Statistical Study of Van Allen Radiation Belt Electron Precipitation during Satellite Conjunctions at Low-Earth Orbit

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INTRODUCTION

Precipitating electrons from the Van Allen Radiation Belts impact the physical and chemical properties of the upper atmosphere; yet the electron flux is not well quantified. This study performs a detailed statistical analysis of energetic electron flux between the FIREBIRD-II CubeSats (FIREBIRD-3 and FIREBIRD-4) and several Polar-orbiting Environmental Satellites (POES) during spacecraft conjunction times. Electron flux in the upper atmosphere is observed by the recent FIREBIRD-II CubeSat mission which provides high energy resolution for electron flux in polar low Earth orbit. The POES satellites have excellent spatial and temporal coverage and are equipped with MEPED, which has a lower energy resolution than FIREBIRD. This study analyzes 51 conjunction events (2018-2020) near L-shell 5 to quantify electron precipitation that corresponds with the peak electron flux in the outer radiation belt. The comparison between FIREBIRD and POES also considers the storm level (Dst) to determine if electron flux differs during geomagnetic storms, but most conjunctions at L-shell 5 occurred during quiet times. FIREBIRD electron count measurements follow the same trend as POES, and can also observe variability at low flux due to instrument geometry. The majority of FIREBIRD electron counts lie in between POES 0° and 90° telescope measurements, and are comparable to the POES geometric mean during later events. This comparison provides valuable information for studying the FIREBIRD-II dataset as well as insight for understanding electron precipitation that affects the upper atmosphere.

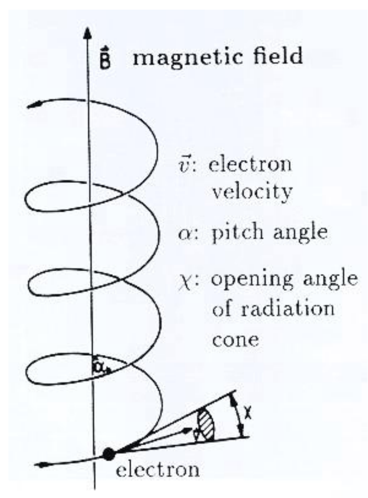


*Illustration of electron spiraling around a magnetic field **B** at velocity **V** with a pitch angle **θ**.*

METHODS

The calculation of the MEPED predicted counts based on FIREBIRD flux allows for a comparison between between FIREBIRD observations and POES 0° and 90° telescopes. The POES 0° telescope is oriented along the magnetic field lines and observes precipitating electrons at latitudes corresponding to the outer radiation belt, and the 90° telescope observes mirrored electrons, resulting in the 90° detector observations to be much higher than those from the 0° detector.

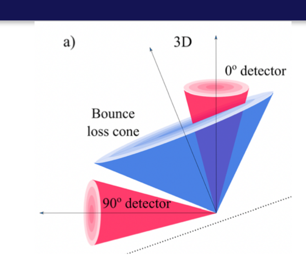


Illustration of pitch angles [Tyssøy, et al. (2016)]

An exponential function is fit to the FIREBIRD differential flux, j_{FB}, and then used along with geometric factors from the POES MEPED instrument, G_M, to estimate the counts that MEPED theoretically should observe in its three integral energy channels, as seen in equation (1).

$$C_M = \frac{j_{FB}}{G_M} \quad (1)$$

The geometric mean between FIREBIRD and POES 0° and 90° telescopes is calculated to estimate precipitation according to the methods of Rodger et al. (2013). Correlations were calculated for FIREBIRD and POES data to compare trends.

Storm level (Dst) averages were calculated to identify geomagnetic activity during each event.

