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RAMMER NETWORK OBSERVATIONS DURING SUMMER 2011/2012

Saraiva, A. C. V.[1], Pinto Jr. O.[1], Zepka, G. S.[1],

[1]INPE, National Institute for Space Research, S. J. Campos, SP, P.O. Box 515, 12201-970, Brazil

1. INTRODUCTION

High-speed cameras have been used to study natural cloud-to-ground lightning since 1990s (Mazur et al., 1995, 1998). In Brazil, the first studies using data from high-speed cameras were conducted in 2005 (Ballarotti et al., 2005), followed by Saba et al. (2006a). From then on, this technique became one of the main tools for the studies of some characteristics of cloud-to-ground lightning, like continuing current (e.g. Saba et al., 2006b). However, as no technique is flawless, recording lightning with these cameras requires a fairly amount of time to save the files and a human operator. Due to this last constraint, the camera must stay in a place of safe and easy access. These are the main reasons why this project was envisioned. After one year in development, this is the first field test of the RAMMER project, an acronym to Automatic High Speed Camera Network to Study Lightning in Portuguese (Saraiva et al., 2011). Two sensors were completed and on field during the summer season, and other camera is being used to observe lightning with help of a human operator. These cameras are capable of recording high-resolution videos up to 1632 x 1200 pixels at 1000 frames per second. A robust housing was assembled to ensure the safe operation of the cameras in adverse weather conditions. The main goal is enable the recordings of large numbers of cloud-to-ground flashes (CG) per storm, bigger than the values reported to date. As the amount of physical memory to record only 1 second of data is something between 3 - 4 GBytes, there is no way to make continuous recordings of thunderstorms, so a triggering system was conceived to address this problem and do the recordings of the 2 seconds of data automatically when lightning is presented. The triggering system is an optical sensor, based on a photodiode.

This work describes the operation of the system during the observations conducted on the 2011/2012 summer, held in São José dos Campos, São Paulo, Brazil. The next section shows an overview of the RAMMER sensor, its features, the observation sites, and future developments. A complete bug report of the sensors operation is presented in section 3. A brief description of the 2011/2012 campaign is provided in section 4. As the summer season did not ended as this work was done, no data reduction was made yet, but some data samples are showed, as well as some discussion on the sensors performance. The RAMMER network is participating also in the joint campaign of the CHUVA experiment (Machado et al., 2011). The summary of this project is presented.

2. EQUIPMENT

The RAMMER project officially started on July, 2010, and from then on several steps and testing were conducted in São José dos Campos in order to prepare the equipment for the first lightning observations. In the summer of 2010/2011 the initial testing of the cameras and the lightning sensor was conducted. The camera and its software features, lenses, GPS and the lightning sensor were tested. The testing equipment is shown in Figure 1. A total of 10 thunderstorm days were recorded but just a few lightning flashes were useful due to the testing nature of the campaign. Two cameras were used, one monochromatic and one colored. The monochromatic camera showed much more sensitivity than the color camera. The development of leaders, for example, was easier seen with the monochromatic camera. The relation between time and space resolution found was 1200 x 500 pixels, at 2500 frames per second. These videos are lower then 4 GBytes, and they take less than 3 minutes to be downloaded from the camera to the PC. In 02/26/2011, 21 out 24 videos recorded were triggered by real cloud-to-ground lightning flashes, resulting in the system detection efficiency of 87%.

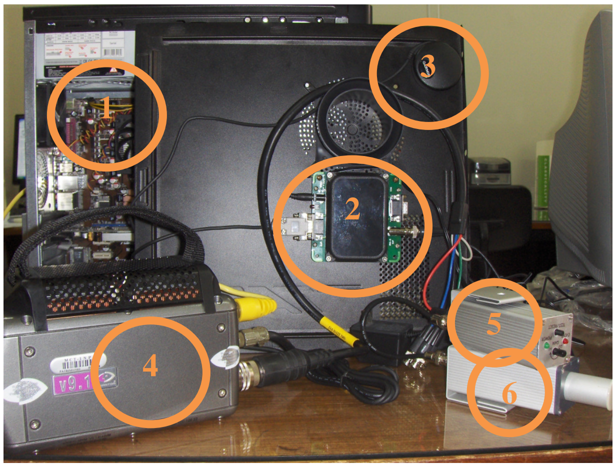

Figure 1. Main components of the testing sensor: 1) PC; 2) IRIG-B Time code generator; 3) GPS Head; 4) High-Speed Camera (Phantom v9.1); 5) Signal Conditioning Unit; 6) Lightning sensor LED-1 (Light Event Detector).

