Three-Dimensional Fractal Modeling of Lightning and Jet Discharges and Comparison with Lightning Mapping Observations

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Numerical modeling of lightning can provide insightful information for understanding electrification mechanisms in thunderstorms, initiation and propagation mechanisms of different types of lightning discharges, as well as blue jet [Wescott et al., Geophys. Res. Lett., 22(10), pp. 1209--1212, 1995; Sentman et al., Geophys. Res. Lett., 93(20), pp. 2857--2860, 1995; Boeck et al., J. Geophys. Res., 19(99), p. 1992, 1995] and gigantic jet [Pasko et al., Nature, 416, pp. 152--154, 2002; Su et al., Nature, 423, pp. 974--976, 2003] discharges, providing a path of electrical contact of tropospheric thunderstorms to the upper regions of the Earth's atmosphere. The development of a GPS-based Lightning Mapping Array (LMA) that accurately locates the source of VHF emissions from lightning in three spatial dimensions and time, has allowed efficient dynamic mapping of individual lightning channels [Rison et al., Geophys. Res. Lett., 26(23), pp. 3573--3576, 1999]. In this work, we present results from an updated version of the three-dimensional probabilistic model developed in [Riousset, MS Thesis, Penn State, 2006; Riousset et al., J. Geophys. Res. 112, D15203, 2007]. The model describes the development of bi-directional structures of positive and negative lightning leaders closely resembling discharges observed by LMA. The model represents a synthesis of the original dielectric breakdown model based on fractal approach proposed by Niemeyer et al. [Phys. Rev. Lett., 52(12), 1033--1036, 1984] and the equipotential lightning channel hypothesis advanced by Kasemir [J. Geophys. Res., 65(7), 1873--1878, 1960] and places special emphasis on obtaining self-consistent solutions preserving complete charge neutrality of the discharge trees at any stage of the simulation. The model results are compared to a representative intracloud discharge measured by the New Mexico Tech Lightning Mapping Array in a New Mexico thunderstorm on July 31, 1999. These comparisons indicate, in particular, that the model is capable of realistically reproducing principal features of the observed event including the initial vertical extension of the discharge between the main negative and upper positive charge regions of the thundercloud, followed by horizontal progression of negative and positive leaders in the upper positive and main negative charge regions, respectively. In this work, we also compare representative simulation runs, including bolt-from-the-blue discharges [Rison et al., Geophys. Res. Lett., 26(23), pp. 3573--3576, 1999; Thomas et al., Geophys. Res. Lett., 28(1), pp. 143--146, 2001] and jet events similar to those observed by Lyons et al. [Bull. Am. Meteorol. Soc., 84(4), 445--454, 2003], to typical lightning discharges measured by LMA over New Mexico and the Great Plains during the STEPS 2000 campaign [Lang et al., Bull. Am. Meteorol. Soc., 85(8), 1107--1125, 2004]. The comparisons of the model and observed discharges reveal that an adequate choice of the electrical structure of the model thundercloud permits the development of model discharges reproducing principal features of the observed events. The present study provides further support of the ideas advanced recently in [Krehbiel et al., Eos Trans. AGU, 88(52), Fall. Meet. Supp., AE23A-0891, 2007] that the mechanisms by which blue and gigantic jet discharges escape out of clouds are similar to those of downward cloud-to-ground lightning.