Comparing Temperature Anisotropy Beta Parameters for an Extreme Ion Temperature Event

Aidan Thayer [1], Lindsay V Goodwin [1], William J Longley [1], Jean-Pierre St-Maurice [2, 3]

1- Center for Solar-Terrestrial Research, Department of Physics, New Jersey Institute of Technology, Newark, NJ, USA
2- Department of Physics and Engineering Physics, University of Saskatchewan, Saskatoon, SK, Canada
3- Department of Physics and Astronomy, University of Western Ontario, London, ON, Canada

Introduction

- Advanced modular incoherent scatter radars (AMISRs) are systems capable of taking volumetric measurements of plasma (ion and electron temperature, plasma density, and line-of-sight velocity) over extended periods of time, with continuous scans on the order of days
- AMISRs like the Resolute Bay Incoherent Scatter Radar North, RISR-N, located in Resolute Bay, Canada have been operational since 2011 in a variety of modes to understand the dynamics of the E and F region of the lower auroral zone
  - Given the limitations of duty cycle, the system is not operational 24/7, but it still catches many periods of geomagnetic activity
- During periods of intense geomagnetic activity, strong electric fields can cause temperatures in the F region to become anisotropic relative to the magnetic field due to a distortion in the O+ velocity distribution [1] [2].
- **The impact of temperature anisotropy during geomagnetic events is not currently corrected for in radar fitting or atmospheric models, and as would like to characterize its effects.**

Figure 1. Photo of Resolute Bay Incoherent Scatter Radar-North (RISR-N) (Photo Credit Craig Heinselman)

Methodology

- In the F-region, plasma along the same magnetic field line will be subject to the same plasma dynamics and E x B drift implying that closely overlapping radar look directions are seeing the same processes, at different angles.
- RISR-N heating events from 2010-2020 were catalogued by ion temperature, electron temperature, and plasma density
  - The event on 9/12/2012 [3] was chosen from these events due to the spike in ion temperature around 3500 K that lasted over an hour, and the lack of corresponding spike in electron temperature or plasma density that would be indicative of a precipitation event
  - Using two look directions, temperatures perpendicular and parallel to the magnetic field were calculated between 200 and 400 km if: 1) the Spearman correlation coefficient between the beams during the ion heating exceeded 0.7, and 2) the ion temperature exceeded 1000 K
- Looking along the magnetic field line provides a calibration beam to check relative electron temperature and plasma density

