Determination of the ionospheric transmission loss of the low frequency EM waves by simultaneous measurements of satellite and ground-based experiments

Y. Hobara[1] , and M. Parrot [2]

[1] Department of Communication Engineering and Informatics, Graduate School of Informatics and Engineering, The University of Electro-Communications, 1-5-1, Chofugaoka, Chofu, Tokyo, 182-8585, Japan, (hobara@ee.uec.ac.jp).

[2] Larboratoire de Physique et Chimie de l'Environnment et de l'Espace, 3A Avenue de la Recherche Scientifique, Orleans, 45071, France.

Abstract

Propagation characteristics of the low frequency electromagnetic waves in the ionosphere are experimentally derived using simultaneous measurements of electromagnetic waves from intensive lightning by French DEMETER satellite and ground-based observations. The transient waveforms generated by worldwide intensive lightning in ELF range are continuously monitored by multi-component measurements in Moshiri, Hokkaido, Japan. Corresponding lightning locations and their electric properties are also derived from the ELF measurement whilst the low altitude satellite (DEMETER) successfully detects electromagnetic pulses over the same lightning sources penetrated through the ionosphere. Direct comparison of ELF transient waves observed by the satellite with the ground experiment gives the unique opportunity to derive the experimental ionospheric property such as an ionospheric transmission loss. The ionospheric transmission loss is obtained for different latitudes and local times by calculating Poynting flux at the lightning and above the ionosphere, and these results are compared with the theoretical calculations by using full-wave numerical method. As a result, the ionospheric penetration loss increases with decreasing the magnetic latitude and with increasing wave frequency. The penetration loss is much larger in daytime rather than night time. The experimentally obtained results are in good agreement with those from theoretical calculations.

1. Introduction

Low frequency waves in the VLF/ELF ranges are excited mostly by a world-wide thunderstorm activity and propagate in the earth-ionosphere waveguide. Part of the electromagnetic energy from these waves penetrate into the overlaying ionosphere, become plasma waves and attenuate during the course of their propagation through the inosphere. In this frequency range the theoretical ionospheric transmission loss is widely used in the scientific community because only small numbers of experimental results are available such as by using spontaneous rocket measurements and by low frequency navigation transmitter signals, which do not cover different latitudes.

In this paper we have derived the full experimental ionospheric penetration loss in the ELF range by using a coordinate measurement of lightning emissions both from the ground-station and the satellite. The latitudinal, diurnal and frequency dependence of the transmission loss are derived. Moreover, the experimentally derived transmission properties are compared with those from the numerical calculations based on the full-wave theory.

2. The data

We have used the electromagnetic waveforms both from low altitude satellite DEMETER and ground-based ELF transient data. The DEMETER satellite has a sun synchronous orbit and provides the full vector measurement of electric and magnetic field waveforms with a sampling frequency of 2.5kHz over the F2 region of the ionosphere at the altitude of 650km during so-called burst mode [1-2]. The ELF transient is continuously monitored with a vertical electric and two horizontal magnetic field components at the sampling rate of 4kHz in Moshiri, Hokkaido, Japan [3].

3. Method of analysis

3.1 Experimental penetration loss of the ionosphere

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The experimental ionospheric penetration properties are obtained by the following process. Firstly, we obtain the world-wide lightning locations and then the frequency dependences of the Poynting vector at the lightning sources are obtained by the ground-based ELF measurement. The lightning location and corresponding electrical properties of the lightning source are determined by so-called ELF method [4]. Secondly, we identify some of the lightning whistlers observed by DEMETER, which are generated by the same lightning sources observed at the ground-based ELF measurement. The event identification is made both in space and time. Thirdly, Poynting fluxes are calculated both at the lightning source and at DEMETER (i.e. over the ionosphere). Finally, the ionospheric transmission loss is calculated by taking the ratio of above two Poyting flux.

