TLE producing ionospheric disturbances: Observation and numerical modeling

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Abstract

This paper reports on the direct comparison between experimental and numerical results of the ionospheric disturbances associated with red sprites in the mesosphere. The ionospheric disturbances due to the sprite ionization column is observed by a continuous monitoring of the amplitude and phase of distant VLF transmitter signals at several locations in Japan, whilst the numerical computation to calculate the spatio-temporal dependence of the observed VLF waves is performed by using a two-dimensional finite-difference time-domain (FDTD) method. As a result, the observed maximum scattered amplitude and phase changes are in close agreement with the numerical results both for carrot and column sprites. The distance variation of the scattered amplitude from the numerical simulation is found to strongly depend on the spatial dimension of the sprite ionization column due to the different scattering mechanisms. The forward scattering amplitude is significantly larger than back scattering amplitude for the carrot sprite indicating the nature of Rayleigh scattering, while both backward and forward scatterings are comparable for a column sprite showing the nature of Mie scattering.

1. Introduction

Recently found mesospheric transient optical events such as red sprites are believed to play an important role on the electro-dynamic coupling between the tropospheric lightning, mesospheric transient events, overlaying ionosphere and even toward the magnetosphere.

The VLF signatures associated with TLEs have been observed at many places for different types of storms in the world [1-3]. However one of the most common characteristics of these events so-called early trimpi is that the occurrence timing of the perturbation is right after the causative lightning stroke (<0.1sec), which is significantly shorter than the case for the ionospheric perturbation due to the whistler-induced electron precipitation (WEP) (about 0.6sec after the lightning stroke).

The theoretical and numerical works have been conducted by various authors [4-6] to investigate the scattering process from the sprite as well as VLF propagation under the existence of the ionospheric perturbations. However rather small attention has been paid to quantitatively compare the observed amplitude and phase values with the simulation results. This kind of approach is quite important in deriving the quantitative characteristics of scattering sources such as the electron number density and spatial extent of the ionization column due to the sprite, scattering patterns for different type of sprites. Moreover fundamental properties of VLF wave propagation in the earth-ionospehre waveguide will be investigated such as the spatial extent where perturbed VLF waves will be observed and the interferences between the wave modes.

In this paper we have performed the numerical computations for the VLF transmitter waves propagating in the earth ionosphere wave guide under the existence of the different types of sprite ionization columns to study their scattering mechanism. The simulation results are compared with our experimental data.

2. Observations

VLF/LF transmitter signals have been observed continuously at our domestic VLF/LF receiving network distributed various places in Japan. In this paper, the data from two stations among them, Moshiri, Hokkaido and Kasugai, Aichi stations are used because the NWC (North West Cape) powerful transmitter (1000kW), two receiving sites and the winter thunderstorm region are in the same great circle path. This configuration greatly simplifies the spatial configuration for the numerical simulation to be two dimensional.

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The time dependence of the amplitude and phase are observed and the scattered amplitude indicative of the intensity of the ionospheric perturbation are determined from the temporal change of the amplitude and phase from the undisturbed condition..

3. Numerical simulations

In this study we use the numerical method so-called FDTD so as to derive the spatio-temporal dependence of the VLF transmitter wave propagation in the Earth-ionosphere waveguide under the existence of a transient ionization column generated by a red sprite. The two dimensional approximation has been applied in this study because of our experimental coordinate mentioned above. We assume the ground is a perfect conductor at VLF waves, while the ionosphere has a finite conductivity with the altitude dependence.

4. Results

4.1. Experimental results

Figures 1 and 2 show the time series of experimental scattered amplitude associated with carrot sprite for Moshiri and Kasugai stations respectively. We expect the forward scattering signal in Moshiri and found the remarkable scattered amplitude about -21dB (Figure 1). On the contrary, the scattered amplitude at Kasugai is quite small (Figure 2) corresponding to the backward scattering.

