Observations of Van Allen Radiation Belt Electron Precipitation during Satellite Conjunctions of FIREBIRD-II and POES

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Introduction

Precipitating electrons impact the physical and chemical properties of the upper atmosphere; yet, the flux and distribution of these electrons is not well known. Measurements of electrons in the atmosphere are usually provided by the Polar-orbiting Operational Environmental Satellites (POES), which are equipped with the Medium Energy Proton and Electron Detector (MEPED). While these satellites have adequate coverage, they have a low energy resolution and electron measurements are impacted by proton contamination. Additionally, the POES instrument geometry provides a narrow field of view which inhibits the measurement of low-flux electrons.

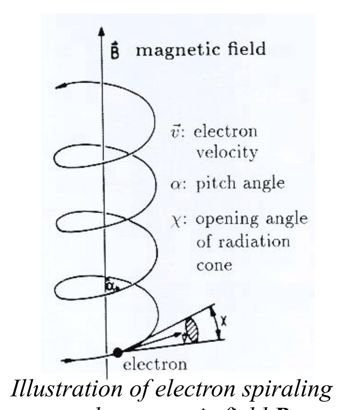
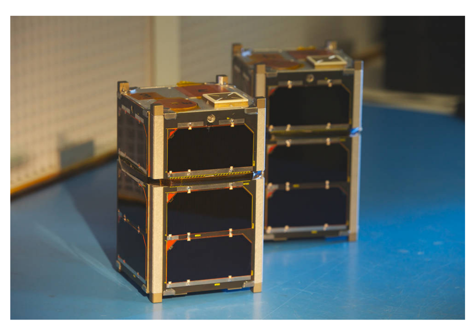


*Illustration of electron spiraling around a magnetic field **B** at velocity **V** with a pitch angle **θ**. Adapted from Singal [2016].*

Fortunately, the recent FIREBIRD-II CubeSat mission provides an opportunity to observe higher resolution electron measurements with a wider field of view in comparison with POES. FIREBIRD-II provides higher energy resolution, with differential as opposed to integral flux, and geometric factors 600 times POES, allowing better observation of electron precipitation during quiet times. This study compares energetic electron flux between the FIREBIRD-II CubeSats (FIREBIRD Unit 3, FU3, and FIREBIRD Unit 4, FU4) and several POES satellites (NOAA-15, NOAA-18, NOAA-19, MetOp-1B, MetOp-2A) during conjunction times between L-shells 3 and 7, which are representative of the outer radiation belt.



The FIREBIRD-II CubeSat.

It is anticipated this study will demonstrate the value of using electron flux instruments capable of higher energy resolution for future satellite missions. Using instruments similar to the FIREBIRD instrument on future satellites instead of the MEPED would ensure a more accurate observation of electron precipitation in the upper atmosphere.

Methods

FIREBIRD electron counts measured during conjunctions with POES satellites were used to calculate FIREBIRD electron flux, as seen in equation (1), where j represents the electron flux (particles s^{-1} cm^{-2} sr^{-1}), C is the instrument count rate (count s^{-1}), and G is a geometric factor.

$$j = \frac{C}{G} \qquad (1)$$

The geometric factor is a function of incidence angle, energy, and particle species and is determined using the Geometry and Tracking (GEANT) particle transport model as described in Yando, et al., [2011]. The formula used to calculate the geometric factor G is defined as seen in (2), where n is the number of registered particles, N is the number of simulated particles, and r is the radius of the source.

$$G = \frac{n}{N} 4\pi^2 r^2 \qquad (2)$$

The FIREBIRD electron flux is presented in panel A of each set of plots. 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 (3).

$$C_M = \frac{j_{FB}}{G_M} \qquad (3)$$

The calculation of MEPED theoretical counts based on FIREBIRD flux allows for a comparison between MEPED theoretical counts and measured counts for the 0° and 90° detectors, where the 0° detector is oriented with the magnetic field and the 90° detector is parallel to the magnetic field. The 0° telescope observes precipitating electrons, and the 90° telescope observes mirrored electrons, resulting in the 90° detector observations to be much higher than those from the 0° detector.

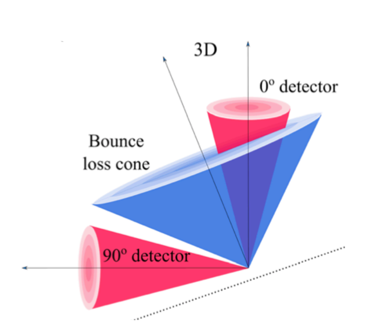


Illustration of pitch angles [Tyssøy, et al. (2016)]

