Relationships Between Core Radiation Belt Electrons and Seed Populations: *Estimates of Total Radiation Belt Electron Content (TRBEC) Components and Their Time Evolution using RBSP-ECT Data from the Van Allen Probes Mission*

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Geospace Revisited: a Cluster/MAARBLE/Van Allen Probes Conference
15 September 2014
Island of Rhodes, Greece
"Radiation Belts and Ring Current – The Energetic Geospace"

Overview and Motivation

- Understanding the relative importance of radiation belt enhancements and decreases relies on a quantitative assessment of the state of the belts before and after and event
- For instance, estimates of belt loss through precipitation only become meaningful when compared to the total belt population
- Previous studies have used observations to quantify the total number of energetic electrons in the Van Allen belts
  - Baker et al. (2004) used measurements from the low altitude SAMPEX mission to estimate the radiation belt content

Pioneering TRBEC Estimates

Baker, D.N., S.G. Kanekal, and J.B. Blake (2004), Characterizing the Earth's outer Van Allen zone using a radiation belt content index,

Space Weather, DOI: 10.1029/2003SW000026.

Characterizing the Earth's outer Van Allen zone using a radiation belt content index

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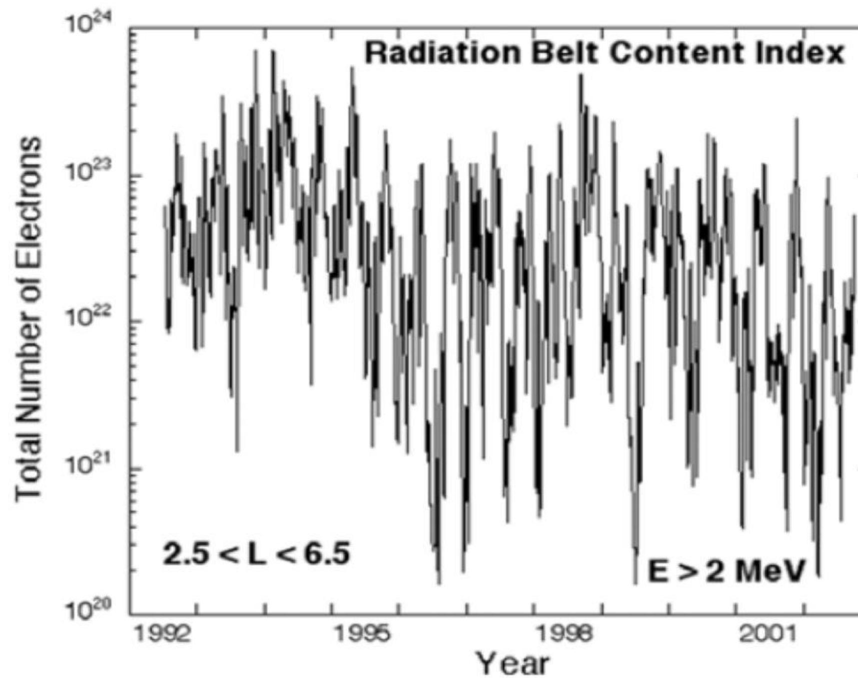
Received 21 August 2003; accepted 28 October 2003; published 11 February 2004.

