Title: RELAMPAGO - Cordoba Argentina Marx Meter Array (CAMMA) Data Documentation

Version 1.1, 8/05/2019

Author(s):

PI: Dr. Lawrence D. Carey

Co-PI: Dr. Phillip M. Bitzer

Bruno L. Medina

Address:

Severe Weather Institute - Radar & Lightning Laboratories (SWIRLL)

The University of Alabama in Huntsville

4801 Bradford Blvd NW

Huntsville, AL 35805

Contact Information:

PI Email: lawrence.carey@uah.edu

PI Phone Number: (256) 824-4030

This material is based upon work supported by the National Science Foundation under Grant Number (NSF AGS 1661785).

1.0 Introduction

The Cordoba Argentina Marx Meter Array (CAMMA) consists of a network of 10 sensors (Zhu et al., 2019) deployed in Cordoba, Argentina during the RELAMPAGO Project designed to detect electric field change in a wide range in the LF/VLF electromagnetic spectrum (Bitzer et al., 2011, 2013). Electric field change waveforms, and LF/VLF source mapping are the type of data provided. From CAMMA data, charge retrieval, and flash type are some of the potential enhanced products, which are currently in development.

2.0 Instrument Description

Each sensor has two antennas, named fast (1.6 kHz - 2.5 MHz) and slow (1 Hz – 57 kHz) channels. The fast channel has a time constant of ~100 μs and mostly detects the contribution from the radiation component of lightning, while the slow channel has a time constant of ~100 ms and can detect the electrostatic component. A given sensor is triggered as the electric field change surpasses a predetermined threshold, which varies for each sensor depending on its location. Figure 1 shows a picture of CAMMA14 deployed in Despenaderos during the RELAMPAGO Project.

Figure 1 – CAMMA14 picture.

2.1 Network

During the RELAMPAGO Project, 10 sensors were deployed at a baseline of approximately 30 km. Sensors names are shown in Table 1 and their locations are depicted in Figure 2.

Table 1 – Sensor names and locations.

Sensor Name	Sensor Location
CAMMA1	Rio Primero
CAMMA2	Monte Cristo
CAMMA4	Villa del Rosario
CAMMA7	Villa Carlos Paz
CAMMA10	Bosque Alegre
CAMMA11	Pilar
CAMMA12	Cordoba
CAMMA13	Almafuerte
CAMMA14	Despenaderos
CAMMA15	Manfredi

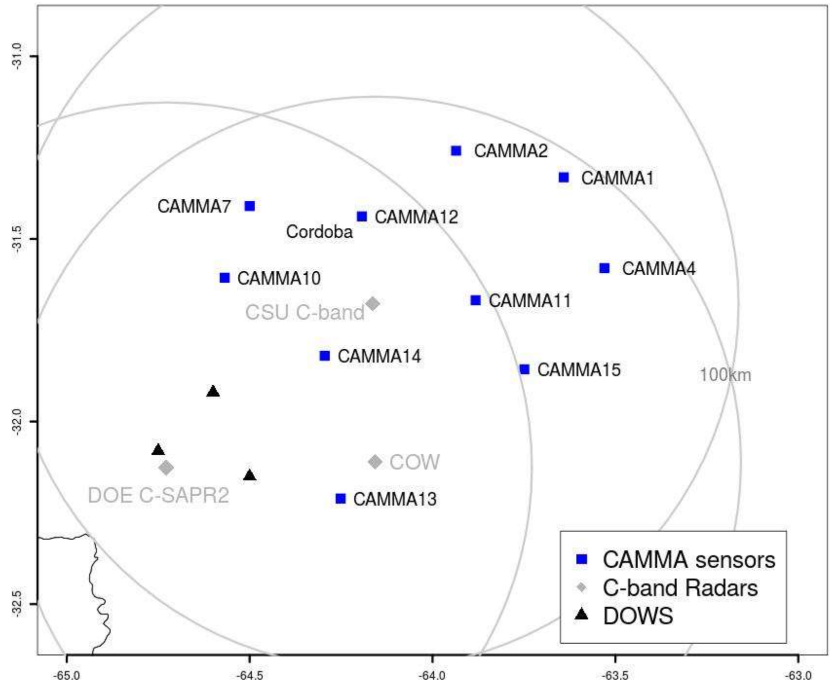

Figure 2 – CAMMA Network (blue symbols), C-band radars locations and 100 km range (gray), and hypothetical DOW locations (black). The DOW locations changed based on IOP deployments.

