Solar Cycle Events and Impacts on Particle Intensity Around the South American Anomaly

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Abstract

The South American Anomaly, or the South Atlantic Anomaly, (S.A.A.) is a region in the Earth's magnetic field that contains an abnormally large amount of charged particles such as electrons and protons. Satellites that fly through this region will suffer damage to their hardware, reducing their lifespan. The potential harmful effects depend on the intensity and energy levels of electrons and protons. The particle intensity of the S.A.A. can vary depending on the conditions of a geomagnetic storm. In particular, we analyzed the effects of geomagnetic storms on the particle intensity levels of the S.A.A. throughout 7 years in Solar Cycle 24, 2013-2019. Using data from PROBA-V, we also determined the abundance and location of different energy-level particles in the S.A.A. to identify if there are any relatively stable regions for satellites passing through during a geomagnetic storm.

Background

- The S.A.A. is a weak spot in the Earth's magnetic field caused by reversed flux patches. Reversed flux patches are a form of secular variation that is caused by our changing magnetic field.
- In the case of the S.A.A., this is where we see the major reverse flux patch (a spot in our magnetic field that points in the opposite direction, causing it to be weaker).
- The Drift Loss Cone (D.L.C.) is the range within the magnetic field where particles that lose energy as a result of azimuthal drift motions stimulated by pitch-angle scattering are trapped as their trajectory (as determined by pitch angle) contrasts against the flow of the magnetic field.
- Satellites traveling through unstable particle flux regions undergo more damage than stable particle flux regions.

Methods

- **Data**: Datasets from PROBA-V mission data, mainly from the Energetic Particle Telescope (EPT) on the satellite between 2013-2021, 800 km above Earth's surface.
- **Processing and Visualization**: Python within Jupyter Notebooks
- **Libraries**: Pandas, NumPy, CartoPy, Matplotlib

A distribution scatter plot chart was generated, categorizing low, medium, and high energy particles. It covers 10 keV to 10 MeV energy level electrons and 9.5 MeV to 248 MeV energy level protons across the South Atlantic Anomaly (SAA). Spatial binning techniques were applied to develop a global electron flux distribution map. We created a time-lapse GIF to illustrate the monthly evolution of global proton and electron flux distributions. For quality control, significant outliers were identified and removed to improve the accuracy of the analysis.

Global Electron Flux Distribution

The figure below demonstrates the flux of **0.5-0.6 MeV electrons** (one channel) during a 2-week time period.

