ON ELECTRON-COHERENT WHISTLER WAVE INTERACTION AND PARTICLE PRECIPITATION

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Introduction

This paper describes the results related to the computational simulation of the resonant interaction between radiation belt energetic electrons and a coherent wave propagating in the whistler mode.

Due to the inhomogeneity of the geomagnetic field the electrons may be kept trapped by the field lines, depending on their pitch angle, their movement being controlled by the field; when a wave field is present the motion of these particles might be affected and, as a result of the resonant interaction with the wave, a precipitation of electrons into the ionosphere may take place due to significant changes of their pitch angles. The study of the mechanisms that lead to stimulated precipitation of electrons was the main purpose of the computational simulation. Introducing a sptatially varying low-amplitude model for a whistler wave we state the importance of a cyclotron resonant mechanism by which, in a single encounter with the wave, a particle may precipitate due to a significant decrease of its $v_\perp$; this mechanism differs considerably from the one that underlies cyclotron resonance with high amplitude whistlers that phase-trap electrons (multiple resonance) and might force its $|v_{/\!/}|$ to grow, thus leading to precipitation.

Computational Model

The simulation was performed for the magnetospheric region L=4 corresponding to the experiment taking place between Siple (transmitter, in Anctarctic)and Roberval (receiver, in Canada).

The geomagnetic field was simulated by a dipolar field and the adopted values for the density of the cold plasma electrons in the equator varied between typical values of 10 and 10^3 el/cm^3;the equatorial plasma frequency is determined by this density value, and the gyrofrequency model was used to describe plasma frequency variation along a field line / 1 /.

The equations of motion of the electrons under the simultaneous effect of the geomagnetic field (B) and of an injected coherent whistler wave (B_w,ω, k(z)) are:

$$\dot{v}_{/\!/} = - v_\perp \; a \sin \phi - (v_\perp^2 /2B) \frac{\partial B}{\partial z}$$

$$\dot{v}_\perp = a(v_{/\!/} - \frac{\omega}{k}) \sin \phi + (v_{/\!/} v_\perp /2B) \frac{\partial B}{\partial z}$$

$$\dot{\phi} = k(v_{/\!/} - V_G) + \frac{a}{v_\perp} (v_{/\!/} - \frac{\omega}{k}) \cos \phi$$

where $(a,\omega_c) = q\,(B_w, B) / m$, $V_G = (\omega - \omega_c) / k$ is the cyclotron-resonance velocity, and ϕ is the angle between $-\underset{\sim}{B}_w$ and $\underset{\sim}{v}_\perp$. It was then possible to track the particles, making use of fourth order Runge-Kutta formulae (in the modification due to Gill). The time step of integration was taken as $h << T_{NL} = 2\pi\,(a\,k\,v_\perp)^{-1/2}$. Early computations were performed with constant amplitude whistlers but we noted that most of the times the final pitch angle of a particle beginning its interaction with the wave in the northern hemisphere was almost the same as in the symetric point in the southern hemisphere, given the simmetry of the geomagnetic field and of the whistler amplitude around the equator. So we built a spatially varying amplitude model, increasing along the equator and reaching saturation values in the northern hemisphere (typically $B_w \sim 50$ mγ) corresponding to experimental values of the amplitude amplification of injected whistlers, which may reach 30 db / 2 /.

Results

We followed the cyclotron-resonance interaction from ~6^{o}N latitude to ~6^{o}S latitude. Outside this region the influence of the geomagnetic field is predominant over the whistler field.

It was possible, near resonance, to check the invariance (variation of 1 in 10000) of the parameter introduced by Karpman et al / 3 /,

$$C^2 = (v_\perp^2 + v_{/\!/}^2) - \frac{v_\lambda^2}{2} \quad .$$

Depending on the initial conditions (Fig.1, table 1) the electrons might go through multiple or single resonances (the resonances in the southern hemisphere being meaningless because of the local lower amplitude of the whistler). In the simulations using low-amplitude whistlers with frequencies between 3 and 8 kHz showed that only single resonances could lead to electron precipitation.

The results for three typical electrons undergoing the interaction with a 4 kHz, $B_{w_{max}}$ ~50 mγ whistler are shown below; these particles had initially the same $v_{/\!/}$ and $v_{\perp}$ (and therefore the same α) but different $\emptyset$ (30^o, 120^o, 210^o).

