Three-dimensional Structure of Sprite Streamers Derived from Aircraft Observations

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The purpose of this study is to identify the spatial distribution of sprites and the three-dimensional structures of sprite streamers. Then we have carried out optical observations of sprite streamers using high-speed cameras from two jet aircrafts and performed triangulation analysis for some sprite events. As a result, it is found that sprites were occurred asymmetrically toward the parent CG, that is, sprites were occurred in a cluster with a horizontal shift of 60-80 km from parent CG. It is also found that upward streamers their diameter are about 0.3 km grew radially from a bottom part of the downward streamer its diameter is about 0.7 km and that the altitudes of upper and lower edge of upward streamers are about 77 km and 72 km, respectively. On the other hand, the altitudes of upper and lower edge of downward streamer are estimated to be 81 km and 71 km, respectively. The velocities of both of streamers were estimated to be10^6-10^7 m/s.

1. Introduction

The spatial distributions of sprites and the three-dimensional structures of sprite streamers are the key parameters to identify the occurrence conditions and the development mechanisms of them. However the three-dimensional structures of sprite streamers have never been identified because it is difficult to capture these images from multiple ground-based observation sites simultaneously due to the atmospheric absorption and scattering effects. Moreover, it is difficult to capture detailed spatial and time evolution of sprite streamers without using high-speed cameras. In order to overcome these difficulties, we have carried out optical observations of sprite streamers using high-speed cameras from two jet aircrafts. Using these high-speed image data, we have studied the characteristic of the spatial and time evolution of sprite streamers, especially three-dimensional structures which have never been revealed.

2. Aircraft Campaign in Japan

On November 28 and December 3, 2010 in winter Japan, we have carried out optical observations using a high-speed camera and a high-vision CCD camera from a single jet aircraft under collaboration between Japanese Broadcasting Corporation (NHK) and Hokkaido University. Using the high-speed camera, it is possible to capture images with a sampling rate of 8,300 fps. Using the high-vision CCD camera, it is possible to capture true color images of sprites with a sampling rate of 30 fps. During the two observation flights, we have succeeded to capture 28 sprite events. We have analyzed a columniform sprite observed at 13:12:35UT on November 28, 2010 and revealed the spatial and time evolution of the sprite streamers. This sprite consists of 4 distinct sprite elements. Each element begins as a bead between 66 and 78 km altitude and moved downward with a speed of $0.8\text{x}10^7$ – $1.1\text{x}10^7$m/s and a remnant emission stayed at the region where the bead passed through. The altitudes of upper and lower edge of columns are estimated to be 85 – 90 km and 65 – 70 km, respectively. It is found that these results are comparable with previous results derived from the sprite observations in North America [1][2].

3. Aircraft Campaign in US

On the other hand, we have carried out simultaneous optical observations using the high-speed cameras, high-vision cameras and WATEC CCD cameras from two jet aircrafts in summer US. In a leading aircraft a high-speed camera (Phantom V7.1) operated by University of Alaska Fairbanks was installed, while in a trailing aircraft a high-speed camera (Phantom V710)

operated by NHK was installed. In the period of June 27 - July 10, 2011, aircraft observations were conducted in 8 nights totally, and succeeded to capture sprite images for over 40 events by the high-speed cameras in each aircraft simultaneously. Using these image data, we have performed triangulation analysis for two sprite events observed at 05:20:49UT on July 3, 2011 and at 08:54:13UT on July 5, 2011, and estimated the spatial distributions. It is found that sprites were occurred not symmetrically toward the parent CG but asymmetrically, that is, sprites were occurred in a cluster with a horizontal shift of 60-80 km from parent CG. The horizontal distance ranging is comparable with previous results [2]. It is also found that upward streamers grew radially from a bottom part of the downward streamer and that the altitudes of upper and lower edge of upward streamers are 76 – 78 km and 72 – 73 km, respectively. Fig.1 shows a columniform sprite with upward streamer and its 3D structure. The diameter and velocity of the upward streamers are estimated to be about 0.3 km and 5.5×10^7 – 5.6×10^7 m/s, respectively. It is found that the velocities are comparable with previous results [3]. On the other hand, the altitudes of upper and lower edge of downward streamer are estimated to be 81 km and 71 km, respectively. The diameter and the velocity of downward streamer were estimated to be about 0.7 km and 4.7×10^7 m/s, respectively. The velocities are also comparable with previous results [1][3].

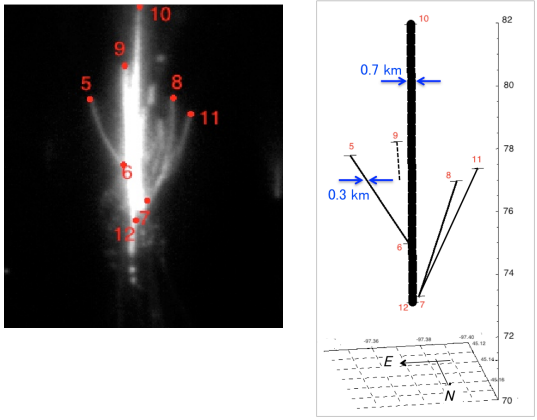

Fig.1 NHK / high-speed image data. Reference points where 3D positions are estimated by the triangulation method are labeled as “5” – “12”. (left) Estimated 3D structure of sprite streamer. (right)

4. References

[1] McHarg, M. G., H. C. Stenbaek-Nielsen, and T. Kammae (2007), Observations of streamer formation in sprites, *Geophys. Res. Lett.*, 34, L06804, doi:10.1029/2006GL027854.

[2] Wescott, E.M., Sentman, D.D., Heavner, M.J., Hampton, D.L., Lyons, W.A., Nelson, T., 1998. Observations of ‘Columniform’ sprites. Journal of Atmospheric and Solar-Terrestrial Physics 60, 733–740.

[3] Cummer, S. A., N. Jaugey, J. Li, W. A. Lyons, T. E. Nelson, and E. A. Gerken (2006), Submillisecond imaging of sprite development and structure, *Geophys. Res. Lett.*, 33, L04104, doi:10.1029/2005GL024969.