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A Statistical Analysis of EMIC waves and Particle Fluxes using POES and RBSP

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1 - Introduction

Electromagnetic ion cyclotron (EMIC) waves are generated through cyclotron instability and propagate at frequencies near the ion cyclotron frequency. These waves are frequent during geomagnetic storms and significantly impact the dynamics of particles in the magnetosphere.

EMIC wave interaction with charged particles can lead to the acceleration and scattering of those particles. Therefore, the presence of these precipitating may indicate the presence of EMIC waves. However, other processes also cause **precipitation**, such as ULF waves.

By examining in situ data during POES and RBSP* conjunctions, characteristics of the plasmasphere, magnetosphere, particle fluxes, and EMIC waves are investigated. See Figure 1 for a cartoon representation.

We conduct a statistical analysis of particle flux under varying conditional limitations associated with the presence or lack of EMIC waves and geomagnetic storms.

*Van Allen Probes previously known as Radiation Belt Storm Probes (RBSP)

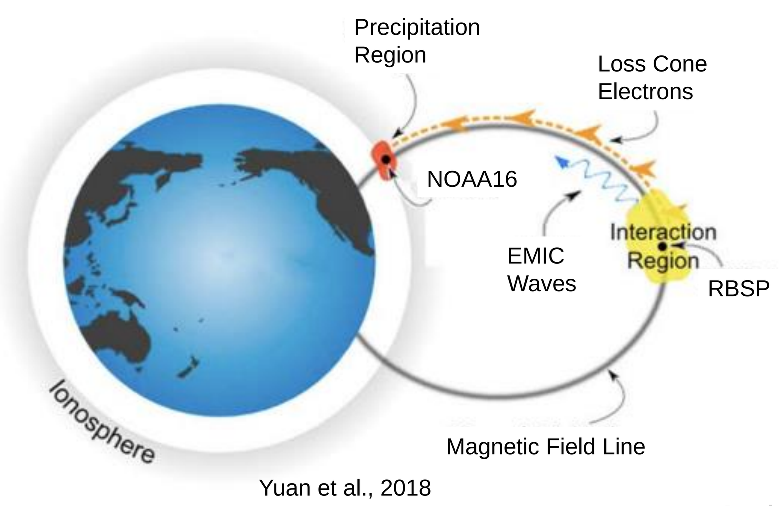


Figure 1: While on the same magnetic field line, one spacecraft (RBSP-A) sees the EMIC waves. The other spacecraft (NOAA16), sees the precipitating particles.

