Novel methods for characterizing ionospheric irregularities in the high-latitude ionosphere

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Introduction

- Ionospheric plasma structures alter radio wave propagation and degrade the performance of critical technologies.
- Since the scale-size and occurrence of a plasma density irregularity is linked to its generation mechanism, it is useful to resolve density structures as a function of spatial frequency, creating "irregularity spectra".
- Kelley et al. [1982] resolved irregularity spectra from Chatanika Incoherent Scatter Radar (ISR) observations of the midnight sector auroral zone and showed that soft electron precipitation is an important mechanism in driving irregularities throughout the entire high-latitude ionosphere.

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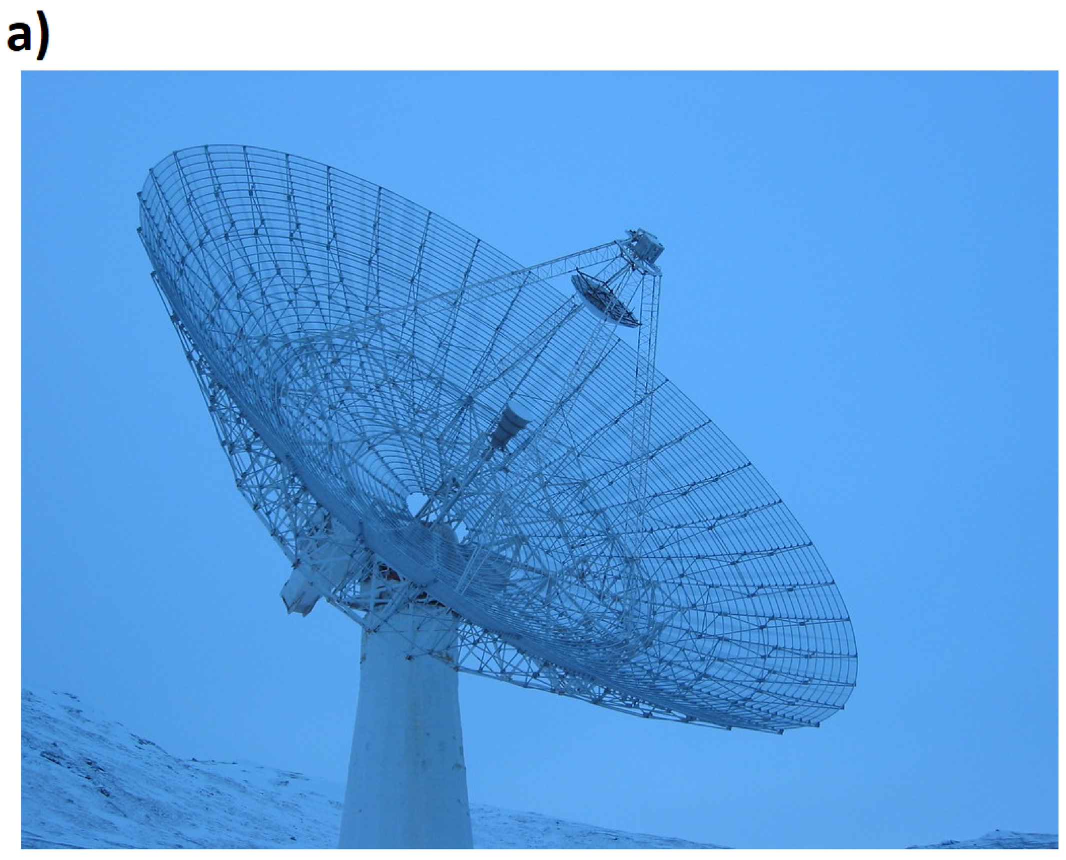

