Farley–Buneman Instabilities in the Auroral E–Region: Hybrid Simulations and Convection Estimates

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The magnetosphere couples with the high latitude ionosphere through the earth's magnetic field lines. This coupling occurs mainly through energetic particle precipitations and electromagnetic fields. In the auroral E region, these processes cause Hall currents that drive Farley–Buneman instabilities, generating a spectrum of field-aligned plasma density irregularities (FAI). Even though coherent radar backscatter from auroral E region FAIs can be measured with great accuracy and precision, the theoretical framework to relate the echo characteristics to ionospheric state variables and convection electric fields is still limited. Furthermore, comparisons between the convection patterns derived from Doppler spectral moments and from ISR measurements are difficult because of the lower spatial and temporal resolution of the latter. Meanwhile, rocket data are finely resolved in space and time but scarce. The limited data available to validate a convection model motivates the need for new validation criteria.

On the other hand, fully kinetic, 3D particle-in-cell simulations of Farley–Buneman instabilities offer the most complete description of the underlying physics, including the complete treatment of collisional and dissipative processes (M.M. Oppenheim and Y.S. Dimant, J. Geophys. Res., 118, 196, 2013). However, the computational cost of PIC simulation codes is tremendous, owing to the necessarily finite number of particles involved and the accompanying particle noise, making the modeling of non-local phenomena extremely challenging. An innovative solution to the problem was offered by Kovalev et. al. (D.V. Kovalev, et.al. Ann. Geophys., 26, 28532870, 2008) who developed a two dimensional simulation of Farley–Buneman waves based on a continuous, hybrid approach. In their approach, electrons were treated using fluid theory, and ions using the unmagnetized Vlasov equation with a BGK collisional term. Their model results demonstrated reasonable qualitative and quantitative agreement with comparable PIC code simulations.

In this paper, we propose a way to assess the mathematical and physical consistency of a convection model (H. Bahcivan, D.L. Hysell, M.F. Larsen, and R.F. Pfaff, J. Geophys. Res., 110, 975, 2005.) which relates coherent scatter spectra with electron convection. Since the electric field in these regions is electrostatic, the convection pattern must be close to incompressible. Given that the convection model does not contain any explicit assumption of incompressibility, we will argue that if the convection field satisfies this condition within experimental error, then the model estimates are accurate. Finally, following Kovalev's approach, we present preliminary results from hybrid simulations of Farley–Buneman waves. We investigate phase speed saturation and examine whether the phase speeds of the waves scale with the background electric field E in the way observed by the coherent scatter radar. We also try to quantify wave turning effects, examine whether wave heating is commensurate with incoherent scatter radar observations and determine the dominant wavelength of the waves.