monthly activity plots. Top: October and November, 2011, Bottom: December, 2011 and January, 2012. For each plot: Top left (month versus hour of day color coded by hourly sources), Top right (UTC hourly histogram: local=UTC-3), Bottom left (Day of month histogram). Bottom right (Density plot as a function of longitude and latitude color coded by source count). All the scales are the same in each panel.*

what days and hours should one use).

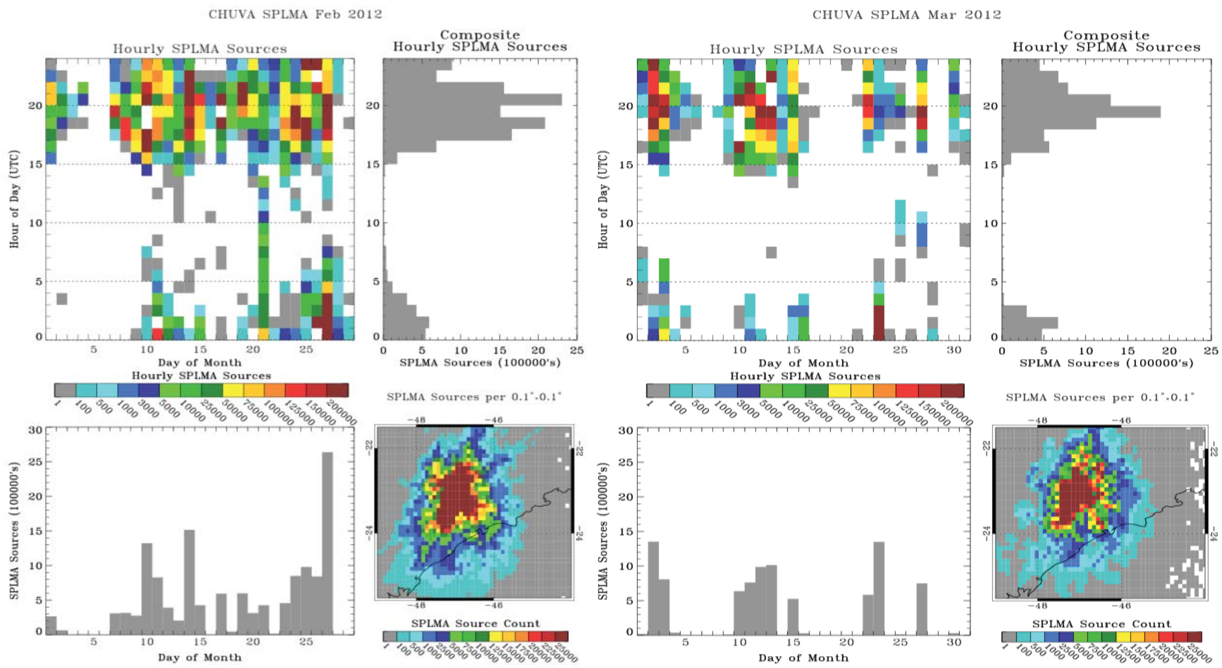
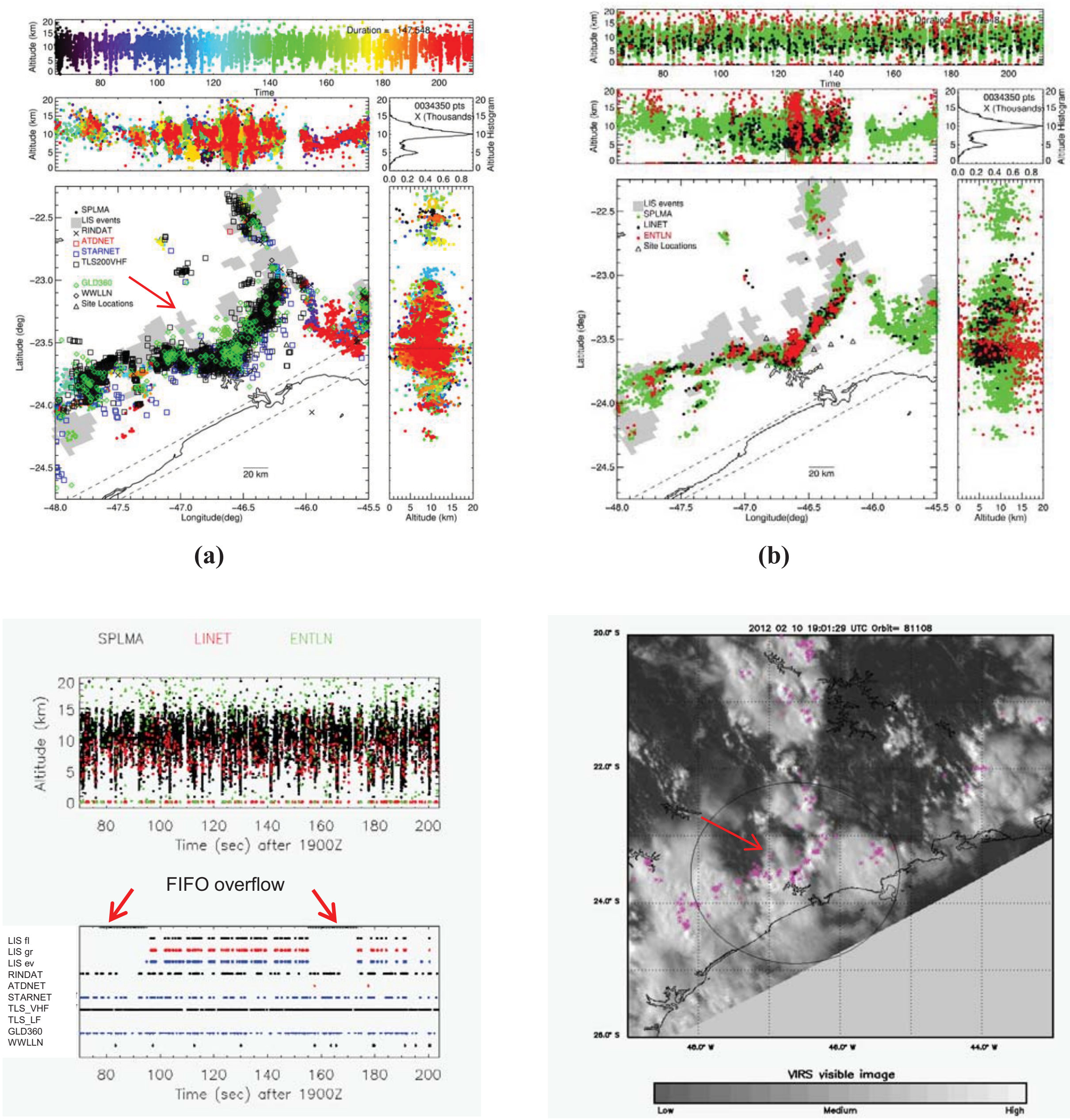