[1] We have utilized knowledge acquired from near-Earth spacecraft missions to construct a "radiation belt content" (RBC) index. This index sums radiation belt electron fluxes above several chosen threshold energies (most commonly, $E > 2$ MeV) and over the range of magnetic L shells $2.5 \leq L \leq 6.5$. The method takes account of pitch angle distribution effects and magnetic flux tube properties. As constructed, the RBC index gives a simple, robust, and readily utilized daily estimate of the total number of electrons throughout the entire outer Van Allen radiation belt. We show correlative comparisons with concurrent solar wind parameters, geomagnetic indices, and geostationary orbit (GOES) data sets. We also examine statistical and recurrence characteristics of the RBC index itself. Results are compared with some of the orbit-integrated dose results from the Highly Elliptical Orbit (HEO) satellite 1997-068 that covers the same L range. The correlation of the RBC index with various spacecraft data clearly illustrates the remarkable coherence of the outer Van Allen radiation belt previously described, for example, by *Kanekal et al.* [2001]. Although the RBC index may be viewed as suppressing much of the spatial information content of the direct electron measurements in the outer trapping zone, it nonetheless gives a useful tool for statistical and time series analysis. The utilization of such a long-term, homogeneous index for space weather purposes is suggested. *INDEX TERMS:* 2720 Magnetospheric Physics: Energetic particles, trapped; 2730 Magnetospheric Physics: Magnetosphere—inner; 2740 Magnetospheric Physics: Magnetospheric configuration and dynamics; 2788 Magnetospheric Physics: Storms and substorms; *KEYWORDS:* space weather, energetic particles, radiation belts, spacecraft charging, geomagnetic storms



SAMPEX daily values of the radiation belt content index from Baker et al. [2004].

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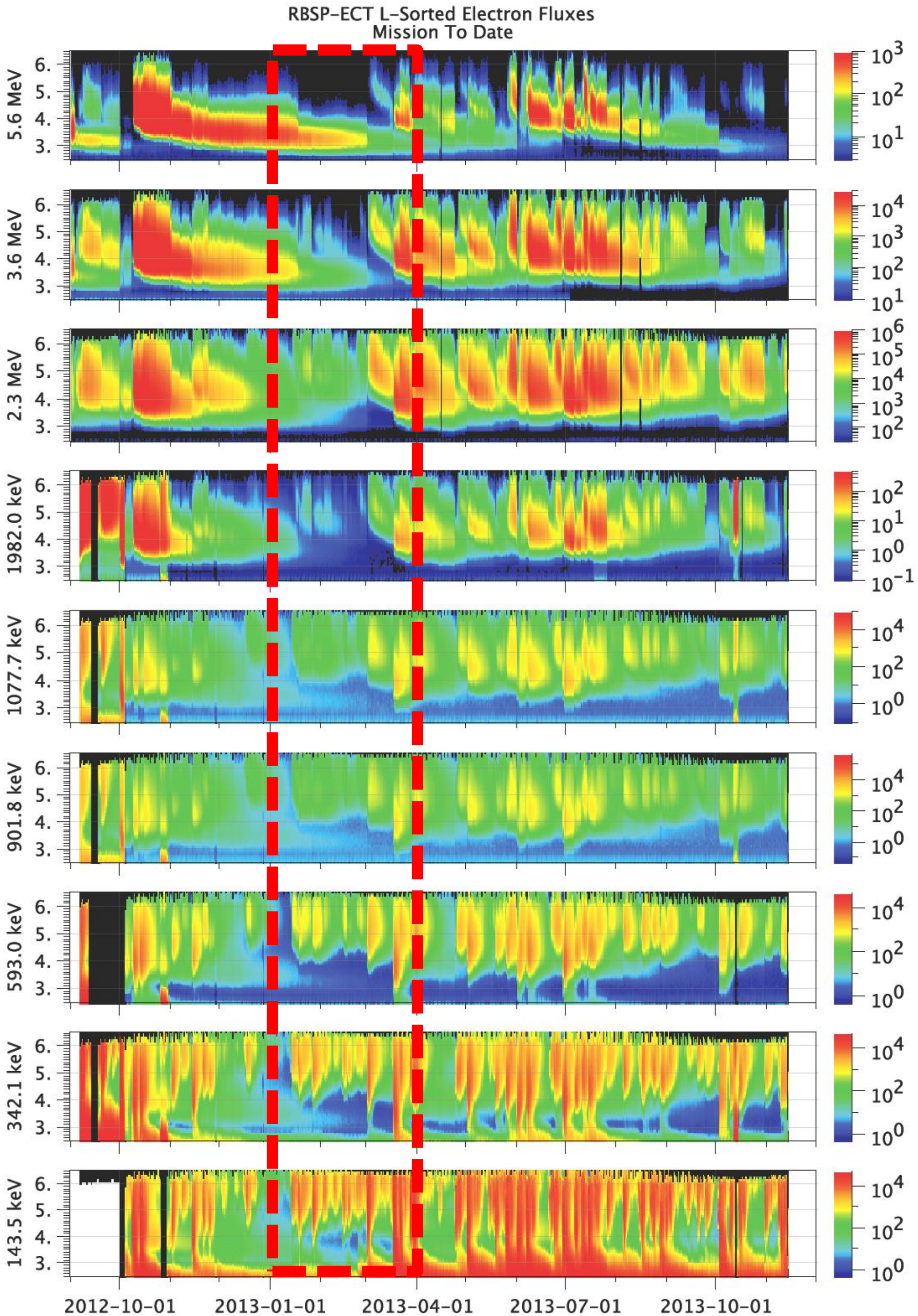
  - Baker et al. (2004) used measurements from the low altitude SAMPEX mission to estimate the radiation belt content
  - Selesnick and Kanekal (2009) used high altitude NASA/Polar measurements
- **Our work extends these pioneering studies by taking advantage of measurements from the Radiation Belt Storm Probes (RBSP) Energetic Particle, Composition, and Thermal Plasma (ECT), providing full coverage of particle energy, pitch angle, and near the magnetic equator with relatively high time cadence**

