Extreme Relativistic Electron Fluxes at Geosynchronous Orbit

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IMC III Workshop, UCLA 23rd - 27th March, 2015

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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

credit: NOAA

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

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

credit: NOAA

Typical Orbital Parameters
Altitude: 35,800 km
Inclination: 0^{o}

Primary Geographic Longitudes

- GOES satellites operate at two primary geographic longitudes, GOES East at 75^o and GOES West at 135^o W
- The satellites are at different magnetic latitudes with GOES East at 11^o N and GOES West at 4^o 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

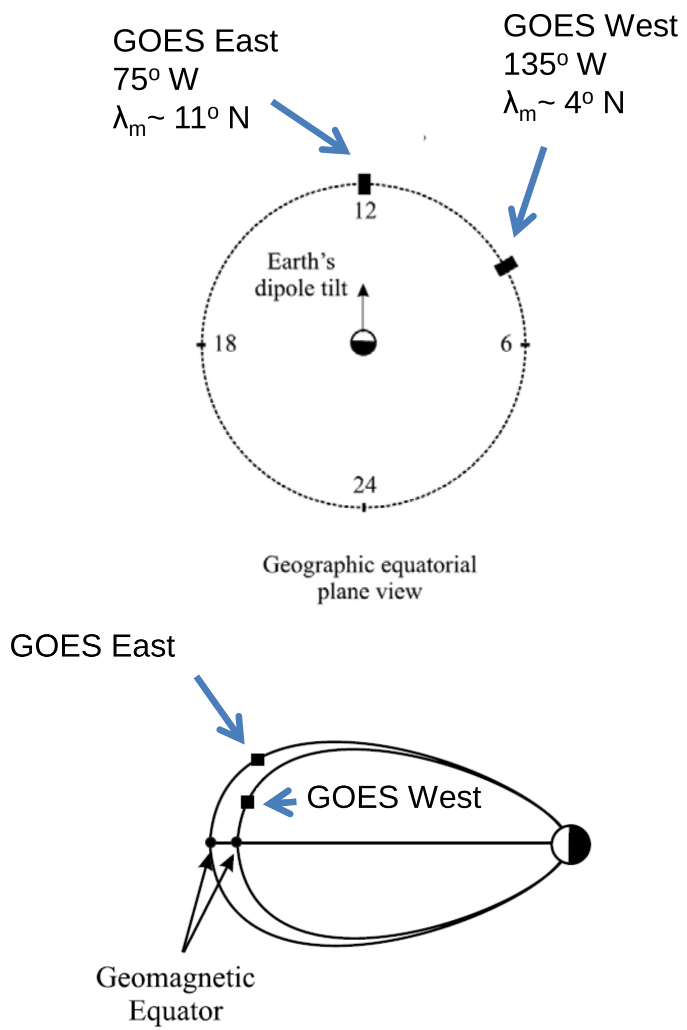


Figure adapted from Onsager *et al.*, 2004

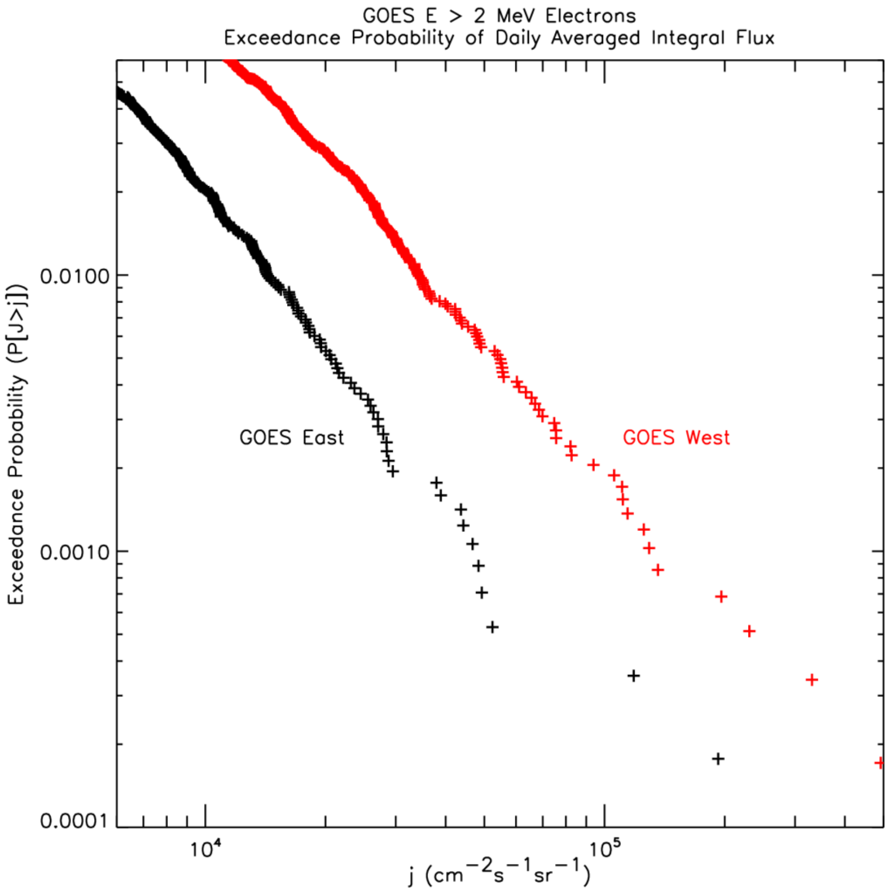
Good Quality Data Points

- 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

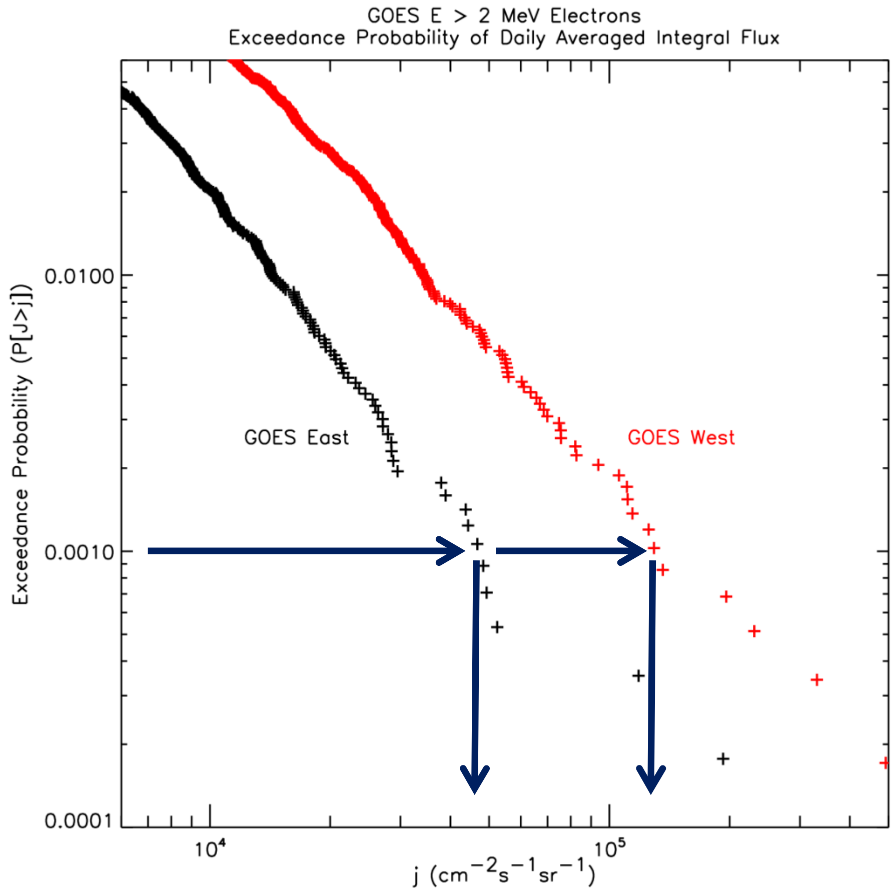
Exceedance Probability

- Probability that an individual sample J is greater than j (P[J>j])



