3D simulation of propagation of EMIC waves in Earth's magnetosphere and ionosphere

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Electromagnetic ion cyclotron (EMIC) waves scatter energetic electrons in Earth's outer radiation belt and precipitate them into the atmosphere. To investigate the properties of these waves, a 3D linear model of plasma wave propagation in the magnetosphere, ionosphere, and neutral atmosphere has been developed. It describes propagation of Pc1-2 waves with periods on the order of 0.1-5Hz and uses spherical geometry. To avoid the singularity in polar areas an overset grid consisting of two structured non-uniform spherical grids rotated relative to each other is used. This so-called "Yin-Yang" configuration was first introduced by [Kageyama and Sato, 2004, *Geochem*., *Geophys*., *Geosyst*., *5*, Q09005]. The plasma in the wave model is represented by electron and multiple ion fluids, the latter including H^+, He^+, N^+, O^+, N_2^+, NO^+, and O_2^+. Ion density profiles are obtained from the International Reference Ionosphere (IRI) (D. Bilitza, International Reference Ionosphere, https://iri.gsfc.nasa.gov/) for altitudes below 2000 km and from the Global Core Plasma Model (GCPM) [Gallaher, Craven, and Comfort, 2000, *J. Geophys. Res*., 105, 18819]. The neutral densities required to calculate collision frequencies are obtained from the MSIS model (A. E. Hedin, Mass Spectrometer Incoherent Scatter neutral atmosphere model, https://ccmc.gsfc.nasa.gov/modelweb/atmos/msis.html).

A typical grid resolution at ground level in the simulation domain of the wave model is 10 km, while the outer radial boundary is at a few tens of thousands of km. In the plasma filled areas the transverse current is due to ion flow and the $\mathbf{E}\times\mathbf{B}$ drift of electrons. The former corresponds to an ion polarization current in the case of low frequency Alfven waves, e.g., Pc5 waves, or was being due to ion gyro-rotation in the case of EMIC (Pc1) waves. The parallel current is due to electrons only. To prevent time step limitations due to the high plasma density in the F-layer, equations for the parallel electric field and electron flow are solved implicitly. A novel configuration of numerical grid nodes is used that avoids having to solve a global system of linear equations in the implicit algorithm. Instead, a set of 3 linear equations is solved at each computational node, a procedure which is relatively numerically inexpensive. The wave model is parallelized with MPI and is being used to study propagation of EMIC waves observed by the Van Allen Probes and their ground signatures. Ground magnetometer observations of EMIC waves with a period of 4 s are compared with near-conjugate satellite observations. The simulations reveal a complex wave propagation process that includes reflection and mode coupling in the vicinity of Buchsbaum resonance locations [Kim and Johnson, 2016, *Geophys. Res. Lett*., 43, 13–21], and transmission through the ionospheric waveguide and atmosphere.