Figure 9: *Same as figure 8 except for February and March,, 2012. The data ends on April 3, 2012*

Figure 10 is an example of data acquired on 10 February 2012 coincident with a LIS overpass from approximately 1901:10 to 1903:24 UTC. The data are limited both temporally and spatially to the LIS overpass limits (total time 133.917 s). In the plan view maps, LIS pixels are indicated by grey squares of denoting the pixel footprint, while the dashed black lines are the southern edge of the corners of the LIS focal plane full field-of-view. Figure 10a shows the active 2-D lightning ground sensors in the plan view map and the SP-LMA data in time-altitude, altitude-longitude, altitude-latitude plots, and plan view. Figure 10b shows the same time period with SP-LMA (green), ENTLN (red), and LINET (black). Figure 10c shows all the data of all the LLS networks detected during this time interval in a form that easily shows the coincidences between the observations. During this interval, there are two LIS FIFO full overflow (black X's at the top of the bottom plot) from approximately 76 to 90 and 165 to 172 seconds after 1900 UTC. In this region, this is caused by excessive noise sources being generated on the LIS focal plane array from radiation occurring in the South Atlantic Anomaly (SAA). No data is acquired by LIS during the short intervals that the FIFO buffers remains overflowed. Figure 10d shows the TRMM VIRS visible image with LIS flashes overlaid. Typically, SP-LMA detects more than 10 times the number of source events than ENTLN or LINET. In the older version of the ENTLN data analysis there appears to be an artifactual high altitude bias (we leave this to ENTLN to figure out the issue). In general, all the ground based systems display good location agreement but there often are large differences in the number of sources detected. Also we find that in some areas there are LIS pixels that are lit up but no lightning was detected in those areas by ground sensors. This may be caused by reflections off of left over clouds in those areas that have no lightning (the red arrows in figure 10a and figure 10d may indicate such a case).

