Landau Damping and Linear Growth of Whistler Mode Waves with the Inclusion of Finite Electron and Ion Temperature

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***Abstract*— Whistler mode waves play a dominant role in the energy dynamics of the earth's magnetosphere. In this work we present numerical raytracing results of a large number of whistler mode waves including Landau damping and linear wave power growth and finite electron and ion temperature. The results are compared with observations made on the Van Allen Probes spacecraft.**

INTRODUCTION

Whistler mode waves have a dominant effect on the energy dynamics of the Earth's magnetosphere. The power flow path of whistler mode waves can be determined using numerical raytracing. The majority of the previous work on raytracing was performed assuming a cold background plasma [1]. But observations show that the actual magnetospheric plasma is at a temperature of around 1 eV [2, 7]. In this work we perform raytracing with inclusion of the damping of wave power due to parallel interactions with the energetic electron distributions (Landau damping) and linear cyclotron wave growth for whistler mode waves. The raytracing is performed with and without the inclusion of finite electron and ion temperature, following the formulations of *Maxworth and Golkowski* [7]. Energetic electron distributions are modelled using the isotropic and bi-Maxwellian distributions. Finally we compare our simulation results with the observations made with EMFSISS instrument in Van Allen Probes spacecraft [6].

TECHNICAL APPROACH

Numerical raytracing is the process of determining the power flow path by solving the Haselgrove's equations. In this work we have introduced temperature corrections to a 3D cold plasma raytracer. Introduction of finite temperature effects increases the complexity of the raytracing. In Haselgrove's equations [3] the properties of the background plasma enters via the refractive index μ. With the inclusion of temperature effects the original fourth order dispersion relation becomes sixth order:

$$q^T A_1 \mu^6 + (A_0 + q^T B_1)\mu^4 + (B_0 + q^T C_1)\mu^2 + C_0 = 0 \quad (1)$$

In Equation 1, μ is the refractive index and q^T is a temperature dependent quantity. All the other parameters are functions of wave normal angle and Stix parameters defined in [5]. In this work we have selected two source locations to launch whistler mode waves L=5 and L=3.8. The plasmapause is located at L = 3.76. Waves are launched with different wave normal angles in the range -70° to 20° in steps of 5°. As mentioned above, in this work we have modelled the energetic electron distribution as a bi-Maxwellian Distribution

$$f = \frac{n_h}{(2\pi)^{3/2} U_{||} U_{perp}} exp\left(\frac{{v_{||}}^2}{2{U_{||}}^2}\right) \frac{1}{1-\beta}\left[exp\left(\frac{{v_{perp}}^2}{2{U_{perp}}^2}\right) - exp\left(\frac{{v_{perp}}^2}{2\beta {U_{perp}}^2}\right)\right] \quad (2)$$

the above equation n_h is the hot electron density, $v_{||}$ and v_{perp} are the parallel and perpendicular velocities with respect to the geomagnetic field and β is the depth of the loss cone set to 0.01 in this case. Parallel and perpendicular momentum per unit mass are given by $U_{||}$ and U_{perp} [4].

RESULTS

The wave power growth is calculated for both an isotropic hot energy distribution and a bi-Maxwellian distribution mentioned above.

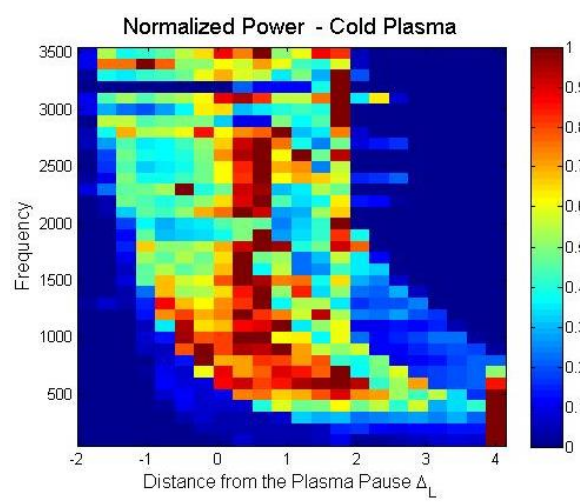

Fig.1: Total normalized power of whistler mode waves launched at L=5, assuming a cold background plasma.

Figure 1 shows the total power from Landau damping and wave power growth obtained by assuming a cold background plasma and a bi-Maxwellian energetic electron distribution for the source location of *L*=5. The plasmapause location was at *L* = 3.76.

