Development and validation of e-SRREM

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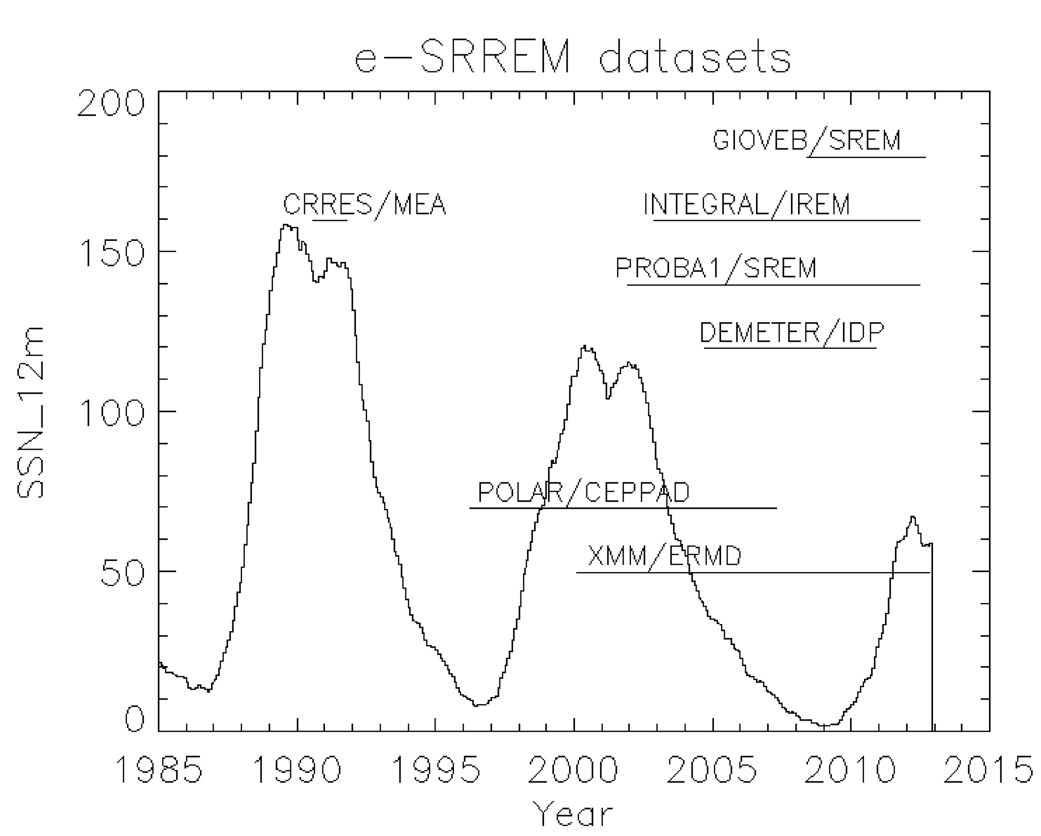
OUTLINE

The basic principles, main characteristics and validation results of electron Slot Region Radiation Environment Model (e-SRREM) are presented. The developed data-based statistical model addresses the variability of trapped electron fluxes in the region between the inner and the outer electron radiation belt. Electron fluxes in the slot region are highly dynamic and may vary by orders of magnitude on both short and long timescales. During quiet times, the particle fluxes are several orders of magnitude lower than those found at the peak of the inner and outer belts and the region is considered benign. During magnetic storms, though, this region can fill with energetic particles as the peak of the outer belt is pushed earthwards and fluxes can increase by several orders of magnitude. There has been a renewed interest in the potential operation of commercial and application satellites in orbits that are at least partially contained within the slot region. The developed model is based on the analysis of a large volume of available data. The analysis that we have followed retains the temporal, spatial and spectral variations at altitudes and inclinations relevant for satellites in the slot region. The output of the model provides mean, peak and particle fluxes determined by confidence level for a user define mission orbit and duration.

The datasets

A large number of radiation measurements from instruments onboard (mainly) European missions has been used for the construction of e-SRREM. Special emphasis was given on the process and analysis of ESA Standard Radiation Environment Monitor (SREM) radiation belt data [1] from the units on-board PROBA-1, INTEGRAL, and GIOVE-B due to their long temporal coverage. For the calculations of proton and electron fluxes from SREM measurements a dedicated technique was applied [2]. In addition, other datasets such as AZUR/EI, CRRES/MEA, XMM/ERMD, DEMETER/IDP and POLAR/CEPPAD were considered and processed. The database system that is used by e-SRREM is a local installation of the ESA Open Data Interface (ODI) database tool.