The sensor can be divided in seven critical parts described as follow:

- High-speed camera: Each sensor uses a Phantom V9.1 camera, with 6 GBytes of memory and capability of recording movies of a few seconds in 1632 x 1200 pixels at 1000 frames per second. This configuration can be altered, changing both the spatial and time resolutions. After several tests, the most suitable configuration for the cameras was 1200 x 500 pixels at 2500 frames per second, with 8 bits images (each pixel may have 256 levels of gray). With this configuration the quality of the image is reduced in behalf of reducing the speed of downloading the videos from the camera to the PC. The interval between each frame is 390 µs, which is enough to identify precisely each stroke of a flash, and also precisely measure other characteristics like flash duration, continuing current, interstroke intervals, etc.

- Computer: The PC is a multi-core CPU, with 12 GBytes of RAM and 2 TBytes of space in hard drive. It is the most important part of the system, since all interaction with the equipment goes through it. The main programs running on the machine are the PCC (Phantom Camera Control) version 1.3 and the “Control Software” that was specially developed to control the pulses from the lightning sensor, and to take the decision of turning on and off the camera.

- GPS: The GPS from Garmin and V-Data USA receive the time code from the satellites and transform it into IRIG-B signal type, the required format for the Phantom cameras.

- Lightning sensor: The camera used in the sensor does not have any image-based trigger or any device that allows the camera to automatically record a lightning event. As the time recording is only a couple of seconds, a sensor is required to be used in order to make the camera trigger at the exact time the lightning occurs. V-Data USA provided a luminosity sensor, which can be directly coupled to the Phantom cameras triggers them on a luminous event. The LED-1 (Light Event Detector) is an optical sensor that emits a short TTL pulse every time it detects a fast difference of luminosity.

- Housing: One of the features of the RAMMER sensor is the capability of installation in outdoor places for better view of the sky. With a long time experience in making housing to protect equipment from weather hazards, the company DKL Telecom developed the shelter. Another shelter was developed at INPE to protect the camera itself, since no camera housing available in the market fit the dimensions of the camera.

- Control circuit: To assure the safety operation of the camera, a control circuit was envisioned to turn it on and off. The heart of the circuit is a PIC microcontroller that not only turn the camera on/off, but also manages the pulses from the lightning sensor and communicates with the PC.

- Control software: This software was developed in C# (C sharp) and controls when the camera as to be turned on or off, the initialization of the PCC software, and do a pulse count on a log file. All the communication with the control circuit is made through serial communication in a RS232 port. The camera is turned on after the third pulse of the lightning sensor, and will shut down after 30 minutes without pulses. Also, all pulses from the lightning sensor, even those that did not trigger the camera, are stored in a file with timestamp to be analyzed later. For the next summer these pulses will also have GPS timestamp, and may be used to triangulate the lightning position.

At the moment, there are two sensors fully operational located at São José dos Campos, showed in Figure 2. Several delays in the delivery of some parts impeded the completion of the full network for this summer season. A third sensor was assembled without the lightning sensor, and is being sporadically operated manually during this summer. Figure 3 shows the positions of the sensors.

