Structure transitions in sprites and their implication of electron density in the lower ionosphere

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Sprites are known as one of lightning-related transient luminous events, occurring at altitudes of 40-90 km above thundercloud, and have a large tree-like structure. From recent satellite observation, we find that they are popular phenomena in the middle and low latitude range, especially in land. From detailed observation of their optical emissions we also find that the vertical structure in sprites shows two clear transitions, one of which is concerned with formation of filamentary channel called streamer. Streamer is one of fundamentals in gas discharge and propagates with high-density plasmas in its body and an impulsive polarization electric field in its tip. In a strong electric field an electron avalanche starts at a certain point through ionization of neutral molecule by accelerated electrons, and a streamer is formed when the polarization field by the produced plasmas cancels out the background field. Since the degree of ionization increases with altitude in the lower ionosphere of weakly-ionized, an upper part of the globally-induced electric field by lightning is shielded in a timescale defined by local conductivity. Above a certain altitude the lifetime of the field is not sufficient to produce a certain amount of plasmas for streamer formation so that the first structure transition is formed there. This transition is estimated to be around 70 km altitude and is characterized by two examples. Above this transition altitude a diffuse optical emission called halo is produced through electron impact excitation of neutral molecules in background electric field; while as to another one, streamer is dissipated without sustaining its structure when it propagates upward below the transition altitude. The second transition is concerned with the branching process of streamers and is observed around 60 km altitude. The structure formation of sprites generally initiates from downward propagation of a cluster of streamers produced around the first transition altitude without noticeable horizontal motion. They are rapidly branched and horizontally expanded when they come across the second transition altitude. On the basis of our understanding the transition is controlled by the effect of sharp gradients of background plasma (electron) density and of mean optical length as a characteristic scale of photoionization.

We can mention that the complexity of structure of sprites is originated from a large variation in a characteristic scale of discharge defined by electron mean free length by an order of 10^3. The macroscopic structure and its transition in consequence of the variation are attracted in the viewpoint of plasma physics because they are also due to a concurrence of electron atomic-molecular processes and behavior as plasmas. In this talk we report about a theoretical modeling of column and carrot structure formations in sprites, which are fundamentals in the macroscopic structure. We try to evaluate and discuss the ambient electron density at the uppermost altitude, the first and second transition altitudes of sprites because all of them are controlled by the electron density.