Improved Methodology and Location

- We use energy-resolved, locally-measured pitch angle distributions of electrons **near the magnetic equator** on the twin Van Allen Probes satellites
  - Magnetic Electron Ion Spectrometer (MagEIS) from 10's keV to a few MeV
  - Relativistic Electron Proton Telescope (REPT) for > a few MeV
- **We integrate consolidated electrons over energy and pitch angle throughout the spatial volume covered by the two spacecraft to establish the Total Radiation Belt Electron Content (TRBEC)**
- We explore different energy (first invariant) ranges in order to track both the lower energy "seed" population as well as the ultimate "core" radiation belt electron population – we will also want to add the "source" (of waves) population, too, but not today…
- Our initial focus is on a three month period starting on 1 January 2013, an interval long enough to begin seeing trends in time variability



- L-sort plots spanning the full mission show the sort of energy dependence and variability of the outer zone electron populations

- Lower energy electrons (seed) variations clearly distinguishably different than the higher energy (core) population

- We focus on a three-month period spanning January-March 2013 for our initial analysis

Quantifying TRBEC: Phase Space Density and Invariants

- To estimate number of electrons using phase space density data $f(\mu, K, L^*)$, we calculate the Jacobian determinant using the three action integrals of the electrons' three quasi-periodic motions, *J1*, *J2*, and *J3*, with respect to gyration, bounce motion, and drift motion [*Schulz*, 1991]. Assuming a dipolar magnetic field, we express *J1*, *J2*, and *J3* in terms of μ, K, L^* and physical constants as:

$$J_1 = \frac{2\pi m_0 c}{e}\mu,$$

$$J_2 = \sqrt{8 m_0 \mu} K,$$

$$J_3 = -\frac{2\pi e \mu_0}{c R_E L^*},$$

- where m_0 is electron mass, e the electron charge, c the speed of light in vacuum, μ_0 the Earth's dipole magnetic moment, and R_E the Earth's radius.

