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Simulational Studies of the Farley-Buneman Instability in the Equatorial Electrojet

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The Farley-Buneman Instability [*Farley*, 1963; *Buneman*, 1963] in the equatorial electrojet current system in the E-region of the ionosphere has been identified as the cause of the observed Type I electron density irregularities. While the linear instability has been understood for nearly three decades, the effects of the nonlinear behavior remain unclear. One of the first calculations of the evolution of this instability in the nonlinear domain was due to *Sudan* [1983]. More recently, *Machida and Goertz* [1988] studied the instability numerically with an explicit particle (PIC) simulation method. They calculate electron heating in the the polar ionosphere in agreement with *Sudan* [1983], but it is not clear how good or complete the match is. Also, more complete parametric evaluation by such explicit methods would be limited, because the electrons must be treated as particles, while the instability occurs on the ion fluid time scale. The implicit ANTHEM code [*Mason*, 1993] can use particle electrons with a time step many times the plasma period, so that by implicit simulation a complete and parametric study of the instability should be feasible. The results of such a program would have important bearing on the understanding of electron heating by low-frequency turbulence in the ionosphere.

Our present goal is to study the instability in the equatorial region. This region was ignored by Machida and Goertz. We seek to determine the cause of saturation, the velocity of the waves in the saturated state (do they travel at the sound speed) and any other nonlinear phenomena. The significance of this work derives from the large number of unanswered questions about Type I waves. These include, among others, the observation of vertically propagating two-stream waves (perpendicular to the current), the constant phase velocity of Type I waves at any angle with respect to the current and the details of the observed wave number spectra [*Kelley*, 1989]. Much of the detailed observational data about these waves was—and still is—gathered by Cornell University researchers. This gives us the ability to closely correlate our results with the experimental data.

We originally planned to evaluate the nonlinear behavior of the Farley-Buneman Instability solely with the ANTHEM implicit plasma mode. This model can treat electron kinetic influences on instability's long time scale evolution. However, Meers Oppenheim has developed two newer models, which allow for speedier electron fluidic treatments. The first is a two-fluid simulation, which also incorporates linear ion kinetic damping. This enables us to evaluate quickly the wave behavior assuming that kinetic effects are negligible. The second is an explicit particle code that uses particle ions and fluid electrons. This enables us to determine whether ion kinetic effects are substantially modifying the ion fluid behavior.

Both the two-fluid and the ion particle simulators have been written and tested. Initial results of the fluid simulation show three nonlinear effects: (1) saturation, (2) nonlinear rotation of the wave direction away from strictly horizontal and (3) nonlinear coupling from the predominant horizontal wave structure of wavelength 1.5 m to a long wavelength

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vertical wave. The first two effects have been confirmed by the PIC code. The third effect is also an interesting result because the observational database shows these, as yet unexplained, waves.

For the fluid model we assume that the effect of the Earth's magnetic field on the ions is irrelevant and that the electron mass is insignificant enough to set to zero. Using the ion continuity equation, the ion momentum equation, the inertialess, collisional electron momentum equation and the assumption of quasi-neutrality, we derived the new set of equations. In order to simulate this system with either a fluid model or an ion PIC code, it was necessary to determine the inertialess, magnetized electron behavior. Solving this problem numerically has been one of the principal difficulties in studying the instability. At least one published result [*Newman and Ott*, 1981] was done incorrectly. Nonetheless, we found and applied a technique that produces accurate solutions for almost all density variations.

Using the new models we have been exploring typical conditions for the daytime equatorial electrojet an altitude of 100 km to 105 km. The simulations produce a "typical" saturated state for the FB waves. From the calculations we estimate a phase velocity for the waves of 430 m/s. which compares to 600 m/s predicted by the linear theory. The simulations are providing evidence that ion Landau damping may not play an important role in eliminating short wavelength modes. After saturation, the distribution of ions in velocity space differs from the initial Gaussian profile only by an offset of its mean velocity by the ion Pederson drift velocity. This implies that a fluid model for ion behavior may be adequate.