DISCUSSION

1. Due to instrument geometry of the MEPED instrument, the POES satellites have a narrower field of view in comparison to FIREBIRD, which results in a high noise floor in the electron flux observations. This noise floor makes it difficult to observe enhancements when the electron flux is low, especially at higher energy levels.
2. Because of the narrow field of view, the POES 0° telescope is expected to under-predict and the 90° telescope over-predict electron precipitation (Nesse Tyssøy et al., 2016). While the FIREBIRD field of view is much wider, it is difficult to determine the exact orientation of the CubeSats as they are not equipped with magnetometers. It is not surprising that FIREBIRD observations are between the POES 0° and 90° counts. [Note: FIREBIRD-3 stopped collecting data at the end of 2019. FIREBIRD-4 instabilities result in a wobble between 0-90 degrees after February 13, 2020.]
3. The MEPED experiences proton contamination, which artificially raises the electron count rate. This explains the general over-prediction in energetic electron flux in comparison to FIREBIRD, particularly at higher energy channels (future work includes correcting this proton contamination so that more accurate calculations can be made).
4. The comparison between FIREBIRD-II and POES also considered the Disturbance Storm-Time (Dst) Indices to determine if conjunctions differ during geomagnetic storms. Events analyzed at L-shell 5 occur during quiet times (Dst index mean is never lower than -26 for all conjunction events).

RESULTS

I) FIREBIRD-II & POES Electron Counts during 51 Conjunctions

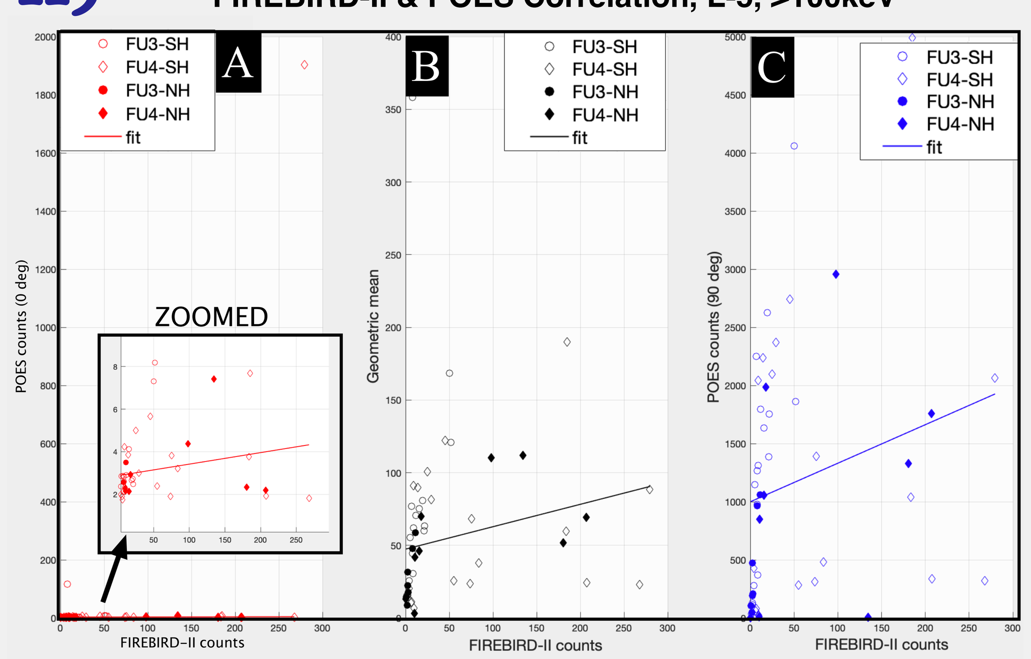
FIGURE CAPTION

The following plots display a few representations of statistical analyses between FIREBIRD-II and POES electron count data.

