Bounce and Drift Invariants from the Rice Convection Model-Equilibrium Versus Empirical Magnetic Models: A Test of Stormtime Electron Observations by the Van Allen Probes

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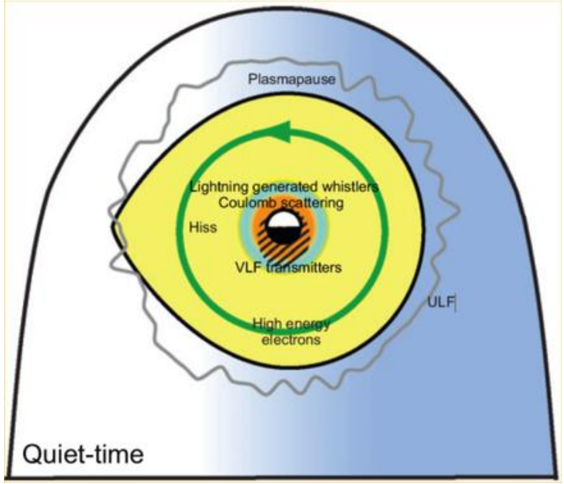
Relativistic Electron Transport, Acceleration, Loss

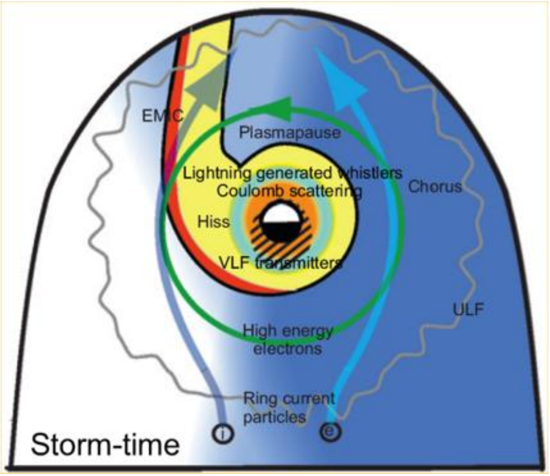
- Competing processes are radial diffusion by ULF waves, and acceleration/loss due to whistler-mode and EMIC waves (see figures from Shprits et al 2009)

- Processes should occur outside plasmapause (~4-6 Re) which dramatically contracts during storm main phase

- Storm recovery causes plasmasphere to expand back to quiet configuration

- Outward radial shift in acceleration and loss processes should be visible in electron populations





Graphic adapted from Sprits et al 2008, J. Atmos. Solar-Terr. Phys., doi:10.1016/j.jastp.2008.06.014

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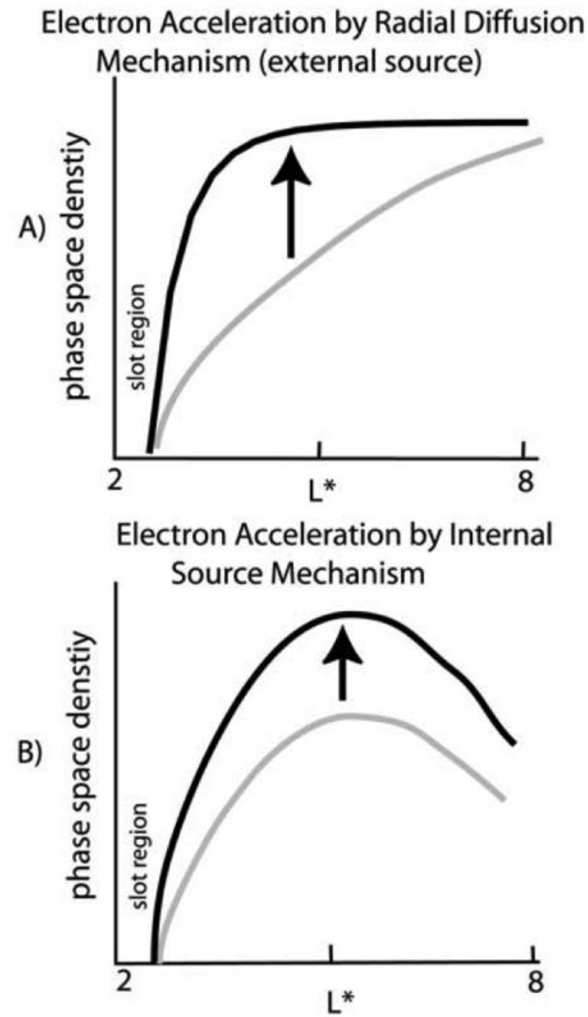
Radial Profiles of Electron Phase Space Density (PSD)

