A Statistical Survey of F2 Layer Peaks Properties in the Polar Cap Ionosphere Observed by RISR-N

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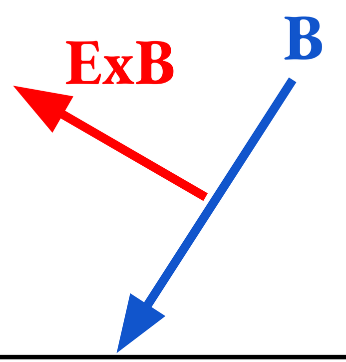
Introduction

- **A full solar cycle's** worth of observations have been collected by the **Resolute Bay Incoherent Scatter Radar.**
- In these high-latitude ionosphere observations, there are **highly dynamic F2 Layer peak features**
- High electron density observations in the **night side** sector of the high-latitude ionosphere are typically transported **across the polar cap** from the **day side**, and would have an **upwards component of their ExB drift**, causing lifted F2 Layer peaks.



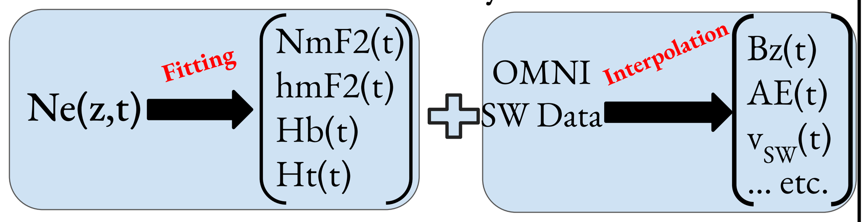
Research Question

What geophysical conditions predict lifted or enhanced F2 Peak electron densities in the polar cap ionosphere?

Data/Methods

Resolute Bay Incoherent Scatter Radar - North (RISR-N)

- **RISR-N** utilizes **long pulse ISR** to collect Ionospheric layer conditions such as **electron density**, temperature, etc.
- **RISR-N** is located at **~75° N, ~95° W** and faces the **magnetic north pole**
- **Altitude resolution** varies in database
- We analyzed the **electron density observations** from the highest-elevation beam, excluding the vertical beam
- Only **1 minute** integration period **long-pulse** data were used for this study



Data Processing Methods

- We fit an **Epstein Layer Model** (Eq. 1) to the electron density observations, weighted by errors from RISR-N.
- A **4-Parameter** (NmF2, hmF2, Ht, and Hb) nonlinear least squares **Levenberg-Marquardt** method was used for fitting

$$N_e(z) = \begin{cases} 4N_{mF2}\frac{e^X}{(1+e^X)^2}, & X = \frac{z-h_{mF2}}{H_b}, \ z \leq h_{mF2} \\ 4N_{mF2}\frac{e^X}{(1+e^X)^2}, & X = \frac{z-h_{mF2}}{H_t}, \ z > h_{mF2} \end{cases}$$