Exceedance Probability

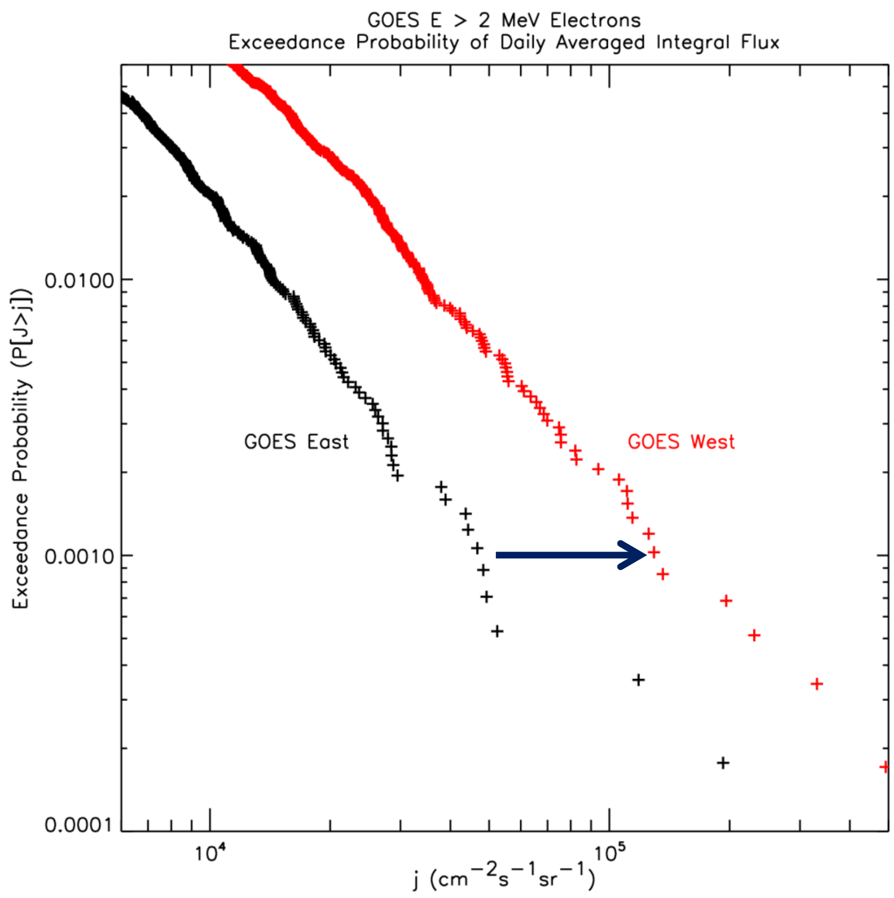
- Probability that an individual sample J is greater than j (P[J>j])
- Flux that is exceeded 0.1% of the time is
  - 4.5×10^4 $cm^{-2}s^{-1}sr^{-1}$ at GOES East
  - 1.35×10^5 $cm^{-2}s^{-1}sr^{-1}$ at GOES West



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

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

where: x are the data values above the chosen threshold u

ξ is the shape parameter which controls the behaviour of the tail

σ 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

Return Level Plot

- The level x_N which is exceeded on average once every N years is given by

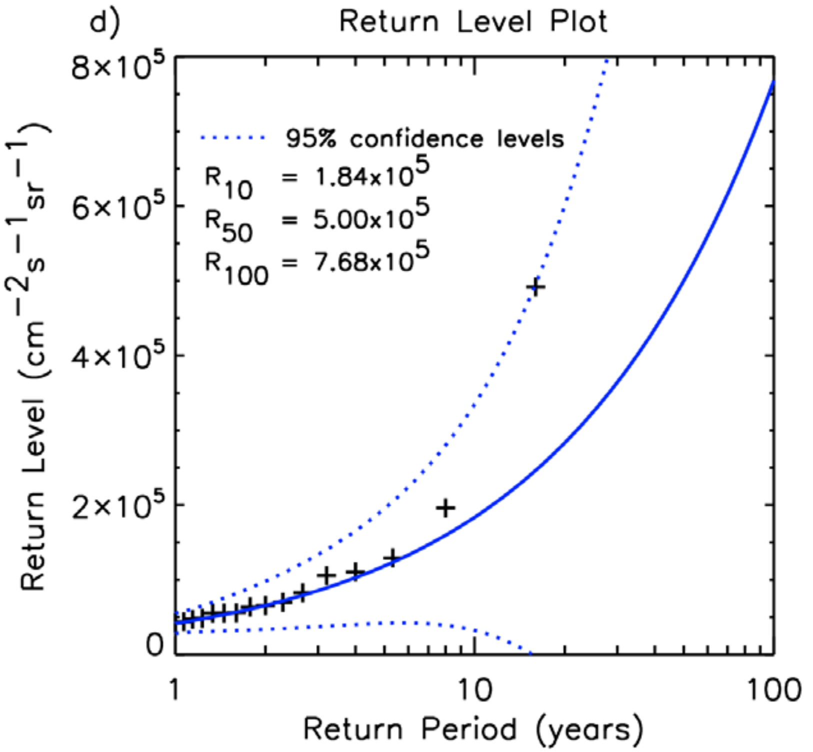
$$x_N = u + (\sigma/\xi)((Nn_d\zeta)^{\xi} - 1))$$

where $\zeta = n_c/n_{tot}$, the number of cluster maxima divided by the total number of daily values and nd = 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