- Radial diffusion conserves first two adiabatic invariants M and K, so these form a set of canonical coordinates for electron analysis
- Analyze by plotting radial profiles of PSD versus L* at constant M and K
- Green and Kivelson [2001; 2004] showed peaks in profiles of Polar electron PSD at high K
- Growing peaks cannot be due to radial diffusion alone and must be connected to acceleration or loss via pitch angle scattering by waves.
- Calculation of L* and K are very dependent on magnetic field models because they are a global integration
- RCM-E simulations of storms may provide improved magnetic field models that match observations [Chen et al. 2012] and could improve L* and K estimates



Graphic adapted from Green and Kivelson 2004,
J. Geophysics. Res., 109, A03213, doi:10.1029/2003JA010153

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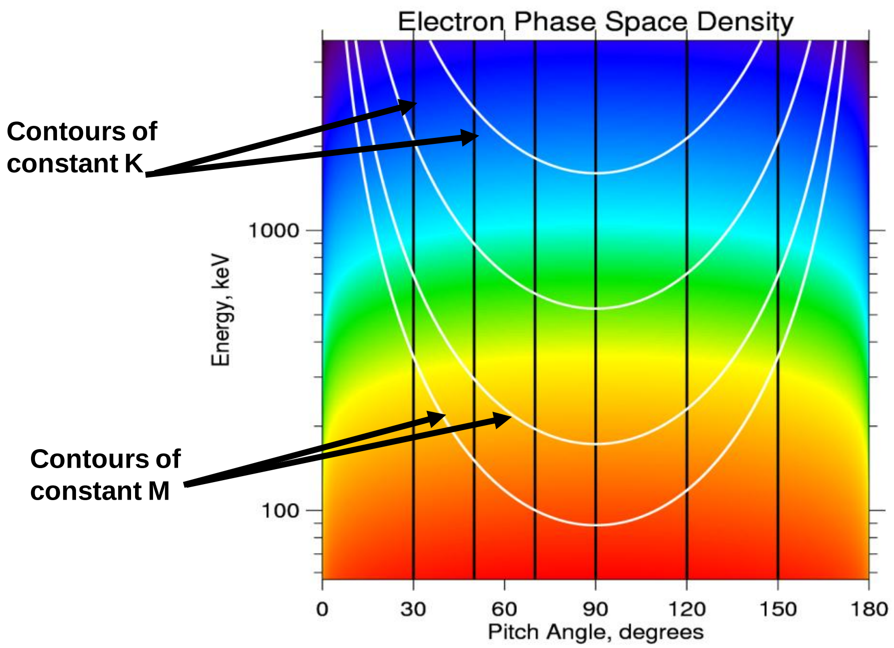
Mapping from Energy and Pitch Angle to Magnetic Moment and Bounce Invariant

- Bounce invariant, K independent of energy so contours of constant K are vertical
- Magnetic Moment, M mixes energy and pitch angle
- Rapid falloff with energy masks angular variations
- Radial gradients of PSD at constant M and K are almost flat compared to the steep falloff of the flux energy spectrum