Partial Density in Phase Space

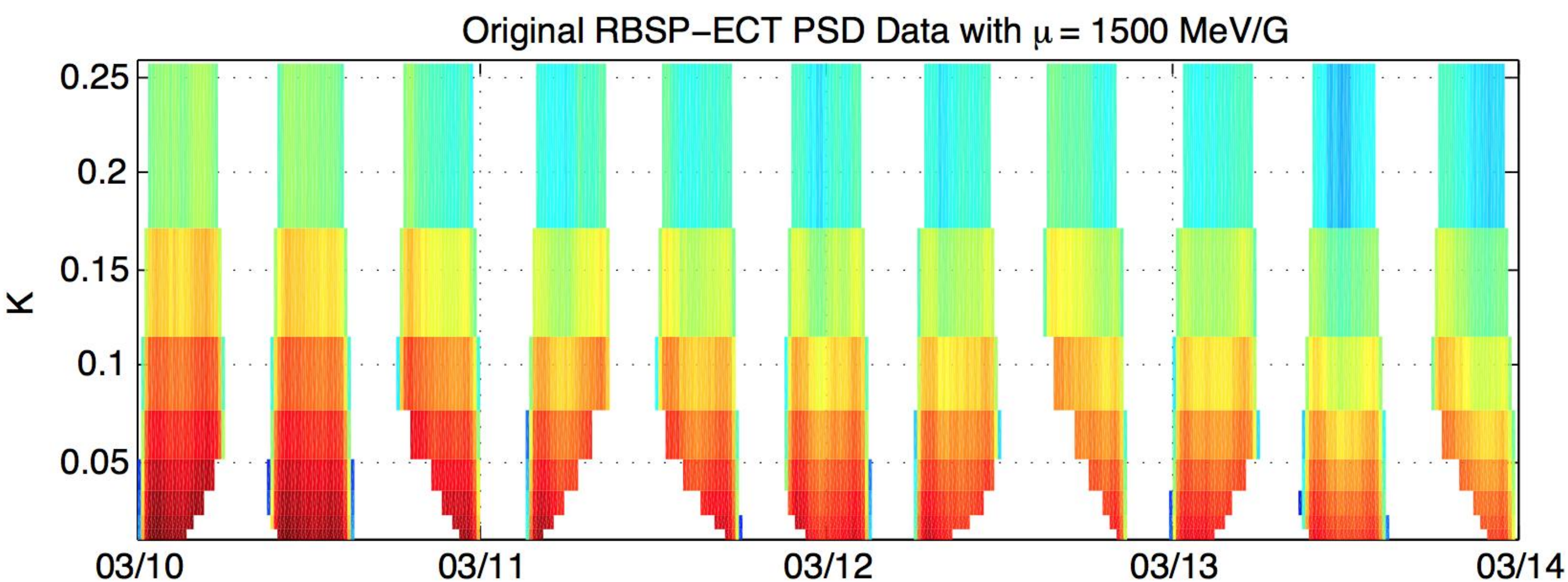
- From these equations, we can estimate values of the Jacobian determinant. Using all variables in natural units and phase space density *f* in $[c/(cm\text{-}MeV)]^3$, the number of electrons in an elemental phase space (*dN*) is:

$$\begin{aligned} dN &= (2\pi)^3 \bar{f}(\mu, K, L^*) \frac{\partial(J_1, J_2, J_3)}{\partial(\mu, K, L^*)} d\mu dK dL^* \\ &= (2\pi)^3 \bar{f}(\mu, K, L^*) \frac{8\sqrt{2}\pi^2 m_0^{3/2} \mu_0}{R_E} \frac{\sqrt{\mu}}{L^{*2}} d\mu dK dL^* \\ &\approx 8.134 \times 10^{29}\, \bar{f}(\mu, K, L^*) \frac{\sqrt{\mu}}{L^{*2}} d\mu dK dL^*. \end{aligned}$$

- where *dμ* is the selected first invariant (derived from energy) range for relativistic electrons, *dK* covers the entire pitch angle (or *K*) measurements, and *dL** is along each half-orbit of the Van Allen Probes, each roughly spanning L-shells 2.5 and 6.