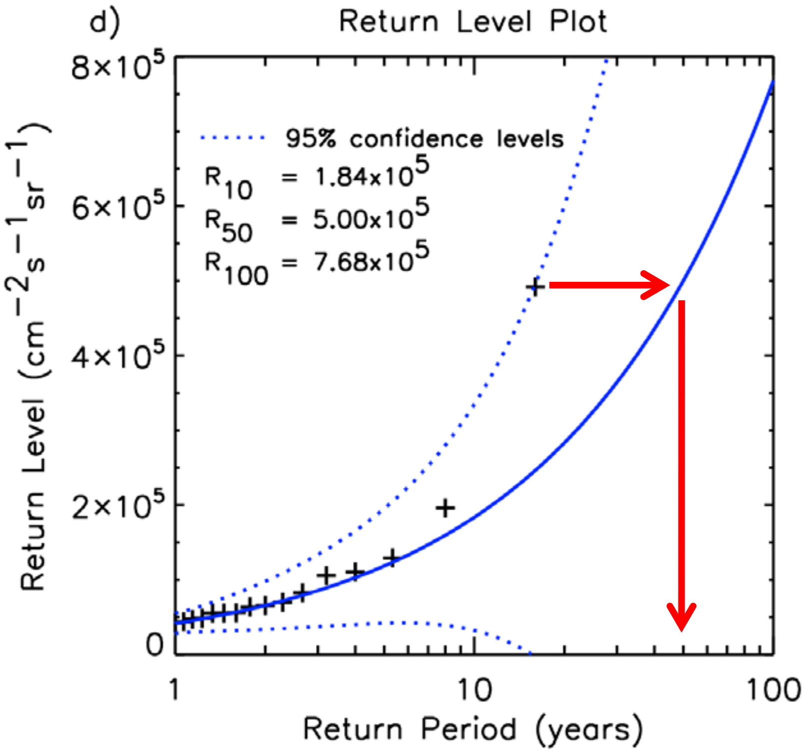
GOES West: Return Level Plot

- One in Ten Year Flux
  - 1.84×10^{5} $cm^{-2}s^{-1}sr^{-1}$
- One in Fifty Year Flux
  - 5.00×10^{5} $cm^{-2}s^{-1}sr^{-1}$
- One in One Hundred Year Flux
  - 7.68×10^{5} $cm^{-2}s^{-1}sr^{-1}$