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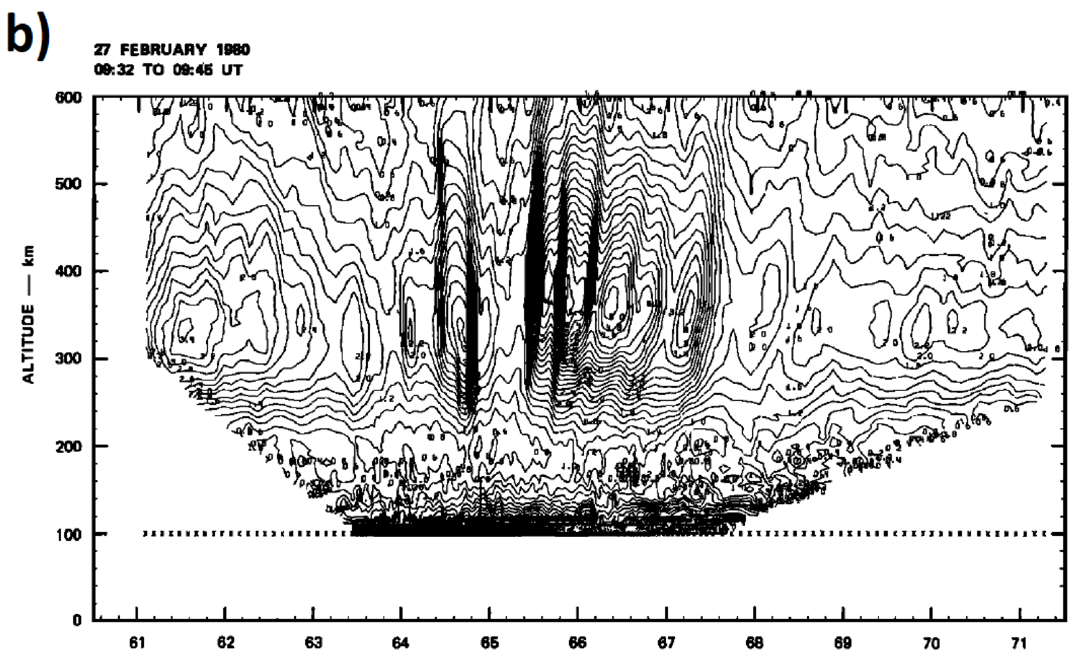

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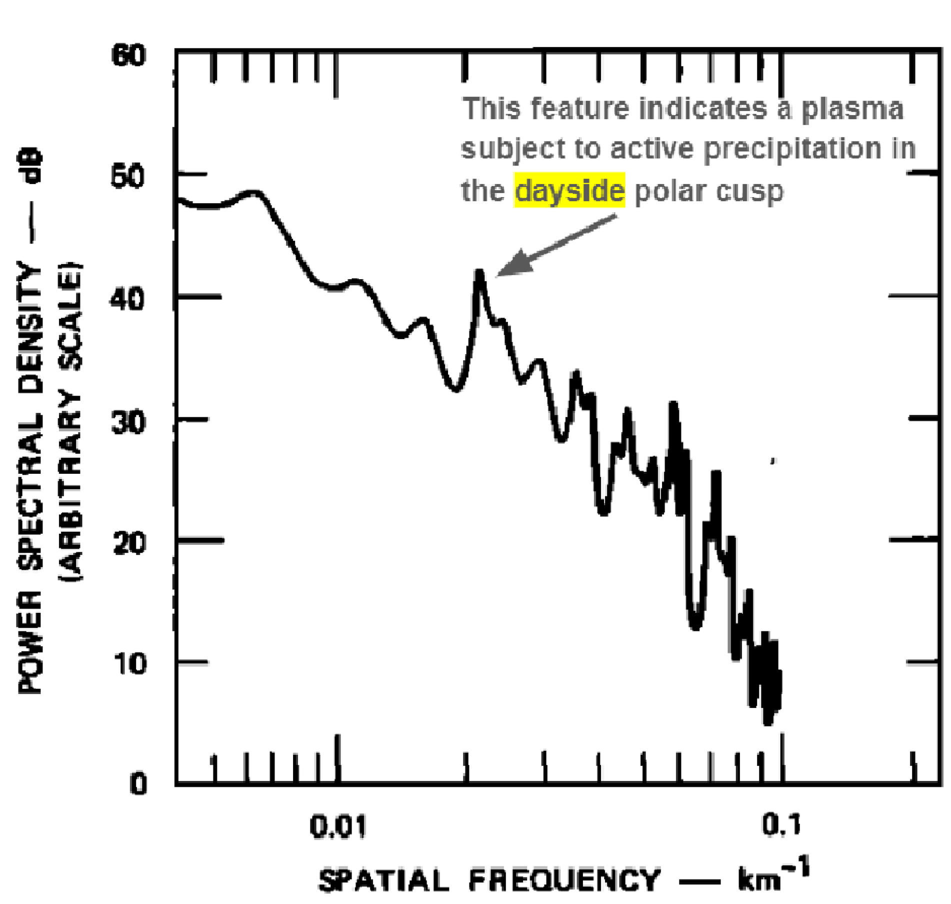

Figure 1: a) Chatanika ISR. b) Midnight auroral zone Chatanika ISR plasma density observations (contour interval is 2e4 cm-3). c) Associated irregularity spectrum developed using observations at 350 km altitude [Kelley et al., 1982].

