Effect of Finite Electron and Ion Temperature on Magnetospheric Whistler Mode Raytracing

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***Abstract*—Numerical raytracing is an important technique that is being used to determine the trajectory of whistler mode waves in the magnetosphere. Previous whistler mode raytracing techniques were developed by assuming cold magnetospheric plasma. In this work we analyze the effect of finite electron and ion temperature on the whistler mode wave trajectories.**

I. INTRODUCTION

Whistler mode waves are a type of electromagnetic wave that exists only in magnetized plasma. This mode of wave propagation exists for frequencies below the electron cyclotron frequency and plasma frequency. Whistler mode waves are very prominent in the near-Earth space environment within the band of 1 kHz 30 kHz. In fact they, belong to the most intense electromagnetic waves in the Earth's magnetosphere, which is the region of space around the Earth out to 12 Earth radii where the Earth's magnetic field is the dominant force [1].

Computing the trajectories of whistler mode waves is known as raytracing and bears many similarities to geometric optics. Although the magnetosphere is inhomogeneous as well as anisotropic, as long as the inhomogeneity of the plasma medium can be assumed to be slowly varying, a WKB approach can be applied. Raytracing identifies the power flow path of a wave by solving the Haselgrove equations [8]. Ray tracing involves discretizing the magnetosphere and calculating the local refractive index at the wave location. The refractive index provides the group velocity magnitude and direction so that the subsequent position of the wave energy can be determined and a ray-path can be traced.

Raytracing has been used successfully for many years. However, all past work on raytracing has assumed cold background plasma with zero temperature for both ions and electrons [2-5]. While the cold plasma assumption is generally valid for the magnetosphere, there are situations where even small finite temperatures of ions and electrons can affect the propagation of whistler mode waves. The goal of this research is incorporate finite temperature effects into magnetospheric raytracing to provide a more accurate numerical tool for tracking the trajectories of whistler mode waves.

II. TECHNICAL APPROACH

Propagation of whistler waves through the magnetosphere is governed by the dispersion relation or the refractive index. In magnetized plasma the index of refraction depends on the plasma density, the strength of the background magnetic field and the wave frequency. The refractive index also changes as a function of the wave propagation direction. The trajectory of a whistler wave depends on the frequency of the wave, source location and the initial wave normal angle. Wave normal angle is the angle between the wave and the geomagnetic field.

In this work the Stanford 3-D cold plasma raytracing code is modified such that the temperature effects can be taken in to consideration. The changes in the refractive index surface and the ray trajectories are observed due to the inclusion of the finite electron and ion temperature.

III. RESULTS AND CONCLUSIONS

The available cold plasma raytracing model contains two near Earth space models, the NGO model and the GCPM (Global Core Plasmasphere Model). Both of the models assume different plasmasphere conditions. In this work it is validated that the NGO model is a better candidate to reproduce the ray trajectories predicted with the Carpenter & Anderson model [2-6], due to the similarity in their electron density profiles. Figure 1 shows the electron density profiles for the three models.

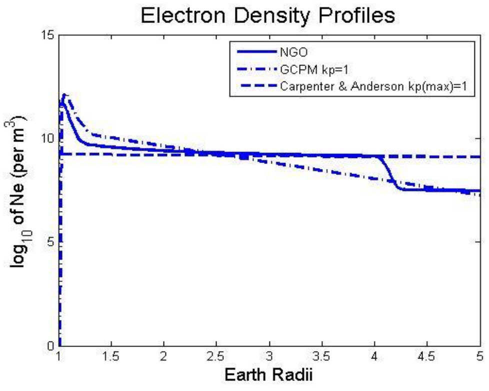

Fig. 1. Electron density profiles from the NGO, GCPM and Carpenter & Anderson Models.

In the recently published literature [7] it was shown that one of the effects of including finite ion and electron temperature closes an otherwise open refractive index surface when the wave frequency is close to the lower hybrid resonance frequency. This factor was validated in this work. Figure 2a shows the ‘closing’ of the refractive index surface at 2.5kHz with the inclusion of the finite ion temperature (1ev), which is otherwise open as shown in Figure 2b.

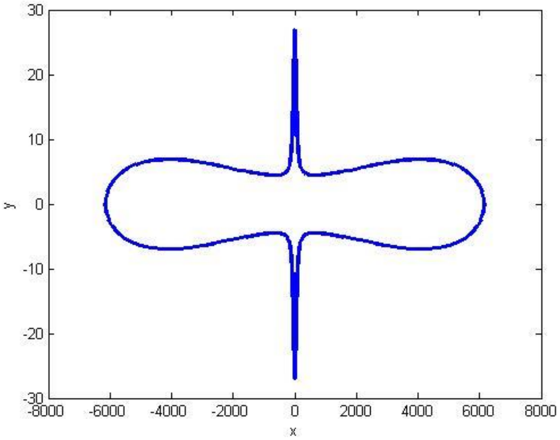

Figure 2a: The refractive index surface at 2.5 kHz with the inclusion of ion temperature.

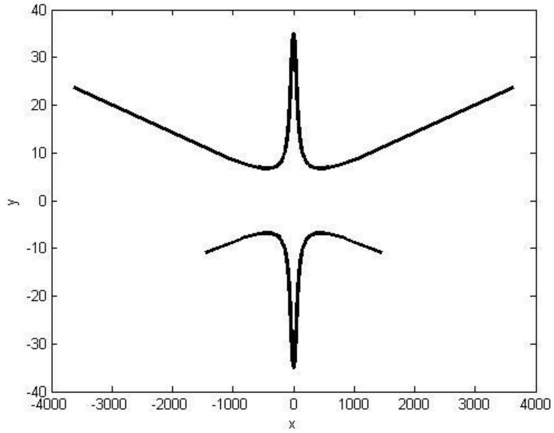

Figure 2b: The refractive index surface at 2.5 kHz without temperature effects.

The ray trajectories were analyzed with the cold plasma assumptions and with the warm plasma assumptions for three different initial wave normal angles. In all these cases the selected frequency was slightly higher (~10 Hz) than the lower hybrid resonance frequency. And it can be concluded that there are significant changes in the ray trajectory when the wave is launched with propagating, resonant and non-propagating wave normal angles.

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