Results

Comparison of FIREBIRD-II and POES

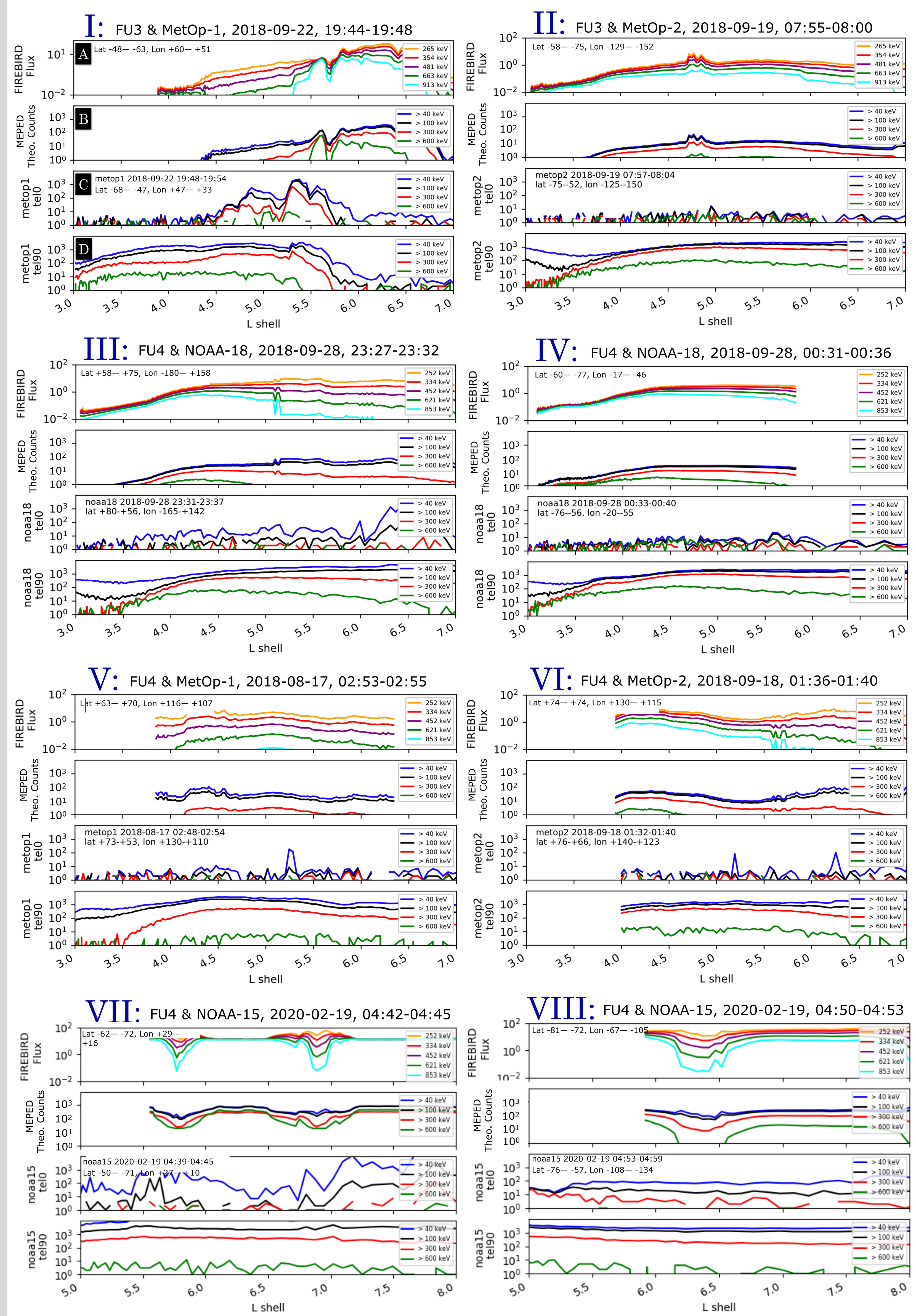


Figure Caption

The above plots display a few representative examples comparing FIREBIRD-II and POES energetic electron counts during satellite conjunctions.

- **A** FIREBIRD electron flux, which is used to estimate MEPED theoretical counts (particles s^{-1} cm^{-2} sr^{-1}).
- **B** MEPED theoretical counts based on FIREBIRD flux (counts s^{-1}).
- **C** MEPED counts detected by the 0º telescope (counts s^{-1}).
- **D** MEPED counts detected by the 90º telescope (counts s^{-1}).

Discussion

There are several explanations for discrepancies between the FIREBIRD-II and POES observations.

- The Tsyganenko T89 magnetic field model was used to calculate McIlwain L-shells from spacecraft location. This model is based on a simplified magnetic field model and can be inaccurate at higher L-shells, which might explain the FIREBIRD over-prediction at high L-shells (Plot I).
- POES also has 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 see enhancements in higher energy levels when the electron flux is low.
- The MEPED also 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.
- It is difficult to determine the exact orientation of the FIREBIRD-II CubeSats, which may result in electron count measurements that are between 0° and 90°. FIREBIRD may be capturing mirrored particles as opposed to precipitating particles in the bounce loss cone.
- The altitude difference between FIREBIRD (400-600 km) and POES (~870 km) may also contribute to the difference in electron count measurements.

In spite of these potential explanations, it is apparent that the higher energy resolution of the FIREBIRD-II instruments allows us to better quantify the variability in electron precipitation, especially during quiet times (periods of low electron flux). This information is crucial for understanding the impacts of electron precipitation from the Van Allen radiation belts on our atmosphere.

Conclusions

This observation of electron precipitation during satellite conjunctions of FIREBIRD-II and POES shows that:

1. POES over-predicts during periods of high flux in comparison to FIREBIRD-II (Plot I).
2. FIREBIRD-II is able to capture the variability at low flux while the POES noise floor obscures these observations (Plots II & IV).
3. The noise floor from POES is too high to capture the low flux values that FIREBIRD-II sees (Plots V & VI).

Future measurements that have the resolution of FIREBIRD energetic electron count observations with POES spatial and temporal coverage could allow for a better understanding and a more accurate estimate of electrons impacting the upper atmosphere.

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