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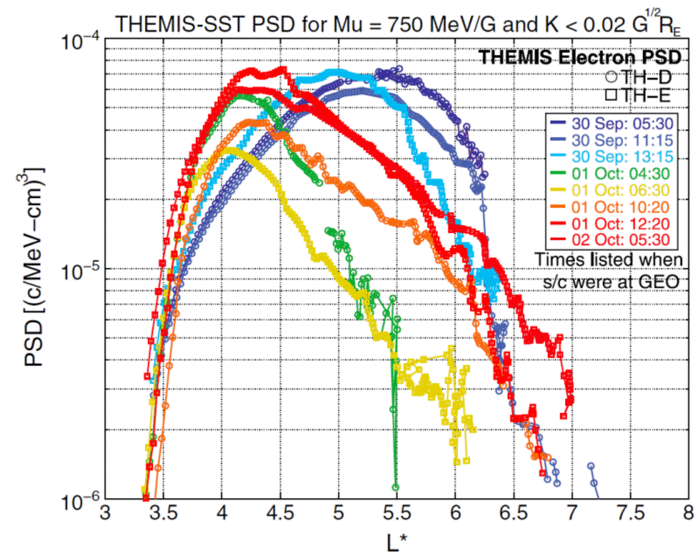
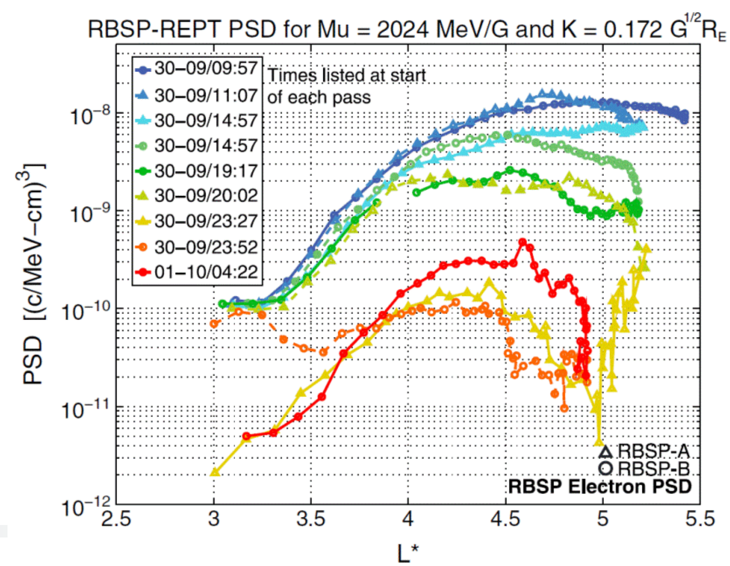
Electron Phase Space Densities at Constant M and K

- Example PSD radial profiles in L* at constant M and K from THEMIS and the Van Allen Probes for the storm of Sept 30, 2012 [Turner et al. 2014]
- THEMIS profiles at low M and small K show dropout of electrons and rebuilding at lower L*
- Van Allen Probe data at high M and K exhibit decrease of flux and rebuilding without radial inward shift
- Concludes that peaks at L* ~ 4.5 are due to acceleration by EMIC waves





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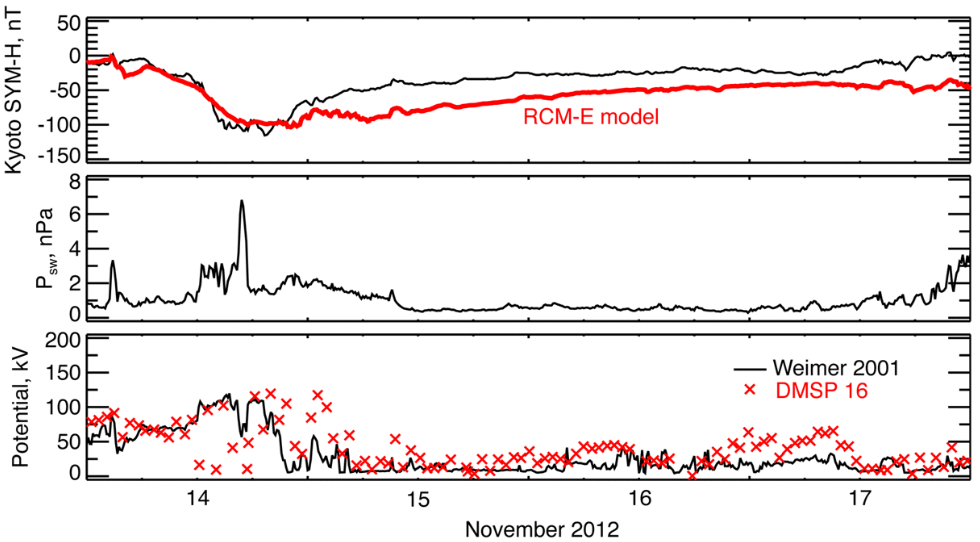
Focus on November 14, 2012 Geomagnetic Storm

