Modeling Pitch Angle Scattering of Radiation Belt Particles by the Injection of Low Frequency Waves with F-region HF-Driven Ionospheric Currents

K. Papadopoulos[1], Bengt Eliasson[1,2], X. Shao[1], and A. S. Sharma[1]

[1]Departments of Physics and Astronomy, University of Maryland, College Park, Maryland, USA. (dpapadop@umd.edu)

[2]Ruhr-University Bochum, D-44780 Bochum, Germany. (bengt@tp4.ruhr-uni-bochum.de)

The Earth's inner radiation belt located inside $L = 2$ is dominated by a relatively stable flux of trapped protons and electrons. The trapped proton energy ranges from a few to over 100 MeV and electron energy is higher than a few hundred keV. Radiation effects in spacecraft electronics caused by the inner radiation belt electrons and protons are the major cause of performance anomalies and lifetime of Low Earth Orbit satellites. For mitigating these hazards it is necessary to investigate ways for reducing the electron and proton life times, for example, through pitch angle scattering by waves. Injection of low frequency Electromagnetic Ion-Cyclotron (EMIC) and shear Alfven waves (SAW) into the Earth's inner radiation belt to pitch-angle scatter and enhance precipitation of energetic electrons and protons provides artificial means of Radiation Belt Remediation (RBR) for electron belt and Proton Radiation Belt Remediation (PRBR).

To pitch angle scatter electrons with waves, the gyro-resonance condition yields the minimum wavelength requirement for given particle energy and local magnetic field. For example, at the magnetic equator at L = 2 the waves resonant with 1 MeV electrons should have wavelengths less than 10 km. Low frequency EMIC waves occur in three bands with frequencies below the hydrogen, helium, and oxygen ion gyro-frequencies, respectively. At frequencies close to the ion gyro-frequencies, the EMIC waves can have wavelength short enough to gyro-resonate with energetic electrons, which can lead to significant changes in the lifetimes of electrons in the inner ration belt. As for protons, the ultra low frequency (ULF) shear Aflven waves can easily satisfy the gyro-resonant condition for pitch-angle scattering of protons. However at the inner belt, the amplitudes of naturally excited EMIC and Alfven waves do not yield significant scattering of the energetic electrons and protons and artificial sources are needed.

Recently, Papadopoulos et al. [2011a,b] (papers presented in URSI session H) present a new concept of generating ionospheric currents in the ULF/ELF range with modulated HF heating using ground-based transmitters even in the absence of electrojet currents. The new concept relies on using HF heating of the F-region to modulate the electron temperature and has been given the name Ionospheric Current Drive (ICD). In ICD, the pressure gradient associated with anomalous or collisional F-region electron heating drives a local diamagnetic current that acts as an antenna to inject mainly Magneto-Sonic (MS) waves in the ionospheric plasma. The electric field associated with the MS wave drives Hall currents when it reaches the E region of the ionosphere. The Hall currents act as a secondary antenna that inject waves in the Earth-Ionosphere Waveguide (EIW) below and shear Alfven waves or EMIC waves upwards towards the conjugate regions. Experimental verifications of the concept of ICD were carried out using the HAARP ionospheric heater.

We have developed a cold Hall MHD model to study ICD and the generation of ULF/ELF waves by the modulation of the electron pressure at the F2-region with an intense HF electromagnetic wave. The model solves equations governing the dynamics of the shear Alfven and magnetosonic modes, of the damped modes in the diffusive Pedersen layer, and of the weakly damped helicon wave mode in the Hall-dominated E-region. The model incorporates realistic profile of the ionospheric conductivities and magnetic field configuration. We use the model to simulate propagation and dynamics of the low-frequency waves and their injection into the magnetosphere around L = 2 region. In this way, we simulate the scenario of using ICD to generate waves in the ULF/ELF range by facilities located away from electrojet regions, such as the upcoming Arecibo heater. The model is able to resolve the EMIC wave mode as the local ion gyro-frequency becomes close to the wave frequency along the wave propagation path. The EM fields produced from the simulation are fed into the particle tracing code to study the pitch angle scattering of energetic electrons and protons. The lifetime reduction of inner belt energetic electrons and protons is assessed and implications for RBR and PRBR are discussed.

This work is supported by US ONR MURI grant

978-1-4244-6051-9/11/$26.00 ©2011 IEEE