Temporal coverage of SRREMs datasets projected on the 12 month running average solar sunspots number.

Data process

We have adopted as magnetic coordinate system the Roederer's L^* value and the equatorial pitch angle α_{Eq} and we use the following grid to bin omni-directional electron differential fluxes $FEDO$:

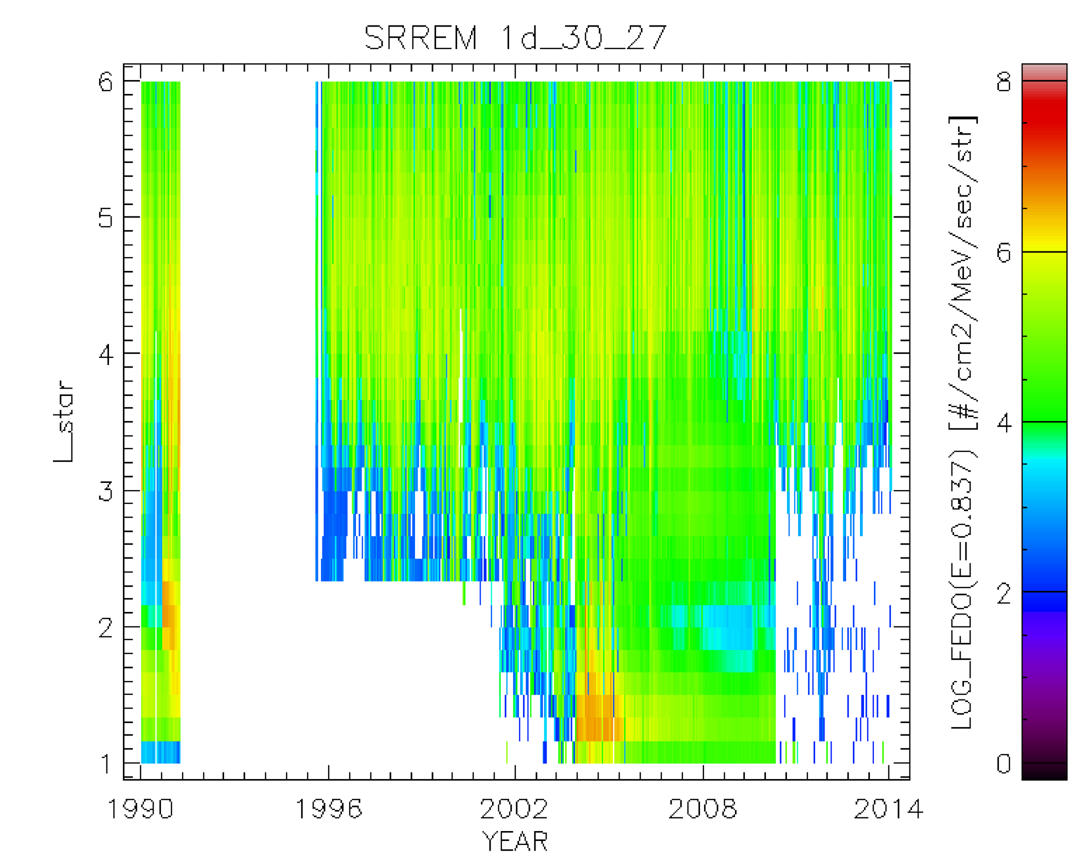
- 30 linear bins for the range of $L^* = 1 - 6$
- 27 bins for the range of $\alpha_{Eq} = [0 \rightarrow \pi/2]$ rads
- 7 log bins for the electron energy range $E_e = 0.1 - 7$ MeV
- log bins for the construction of the model $FEDO$ histograms.

The measurements of each dataset are binned into the SRREMs grid $(L^*,\ \alpha_{Eq})$ and the resulted time-series of differential fluxes are separated in time-windows of 1-day length. The daily data are averaged using as weighting factor the integration (accumulation) time of each measurement. As a result, we create virtual time-series of the mean, the standard deviation σ and the measurement time for each energy range of FEDO at each SRREMs magnetic hyperbin with resolution equal to the averaging time $\delta t = 1$ day. The average and the standard deviation values are then re-binned through a piece-wise power-law interpolation to the selected energy ranges.
For the cross-calibration of the selected datasets, we currently apply the following scheme:

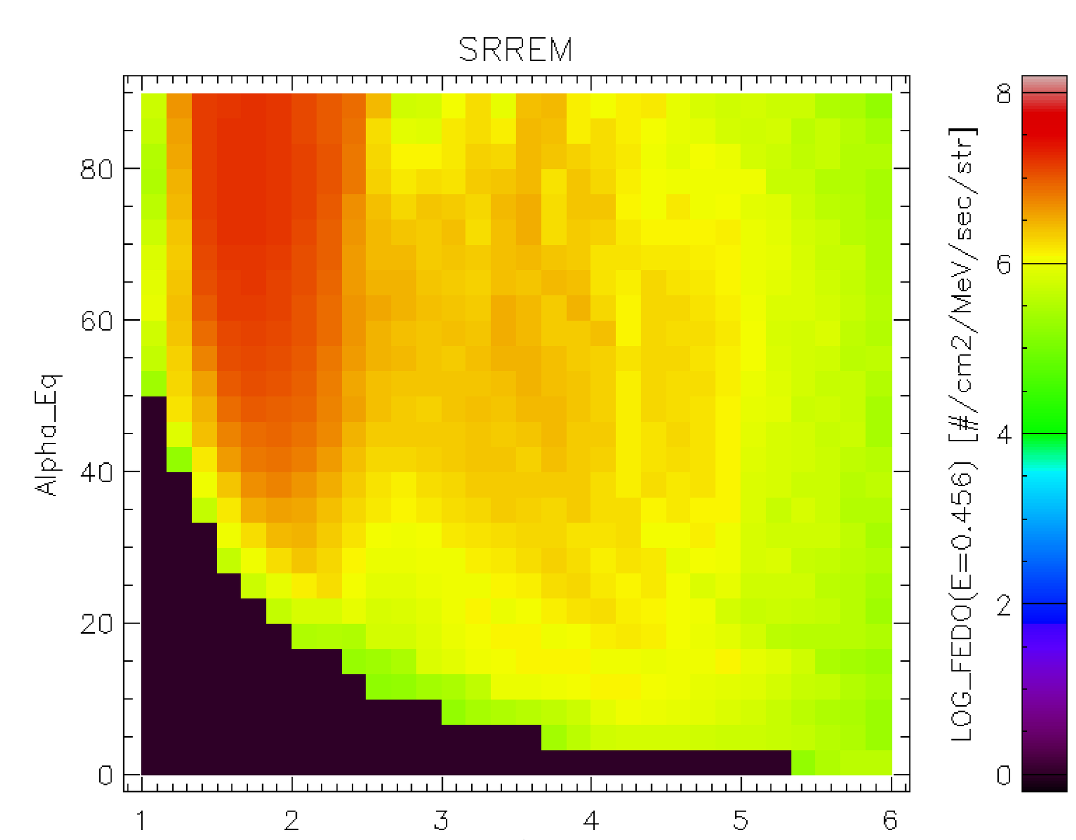
- Define "quite" space weather conditions: index $K_p < 2$ for 3 successive days)
- Choose CRRES/MEA dataset as reference calibration dataset
- Average all datasets in SRREMs grid for selected conditions
- Compare and calculate calibration factors

Construction of SRREMs synthetic database

The calibrated datasets are merged into a single virtual $FEDO$ series of time resolution equal to 1 day for each spatio-temporal bin $(t; L_i^*, \alpha_{Eq\ j})$ using as weighting factor the integration time of each dataset within the bin. Using the 1-day SRREM data series we construct data-series for larger averaging times in order to reflect the dynamics of the fluxes in model outputs.



