RELATIONSHIP BETWEEN ELF TRANSIENTS AND IONOSPHERIC DISTURBANCES IN ASSOCIATION WITH SPRITES AND ELVES.

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1. Abstract

Mesospheric optical events especially Red Sprites and Elves were detected in Japan during winter lightning activity in Hokuriku region by Tohoku Univ. [personal communication (1998)]. Coordinated measurements were performed including the above-mentioned period when optical events were recorded, which were consisting of (1)ELF transient observation in Moshiri, Hokkaido, (2)ionospheric disturbances by means of VLF Trimpi obserbation in Kasugai, Aichi,(3)lightning data (location, onset time, peak current) provided by JLDN. The interrelation between optical events and those parent lightning in the troposphere, perturbations in the ionosphere and electromagnetic radiation particularly in lower frequency range was deduced based on the quantitative information from each measurement.

2. Introduction

Recent findings of the optical emissions 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. Sprites and Elves were observed for the first time during winter thunderstorm activity over Japan sea, which has some unique characteristics comparing to the usual summer lightning. Those are (1)quite large number of positive cloud to ground discgarges (CGs) rather than negative CGs,(2)large peak current especially for +CGs and (3)relatively low altitude of the cloud top ~5km etc. Present theories predict that the Sprite is produced by the large quasi-electrostatic (QE) field due to the large positive charge lowered to the ground by +CGs, while Elve is believed to occur as a result of the direct heating of the lower ionosphere by the electromagnetic pulse from the lightning. So far various phenomena in association with these optical events were observed e.g. (1)ELF transients, (2)VLF scatterring and (3)Gamma-ray burst. To deduce the quantitative information on coupling between the tropospheric optical phenomena and lightning, optical emissions and the ionosphere, coordinated measurement is extremely important.

In this paper we present the results of our winter lightning campaign especially focused our attention on the phenomena in association with optical emissions over Japan sea as a case study. Along with our objectives we have the optical measurement (consisting of CCD camera and Spectrometer installed by Tohoku University) to detect the Sprite and Elves.

ELF transient measurement is used to extract the charge moment of the parent lightning strokes, VLF scattering measurement is a sensitive tool to obtain the ionospheric perturbation, and the data from Japanese Lightning Detection Network recently cover all over Japan allow us to locate the event, time and its peak current.

Our results show that the magnitude of the atmosphere-mesosphere-ionosphere coupling is depending on the different types of parent lightning classified mainly by its spectrum slope and the ionospheric conditions. According to the data on December 19, 1998 there is a strong direct proportionality between the perturbation of the ionosphere and the charge moment (or charge transfer) attributed to the low frequency component of ELF radiation (f<15Hz) rather than its peak current. Nevertheless Sprites and Sprite with Elve appeared with rather large charge moment in comparison with that for Elve only.

3. Description of the Experiment

We have the optical data describing the type of the emission (Elves, Sprites) and onset time for events on 19 Dec. 1998 during severe winter thunderstorm activity over Japan sea (provided by Tohoku university). The distance between thunderstorm active region and ELF station (Moshiri) is about 1000km. Location of VLF receiving station (Kasugai) and GCP (great circle path) of VLF transmitter signals from North West Cape (NWC) in Australia crossing Kasugai station is shown as well. Ionospheric perturbation near GCP can change significantly the amplitude and phase of the VLF signal detected at Kasugai receiving station

4. Case study: December 19, 1998

During the above mentioned period totally 13 optical emissions were detected (Table 1). Among them 8 events were identified in association with Elves without Sprites and the remaining events were Sprites only or Sprites with Elves. According to JLDN data, most lightning with optical events were located on the coastal region of Noto-peninsula (A9, A10 and A12) and over the Japan sea ~100km north-west away from the peninsula (A2).