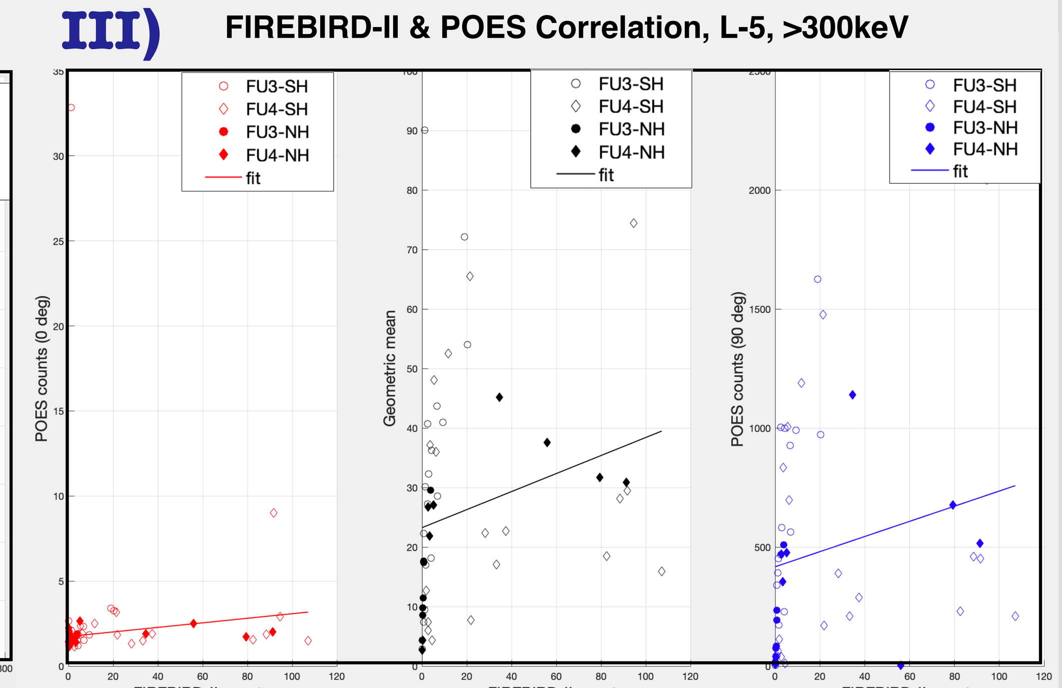
- **A** MEPED counts detected by the 0° telescope (counts s^{-1}).
- **B** FIREBIRD-II counts (counts s^{-1}).
- **C** MEPED counts detected by the 90° telescope (counts s^{-1}).

Note: dotted line in Plots IV & V indicates first conjunction event observed at L=5 where FIREBIRD-4 wobbles between 0-90 degrees (Feb. 13, 2020).

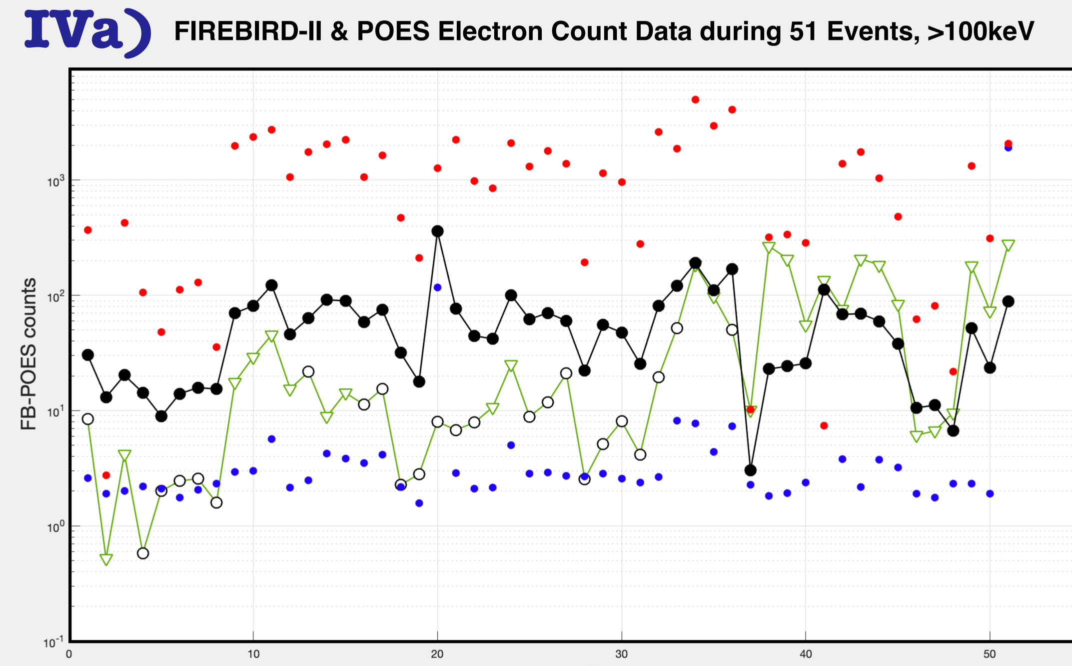
II) FIREBIRD-II & POES Correlation, L-5, >100keV



