Correlation between halos and their parent lightning

C. L. Kuo[1], E. Williams[2], J. Bór[3], Y. H. Lin[1], J. K. Chou[1], A. Chen[1], H. T. Su[1], R. R. Hsu[1], G. Satori[3] and L. C. Lee[4]

[1] Department of Physics, National Chen Kung University, Tainan, Taiwan
[2] Parsons Laboratory, Massachusetts Institute of Technology, Cambridge, MA
[3] Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences, GGI, Sopron, Hungary
[4] Institute of Space Science, National Central University, Jhongli, Taiwan

This article extends the work of Williams et al. [1] on halos, and addresses major issues on halo observations. Using ISUAL and lightning data, the displacement between the parent lightning stroke and the geometric centre of halos is re-examined. The current moment of the halo parent lightning can be derived using the ISUAL 777.4-nm lightning spectral data [2]. The inferred lightning current moment was found to be highly correlated with the brightness of the pure halos. Ionization associated 391.4-nm emission in halos were identified in two out of the five behind-the-limb halos, where the lightning emissions are blocked by the Earth surface. The impacts of halos on the ionosphere will also be discussed.

1. Halos

Thunderstorm-induced transient optical emissions near the lower ionosphere and in the middle atmosphere are collectively termed as transient luminous events (TLEs), and categorized into sprites [3], elves [4], blue jets and gigantic jets [5,6,7]. In this paper, the focus of interest is on halos.

The halo is a bright pancake-like disk (~80km in size) occurring at altitude ~85 km above thunderstorms [8]. Unlike sprites are triggered by +CG exclusively, most halos are induced by -CGs that occur almost exclusively over the open water [9]. Halos were initially thought to be elves by most ground observers using conventional cameras with 30 frame-rates per second. Barrington-Leigh et al. [10] were the first to prove that halos are distinct from elves (with a much larger diameter of ~300 km and a shorter luminous duration of less than 1ms).

2. The ISUAL payload

The ISUAL (Imager of Sprites and Upper Atmospheric Lightnings) payload on FORMOSAT-2 comprises of three sensor packages including an intensified CCD imager, a spectrophotometer and a dual-band array photometer. FORMOSAT-2 is the first satellite that features a payload mission for the survey of the upper atmospheric TLEs. For the halo events reported in this paper, the imager data were recorded through a 623-750 nm N_2 1P filter and with an image frame integration time of 29 ms.

3. Optical data analysis and discussions

3.1. Spatial correlation between halos and their parent lightning

Wescott et al. [8] compared the maximum brightness point of halos and the parent lightning location from a triangulation measurement. They found that the maximum brightness of the halo is very close to the location of the parent lightning. Here we examine 28 halos for the spatial displacement between the geometric centres of halos and their parent lightning. Our results are consistent with that reported in Wescott et al. [8].

3.2. The brightness of halo and the current moment of the causative lightning

We analyzed 185 ISUAL-recorded pure halo events from July 2004 to December 2007. The average brightness of halos through the 1PN_2-filter Imager is ~ 0.25 MR. The current moment of the halo parent lightning is inferred from the 777.4-nm lightning spectral data [2]. A firm linear relationship is found between the lightning peak current and brightness of the halo. Of the 185 halos, 121 events were found to have identifiable ELF sferics from the recording of the Nagycenk station (NCK), Hungary. Among the coincident events, 23 were induced by positive CG lightning and 98 are from negative CG lightning [1]. Through analyzing the inferred charge moment change (CMC), the correlation between the CMC and the halo brightness is relatively weak. These findings reflect that lighting peak current plays an important role in the generation of halos and the peak current of the oceanic lightning likely is substantially higher than that of the land lightning.

3.3. Ionization emissions in halos

In the halo dataset, five events occurring behind the Earth limb and thus free from the lightning emission contamination were analyzed. Two of the five behind-the-limb halos were found to have significant 391.4 nm emissions. The 391.4 nm emissions in TLEs are mostly from N_2^+ 1N (0,0) emission and is considered to be an good indicator of ionization. Therefore, the generation of halos likely also involves ionization processes. However, even with the extra ionized electron seeds not all the halos can develop further to initiate sprite streamer structures.

3.4. Possible effects of halos on the ionosphere

Halos not only are products of electron-impact processes near the lower ionosphere, but also stand as optical evidence of current flowing from atmosphere into the ionosphere. Recently, a atmosphere-ionosphere model was developed to study how the atmospheric current affects the ionosphere dynamics [11]. For night-side thunderstorm systems with extremely high flash rates (~1/s) and large accumulated charge (~300C), halos may induce significant variations in the total electron content and plasma bubbles in the ionosphere.

4. Summary

The ISUAL-recorded halos were used to explore the correlation between halos and their parent lightning. The geometric centres of halos were found to locate directly above their parent lightning strokes. The brightness of the halos is proportional to the current moment of the parent lightning. Halo emissions were found to include both the emissions from the electron-impact excitation and the emissions from the ionization processes. The thunderstorms with extremely-high lightning activities may cause density variations and plasma bubble formation in the nighttime ionosphere.

5. Acknowledges

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6. References

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