Event	Onsettime[UT]	Type	JLDN Peak Current[kA]	ELF Peak Amp.		Charage Transfer[C]	VLF(NWC)		
				Peak Amp. [μA/m]	Polarity	ds=5km Impulsive estimation	Scattering Amp.	Phs.	Amp.[dB]
A1	10:53:47.300	Elve							
A2	11:37:11.750	Elve	+409	731.45	+	30.0			
A3	13:45:50.200	Elve		505.54	+	24.3	*	*	-21.49
A4	13:52:24.410	Elve							
A5	16:12:45.460	d-Sprite		213.81	+	53.4	*	*	-4.14
A6	16:21:38.450	Sprite					*	*	-2.51
A7	16:26:03.560	Cu-Sprite					*	*	-12.30
A8	17:12:26.980	Elve					*	*	-3.50
A9	17:14:35.470	Elve	+470	742.74	+	35.0	*	*	-8.67
A10	17:38:52.890	Ca-Sprite	+39	258.24	+	60.1	*	*	+1.92
A11	17:43:11.280	dn-Sprite		336.81	+	67.6	*	*	+4.60
A12	18:12:45.200	Elve	-30						
A13	18:24:27.050	Elve		242.91	+	48.9			

Table 1. Summary of the optical events and associated phenomena (ELF transients, VLF subionospheric scattering, and lightning detecdtion network data) .

Typical examples of the time series of fully calibrated H field waveform for the event associated with Elve (A9) and Carrot-type Sprite (A10) show the clear transient signature in ELF range (Figure 1(a) and 1(b)). Corresponding amplitude spectra were calculated for 512ms. Sprite associated event (A10) is of (much) lower peak amplitude (~258μA/m) than ELF associated events (A2, A9) (~731μA/m, ~743μA/m). The ELF peak amplitude observed (f≤800Hz) is proportional to the peak current from JLDN. The polarity of the parent lightning is estimated from the sign of the first peak of Ez and all the events have a positive polarity coinciding with those from JLDN peak current estimation (Table 1). The frequency dependence of calculated current moment using the normal mode equations for different ELF events are shown in Figure 2. For Sprite-producing discharges (A5, A10 and A11), estimated current moments are large (3 largest ones) for lower frequency range (f≤50Hz) and are small for high frequency range (50≤f≤1000Hz). While elve-producing discharges (A3 and A9) exhibit the small current moment (f≤50Hz) comparing to Sprite events but increase in higher frequency component (f≥100Hz). Furthermore averaged Qds are derived using the frequency range (f≤15Hz). Assuming the lightning channel length 'ds' as 5km typical altitude of the cloud top of the winter lightning cloud we obtain the charge transfer. Sprite-producing discharges have a larger discharge transfer ranging from 53.4C to 67.6C than those for elves (ranging from 24.3C to 48.9C (Table 1).

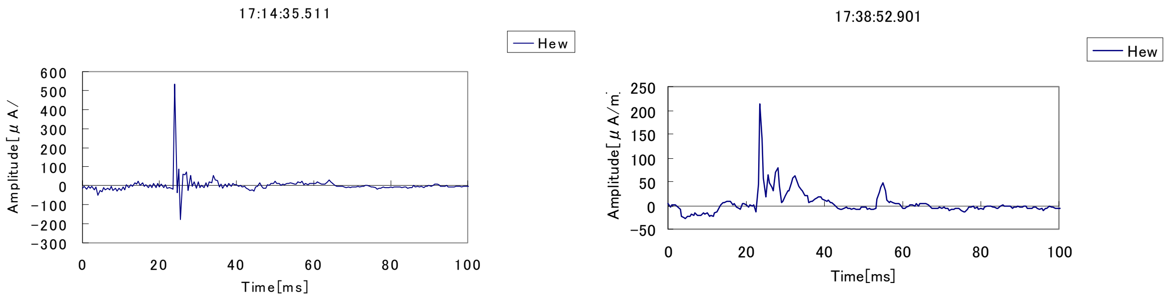

Figure 2(a) Time series of waveform of ELF transient (Hew component) in association with Elve, which has a large +CG (Ip~470 kA according to JLDN) at 17:14:35.511 UT (A9) in Moshiri station, **(b)** similar time series waveform for Sprite with a small peak current of Ip~+39 kA received at 17:38:52.901 (A10) .

