ITMA-4: Investigating Drivers of Cusp Region Neutral Density Enhancements Using RENU 2 and Satellite Observations

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INTRODUCTION

The polar cusp is a dynamic and complex region where Earth's magnetic field allows direct entry of solar wind particles into the upper atmosphere as well as the exit of ionospheric ions (Fritz 2018). Despite its importance, the dynamics of the cusp remain poorly understood and are not well captured by existing geospace models (Deng et al., 2013).

Anomalous neutral density enhancements in the cusp region—localized increases in atmospheric mass density— affect satellite drag, thermospheric circulation, and space weather prediction. Several mechanisms may contribute to these density increases:

- Soft particle precipitation (Clemmons et al., 2008; Deng et al., 2013)
- Small-scale field-aligned currents (FACs) and associated Joule heating (Lühr et al., 2004)
- Atmospheric gravity waves (GWs) propagating from below (Huang et al., 2017)

Understanding the interplay between these processes is critical for predicting space weather impacts on satellites in low Earth orbit and for improving our knowledge of coupling in the magnetosphere, ionosphere, and thermosphere.

RENU2/SATELLITES USED

Rocket Experiment for Neutral Upwelling 2 (RENU2) (Fritz et al., 2020; Lessard et al., 2020)

- launched December 13, 2015
- transited the cusp region during a neutral upwelling event
- extensive instrument suite, including an ultraviolet photomultiplier tube (UV PMT) instrument neutral atomic oxygen emissions (OI 1304 Å and OI 1356 Å)

Special Sensor Ultraviolet Limb Imager (SSULI) (Dymond et al., 2017)

- measures vertical profiles of the airglow through scans of the Earth's limb
- wavelength range: 80 nm to 170 nm, 1.8 nm resolution

Gravity Recovery and Climate Experiment (GRACE)

- neutral mass density is inferred from GRACE accelerometer data

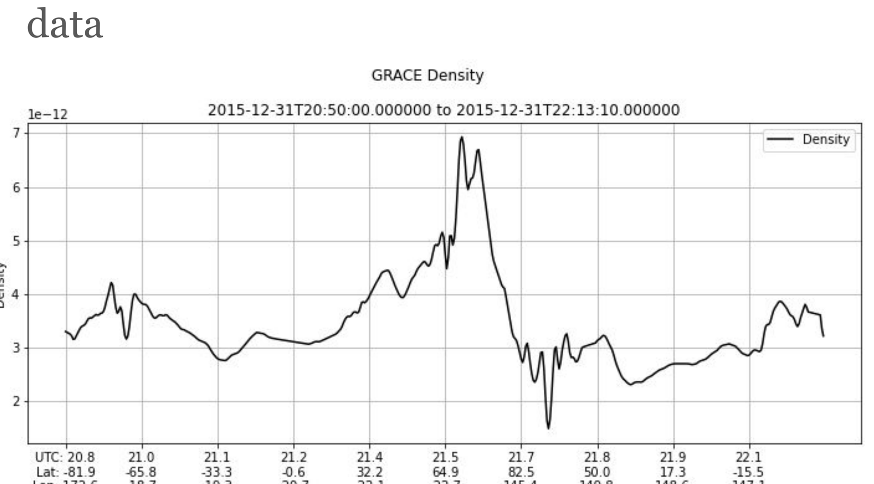

Fig. 1: Example of density enhancement in 12/13/15 GRACE neutral mass density data

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References

METHODOLOGY

SSULI Data Acquisition

Far ultraviolet (FUV) Volume Emission Rate (VER) data collected from SSULI was used in this study

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Cusp Region Identification

Cusp-region observation intervals were determined using SSULI satellite position data; cusp equatorward boundary was calculated with the equation 77° + 0.76 IMF Bz (from Newell et al., 1989)

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Neutral Density Enhancement Detection

Coincident GRACE neutral mass density data was used to identify localized enhancements during cusp crossings. These days were compared with days without neutral mass density enhancements

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Tomographic Reconstruction of Along-Path VER

Volume Emission Rate Tomography (VERT) methods (Hei et al. 2017, Dymond et al. 2017) were used to reconstruct an along-path vertical profile of VER from SSULI limb-scan data

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Comparison with GLOW Model

The reconstructed VER profiles were compared to outputs from the Global Airglow (GLOW) model, which calculates optical emissions in the upper atmosphere

