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Statistical Analysis of Extreme Electron Fluxes in the Radiation Belts

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Abstract. The main aim of this work is to study the frequency of extreme Space Weather events, in particular to analyse the tails of the daily averaged electron fluxes distribution function for different channels of energy between 0.249–1.192 MeV measured at $\sim$ 600 km of altitude with the particle detector ICARE-NG/CARMEN-1 on board argentinian polar satellite SAC-D. An extreme value theory was applied to estimate the maximum values of the electron flux in the outer radiation belt for different return levels. We found that the cumulative distribution function of the extreme electron fluxes presents a finite upper limit in (1) the core of the outer radiation belt for the lower energy channels and (2) in the inner edge of the outer radiation belt for energy channels larger than 0.653 keV. The results presented in this work are important to characterise Space Weather conditions.

Keywords. interplanetary medium, methods: statistical, (Sun:) solar-terrestrial relations

1. Introduction

The radiation belts were discovered in 1958 by van Allen. These regions in the terrestrial space environment present ions and energetic electrons (e.g., Prölss 2012) trapped by the geomagnetic field. In particular, the outer radiation belt populations present large variability in time and the fluxes can significantly increase, mainly during a geomagnetic storm, due to interplanetary plasma perturbations near Earth (e.g., Lugaz 2016). These suprathermal electrons can affect the satellite technologies in different ways depending on their energy. Electrons with energies of $\sim$ 100 keV can produce damage on the surface materials of the satellite (Koons & Fennell 2006). Larger energy electrons, a few MeV, can penetrate into the outer shield of the satellite and produce damage inside the spacecraft (Wrenn 2002). Thus, it is very important to have knowledge about extreme fluxes of energetic electrons for the development of new satellite technologies.

Koons (2001) and Meredith *et. al.* (2015) studied daily electron fluxes with energies larger than 2 MeV with GOES satellite and using the peaks over threshold (POT) method. Other analyses were done with the Maximum of Blocks method and for energies levels between some kev–MeV (e.g., O'Brien 2007 and Meredith *et al.* 2016).

In this work, we explore the extreme electron fluxes with energies in the range of 0.249 MeV to 1.192 MeV measured with the particle detector ICARE-NG on board the argentinian polar orbit satellite SAC-D. We applied the POT method in two regions of the outer radiation belt: the inner edge (L = 3.5–3.75) and in the core (L = 4.75–5), with L the McIlwain parameter. In the "Method" section, the extreme value analysis used to study the extreme electron fluxes in the outer radiation belt is described. In the

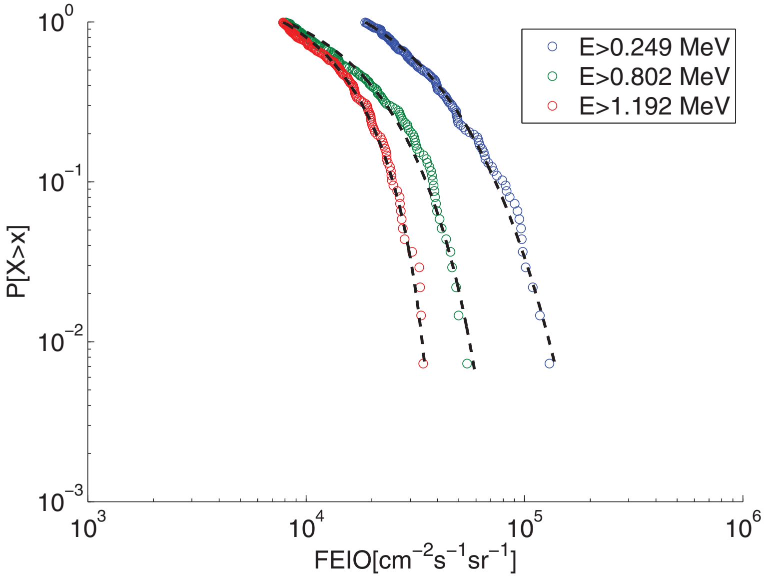

Figure 1. Extreme value analysis for three energy channels. Cumulative distribution from observations (circles) and associated fitted GP functions (dashed)

"Results" section we present the shape parameters that describe the distribution tails behaviour and the return levels for both radiation belts regions. Finally, we present the conclusions of this work.

2. Method

The extreme value theory is a statistical technique used for modelling and estimation of the tail distribution behaviour. In this work, the POT method is applied to daily averaged electron fluxes, measured by the particle detector ICARE-NG on board the argentinean satellite SAC-D during the whole mission (i.e., August/2011 to June/2015). Since the electron fluxes data have been contaminated by protons fluxes during solar proton events (SPE), we removed the data corresponding to SPE using the SPE list documented by NOAA (ftp://ftp.swpc.noaa.gov/pub/indices/SPE.txt). In particular, to study the extreme fluxes in the outer radiation belt, the threshold was defined for each energy channel and for each L value by the percentile 90% of the daily averaged electron flux. The extreme values series are reconstructed for 20 energy channels in the range of 0.249 MeV to 1.192 MeV and for the two regions in the outer radiation belt. In the case of the POT method, the appropriate function to fit the cumulative PDF of extreme events is the Generalised Pareto (GP) distribution (Picklands, 1975). We applied the maximum likelihood method to find the free parameters of the generalised Pareto cumulative distribution function, defined such as:

$$G_{(\kappa,\mu,\sigma)}(X) = \begin{cases} 1-\left(1+\frac{\kappa(X-\mu)}{\sigma}\right)^{-\frac{1}{\kappa}}, & \text{for} \quad \kappa \neq 0 \\ 1-\exp\left(-\frac{X-\mu}{\sigma}\right), & \text{for} \quad \kappa = 0 \end{cases}$$

where X is the random variable associated with the electron flux (FEIO), μ and σ are the location and scale parameters, respectively. The shape parameter, κ, describes the