2.2 Time period covered by the data

During the campaign, sensors became unavailable for some days, which resulted in the number of available sensors varying day-by-day. The availability of each sensor and the number of active sensors per day are shown on figure 3.

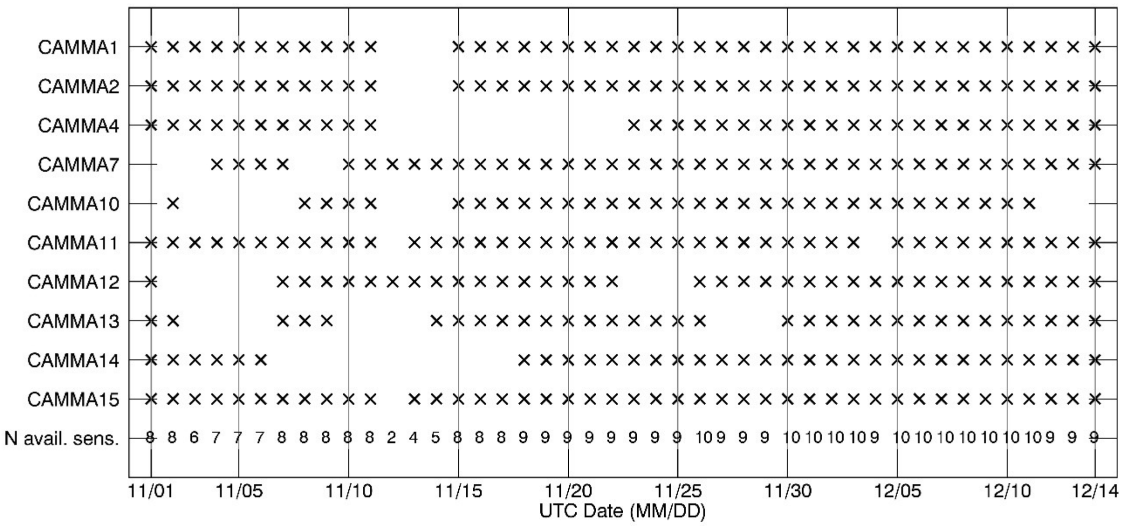

Figure 3 – Individual CAMMA sensor availability during the campaign and the total number of sensors operating per UTC day.

3.0 Data Processing

3.1 Level 0 and Level 1 Data

The raw electric field change waveform data collected in the field from each sensor consists of the Level 0 (L0) data. The L0 data were pre-processed to get the Level 1 data (L1). For example, the L1 data have been lightly processed to insure the filename is the correct date and time of the first trigger in the file and to remove waveform triggers that may contain the wrong GPS information. The L1 data consist of binary data of electric field change waveforms. An example of the L1 data waveforms for different CAMMA sensors is shown in Figure 4.

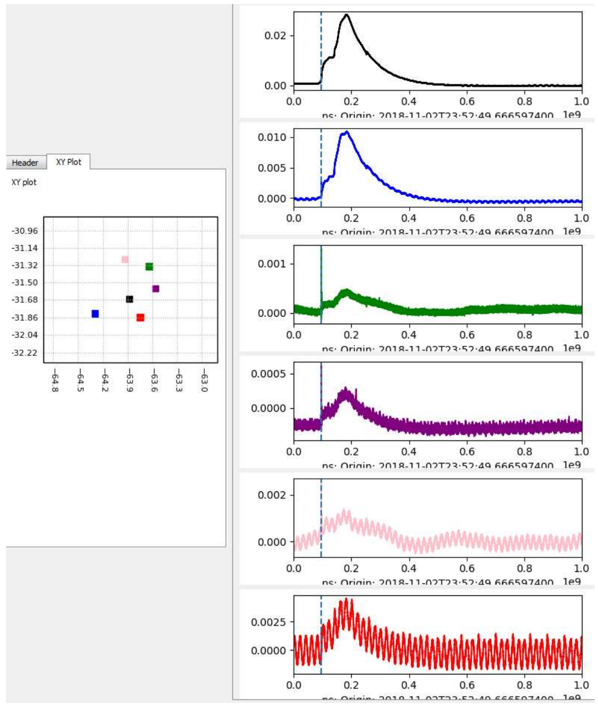

Figure 4 – Level 1 waveforms for 11/02/2018 23:52:59.665 UTC for sensors CAMMA11, CAMMA14, CAMMA1, CAMMA4, CAMMA2, and CAMMA15 (from top to bottom).

