Supporting Information for "On the Formation of Phantom Electron Phase Space Density Peaks in Single Spacecraft Radiation Belt Data"

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Text S1. This supplementary information provides an overview of the magnetic field measurement data from NASA Van Allen Probes mission in comparison with the Tsyganenko and Sitnov (2005) magnetic field model. This comparison is crucial for evaluating the validity of the conversion from the measured electron flux (as a function of the location, energy, and pitch angle) to electron phase space density (PSD) as a function of the three adiabatic invariants μ, K, and L^*. We also use data from the THEMIS-D satellite (Angelopoulos, 2008) to determine the location of the magnetopause from particle detector data and hence further validate the importance of magnetopause shadowing for radiation belt loss and the significance of the location of the last closed drift shell (LCDS) for the storm-time radiation belt dynamics during storm recovery phase.

Figure 4 of the main paper shows the two measured PSD profiles as a function of L^* for fixed μ and K observed by Van Allen Probes A and B. It also shows the instantaneous PSD gradients inferred from the satellite data at different L^* at the same time. These gradients are shown for the period from 13:00 UT until 13:20 UT on September 8, 2017. During this time, the measured magnetic field is in good (<10% difference in magnitude) agreement with the Tsyganenko and Sitnov (2005) magnetic field model and the Van Allen Probes are sufficiently apart to infer the PSD gradients. However, outside of the aforementioned time slot, the Van Allen Probes are close to the magnetopause and boundary layer currents, which causes a disagreement with the magnetic field model. Figures S1 and S2 provide an overview of the magnetic fields observed by the satellites around that time. Hence, only the instantaneous gradients are only shown for the valid time period from 13:00 UT until 13:20 UT.

Figure S1 shows three components of the magnetic field in the GSM coordinate system measured by the Van Allen Probe A during its outbound pass. Figure S1 also shows the absolute value of the measured magnetic field vector as well as that from the Tsyganenko and Sitnov (2005) magnetic field model. Note that the measured magnetic field is in good agreement with the one from the model until 13:40 UT on September 8. However, the PSD data for Probe A at the value of second adiabatic invariant K =0.04 $R_E G^{0.5}$ assessed in this study exists only until 13:20 UT, because at later times the particles with K =0.04 $R_E G^{0.5}$ mirror below the satellite.

Similarly, Figure S2 shows the measured and modeled magnetic field for Van Allen Probe B during its inbound pass. As the satellite moves inwards, it leaves the boundary Chapman-Ferraro layer at 12:45 UT, which is evident by the decrease in the absolute value of the magnetic field. At 12:45 UT the L^* values of both Van Allen Probes are the same (difference in L^* is $<$0.1), therefore it is hard to infer the directionality of the PSD gradients until the time past their crossing in L^* crossing, i.e., only after 13:00 UT.

To verify that the Van Allen Probes are indeed close to the magnetopause at the assessed times, we show a summary of THEMIS-D satellite measurements in Figure S3. THEMIS-D crosses the magnetopause around 13:00 UT on September 8, 2017, which is evident in the magnetic field and the particle flux data from the satellite. Interestingly, this is the time of rapid last closed drift shell (LCDS) compression (cf. Figure 1 of the main paper). At the time of the magnetopause crossing by the THEMIS-D satellite at around 13:00 UT, which is also the time of the Van Allen Probe conjunction, its L^* location is 4.3 (according to Tsyganenko & Sitnov, 2005, magnetic field model for K =0.04 $R_E G^{0.5}$). This suggests that the magnetic field model underestimates the extent of the rapid magnetopause compression and is not capable to invalidate the PSD data at that time. Such observations further strengthen the selected timeslot of 13:00-13:20 used in the analysis of the PSD gradients in the main paper.

