Resolving Discrepancies in Electron Ring Current Models: The Importance of a Pre-Midnight Loss Process

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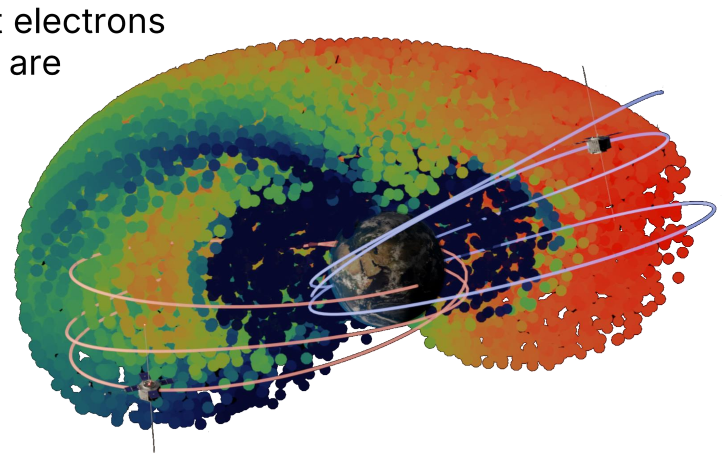
Motivation

During geomagnetic storms, surface charging effects occurring on satellites can damage their solar panels and electronics. To predict and mitigate these effects it is essential to understand the particle population causing these phenomena: the electron ring current.

In this work, we try to improve our understanding of the storm dynamics of the ring current electrons with energies of around 10 keV, which are an important factor for determining the surface charging effects.



Methods

Simplified VERB-4D simulations

VERB-4D solves for the transport of ring current particles while accounting for the loss to the atmosphere due to interactions with chorus and hiss waves:

$$\frac{\partial \bar{f}}{\partial t} = -\langle v_\varphi \rangle \frac{\partial \bar{f}}{\partial \varphi} - \langle v_R \rangle \frac{\partial \bar{f}}{\partial R} - \frac{\bar{f}}{\tau_{\mathrm{wave}}}$$

Empirical models are used to specify the input parameters:

Electric field:	Volland (1973), Stern (1975)
Magnetic field:	Tsyganenko (1989)
Boundary condition:	Denton et al. (2015)
Chorus lifetimes:	Wang et al. (2024)
Hiss lifetimes:	Orlova et al. (2014)

Calculation of precipitating flux

To calculate the precipitating flux from the simulations, we assume a steady-state solution of the local pitch-angle diffusion equation inside the loss cone:

$$j_{\mathrm{LC}}(\alpha_{\mathrm{eq}}) = N z_0 \frac{I_0\left(z_0 \frac{\alpha_{\mathrm{eq}}}{\alpha_{\mathrm{LC}}}\right)}{I_1(z_0)} \qquad z_0 = \frac{2\alpha_{\mathrm{LC}}}{\sqrt{\tau_{\mathrm{Bounce}}/\tau_{LT}}} \qquad N = \frac{j_{\mathrm{sim}}^{\mathrm{prec}}}{j_{\mathrm{LC}}^{\mathrm{prec}}\Big|_{N=1}}$$

The flux profile inside the loss cone is normalized by the total number of particles lost in the simulation for a given time step.

Fitting of empirical lifetimes

The empirical lifetimes were created by multiplying an energy-dependent factor to the lifetimes due to chorus waves.

$$\log 10(\tau_{\mathrm{empirical}}) = \log 10(\tau_{\mathrm{chorus}}) - \frac{a-E}{b}$$

The empirical lifetimes were found by manually adjusting the fitting parameters *a* and *b* while comparing the trapped population against Van Allen Probes measurements