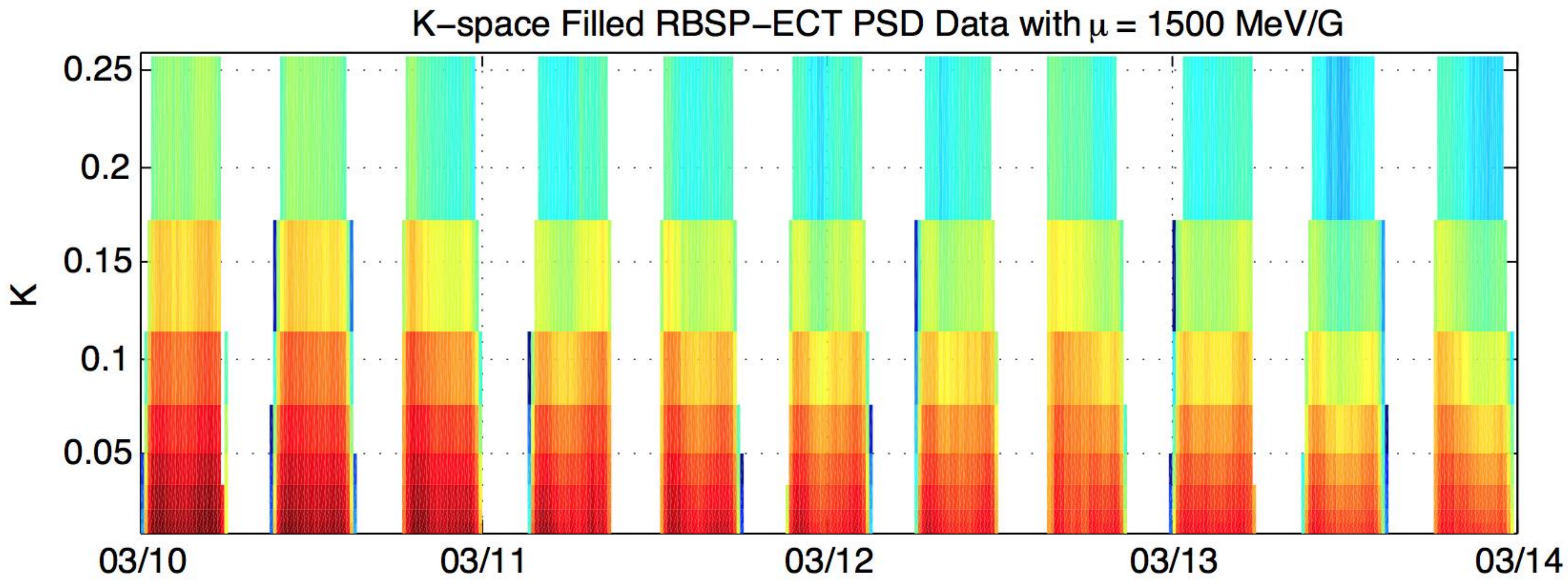
Improving an Improved Location

- Unlike SAMPEX and Polar, Van Allen Probes orbit near magnetic equator and thus sample nearly all particles – improved location
- However, the spacecraft periodically move slightly off equator due to Earth's rotation; phase space density has gaps at low *K* at times.
- Filling *K* gaps is important because they have much higher flux; ignoring gaps cause derived TRBEC value to be lower than real value