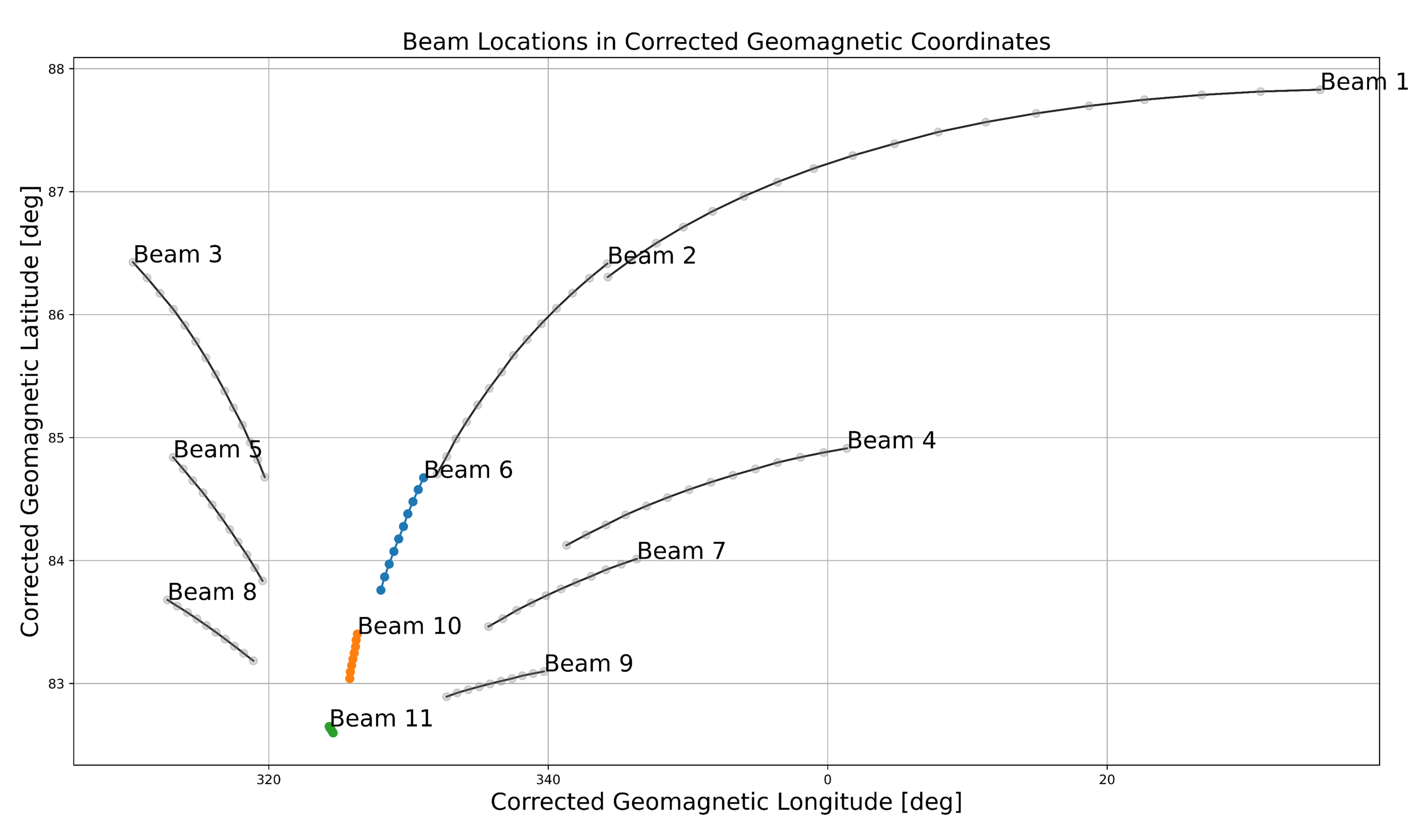
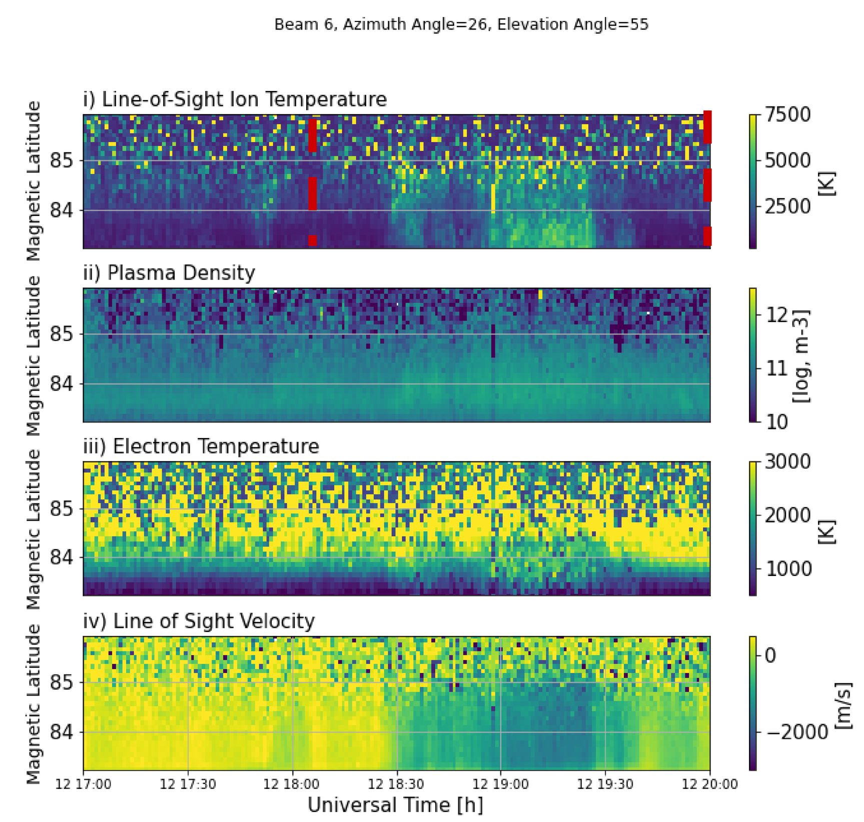