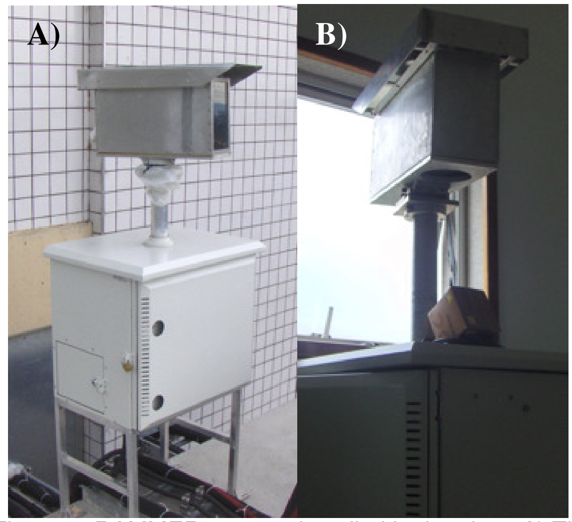

Figure 2. RAMMER sensors installed in the sites. A) The first sensor exposed to weather conditions. B) the second sensor inside a building. Both sensors are fully operational.

1.1 Future development

The first step in the future developments will be a complete bug fix of everything that went wrong with the equipment this summer. The bug report is presented in more details in next section. After that, there will be the first upgrade to the system with the integration of the fast E-field system developed by Schulz et al. (2005).

The lightning sensor will trigger both the E-field and the camera simultaneously, and they will be GPS time stamped.