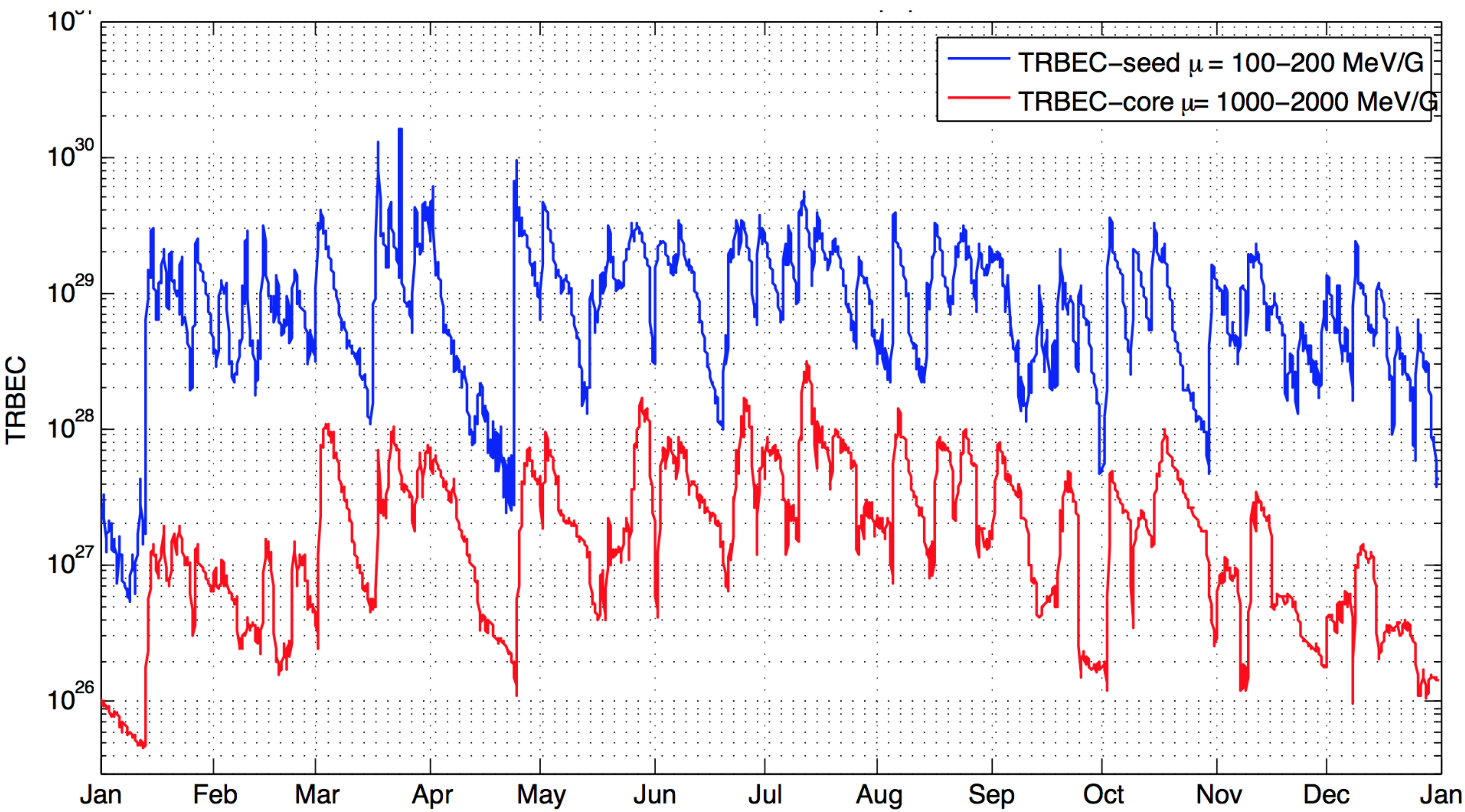


Filling K Gaps Before Integrating dN

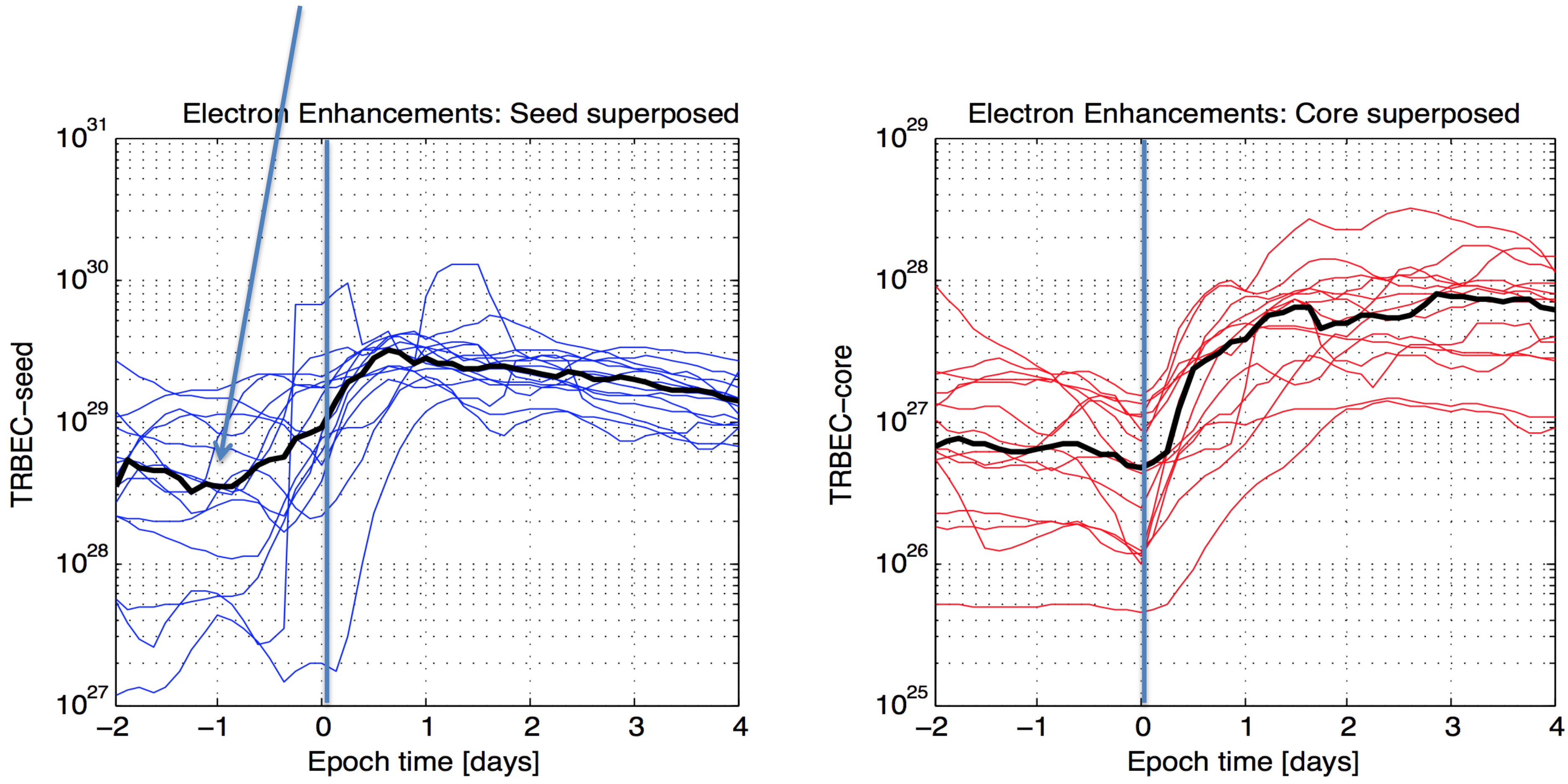
- We thus next fill the gaps in *K* space using a cubic spline fit.
- This allows us to better estimate the highest-intensity electron phase space density found at lowest *K*, before integrating over all three invariants
- With 2 spacecraft, RBSP-a and -b, we determine a TRBEC value in every ~3 hours, over each spacecraft's half orbit (between 2.5 < L < 6)



