Modelling of streamer ignition and propagation in the system of two approaching hydrometeors

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The lightning initiation in low thundercloud fields represents an unsolved problem in lightning discharge physics. One of the initial conditions required for formation of a hot leader channel is initiation of non-thermal streamer discharges. Streamers can be initiated from electron avalanches, however, the problem of existence of an electric field strong enough for streamer initiation in thunderclouds is still open. The maximum electric field in thunderstorms measured by balloons is typically ~3-4 kV/cm/atm, that is significantly smaller than the breakdown electric field needed for avalanche multiplication of electrons Ek=28.7 kV/cm/atm. One of the possible explanations for the streamer corona initiation is that hydrometeors greatly intensify the local electric field by at least an order of magnitude to initiate an electron avalanche. It was suggested that a particle pair or chain create more favorable conditions for initiation of lightning discharge than a single precipitation particle in low electric fields. Recently, Cai et al. [GRL, 44, 5758-5765, 2017] and Cai et al. [JGR, 123, 7050-7064, 2018] analyzed the ignition conditions for two hydrometeors of same and different radii. In the present work we use first principles plasma fluid model to study streamer initiation scenarios in a system of two hydrometeors with typical radii on the order of several millimeters under thunderstorm conditions (i.e., at an elevated location in the Earth's atmosphere corresponding to half of air density at ground level and at applied electric field approximately half of that required for avalanche multiplication of electrons in air). It is demonstrated that UV photons produced by the electrical discharges developing due to the electric field enhancement in the gap between two hydrometeors and resultant photoionization in the discharge volume lead to much less stringent conditions for conversion of these discharges to a filamentary streamer form than in the case not accounting for the effects of photoionization. It is also demonstrated that this photoionization feedback [Naidis, JPD, 38, 2211-2214, 2005; Liu et al., JASTP, 80, 179-186, 2012] is critical for understanding and correct description of the subsequent streamer discharges developing on the outer periphery of two hydrometeors whose potential is equalized due to the electrical connection established by the initial streamer discharge between them. The initial streamer ignition between the hydrometeors can be preceded by the corona development, that can have detrimental effect on the ignition. However, it is demonstrated that for hydrometeors approaching with a speed of 10 m/s the effect of this onset corona is small.