- Kelley et al., [1982] focused on the auroral zone.
- Since the Chatanika radar dish needed to be steered to resolve parameters from different lines-of-sight scans could take upwards of 12 minutes to complete.
- **The goal of this work is to use ISR observations to quantify the irregularity spectra of the high-latitude ionosphere with precise and uniquely capable techniques.**

Methodology

- Advanced Modular ISRs (AMISRs) utilize an array of antennae and electronic beam steering to observe multiple directions nearly simultaneously.
- Resolute Bay ISR - North (RISR-N) and Resolute Bay ISR - Canada (RISR-C) are located deep in the northern polar-cap, while the Poker Flat ISR (PFISR) is positioned to observe auroral and subauroral regions, depending on geomagnetic activity.

a)

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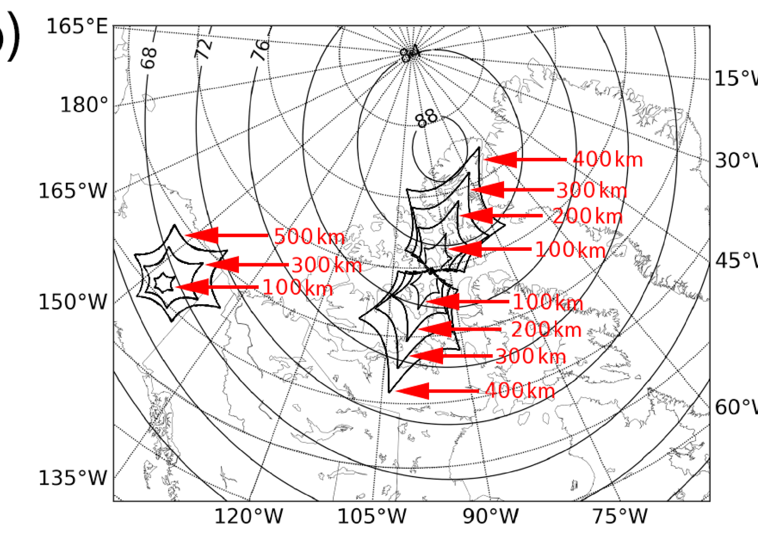

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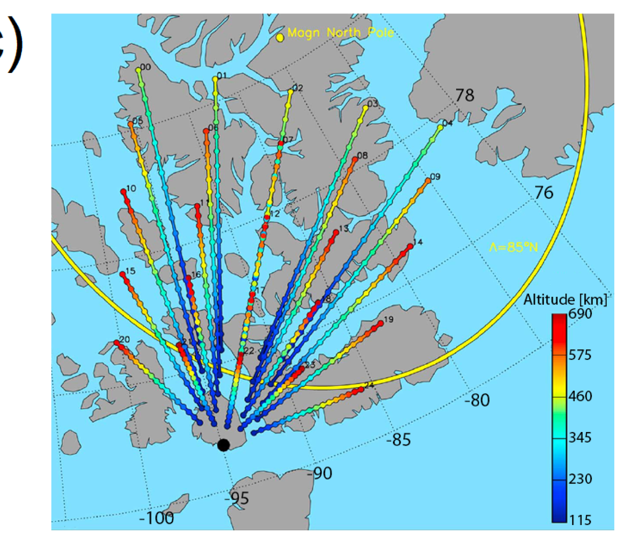

Figure 2: a) RISR-N. b) Field-of-view for the high-latitude AMISR facilities at a variety of altitudes. c) An example of how RISR-N's sampling points can be spread in space during a 25 beam WorldDay55m mode [Forsythe and Makarevich, 2018].

