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Quantification of the Precipitation Loss of Radiation Belt Electrons Observed by SAMPEX

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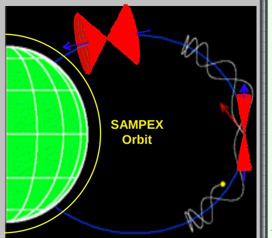
Abstract

Based on SAMPEX/PET observations, the rates and the spatial and temporal variations of electron loss to the atmosphere in the Earth's radiation belt were quantified using a Drift-Diffusion model that includes the effects of azimuthal drift and pitch angle diffusion. Three magnetic storms of different magnitudes were selected to estimate the various loss rates of ~0.5-3 MeV electrons during different phases of the storms and at L shells ranging from L=3.5-6.5 (L represents the radial distance in the equatorial plane under a dipole field approximation). Model results for a small storm, a moderate storm and an intense storm showed that fast precipitation losses of relativistic electrons, as short as hours, persistently occurred in the storm main phases and with more efficient loss at higher energies, over wide range of L regions, and over all the SAMPEX covered local times. Other properties of the electron loss rates such as the local time and energy dependence were also estimated. This method combining model with the low-altitude observations provides direct quantification of the electron loss rate, a prerequisite for any comprehensive modeling of the radiation belt electron dynamics.

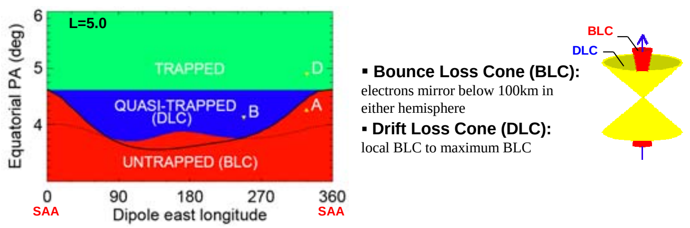
Background

- Electron precipitation into atmosphere [e.g., Millan and Thorne,2007]
  - Due to pitch angle scattering by plasma waves
  - An important loss mechanisms of radiation belt electrons
- To quantify the loss rate of Radiation Belt electrons is important for: [e.g., Shprits and Thorne, 2004; Summers et al., 2007]
  - Comprehensive models for radiation belt dynamics
  - Theoretical wave-loss studies
- However, **erratic electron lifetimes** used in RB models
  - Empirical, diverge by an order of magnitude [e.g., Barker et al., 2005]
- **Low altitude measurements** are most useful in determining the electron loss rate
  - Electron Bounce Loss Cone opens up at low altitude
  - **SAMPEX** (550×675 km, 82°) data have been continuously collected since 1992

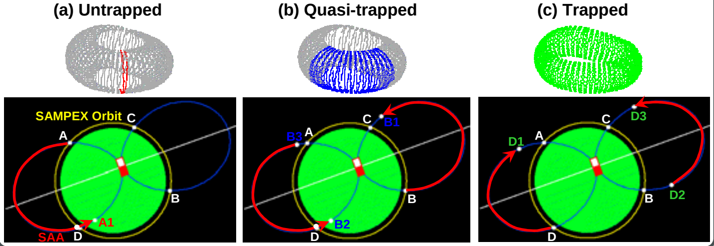


SAMPEX Data Geometry

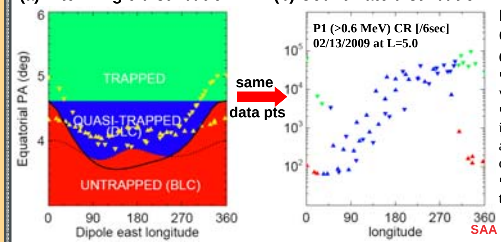
- The measured electrons by SAMPEX can be distinguished as **trapped, quasi-trapped** (in the Drift Loss Cone) **and untrapped** (in the Bounce Loss Cone).



- **Bounce Loss Cone (BLC):** electrons mirror below 100km in either hemisphere
- **Drift Loss Cone (DLC):** local BLC to maximum BLC



- SAMPEX crosses given L shell: 4 times/orbit, ~60 times/day



Panel (b) is a typical CR distribution for a quiet day:

- Trapped electrons (green) with the highest CR;
- DLC electrons (blue) increase eastward due to azimuthal drift; lost within one drift orbit in the SAA;
- BLC electrons (red) with the lowest CR.

