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Understanding the ionospheric irregularities using a plasma simulation model, a radio wave propagation model and GNSS observations

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Electromagnetic signals passing through ionosphere experience amplitude and phase fluctuations. These scintillations observed on the Global Navigation Satellite Systems (GNSS) signals can be used to determine the underlying plasma instabilities in the ionospheric irregularities with the help of a combination of a plasma simulation model and an electromagnetic wave propagation model. In order to investigate the different types of instabilities that affect the GNSS signals, we use this novel hybrid modeling approach. A plasma instability model called Geospace Environment Model of Ion-Neutral Interactions (GEMINI) is used to simulate plasma instabilities in a confined region of ionosphere. Satellite-beacon Ionospheric-scintillation Global Model of the upper Atmosphere (SIGMA) is a model that simulates GNSS signal propagation through random media. GEMINI is a physical model that can provide the simulated ionospheric number density for different instabilities as an input to SIGMA. SIGMA-GEMINI together can be used to model GNSS scintillations on ground through different types of plasma instabilities and can prove to be an excellent tool to investigate evolution of instabilities at small to medium scale sizes. This kind of modeling approach combined with inputs from multi-instrument observations could prove to be a unique way of studying the cascading phenomena in the ionosphere as well as identifying sources of irregularities in the interest of space weather forecasting. We studied the propagation of GNSS signals from plasma instabilities such as gradient-drift instability (GDI) and Kelvin-Helmholtz instability (KHI) and a combination of the two, since these are the likely processes contributing to intermediate-scale density structures in the high latitude ionosphere. We present a sensitivity study of this hybrid modeling approach for different aspect angles and altitude. We also present case studies of GNSS scintillation observations associated with polar cap patches over Resolute Bay. With multi-instrument observations, we relate the instabilities producing GNSS scintillations to the geomagnetic conditions and further predict the type of instability (KHI or GDI) using our modeling approach. Our analysis indicates that predominantly GDI instabilities are responsible for GNSS scintillations in polar cap.