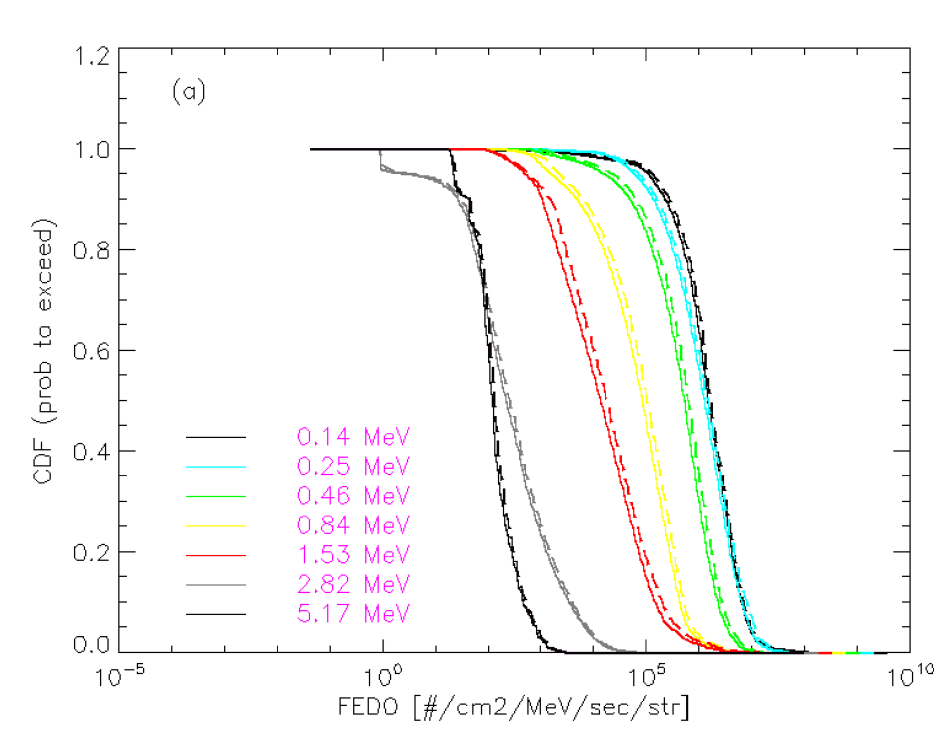
The resulting SRREMs FEDO dataset (averaged over α_{Eq}).



Time averaged SRREMs dataset projected on SRREM grid.

e-SRREM histograms and model outputs

Using the time averaged FEDO datasets, logarithmic histograms (of base 2) are constructed for each grid bin $(L_i^*, \alpha_{Eq\ j})$ and energy range for the selected averaging times. For a user defined satellite orbit and duration, the L^* and the α_{Eq} values are calculated. This permit us to derive "a flux orbit histogram" using the histograms *hist_FEDO* of e-SRREM grid the orbit crosses. The weighed summation is actually performed using as weighting factor the time the orbit spends in each grid bin $(L_i^*, \alpha_{Eq\ j})$.



Example of a CDF derived by e-SRREM model.

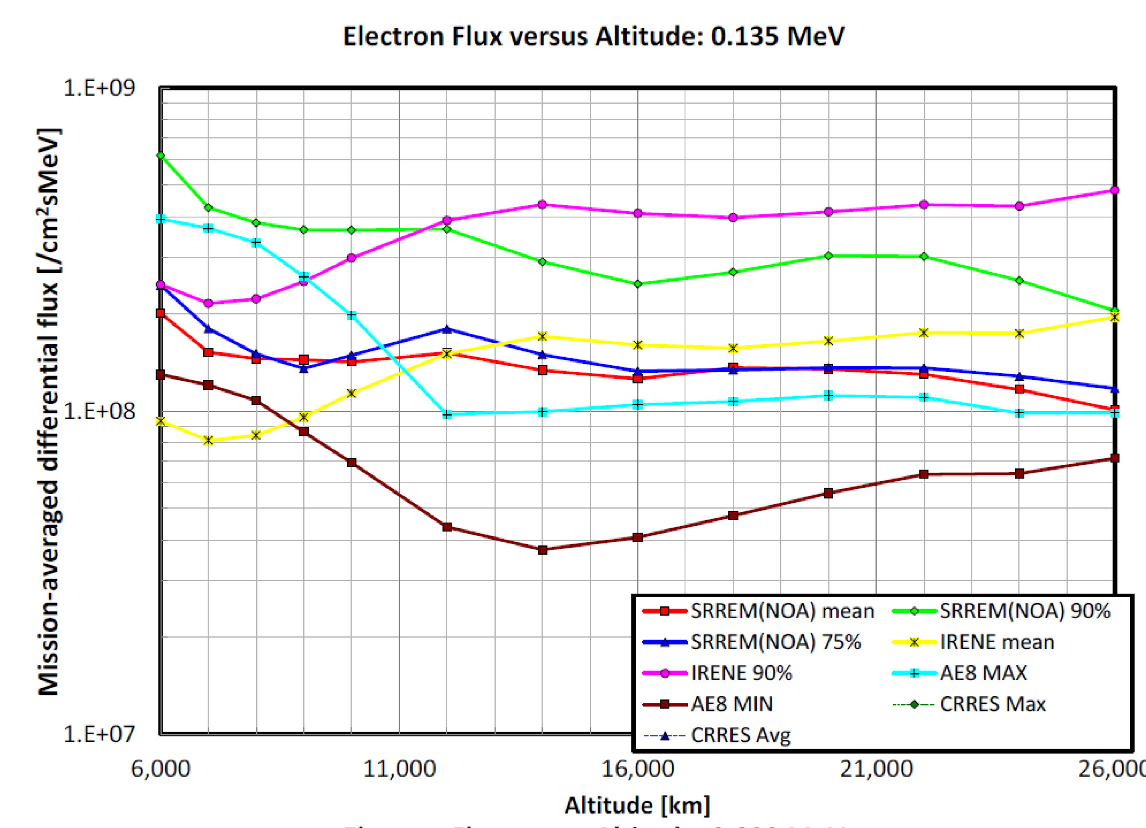
Using the analysis presented above, a cumulative distribution function (CDF) is calculated and the following outputs are provided:

