Fractal properties of lightning from high-speed video observations

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Abstract

The concept of fractals has been used to describe and understand complex development and spatial structure of lightning, jets, and sprites. In those transient electrical discharges, the discharge channels may branch repeatedly or extend with irregular paths, forming a discharge network beyond the ability of fluid or particle models. The modeling studies based on the fractal concept has achieved certain success, reproducing phenomenological properties of lightning [Mansell et al., JGR, 107, 4075, 2002; Riousset et al., JGR, 112, D15203, 2007;], jets [Pasko and George, JGR, 107, 1458, 2002; Krehbiel et al., Nat. Geosci., 1, 233, 2008; Riousset et al., JGR, 115, A00E10, 2010] and sprites [Pasko et al., GRL, 27, 497, 2000]. The fractal models used in those studies are all based on the stochastic growth approach proposed by Niemeyer et al. [PRL, 52, 1033, 1984] to model dielectric breakdown. There are several key parameters in the dielectric breakdown model of Niemeyer et al [1984], the values of which were determined by comparing the modeling results with laboratory electrical discharge experiments. Those values have never been rigorously validated for the natural discharges.

We conducted an observational campaign in the summer of 2016 to study lightning, jets, and sprites. A few interesting lightning discharges were recorded by a high-speed camera. The video recordings show that the propagation of lightning discharge channels is very complex, particularly for high-peak current lightning. The downward propagating lightning typically has multiple branches when it first enters the field of view of the camera, and each of them splits repeatedly during the subsequent propagation. In this talk, we present a detailed analysis of the high-speed images and formulate useful constraints to the fractal model of lightning.

Introduction

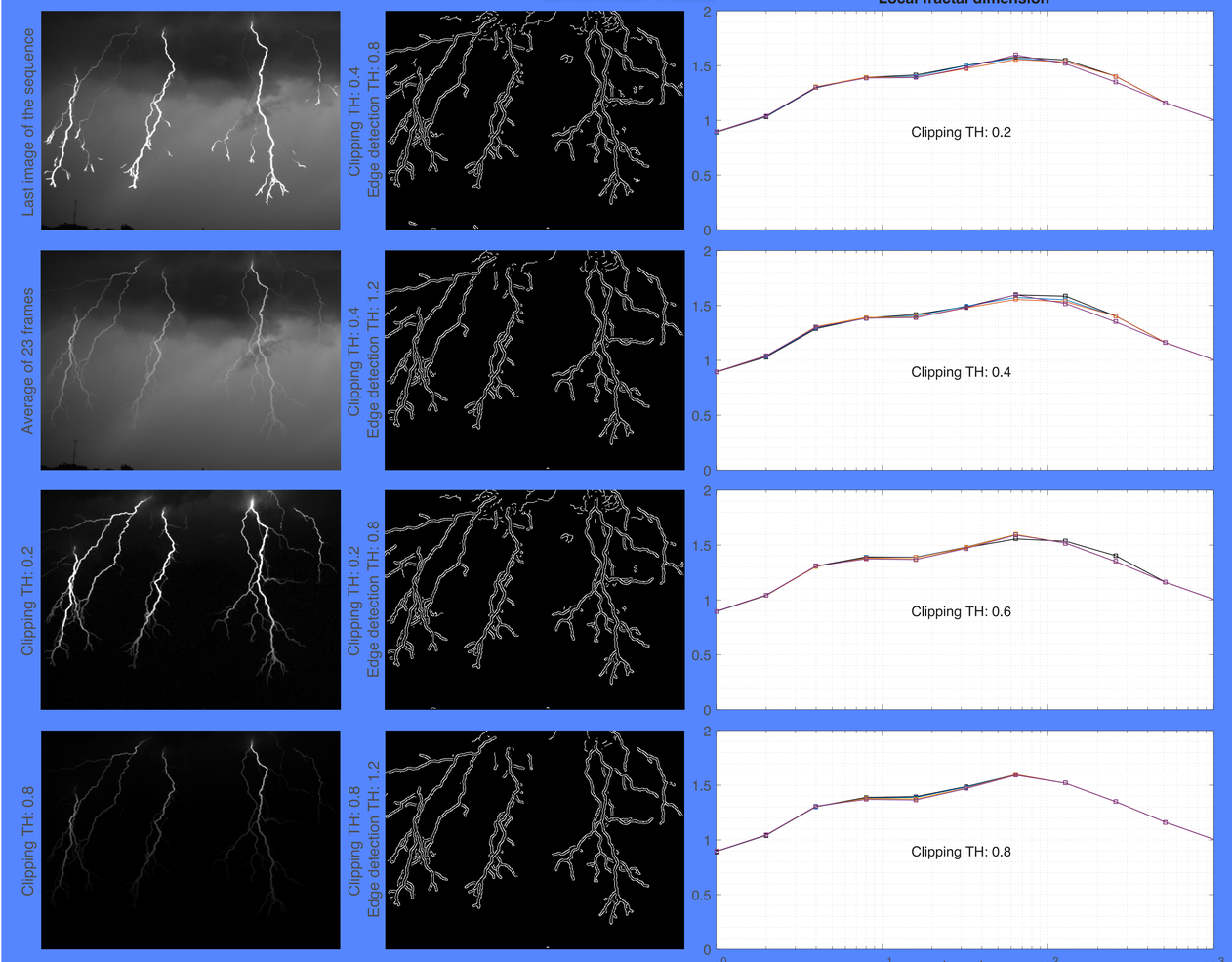
Many recent studies have investigated the details of individual lightning channels or leaders by analyzing high-speed video observations of lightning. Here we study the overall morphology of lightning with the high-speed images, the fractal dimension of lightning in particular. The images were recorded by a Phantom v1210 camera. Two flashes are analyzed here.

