

EGU21-13711

<https://doi.org/10.5194/egusphere-egu21-13711>

EGU General Assembly 2021

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The Impulsive Nature of Lightning Initiation

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We report results from imaging the initiation region of lightning via 3D interferometric beamforming on data collected by the Netherlands-based core of the Low Frequency Array of Antennas (LOFAR). LOFAR achieves 1 nanosecond timing accuracy and meter-scale spatial precision in lightning imaging on pulses observed in the 30-80 MHz band via the 38 Dutch-based stations. This project complements and enhances the previous work of the LOFAR lightning group of Groningen [Hare, B.M., et al., *Nature* 568, 360363 (2019)], and [Scholten, O., et al., *ESSOAr* 10503153] in order to improve image detail in regions with weak sources. This project incorporates beamforming techniques to improve upon previously employed methods with the result of improving both spatial and time resolution of lightning sources. In doing so, we have located and imaged the first non-impulsive sources in lightning flashes. These sources are believed to be caused by a streamer-cascade-like initiation event leading to the formation of the first leader in two separate lightning flashes. The initiation starts from essentially background and within a tens of microseconds ramps up a few orders of magnitude before the first impulsive sources connected with lightning leaders are observed. The events are likely an analog of fast breakdown in narrow bipolar events, and here we report their ramp-up rate, propagation speed, and trajectories.