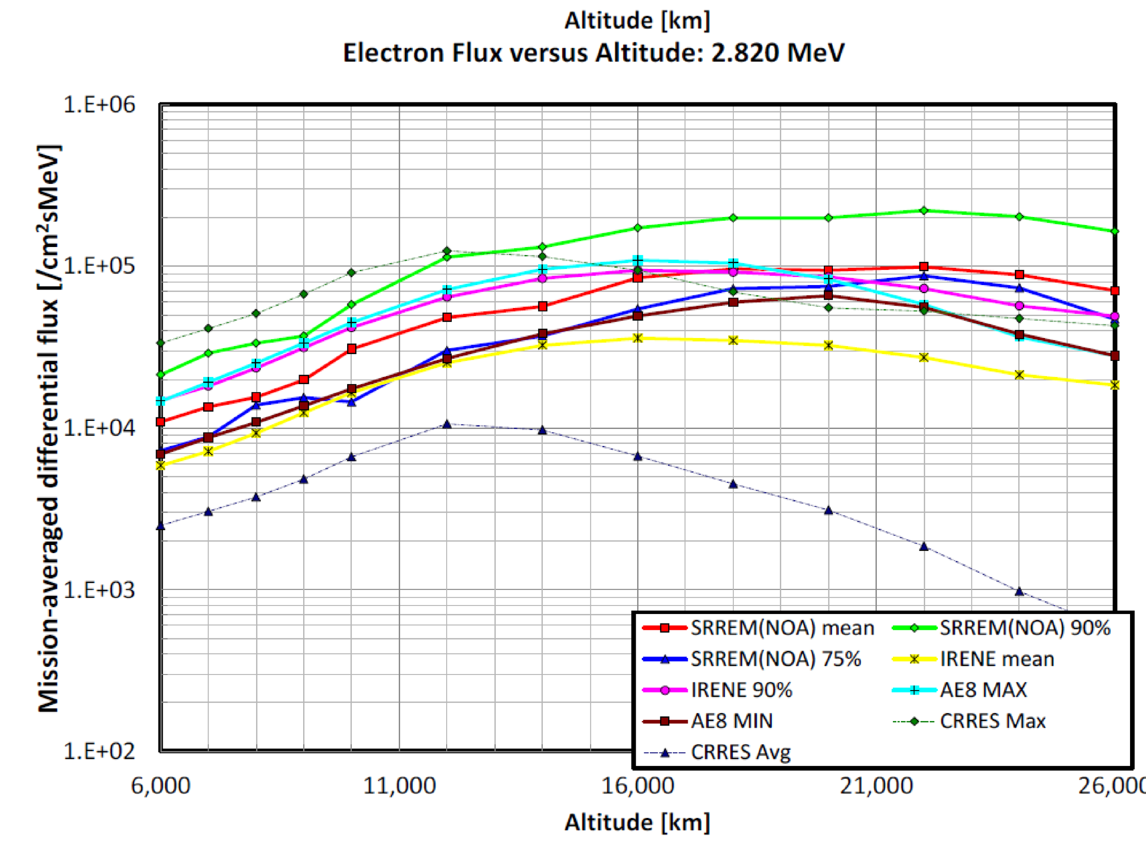
- The worst case max[FEDO(E)] value along the orbit.
- The FEDO values for user-defined percentiles.
- The percentiles for user-defined FEDO values.
- Same as above for fluence and integral flux values

The differences between the flux orbit histograms of different averaging times address the variability of trapped electrons for the considered orbit.

