Identification of the Plasma Instabilities Responsible for Mid-Latitude Decameter-Scale Ionospheric Irregularities

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Joint measurements by the Blackstone SuperDARN radar, and the Millstone Hill Incoherent Scatter Radar (ISR) are analyzed to investigate the generation source responsible for the observed decameter-scale irregularities in the nightside sub-auroral ionosphere during quiet and active geomagnetic periods. 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. A critical comparison of TGI and GDI is made for the observed mid-latitude irregularities. To perform this comparison, the nonlinear evolution of the TGI is investigated utilizing gyro-kinetic Particle-In-Cell (PIC) simulation techniques with Monte Carlo collisions for the first time. The purpose of this investigation is to identify the mechanism responsible for nonlinear saturation and associated anomalous transport and ultimately the implications on the observed steady state irregularities. It is found that the saturation amplitude level and the associated diffusion are greatly enhanced as a result of electron collisions. The simulation results show that the nonlinear $E \times B$ convection (trapping) of electrons is the dominant saturation mechanism for the TGI instability. The spatial power spectra of the electrostatic potential and density fluctuations associated with the TGI are also computed and the results show wave cascading of TGI from kilometer scales into the decameter-scale regime of the radar observations. The ground GPS spectral density measurements are calculated and found to be consistent with simulation results and previous in situ satellite measurements, revealing that the spectral index of mid-latitude density irregularities are of the order 2. The spectral calculations suggest that initially TGI or/and GDI irregularities are generated at large scale size or sizes (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, co-exist with kilometer-scale irregularities that cause GPS L band scintillations during active geomagnetic periods. The reasonable agreement between 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. This lends further support to the E region being responsible for shorting out the F region TGI and GDI electric fields before and around sunset and ultimately resulting in irregularity suppression.