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A LIGHTNING FLASH AS SEEN BY VIDEO, OKLAHOMA LIGHTNING MAPPING ARRAY, THE NATIONAL LIGHTNING DETECTION NETWORK AND THE LOS ALAMOS SFERICS ARRAY

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1. INTRODUCTION

On June 10, 2007 at about 0100 UT, a small thunderstorm occurred about 15 km to 20 km north northeast of the National Weather Center building in Norman, OK. We obtained HD video images of a number of lightning flashes during the storm and by chance also a still photograph of one of the flashes. In this paper we examine the video record of that flash and compare it with the VHF source location data from the Oklahoma Lightning Mapping Array (OKLMA), Ground-Strike data from the NLDN and waveform data from the Los Alamos Sferics Array (LASA). The use of these data sets of such different character enables us to construct a more complete picture of the flash than any one the data sets can provide.

2. STILL PHOTO AND VIDEO

The still photo of the flash is presented in Figure 1. The flash appears to have some of the characteristics of a positive "bolt from the blue" flash as defined in Edens et al. (2007). For example, we note that the channel comes out of the side near the top of the cloud. However, the data show that it was a multiple-channel, multiple-stroke negative cloud-to-ground (CG) flash. Example frames from the video record are provided in Figure 2. The times of occurrence of the return strokes were obtained from the NLDN data. The times between strokes obtained by counting video frames were consistent with the NLDN assigned times.

Figure 1. Still photo of flash.

The video frame corresponding to the time of the first NLDN located stroke (10.848 seconds) is shown in Figure 2a. Careful examination of the video shows that there were two channels to ground visible in that frame, one relatively easy to see to the right of the blue water tower about halfway between it and the white water tower, and another faintly visible to the left of the blue water tower. An air discharge at approximately 11.181 seconds is

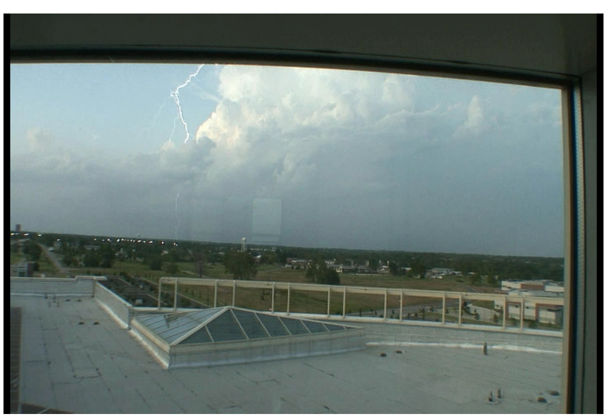

Figure 2a. First stroke at 10.848 seconds.

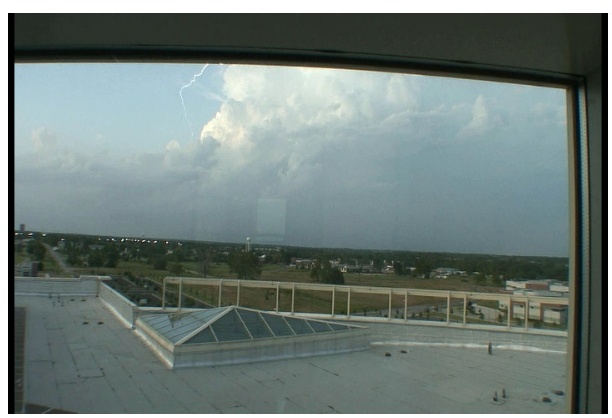

Figure 2b. Air discharge at 11.181 seconds.

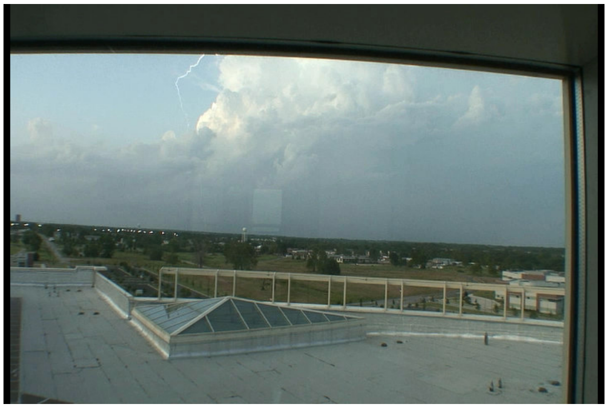

Figure 2c. First stroke in new channel at 11.311 seconds.