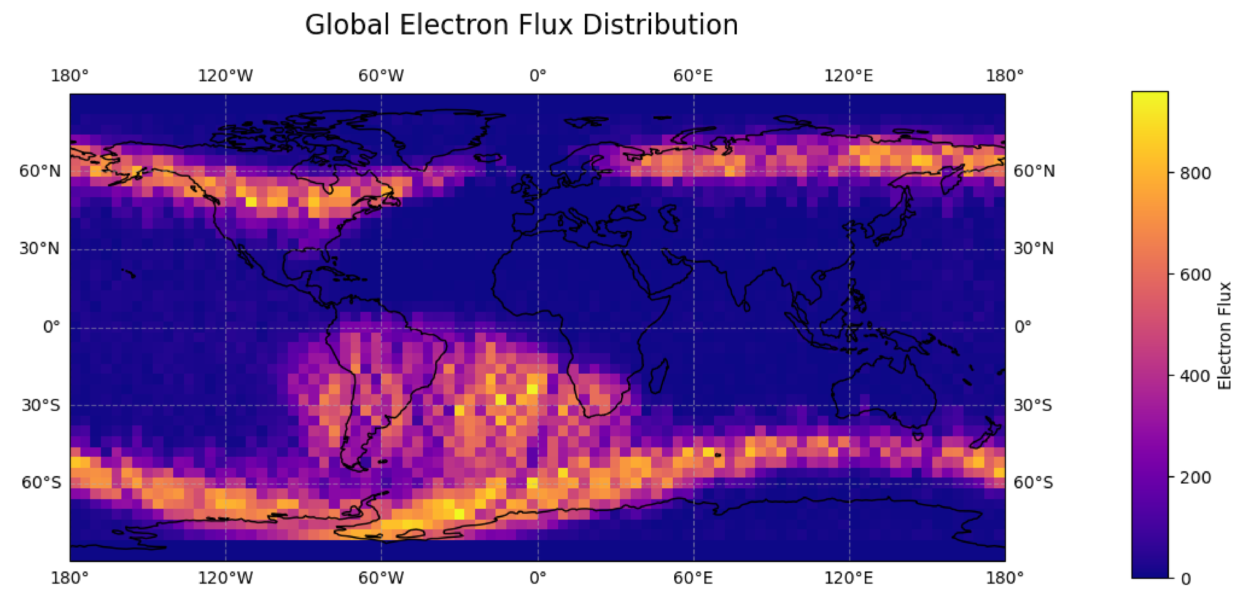

Figure 1. Global Electron Flux Distribution (June 1 - June 15, 2013)

- **Flux** magnitude is in bins of 4°latitude x 4°longitude.
- **The S.A.A.** is visually documented on the figure as the anomaly separate from the flux patterns from 90-30°North and 90-30°South.

We are looking to quantify the magnitude of change of flux within the S.A.A before and after geomagnetic storms. Binning is vital in executing this process to return a viable flux drop-out or increase value.

Proton and Electron Fluxes vs. Latitude

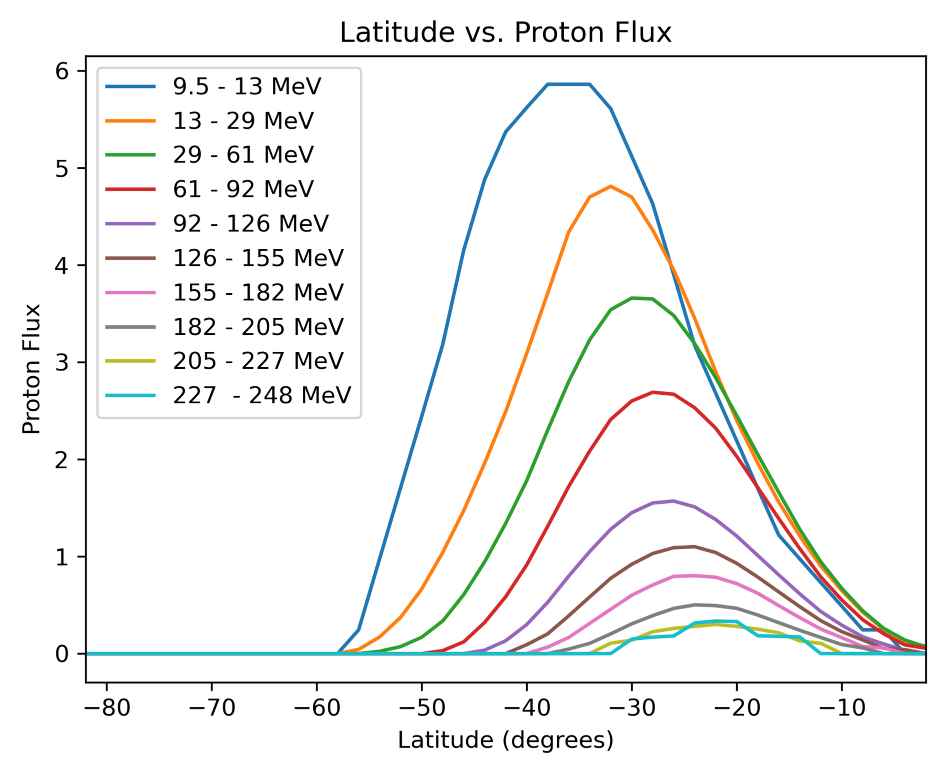

Figure 2. Latitude vs. Proton Flux (All Channels, January 1 - June 30, 2014)