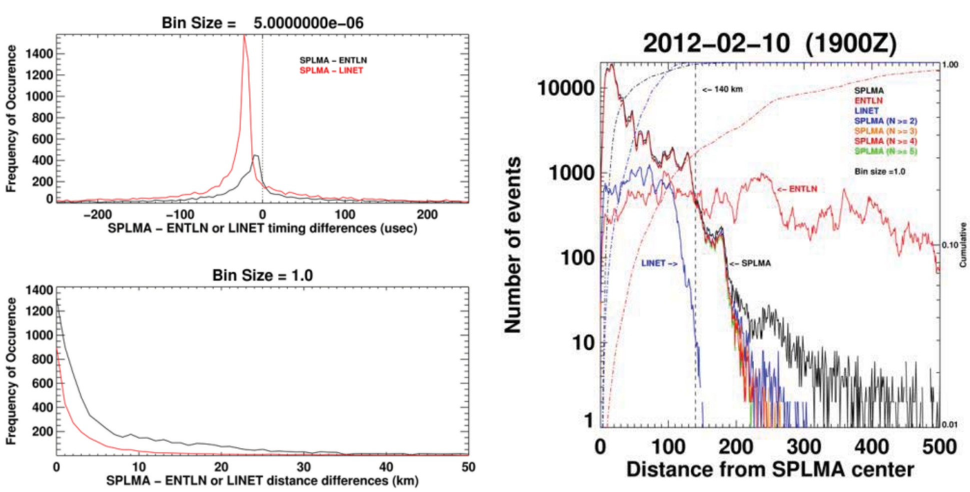
For the previous hour (1800 UTC), lightning was detected in those areas by ground sensors. It appears that no one sensor (SP-LMA included) detects all the lightning and SP-LMA and TLS200VHF are about tied for detecting LIS events.



(a) **(b)** **(c)** **(d)**

Figure 10. *Coincident lightning observations on 10 February 2012 at 1900 UTC during a LIS overpass. (a) Observations from SP-LMA and the 2D LLS networks. (b) Observations from the 3D LLS networks including SP-LMA (green), ENTLN (red), and LINET (black). (c) Simultaneous observations shown as a function of time for all networks, now with SP-LMA (black), ENTLN (green), LINET (red). (d) TRMM VIRS visible with LIS flashes overlaid.*

A timing and distance comparison (Figure 11a) shows a slight offset between SP-LMA and ENTLN (black) / LINET (red) of about 8 / 22 usec but the overall agreement is good. The data for both the timing and distance differences is SP-LMA – ENTLN or SP-LMA – LINET. SP-LMA time precedes ENTLN time which precedes LINET time. This is likely due to the different frequencies that each sensor detects and the different part of the waveform that is used to report the time (a waveform analysis would probably verify this). SP-LMA uses the time of the strongest source (VHF) within an 80 usec window as long as there are sources above the threshold. ENTLN (5 kHz to 12 MHz) and LINET (LF) report the time of the maximum part of the waveform. LINET uses approximately a 500 usec window and usually detects the larger currents in longer channels. The data has been produced by taking the nearest points in time of ENTLN / LINET compared to SP-LMA (no other criteria such as limiting the initial timing difference to 330 msec or a distant limit has been used). The distance differences use the same indexes that are used for the timing differences. For ENTLN, the recent data that ENTLN submitted to the CHUVA archive has been used (usec or better versus msec timing with the older data set). Both LINET and ENTLN timing distributions appear to fall off a bit sharper on the right than the left side. The distance difference



a) **b)**

Figure 11: *Left Panel: Time (top) and distance (bottom) difference comparison between SP-LMA and ENTLN (black)/LINET (red) for February 10, 2012 (1900 – 2000 UTC). The time/distance bin sizes were 5 usec/ 1 km. The distance comparison is based on the indexes from the top plots. A vertical line at 0 usec has been added to the timing comparison plot. Right Panel: Histogram (log scale) of number of sources as a function of distance from the SPLMA center for SPLMA (black), ENTLN (red), and LINET (blue). For SPLMA, the data was further filtered for flashes with number of sources per flash of ≥ 2 (blue), ≥ 3 (org), ≥ 4 (red), and ≥ 5 (grn). The cumulative distribution (right scale) is given by dashed lines for each sensor. The approximate cross over point (dashed black vertical line: ~140 km) where ENTLN (due to a larger network) out performed SPLMA is indicated on the figure.*

fall off appears to be about the same for both ENTLN and LINET as compared to SP-LMA.

