Parametric Wave Growth in a Hybrid PIC/Fluid Simulation of the Equatorial E Region.

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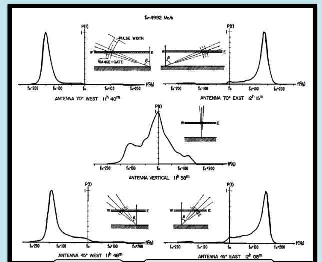
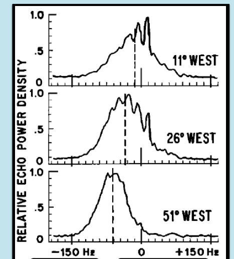
Background

This work models the **equatorial ionosphere** around 100 km. The plasma is **electrostatic** and **quasineutral**. Ions are demagnetized by collisions while electrons E x B drift westward. Density gradients and electric fields can cause this plasma to become unstable to both the **gradient-drift** and **Farley-Buneman** instabilities. These are the **first simulations** of coupled Farley-Buneman/gradient-drift instability initiated by a large-scale density perturbation.

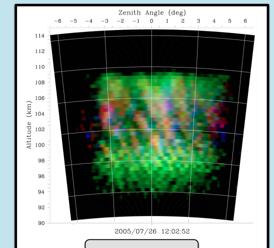
Motivation

The 50-MHz radar at Jicamarca has observed so-called Type I and Type II irregularities for decades (e.g. Cohen & Bowles (1967) and Balsley (1969)). Type I spectra are narrow with a constant Doppler shift; Type II spectra are broad with Doppler shift that increases with look angle. Type I are attributed to the Farley-Buneman (FB) instability and Type II are attributed to the gradient-drift (GD) instability, but both are special cases of the same dispersion relation. More recent observations by Hysell et al. (2007) suggest that meter-scale irregularities observed at Jicamarca can trace kilometer-scale structures. Thus far, no simulations have reproduced this coupled turbulence.


Type I | Cohen & Bowles (1967)



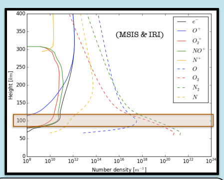
Type II | Balsley (1969)


Hysell et al. (2007)

Simulation

- Ions: particle-in-cell method with ≈ 1 billion particles.
- Electrons: inertialess, isothermal fluid (quasineutral with ions).
- Density: initialized as a Gaussian (FWHM = 146 m) perturbed by a 512-m wave.
- Electrostatic potential: Calculated from background electric field (E x B drift), total density, ion flux, and electron fluid quantities.
- Background densities and temperatures taken from MSIS & IRI model data (01 Jan 2000 @ noon).

Physical Setup



Equatorial E region around 100 km
Dominant neutrals are N_2 and dominant ions are NO^+. Ions are demagnetized by collisions with neutrals.

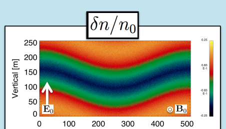
$(dx,\ dy) = (0.25,\ 0.25)$ m
$(nx,\ ny) = (2048,\ 1024)$ cells
$dt = 5\times10^{-5}$ s
$nt = 8192$ steps
$\mathbf{B}_0 = -2.5\times10^{-5}\,\hat{y}$ T
$m_e = 9.1\times10^{-31}$ kg
$m_i = 5.0\times10^{-26}$ kg
$m_n = 4.6\times10^{-26}$ kg
$n_0 = 10^{10}$ m^{-3}
$\nu_e = 3.0\times10^{4}$ s^{-1}
$\nu_i = 3.0\times10^{3}$ s^{-1}
$T_e = T_i = T_n = 220$ K

Potential Solver

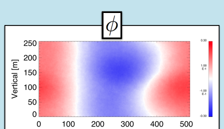
$$\epsilon \equiv \begin{pmatrix} 1 & -\kappa_e \\ \kappa_e & 1 \end{pmatrix} \qquad \kappa_e \equiv \frac{\Omega_e}{\nu_e}$$

Cyclotron frequency
Collision frequency

$$\nabla\cdot(n\epsilon\nabla\phi) = \nabla\cdot\left\{\epsilon\left[n\mathbf{E}_0 + \left(\frac{\gamma T_e}{e}\right)\nabla n\right] + (1+\kappa_e^2)\frac{m_e\nu_e}{e}n\mathbf{v}_i\right\}$$