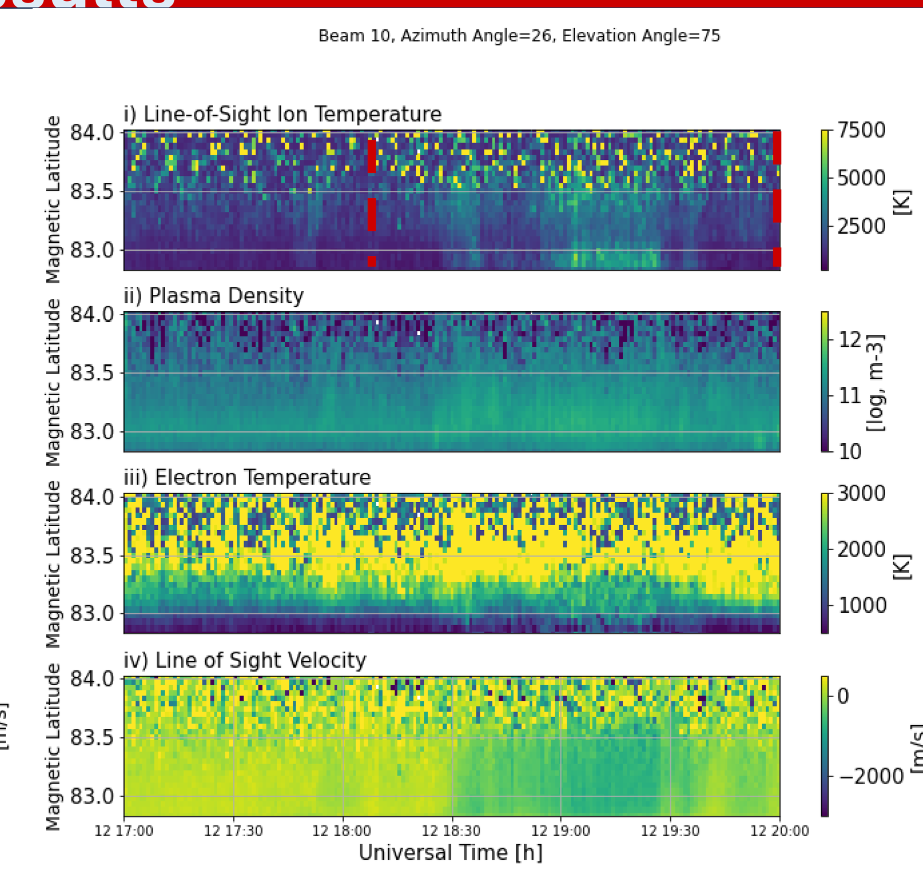