Results

Ring current simulations for geomagnetic storms

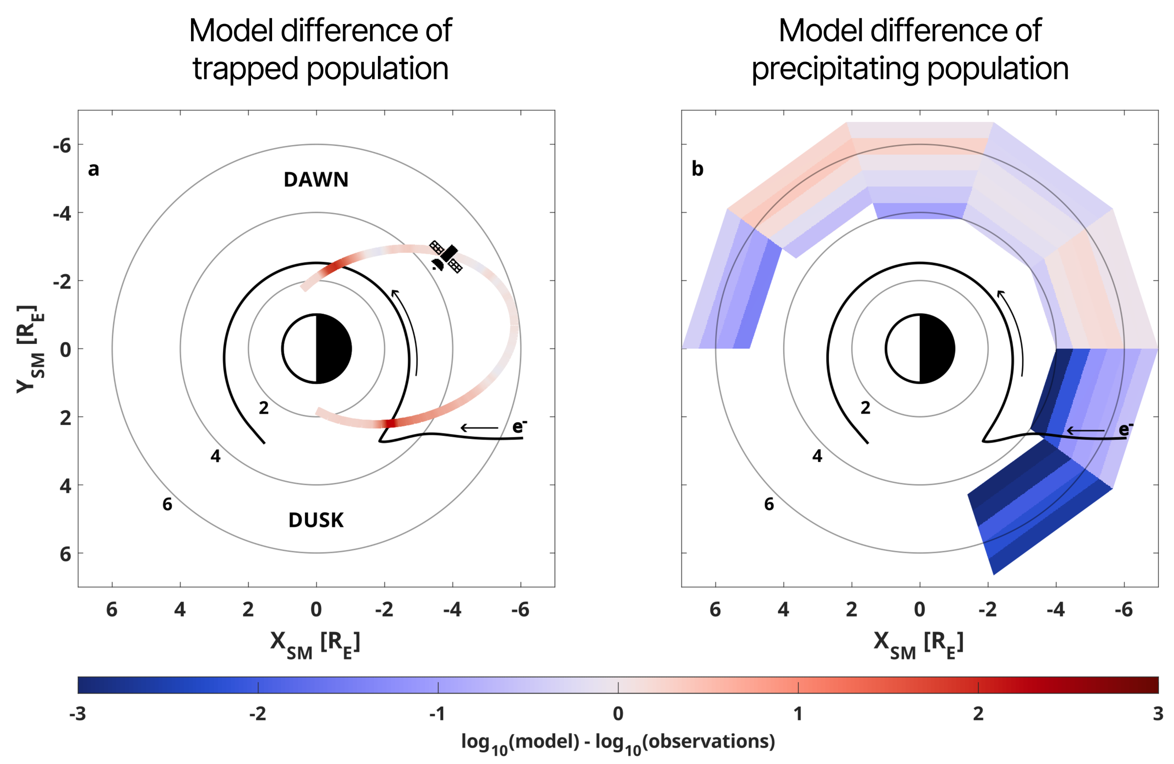


Fig. 1

Model errors observed during strong geomagnetic storms. (a) Overestimation of the trapped population compared to a Van Allen Probes satellite. The black path shows the drift trajectory of electrons. (b) Underestimation of the precipitating flux compared to the POES satellites.

Empirical lifetimes to estimate the missing loss

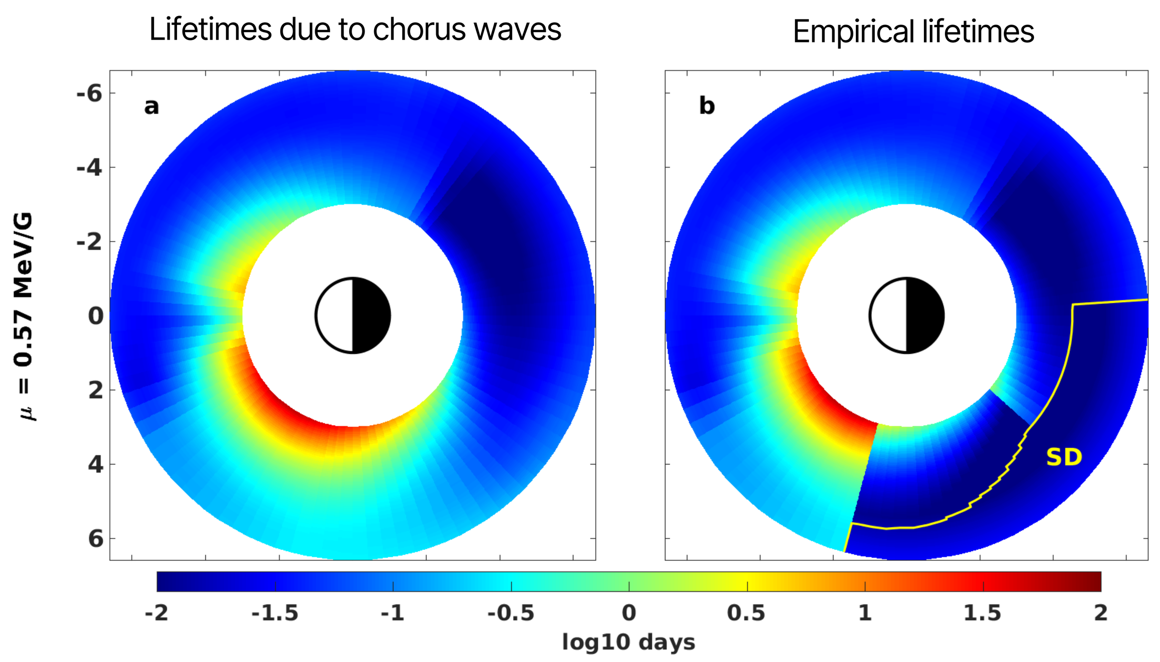


Fig. 2

Electron lifetimes for 1-10 keV electrons. (a) Original lifetimes due to chorus wave scattering. (b) Fitted lifetimes with increased loss in the pre-midnight sector

