Validating the BAS Radiation Belt Model with Giove-B satellite data

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Abstract The EU FP7 project SPACECAST uses the BAS Radiation Belt Model to forecast the high energy electron flux in the Earth's radiation belts and to provide an associated risk index for satellites in Earth orbit. Part of the project is model verification and this is particularly important in the heart of the Earth's outer radiation belt where the flux of energetic electrons are highest, and, potentially, most damaging. This is the region which is traversed by global positioning satellites such as the US GPS system and the developing European Galileo satellite navigation system. In this study we take output from version 1 of the BAS Radiation Belt Model and apply calibration curves to convert electron differential number flux to count rates which would be observed by SREM on Giove-B. We show comparisons of the SREM data with modelled count rates for L* > 4.5 for a geoeffective coronal mass ejection and a high speed solar wind stream.

1. BAS Radiation Belt Model

The BAS Radiation Belt Model is a physics-based model driven by the Kp index that includes the effects of:

- radial diffusion
- pitch angle and energy diffusion
- losses to the atmosphere
- collisions

The model solves a time-dependent Fokker Planck equation for phase space density (f)

- variables: equatorial pitch-angle (α), energy (E) and L* (L)
- the diffusion coefficients D_{LL}, $D_{\alpha\alpha}$ and D_{EE} are activity and location dependent

$$\frac{\partial f}{\partial t} = \frac{1}{g(\alpha)}\frac{\partial}{\partial\alpha}\bigg|_{E,L}\left(g(\alpha)D_{\alpha\alpha}\frac{\partial f}{\partial \alpha}\bigg|_{E,L}\right) + \frac{1}{A(E)}\frac{\partial}{\partial E}\bigg|_{\alpha,L}\left(A(E)D_{EE}\frac{\partial f}{\partial E}\bigg|_{\alpha,L}\right) + L^2\frac{\partial}{\partial L}\bigg|_{\mu,J}\left(\frac{1}{L^2}D_{LL}\frac{\partial f}{\partial L}\bigg|_{\mu,J}\right) - \frac{f}{\tau(\alpha,E)}$$

$$g(\alpha) = \sin 2\alpha(1.3802 - 0.3198(\sin\alpha - \sin\alpha^{1/2}))$$

$$A(E) = (E+E_0)(E(E+2E_0))^{1/2}$$

2. Giove-B Satellite Data

The data used in this study were collected by the Standard Radiation Environment Monitor (SREM) on board Giove-B. Giove B, which was launched on 26th April 2008, operated in a Medium Earth Orbit with an altitude of 23,200 km and an inclination of 56°. SREM consists of three solid state detectors designed to measure electrons with energies greater than 500 keV and protons with energies greater than 10 MeV. For the present study we use the count rates provided by the TC1 and TC3 channels which respond to electron energies greater than 2 MeV and 800 keV respectively.

3. Conversion of Model Flux to SREM Count Rates

The BAS Radiation Belt Model determines the electron differential number flux, j, as a function of energy, E, equatorial pitch angle, L* and time. We calculate the associated count rate, CR, that would be recorded in a given energy band, E_b, of a given SREM energy channel at a given position in space using the following expression:

$$CR = \int_0^{\pi/2}\int_{E_{bl}}^{E_{bu}} j(E,\alpha_l,L^*,t)\sin\alpha_l\, dE\, d\alpha_l \int_0^{2\pi}\int_0^{\pi} R(E_b,\theta,\phi)\sin\theta\, d\theta\, d\phi$$