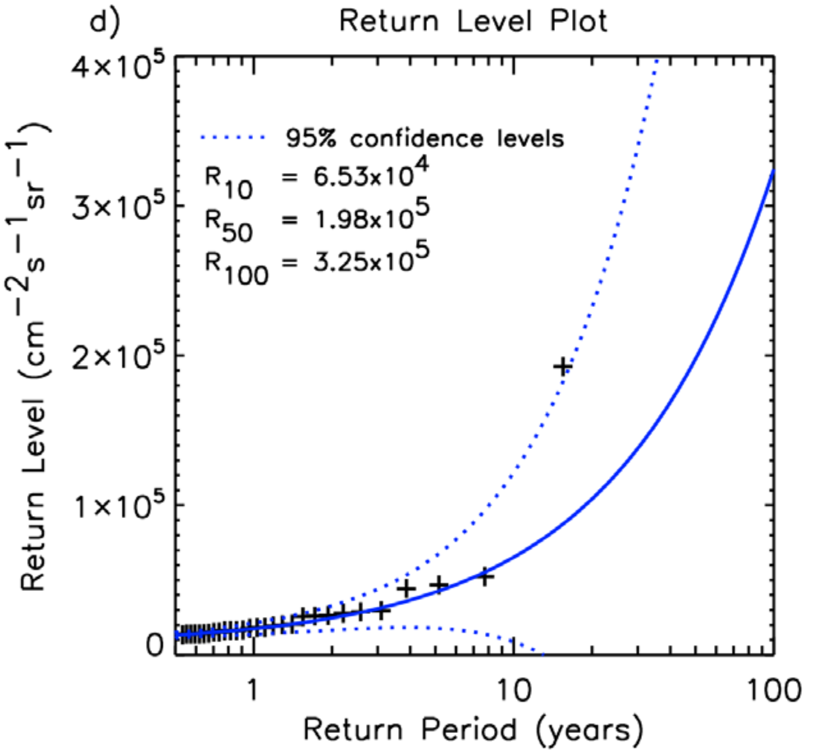
GOES West: Return Level Plot

- Largest observed flux is a one in fifty year event



GOES East: Return Level Plot

- One in Ten Year Flux
  - 6.53×10^{4} $cm^{-2}s^{-1}sr^{-1}$
- One in Fifty Year Flux
  - 1.98×10^{5} $cm^{-2}s^{-1}sr^{-1}$
- One in One Hundred Year Flux
  - 3.25×10^{5} $cm^{-2}s^{-1}sr^{-1}$



GOES East: Return Level Plot

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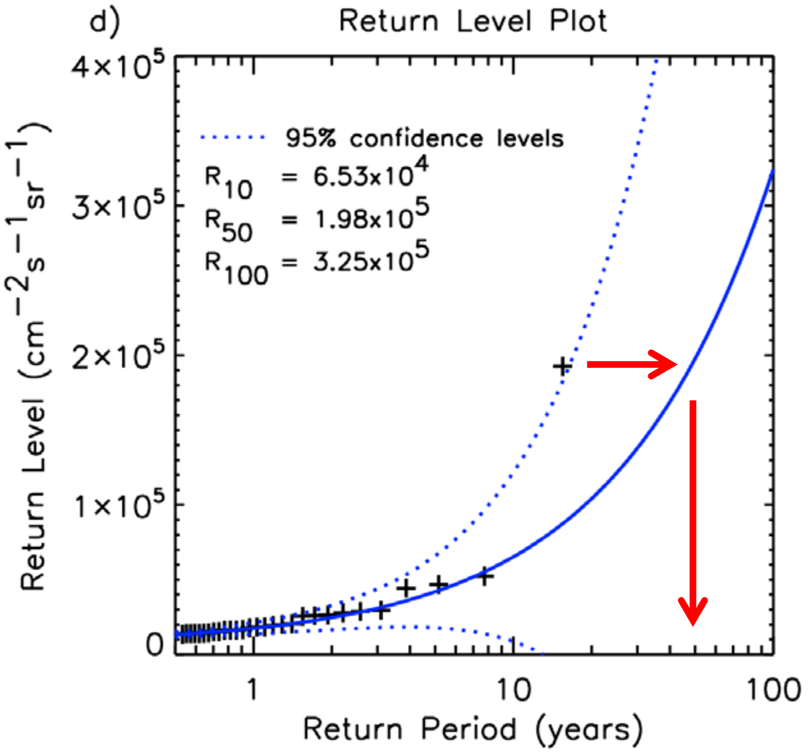