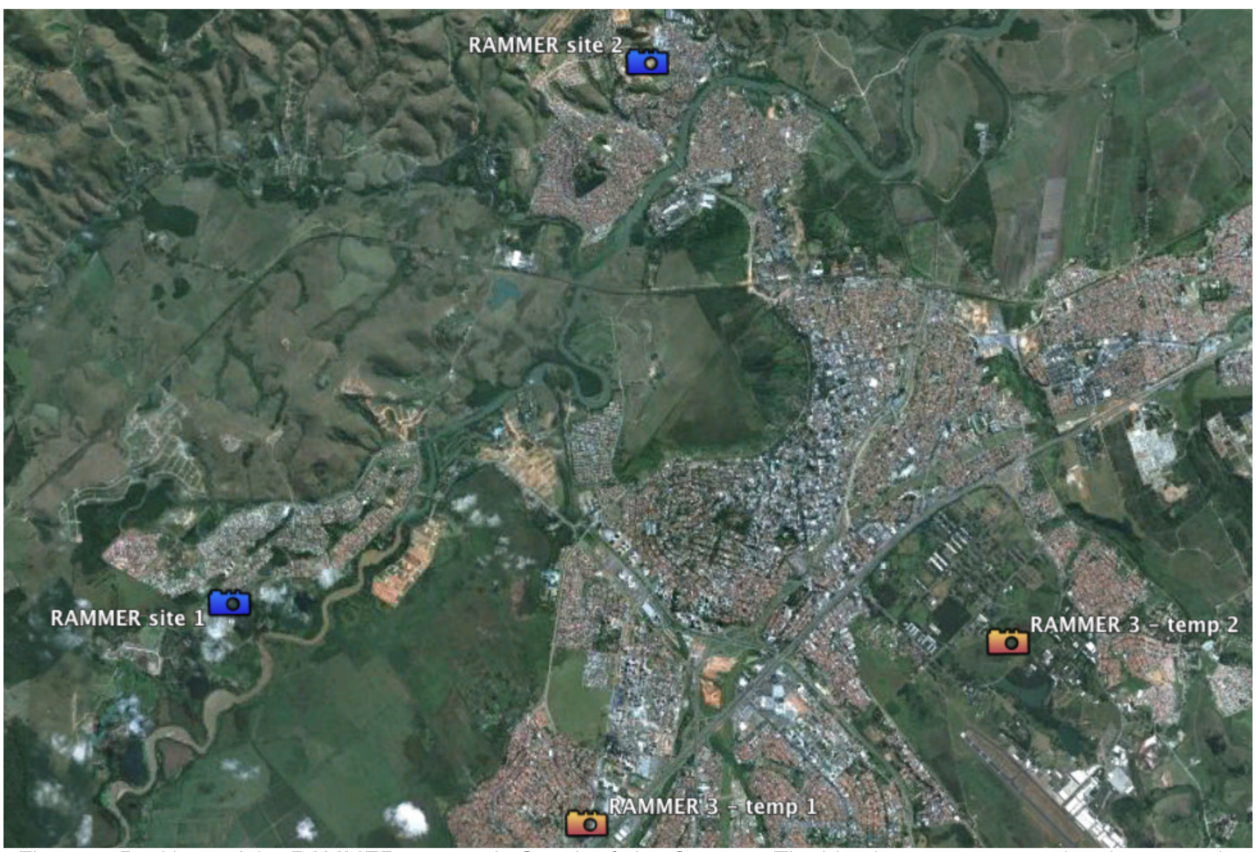

Figure 3. Positions of the RAMMER sensors in São José dos Campos. The blue icons represents the sites were the working sensors are installed. The orange icons are the temporary places were the third sensor operated.

3. BUG REPORT

This summer was the first time the RAMMER sensors were on field for real testing and observations. As expected, several issues were found, and bug fixes were required through the course of this first campaign. A description of the severity of bugs for each part of the sensor is summarized in Table 1.

TABLE 1. Bug report of RAMMER sensor's critical parts.

System part	Bug Level
High speed camera	Green
Computer	Red
GPS	Yellow
Lightning sensor	Yellow
Housing	Green
Control circuit	Red
Control software	Red

The items marked in red in the table require a partial/total review. The main problematic parts are the PC, the control circuit, and the control software. The PC crashed more than it would be considered "normal", and the heating may be one of the main causes. A total change in the motherboard and/or an improved cooling system will be implemented, and several tests will be conducted to avoid loss of observation days due to malfunctioning of the PC. The control software is bounded to the control circuit, so they both are shown in red. The big constraint here is the serial communication that often crashes, and avoids the pulses to be received by the control software, and the camera will not be triggered. To solve that, we are restructuring the communication system, which involves changes on both the circuit and the software.

The GPS is marked yellow because it will be replaced by another GPS module, required to the E-field system that also works in parallel with the camera. Although the lightning sensor has worked as expected, it is very sensitive, even in the lowest gain option. Several faint intra-cloud pulses triggered the camera, and during the recording time, it missed cloud-to-ground flashes. We are currently studying ways to maximize the detection efficiency (DE) of the sensor for CG flashes.

The camera presented only minor bugs related to its operation, and received the green mark, as well as the housing that worked flawlessly. During all period of operation no damage was reported to the equipment due to weather conditions.

4. CAMPAIGN OF 2011/2012

The summer season over the region covered by the cameras was atypical, no official report was given yet, but the average number of thunderstorm days per week was close to 1. For that reason, and due to bugs reported in the last section, only few thunderstorms were recorded by the system so far. By the time this paper was written, there was still one month to the end of the summer season, and the sensors are still installed and working.

4.1 Statistics of the recorded lightning

No data reduction was made so far, but we were able to download all data recorded by one sensor, and search quickly for the presence of CG flashes on the videos. Table 2 presents the statistics of days with recordings for that sensor.

TABLE 2. Thunderstorm days observed by one sensor of the RAMMER network.

Day	# of movies	# of CG lightning recorded	Daily ED	Thunderstorm ED
11/30/11	4	4	100%	-
12/01/11	3	3	100%	-
01/06/12	1	1	100%	-
01/18/12	33	1	3%	-
01/25/12	14	2	14%	33%
02/09/12	13	5	39%	100%
02/10/12	69	13	19%	34%
02/12/12	32	3	9%	50%
02/14/12	21	7	33%	100%
02/17/12	48	5	10%	71%
02/23/12	25	24	96%	96%
02/24/12	6	1	17%	-
03/02/12	39	35	90%	95%

The thirteen days of recording so far show a wide variation of the number of recorded videos, and the proportional recorded videos with CG flashes. Part of the reason was explained in the previous section, and the lightning sensor is partially responsible for recording too much intra-cloud pulses, and misses CG flashes. System malfunction also prevented some possible observations. The configuration of the thunderstorms also plays a role on this subject, and will be explained in details below.