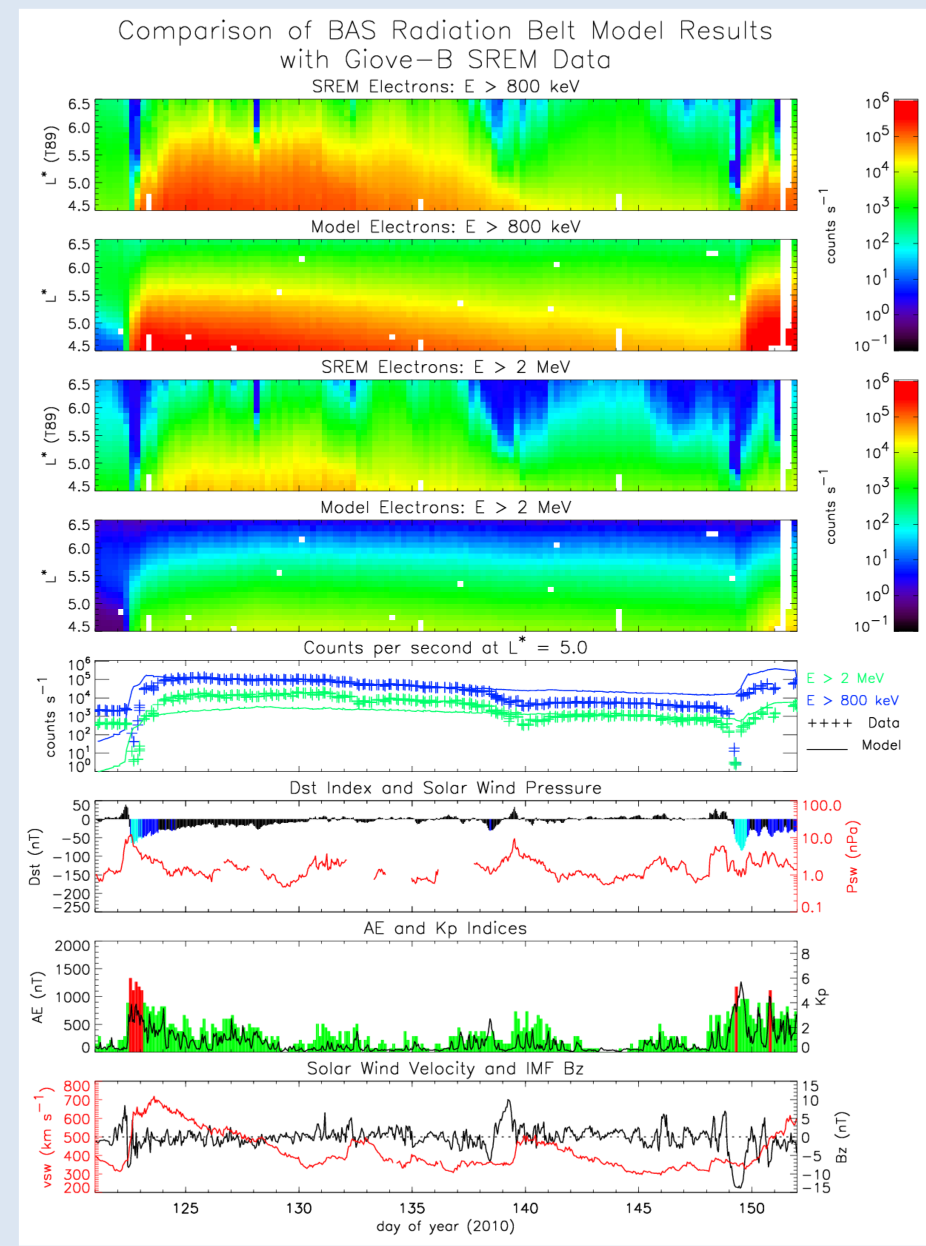
where α_l is the local pitch angle and R is the channel response function, which is itself a function of energy, azimuthal angle and polar angle.

For this study we used the response functions of the SREM instrument on Rosetta since the response functions for the SREM instrument on Giove-B have not yet been determined . The error introduced by using the response function for an instrument with different diode sensitivities is unlikely to be more than 20% which is acceptable for this preliminary study. The final count rate in a given channel is computed by summing the count rates in each energy band for each channel according to:

$$SREM(channel, r(t)) = \sum_{E1}^{E16} CR(E_b, r(t))$$

where r is the satellite position.