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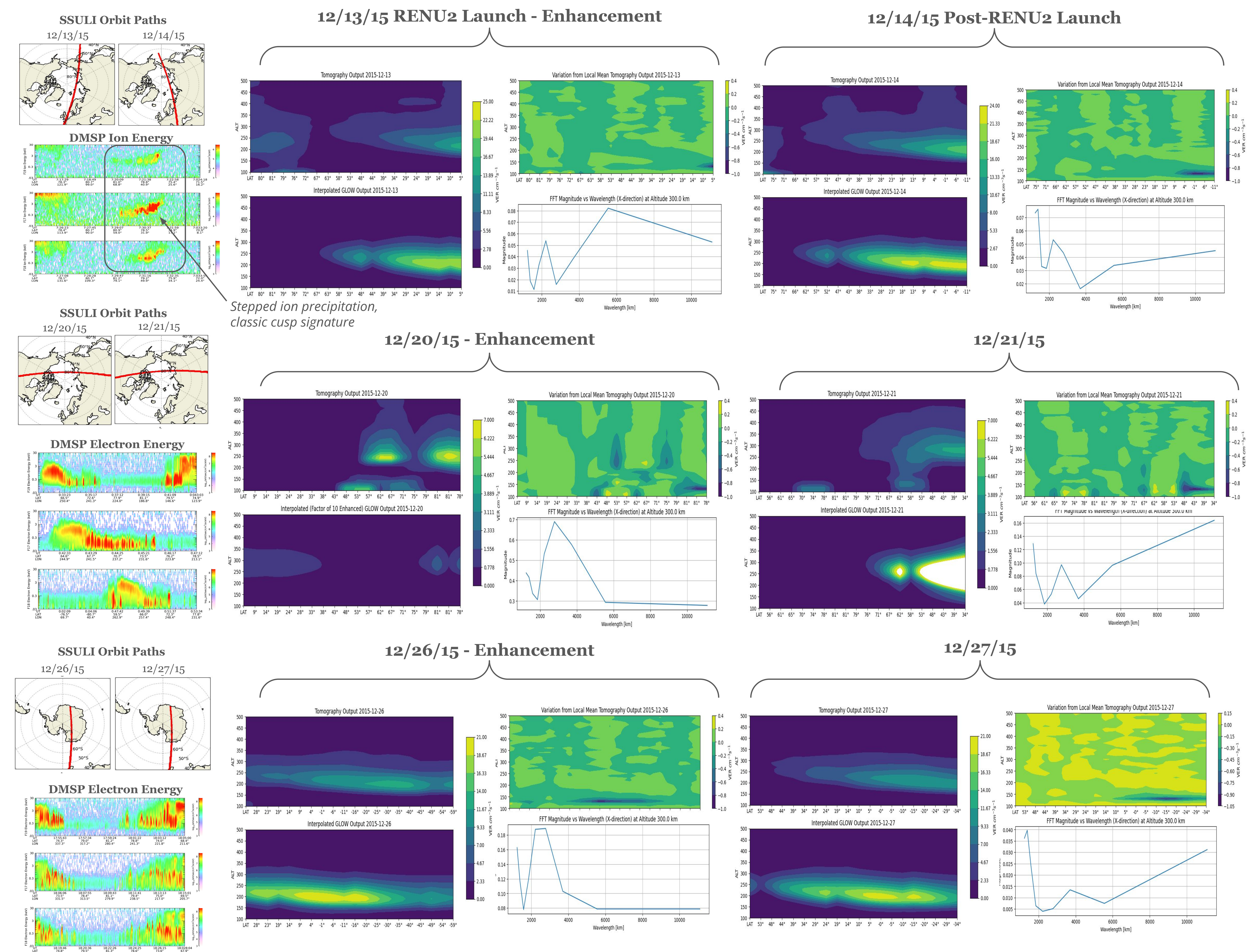
Analyzing Structures

To identify any small-scale features in the VER profiles, a Hamming window low-pass filter was used. Deviations from the smoothed signal were calculated as:

$$\text{Variation} = \frac{\text{VER - Filtered VER}}{\text{Filtered VER}}$$

Fast Fourier Transform (FFT) is applied to identify significant wavelengths in the structures

RESULTS/DISCUSSION



- We can confirm the SSULI data to be within the cusp region boundaries by checking that the orbit paths pass over the high latitudes and identifying the stepped increase in ion or electron energy that is a classic signature of the cusp region
- In general, the tomographic reconstructions of along-track VER are somewhat similar in structure to the expected VER profiles as modeled by GLOW; however magnitudes tend to vary significantly
- GLOW is sensitive to factors such as particle precipitation, which we have not accounted for as of yet; future work will adjust GLOW parameters to improve further comparisons
- FFT plots for non-enhancement days appear more convex (higher magnitudes at high and low wavelengths), while there does not appear to be a clear pattern distinctive to the enhancement events
- FFT of the variations from the local mean all show a peak between 2000-4000 km wavelength, which could potentially point to the presence of large-scale gravity waves
- In future work, we will identify and separate out the density enhancement events that are associated with FACs and the ones without FACs present (possible gravity wave sources instead)