4.2 Characteristics of the thunderstorms

The region of the Vale do Paraiba is a valley surrounded by two chains of mountains, showed in Figure 4, marked by the purple arrows. Usually cold fronts come from the southern Brazil, and pass through the region from southwest to northeast direction. The local convection is usually formed on the edges of both sides of the valley as show in the example of Figure 4. Both working cameras marked on Figure 2 are pointed at the eastern portion of the edges of the mountain. The third camera will be faced to northwest edge when it is operating regularly.

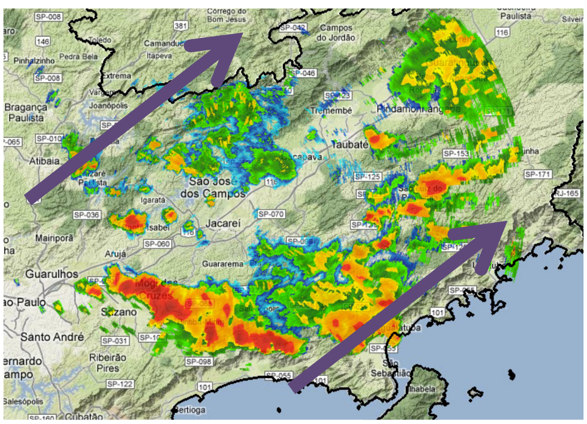

Figure 4. Example of thunderstorm case plotted over the terrain configuration of the Paraíba valley. The radar data is from CHUVA's weather radar and shows the precipitation at 19:45 UT of 03/13/2012.

Basically, three types of thunderstorm configuration can happen during the recordings:

- Far away thunderstorms: This is the best scenario when the thunderstorm is 20-30 km away from the camera. In this situation, almost the entire area is covered by the field of view of the camera if it is pointed in the right direction. The intra-cloud pulses are weaker enough to produce only a small effect on the lightning sensor, and mostly CG flashes trigger the camera. That is the case of the 02/23/12 and 03/02/12 thunderstorms. Note that the DE of those days are the bigger of all.

- Close thunderstorms: In this case, the thunderstorm is occurring very close to the observation site, or even over it. Not only the lightning in front of the camera can trigger it, but also, all luminosity from the lightning happening in the surroundings. In this case the DE drops considerably.

- Thunderstorms behind the camera: If the storms are behind the camera, and close enough to it, the luminosity of the lightning can spread towards the clouds, and excite the lightning sensor. This was a common situation faced. An examples of this type of thunderstorm are days 01/18/12 and 02/24/12, were only one CG flash was recorded.

Any of the above mentioned thunderstorms can also move in any direction. At some point, a close one can go in front of the camera, and then move away, allowing the sensor to record only a small sample of the lightning from that storm. This happened in most of the cases, and future analyses will show the exact time when the storm was in front of the sensor, and then an accurate DE will be calculated. A rough approach is presented in Table 2. We selected the videos in the interval between the first and the last flash recorded, and calculated the DE again (Thunderstorm DE). It is clear that the DE now increased considerably (avg. of 64%), as expect from a moving thunderstorm condition.

4.3 Data samples

Even with this small dataset so far, some interesting lightning events were already recorded, and they can contribute to the knowledge of lightning physics. Some examples are showed in Figures 5 to 10.

In Figure 5, a rare connecting discharge shows up in the middle of the video, and it is possible to infer its size. Figure 6 shows one frame of a stroke that had more than 600 ms of continuing current. This flash will be studied in details later, and compared with LMA (Lightning Mapping Array) data. Other case where two flashes happen within a very close time interval, and also very close to each other, is presented in Figure 7. The response of the lightning location system (LLS) for this type of events will be also studied. So far we recorded one case of spider lightning measured by both cameras, and is showed in Figure 8.

Figure 5. Example of an attempted connecting leader from the ground.

Figure 6. One frame from a flash with a very long continuing current of more than 600 ms, recorded by the RAMMER sensor.

