Detailed Streamer Observations & Modeling of a Nearby Negative Flash

Poster AE11A-2409

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Abstract (Revised)

The streamer to leader transition defines much of the physics of long sparks near atmospheric pressures. Streamer length is an important parameter in understanding lightning protection because of its link to step length and striking distance. While streamers are routinely observed in the lab, there have been only a few observations in the field. Fewer still are of natural flashes, and almost none have been observed much above sea-level.

Leaders: bright-tips, heated by streamers, many observations

Streamers: dimmer, field-driven, few field observations

Prior Work

Much was learned about leader-stepping process and space stems via high-speed video studies of triggered lightning at ranges of 440–1000 m [1, 2, 3]. Stepping of natural lightning has also been captured [4, 5, 6, 7, 8]. The attachment process of natural lightning has also recently been visualized [9, 10, 11]. However, only Petersen and Beasley , Edens, Tran [12, 13, 10], and most spectacularly Saba et al. [11] have obtained clear videos of the streamer zone in natural lightning that we know from lab, theory, and triggering studies to be present.

This Work

For July 2019 storms over Langmuir Lab we obtained:

Video Phantom7, 21 Kfps, 20 mm lens, 512x256 px
Slow Ant. LEFA, 0-50 kHz, 25 bit
LMA Lightning Mapping Array
INTF Lightning interferometer

Phantom camera set to capture leaders over South Baldy (1500 m distant) without saturation. A complex flash put a leader 280 (+200 / -100) m from the camera. Sensitivity was correct to resolve the streamer zone ahead of the leader tips.

3-Views of flash

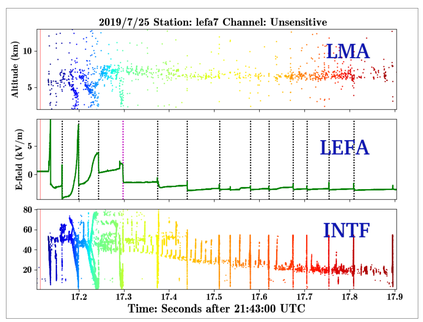

Figure 1: Negative leader of interest occurs at 17.199 seconds and is clearly visible in LMA, LEFA and 2D-INTF.

Streamer zone feeding a stepped leader

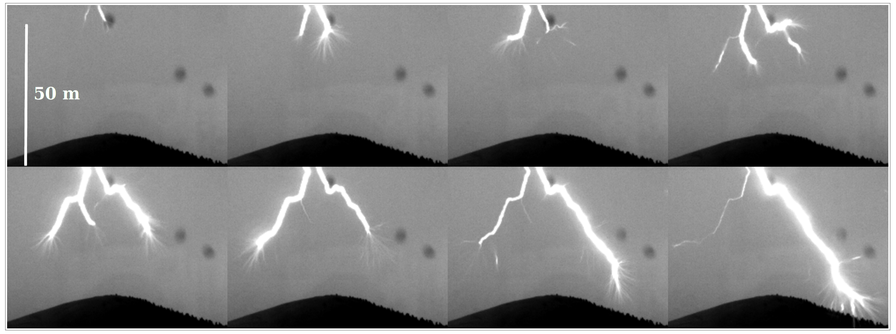

Figure 2: Time lapse at 21,000 frames/second of a negative cloud-to-ground flash occurring 200-400 m from the camera. Frames cover final 400 μs before attachment. One can see the filamentary streamer zone in each frame. Space stems are also apparent in some frames.

Flash-range / Streamer-lengths

Measurem't method –	Leader range (meters)	Streamer-zone length shortest (meters)	longest (m)	median (m)
Laser range	180 (+?/-10)	2.1	9.3	4.7
INTF	280 ±50	3.3	14.5	7.3
NLDN	390 ±200	4.5	20.2	10.2

Table 1: Summary of measurements of 21 streamers from the eight frames of figure 1. 2-D length depends on range.

Figure 3: **Minimum range** determined by inspecting this still video frame as beginning of return stroke (RS). Trees illuminated by the RS were identified and their distance from camera measured with laser range-finder long after the storm ended. Since trees obscure the RS, the 180 m laser measurement is a lower bound.

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Image Processing

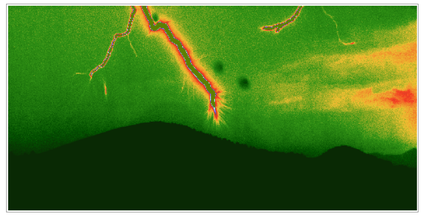

Figure 4: Unsharp masking, followed by a color gradient to enhance contrast, allowed streamer length measurement by pixel counting.

Ranging with LMA/INTF

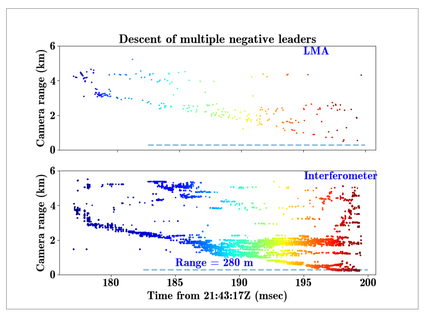

Figure 5: LMA data (top) was combined with 2D Interferometer to create a higher resolution 3D data set (bottom).

Streamer-zone length on Negative leaders

Alt. (meters)	Streamer lengths -median-	Range (meters)	Location –	Author –
50	14	440	LOG, FL	Tran [10]
350	10	770	Norman, OK	Petersen [12]
600	2.5	200	Saõ José dos Campos, Brazil	Saba [11]
3200	7.3	280	Langmuir, NM	This Work
9000	80	10000	Langmuir, NM	Edens [13]

Table 2: Comparison of the few studies of negative natural lightning

Rough Model

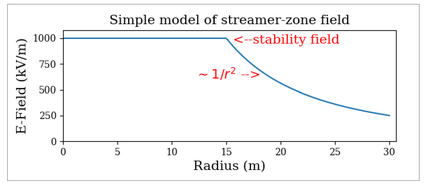

Figure 6: Simple model of a streamer zone maintains a constant stability field E_{st} to end of streamer zone, then resumes $1/r^2$ behavior. Zone radius from Table 1, E_{st} (approximate) from Pasko and Kochkin [14, 15]

$$L = \frac{\Delta V}{2E_{st}} \quad (1)$$

$$\frac{E_{st}}{E_0} = exp(-z/9.7\ km) \quad (2)$$

$$\frac{L_{st}}{L_0} = exp(z/9.7) \quad (3)$$

Altitude dependence?

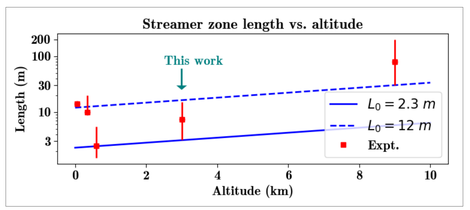

Figure 7: For multi-measurement data sets, the bars show the max, median and min lengths of the streamer zone. There is no reason to suppose that ΔV is the same for all published measurements.

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Summary

Novelty: There are few clear high-speed images of natural lightnin.g streamer zones.

Relevance: Zone length should relate to step length and attachment.

Main result: 21 streamers varied from 3–15 m (median 7 m) based on INTF/LMA.

Multi-modal: NLDN and laser bracketed the INTF/LMA measurements, giving added confidence.

Altitude dependence: Is expected. Data set too small to separate z-dependence from other factors (e.g. ΔV, frame-rate, visibility).

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