Figure 2. Beam Map of WorldDay Beams. In color are the beams shown in Figures 3-5

Results





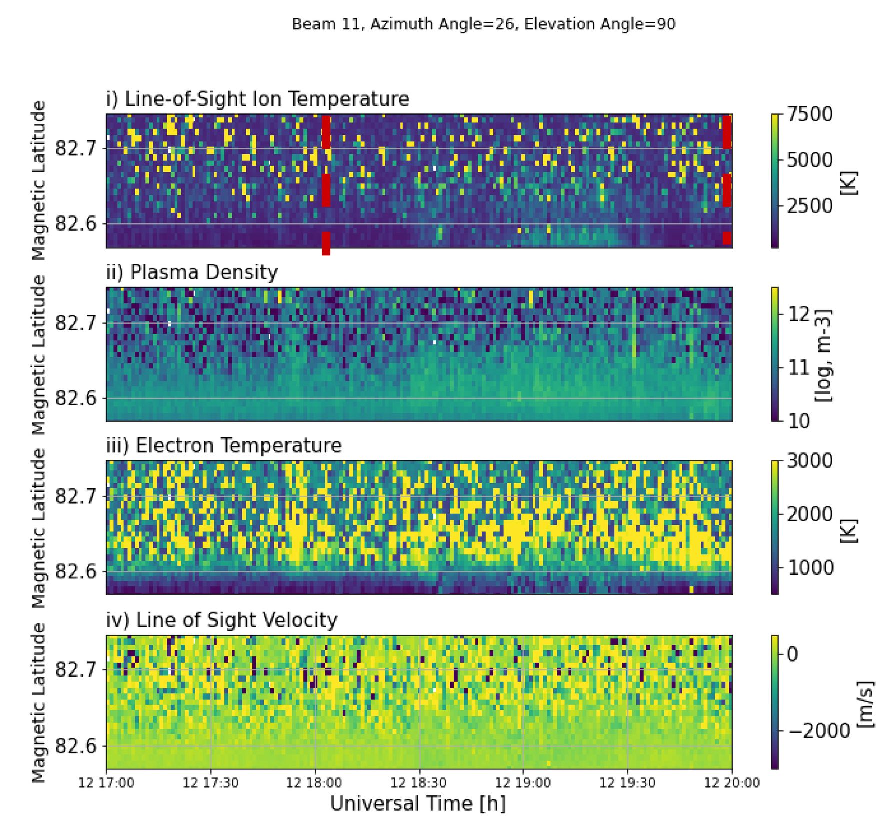


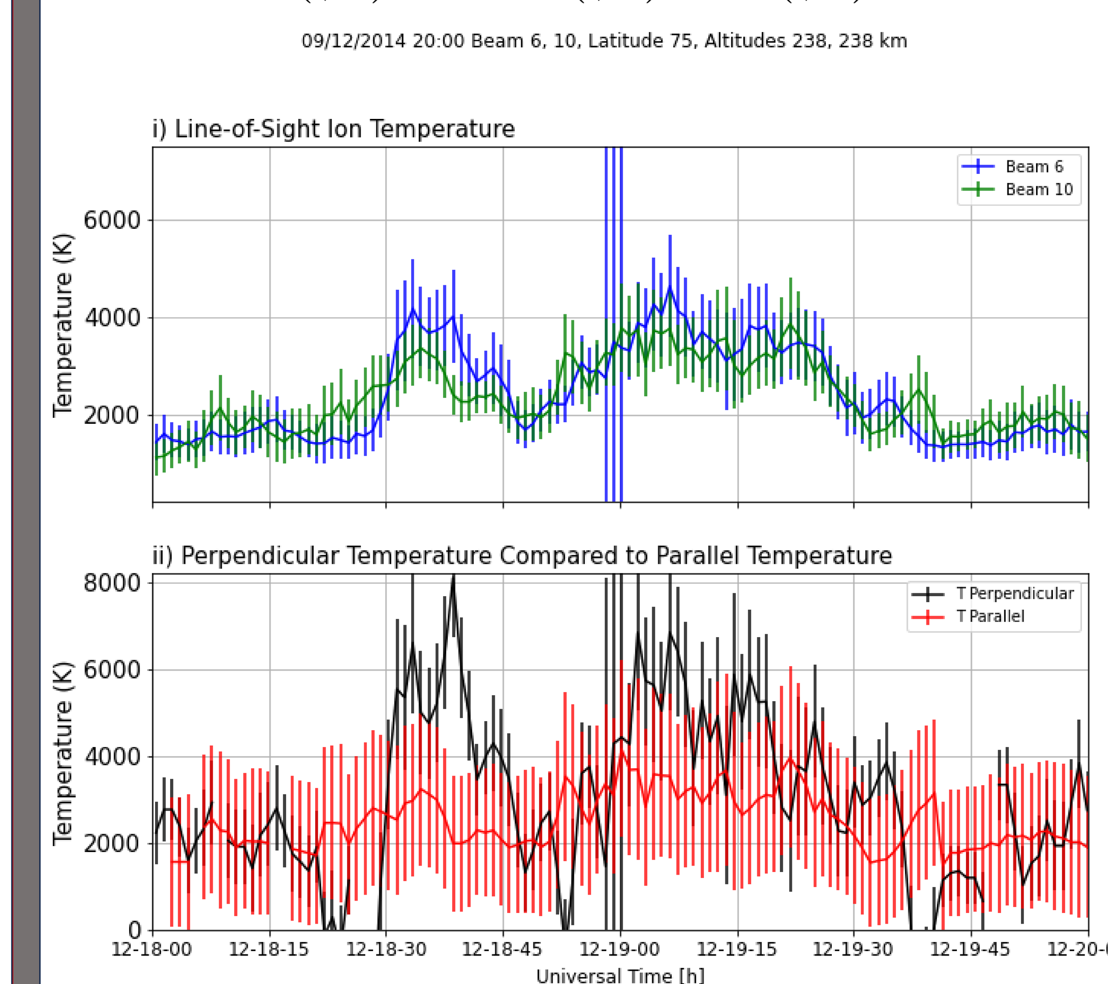
Figure 3-5. Range Time Intensity Plots of RISR-N Data from WorldDay 9/12/2012. Beams 6, 10, and 11, respectively. Azimuth Angle of 26 degrees, Elevation Angle 55, 75, and 90 degrees, respectively.
For these figures, Panel i) is ion temperature, Panel ii) is plasma density on a logarithmic scale, panel iii) is electron temperature, and panel iv) is line of sight ion velocity