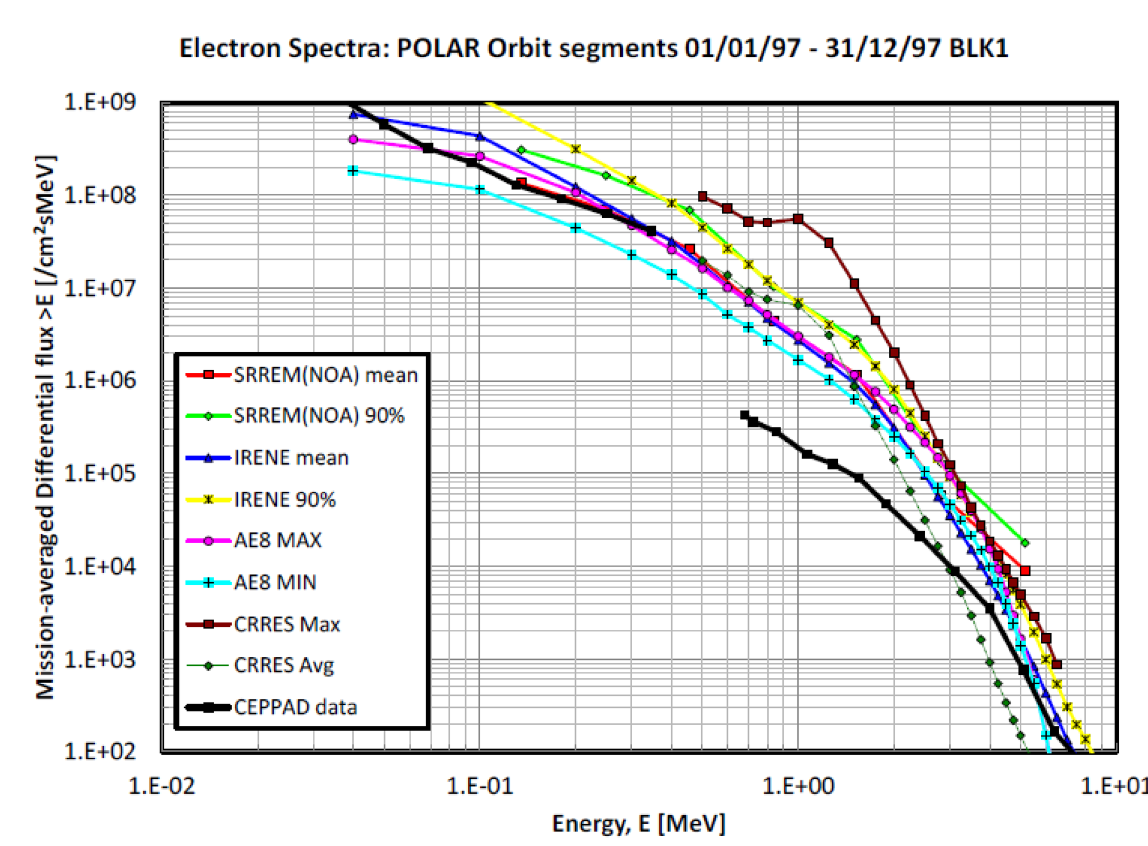
Validation studies

For the validation and verification of e-SRREM, a series of independent validation studies were performed. Comparisons were made with STRV1-D/CREDO-SURF, GIOVE-A/MERLIN-SURF, and POLAR/CEPPAD data. In addition comparisons were performed with established models such as AE8, IRENE/AE9 and CRRESELE.





Comparison of predicted FEDO for e-SRREM energy bins 0.135 MeV (upper plot) and 2.82 MeV (lower plot) as a function of altitude for 60 degrees inclination. Results are averaged over 0, 90, 180, and 270 degrees RAAN orbits.



Comparisons of predicted and measured mean FEDO spectra using Polar segments during 1997. The comparisons include results from AE8MIN, AE8MAX and CRRESELE.

The validation analysis identified the principal differences between the new and older models and provided recommendations for future model updates.

Conclusions

e-SRREM is a new data-based slot region radiation environment model. The confidence levels are calculated after the folding of the user defined orbit with the e-SRREM db. Using different averaging times, the model captures different temporal scales of RB dynamics. The construction and the update of SRREM database is semi-automated and permits the modelling region to be extended such that to include larger L-shells. The e-SRREM model will be hosted on ESAs Next Generation Space Environment Information System (SPENVIS-NG) platform and become available to all registered users.

References

[1] Evans, H.D.R. et al., *Advances in Space Research*, *42*, 1527–1537.
[2] I. Sandberg et al (2012), *IEEE Trans. Nucl. Sci.*, *59*, No. 4
[3] I. Sandberg et al (2014), *IEEE Trans. Nucl. Sci.*, DOI 10.1109/TNS.2014.2304982