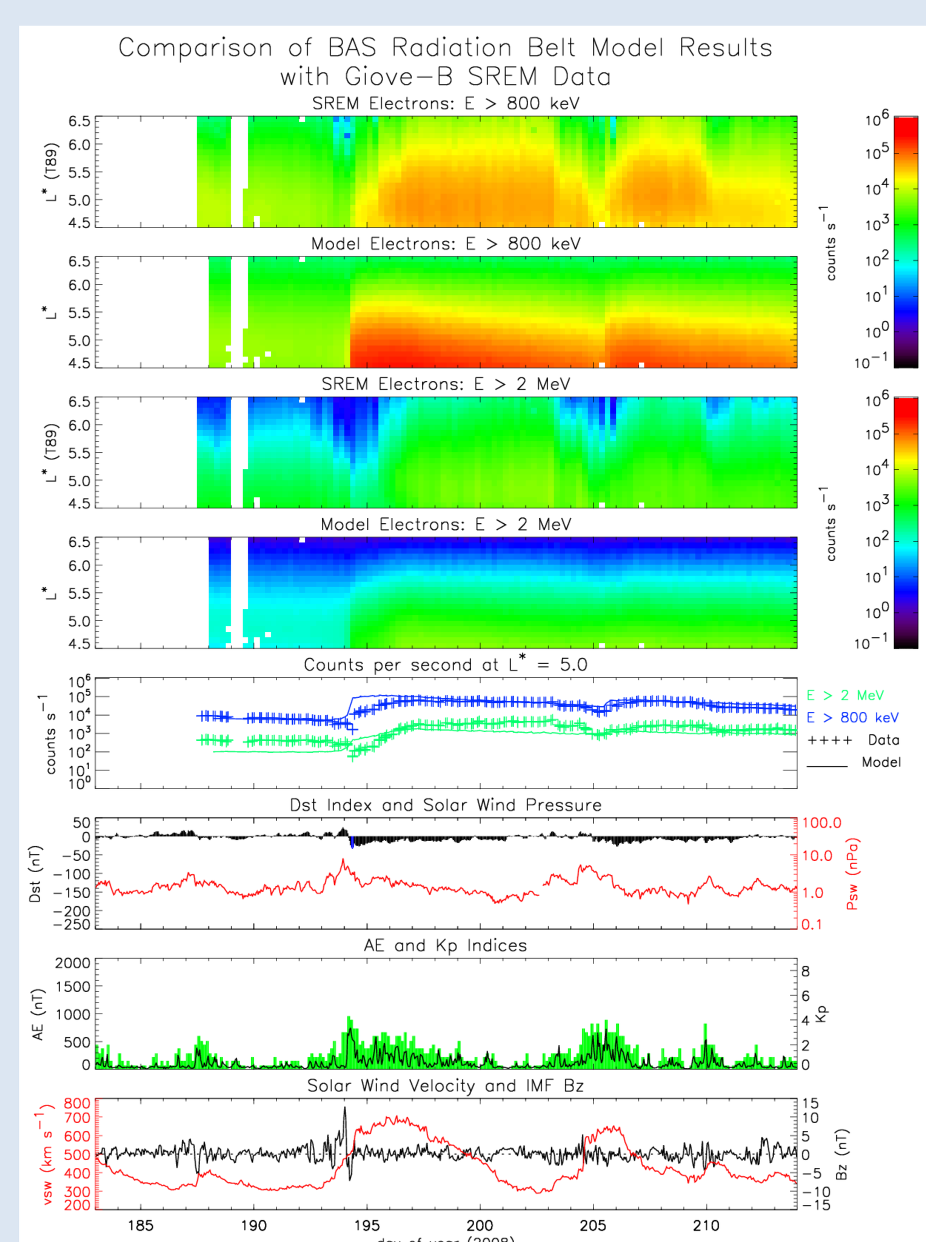
4. Geoeffective Coronal Mass Ejection



At L* = 5:

- SREM count rates of E > 800 keV and E > 2 MeV electrons increase during the storm recovery phase and exceed pre-storm levels by two orders of magnitude
- SREM count rates subsequently decay to pre-storm levels over the next 10-15 days
- For E > 800 keV electrons the model reproduces the peak storm time count rate and captures the gradual decay following the storm enhancement
- For E > 2 MeV electrons the model underestimates the peak storm time count rate

5. High Speed Solar Wind Stream



At L* = 5:

- SREM count rates of E > 800 keV and E > 2 MeV electrons increase during the storm recovery phase and exceed pre-storm levels by an order of magnitude
- SREM count rates subsequently decay over the next 7 days prior to the arrival of the next high speed stream
- For E > 800 keV electrons the model reproduces the peak storm time count rate but the model count rate rise more rapidly than the observed count rates

6. Conclusions

- We have developed a technique to convert the output of the BAS Radiation Belt Model to SREM count rates using instrument response functions
- Using version 1 of the BAS Radiation Belt Model and the Rosetta SREM response functions the model results show the same general trends as the data at L* = 5 but differences exist
- In the future we plan to use the Giove B SREM response functions and the most recent version of the BAS Radiation Belt Model to conduct a thorough validation of the model in the heart of the outer radiation belt

7. Acknowledgement

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