Equation 1: The Epstein Layer Model

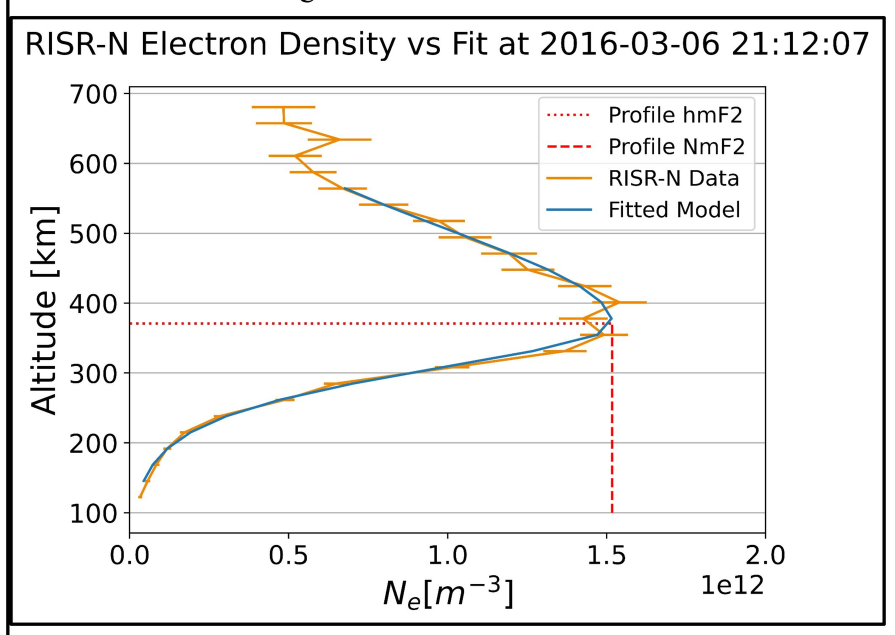


Figure 2. Electron Density Vertical Profile Fit

- Only observations between **140-570 km** were considered to isolate the F2 peak
- We compared **adjacent time steps** and **beams** to check for **satellite** echoes **corrupting electron density** observations
- Along with fitting, **solar wind** parameters from **NASA's OMNI** satellite were **interpolated** over the **RISR-N data** for direct comparison
- We also collected **empirical model** estimations of **hmF2** and **NmF2** at the time of each RISR-N observation from the **Empirical Canadian High Arctic Ionospheric Model (E-CHAIM)** and the **International Reference Ionosphere Model (IRI).**

Lifted or Dense Event Detection Algorithm

- Compared our **fitted hmF2** and **NmF2** to **empirical model outputs** from **E-CHAIM**
- Defined two metrics (**ΔNmF2 and ΔhmF2**) to quantify exceptionally high hmF2 and NmF2, and calculated both for the **database.**

$$\Delta h_{mF2} = \frac{h_{mF2-RISR} - h_{mF2-E-CHAIM}}{h_{mF2-E-CHAIM}}$$

$$\Delta N_{mF2} = \frac{\log_{10}(\frac{N_{mF2-RISR}}{N_{mF2-E-CHAIM}})}{\log_{10}(N_{mF2-E-CHAIM})}$$

Equations 2, 3: ΔhmF2 and ΔNmF2

- Each experiment was iterated through, and if a point's ΔNmF2 or ΔhmF2 were greater than **1.5x the IQR** of the **median** ΔNmF2 and ΔhmF2, the point would be labeled dense or lifted respectively.
- Lifted events were detected when **two consecutive points** were labeled as lifted. Once **two consecutive points** were **not** lifted, **the end of the event was marked**.
- This procedure was **repeated 3 times** to generate our **lifted event, dense event,** and **lifted & dense (both) event** distributions.