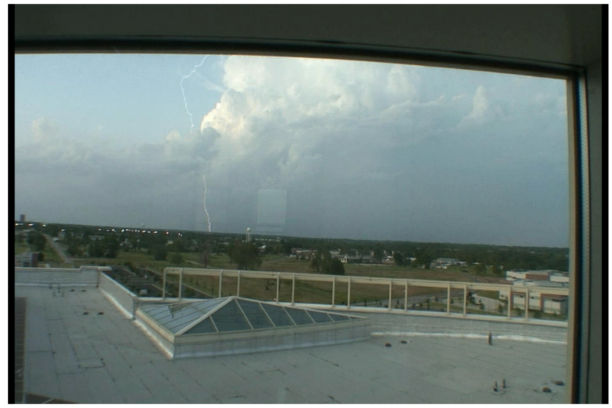

Figure 2d. Subsequent stroke in new channel at 11.706 seconds.

shown in Figure 2b. Figure 2c shows the image (quite faint) of a first stroke in a new channel to the right of the first two at 11.311 seconds. According to the NLDN data, subsequent strokes (in this channel as best we can tell from the video) occurred at 11.408 seconds, 11.535 seconds and 11.706 seconds. The last of these is shown in Figure 2d. The stroke at 11.535 seconds was not perceptible on the video.

3. NLDN Data

We present the NLDN data for this flash in Table 1

Table 1. NLDN data for flash at 01:17:ss.hto.

Ch.#	RS#	U.T. (ss.hto)	lat degrees	lon degrees	)x m	)y m	I_{peak} est. kA
1/2	1	10.848	35.3119	-97.3882	-	-	-18
3	1	11.311	35.3116	-97.3774	+980	-33	-22
3	2	11.408	35.3078	-97.3739	+50	-423	-10
3*	3	11.535	35.3083	-97.3735	+6	+56	-08
3	4	11.706	35.3091	-97.3759	-35	+89	-12

The times given are seconds after 0117 U.T. Note the fact that there was a stroke located at 01:17:11.535 seconds that was not visible on the video. Note further that it had the lowest peak current estimate, but not by much less than the strokes before and after it. Since we do not have a video record of this stroke, we placed an asterisk by the channel attribution in the table, but in view of the relevant LMA data and waveforms (showing a dart leader) for the stroke, we think it is reasonable to assume it also followed the same channel. The occurrence of two separate channels to ground at the time of the first NLDN location is indicated in the table. The data show that it was the brighter channel to the right of the blue water tower in Figure 2a that was located by the NLDN.

In the)x and)y columns of Table 1 we calculate the horizontal distances between each successive NLDN ground-strike location. The successive ground-strike locations of the four strokes in the third channel are well within the error expectations for the NLDN. Waveforms from the LASA suggest that the leader preceding the last stroke was a dart-stepped leader. The leader for the second stroke also showed faint evidence of possible steps.

4. OKLMA DATA

The OKLMA comprises 11 VHF receiving stations in central Oklahoma with wireless communication to a central receiving and data processing site in Norman.

The OKLMA uses difference in time of arrival of VHF signals radiated by lightning discharge channels to provide location and time of occurrence of the radiation in 3d near the center of the array and in 2d at more distant locations. A typical lightning flash will generate thousands of locations that in essence map out the discharge channels in the cloud. (Thomas et al. (2004)). In the case under study here, there were 3285 VHF source locations generated during the discharge that lasted about 0.9 seconds. We present snapshots of the VHF source locations associated with the flash in Figure 3. For reference to the video images we have labeled the water towers seen in the video (blue and white balloons), the NLDN ground-strike points (white arrows) and the line of sight from the vantage point for the video and still photograph (7th floor observing deck of the NWC) to the first ground- strike point (yellow line). In Figure 3a, the two channels we see in the in the video (Figure 2a) at 10.848 seconds are clearly delineated in

Figure 3a. VHF source locations at ~ 10.848 seconds, the time of the NLDN located first stroke.

Figure 3c. VHF source locations at ~ 11.311 seconds, the time of the first stroke in the new channel.

the VHF source location data. The VHF source locations associated with the air discharge in the video (Figure 2b) are shown in Figure 3b. Source locations associated with the first stroke in the new channel (Figure 2c) are shown in Figure 3c. The VHF source locations associated with the NLDN located stroke at 11.535 seconds, not seen on the video, are shown in Figure 3d.