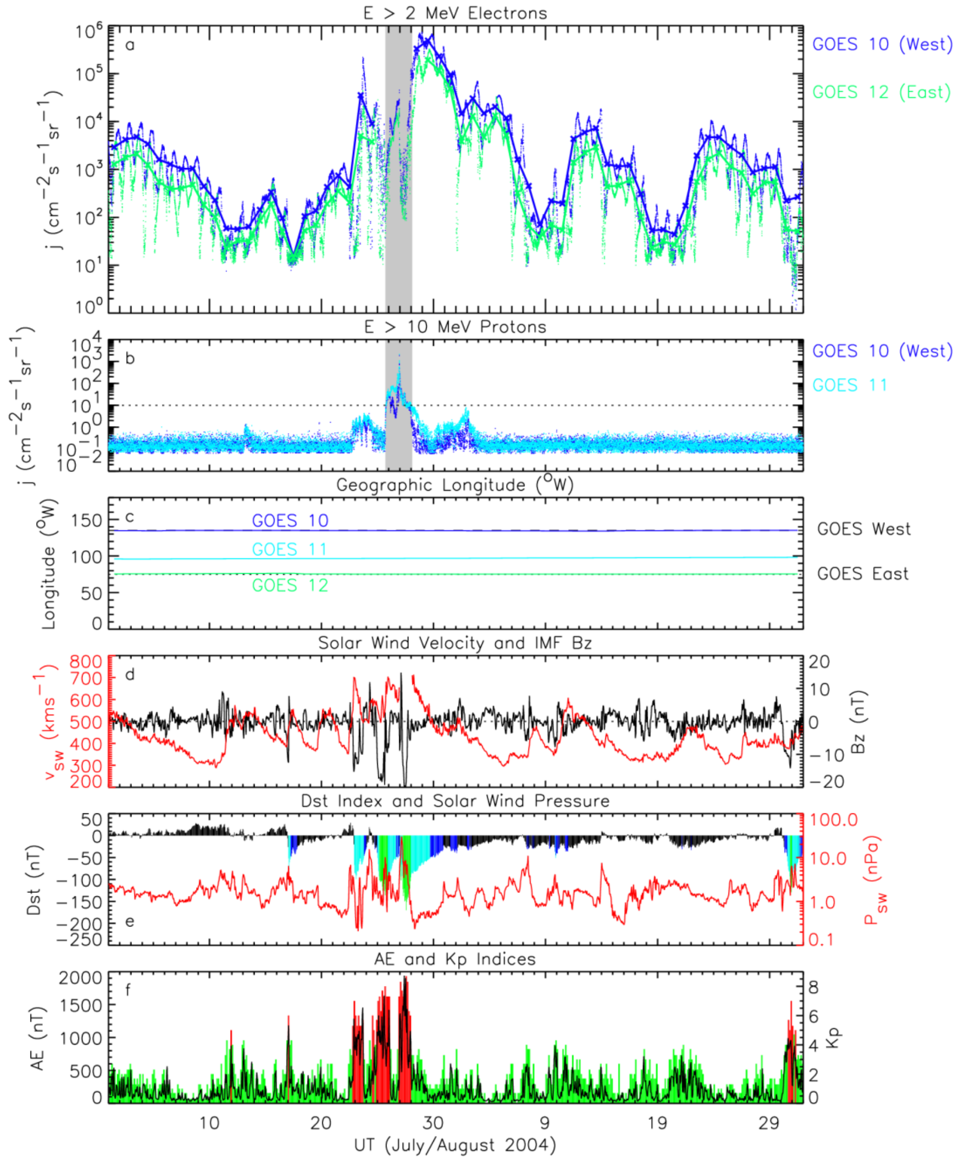
Comparison with Koons [2001] Study

Event	GOES West ($cm^{-2}s^{-1}\ sr^{-1}$)	Koons [2001] ($cm^{-2}s^{-1}sr^{-1}$)
1 in 10 yr	1.84×10^5	6.78×10^4
1 in 20 yr	2.83×10^5	7.98×10^4
1 in 50 yr	5.00×10^5	9.57×10^4
1 in 100 yr	7.68×10^5	1.08×10^5

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

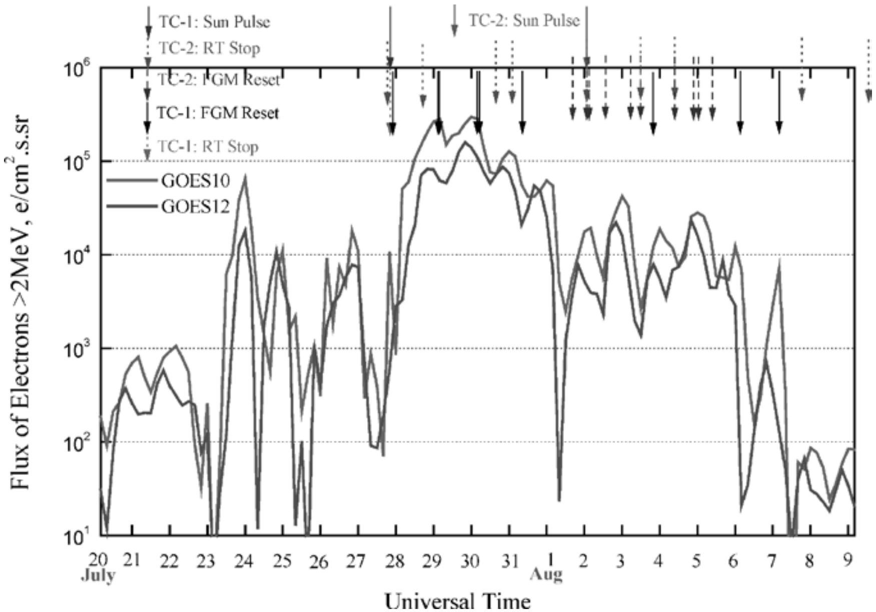
- Largest E > 2 MeV flux of 4.91x10^5 cm^{-2}s^{-1}sr^{-1} observed at GOES-West on 29th July 2004
- Coincided with the largest E > 2 MeV flux of 1.93x10^5 cm^{-2}s^{-1}sr^{-1} at GOES-East
- Independent measurements of this extreme flux event suggests the flux event is real
- GOES-West flux exceeded 10,000 cm^{-2}s^{-1}sr^{-1} for nine consecutive days from 28th July to 5th 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]