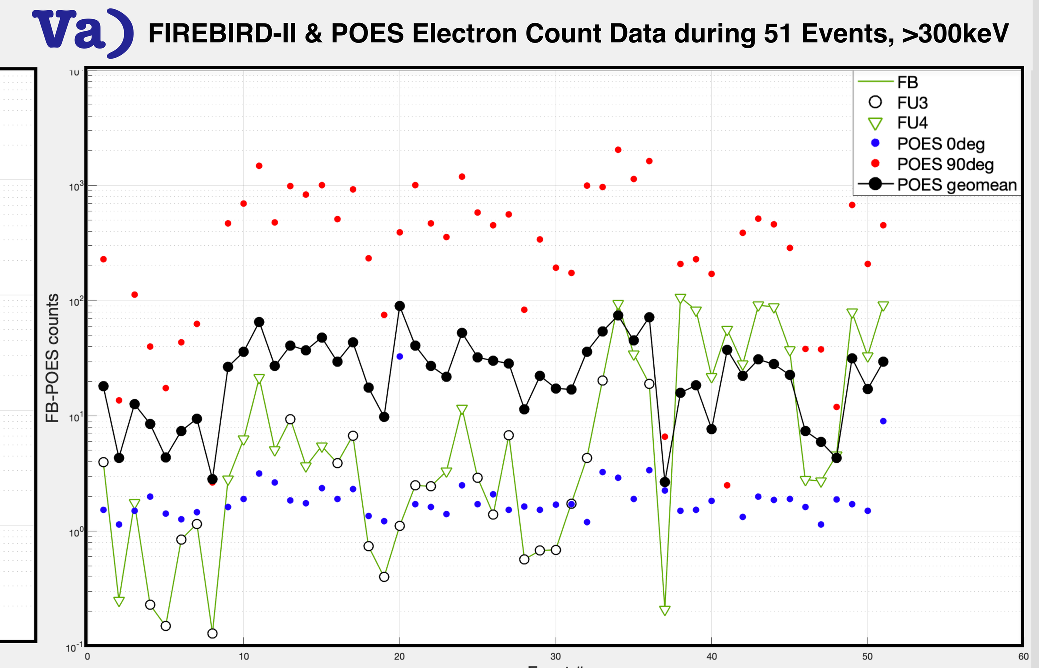
III) FIREBIRD-II & POES Correlation, L-5, >300keV



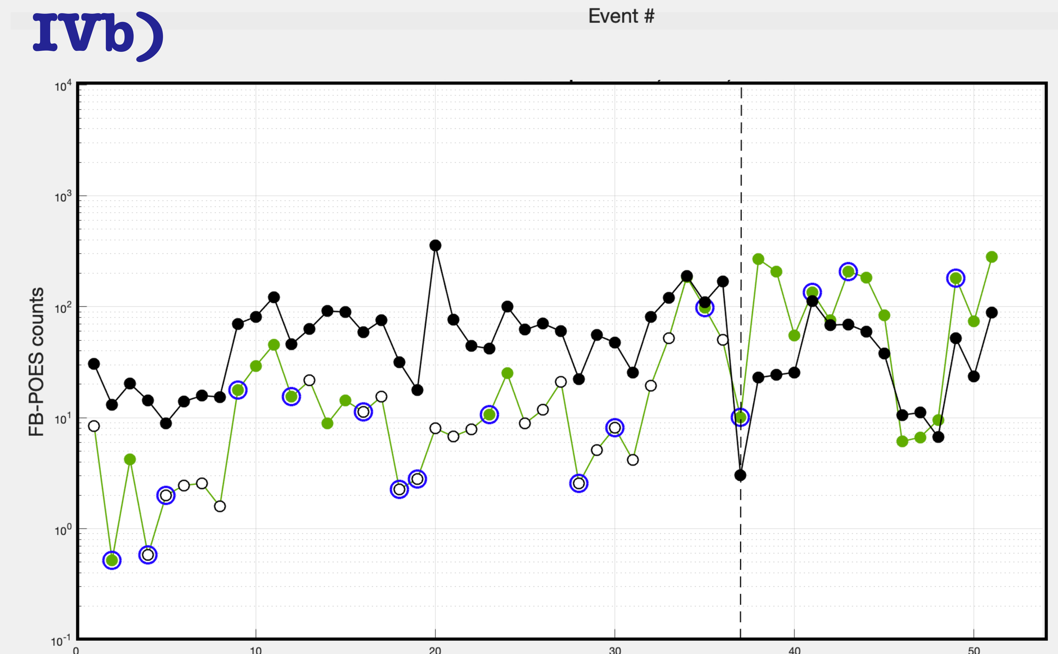
IVa) FIREBIRD-II & POES Electron Count Data during 51 Events, >100keV