Time Evolution of TRBEC During 2013: “Core” and “Seed” Populations



Superposed Epoch Analysis: Seed Typically Precedes Core by ~ 1 day



Comparison with External Drivers

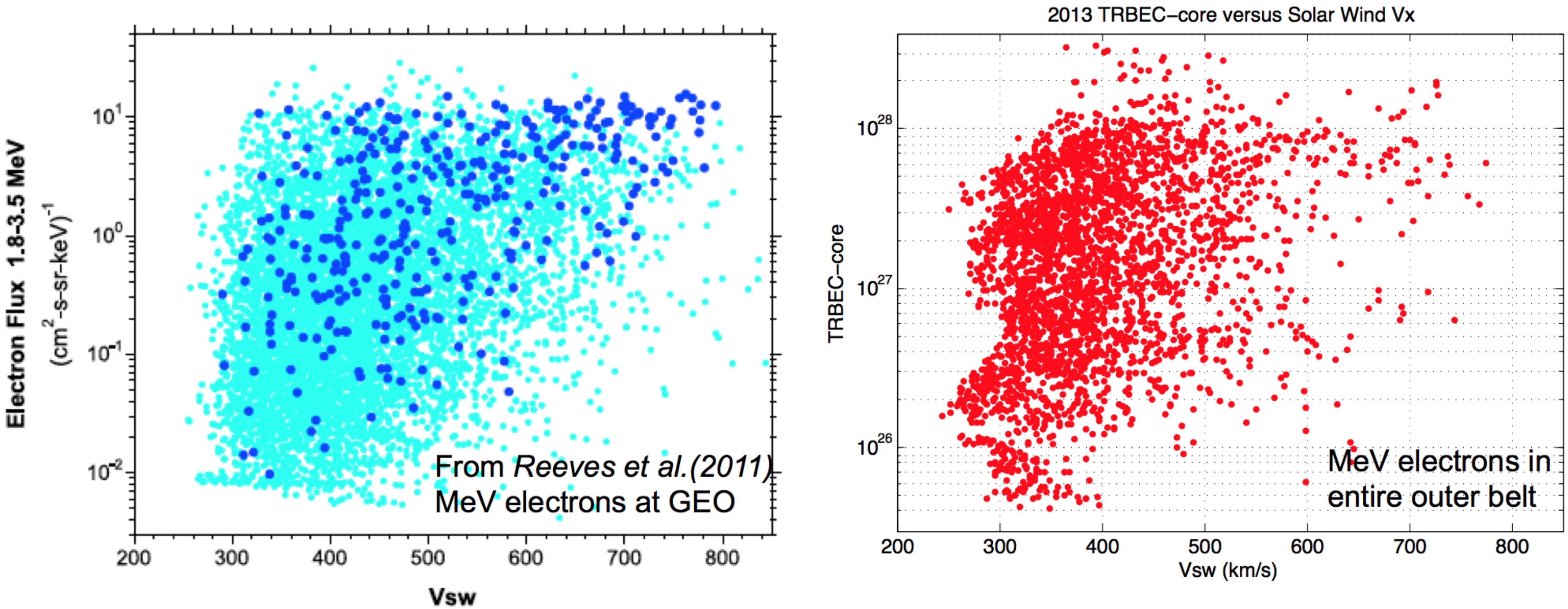


Figure 2. Distributions of MeV electrons and solar wind velocity. Left panel is adapted from *Reeves et al.* [2011] using MeV electron flux measured at geosynchronous orbit (light blue includes all data points; dark blue only include 1994 data). Right panel shows the Van Allen Probes' total radiation belt electron content versus solar wind velocity.

Summary and Conclusions

- Improved quantification of TRBEC using ECT observations confirms variability of belt content seen in earlier works and extends it by improved proximity to equator and more comprehensive coverage in first and second invariant (energy and pitch angle)
- Increases in seed population do not necessarily always lead to an enhanced core population (waves needed, too, obviously – see Alex's TRBEC presentation)
- Increases in core most often are accompanied by a prior increase in seed (but not always)
- Typical time lag between enhancement in seed population and core enhancement is less than a day (~19 hours) but can sometimes be much less than a day
- Next steps include:
  - Explore variability of TRBEC with external and internal drivers
  - Estimate impacts of atmospheric precipitation loss during favorable intervals