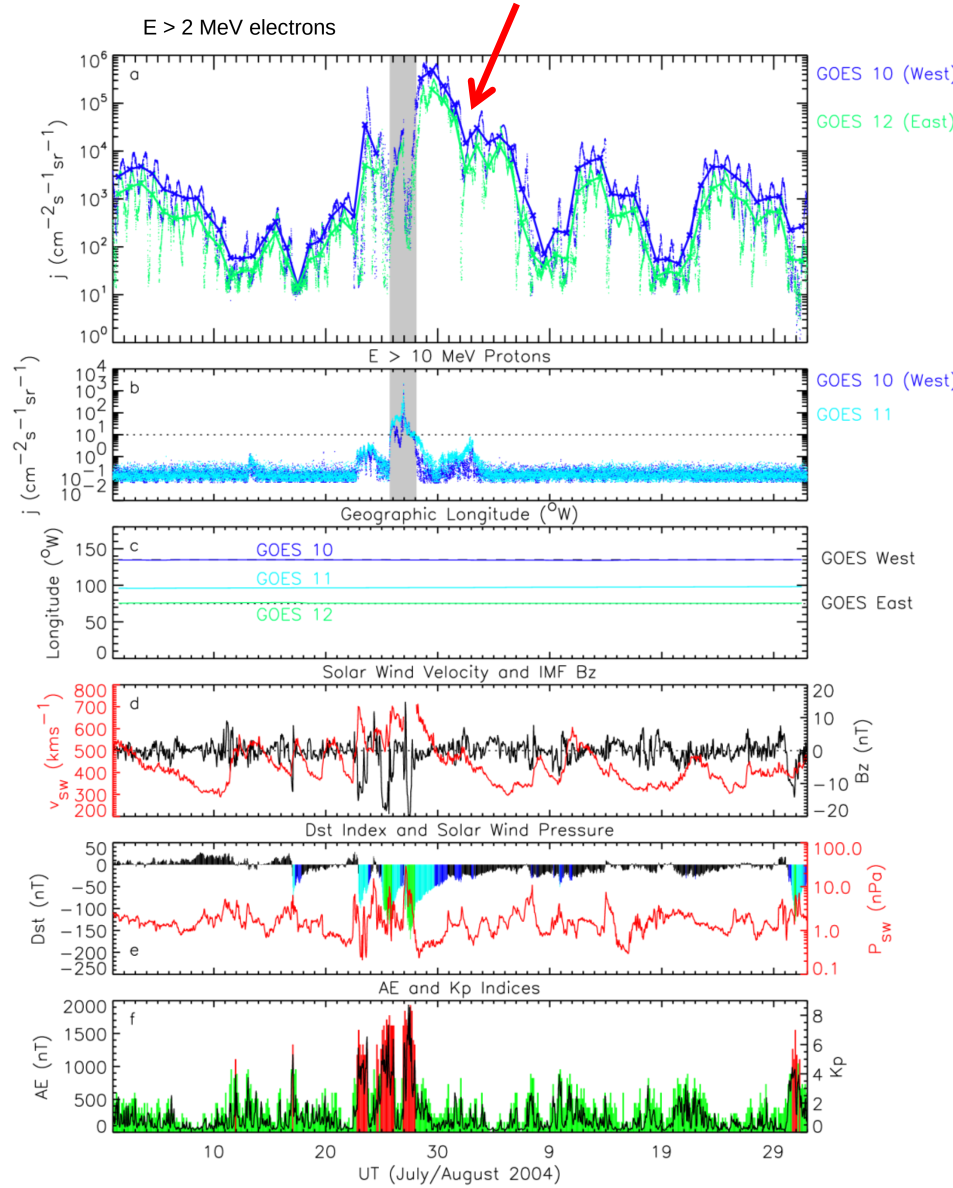
- These anomalies largely occurred in the Earth's radiation belt and were attributed to internal charging [Han *et al*., 2005]