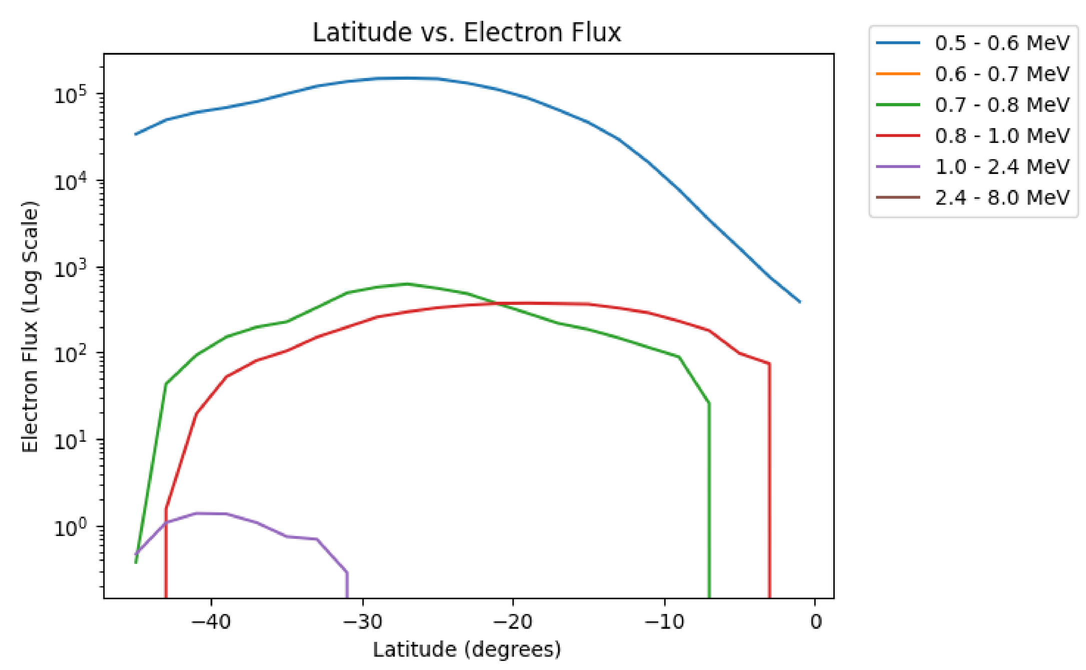

Figure 3. Latitude vs. Electron Flux (All Channels, January 1 - June 30, 2014)

We analyzed proton and electron flux data from periods before and after geomagnetic storms to assess the impact on the South Atlantic Anomaly (SAA) particle population. Our results indicate that while higher-energy particles—associated with greater radiation hazards—were less abundant, lower-energy particles had a significantly higher population density.

During this period, we notice there is a significant magnitude of flux for one energy channel ("e-fl-00"). Going forward, we will focus on these high-magnitude flux channels to quantify any changes as a result of geomagnetic storms. Another thing of note is that there are more protons than electrons in the S.A.A.

Key Findings & Conclusions

- When the S.A.A is stable, we find that the dominate particle energy level for electrons is 0.5-0.6 MeV. When comparing to other electron and proton energy channels, there is a lot more lower level electron and proton energy channels than higher ones overall.
- The outer layer of the S.A.A is considerably more unstable and thus more dangerous than the center, because of the severe difference of electron and proton flux. We found the difference to be 2-4 orders of magnitude greater than the particles in the middle of the S.A.A. This outer layer can impact satellites the most.
- Traveling through the outer edge of S.A.A is shown to be safer in the absence of a storm. But the center of the S.A.A may be a relatively safer route for satellites due to the center being stable in the event of a solar storm.
- The safest region to launch a satellite is on a path avoiding the S.A.A., however, knowing the intricacies of how particle flux changes in the S.A.A throughout the solar cycle is useful for determining safer reliable paths for satellites traveling through this region for future missions.

Change of Electron Flux

The figure below demonstrates the flux of **0.5-8.0 MeV electrons** (all channels) over 2 weeks.