To better characterize anisotropy independent of beam pair, the ion temperature perpendicular and parallel to the magnetic field was calculated using the overlapping beams, using the method proposed by [1].

$$T_\parallel = \frac{T_{\phi_1} - T_\perp \sin^2(\phi_1)}{\cos^2(\phi_1)} \qquad \frac{\beta_\parallel}{\beta_\perp} = \frac{T_\parallel - T_n}{T_\perp - T_n}$$

$$T_\perp = \frac{T_{\phi_2} - \frac{T_{\phi_1}\cos^2(\phi_2)}{\cos^2(\phi_1)}}{\sin^2(\phi_2) - \tan^2(\phi_1)\cos^2(\phi_2)}$$

- T_{ϕ_1} Temperature of First Beam
- T_{ϕ_2} Temperature of Second Beam
- ϕ_1 Aspect angle of First beam with respect to. magnetic field
- ϕ_2 Same for second beam



Top panel: Line-of-sight ion temperatures for Beams 6 and 10 at 238 km with one sigma error bars. Bottom panel: Corresponding perpendicular and parallel ion temperature. A three-point rolling average is applied.

Results (cont.)

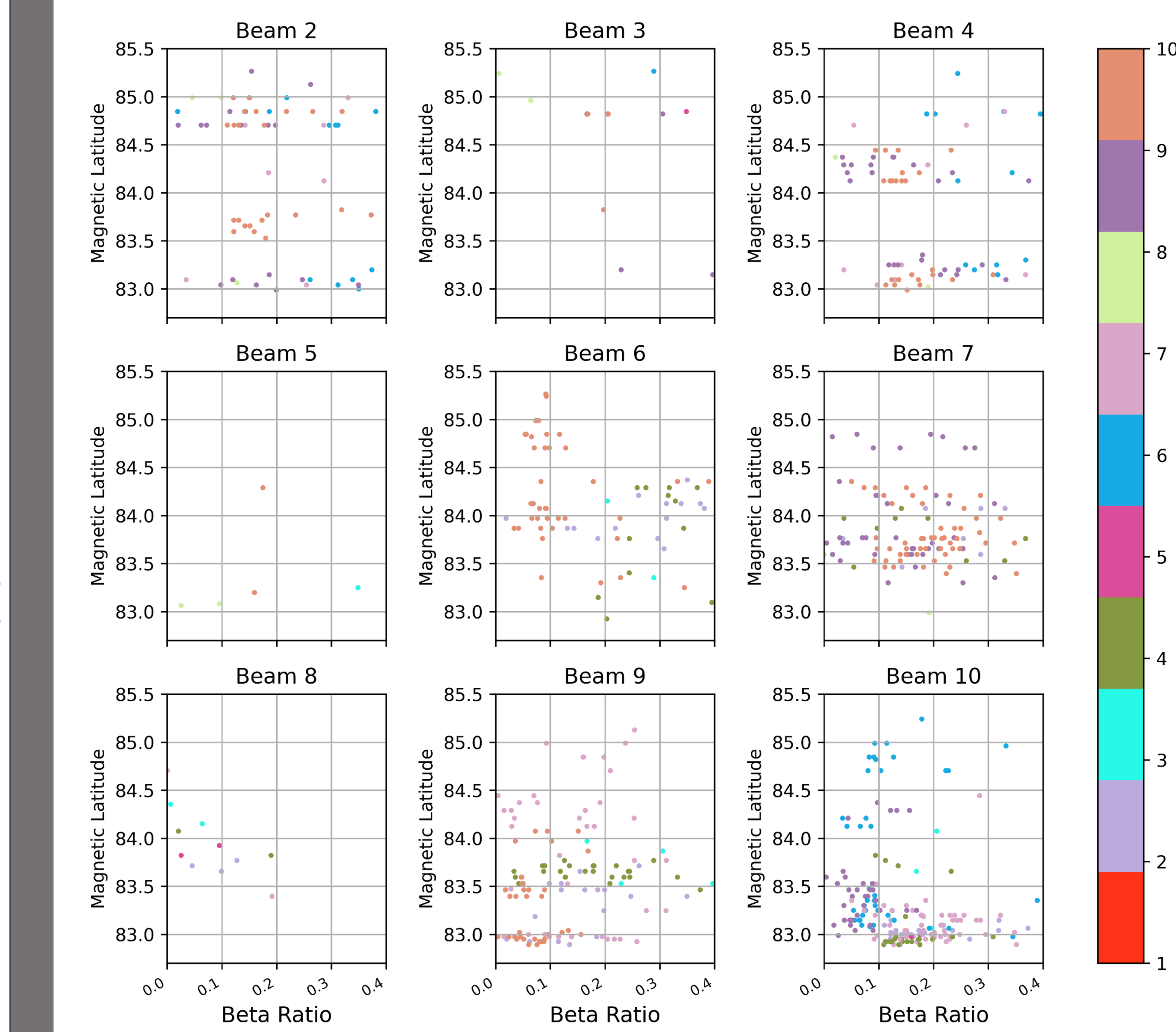


Figure 7: Comparing each beam pair's beta ratio as a function of magnetic latitude to one another, colored by the corresponding paired beam. The beta ratio is calculated for 1800 to 2000 UTC 9/12/24 for nearest 4 range gates for altitudes between 200-400 km

Discussion and Future Work

This event shows very strong temperature anisotropy through the calculated beta ratio but requires careful filtering and curation of the data to avoid non-physical results. Beam 6 and 10 have consistent correlation and beta ratios of roughly 0.15 across magnetic latitude, suggesting they are looking at the same electric field structure. The same can be said with less confidence for 9 and 10 (0.1) and 10 and 2 (0.18).