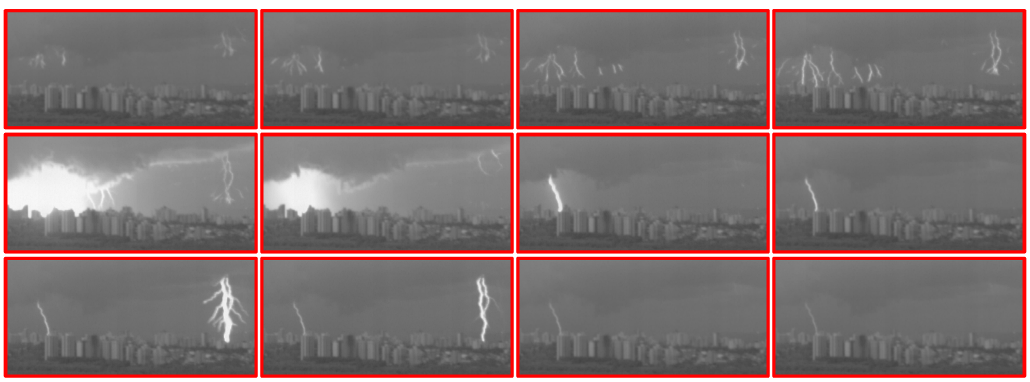

Figure 7. Example of two simultaneous flashes that occurred near each other at almost the same time. The sequence of images show the development of both leaders and the first return stroke is still connected to the ground when the second connect to the ground.

The last case is two flashes observed simultaneously from both cameras in Figure 9. They will be used to perform the channel reconstruction in 3D, and measure the location efficiency of the LLS using natural lightning. To the location efficiency methodology, other CG flashes recorded by both cameras will be also used.

In summary, the number of flashes recorded went from 1 to 69, and the CG flashes, 1 to 35. The detection efficiency for each day (called Daily DE) had a minimum value of 3%, and a maximum value of 100%, and an average DE of 33%. A rough correction to the DE showed an increased, from 33% to 100%, an average of 69%.

5. PARTICIPATION IN THE CHUVA CAMPAIGN

The CHUVA Project (Machado et al., 2010) consists of seven campaigns in different regions of Brazil that will define the characteristics of the main microphysical precipitation regimes of the country, and consequently improve the estimation of rainfall by radar and satellite, the modeling in high spatial resolution, the prediction of storm, and immediate improve the understanding of physical processes involved in the formation and life cycle of cloud and precipitation.

The experiments use a dual polarization weather radar, the most modern in the country, and various instruments, such as: radar pointing vertically to measure vertical profiles of clouds; Lidar for measurement of particulates in the atmosphere; a network of GPS to measure the moisture in atmosphere; a network of radiosondes to make high resolution measurements of the atmosphere dynamics and thermodynamics; rain gauges to measure the amount of rain; a tower of measures of flows on the surface; a microwave radiometer to measure the amount of liquid water clouds.

Figure 8. Example of spider lightning recorded by the cameras.

For the CHUVA-GLM-Vale do Paraíba, the experiments use dual polarization weather radar, installed at the same site of one of the cameras of RAMMER project, where the operational center of the campaign works. Toward the coast there are several sites with instruments to study changes in the characteristics of clouds and storms from there and the Valley. Also scattered in the region, there are several networks of lightning detectors. These instruments will provide a unique set of measures in the region and in Brazil.

Figure 9. Example of two CG lighting flashes recorded by both cameras that will be used for the 3D channel reconstruction.

6. CONCLUSIONS

This work showed the preliminary results of the first campaign of the RAMMER network. Two of the three cameras were installed in the sites previously established, and the third one was operating manually for some cases. Some bugs on the system were observed, and the solutions are in development.

During its operation, one camera recorded 104 CG flashes in 308 movies recorded, resulting in an average efficiency of 34%. Considering the movement of the thunderstorms, a more appropriate DE calculated was 69%.

Although the data analysis is preliminary, some interesting cases were already recorded, and they will be further studied.

Both cameras also recorded some CG flashes at the same time. It will provide means to develop a technique to reconstruct the lightning channel in 3D, and analyze some properties of the lightning, like the leader speed in details. There will be also some studies on the location efficiency of the LLS over the Vale do Paraiba with this data.

The partnership with CHUVA experiment will be benefic for both groups, and will provide a unique dataset of lightning.

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