- Large storm with a minimum SYM-H of –115 nT and a 12-hr main phase

- The model and observed SYM-H agree very well during the storm main phase, but not as well during the recovery phase. The RCM-E shows a slower recovery than the real magnetosphere.

- Comparison between Weimer 2001 potentials and cross polar cap potentials measured by DMSP show that Weimer potentials used in boundary conditions are similar magnitudes.



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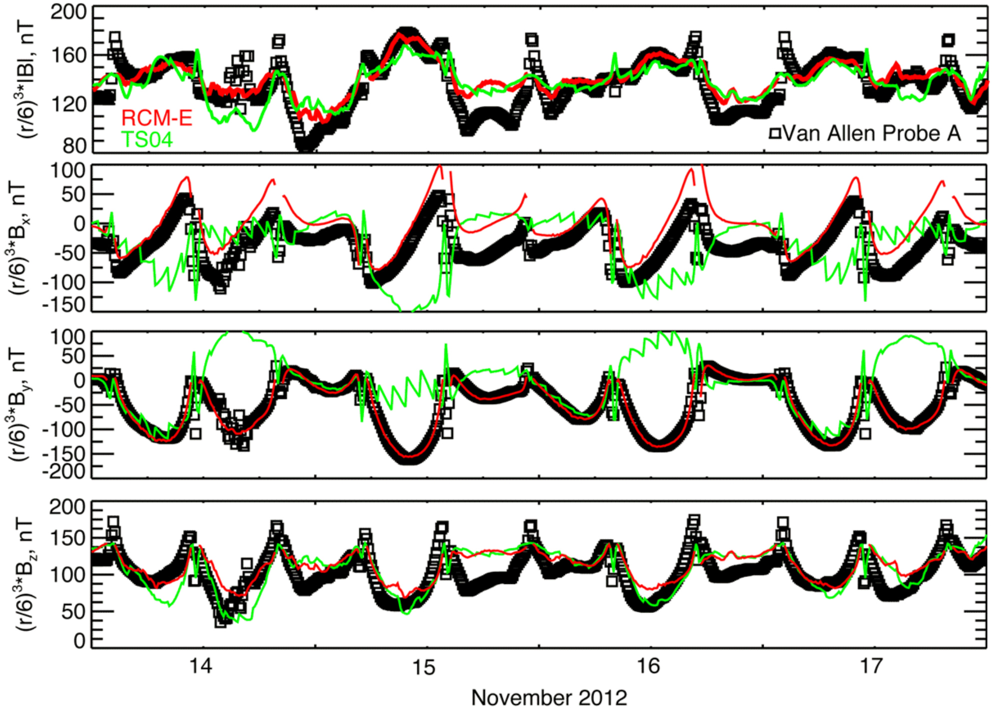
Comparison of Van Allen Probe Magnetic Fields with RCM-E Model

- Probe A's apogee is at geocentric distance r ~ 1.1 RE and perigee is at r ~ 5.8 RE. It passes through the heart of the radiation belts and ring current several times during this event.



- The RCM-E agrees with Probe A magnetic field components better than TS04 particularly for the y-component.

- Refinements in the description of the IGRF dipolar field in the RCM-E code may lead to improved agreement between RCM-E and measured B_x and B_y when near apogee.

