ELF TRANSIENTS AND IONOSPHERIC DISTURBANCESS IN ASSOCIATION WITH SPRITES AND ELVES

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ABSTRACT: Quantitative analysis is performed using the data from coordinated measurement consisting of ELF field, VLF subionospheric disturbances and lightning discharges associated with TLEs. These TLEs (sprites and elves) were observed during the lightning storm in wintertime over Japan sea in 1998/99. We find the clear straightforward relationship between charge transfer of the parent discharge calculated from ELF (f<15 Hz) and the ionospheric disturbances with correlation ratio of 0.97 regardless of the types of TLEs indicating significant atmosphere-mesosphere-ionosphere coupling. This result implies the fact that a large QE filed change above lightning with TLE plays a significant role for modifying the electric property of lower ionosphere. Sprites tend to associate with a large ionospheric disturbance (-13~+4.6 dB) with a large charge transfer (52~175 C), whereas a large lightning peak current (+223~+470 kA) (or slow-tail amplitude) leading to the strong EMP is necessary to initiate elves, but with rather small ionospheric disturbances.

INTRODUCTION

Recent findings of TLEs (transient luminous events) in the mesosphere in the various places over the world attract a lot of interests about the electrodynamic coupling between the lightning in the troposphere, mesosphere and lower ionosphere [e.g. review by Rodger, 1999]. In Japan TLEs were observed during the winter thunderstorm activity over Japan sea [Fukunishi et al., 1999; Hayakawa et al., 2002]. However, in order to have the comprehensive understanding on the coupling mechanism between the mesospheric optical phenomena and tropospheric lightning, and the ionosphere, coordinated measurement with quantitative information is extremely important.

In this paper we present the results of our winter lightning campaign especially payed our attention on the phenomena in association with TLEs over Japan sea as a case study.

OBSERVATION

TLE data (onset time and type of optical emission) on 19 December 1998 and 22 January 1999 are provided by Tohoku University during severe thunderstorm activity in the Hokuriku area. Low noise CCD camera and 16-channel array photometers were deployed to identify the optical events, and these instruments were set in Dodaira Astronomical Observatory (36.0 N, 132 E) and Sendai (38.3 N, 140.9 E). Elves and sprites were identified mostly by the photometers and CCD camera respectively, and 'elve with sprite' event was identified when sprite occurred within 200ms after elve onset time.

Continuous wide-band ELF transient measurement is performed in Moshiri station, Hokkaido (geographical coordinate, 44.2 ° N, 142.2 ° E). We have fully-calibrated three field components (vertical electric field, Ez and two horizontal magnetic field components, Hew ad Hns) with the observed frequency between 1 and 800Hz (a sampling frequency of 2kHz).

Different VLF transmitter signals (NWC, NPM, NLK, NSS) are recorded continuously at Kasugai, Aichi (35.25N, 138.98E) to monitor the ionospheric disturbances. This system (OMNIPAL) calculates the amplitude and phase of the individual VLF transmitter signal with 100ms time resolution by using GPS high accuracy timing unit.

Japan lightning detection network (JLDN) provides the absolute time, location and peak current of most cloud to ground lightning discharges. We use this data to determine the location and peak current of parent lightning discharges of optical events.

RESULTS

During the period 0:00-20:00 UT on 19 December 1998, 13 optical emissions were detected, while 9 elves without sprites and 16 sprites or sprites with elves were detected optically.

