SPECTRAL STUDIES OF TYPE 1 E-REGION INSTABILITIES USING A NEW GENERATION OF HIGH-RESOLUTION SIMULATIONS

Meers Oppenheim, Yakov Dimant, Lars Dyrud

Center for Space Physics, Boston University,
725 Commonwealth Ave., Boston, MA, 02461, USA
meerso@bu.edu

ABSTRACT

In the E-region ionosphere, turbulent processes driven by strong ambient DC electric fields create plasma density irregularities responsible for type 1 radar echoes. These irregularities have been studied experimentally and theoretically for five decades. In the last decade, numerical simulations became an important tool in exploring the nonlinear behavior of E-region instabilities. However, these simulations were limited to 2-D and meshes resolving only 4096 (64 by 64) modes. Today, taking advantage of modern, massively parallel, supercomputers, we can resolve over 262,144 (512 by 512) modes in 2-D or over a million modes in 3-D. In this paper, we will describe the spectra of type 1 waves from these high-resolution simulations and how they relate to measurements of type 1 waves.

In 2-D, our simulator modeled electron dynamics with an adiabatic, inertial, fluid solver while resolving ions kinetically with a particle-in-cell method (PIC). We ran a set of simulations appropriate for the auroral E-region at 106 km altitude starting with a 70mV/m electric field driver, then stepping down to 50mV/m and to 40mV/m. The instability threshold is approximately 30mV/m. In all of these cases, the phase velocity of the most energetic modes lies well below the linearly predicted phase velocity. Further, we see that for short wavelengths (< 1m), the dominant mode maintains a roughly constant phase velocity as the angle with respect to the drift direction increases from 0° to nearly $\pm 90^{\circ}$. For the longest wavelengths in the system (> 6m), the phase velocity changes in proportion to the cosine of the angle. Intermediate modes show a "flattened cosine" phase velocity relationship. The simulations with the weakest drivers - best representing the physics found in the equatorial electrojet - generated short wavelength spectra with the least dependence on angle.

In 3-D, our latest generation simulations model both electrons and ions with kinetic algorithms. This allows us to explore thermal effects with great accuracy but requires us to resolve the system Debye length and electron gyrofrequency. We use artificial values for electron mass (m_{ion}=625 m_e) and adjust all other parameters appropriately. This also forces us to resolve short wavelengths, limiting our total resolution. Nevertheless, we see similar spectral features similar to those described in the 2-D system and we observe coupling to modes with a small component parallel to the geomagnetic field. Finally, we measure wave driven electron heating, a phenomena clearly observed by radars.