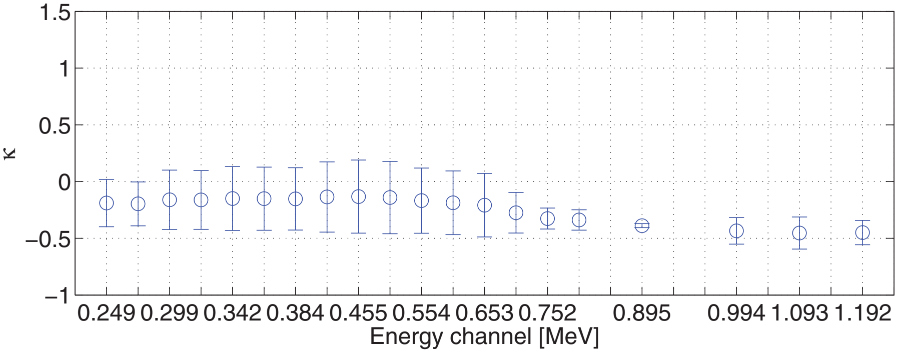

Figure 2. Shape parameter values (κ) for 20 energy channels (circles), and 95% interval confidence (bars) in the inner edge of the outer radiation belt ($L = 3.50$–3.75).

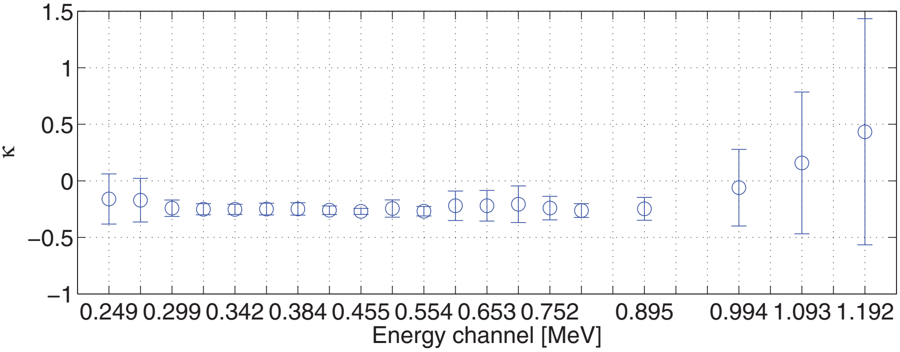

Figure 3. Same as Fig. 2 but in the core of the outer radiation belt ($L = 4.75$–5.00).

extreme behaviour of the distribution. The GP distribution has three basic forms depending on the value of the shape parameter: i) distributions whose tails decrease exponentially, such as the normal, lead to a GP shape parameter of zero, ii) distributions whose tails decrease as a polynomial, such as Student's t, lead to a positive shape parameter and iii) distributions whose tails are finite, such as the beta functions, as such as functions decaying as a power law, lead to a negative shape parameter (Coles, 2001).

The cumulative frequencies for three different energy channels in the inner edge of the outer radiation belt are shown in Figure 1.

3. Results and Conclusions

The shape parameter (κ) values and the 95% interval confidence for the 20 energy channels in the inner edge and in the core of the outer radiation belt are shown in Fig. 2 and Figure 3. It is observed in Figure 2 that for the higher energy channels ($E >$0.653 MeV to $E >$1.192 MeV) the shape parameter is negative with 95% confidence. While in the lower energy channels, it is not possible to determine the sign of κ. A different behaviour is observed in the core of the outer radiation belt (Figure 3). In this case the channels of lower energy (0.3 MeV$< E <$0.994 MeV) have values of κ significantly negative.

A statistical study of the extreme values of the daily averaged electron flux in the range of energies $E = 0.249$ MeV to $E = 1.192$ MeV in two regions of the outer radiation belt was carried out, using data from SAC-D between August/2011 and June/2015. Our results show a different behaviour in the interior and in the core of the outer radiation belt. For energies of 0.653 MeV$< E < 1.192$ MeV, an accumulated distribution of flows with finite upper limit was found at the inner edge of the outer belt. On the other hand, in the core of the outer radiation belt, κ presents significantly negative values in channels of lower energy ($E = 0.249$ to $E = 0.895$) MeV. The expected extreme value distribution for different energy ranges, as the ones studied here, will be useful for decisions makers. In particular, it will be very important during the design of satellites and new satellite technologies, according to the orbit location and to the potential damages on the devices on board produced by energetic particles, and considering different energy ranges.

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