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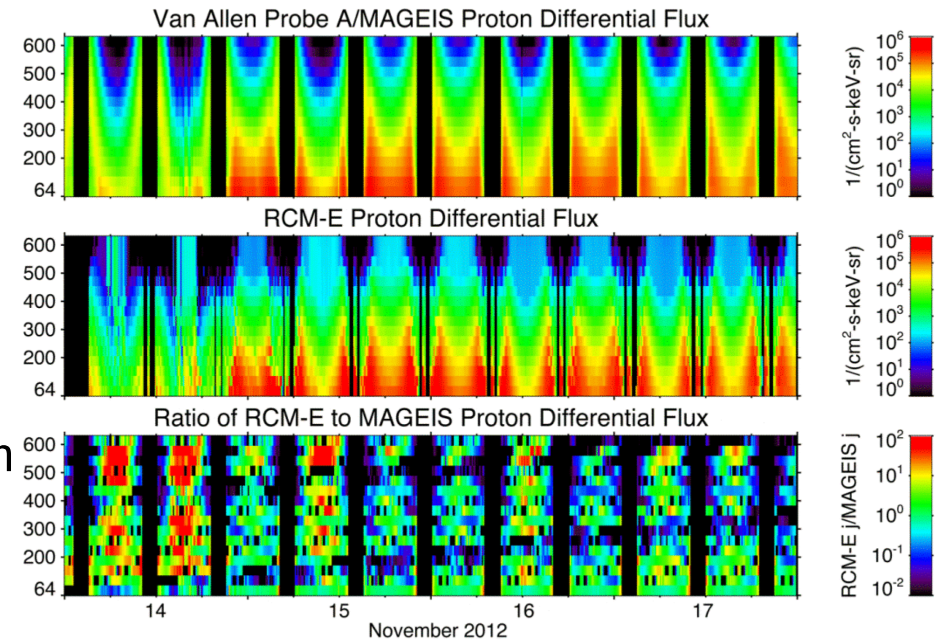
Comparison of Van Allen Probe Proton Observations with RCM-E Model

- The spectrograms show proton differential flux from Probe A, RCM-E, and the ratio of RCM-E to Probe A. Observations taken at r < 3 may be contaminated by background high-energy particles (not shown).
- During the storm main and early recovery phases, proton fluxes below ~300 keV are enhanced from pre-storm levels. Farther out at r ~5.8 RE, the most intense proton fluxes occur at lower energies than r~3-5 RE.



- The RCM-E tends to overestimate proton fluxes at higher energies. This is due mainly to over simplified specification of a constant k parameter in proton boundary spectra.

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L* and K Calculation Using RCM-E

- Preliminary comparison of the RCM-E model with Van Allen Probe data shows that the RCM-E reproduces fairly well the observed stormtime magnetic field, particularly at r ~3 to 5 RE where the geomagnetic field is distorted by the ring current field.

- Use of the RCM-E model magnetic field for computation of L* and K may improve the phase space density analysis of radiation belt particles, especially during the main phase of geomagnetic storms where empirical magnetic models do not match observations

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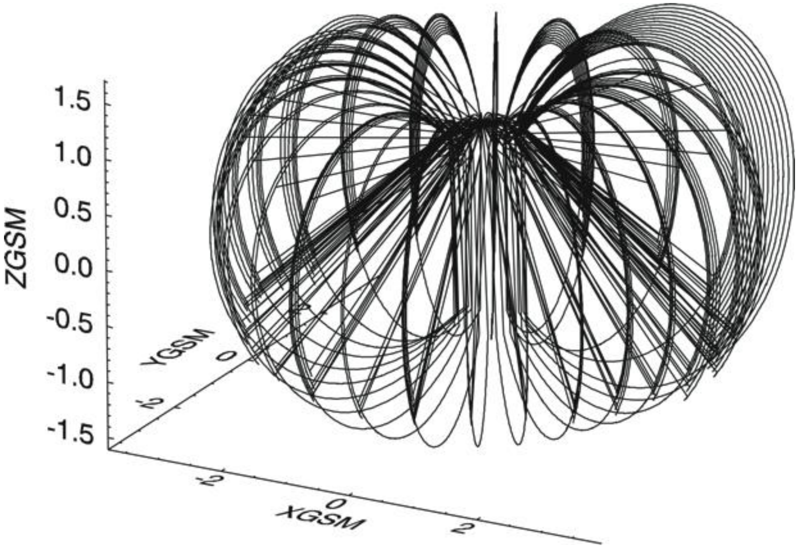
L* and K Calculation Using IRBEM-LIB 4.4