- AMISRs cannot provide an irregularity spectrum as finely resolved at 350 km altitude as the 10 km scale provided by the Chatanika ISR along a fixed magnetic meridian.
- To resolve this short-coming, we will use the fact that: 1) the dominant transport mechanism parallel to the magnetic field between 200 km and 400 km altitude is diffusion, 2) the cross-field diffusion is negligible at these scales, and 3) that the irregularity spectrum maps vertically along the magnetic field lines between 200 and 400 km.
- By correcting for density variations with an empirical model, all of the sampling points between 200 and 400 km can be mapped to the same altitude, increasing the density of sampling points and allowing a more highly resolved irregularity spectrum.

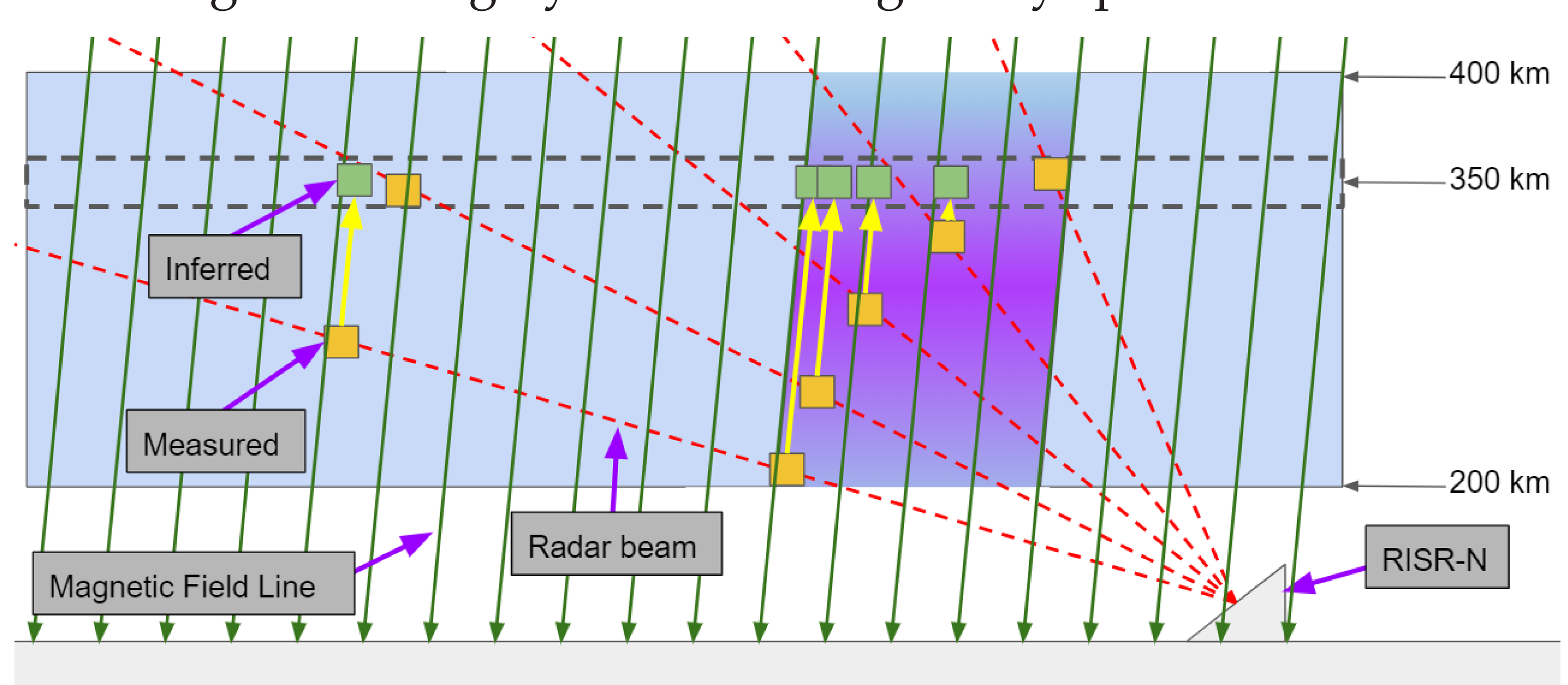

Figure 3: The field-line mapping technique used to infer plasma densities at 350 km in the presence of a plasma structure (shown in purple). The red lines are radar lines-of-sights, the orange squares are positions measured, the green squares are inferred measurements, and the green arrows are magnetic field-lines.