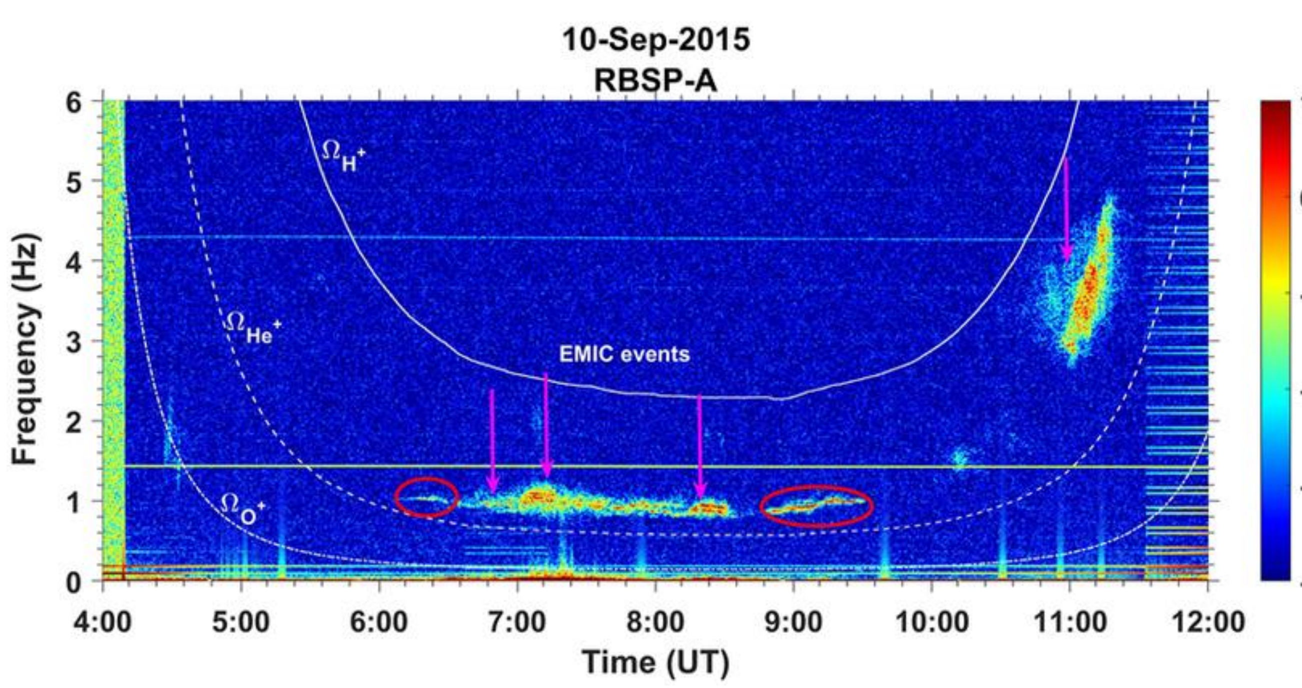


Figure 2: EMIC events identified (arrows) and missed (red circles) using automated wave detection for RBSP-A. The hydrogen, helium, and oxygen cyclotron frequencies are shown as white lines. (Remya et al., 2023)

2 - Data

Ion and electron particle fluxes are from Polar Operational Environmental Satellites (POES) Medium Energy Proton and Electron Detectors (MEPED).

We look at Bounce Loss Cone (BLC) and trapped electrons and hydrogen ions.

An EMIC event list from previous RBSP work (Remya et al., 2023) is used. This list was created using an automated wave detection algorithm. See Figure 2 for an example.

Conjunctions between RBSP and POES occurring from 2014 through 2017 were calculated as times where the spacecraft have $\Delta L \leq 0.5$ and $\Delta MLT \leq 1$ hour.

See Figure 3 for a cartoon of L shells. MLT is magnetic local time.

Storms and storm phases are from a list as described in Murphy et al., 2018 & Murphy et al., 2020.