Han *et al*., JSR, 2005

July/August 2004

Galaxy 10 R secondary XIPS failure

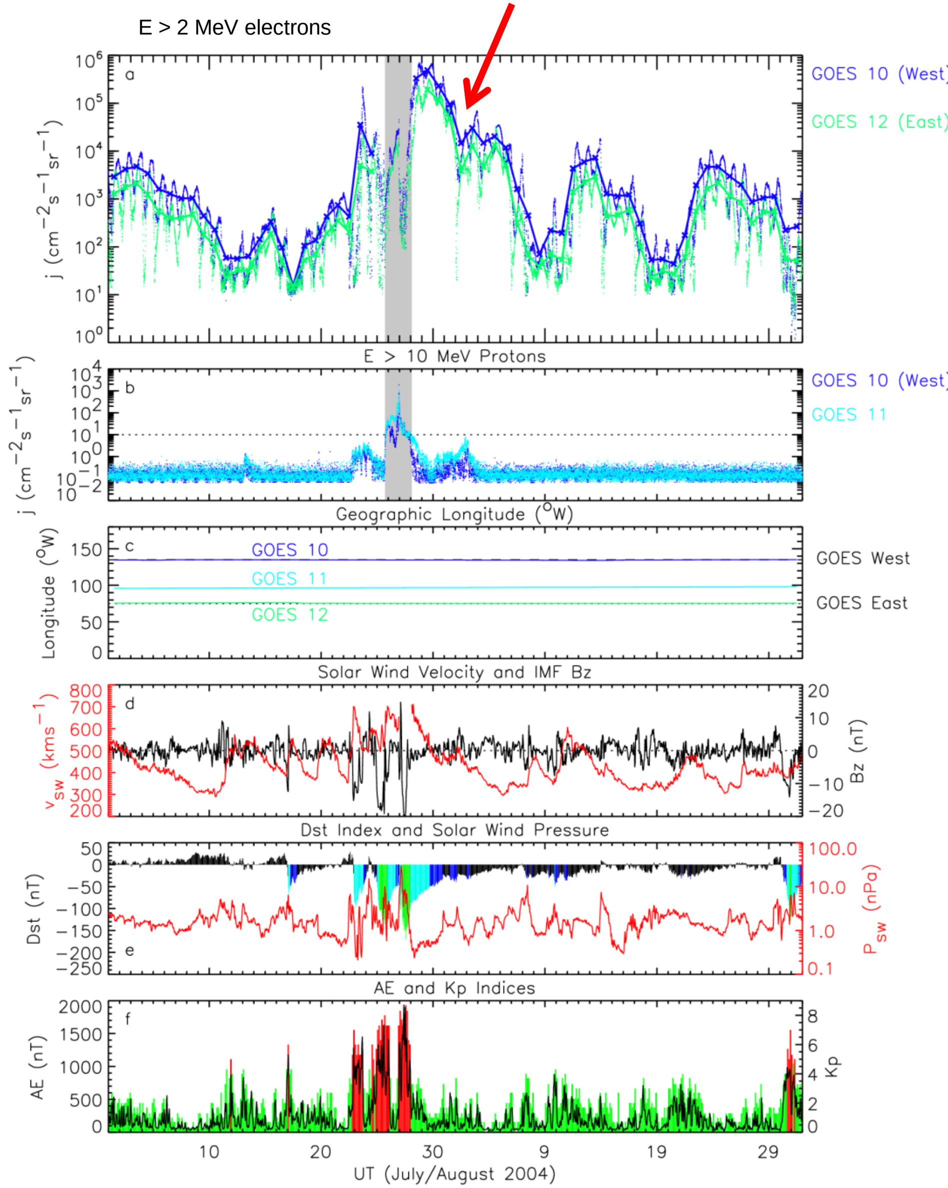


- On 3 August, during the extended period of enhanced E > 2 MeV electron fluxes, Galaxy 10R lost its secondary xenon ion propulsion system [Choi *et al*., 2011]
- This reduced its lifetime significantly resulting in an insurance payout of US $75.3 M

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, 1in 50 and 1 in 100 year event at GOES West are 1.84×10^5 5.00×10^5 and 7.68×10^5 $cm^{-2}s^{-1}sr^{-1}$ 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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