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Plasma instability-driven mid-latitude ionospheric irregularities and potential consequences for radar and GPS scintillation observations

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Extended Abstract

Measurements by the Blackstone SuperDARN HF radar, the Millstone Hill Incoherent Scatter Radar (ISR), and GPS scintillation monitors are used to investigate the generation mechanism responsible for observed decameter-scale irregularities in the nightside sub-auroral ionosphere during both quiet and active geomagnetic periods. Both the temperature gradient instability (TGI) and the gradient drift instability (GDI) are considered for their potential to generate the observed irregularities. A critical comparison of TGI and GDI is made for the observed mid-latitude irregularities. A kinetic theory approach is used due to the HF radar observations that show short decameter wavelength scales near the ion gyro-radius.. Although there has been considerable computational plasma modeling of the GDI, this is not the case for the TGI. Therefore, the nonlinear evolution of the ionospheric TGI is investigated for the first time utilizing gyro-kinetic Particle-In-Cell simulation techniques with Monte Carlo collisions (PIC-MCC). The computational plasma model is used to identify the mechanism responsible for nonlinear saturation, associated anomalous transport, spectral characteristics in the nonlinear saturated state, and ultimately, the implications on the steady state irregularities in the radar and GPS observations. The saturation amplitude level and the associated diffusion are found to be greatly enhanced as a result of electron collisions. The simulation results also show that nonlinear $E \times B$ convection (trapping) of electrons is the dominant saturation mechanism for the TGI. The spatial power spectra of the electrostatic potential and density fluctuations associated with the TGI show wave cascading of the TGI driven turbulence from kilometer scales into the decameter-scale regime of the HF radar observations. Ground GPS scintillation spectral density measurements are calculated and found to have consistencies with the simulation results and previous *in situ* satellite measurements, revealing that the spectral index of mid-latitude density irregularities is of the order 2. The spectral calculations suggest that initially TGI or/and GDI irregularities are generated at large scale size or sizes (say km-scale) and the dissipation of the energy associated with these irregularities occurs by generating smaller and smaller (decameter-scale) irregularities. The GPS measurements along with radar observations suggest that the mid-latitude decameter-scale irregularities observed by SuperDARN radars may co-exist with kilometer-scale irregularities that cause GPS L band scintillations during active geomagnetic periods. The alignment of the experimental, theoretical, and simulation results of this study suggests that a TGI turbulent cascade is the most likely generation mechanism for the quiet time irregularities that cause the observed low-velocity Sub-Auroral Ionospheric Scatter (SAIS), while turbulent cascade processes of both TGI and GDI may cause the observations of mid-latitude GPS scintillations during disturbed geomagnetic conditions.