THEORY AND LARGE-SCALE SIMULATIONS OF PLASMA TURBULENCE IN LOWER IONOSPHERE

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For five decades, radars and rockets have observed plasma turbulence in the weakly ionized, highly collisional plasma of the lower E/upper D-region ionosphere at altitudes between 90 and 130 km. At these altitudes, electrons are strongly magnetized, while ions are demagnetized by frequent collisions with the neutral atmosphere. Low-altitude plasma turbulence is mainly observed near the geomagnetic equator and at high latitudes, where strong DC electric fields perpendicular to the geomagnetic field occur. These fields result in strong Hall currents named electrojets and drive low-frequency plasma instabilities. The coupled turbulent electric fields and plasma density irregularities caused by instabilities play a role in ionospheric conductivity, temperatures, as well as in radio wave propagation and reflectivity.

Relevant instabilities include the modified two-stream (Farley-Buneman) and gradient drift instabilities, as well as recently predicted thermal instabilities. In the high-latitude electrojet, during strong magnetospheric perturbations (storms and sub-storms), radars observed anomalous electron heating (AEH) caused by turbulent electric fields. A combination of low-frequency instabilities also plays an important role in plasma trails left behind meteoroids that routinely enter the Earth's atmosphere. The instabilities give rise there to field-aligned irregularities that result in so-called 'non-specular' radar echoes observed by high-power large-amplitude radars.

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 2D and meshes resolving typically around 4096 (64×64) cells. Having improved the method of parallel processing of our fully kinetic, Particle-In-Cell (PIC), code, EPPIC, we can now take advantage of supercomputers with thousands of processors to run simulations with more than a billion of particles and enormous meshes in 2D or 3D.

In this talk we will present results of recent 2D and 3D fully kinetic simulations that reproduce many of the observational characteristics of radar signals. As predicted by theory, the 3D simulations show the development of waves with a small component of the turbulent electric field parallel to the geomagnetic field. This field component is mainly responsible for AEH observed by radars. For the first time, we can now quantify this effect using accurate simulations. These simulations provide information useful in accurately modeling plasma turbulence and demonstrate the significant progress we have made simulating physical processes in E-region electrojets.