A histogram (figure 11b) of the number of sources (log scale) as a function of distance (bin size – 1.0 km) from the SP-LMA center for SP-LMA, ENTLN, and LINET indicates that SP-LMA out performs

LINET and ENTLN at distances less than approximately 140 km. At distances greater than 140 km, then ENTLN is the best sensor to use due to a larger ENTLN network in Brazil. Also, it should be stressed that this figure is for strokes only. Due to the increased noise caused by the channel 9 TV station, SP-LMA can miss weaker flashes at larger distances from the SP-LMA center (especially if you don't include the singletons (loosely defined as number of sources per flash ≤ 4)). Occasionally, we have seen that SP-LMA can miss an entire storm cell at distances of approximately ≥ 150 km if you do not include the singletons. For SP-LMA, the data (see figure 11) was further filtered for flashes with number of sources per flash of ≥ 2 (blue), ≥ 3 (org), ≥ 4 (red), and ≥ 5 (grn) giving an indication of how the singletons fall off with range.

Figure 12 shows a variety of SP-LMA statistics generated to better characterize the overall operation of the LMA network. These statistics are for one hour of data on 10 February 2012, beginning at 1900 UTC. These plots only contain flashes with 5 sources or more. Any residual noise appears not to significantly affect the statistics. One might get dramatically different results if these plots were re-done without removing the noise so bulk statistics can provide a sanity check of data. Also, these results are for one hour of data only so they might need to be adjusted for the whole day (there were about 8.5 hours of lightning for this day). Some key results include: 1) Minimum flash duration is proportional to number of sources per flash but not maximum flash duration, 2) Flash duration is not a function of distance from network center, 3) As expected, more sources are detected at closer distances, and 4) Mean charge centers are at approximately at an altitude of 5.5 and 11 km. For this hour of data there were 36 flashes with more than 1000 sources per flash.

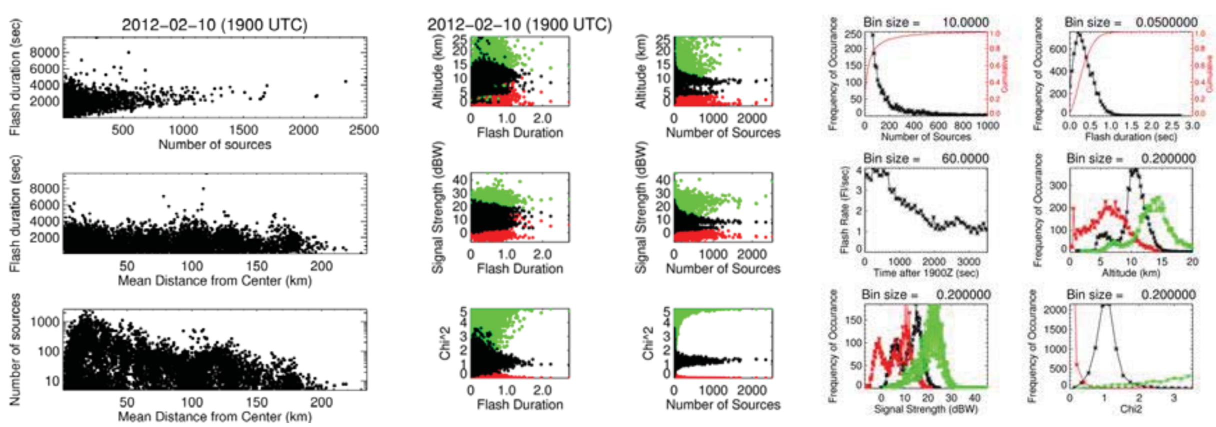


Figure 12: *Statistics from February 10 (1900 to 2000 UTC). Left panel (top to bottom): Number of sources versus flash duration (sec), Mean distance from SP-LMA center versus Flash duration (sec), Mean distance from SP-LMA center versus number of sources (log scale). Center panel (left side): Flash duration versus altitude (top), signal strength (middle), and chi*^{2} *(bottom). Center panel(right side): Number of sources versus altitude (top), signal strength (middle), and chi*^{2}*. Right panel: Top two plots are histograms (black) and cumulative distributions (red) for the number of sources per flash (top left) and the flash duration (top right). Other statistics include flash rate as a function of time of hour (middle left), altitude distribution (middle right), signal strength (bottom left) and Chi-square (bottom right).The red, green and black are the minimum, mean, and maximum for each relevant plot.*