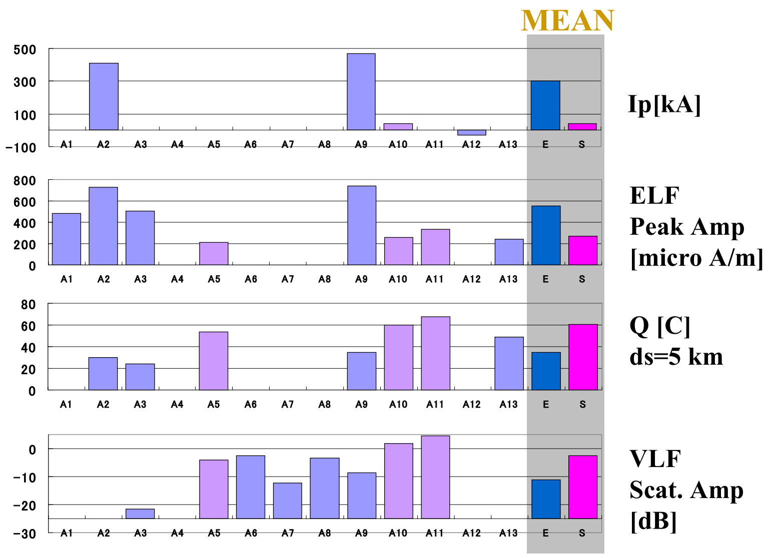


Figure 1. Summary of parameters for different types of TLEs on December 19, 1998.

Figure 1 and Figure 2 show the summary of different parameters for different types of TLEs on December 19 and January 27. Bars in panels indicate the value of each event for the same parameter derived experimentally. Right most 2 bars are mean values of each parameter for elve (indicated by E) and sprite (indicated by S). As is seen from figure, not all the events produce the different parameters simultaneously. But, as long as mean value is concerned peak current (IP) and ELF peak amplitude have similar tendency, which is large mean values for elves and small mean value for sprite. This result implies that large EMP is necessary for elve generation. On the contrary, change transfer (Q) and VLF scattered amplitude has an opposite characteristic. That is large value for sprite and small value for elve. In this case, sprite need large QE field and produce large ionospheric perturbation. In the case of January event we have similar tendency seen in December except ionospheric perturbation. Values between the two are nearly identical and difference between the events is relatively small, which probably indicates the response of ionosphere is quite different between two different days.

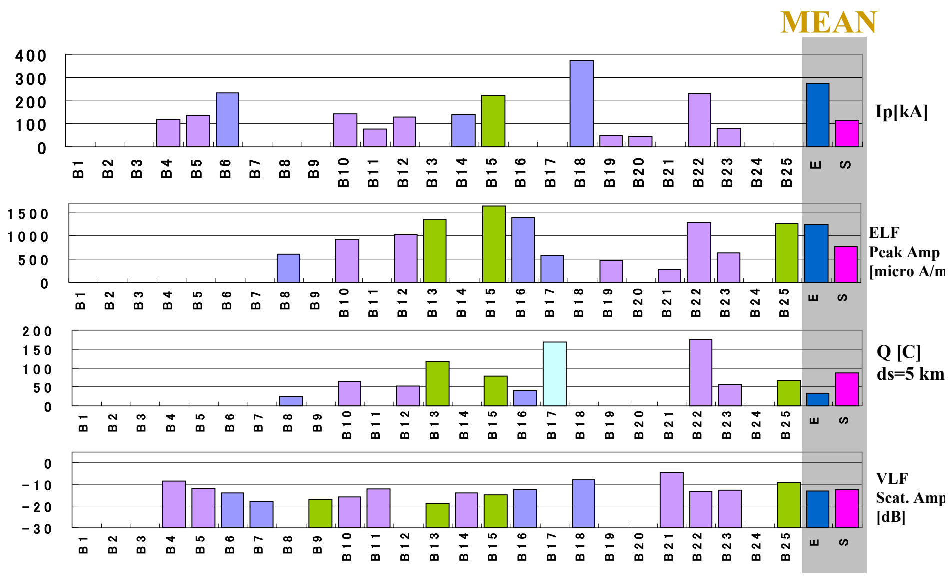
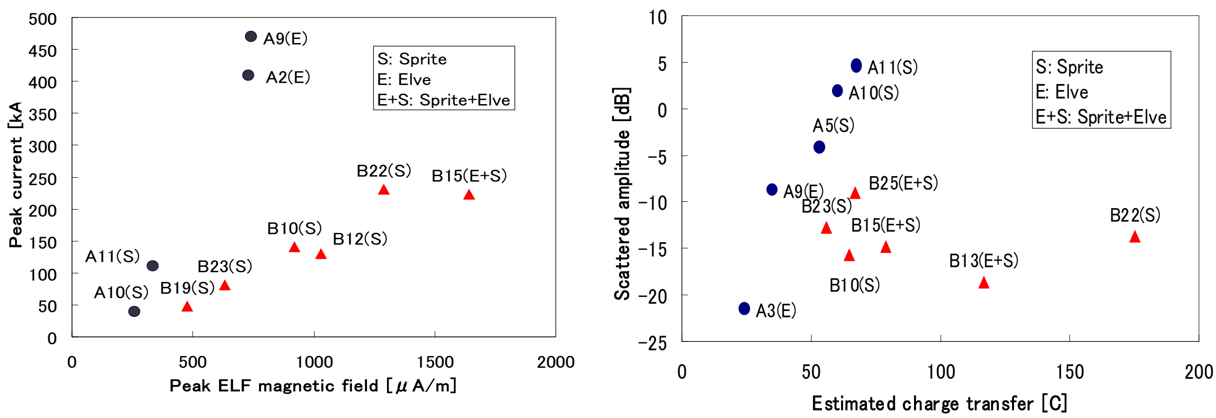


