Extreme Relativistic Electron Fluxes at Geosynchronous Orbit

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Extreme Relativistic Electron Fluxes at Geosynchronous Orbit

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Motivation

- Satellite operators, designers and insurers are interested in extreme space weather events to help them better understand the satellite environment and assess the impacts of an extreme event.
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• The objective of this study is to calculate the electron flux for the 1 in 10, 1 in 50, and 1 in 100 year space weather event at geosynchronous orbit
Data Analysis

- Use GOES E > 2 MeV electron data from 1st January 1995 to 30th June 2014

- Study uses data from GOES 8, 9, 10, 11, 12, 13 and 15

Typical Orbital Parameters
Altitude: 35,800 km
Inclination: 0°

credit: NOAA
Data Analysis

• Electron data
  • have been corrected for proton contamination
  • for the first time the data have been corrected for dead time
  • dead time correction ranges from a factor of 1.0-1.15 for fluxes around 5000 cm$^{-2}$s$^{-1}$sr$^{-1}$ to ~2 for the largest fluxes observed

Typical Orbital Parameters
Altitude: 35,800 km
Inclination: 0°

credit: NOAA
Primary Geographic Longitudes

- GOES satellites operate at two primary geographic longitudes, GOES East at 75° and GOES West at 135° W

- The satellites are at different magnetic latitudes with GOES East at 11° N and GOES West at 4° N

- GOES East and GOES West are at different L shells

- Since the flux of energetic electrons generally decreases with L near geosynchronous orbit we conduct our analysis for GOES East and West separately

Figure adapted from Onsager et al., 2004
Good Quality Data Points

- In total there are 5844 good quality data points at GOES West, corresponding to approximately 16 years of operational data.

- There are 5649 good quality data points at GOES East, corresponding to approximately 15.5 years of operational data.
Exceedance Probability

- Probability that an individual sample J is greater than j \( (P[J>j]) \)
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- Flux that is exceeded 0.1% of the time is
  - \(4.5 \times 10^4 \text{ cm}^{-2}\text{s}^{-1}\text{sr}^{-1}\) at GOES East
  - \(1.35 \times 10^5 \text{ cm}^{-2}\text{s}^{-1}\text{sr}^{-1}\) at GOES West
Exceedance Probability

- Fluxes at GOES West are typically a factor of 2.5 higher than those at GOES East.
- This is largely due to the fact that the satellite at GOES West is at a lower magnetic latitude and hence L shell.
Extreme Value Analysis

• Two main methods for extreme value analysis
  • block maxima
  • exceedances over a high threshold

• For comparison with earlier work (e.g., Koons [2001]) we use the exceedances over a high threshold method

• For this approach the appropriate distribution function is the Generalised Pareto Distribution (GPD)
Generalised Pareto Distribution

• The GPD may be written in the form

\[ G(x-u) = 1 - (1 + \frac{\xi(x-u)}{\sigma})^{-1/\xi} \]

where: \( x \) are the data values above the chosen threshold \( u \)
\( \xi \) is the shape parameter which controls the behaviour of the tail
\( \sigma \) is the scale parameter which determines the dispersion or spread of the distribution

• The GPD is a distribution function

• \( 1-G(x-u) \) representing the probability that a random variable \( X \) exceeds some value \( x \) given that it already exceeds a threshold \( u \)
Declustering

• Values can exceed the threshold on consecutive days

• The statistical analysis assumes that the individual exceedances are independent

• Technique to deal with this is known as declustering
Declustering

- Use an empirical rule to define clusters of exceedances and consider cluster to be active until 3 consecutive daily averages fall below the threshold.

- Identify the maximum excess in each cluster and assume cluster maxima to be independent, with conditional excess given by the GPD.

- Fit the GPD to the cluster maxima.
The level $x_N$ which is exceeded on average once every $N$ years is given by

$$x_N = u + \left(\frac{\sigma}{\xi}\right)(Nn_d\zeta^\xi - 1))$$

where $\zeta = n_c/n_{tot}$, the number of cluster maxima divided by the total number of daily values and $n_d = 365.25$ is the average number of days in any given year.

