Energetic Particle Hybrid Simulations on Geomagnetic Pulsations

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It has long been known that geomagnetic pulsations in mHz frequency range may be generated either by the field line resonance mechanism [Southwood, 1974, Chen and Hasegawa, 1974], or by local plasma instabilities [Southwood et al., 1969]. The former is essentially due to mode conversion from fast mode waves into local Alfven eigenmodes. The source of the waves are believed to be external, such as fluctuations in the solar wind and/or waves emitted by the Kelvin-Helmholtz instability at the magnetopause. Generally speaking, such externally driven waves are thought to generate pulsations with small azimuthal wavenumbers m ~ a few, which have been observed on the ground magnetometers. On the other hand, those generated by internal plasma instabilities may have high mode number m ~ 100. Such large wavenumber modes have been primarily observed by satellite measurements during storm times, associated with enhanced injection of ring current ions into the inner magnetosphere. The low-frequency geomagnetic pulsations can be an efficient driver for the radial transport of radiation-belt electrons. The classical drift resonance theory indicates that, despite relatively larger amplitude of internally driven modes, only externally driven modes can contribute to the radial diffusion [Elkington et al., 2003]. However, recent studies have suggested that the internally driven pulsations may also play a role [Ukhorskiy et al., 2009].
It is well known that the so-called drift-bounce resonance of energetic ring-current particles may be responsible for the generation of high mode number ULF waves. Although the idea of drift-bounce resonance is intuitively quite easy to understand, analysis of the instability in reality is much more complicated than this simple picture [Chen and Hasegawa, 1991, Cheng, 1991]. Earlier theoretical studies indicated that it is the inward ring-current pressure gradient that drives the instability via drift-bounce resonance between the fast energetic particles and MHD waves. To the authors knowledge, however, nonlinear simulations of this instability have not been performed so far.
According to the theoretical analysis, kinetic dynamics of the energetic ring current particles is essential for the instability, including finite Larmor radius effect, fast bounce motion along the magnetic field line, as well as finite drift across the magnetic field. On the other hand, a cold dense thermal population that dominates the total mass density but with negligible thermal pressure may well be approximated by MHD. This motivates us to adopt a new simulation model called the energetic particle hybrid simulation, in which the cold ions and electrons are approximated by fluids whereas the energetic population is treated as kinetic particles. By using this newly developed simulation model, we will discuss the internal generation mechanism of geomagnetic pulsations.
We have constructed a two-dimensional pressure-balanced equilibrium by iteratively solving a Grad-Shafranov-like equation for an anisotropic bounce-averaged ring-current pressure distribution in a dipole-like background magnetic field. We adopt this equilibrium as the initial condition for nonlinear simulations. Preliminary three-dimensional simulation results will be presented, focusing on, in particular, the dependence on the plasma beta, the scale length of the pressure gradient, and the temperature anisotropy.

Keywords: magnetosphere, ring current, MHD waves