5. LOS ALAMOS SFERICS ARRAY WAVEFORMS

One of the broadband electric-field stations in the LASA is located at the NWC building in Norman. The system recorded return-stroke waveforms as well as waveforms from other processes associated with the flash. These waveforms verified the NLDN identification of the flash as a negative CG. In Figure 4 we show two of the many waveforms associated with the flash. In Figure 4a the return-stroke waveform at 10.848 seconds shows three peaks, consistent with the video and LMA data indicating that there were at least two channels to ground. The third peak suggests there could have been even a third channel not seen in the video. The waveform associated with the air discharge is shown in Figure 4b.

Figure 3b. VHF source locations at ~ 11.181 seconds, the time of the air discharge shown in Figure 2b.

Figure 3d. VHF source locations at ~ 11.535 seconds, the time of the third stroke in the new channel, not seen in the video.

The waveform (not shown) associated with the first stroke in the new channel (Figure 2c) at 11.311 seconds has pulses typical of stepped-leaders. The waveforms associated with the stroke at 11.408 seconds is typical of a dart leader, but shows faint evidence of possible step pulses near the end. If indeed that stroke did produce a new ground-strike point it would be consistent with the fact that the NLDN ground-strike location was more than 400 meters from the first location, although this is also well within the typical error of ground-strike locations. The waveform associated with the stroke at 11.535 seconds is typical of a dart leader, with no evidence of step pulses. The waveform associated with the final stroke in the channel at 11.706 seconds has a few pulses typical of a dart-stepped leader just before the return stroke, suggesting that there could have been a new ground-strike point for the last stroke, though the NLDN data show it to be relatively close to the previous stroke. A dart stepped leader would also be consistent with the fact that the time between this stroke and the previous one was relatively long, 171 milliseconds.

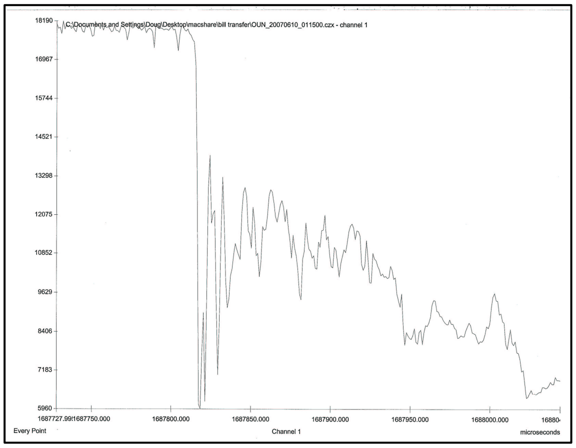

Figure 4a. Return-stroke waveform at 10.848 seconds showing three peaks. The vertical scale for magnitude of electric field is in arbitrary units. Horizontal scale is 50 microseconds per division.

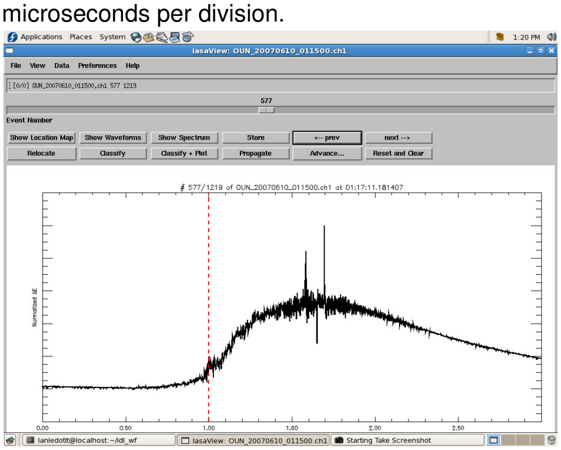

Figure 4b. Waveform associated with air discharge at 11.181 seconds. Vertical scale for magnitude of electric field is arbitrary, horizontal scale is 100 microsceonds per division.