3.2 Level 2 Data

The Level 2 (L2) data consists of lightning mapping data in the form of CAMMA sources (e.g., lightning pulses) obtained from the L1 data. A minimum of 6 triggered sensors are necessary to locate a pulse. The overlapping period in which those sensors are active is considered, with a 1-second maximum time period cut-off.

The time period being considered is divided into "big" windows of 750 µs. Then, the cross-correlation is calculated between the best station (defined on the next paragraph) and all other available stations.

The best station is CAMMA11 because it is considered to be the station with the highest signal-to-noise ratio (SNR) through the campaign based on waveforms. If that best station was not triggered for a given flash, then CAMMA14 is used as the station with the second highest SNR, and so on. The order of best stations is: CAMMA11, CAMMA14, CAMMA4, CAMMA15, CAMMA2, and CAMMA1.

The waveforms between stations are aligned by shifting the waveforms in time. The alignment is performed by correcting the arrival time difference between the stations by shifting waveforms in time and finding the maximum correlation. If the correlation is greater than 0.2 for at least 3 pairs of sensors, it goes to the next step for source definition.

The next step is the partition of the big window period into 30 µs windows, referred to here as small windows. The same cross-correlation calculation process performed for the big window is applied for small windows. A temporal shift is performed for small windows to obtain the maximum correlation just as performed for the big window. Correlation is calculated between the best sensor and other sensors for each small window, and if the correlation surpasses a 0.7 threshold for at least 5 pairs of sensors, it goes to the next step for source definition.

Finally, a time-of-arrival (TOA) solution with minimized χ^2 is calculated using all N available sensors. Then, a TOA solution for a combination using N-1 sensors is also calculated. If χ^2 from both solutions are smaller than 5 and the difference in location solutions in x, y, and z are smaller than 100m, 100m, and 400m, respectively, a source is then defined. The solution with the smaller $\chi^2 * \sigma_z$ is chosen as the solution for the source, where σ_z is the estimation of the error in z. If these conditions are not met, a different combination using N-1 sensors is tested and the process is repeated until these conditions are met. These conditions are tested until combinations of N-2 sensors, or combinations of 6 sensors (whichever is larger).

This methodology of locating sources is somewhat different than other typically used lightning locating systems. For example, Lightning Mapping Arrays use only the time of arrival to arrive at a solution, as did previously deployments of arrays of electric field change meters (Bitzer et al., 2013). The current methodology allows many more sources to be located. We refer to the methodology used as a "hybrid" approach that combines cross-correlation and TOA.

Currently, the provided sources are not grouped into flashes. In order to make flashes, a researcher could use a temporal and spatial clustering implementation similar to that typically used when processing LMA data. Future processing and updates of L2 data could include this flash level data.

4.0 Data Format

4.1 Level 1 Data

The L1 data are saved in binary files organized in UTC days folders, in the following directory structure: level1/2018MMDD. File names has the convention:

hammaNN_2018-MM-DDThh_mm_ss.bin

where NN is the sensor number (Table 1) and hh_mm_ss is the UTC time at the beginning of the recording. Python code to read these binary files is also provided, and online documentation is available at https://www.nsstc.uah.edu/users/phillip.bitzer/python_doc/hamma/. A graphical user interface (the HAMMA User Data Analysis Technology (HUDAT) is also available, which can read in and display CAMMA data, as well as other lightning data sets (e.g., LMA, ENTLN, GLM).

4.2 Level 2 Data

The L2 data are saved as ASCII (.txt) files with the source locations based on the L1 data. Quick-images are also provided for these files. Source location ASCII files are organized in the directory structure level2/source_files/2018MMDD, while the quick-look images are in the directory structure level2/figs/2018MMDD where MM here is UTC month and DD is UTC day.