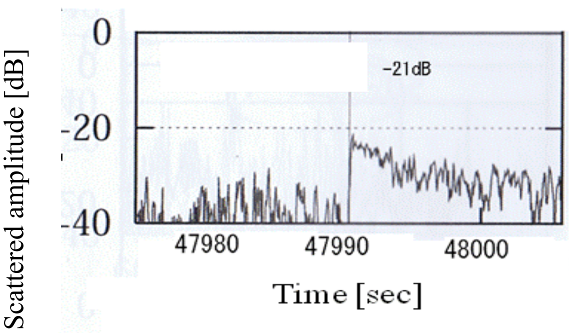

Figure 1. Time series of scattered amplitude normalized by the direct wave at Moshiri station around the occurrence time of carrot sprite.

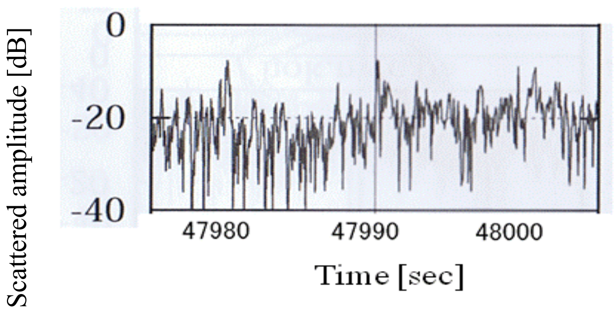

Figure 2. Time series of scattered amplitude normalized by the direct wave at Kasugai station around the occurrence time of carrot sprite.

4.2 Numerical results

Figure 3 illustrates the distance variation of maximum scattered amplitude of NWC transmitter in Australia for the carrot sprite. As is seen from the figure, the scattered amplitude reveals strong asymmetry in distance from the ionization column (i.e. carrot sprite), the significant forward scattering is expected. The scattered amplitude at the proximity of the Moshiri station is in good agreement with the simulation results. On the other hand the scattered amplitude at Kasugai station (at the side of back scattering) is not significant at the time of sprite indicative of the low back scattering amplitude from the carrot sprite.

Figure 4 shows the distance variation of maximum scattered amplitude of NWC for the column sprite, whose horizontal scale is much smaller than the carrot sprite. The distance dependence of the scattered amplitude from the column sprite has a significant difference from that of carrot sprite by the following two points. Firstly, more symmetrical dependence on the scattered amplitude is obtained in reference to the sprite location, i.e. rather large backscattering amplitude is expected. Second, a significant oscillatory dependence is seen both for forward and backward directions.

We also perform the simulation by changing the electron density of ionization column for both carrot and column type sprites by keeping other parameters same, and obtain the distance dependence of the scattered amplitude changing from 10^3cm^{-3} and 10^6cm^{-3}. As a result, although the scattering pattern does not change, a remarkable increase/decrease in scattered amplitude is obtained for large/small electron densities respectively.