Simulations including the empirical lifetimes

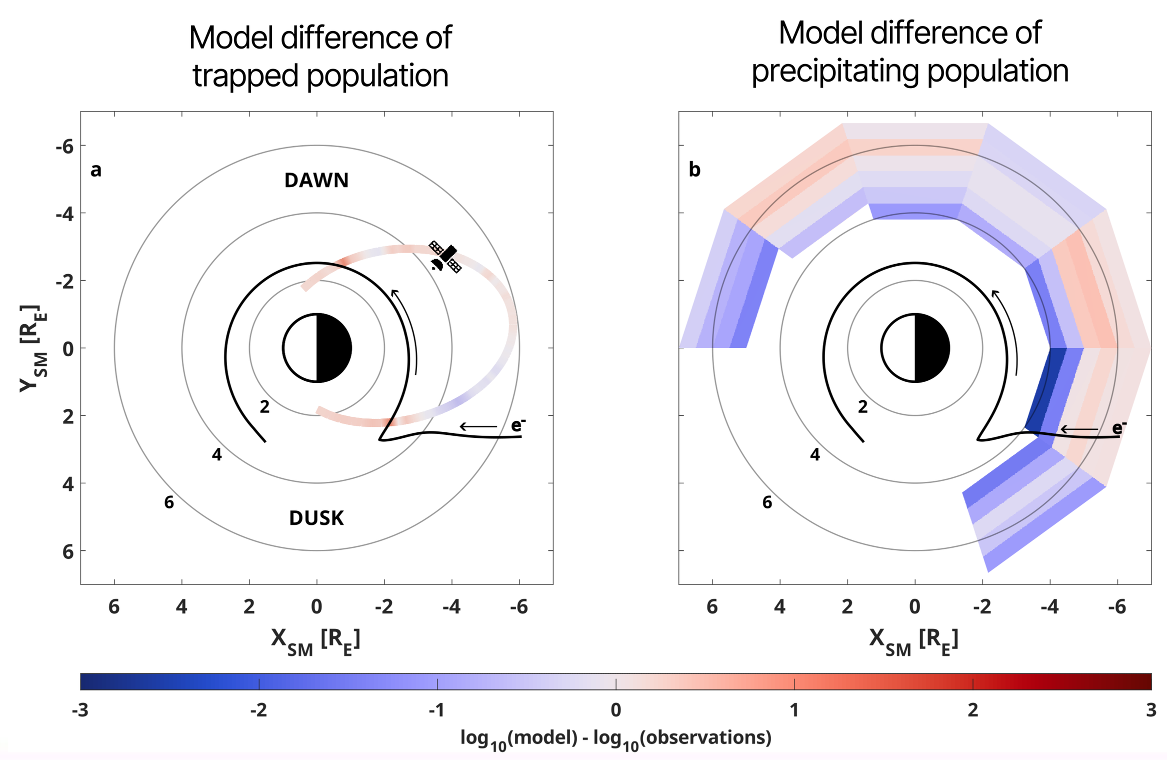


Fig. 3

Same format as Fig. 1, but now the model with increased loss in the pre-midnight sector is used.

Outlook

Possible physical explanations for the missing loss

Waves not accounted for in VERB-4D:

- Electrostatic Electron Cyclotron Harmonic (ECH) waves
- Time-domain-structures (TDS)

See X4.93

Potential inaccuracies in VERB-4D regarding electron loss:

- Average behaviour of chorus waves might be inaccurate during strong storms due to lack of statistics
- Changes in the cold plasma density are not reflected in changes of the electron lifetimes

