



## High-speed video of competing and cut-off leaders prior to “upward illumination-type” lightning ground strokes

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This study presents evidence to test a hypothesis regarding the physical mechanism resulting in very weak “upward illumination” (UI) type ground strokes occurring within a few milliseconds after a normal return stroke (RS) of a negative lightning flash. As described in previous work [Stolzenburg et al., JGR D15203, 2012], these short duration (< 1 ms) strokes form a new ground connection, without apparent connection to the main RS, over their relatively short (< 3 km) visible upward return path. From a dataset of 170 video flashes acquired in 2011 (captured at 50000 frames per second), we find 20 good UI examples in 18 flashes at 2.5-32.3 km distance from the camera. Average separation values are 1.26 ms and 1.9 km between the ground connections of the UI and main RS. Based on electric field change data for the flashes, the estimated peak current of the UI strokes averages -5.0 kA, about one-third the average value for the preceding RS. In 15 cases the video data show a distinct stepped leader to the UI which develops concurrently with the stepped leader to the main RS. Estimated altitude of the UI leader tip just before the main RS occurs ranges from 0 to 610 m, and in 7 cases steps are visible in the UI leader after the main RS. In most of the examples the RS and UI appear as separate channels for their entire visible portion, but in 5 cases there is a junction indicating the UI leader is a cut-off branch from the main leader. A generalized schematic of the seven main luminosity stages in a typical UI, along with video examples showing each of these stages and electric field change data, will be presented.