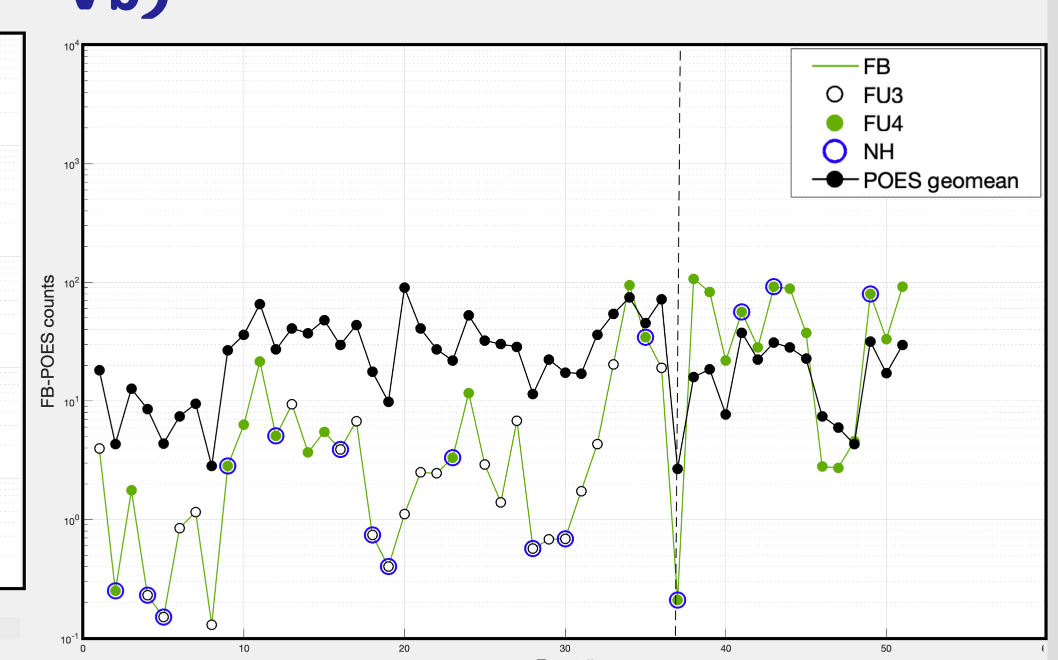
Va) FIREBIRD-II & POES Electron Count Data during 51 Events, >300keV



IVb)



Vb)



CONCLUSIONS

This comparison of energetic electron flux between FIREBIRD and POES shows that:

1. FIREBIRD measurements follow the same linear trends as POES.
2. FIREBIRD is able to capture variability at low flux while the POES noise floor obstructs these measurements.
3. FIREBIRD data lies between the POES 0° and 90° data and is less than the POES geometric mean on average (at least prior to 2020)
4. FIREBIRD-4 data closely resembles POES geometric mean data for the duration that FIREBIRD-4 sways between 0-90 degrees (events after 2020).
5. Conjunctions that occur within the southern hemisphere tend to have higher electron flux.
6. POES 0 degree counts are linearly coordinated with FIREBIRD despite the high noise floor of MEPED.

FUTURE WORK

It is anticipated that this study will demonstrate the value of using electron flux instruments capable of higher energy resolution for future satellite missions. Future work includes:

1. Correcting POES proton contamination and comparing to the work of Josh Pettit at U. Colorado (in communication).
2. Comparing results of this study with results of EMIC wave enhancement study and compare to the work of Timothy Raeder at UNH.
3. Using these results to help determine the best methods for combining the POES 0° and 90° data to estimate electron precipitation (e.g., Peck et al., 2015; Nesse-Tyssøy et al., 2016).

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