Estimation of spatial structure of lower ionosphere with two-dimensional FDTD simulations

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Abstract

We performed a series of FDTD simulations with different types of electron density profiles in the lower ionosphere, and then confirmed characteristics of MF wave propagations in the lower ionosphere. According to sounding rocket experiments, we can only obtain an altitude profile of wave intensity, especially magnetic field intensity, by rocket observations. In this study, therefore, we are going to try to estimate spatial structure in the lower ionosphere by analyzing altitude profiles of magnetic field intensities of waves with various frequencies. Simulation results indicate that spatial structure in the lower ionosphere can be estimated by analyzing altitude profiles of different waves emitted from different wave sources with various frequencies.

1 Introduction

The electron density distribution affects propagation characteristics of electromagnetic waves in the lower ionosphere. Especially, the sporadic E layer appears spontaneously as well as locally, and disturb MF radio broadcast waves at mid-latitude region. The electron density in the lower ionosphere can be observed by MF radar or rocket experiment. Though MF radar can observe electron density profile in the lower ionosphere continuously, its observation data is not accurate sufficiently [1]. In the rocket experiments, on the other hand, the electron density cannot be measured directly with metal probes in the lower ionosphere, since the electron density is very small in this region. The most accurate observation of the electron density profile in the lower ionosphere is to observe MF wave propagation characteristics by sounding rocket, then apply MF wave absorbing method to observation data [2]. We can obtain an altitude profile of wave intensity, especially magnetic field intensity, by the sounding rocket experiments, as shown in Fig.1. On the basis of this altitude profile of magnetic field intensity, we estimate the appropriate electron density profile with using Full-wave simulation method.

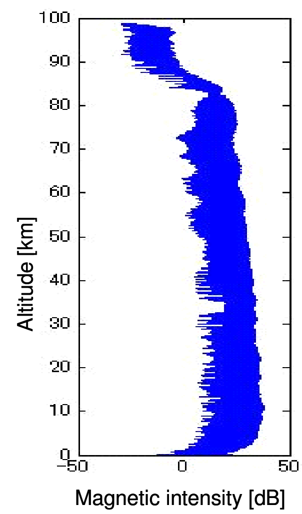

Figure 1: MF wave observation by the rocket experiment

Though the MF absorbing method is effective to estimate the electron density profile in the lower ionosphere, the electron density distribution is assumed to have a priori one-dimensional profile, only change along the altitude, in this method. According to recent observation of sporadic E layer, however, spatial structure of sporadic E layer is not always one-dimensional, so-called “layer”, but frequently two- or three-dimensional, so-called “electron cloud”. To simulate wave propagation in the lower ionosphere with two-dimensional sporadic E layer, we performed two-dimensional FDTD simulations. In this study, we performed a series of FDTD simulations with different types of electron density distributions, and then confirmed characteristics of MF wave propagations in the lower ionosphere. We demonstrate altitude profiles of wave intensity observed in the rocket experiments from simulation results, then verify the possibility to estimate spatial structure of sporadic E layer from rocket observation data.

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2 Computing Method

To study propagation characteristics in the ionosphere, we developed a two-dimensional FDTD simulation code which can treat wave propagations in magnetized plasma. Though we need to perform full-particle simulations in order to recognize accurate characteristics of waves propagating in space plasma, FDTD simulations can be performed with much less computer resources than those necessary for full-particle simulations, in memories as well as CPU times. Since the ionospheric plasma is magnetized, it is necessary to incorporate the dielectric tensor with anisotropy and dispersibility in FDTD simulation code, in order to calculate the electromagnetic field in space plasma. We use PLRC method to formulization FDTD scheme to reduce numerical errors. In FDTD simulation, it is essential that how to realize an effective absorbing boundary. We developed PML (Perfectly Matched Layer) absorbing boundary condition with anisotropy and dispersibility, and succeeded to realize very effective absorbing boundary.

3 Simulation model

We performed a series of FDTD simulations with different types of electron density profiles in the lower ionosphere, and then confirmed characteristics of MF wave propagations in the lower ionosphere. Simulation parameters in this study are listed in Table.1. In this study, the simulation plane is relatively small, which is only 50km×50km, to examine qualitative characteristics of wave propagation. We especially study on effects of wave frequencies, therefore, we performed simulations with three different frequencies of wave source, 0.5MHz, 1.0MHz, 2.0MHz. The strength of Earth's magnetic field is defined by the electron cyclotron frequency, 1.5MHz. Many simulation parameters, such as the electron cyclotron frequency, are defined from the SRP-5 rocket experiment carried out in the Alaska Poker-Flat.

Table 1: Simulation parameters

simulation plane[cell]	2000×2000
boundary condition	PML(64cell)
cell size[m]	25
time step[sec]	1.0×10^{-8}
simulation time[sec]	4.0×10^{-4}
source freq.[MHz]	0.5, 1.0, 2.0
source waveform	sinusoidal
source position[cell]	(1000,5)
source current direction	z
cyclotron freq.[MHz]	1.5
$\boldsymbol{B}$ direction	$-z$

We assumed two types of sporadic E layer models in this simulation study, uniform ionospheric layer model and oval shape electron clouds model, as shown in Fig.2. This figure shows spatial electron density distribution corresponding two sporadic E layer models used in this simulation study. In this figure, electron density is presented with color contour map. We performed a series of two-dimensional FDTD simulations with these two models, then made altitude profiles of magnetic field intensities of waves with various frequencies, which demonstrate observations in sounding rocket experiments, as shown in Fig.1. Altitude profiles of magnetic field intensities are observed along the white lines in Fig.2, 5km from the left edge in the layer model, 5km (demonstrating a rocket passes through a cloud) and 10km (demonstrating a rocket passes between clouds) in the electron clouds model.