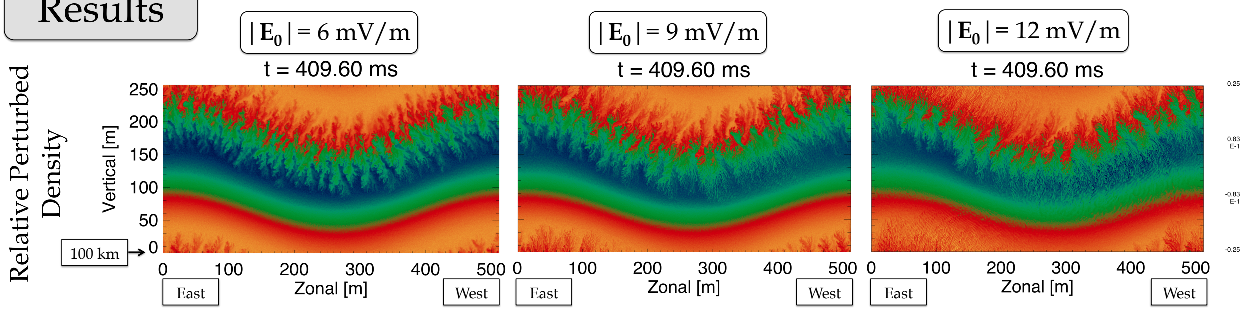


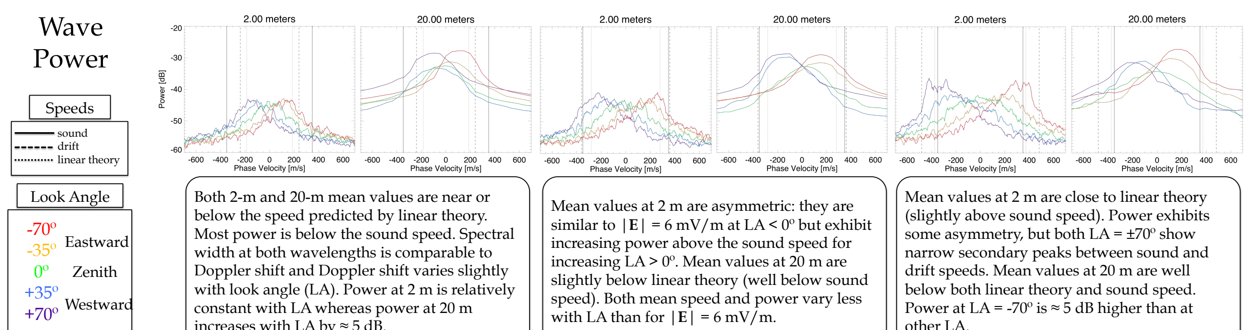
Initial relative perturbed density



Initial electrostatic potential

Results





Both 2-m and 20-m mean values are near or below the speed predicted by linear theory. Most power is below the sound speed. Spectral width at both wavelengths is comparable to Doppler shift and Doppler shift varies slightly with look angle (LA). Power at 2 m is relatively constant with LA whereas power at 20 m increases with LA by ≈ 5 dB.

Mean values at 2 m are asymmetric: they are similar to $|\mathbf{E}| = 6$ mV/m at LA < 0° but exhibit increasing power above the sound speed for increasing LA > 0°. Mean values at 20 m are slightly below linear theory (well below sound speed). Both mean speed and power vary less with LA than for $|\mathbf{E}| = 6$ mV/m.

Mean values at 2 m are close to linear theory (slightly above sound speed). Power exhibits some asymmetry, but both LA = ±70° show narrow secondary peaks between sound and drift speeds. Mean values at 20 m are well below both linear theory and sound speed. Power at LA = -70° is ≈ 5 dB higher than at other LA.

Conclusions

Two-meter irregularities with speeds at or above the sound speed grow asymmetrically with increasing $|\mathbf{E}|$.

Power spectra are mostly Type II with subsonic mean but show fast, narrow peaks at 2 m for largest $|\mathbf{E}|$.

Fourier spectra (not shown) for $|\mathbf{E}| > 9$ mV/m exhibit an initial burst of meter-scale power before growth of longer wavelengths