Numerical Study of Artificial Generation and Propagation of ULF Waves in the Ionospheric F Region at Different Latitudes

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1. Extended Abstract

Powerful high-frequency (HF) radio waves can be pumped into the upper ionosphere, efficiently modifying the local ionospheric plasmas. When the pump wave is amplitude modulated by ultralow-frequency (ULF) wave, the pressure gradient induced by the local electron heating will drive an oscillating diamagnetic ring current source, radiating ULF waves at the modulation frequency into the ionosphere. This theory has been validated by a series of relevant experiments[1] conducted at the High Frequency Active Auroral Research Program (HAARP) and at the European Incoherent Scatter Scientific Association (EISCAT), which makes it possible that ULF wave can also be used in communication with submarines like VLF waves excited by lower ionospheric modulation. However, the experiments carried out so far are only at high latitude, which makes it an intriguing question that whether this theory can be applied to mid-latitude and equatorial latitude, and how the ionospheric background and modulation parameters can affect the generation and propagation of the artificial ULF waves.

In this project, we investigate the effects of ionospheric background and modulation parameters on the ULF wave generation and its subsequent propagation at three typical latitdues (HAARP, Wuhan and Jicamarca) at 02:00 and 14:00 LT by numerical simulation. Firstly, based on a relation among the radiation efficiency of the ring current source, the size of the spatial distribution of the modulated electron temperature and the wavelength of ULF waves, we quanlitatively discuss the possible effects of the background ionospheric parameters and the modulation frequency. Then, we decompose the problem into two parts and study them respectively. (1) We build a two-dimensional self-consistent HF heating model[2] for the ionospheric F region and utlize it to simulate the electron temperature response to the modulated HF heating. By analyzing the spatial distribution and temporal evoluation of the electron temperature, we find that the size of the spatial distribution of the electron temperature is larger in the nighttime ionosphere than in the daytime ionosphere, and it is smaller in the ionosphere at low latitudes than at high latitudes, which indicates a higher radiation efficiency of the ring current source in the daytime ionosphere at low latitudes with a fixed ULF wavelength. Also, the oscillation amplitude of the electron temperature increases with latitude in the nighttime ionosphere, while it decreases with latitude in the daytime ionosphere and it is approximately inversely proportional to the modulation frequency. (2) By using a two-dimensional wave model[3], we study the generation and propagation of artificial ULF waves under different ionospheric parameters and modulation frequencies when the electron temperature spatial distribution and oscillating amplitude are fixed. After analyzing the simulation results, we come to the following conclusion: (a) The radiation efficiency of the ULF ring current source is larger in the nighttime ionosphere than in the daytime ionosphere regardless of different geomagnetic field dip angles, while the energy conversion efficiency from electron temperature oscillation to ULF waves is lower in the nighttime ionosphere; (b) The daytime ionosphere produces more energy dissipation during the propagation of artificially generated ULF waves due to Joule heating, and this propagation loss is larger when the modulation frequency is raised; (c) The ground magnitude of the magnetic field of the artificial ULF wave is larger in the nighttime ionosphere than the daytime ionosphere, and the difference between daytime and nighttime conditions expands as the modulation frequency increases. Also the ground ULF wave amplitude decreases when the modulation frequency increases.

2. References

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