For the initial values of $v_{\perp} = 5 \times 10^6$ m/s, $|v_{/\!/}| = 2.9 \times 10^7$ m/s, $\alpha = 9.75^o$ at 5.7^oN latitude, the following final values around latitude 6°S (α_{1c}~5.45^o) were obtained:

	$\emptyset_{initial}$ (°)	$\lvert v_{/\!/}\rvert$ (10^7m/s)	$v_{\perp}$ (10^6m/s)	α (°)
1	30	2.92	2.56	5.00
2	120	2.80	10.31	20.23
3	210	2.91	4.23	8.26

TABLE 1

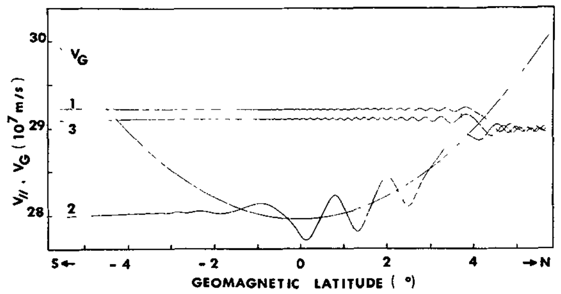

FIG.1 Evolution of $|V_G|$ and $|v_{/\!/}|$ of the electrons (1,3-single resonances; 2-multiple resonance)

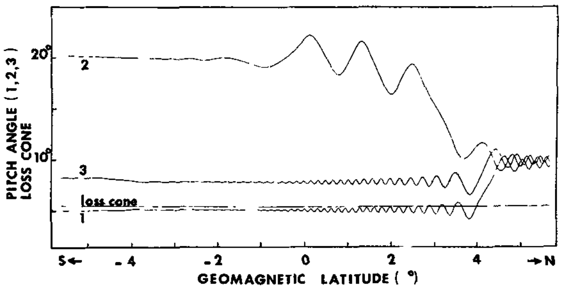

FIG.2 Evolution of loss cone and electron pitch angles

As clearly shown in FIG.2 only particle 1 precipitated ($\alpha_f < \alpha_{1c}$).

Conclusion

For particles submitted to single resonances, their pitch angle changes are mainly due to $v_{\perp}$ variations. The Doppler-shifted frequency equals the gyrofrequency, and thus the wave fields seen by these particles rotate with the gyrofrequency as their $v_{\perp}$ nearly do. As long as a particle is close to a resonance, which happens for a significant time interval, its v will be changed by the continuously cumulative action of the wave electric field upon the particle. It is easily seen (FIG. 3) that if $(v_{\perp} . E_w) > 0, (0 < \emptyset < \pi)$, $v_{\perp}$ will decrease and if $(v_{\perp} . E_w) < 0$, $(-\pi < \emptyset < 0)$, $v_{\perp}$ will increase.

In the case of multiple resonances, although $v_{\perp}$ oscilates, the associated particle trapping leads to a decrease of $|v_{/\!/}|$ for electrons approaching the equator, and thus to a growth in pitch angle.

Since the adopted amplitude model leads to detrapping near the equator, in this case there is no precipitation. Note, however, that different amplitude models could lead to different conclusions. We must emphasize that, according to the adopted model, only singly resonant particles can precipitate when low amplitude whistlers are considered.

Another important result of the computation was to suggest a simplified analytical model of the cyclotron resonant interaction near $v_{/\!/} = V_G$; integration of the equations of motion can then be simply performed. Work along these lines will be the object of future comunications.

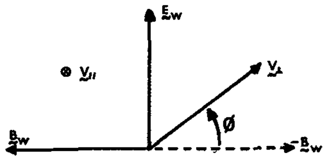

FIG. 3
Relative position of particle velocity and whistler fields.

References

/1/ - R.A. HELLIWELL, Rev.Geophys.Space Phys.7,281, (1969)

/2/ - R.A.HELLIWELL, Phil.Trans.R.Soc.Lond.B,279, 213 (1977)

/3/ - KARPMAN, ISTOMIN and SHKLYAR, Plasma Physics 16, 685 (1974).