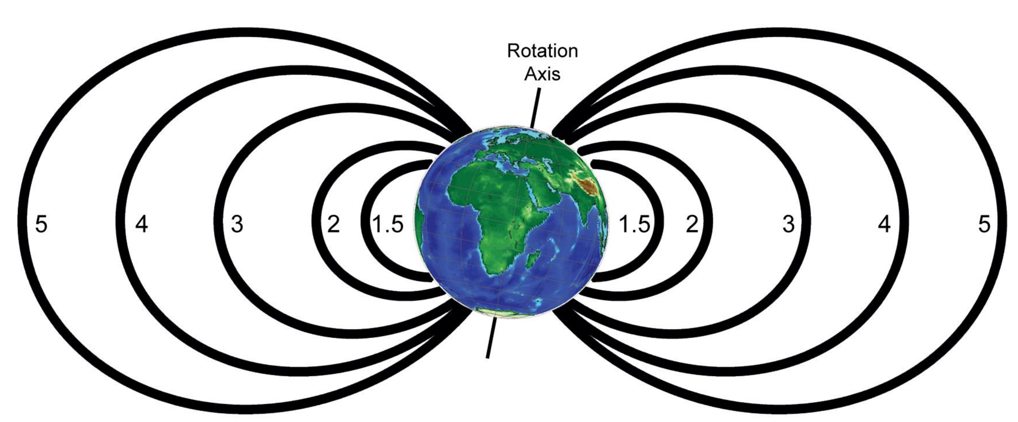
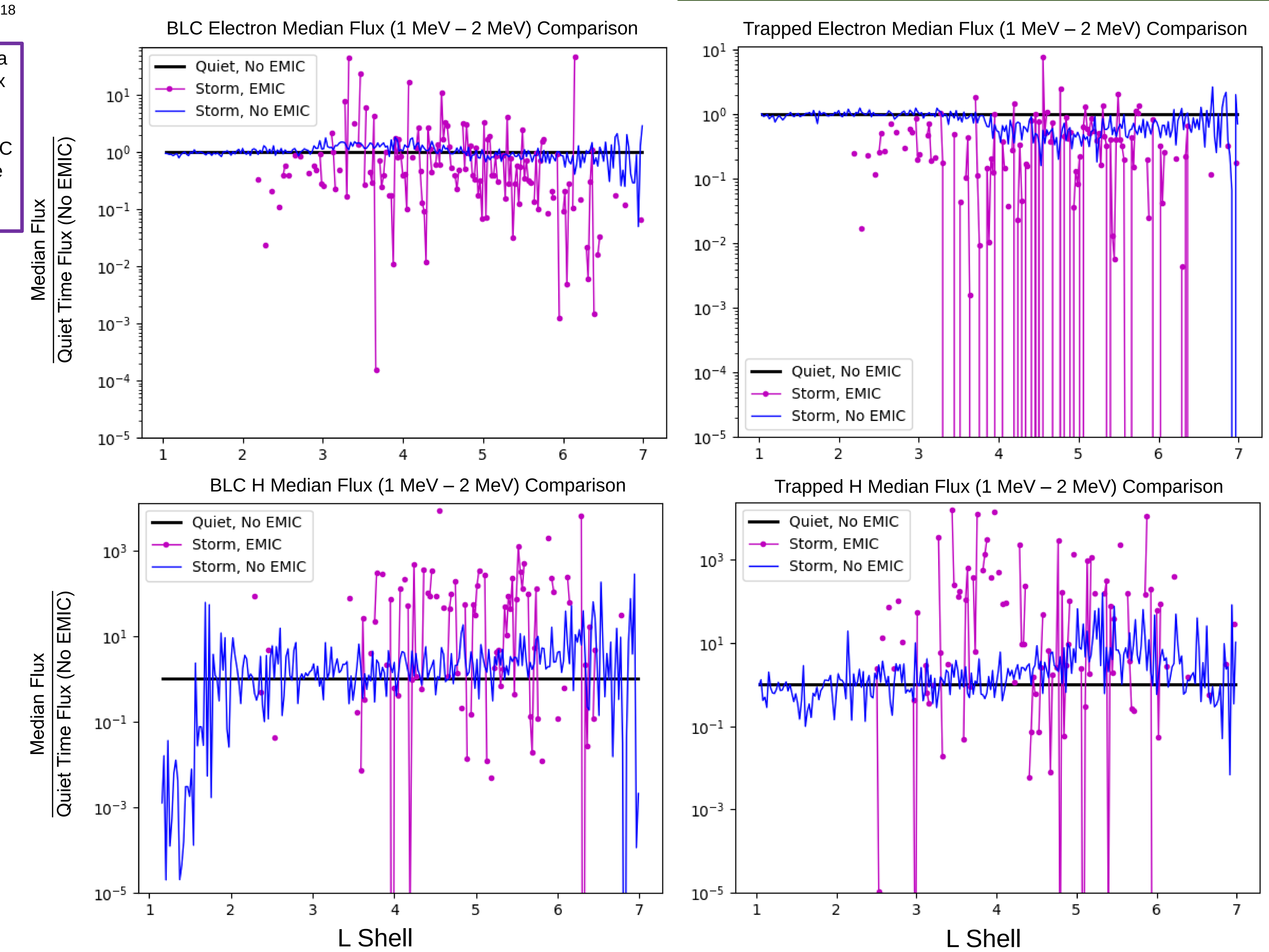
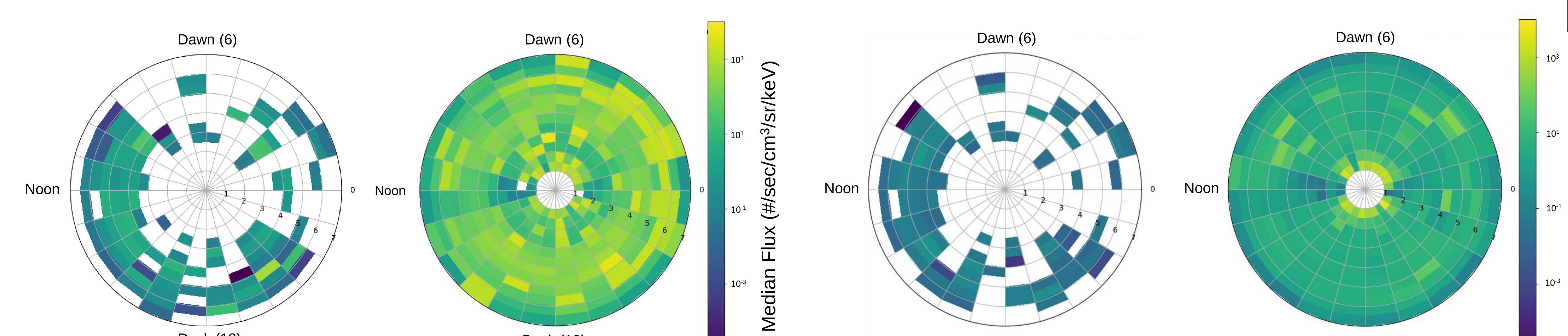


Figure 3: Cartoon representation of L shell values. At the magnetic equator, each L ~ 1 R_E.

The figures to the right show a comparison of the median flux during quiet times without EMIC waves to the median fluxes during storm time (EMIC and No EMIC). The fluxes are normalized to quiet time without EMIC waves.