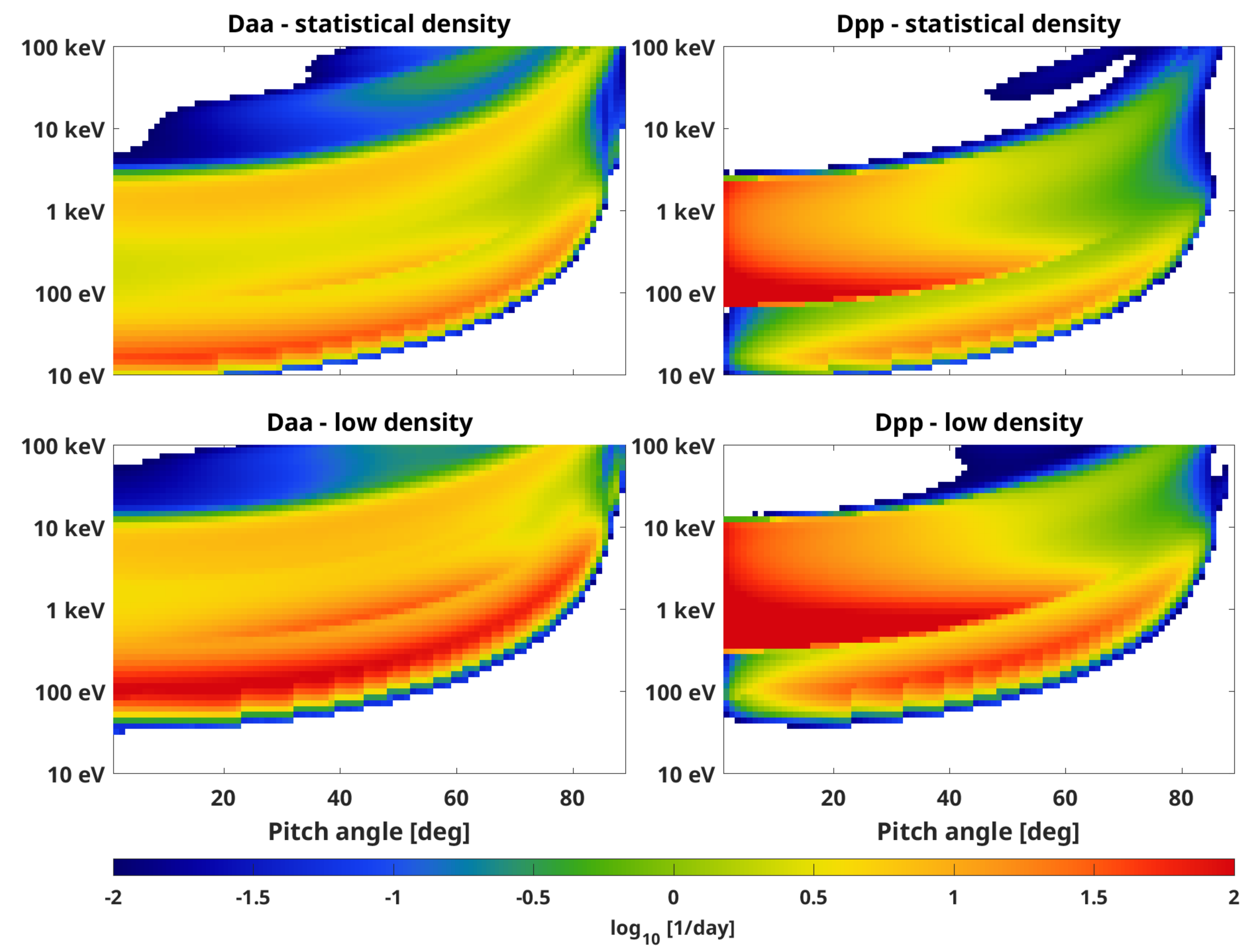


Fig. 4

Diffusion coefficients for average cold plasma conditions and depletions at L=4.5 and MLT = 21. Statistical density is calculated based on Sheeley et al. (2001) and low density is assumed to be a factor of 5 smaller than Sheeley.

Conclusions

- Increased loss in the pre-midnight sector is required to reproduce trapped and precipitating electron ring current fluxes between 10 and 50 keV
- The theoretical upper limit of electron scattering (strong diffusion) must be reached over a broad region
- Simulations including the variability of cold plasma density might be necessary

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Haas, B., Shprits, Y. Y., Allison, H. J., Wutzig, M., & Wang, D. (2023). A missing dusk-side loss process in the terrestrial electron ring current. *Scientific Reports*

Haas, B., Shprits, Y. Y., Himmelsbach, J., Wang, D., Drozdov, A. Y., Szabó-Roberts, M., & Hanzelka, M. (2024). Modeling Pitch Angle Dependent Electron Precipitation Using Electron Lifetimes. *Journal of Geophysical Research: Space Physics*

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