Localized electromagnetic waves in the Earth’s magnetosphere caused by magnetosphere-ionosphere interactions at high latitudes

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Results from a modeling study of small-scale (with a perpendicular wavelength of the order of 10 km at 100 km altitude), localized electromagnetic waves observed by Polar and Cluster satellites in the highlatitude magnetosphere at radial distance from 4 to 6 $R_E$ are presented. Usually, these waves are registered on the boundaries between downward and upward large-scale magnetic field-aligned current channels or inside the downward current channel. (The downward current is curried by the electrons flowing from the ionosphere and the upward current is curried by the electrons flowing into the magnetosphere.) The goal of this study is to explain spatial structure (in particular, perpendicular wavelength of the order of 12-14 km at 100 km altitude) and frequency (0.05-0.025 Hz) of small-scale electromagnetic waves observed by Cluster satellites inside two neighboring downward current channels in the auroral magnetosphere at the radial distance of 4 $R_E$. The main hypothesis investigated in this study is that these waves are generated by the interaction between large-scale magnetic field-aligned currents and the ionosphere. The numerical model used to investigate these interactions is based on a nonlinear system of partial differential equations representing reduced, two-fluid MHD model in a dipole, axisymmetrical magnetic field geometry. The model includes effect of the active ionospheric feedback on structure and amplitude of magnetic field-aligned currents interacting with the ionosphere and modifying the ionospheric conductivity. This model is two-dimensional (no azimuthal variations) and it does not include effects of the Hall conductivity in the ionosphere as well as effects of additional ionization of the ionosphere by the accelerated energetic electrons.

Simulations show that localized electromagnetic waves with parameters close to ones observed in the magnetosphere indeed can be generated by a large-scale, slowly evolving current system interacting with the ionosphere when the background ionospheric conductivity $\Sigma_{P0}$ is low but higher than the Alfvén conductivity, $\Sigma_A = 1/\mu_0 v_A$, above the ionosphere. When $\Sigma_{P0} \approx \Sigma_A$ the ionospheric feedback mechanism generate electromagnetic waves with smaller perpendicular wavelengths (less than 10 km at 100 km altitudes) and higher frequencies (of the order of 0.2 Hz) than the waves observed on Cluster satellites. These waves can be trapped and amplified inside the classical ionospheric Alfvén resonator, and they also modify the development of the waves escaping from the resonator and propagating to higher altitudes. Therefore simulations confirms that the ionospheric activity, driven by the perpendicular electric field inside the downward current channels, provides a reasonable, quantitative explanation of the structure, amplitude and frequency of small-scale electromagnetic waves observed in the magnetosphere.