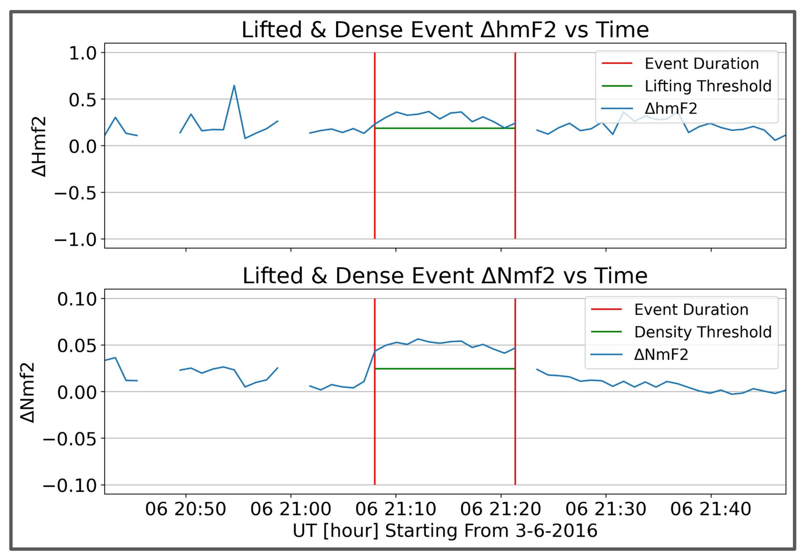


Figure 3. Example Lifted & Dense (Both) Event

Fitted RISR-N Electron Density Example

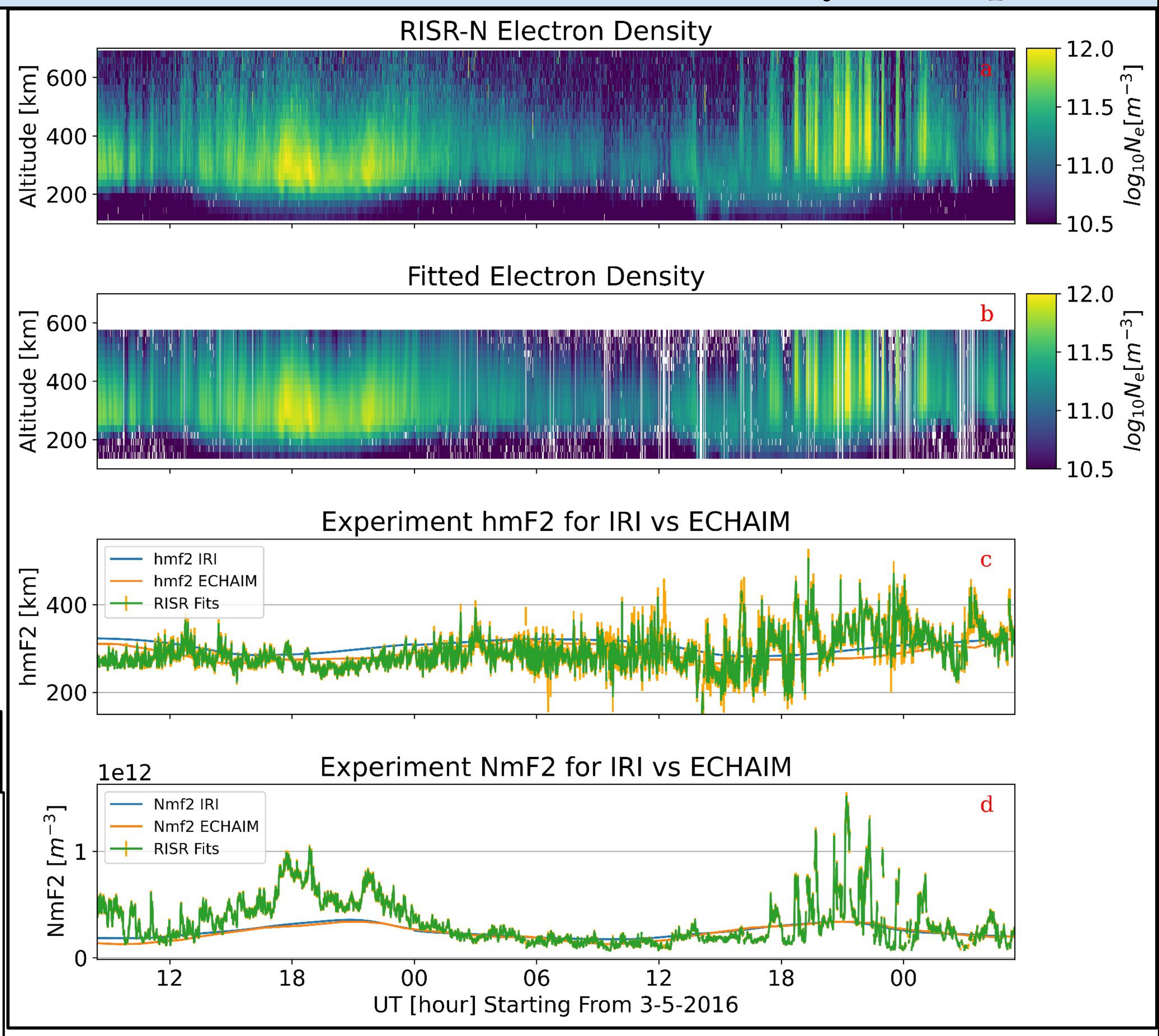


Figure 4(a-d): 4a highlights raw range, time, and intensity (RTI) plots of RISR-N electron density. 4b is the same RTI after going through our fitting process. 4c-d show the isolated hmF2 and NmF2 compared with empirical model outputs from IRI and E-CHAIM.