- Calculation of L* and K is a global integration, even for a single observational point
- The figures show in perspective the 80,000 GSM positions at which the model magnetic field is needed to compute L* and K for a single point and pitch angle.
- Traces out particle drift path in local time by searching for field lines that preserve the particle mirror point magnetic field magnitude and K [Roederer 1970]



- Integrates over the polar cap to obtain the magnetic flux Φ, enclosed by the drift path and converts to equivalent L*
- Alternatively, L* may be computed with a neural net created for a particular empirical field model [Yu et al., 2012]

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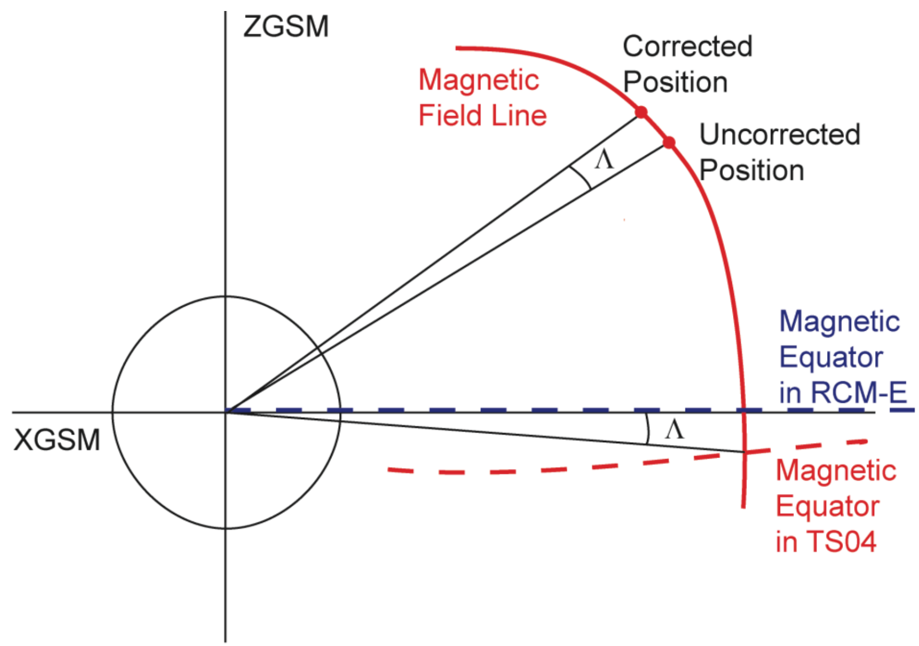
Correction for tilt of Earth's internal field

- RCM-E model magnetic field contains no tilt of the Earth's dipole component so that the magnetic equator is on the Z = 0 plane
- Comparison with observations in the inner magnetosphere requires a tilt correction [Chen et al. 2012]
- Trace along field line in TS04 model to magnetic equator (minimum B surface)
- Compute latitude of equatorial point in GSM coordinates
- Trace along field line in RCM-E model to corrected point with similar latitude difference to the magnetic equator
- Comparison of model field with magnetometer observations give favorable results for several storms



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Summary

- RCM-E model magnetic fields match satellite observations during geomagnetic storms, especially during the main phase at L ~ 3-5 in the heart of the ring current region

- Better fidelity magnetic field models can help improve computational estimates of the second and third adiabatic invariants, L* and K, that are used in phase space density analyses of relativistic radiation belt electrons

- More accurate invariant computations may help resolve problems in radiation belt dynamics during storms. In particular, the dropout of electron flux during the storm main phase could be better explained with improved analysis of radial diffusion.

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