3.2 Theoretical penetration loss of the ionosphere

The theoretically estimated ionospheric penetration loss is calculated for the electromagnetic waves in the ELF frequency range based on the full-wave approach [5]. The electromagnetic waves from the lightning in the ELF range are assumed to have a vertical incidence.

4. Results

Figure 1 shows the latitudinal dependence of the ionospheric transmission loss for 100Hz. The filled circles with error bars indicate the median value of the transmission loss with an interquartile range for different lightning events in the daytime. The crosses with error bars are for night time lightning events with a same format as the daytime events. The transmission loss decreases with increasing the magnetic latitude for both daytime and night time. The loss for the night time ionosphere is significantly smaller than daytime by about 20 to 10dB. The curves with triangles and inverted triangles represent the theoretical penetration loss calculated by the full-wave numerical computations for daytime and night time respectively assuming the vertical incidence and suitable electro density and collision frequency profile. The penetration loss of the ionosphere from these theoretical curves decreases with increasing magnetic latitude and are found to have rather good agreement with experimentally obtained results.

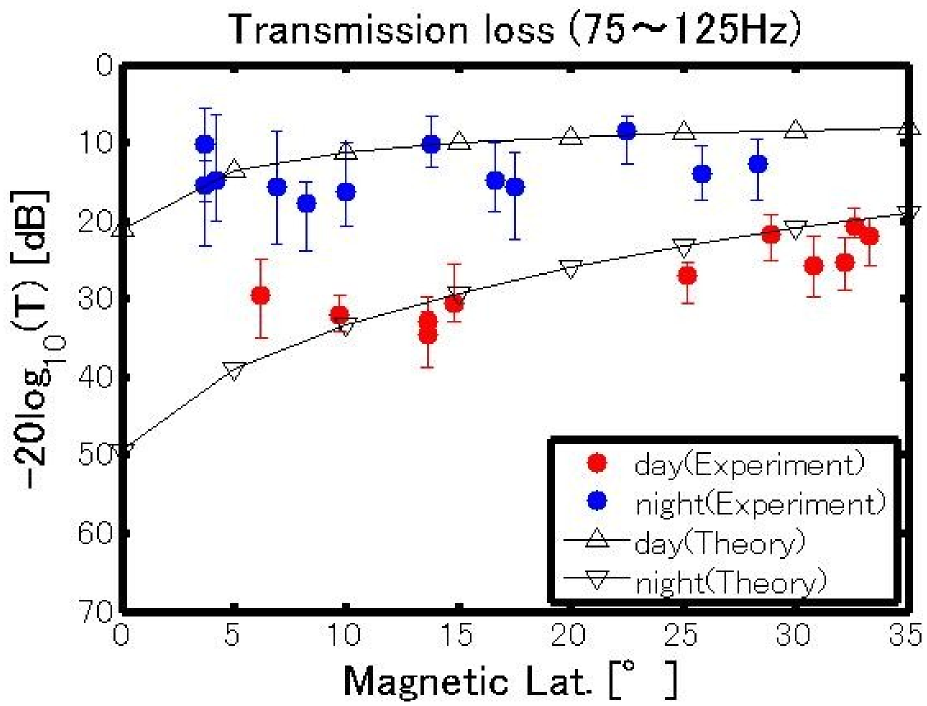

Figure 1. The experimentally and theoretically derived transmission losses as a function of the geomagnetic latitude for daytime and night time.

5. Conclusion

The experimental penetration loss of the electromagnetic waves in the ionosphere for the ELF frequency range is obtained by using the data from simultaneous measurement of lightning producing ELF transient at the ground and the low altitude satellite over the F2 region. The lightning events occurred at different magnetic latitude and local times give us latitudinal and local time dependence of the ionospheric transmission loss. The transmission loss increases with decreasing the magnetic latitude and is significantly larger in daytime rather than in night time. The theoretical calculation of the transmission loss by using the full-wave numerical calculations quantitatively supports the experimentally derived values.

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