This work can be continued for:

- More events now that a procedure has been standardized
- The evolution of the beta ratio can be studied with respect to altitude or as the intensity of the heating event decreases

References

1- Raman, R. S. V., St-Maurice, J. P., & Ong, R. S. B. (1981). Incoherent scattering of radar waves in the auroral ionosphere. *Journal of Geophysical Research*, *86*(A6), 4751–4762. https://doi.org/10.1029/ja086ia06p04751

2- St-Maurice, J.-., Hanson, W. B., & Walker, J. C. G. (1976). Retarding potential analyzer measurement of the effect of ion-neutral collisions on the ion velocity distribution in the auroral ionosphere. *Journal of Geophysical Research*, *81*(31), 5438–5446. https://doi.org/10.1029/ja081i031p05438

3- Clauer, C. R., Z. Xu, M. Maimaiti, J. M. Ruohoniemi, W. Scales, M. D. Hartinger, M. J. Nicolls, S. Kaeppler, F. D. Wilder, and R. E. Lopez (2016), Investigation of a rare event where the polar ionospheric reverse convection potential does not saturate during a period of extreme northward IMF solar wind driving, *J. Geophys. Res. Space Physics*, 121, 5422–5435, doi:10.1002/2016JA022557.

Acknowledgements

Efforts by AT, LVG, and WJL are supported by the NSF under CEDAR award #2330254. The authors wish to thank Chirag Skolar for their personal correspondence. This material is based upon work supported by the Resolute Bay Observatory, which is a major facility funded by the National Science Foundation through cooperative agreement AGS-1840962 to SRI International. RISR-N data is available through the SRI International ISR Database (https://amisr.com/database/)