Each source location ASCII file consists of one or more flashes during a contiguous temporal period (i.e., all sources detected during a lightning active period), and has the following file name convention:

2018-MM-SSThh-mm-ss-MMM_DUR_N.txt

where hh-mm-ss-MMM is the UTC beginning time of the lightning period with hh hours, mm minutes, ss seconds and MMM milliseconds, DUR is the duration in milliseconds (can have 2, 3, or 4 digits, maximum value is 1001), and N is the number of sensors triggered for those lightning sources (can have 1 or 2 digits, maximum value is 10). Each line in the file is a CAMMA source, while data content in columnar ASCII format are described in Table 2.

Table 2 – Columns description for the source locations ASCII (.txt) files. Future updates to L2 data will include additional source information in columns 6 and 7.

Column Number	Column Description
1	x (east-west) in km from CAMMA11
2	Y (north-south) in km from CAMMA11
3	Z vertical above mean sea level (MSL) in km
4	t in seconds from 00 UTC
5	χ^2 for the solution
6	Amplitude (0 for now)
7	Flash type (0 for now)
8	σ_x for the solution
9	σ_y for the solution
10	σ_z for the solution
11	σ_t for the solution
12	Arrival time in seconds from 00 UTC for CAMMA1
13	Arrival time in seconds from 00 UTC for CAMMA2
14	Arrival time in seconds from 00 UTC for CAMMA4
15	Arrival time in seconds from 00 UTC for CAMMA7
16	Arrival time in seconds from 00 UTC for CAMMA10
17	Arrival time in seconds from 00 UTC for CAMMA11
18	Arrival time in seconds from 00 UTC for CAMMA12
19	Arrival time in seconds from 00 UTC for CAMMA13
20	Arrival time in seconds from 00 UTC for CAMMA14
21	Arrival time in seconds from 00 UTC for CAMMA15

Quick-look figures are generated for lightning active periods detected with more than 30 sources. Files with the following convention 2018-MM-DDThh-mm-ss-MMM_DUR_N.png displays the best station waveform, source locations in time, x-y plan view, x with height, y with height, and a histogram of the number of sources with height. Also, a quick-look figure with the convention 2018-MM-DDThh-mm-ss-MMM_DUR_NwithSENSORS.png is provided, showing source locations in a x-y plan view, the sensor locations, and active sensors for that lightning period. An example of these two types of quick-look figures are shown in Figure 5.

