Ionospheric density irregularities and electromagnetic magnetosphere-ionosphere interactions at high latitudes

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Results from a numerical study of interactions between magnetic field-aligned currents (FACs) carried by the ultra-low-frequency (ULF) Alfvén waves along the auroral magnetic field lines and the ionospheric plasma are presented. The study is based on numerical modeling of a time-evolving, nonlinear system that describes multi-scale electrodynamics of the magnetosphere-ionosphere coupled system in terms of field-aligned currents, both quasi-static or Alfvénic. Simulations show that intense electric fields and currents with a perpendicular size of 10-20 km at 100 km altitude can be generated by a large-scale, slowly evolving current system interacting with the ionosphere when the background ionospheric Pedersen conductivity, Σ_P, is low but higher than the Alfvén conductivity, $\Sigma_A = 1/\mu_0 v_A$, above the ionosphere. When $\Sigma_P \approx \Sigma_A$ the ionospheric density irregularities generate electromagnetic waves with perpendicular sizes less than 10 km. These waves can be trapped and amplified inside the classical ionospheric Alfvén resonator. Simulations also show that interactions between a pair of FACs and the ionosphere can lead to the narrowing of the upward current channel and broadening of the downward current channel such that the total width of the initial current pair remains the same. In this case the intensity of the upward current increases and the intensity of the large-scale downward current decreases. Conditions promoting this asymmetry between the upward and downward FACs include low ionospheric conductivity and a moderate magnitude of the current density ($\leq 5\ \mu\mathrm{A/m}^2$). Simulations show that the ionosphere also causes significant asymmetry in the structure and amplitude of the corresponding parallel electric fields. Thus dynamics of the parallel electric field in the upward current channel is similar to the dynamics of the current itself, but the dynamics of the field in the downward current channel differs from the dynamics of the current. The major difference is that the width of the downward current channel becomes broader with time but the scale-size of the parallel electric field becomes smaller inside the channel. This effect may explain why the so-called "black" auroral arcs, which are produced by the electrons flowing along the magnetic field lines from the ionosphere, always appear in the form of very narrow, discrete dark lines.