- **The relative trapped and quasi-trapped intensities determine the loss rate**

Drift-Diffusion Model

- Developed by Dr. Selesnick [2003, 2004, 2006]
- Low-altitude electron distribution is a balance of pitch-angle diffusion, azimuthal drift and possible sources:

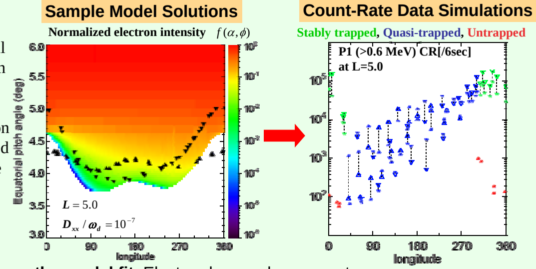
For given L and E : $$\frac{\partial f}{\partial t}+\omega_d\frac{\partial f}{\partial \phi}=\frac{\omega_b}{x}\frac{\partial}{\partial x}\left(\frac{x}{\omega_b}D_{xx}\frac{\partial f}{\partial x}\right)+S$$

$f(x,\phi,t)$: Bounce-averaged distribution function; $x=\cos\alpha_0$, α_0 : equatorial PA

$$S=S_0\tilde{E}^{-\nu}\tilde{g}_1(x)/p^2;\ D_{xx}=D_{dawn/dusk}\tilde{E}^{-\mu}\frac{1}{10^{-4}+x^{\sigma}}\quad (\tilde{E}=E/1\mathrm{MeV})$$

- Given parameterized D_{xx} and S, this Eqn can be solved to model the SAMPEX data

After locating all the data points in the simulation domain, the observed electron count rates (filled triangles) can be simulated (open triangles).



- **Outcomes from the model fit:** Electron loss and source rate

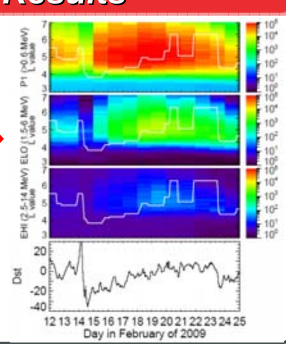
Event Study Results

- 3 different types of storms were selected
  - A small storm in 2009/02
  - A moderate storm in 2008/03
  - An intense storm in 2002/09

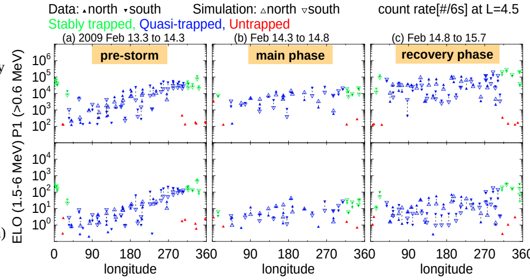
sample storm: 2009/02 storm

SAMPEX/PET daily averaged count rate

(White curves: Lpp based on an empirical model [O'Brien and Moldwin, 2003])



- All the storm phases were simulated
  - Pre-storm, main phase, recovery phase
- 4 different L regions were simulated
  - L=3.5, 4.5, 5.5, 6.5
- The **temporal and spatial variations of electron loss/source rates** during each storm event were quantified

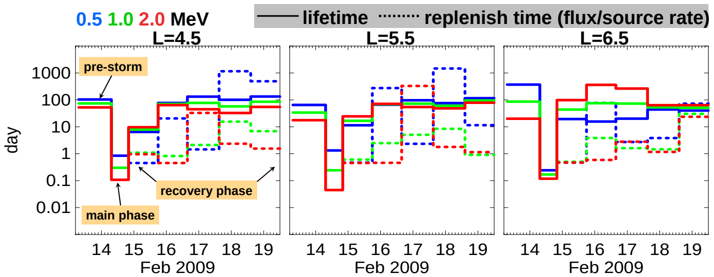


- **Storm main phase:**
  - Trapped flux greatly decreased, more significantly for higher energy electrons.
  - DLC electrons flatly distributed, comparable to trapped flux

  ⟹ strong PA diffusion
- **Recovery phase:**
  - Trapped electron flux increase back and even to a higher level later (not shown)

  ⟹ active source

- From above comparisons, the variations of both trapped and quasi-trapped electrons were well-simulated by our model. Based on the best fit from our model, some model outcomes are shown below:



- **Pre-storm quiet time**: Electron lifetime above 10 days for all energies at L=4.5-6.5.
- **Main phase**: Loss rate was significantly faster; higher energy electrons with shorter lifetimes (e.g., on the order of hours for >2 MeV electrons over broad L regions).
- **Recovery phase**: Loss rates quickly returned to low values; source started, generally faster than loss.

Summary and Conclusions

- **Common features on the electron loss rate**
  - **Loss was always the fastest during the storm main phases**
  - With **more efficient loss at higher energies** (quick scattering processes functioning preferably on higher energy electrons)
  - **Lifetimes for the high energies can be as short as hours** for the small and moderate storms and minutes (strong diffusion) for the intense storm
  - **Fast losses occurred over wide L regions** around the peak electron flux location
- **Local time dependence in loss rate** resolved from D_{dawn} and D_{dusk}
  - Significant dawn/dusk asymmetry: e.g. D_{dawn}/D_{dusk}=1000, main phase of 2009/02 storm, L=5.5
- **Merits of our model**
  - Direct quantification of the electron precipitation loss rate by low-altitude electron data
  - To determine the spatial and temporal variations of electron losses
  - Applicable to the particle tracing code, the RB dynamics model, theoretical wave-loss study etc.

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Acknowledgment: This work was mainly supported by NASA/LWS/RBSP grants.