Preliminary Results

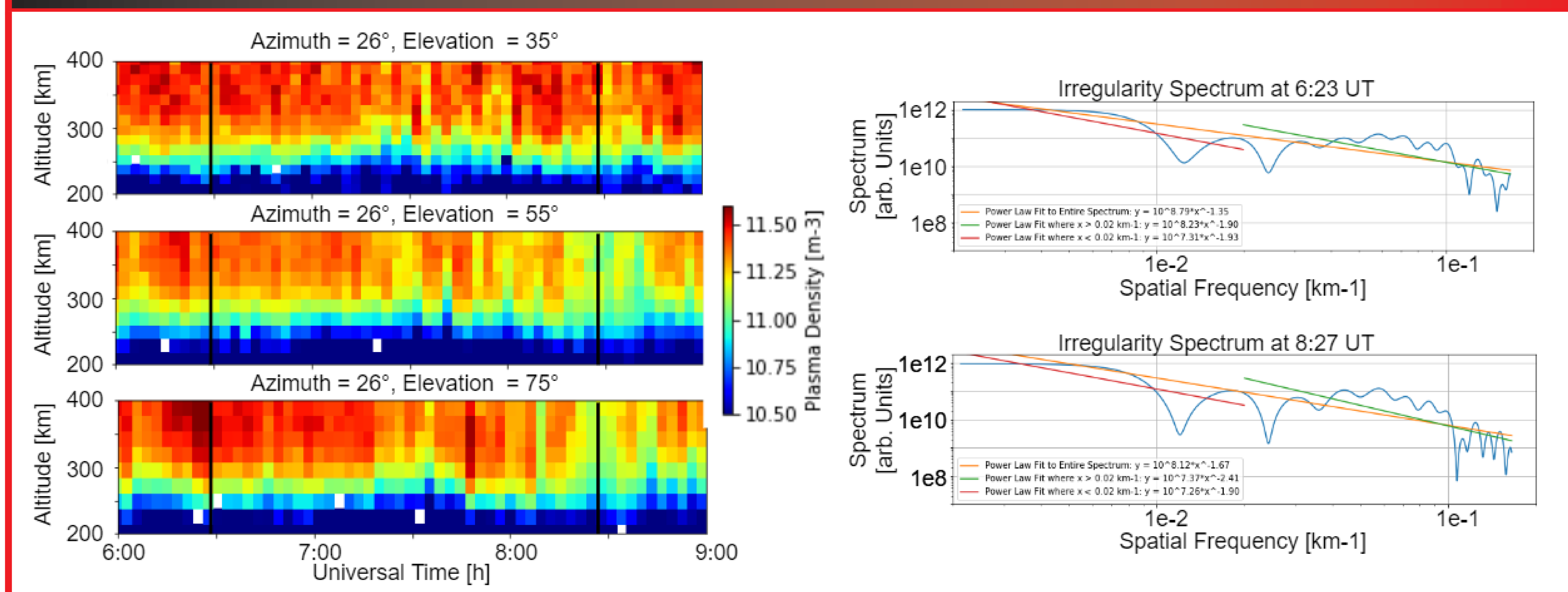

Figure 4: Right) September 12, 2014 plasma density measurements from three overlapping RISR-N beams. Left) Irregularity spectra resolved from plasma density data at two separate times. Different power law fits are shown ($y = 10^A x^B$), where the yellow lines are fits to the entire spectrum (top: $A = 8.79, B = -1.35$, bottom: $A = 8.12, B = -1.67$), the green lines are fits where $x > 0.02$ km^{-1} (top: $A = 8.23, B = -1.90$, bottom: $A = 7.37, B = -2.41$), and the red lines are fits where $x < 0.02$ km^{-1} (top: $A = 7.31, B = -1.93$, bottom: $A = 7.26, B = -1.90$).

Conclusions

- Using novel ISR techniques and observation methods, high-latitude irregularities that disrupt radio propagation can be resolved at a finer spatio-temporal resolution than has been previously possible with ground-based observations.
- These measurements are used to compute irregularity spectra, which can then be used to find the typical spatial-scales, temporal-scales, and locations of irregularities in the high-latitude ionosphere.