First flash. The flash was recorded at 7000 fps on May 20, 2016. The storm developed over central FL, and reached its maximum intensity as it moved eastward over Melbourne. It then moved offshore and gradually dissipated. At the time of recording, the camera system didn't have a GPS unit, but after comparing relative timings of subsequent lightning flashes/strokes, it is found that the flash likely corresponds to one of these two NLDN events: 19:47:02.265 28.0558 -80.6499 -14kA, 19:47:02.379 28.0561 -80.6507 -29kA. The distance to the camera is about 2.6 km.

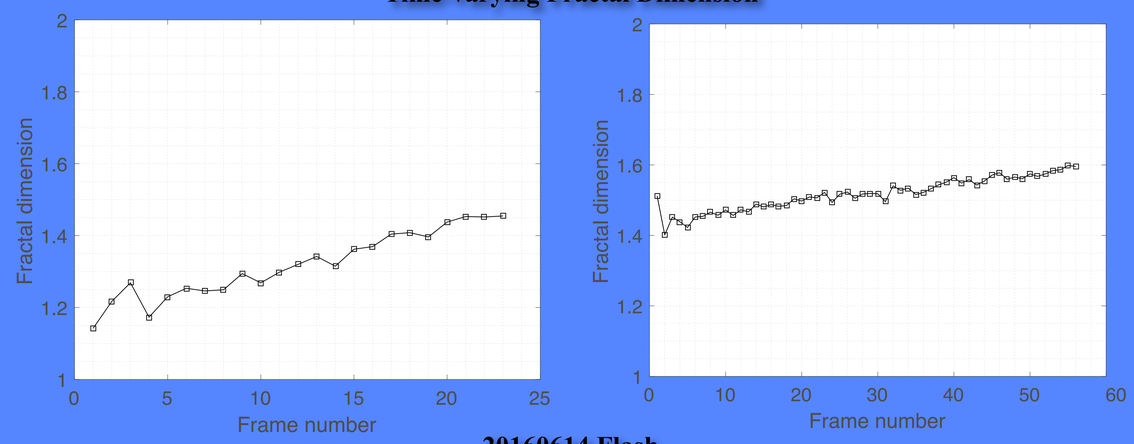
Second flash. The flash was recorded at 35000 fps on June 14, 2016. It occurred during a short-lived, intense pulse of convection with strong divergence at the cloud top. The flash is a BFB discharge and corresponds to this NLDN record: 20:33:20.005 28.0411 -80.6864 -169.1kA. The distance to the camera is about 6.6 km.

Box counting method. The fractal dimension of the lightning leader is found by using the box counting method. The image is covered by a grid with a mesh size r, and the grid boxes that contain any part of the lightning leader are counted. The obtained number N(r) depends on the size r. The fractal dimension is the ratio of the logarithms of N(r) and 1/r.