Results

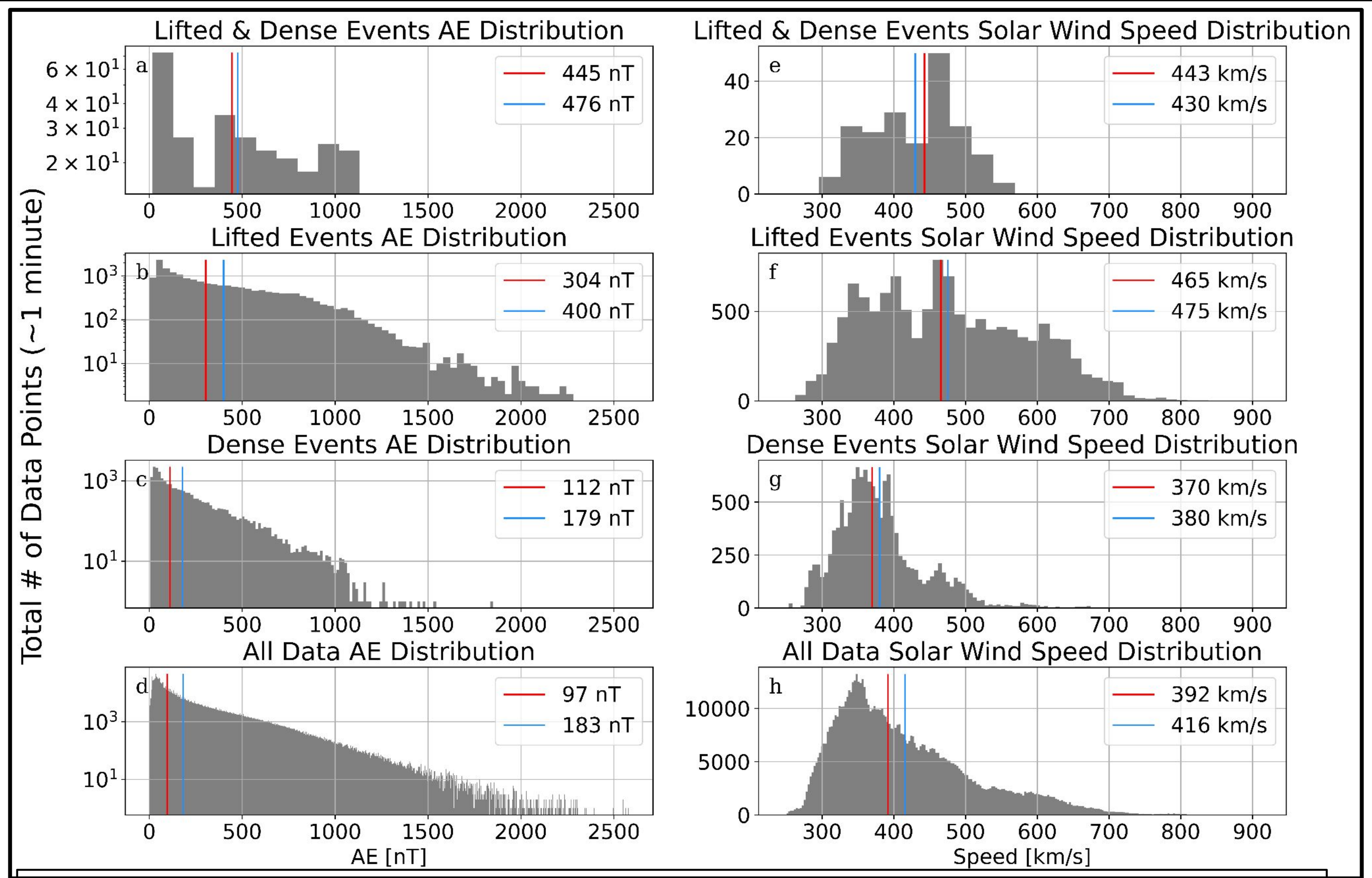


Figure 5 (a-d): Distributions for Auroral Electrojet (AE), Figure 5 (e-h): Distributions for Solar Wind Velocit.

- **Lifted events** happen much more frequently during high AE times (geomagnetically active periods).
- **Dense events** rarely occur during times of AE > 1000 nT.
- **Lifted events** occur **more frequently** during times of **fast solar wind.**
- **Dense events** occur more frequently during times of slow solar wind.
- **Lifted Events** are more likely at **low Solar Zenith Angles**.
- **Lifted & Dense** or **Dense** events do not show a clear SZA preference.
- **Lifted Events** have a strong preference for **Spring and Summer** (April-June).
- **Dense Events** occur **more frequently** during **winter.**
- **Dense Events rarely** occur in **summer.**

