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Streamer network critical behavior and lightning initiation

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In [1] it was established that collective dynamics of charged hydrometeors that involved in turbulent motion play a fundamental role in thundercloud electrostatic energy redistribution and dissipation. The main reservoirs for accumulating electrostatic energy in thunderclouds are i) the large-scale field of the main charged layers that appear due to the large-scale separation of oppositely charged hydrometers, ii) the intermediate-scale field of charged hydrometeors distributed in the turbulent flow, and finally iii) the small-scale field of net and polarization charges on the surface of individual solid and liquid water particles. Since three different spatial scales are involved into the process of electrostatic energy dissipation, we represent the lightning initiation scenario as a sequence of two transitions of discharge activity to progressively larger spatial scales: the first one is from small-scale avalanches to intermediate-scale streamers; and the second one is from streamers to the lightning seed. At the first stage of the proposed scenario, the essentially non-conducting cloud becomes seeded by elevated ion conductivity regions with spatial extent of 0.1 - 1 m and a lifetime of 1 - 10 s. These regions can serve to promote the intermediate electric field enhancements and increase in pre-ionization level that is sufficient for the initiation and development of streamers. Due to the positive the proposed streamer generation mechanism has an important feature: streamers in our scenario are not exponentially rare events, but continuously fill the entire volume. The collective dynamics of such a nearly continuous, volume filling streamer network appears to be very sensitive to both the magnitude of external large-scale electric field and longitudinal extent of the region occupied by the field. Moving in the course of its development along the external field, a positive streamer can get into the negative trails left by other streamers (relay race effect). In this way, the size of the streamer discharge along the external field can grow, providing the emergence of a kind of streamer trees, thereby tapping electrostatic energy from a relatively large cloud volume. Over time, many streamer trees are feeding their current into narrow channels, where the heating occurs (the bottleneck effect). The hot segments of the network can get polarized and grow within its overall channel system even if the ambient field amplitude is much smaller than the critical field of streamer propagation. Successful initiation of lightning also requires that potential difference across the layer occupied by the large-scale electric field makes about three megavolts. The proposed scenario can possibly lead to a paradigm shift in our approaches to the still unsolved mystery of lightning initiation, because it does not require the presence of super-energetic cosmic ray particles, unrealistic potential difference inside the cloud, or unrealistically large hydrometeors.

1. Iudin, D.I., Rakov, V.A., Syssoev, A.A. et al. Formation of decimeter-scale, long-lived elevated ionic conductivity regions in thunderclouds. npj Clim Atmos Sci 2, 46 (2019) doi:10.1038/s41612-019-0102-8.