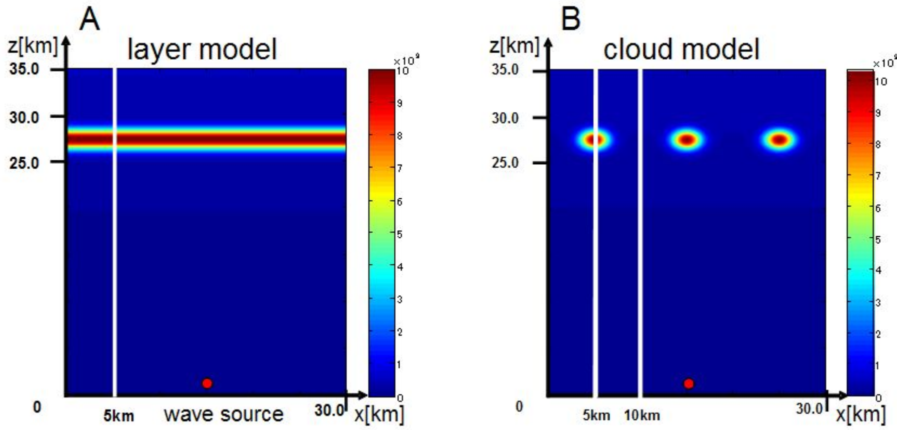

Figure 2: Simulation models (A: uniform layer model, B: electron cloud model).

4 Simulation result

Fig.3 shows altitude profiles of magnetic field intensity observed in FDTD simulations. Upper panels show simulation results with the source wave frequency of 2.0MHz, loser panels show those with the source wave frequency of 0.5MHz. Left panels (A) correspond to the altitude profiles of magnetic field intensity in the simulations with one-dimensional layer shape sporadic E layer model. Center panels (B) correspond to the altitude profiles along the line of 5km from the left edge, which is demonstrating a rocket passes through a cloud, in the simulations with the oval electron clouds as sporadic E layer model. Right panels (C) correspond to the altitude profiles along the line of 10km, which is demonstrating a rocket passes between clouds, in the simulations with the oval electron clouds model.

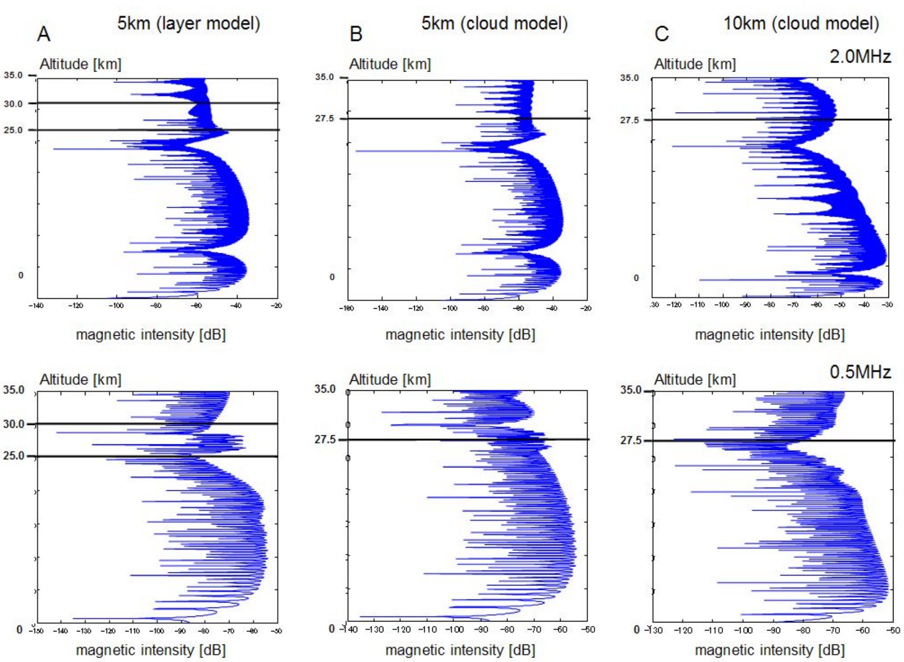

Figure 3: Simulation result (A: uniform layer model, B,C: electron cloud model)

In the upper panels of this figure, simulation results with 2.0MHz, clear characteristics are found in the altitude profile of magnetic field intensity of (C). We can easily distinguish the altitude profile of (C) from those of (A) and (B). However, we cannot distinguish between the altitude profile of (A) and that of (B), since no clear difference is found between these two profiles. In the lower panels which present simulation results with 0.5MHz, on the other hand, clear characteristics are found in all the altitude profiles of magnetic field intensity of (A), (B) and (C). We can easily distinguish all the altitude profiles. Especially, clear difference in these three altitude profiles are found above the altitude of sporadic E layer. Simulation results indicate that spatial structure of sporadic E layer in the lower ionosphere can be estimated by analyzing altitude profiles of different waves emitted from different wave sources with various frequencies.

5 References

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