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Analysis and Modeling of Mid-latitude Decameter-Scale Plasma Wave Irregularities Utilizing GPS and Radar Observations

Abstract:
The mid-latitude SuperDARN radars frequently observe decameter-scale irregularities in the nightside sub-auroral ionosphere during quiet and active geomagnetic periods, however, the mechanism responsible for the growth of such irregularities has not yet been established. In this work, the Temperature Gradient Instability (TGI) and the Gradient Drift Instability (GDI) are extended into the kinetic regime appropriate for HF radar frequencies and analyzed as the cause of these irregularities. Co-located experimental observations by Blackstone SuperDARN radar, and the Millstone Hill Incoherent Scatter Radar (ISR) are performed under quiet and disturbed sets of geomagnetic conditions to identify what plasma instability mechanisms predominate.

A critical comparison of TGI and GDI is made for these observations. The growth rate comparison suggests that the TGI is the most likely generation mechanism for the quiet time irregularities that cause the observed low-velocity Sub-Auroral Ionospheric Scatter (SAIS), while the GDI does not have a significant role in the generation of these irregularities. Also, the calculations suggest that the TGI in association with the GDI may drive the ionospheric irregularities that cause GPS scintillations during disturbed geomagnetic conditions. The nonlinear evolution of the TGI is studied utilizing gyro-kinetic Particle-In-Cell (PIC) simulation techniques with Monte Carlo collisions, allowing further investigation of the TGI as the cause for the SuperDARN observations and GPS scintillations. The spatial power spectra of the density fluctuations associated with the TGI is calculated and found to be consistent with ground GPS spectral density measurements. The spectra calculations of TGI lie in the same range of previous numerical simulations of GDI [e.g., Keskinen and Huba, 1990; Guzdar et al., 1998], showing that the spectral index of TGI and GDI density irregularities are of the order 2. These spectral calculations are comparable with previous in situ satellite spectral measurements at mid-latitudes. An interpretation of the spectral analysis is that TGI and GDI irregularities are initially generated at kilometer-scale, become unstable and dissipate their energy by generating smaller sized (decameter-scale) irregularities. The GPS measurements along with radar observations suggest that the observed decameter-scale irregularities that cause SuperDARN backscatter, co-exist with kilometer-scale irregularities that cause L band scintillations during active geomagnetic conditions.

The alignment between the experimental, theoretical, and computational results of this study suggests that a TGI turbulent cascade may be responsible for decameter-scale irregularities that occur under quiet conditions of the mid-latitude F-region ionosphere, while the TGI in concert with the GDI or a cascade product from them may cause the observed ionospheric irregularities that cause GPS scintillations during disturbed times.