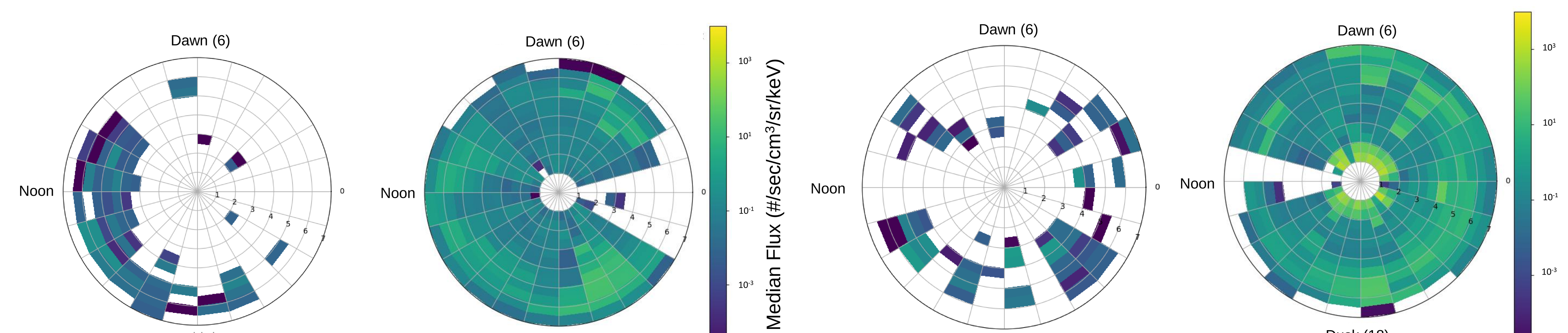


BLC Electrons Median Flux with EMIC waves (1 MeV – 2 MeV)

BLC Electrons Median Flux with no EMIC waves (1 MeV – 2 MeV)

Trapped Electron Median Flux with EMIC waves (1 MeV – 2 MeV)

Trapped Electron Median Flux with no EMIC waves (1 MeV – 2 MeV)



BLC H Median Flux with EMIC waves (1 MeV – 2 MeV)

BLC H Median Flux with no EMIC waves (1 MeV – 2 MeV)

Trapped H Median Flux with EMIC waves (1 MeV – 2 MeV)

Trapped H Median Flux with no EMIC waves (1 MeV – 2 MeV)

3 - Statistical Testing

The Kolmogorov – Smirnov (KS) Test, a goodness of fit test, is used to test null hypotheses **(See Table 1)**.

Null hypotheses are claims that **no relationship exists between two sets of data** being analyzed. If the resulting p-value is small (we chose a **significance level of 0.05**), it indicates that the two samples are **significantly different**. If the p-value > 0.05, it implies that the samples are *not* significantly different.

KS Test Assumptions: a) All the observations in the samples are randomly selected and independent and b) The scale of measurement is at least ordinal

By inspection, we can determine what the difference is between the datasets (i.e. higher or lower flux).

Energies are binned as follows: 10-500 keV, 500-800 keV, 800-1000 keV, 1000-2000 keV, 2000-5000 keV, and above 5000 keV

Species	Null Hypothesis datasets	MLT Limitation	Energy Bins with Sig. Differences (keV)
BLC Electron	Storm EMIC vs. Storm No EMIC	3 - 9	10 – 500, 500 – 800, 800 - 1000
		9 - 15	All
		15 - 21	All, **except** 1000 - 2000
		21 - 3	All, **except** 1000 - 2000
Trapped Electron	Storm EMIC vs. Storm No EMIC	3 – 9	10 – 500, 800 – 1000, 1000 - 2000
		9 - 15	All
		15 - 21	All
		21 - 3	All
BLC H	Storm EMIC vs. Storm No EMIC	3 - 9	10 – 500, 800 – 1000, 1000 – 2000, 2000 - 5000
		9 - 15	All
		15 - 21	All
		21 - 3	None
Trapped H	Storm EMIC vs. Storm No EMIC	3 - 9	10 – 500
		9 - 15	10 – 500, 500 – 800, 800 – 1000
		15 - 21	All
		21 - 3	All, **except** >5000
Trapped Elec / BLC Elec	Storm EMIC vs. Storm No EMIC	None	All
Trapped H / BLC H	Storm EMIC vs. Storm No EMIC	None	All
All	Quiet EMIC vs. Quiet No EMIC	None	All

Table 1: Tested null hypotheses and the results. All differences noted are for **median** fluxes.

The plots to the left show BLC & Trapped electron and proton flux binned by MLT and L. For each pair, the left polar plot shows the precipitation when EMIC waves are present and the right plot shows the precipitation when there are no EMIC waves. Empty bins represent Earth, lack of data, or lack of EMIC waves during observations.

4 - Results, Discussion, Future

1) Our results tell you that **the environment** when there is an EMIC wave **looks different** from when there is no EMIC wave
2) There are **many more questions** to answer. We start with simple questions to test our method, build up to more complex questions, and more easily keep track of assumptions.
3) More tests have been conducted (e.g., initial and main phase of storm vs. recovery phase), but are not shown
4) Future work includes case studies, testing of using distributions to find EMIC waves (contingency table), and more!