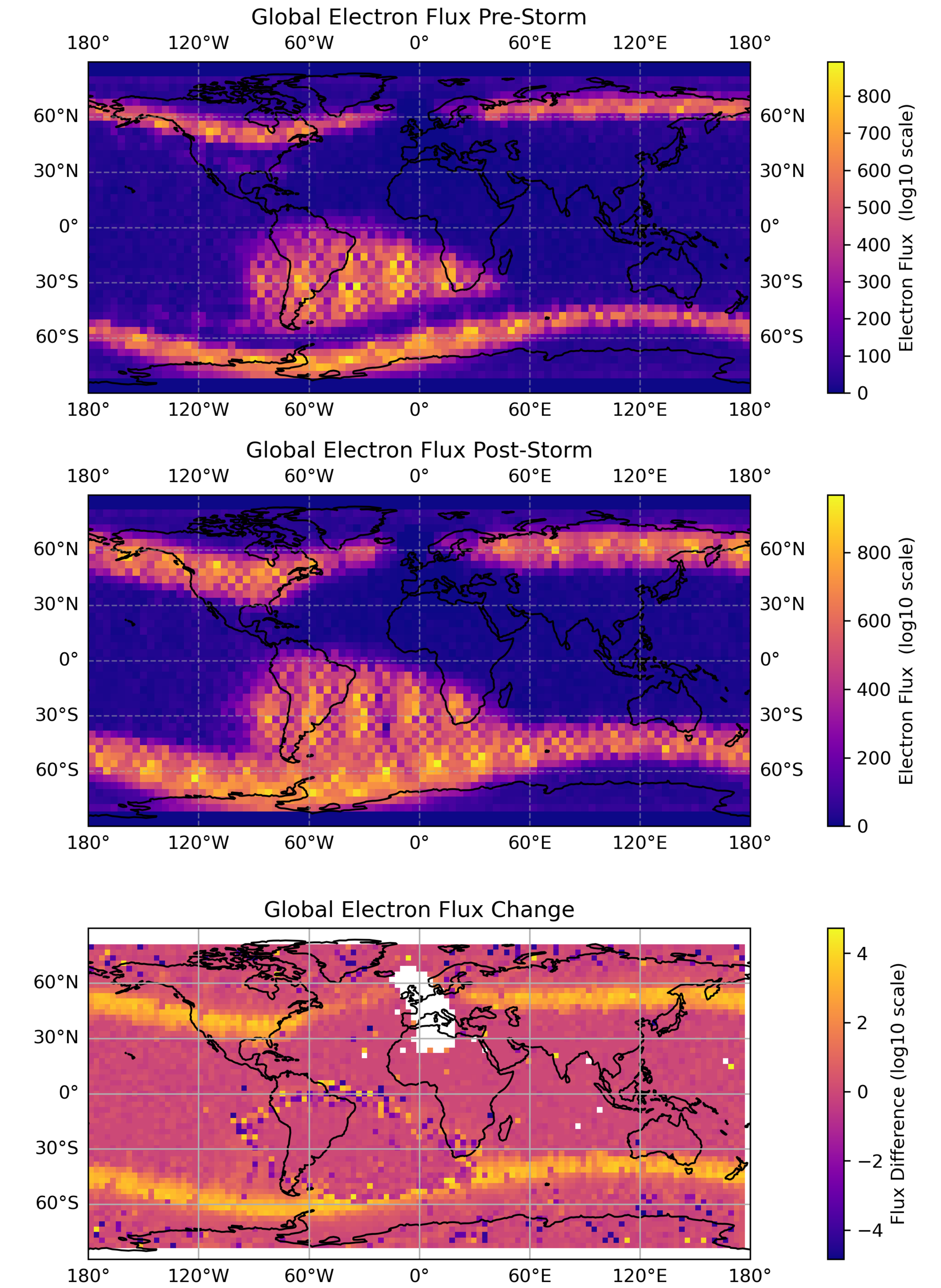

Figure 4. Electron Flux Distribution Pre-Storm (March 7–17, 2015), Post-Storm (March 17–27, 2015), and Change in Electron Distribution, respectively

- The change of flux of electrons visually represented as a result of **St. Patrick's Day Solar Storm** of degree G-4 on March 17, 2015.
- **The Change of Flux** for one bin (-68°to -64°longitude, 66°to 70°latitude) has a maximum magnitude of -4.52 (log scale).

Future Works

- We can characterize changes in flux corresponding to different types of geomagnetic storms (CIRs and CMEs).
- Analyze the behavior of protons and electrons within the S.A.A over a continuous solar cycle, including solar maxima and minima.
- Analyze how long charged particles are trapped in the S.A.A after geomagnetic storms. We could also find the standard deviation on the particle fluxes of geomagnetic storms in one solar cycle.
- Cross references between analyzed data from different satellites can be conducted to complete our data set and get more precise numerical conclusions.

References

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