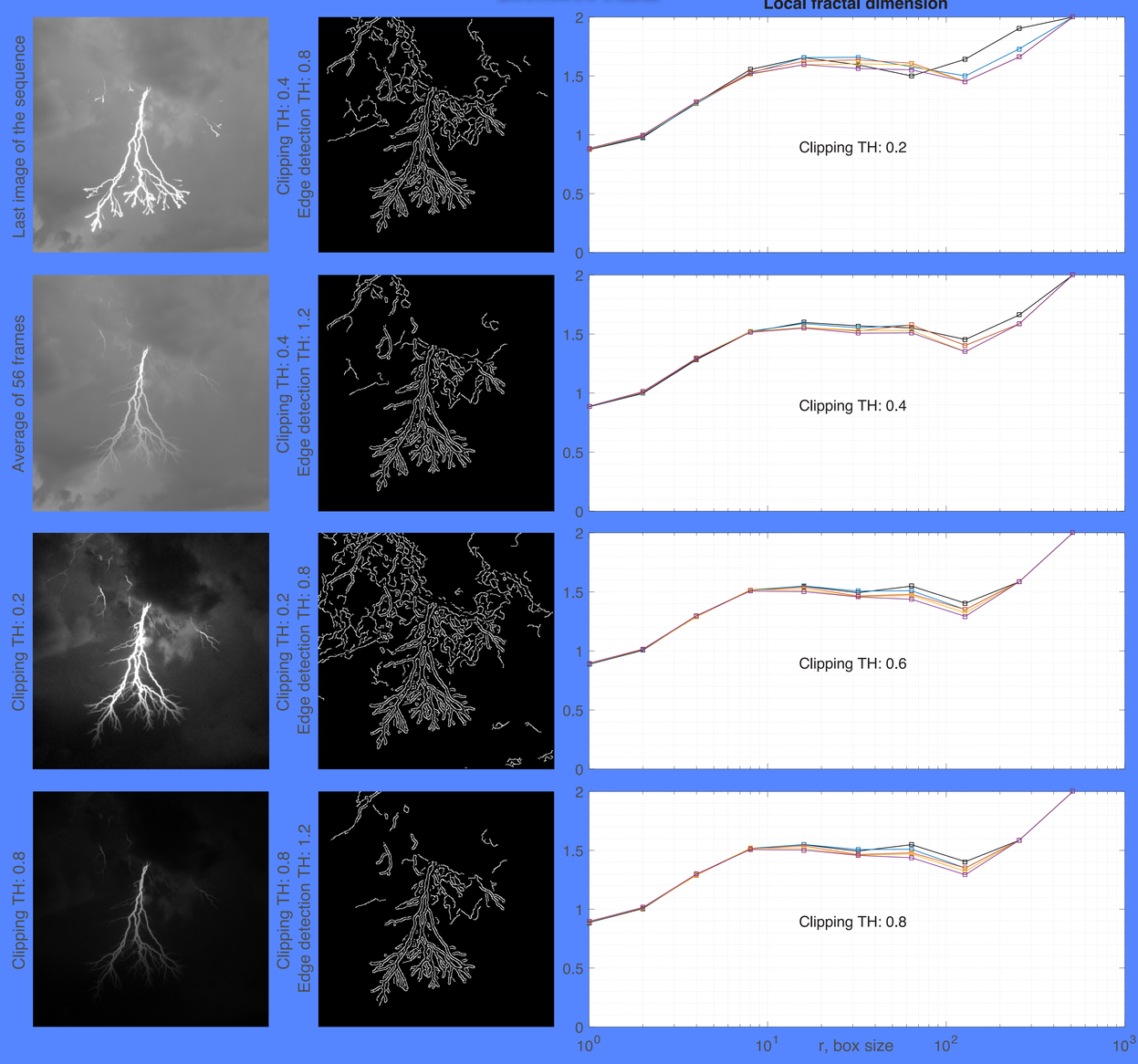
20160520 Flash



Time-varying Fractal Dimension



20160614 Flash



Summary and Conclusion

1. The high-speed images of the two lightning flashes analyzed in this study show they have complex temporal and spatial properties.

2. The fractal dimension of the lightning leader found by using the box counting method varies from 1.4 to 1.6 for one flash and from 1.5 to 1.6 for the other, when the lightning almost reaches ground.

3. As the lightning leader propagates downward, the fractal dimension increases. The rate of the increase is different between the two flashes.

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