Sprite halo structures and streamer onset

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Abstract

Imaging of sprites at 16,000 frames per second indicates that streamers may be spawned from spatial structure in the preceding sprite halo. The halo structures descend rapidly with the sprite halo, but slow down and stop to form the stationary glow seen in the vicinity of the streamer onset. The streamers emerge suddenly from the halo structure propagating downwards at ~10^7 m/s. The velocities during the rapid descend of the halo are similar to those of the streamers. The luminous halo structures last longer than the main halo, which fades prior to streamer formation.

1. Introduction

Sprites are spectacular optical emissions in the mesosphere caused by transient electric fields originating from cloud to ground lightning strikes. The altitude of most sprites is between 55 and 90 km, although they have been observed reaching all the way down to near cloud tops at ~25km altitude and up to about 100 km altitude. Typically a sprite event is a combination of three optical features or elements: Elve, halo, and sprite streamers lasting from a few milliseconds to a few tens of milliseconds. The three features may vary considerably in brightness and may not be detected, or may not be present, in all events. The elve is well understood; it is caused by the electromagnetic pulse radiated out from the lightning strike exiting airglow emissions at an altitude near 95 km [1, 2]. The halo and sprite streamer elements follow the elve. They are caused by the quasi-electrostatic field in the mesosphere resulting from the lightning strike causing a redistribution of electric charges. The fundamental physics involved was first described by Pasko, Inan, and Bell [3].

The halo is a large, ~50 km horizontally, pancake like luminous feature [2], while the sprite streamers are small, ~100 m across the streamer. Cummer, Jaugey, Li, Lyons, Nelson, and Gerken [4] have presented data indicating that the streamers form near the bottom of the halo. The streamers are the result of an electrical break-down in the local atmosphere similar to electrical discharges observed in laboratory experiments [5, 6].

Recently Luque and Ebert [7] and Qin, Celestin and Pasko [8] have presented modeling efforts investigating streamer formation as part of the larger response of the mesosphere to an electric pulse caused by a cloud to ground lightning strike. In particular, Luque and Ebert [7] suggest that the sprite streamer is formed out of an ionization wave associated with the sprite halo. Thus the issue of the relation between the halo and streamer formation is raised.

2. Data

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The sprite halo has generally been assumed to be without internal spatial structure, but high-speed (16,000 frames per second) observations made in August 2009 from the NSF supported HIAPER aircraft flying at 13 km altitude near sprite producing thunderstorms over the US mid-west show considerable spatial structure in the halo. Halo structure was already noted in our first high-speed (1000 fps) sprite observations made in August 1999 from the Wyoming Infrared Observatory on Jelm Mountain, WY [9], but it was not possible to exclude very thin clouds in the field of view as the cause. In particular aircraft contrails are frequently a problem for ground based sprite observations. Clouds are not a problem at 13 km, and further, the observed halo structures moved with the halo in a way wholly inconsistent with them caused by obscuring thin clouds.

The 2009 aircraft sprite observations were made with two intensified Phantom high-speed cameras operating at frame rates between 10,000 and 20,000 fps. The imagers respond to light in the 400 – 950 nm wavelength range. One camera was configured as a slittless spectrograph to identify ionization associated with sprite streamers. Results from this data set are reported elsewhere [10]. The second camera was used as an imager recording mainly at 16,000 frames per second. Each recorded image is 640x256 pixels at 14 bit (16,384 gray levels) with a field of view of 15.2x6.0 degrees.

3. Analysis

Halos were not observed with all sprite events recorded during the 2009 aircraft campaign. In the events with a halo present sprite streamers appeared to spawn from brighter spatial structures in the halo clearly indicating a relationship. Prior to the streamer formation the halo structures descend with the halo. As mentioned above, the downward motion of the structures within the halo eliminates the possibility that the halo structures might be the product of obscuring thin clouds. The initial downward velocity is estimated in the 10^5 to 10^7 m/s range. At the time of streamer formation the downward motion of the halo has essentially stopped and further, the optical emissions in the halo surrounding the halo structures have largely decayed to below our detection level. Streamers are observed to suddenly appear from the remaining halo structure, brighten rapidly and move down at velocities near 10^7 m/s. We have in earlier campaigns observed streamer velocities up to 10^8 m/s, a third of the speed of light [11, 12]. After the streamer formation the initial luminous halo structure brightens and become part of the stationary glow at or near the top of the sprite. We have in various publications [12-15] referred to this as 'afterglow'. We suggested that the glow could be associated with the passage of the streamers, but we also clearly recognized that the energy driving the glow emissions could not come exclusively from the streamer passage. With the new observations presented here it seems more likely that the stationary glow near the streamer onset altitude is associated with the halo structure spawning the streamer. It is interesting to note that the range of the downward velocity of the halo is the same as that of the streamers. Also, the duration and speed of the downward motion makes it unlikely that the halo structures would be detectable in sprite data recorded at normal video rate (25 of 30 fps).

Triangulation of sprite streamers shows the onset to be in the 65 to 85 km altitude range [16]**.** Streamers occurring immediately after the causal lightning strike, prompt sprites, tend to have their onset at higher altitude than delayed sprites [17-19]**.** The onset altitude dependence on delay time is related to effects of the continuous current in the troposphere, as first suggested by Cummer and Fullecrug [20]. The charge buildup associated with the continuous current will add to the electric field in the mesosphere which, if conditions are right, can eventually exceed break-down and cause streamers to form. We do not at this time have data enough to investigate the relationship between halo/streamer formation and delay from the causal lightning strike.

4. Conclusions

Sprite observation made from an aircraft show that sprite streamers may be spawned from luminous structures within the sprite halo. Similar high-speed sprite data recorded in earlier campaigns, but from the ground, are consistent with these new findings, although the identification of structure within the halos is not as definitive as in this newer data set. The halo/streamer observations are largely supportive of the Luque-Ebert streamer formation model [7] in which streamers emerges from a halo ionization wave. Halos

are not observed in all sprite events, which, as suggested by Luque and Ebert [7], may just be because of insufficient imager sensitivity. If this is the case then it would suggest that the brightness of sprite halos vary much more than the brightness of streamers.

5. References

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