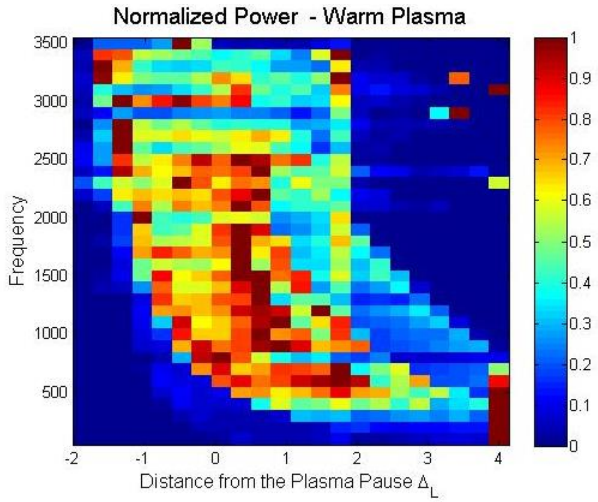

Fig.2: Total normalized power of whistler mode waves launched at *L*=5, assuming a warm background plasma.

Figure 2 shows the total power from Landau damping and wave power growth obtained by assuming a warm background plasma (*Te* = 2.3eV, *Ti* = 1 eV) and a bi-Maxwellian energetic electron distribution for the source location of L=5. One main observation from Figure 2 is that the total power concentrates into the region about one Earth radii from the plasmapause, towards the Earth. And as the frequency increases the power concentration moves further towards the Earth. This type of distribution of wave energy is also seen in Van Allen Probe data [6].

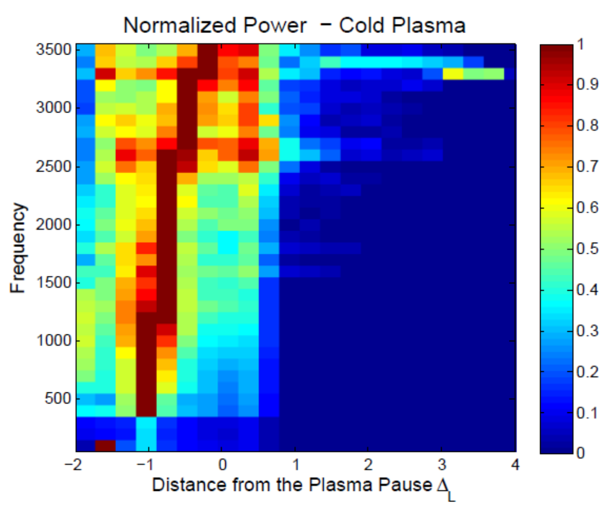

Fig.3: Normalized Landau damped power of whistler mode waves launched at L=3.8, assuming a cold background plasma.

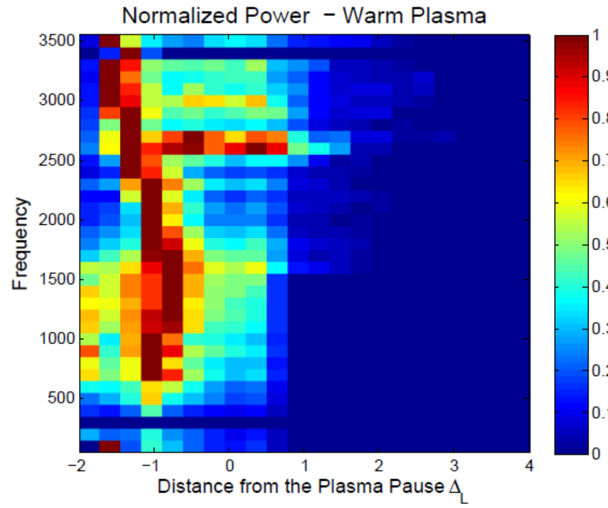

Fig.4: Normalized Landau damped power of whistler mode waves launched at *L*=3.8, assuming a warm background plasma.

Figure 3 and 4 show the normalized power after Landau damping. For Landau damping the hot electron distribution was assumed to be bi-Maxwellian. One main observation made with the new source location is the spreading of power away from the Earth at frequencies around 3 kHz, also in agreement with Van Allen Probe data [6].

CONCLUSIONS

From the comparison between Van Allen Probe observations and our simulation result it is observed that a warm background plasma improves the agreement between observed and simulated wave power distributions. Also assuming a source location closer to the plasmapause further increases the similarities between actual and simulated results.

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