5. SUMMARY

The 12 station time of arrival SP-LMA network that operated from October 23, 2011 to April 3, 2012 in the Sao Paulo, Brazil area has been described including the noise removal procedure. The noise removal procedure effectively removes most of the noise around a primary and a secondary noise source *without* removing much real lightning data especially at low altitudes. Once the noise was removed, monthly activity plots and various statistics and histograms were created and discussed. February and March are the most active months with daily peak hours in the afternoon around 1600 local time (a secondary peak around 2300 local time exists on some months). Any residual noise appears not to significantly affect the statistics but it is essential to remove the noise prior to calculating any bulk statistics. Average flash duration and maximum flash duration appears to be independent of both the number of sources per flash and the distance from the center of the network. Additionally, more sources are detected at closer ranges (expected) and the mean charge centers are at approximately at an altitude of 5.5 and 11 km. Initial inter-comparisons have been made with LIS and the VIRS visible sensor on the Tropical Rainfall Measuring Mission (TRMM) satellite, and with other local lightning detection networks in the Sao Paulo area including LINET, ENTLN (BrazilDat), RINDAT, STARNET, ATDNET, TLS_VHF, TLS_LF, GLD360, and WWLLN. In particular, timing difference plots have been made between the three 3D sensors. For sources that are closest in time, SP-LMA time precedes ENTLN / LINET by an average of about 8 / 22 usec. Otherwise, the temporal and spatial comparisons among the various sensors appears quite good although LIS does have some pixels that are lit up that none of the ground sensors detected (probably reflections off of nearby non-lightning producing clouds). The effective range of the better quality data (e.g.: 10 or more sources detected at a given range) for LINET and SP-LMA appears to be about 140 and 200 km respectively from the SP-LMA network center. If the singletons (number of sources per flash $\leq$ 4) are included for SP-LMA data, then this distance extends to about 260 km. Beyond these distances, the number of sources detected by both falls off quickly. The ENTLN range extends further out due to the networks larger size. A more detailed climatology investigation (e.g.: statistics on a monthly or daily time scale) is required to more fully understand the data. LIS overpasses and radar data also need to be more fully investigated (other papers at this conference may have more information).

6. ACKNOWLEDGEMENTS

We look forward to the exciting science returns that will result as the analysis of the CHUVA lighting data sets unfold. We gratefully thank the NOAA GOES-R program and the participating organizations in the United States and Brazil (NASA MSFC, UAH, NOAA, USP, INPE CPTEC, and INPE DGE) for the successful deployment and execution of the SP-LMA. We also extend appreciation and thanks to all the other collaborating science groups and lightning location networks. This work is supported by NOAA grant DB133E-10-SE-2455

REFERENCES

Boccippio, D. J., W. J. Koshak, and R. J. Blakeslee, Performance assessment of the Optical Transient Detector and Lightning Imaging Sensor: 1. Predicted diurnal variability, *J. Atmos Ocean Tech*, 19, 1318-1332, 2002.

Christian, H. J., R. J. Blakeslee, and S. J. Goodman, "Lightning Imaging Sensor (LIS) for the Earth Observing System," *NASA TM-4350*, available from Center for Aerospace Information, P.O. Box 8757, Baltimore Washington International Airport, Baltimore, MD 21240, 44 pp., 1992.

Christian, H. J. et al., Global frequency and distribution of lightning as observed from space by the Optical Transient Detector, *J. Geophys. Res*., 108 (D1), 4005, 10.1029/2002JD002347, 03 January 2003.

Mach D. M., H. J. Christian, R. J. Blakeslee, D. J. Boccipio, S. J. Goodman, W. L. Boeck, Performance assessment of the Optical Transient Detector and Lightning Imaging Sensor, J. Geophys. Res., 112, D09210, doi:10.1029/2006JD007787, 2007.

McCaul, E. W. Jr., J. C. Bailey, J. Hall, S. J. Goodman, R. J. Blakeslee, and D. E. Buechler , A flash clustering algorithm for North Alabama Lightning Mapping Array data, Presented at the 85 AMS Annual Meeting, January, 2005.

Goodman, S. J., R. Blakeslee, H. Christian, W. Koshak, J. Bailey, J. Hall, E. McCaul, D. Buechler, C. Darden, J. Burks, T. Bradshaw, and P. Gatlin, The North Alabama Lightning Mapping Array: Recent Severe Storm Observations and Future Prospects, Special Issue (ICAE), *Atmos. Research*, *76*, 423-437, 2005.