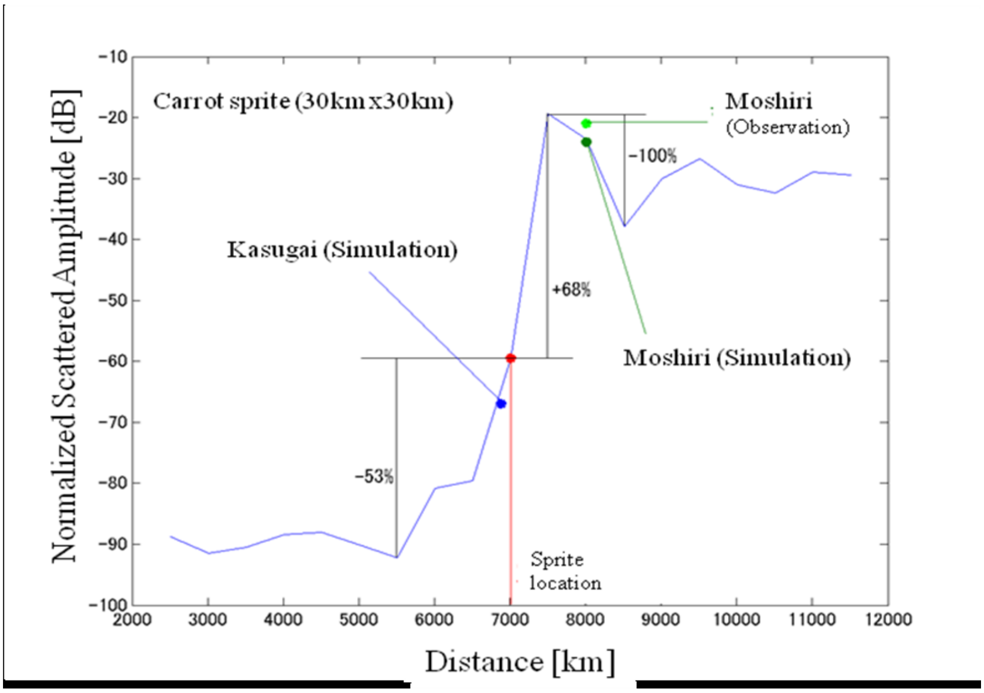

Figure 3. Simulated distance dependence of the scattered amplitude of NWC transmitter signals for carrot sprite (horizontal scale =30km, vertical scale=30km, and electron density=10^4cm^{-3})

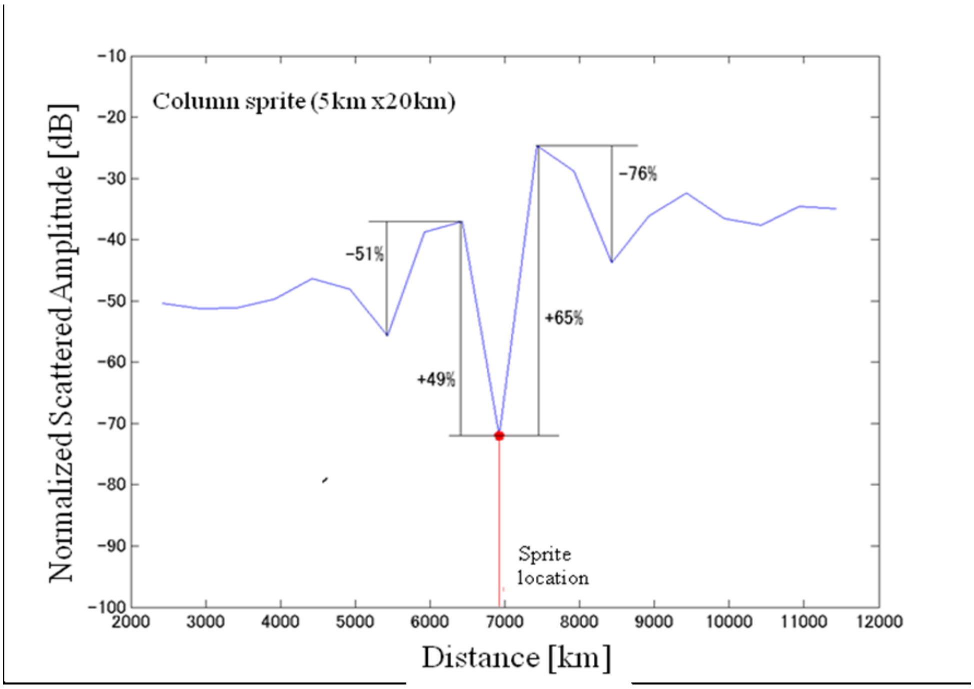

Figure 4. Simulated distance dependence of the scattered amplitude of NWC transmitter signals for column sprite (horizontal scale =5km, vertical scale=20km, and electron density=10^4cm^{-3})

5. Conclusion

Ionospheric disturbances by using VLF transmitter signals associated with red sprites are simulated by using 2D FDTD method. Rather good agreement between the results from experiment and those from the FDTD numerical modeling has been obtained. Distance variation of the scattered amplitude from sprites is controlled mainly by the horizontal scale (especially. backward scattering) and electron density of the ionized column by sprite.

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