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Unraveling High-Latitude Plasma Density Irregularities: New Techniques and their Scientific Impact

Lindsay V. Goodwin*(1), and Bimal Dahal(1)
(1) New Jersey Institute of Technology, Newark, NJ, 07102, e-mail: lindsay.v.goodwin@njit.edu

Polar cap patches, or simply "patches", are defined to be plasma density enhancements twice the background, typically 100 km wide. However, this definition mixes different creation mechanisms, including those driven by thermospheric phenomena ("coupling from below") and magnetospheric phenomena ("coupling from above"). Furthermore, it is unclear what the "background" plasma density is, given that the high-latitude is frequently highly-structured with enhancements and depletions, which are both disruptive to radio wave propagation and spacecraft. Given these challenges, we question whether the term "patch" remains a scientifically useful classification or whether a more nuanced framework is needed to describe polar cap density structures.

To gain new insights into plasma density scale sizes and structuring beyond traditional "patch" definitions, we generate irregularity spectra by applying Fourier Transforms and Lomb-Scargle periodograms to plasma density datasets. While this technique is applicable to various geospace datasets, an important focus of this work is high-latitude Advanced Modular Incoherent Scatter Radar (AMISR) measurements. First, volumetric plasma density measurements are mapped to a common altitude under the assumptions of slow F-region cross-field plasma diffusion at scales greater than 10 km and the near-vertical orientation of high-latitude geomagnetic field lines. Irregularity spectra are then generated and examined as a function of several conditions, including magnetic local time, solar activity, and geomagnetic conditions. Analysis of 2016–2018 imaginglp mode data from Resolute Bay Incoherent Scatter Radar -North reveals a distinct contrast between sunlit and dark conditions. During the day, the most prominent spectral features appear above 100 km, whereas at night, they are concentrated below 100 km. This suggests that photoionization drives large-scale structuring while potentially suppressing smaller irregularities through E-region shorting, whereas plasma flows, recombination, precipitation, and instabilities contribute to small-scale structuring. This work further investigates these findings, explores the broader applicability of this technique to other datasets, and considers alternative approaches to studying plasma density irregularities without the constraints of conventional patch definitions.