A plot of $x_N$ against $N$ is known as a return level plot.
GOES West: Return Level Plot

- One in Ten Year Flux
  - $1.84 \times 10^5 \, \text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$

- One in Fifty Year Flux
  - $5.00 \times 10^5 \, \text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$

- One in One Hundred Year Flux
  - $7.68 \times 10^5 \, \text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$
• Largest observed flux is a one in fifty year event
GOES East: Return Level Plot

• One in Ten Year Flux
  • $6.53 \times 10^4 \text{ cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$

• One in Fifty Year Flux
  • $1.98 \times 10^5 \text{ cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$

• One in One Hundred Year Flux
  • $3.25 \times 10^5 \text{ cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$
GOES East: Return Level Plot

- Largest observed flux is a one in fifty year event
Comparison with Koons [2001] Study

- Our results are generally larger than those presented in Koons [2001].

<table>
<thead>
<tr>
<th>Event</th>
<th>GOES West (cm$^{-2}$s$^{-1}$ sr$^{-1}$)</th>
<th>Koons [2001] (cm$^{-2}$s$^{-1}$ sr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 in 10 yr</td>
<td>1.84x10$^5$</td>
<td>6.78x10$^4$</td>
</tr>
<tr>
<td>1 in 20 yr</td>
<td>2.83x10$^5$</td>
<td>7.98x10$^4$</td>
</tr>
<tr>
<td>1 in 50 yr</td>
<td>5.00x10$^5$</td>
<td>9.57x10$^4$</td>
</tr>
<tr>
<td>1 in 100 yr</td>
<td>7.68x10$^5$</td>
<td>1.08x10$^5$</td>
</tr>
</tbody>
</table>

- For example, the 1 in 10 year event at GOES West is about a factor of 2.7 times that estimated by Koons [2001].

- For more extreme events, the 1 in 100 year event at GOES West is about a factor of 7 times that estimated by Koons [2001].
July/August 2004

- Largest $E > 2$ MeV flux of $4.91 \times 10^5$ cm$^{-2}$s$^{-1}$sr$^{-1}$ observed at GOES-West on 29$^{th}$ July 2004

- Coincided with the largest $E > 2$ MeV flux of $1.93 \times 10^5$ cm$^{-2}$s$^{-1}$sr$^{-1}$ at GOES-East

- Independent measurements of this extreme flux event suggests the flux event is real

- GOES-West flux exceeded 10,000 cm$^{-2}$s$^{-1}$sr$^{-1}$ for nine consecutive days from 28$^{th}$ July to 5$^{th}$ August
July/August 2004

- Double Star TC1 and TC2 reported over 30 anomalies during the period from 27 July to 10 August [Han et al., 2005]

- These anomalies largely occurred in the Earth’s radiation belt and were attributed to internal charging [Han et al., 2005]

Han et al., JSR, 2005
July/August 2004

- On 3 August, during the extended period of enhanced E > 2 MeV electron fluxes, Galaxy 10R lost its secondary xenon ion propulsion system [Choi et al., 2011]

- This reduced its lifetime significantly resulting in an insurance payout of US $75.3 M
What Caused the Extreme Event?

- Three consecutive storms
- IMF Bz remained southward for significant periods during recovery phase of each storm
- Average value of AE index around 900 nT for first 10 hours of each recovery phase
- Such high and sustained levels of AE are likely to be associated with
  - strong and sustained levels of whistler mode chorus
  - elevated seed electrons
  - strong acceleration of electrons to relativistic energies

Galaxy 10 R secondary XIPS failure
Conclusions

• The daily average flux of E > 2 MeV electrons measured at GOES West is typically a factor of 2.5 higher than that measured at GOES East.

• The 1 in 10, 1 in 50 and 1 in 100 year event at GOES West are $1.84 \times 10^5$, $5.00 \times 10^5$ and $7.68 \times 10^5$ cm$^{-2}$s$^{-1}$sr$^{-1}$ respectively.

• The largest event seen during the study period was particularly extreme. Our study suggests that this was a one in fifty year event.
Acknowledgements

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