6. DISCUSSION

Using all the data sources, we have pieced together a description of the sequence of events for this flash, presented in Table 2. There are notable differences in the manifestations of this flash in the data sets. For example, we note that in the video of the four-stroke flash in the rightmost channel, the last stroke, at 11.706 seconds, appears to be brighter than the stroke at 11.408 seconds, which in turn is brighter than the first stroke at 11.311 seconds. Furthermore, the video did not even register the third stroke at 11.535 seconds. Careful examination of the video shows that the upper portions of the channel were the same for all three channels and all four strokes in the third channel. Even the air discharge appears to cover the same channel as far as it goes and therefore may be seen as a failed leader. The video images of the four-stroke flash in the third channel appear to show that the same channel is illuminated each time, including the first, but especially in the case of the first stroke, which is rather faint, it is difficult to tell if the paths are identical near the ground. If there were multiple ground-strike points for the successive strokes, we would expect that there would have been dart-stepped leaders. As noted above, the waveform records show that the strokes at 11.408 seconds and 11.535 seconds were preceded by dart-leader field changes and that the final stroke at 11.706 appears to have been preceded by a dart-stepped leader. However, as shown in Table 1, the difference in NLDN assigned ground strike point is not significantly different for the last stroke from the others. Further, the difference in ground strike position between first and second strokes in the third channel is greater than any others, yet the video shows no difference in the channels, at least to the resolution of the images, and there is only faint evidence of step pulses near the end of the leader for the second stroke.

Finally, we examined the LMA data associated with each stroke as suggested in Figure 3. We found that the VHF source location data associated with the first return stroke located at 10.848 seconds is consistent with the video observation of two channels to ground and with the multiple peaks in the first stroke waveform. We note that there are many VHF source locations over a wide range during the time leading up to the return stroke, suggestive of branching. This is more easily seen in animation than in the snapshots in Figure 3.

Table 2: Sequence of Events for flash on June 10, 01:17:ss.hto

Flash component	C1/C2S1	air disch	C3S1	C3S2	C3S3	C3S4
Video time*	10.848*	11.181	11.305	11.405	no obs	11.705
NALDN ss.hto	10.848	n.a.	11.311	11.408	11.535	11.706
OKLMA low point***	10.845	11.182	11.302	11.407	11.535	11.704
LASA waveforms	10.848	11.181	11.311	11.408	11.534	11.707
Still Image						11.705 (most likely time)

* Video frames referenced to time of C1/C2S1 according to NALDN and LASA.
** All times refer to a 33.33 ms frame. Event could have been at any time in that interval.
*** Times of lowest points relevant to ground stroke or air-discharge.

Similarly, the air discharge is accompanied by widely dispersed VHF source locations. The first stroke in the third channel has fewer widely dispersed VHF sources, but many more than associated with the second, third and fourth strokes. The fourth stroke has more VHF source locations associated with it than the second and third, and as we noted, also appears to have been preceded by a dart-stepped leader. The third stroke has very few VHF source locations, consistent with the fact that it was not observed on the video and had the lowest estimated peak current. The second stroke, also having a low peak current also had relatively few VHF source locations associated with it. Finally, as a different form of summary, and to put the concept of a lightning flash in perspective, we present in Figure 5 all 3285 VHF source locations in a 3-d projection.

Figure 5. All 3200 VHF source locations for the flash on June 10, 01:17:10+ U.T.

7. CONCLUSION

For some time, the authors have been fascinated with the question of what constitutes a lightning flash, or, if you will, the definition of a "flash". The answer, for ground flashes, in terms of electric-field records and visible light imaging has been fairly well accepted for many decades. The availability of VHF source location data from lightning mapping arrays adds a new dimension to the picture, allowing us to compare visible light, broadband electromagnetic emissions, and VHF source locations from the same processes at a level of detail not possible before. We hope with further studies of this type to begin to address questions about how intra-cloud and ground-flash processes are related and thus questions about how lightning is initiated, why some flashes have connections to ground and others do not, and in general what constitutes a lightning flash.

8. REFERENCES

Edens, H.E., W. Rison, P.R. Krehbiel, R.J. Thomas, Bolt-from-the-Blue Lightning Discharges, American Geophysical Union, Fall Meeting 2007, abstract #AE41A-04 12/2007,2007AGUFMAE41A.04E

Thomas, R.J., P.R. Krehbiel, W. Rison, S. J. Hunyady, W.P. Winn, T. Hamlin, J. Harlin, Accuracy of the Lightning Mapping Array, J. Geophys. Res., Vol. 109, No. D14, D14207 10.1029/2004JD004549, 29 July 2004

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