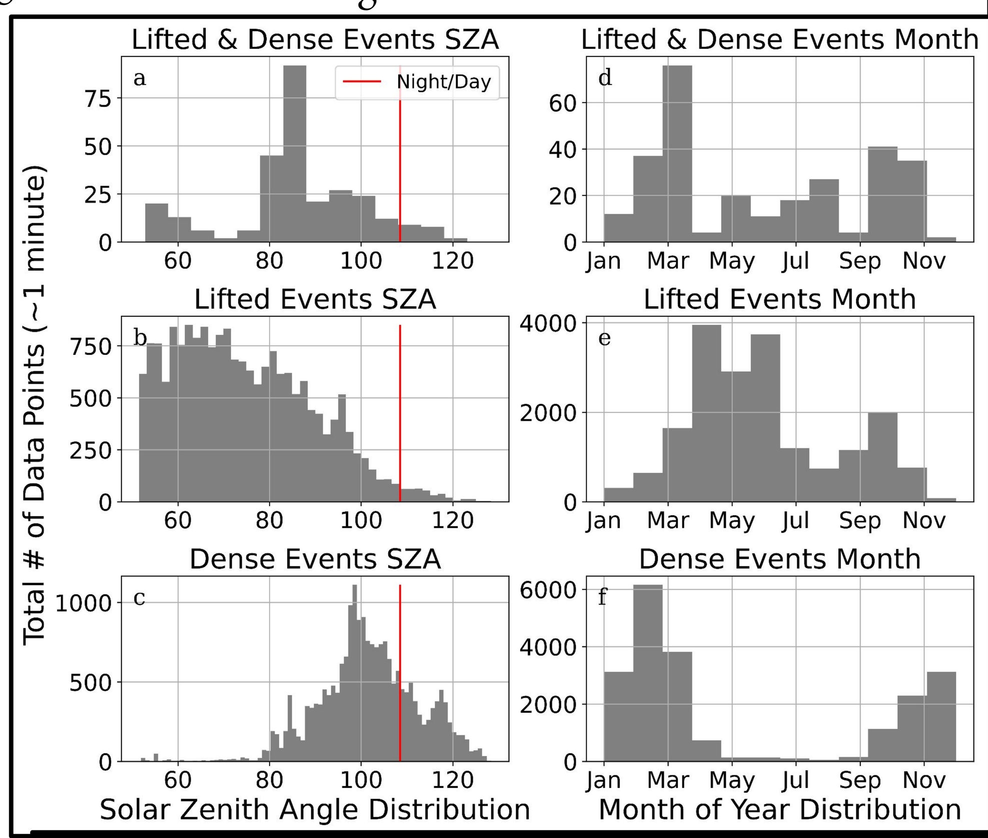


Figure 6 (a-c) Solar Zenith Angle Distributions, Figure 6 (d-f) Seasonal Distributions

Statistical Analysis

- Used the **Welch's t-Test**, assuming unequal variances between the lifted, dense, and both events' geophysical conditions and the geophysical conditions over all **RISR-N one minute integration period observations.**
- **Decoupled events** by averaging over all events within a 24-hour range to ensure independence in the sampling of geophysical parameters. Hence the decoupled array mean/medians **differ** from means/medians over all lifted, dense, or both events.
- Red signifies statistically significant negative t-score and blue signifies statistically significant positive t-score for p < 10^3.

Variable	Case	Mean	Median	p-Value
Solar Wind Speed [km/s]	Lifted	440	422	2.55e-08
	Dense	395	383	5.22e-07
	Both	406	395	0.326
	Database	416	392	
AE [nT]	Lifted	252	184	3.12e-15
	Dense	182	130	0.902
	Both	323	161	0.004
	Database	183	97	
Dynamic Pressure [nPa]	Lifted	2.50	2.04	1.62e-05
	Dense	2.12	1.71	0.823
	Both	3.31	2.56	0.005
	Database	2.11	1.67	
B_z [nT]	Lifted	-0.582	-0.494	0.003
	Dense	-0.76	-0.50	3.85e-04
	Both	-2.67	-0.86	0.006
	Database	-0.19	-0.20	
B_y [nT]	Lifted	0.388	0.208	0.004
	Dense	0.282	0.410	0.062
	Both	0.424	1.287	0.542
	Database	-0.04	-0.18	
E_y [mV/m]	Lifted	0.30	0.23	3.35e-04
	Dense	0.32	0.22	1.35e-04
	Both	1.21	0.50	0.004
	Database	0.08	0.07	
F10.7 [sfu]	Lifted	108	83	2.21e-04
	Dense	117	106	0.822
	Both	137	133	0.008
	Database	116	95	

Table 1. Means, medians, and calculated p-values for geophysical parameters.

Conclusion / Discussion

- **Dense Events** are **heavily uncorrelated** with **geomagnetically active times** (High AE).
- **Lifted Events** are **heavily correlated** with high speed streams / **fast solar wind speeds.**
- Lifted Events are correlated with periods of **low F10.7.**
- This hints at a correlation between **lifted F2 Layer peaks** and the appearance of **corotating interaction regions (CIRs)** due to their **high solar wind speed** and moderate level of geomagnetic activity, but further analysis is required to understand the underlying driving processes.
- There is a strong dependence on **winter months** to produce **dense events**, consistent with previous polar cap patch studies.
- Time of day and seasonal dependencies for **dense events** are consistent with previous statistical surveys on polar cap patches (David 2016).
- **Lifted Events** show a **strong preference** for **low solar zenith angles**, likely due to the extreme high latitude of RISR-N causing dramatically different solar zenith angle ranges for each season.

Acknowledgements

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