Figure 2. Same type of variation as Figure 1 but for January 27, 1999.

JLDN peak current as a function of ELF peak amplitude is plotted in Figure 3(a). The peak amplitude correlates very well with peak current in the case of sprite-producing discharges either in December or January events. Correlation ratio r=0.98 for December events (indicated by circles) and r=0.95 for January events (indicated by triangles). However the slope for December is significantly larger than that for January. This difference may be attributed to the existence of energy in slow-tail frequency band. Nevertheless these large correlation ratio is understandable because JLDN use VLF frequency range to estimate peak current.

One of the most striking features seen in this study is a clear straightforward relationship between the charge transfer and VLF scattered field on December 19 events with quite high correlation ratio r=0.97(Figure 3(b)). Sprite-producing discharges (A10, A11 and A5) with a large charge transfer have a large scattered field and in particular dancing sprite (A11) has the largest charge transfer and scattered field among them, whereas elve-producing events (A3 and A9) with a small charge transfer have a small scattered field.

(a) (b)



Figures 3(a)JLDN peak current as a function of ELF peak amplitude for two different days. (b)VLF scattered field (NWC) as a function of calculated charge transfer from ELF transient.

Moreover, peak current (or ELF peak amplitude) is not clearly indicative of the quantitative information on VLF scattered field. For January event, only sprite-associated scattering field was detected, and all the events have a rather large charge transfer which would be large enough to excite sprites; however all the scattered field was quite small and there is no clear relationship between charge transfer and scattered amplitude (r=0.28). The quantitative discrepancy in scattering amplitude between the two days may be due to the different ambient conductivity of the D-region by quasi-electrostatic thundercloud fields during the storm activity. According to the JLDN data, storm region on December 19 is much closer to the land comparing to January 27, and it would modify strongly the lower ionosphere around the scattered path from the source to the Kasugai station.

CONCLUSION

We have analyzed quantitatively the results of the coordinated campaign performed during the winter lightning activity over the Japan Sea consisting of measuring mesospheric optical emissions, ELF transients, subionospheric VLF signal perturbations and lightning detection network data. During two days when optical events were detected by Fukunishi et al. [1999], we found several important natures suggesting atmosphere-mesosphre-ionosphere coupling by combining the results from above-mentioned measurements, which are summarized as follows:

(1)The magnitude of the ionospheric disturbances in association with mesospheric TLEs has a positive correlation to the charge transfer deduced from the averaged current moment in low frequency component of ELF transient ($f<15$ Hz) (correlation ratio r=0.97 for December events) but it is sensitive to the ionospheric condition.

(2) Positive correlation between the slow-tail component in ELF range (frequency about a few hundred Hz) and peak current according to JLDN observing much higher frequency have found ($r\geq0.95$) but none of those two is the major factor to determine the magnitude of ionospheric perturbation.

(3) Sprites tend to occur in association with their parent lightning with relatively large positive charge moment during our observation (Qds>250 Ckm) even with small peak current of slow-tail amplitude, whereas elve may have much smaller threshold value for charge moment but its peak current (or slow-tail amplitude) should be large enough.
(4) By combining the above results (1) and (3), local quasi-electrostatic (QE) heating in relation to the sprite and/or ionized column from sprite will be the major control parameter of the magnitude of ionospheric perturbation rather than EMP heating from elve-producing discharge and/or elve itself.

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