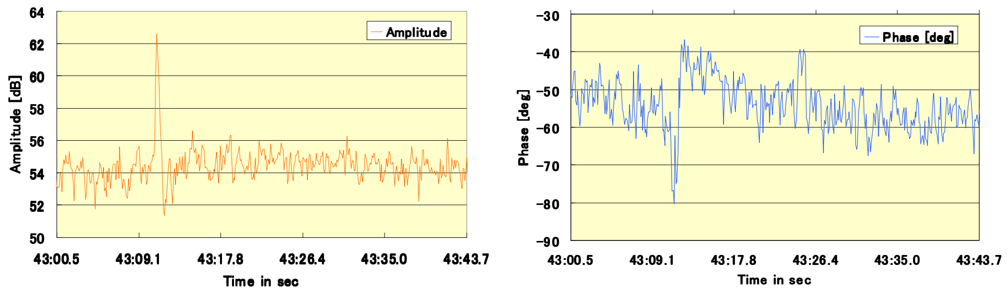

Figure 3(a). An example of the amplitude of VLF transmitter signal (NWC) receiving at Kasugai station in association with Sprite observed at 17:43:11 (A11), **(b)** phase variation for the same event.

Figure 3(a) and 3(b) show well-defined VLF perturbations in association with

Sprite (A11) exhibiting early/fast or RORD (Rapid Onset Rapid Decay) nature in amplitude and phase (post-onset type). They are used to convert into scattered field magnitudes by vector addition of the unperturbed (mean value here) and scattered field vectors (peak value is at least two times larger than standard deviation). Then we derived the scattered amplitude as +4.60 dB. Performing the similar analysis of the remaining VLF events, we could obtain the scattered field ranging from –21.49 dB to +4.60 dB for 8 events (Table 1). Among them mean scattered amplitude for Elves (A3, A8 and A9) is –11.22 dB, which is significantly smaller than that for Sprites (A5, A6, A7, A10 and A11) as –2.49dB.

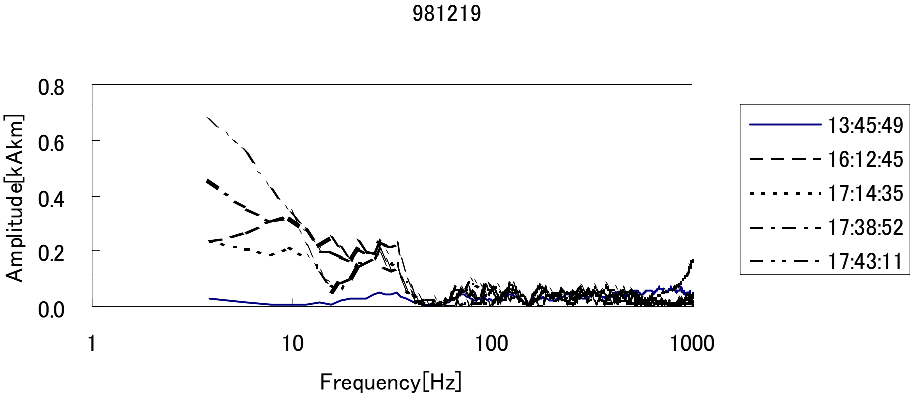

Figure 4. Frequency dependence of the current moment calculated from ELF transient data for different events observed on December 19.

Conclusion

We have analyzed the results of coordinated campaign performed during the winter lightning activity over the Japan Sea consisting of measuring mesospheric optical emissions, ELF transients, VLF subionospheric disturbances and lightning detection network data. During two days when optical events were detected, we found several important nature suggesting atmosphere-mesosphre-ionosphere coupling combining the results from above mentioned measurements summarized as follows:

(1)The magnitude of the disturbances in the lower ionosphere may have a close relationship with charge transfer due to low frequency component (f<15Hz). (2)Direct proportionality between the slow-tail component in ELF range (frequency ~a few hundred Hz) and peak current from JLDN observing much higher frequency have been found but none of them had a clear indication for the magnitude of the ionospheric perturbation. (3)Sprites tend to occur in association with the lightning having relatively large positive charge moment during our observation (Qds>250 Ckm). While Elve may have much lower boundary for charge moment for its generation or is not sensitive to the charge transfer but the peak current (or slow-tail amplitude) should be large enough.