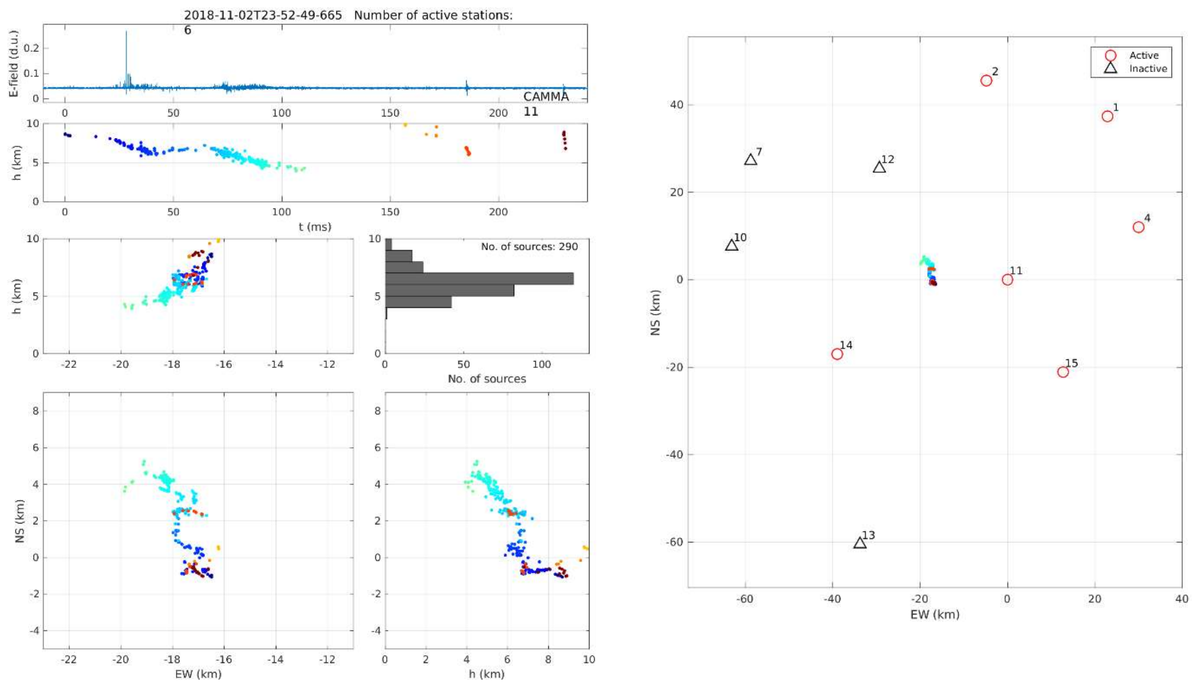

Figure 5 – Example of quick-look lightning mapping figures for the same period as shown in Figure 4.

5.0 Updates

5.1 Version 1.0

The version 1.0 of the CAMMA Level 2 dataset provides every source located for active periods (6 triggered sensors) with no distance restrictions. However, missing periods in multiple dates in this dataset were observed due to a bug in the code processing. This issue was addressed and corrected in the following versions.

5.2 Version 1.1

The version 1.1 data only provide sources located at a distance less than 100 km from the best performing CAMMA station (CAMMA11). Sources at a far distance from the network were observed to have large uncertainties in the determination of their height. These large height errors at far range are due to the fact that CAMMA root mean square timing error is large (150 ns) when compared to a network such as the LMA (40 ns). Importantly, code for version 1.1 also corrected programming bugs observed for version 1.0, allowing for the number of lightning active period Level 2 output data files to increase by about a factor of 2.

5.3 Future versions

Future versions to be delivered will include sources mapped with a higher resolution in terms of window size, and flash typing.

6.0 Data Remarks

The fact that this array measures the electric field change in LF/VLF provides potential for inferring a variety of lightning and charge properties, which are still being investigated. CAMMA obtains measurements from a different electromagnetic spectrum than usual Lightning Mapping Array (LMA) VHF-based networks, providing information from different components of lightning. For example, CAMMA sources can locate lightning return strokes, K-changes, other IC pulses and leaders. Near-continuous radiation process, like dart leaders, can also be located by CAMMA. Finally, it is possible to obtain charge retrievals from the slow antenna data using charge models (Krehbiel et al. 1979, Bitzer 2011) and a subjective determination of flash type (Bitzer et al. 2013). Flash typing and charge retrievals using CAMMA are still in development and may be provided in future data releases. The L2 mapping data provided here are in the so-called "low-resolution" mode, which has coding restrictions in terms of window sizes, cross-correlation threshold, χ^2 threshold, and number of sensors combinations necessary to be correlated. In general, when compared to sources from a VHF instrument, the CAMMA low-resolution mode provides less sources. However, a high-resolution mode can be obtained by changing the aforementioned processing settings and, consequently, a more detailed characterization of the lightning structure can be obtained. Future updates to L2 data will include CAMMA high-resolution mapped lightning flashes for select IOP's and storms.

References

Bitzer, P.M., 2011. New revelations on lightning initiation and evolution using a newly developed array of wideband electric field sensors. PhD thesis, The University of Alabama in Huntsville.

Bitzer, P.M., Christian, H.J., Stewart, M., Burchfield, J., Podgorny, S., Corredor, D., Hall, J., Kuznetsov, E. and Franklin, V., 2013. Characterization and applications of VLF/LF source locations from lightning using the Huntsville Alabama Marx Meter Array. *Journal of Geophysical Research: Atmospheres*, **118**, 3120-3138.

Krehbiel, P. R., M. Brook, and R. A. McCrory, 1979: An analysis of the charge structure of lightning discharges to ground. *Journal of Geophysical Research: Atmospheres*, **84**, 2432-2456.

Zhu, Y., P. M. Bitzer, M. F. Stewart, S. Podgorny, D. Corredor, J. Burchfield, K. Brunner, J. Ringhausen, S. I. Fairman, and S. Pendleton, 2019. Huntsville, Alabama, Marx Meter Array 2: Upgrade and Capability. 99th American Meteorological Society Annual Meeting, Phoenix, AZ.