Project Details

ROSES ID: NNH20ZDA001N
Selection Year: 2020
Program Element: Focused Science Topic

Topic: Modeling and Validation of Ionospheric Irregularities and Scintillations

Project Title:
Contributions of auroral electron precipitation and plasma fluid instabilities to the formation of high-latitude ionospheric density structures and scintillation

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Summary:
Intermediate scale ionospheric density irregularities can lead to fluctuations in amplitude and phase, i.e. scintillation, of trans-ionospheric radio signals, potentially resulting in degradation of GPS accuracy, scattering of HF radio signals, and other effects. Scintillation is common in high-latitude regions including the cusps, where it has been associated with flow shears and density gradients, and the polar cap, where it has been associated with high-density plasma patches. Background inhomogeneities in the plasma in these regions (strong gradients and flow shears) have led to identification of ionospheric gradient-drift and Kelvin-Helmholtz instability as processes involved in irregularity generation. By contrast, scintillation in the auroral zone is often associated with visible auroral arc structures, suggesting an important role for energetic electron precipitation along with density gradients and complicated flow structures. Due to a confluence of many different processes that could, in principle, contribute to irregularity generation, processes leading to auroral scintillation events are relatively poorly understood compared to their cusp and polar cap counterparts.

The proposed work plans to investigate the role of electron precipitation in producing auroral scintillation by addressing a single top-level science question concerning specific physical mechanisms which lead to scintillation, and the conditions under which auroral scintillation occurs: (SQ) What are the features of density structuring and scintillation produced by electron precipitation (a) directly via impact ionization and (b) indirectly through seeding of ionospheric fluid instabilities triggered from inhomogeneous background conditions?

Comprehensive modeling and data analysis efforts for this project will leverage ionospheric and radio propagation models combined with in situ and remote sensing data from Poker Flat, Alaska. Our ionospheric model, GEMINI, self-consistently describes effects of electron precipitation (i.e. impact ionization, heating, and optical emissions), and fluid-electrodynamic processes responsible for plasma interchange instabilities. GEMINI is coupled to a radio propagation model, SIGMA, to simulate scintillation from a modeled field of density irregularities - creating a full physics based pathway for simulating synthetic scintillation data from hypothetical auroral configurations. These models will be used for physics-based investigations of density irregularities and attendant scintillation produced by precipitation directly (structured impact ionization) and indirectly (seeding of instabilities). High-rate fluctuation data (50 Hz) from the SAGA L-band array at PFRR will be used to directly monitor scintillation during auroral events. Conjunctions between SAGA and other data sources will establish connections between different plasma state parameters and suggest physical mechanisms responsible for structures. Swarm fine-scale measurements of density and drift above the ionosphere, will characterize irregularities and seed structures, while the background state of the ionosphere will be monitored via the Poker Flat Incoherent Scatter Radar. Finally, precipitation will be monitored via inversion of filtered allsky camera measurements which will provide images of structured precipitating electron flux and energy. Data analysis activities will both serve to provide much-improved characterizations of auroral scintillation and to guide selection of parameters for modeling hypotheticals and case studies.

This project directly addresses FST 1 in the B.5 solicitation concerning modeling and validation of irregularities and scintillation and is relevant to LWS program goals 2 and 3 and Heliophysics Decadal survey key science goal 2. The likely role of this project within the FST group is to provide theoretical guidance on sources of auroral small -scale density struc tures and their connection with scintillation.

Publication References:

Summary: Blah

Reference: Vaggu, P. R.; Deshpande, K. B.; Datta-Barua, S.; Bust, G. S.; Hampton, D. L.; Rubio, A. L.; Conroy, J. P. (2023). Morphological and Spectral Features of Ionospheric Structures at E- and F-Region Altitudes over Poker Flat Analyzed Using Modeling and Observations. Sensors, 23, 2477. https://doi.org/10.3390/s23052477

- **Investigation Type:** Other Investigations
- Electron density irregularities in the ionosphere modify the phase and amplitude of trans-ionospheric radio signals. We aim to characterize the spectral and morphological features of E- and F-region ionospheric irregularities likely to produce these fluctuations or “scintillations”. To characterize them, we use a three-dimensional radio wave propagation model—“Satellite-beacon Ionospheric scintillation Global Model of upper Atmosphere” (SIGMA), along with the scintillation measurements observed by a cluster of six Global Positioning System (GPS) receivers called Scintillation Auroral GPS Array (SAGA) at Poker Flat, AK. An inverse method is used to derive the parameters that describe the irregularities by estimating the best fit of model outputs to GPS observations. We analyze in detail one E-region and two F-region events during geomagnetically active times and determine the E- and F-region irregularity characteristics using two different spectral models as input to SIGMA. Our results from the spectral analysis show that the E-region irregularities are more elongated along the magnetic field lines with rod-shaped structures, while the F-region irregularities have wing-like structures with irregularities extending both along and across the magnetic field lines. We also found that the spectral index of the E-region event is less than the spectral index of the F-region events. Additionally, the spectral slope on the ground at higher frequencies is less than the spectral slope at irregularity height. This study describes distinctive morphological and spectral features of irregularities at E- and F-regions for a handful of cases performed using a full 3D propagation model coupled with GPS observations and inversion.