References

Angelopoulos, V. (2008, apr). The THEMIS Mission. *Space Science Reviews*, *141*(1-4), 5–34. Retrieved from `https://doi.org/10.1007%2Fs11214-008-9336-1` doi: 10.1007/s11214-008-9336-1

Tsyganenko, N. A., & Sitnov, M. I. (2005). Modeling the dynamics of the inner magnetosphere during strong geomagnetic storms. *Journal of Geophysical Research*, *110*(A3). Retrieved from https://doi.org/10.1029%2F2004ja010798 doi: 10.1029/2004ja010798

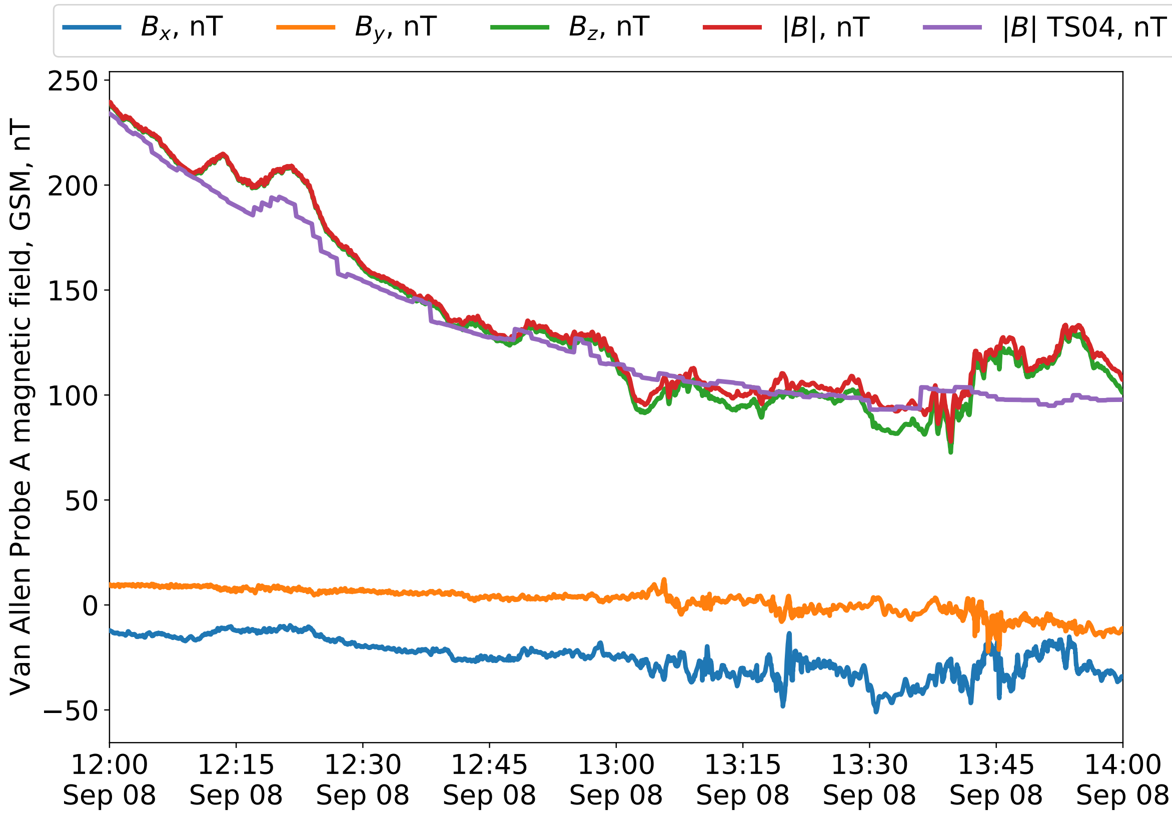

Figure S1. Van Allen Probe A model and measured magnetic field data during the acceleration phase from 12 UT until 14 UT on September 8, 2017. Measured components of the magnetic field in the GSM coordinate system are shown in blue, orange, and green colors. The red color corresponds to the absolute value of the measured magnetic field vector and is used in the calculation of the first adiabatic invariant μ. The absolute value of the modeled magnetic field vector (Tsyganenko & Sitnov, 2005) is shown in purple. A comparison between the measured and modeled data provides a reliable assessment of the model data quality and is used to distinguish where the quantitative analysis of PSD is valid.

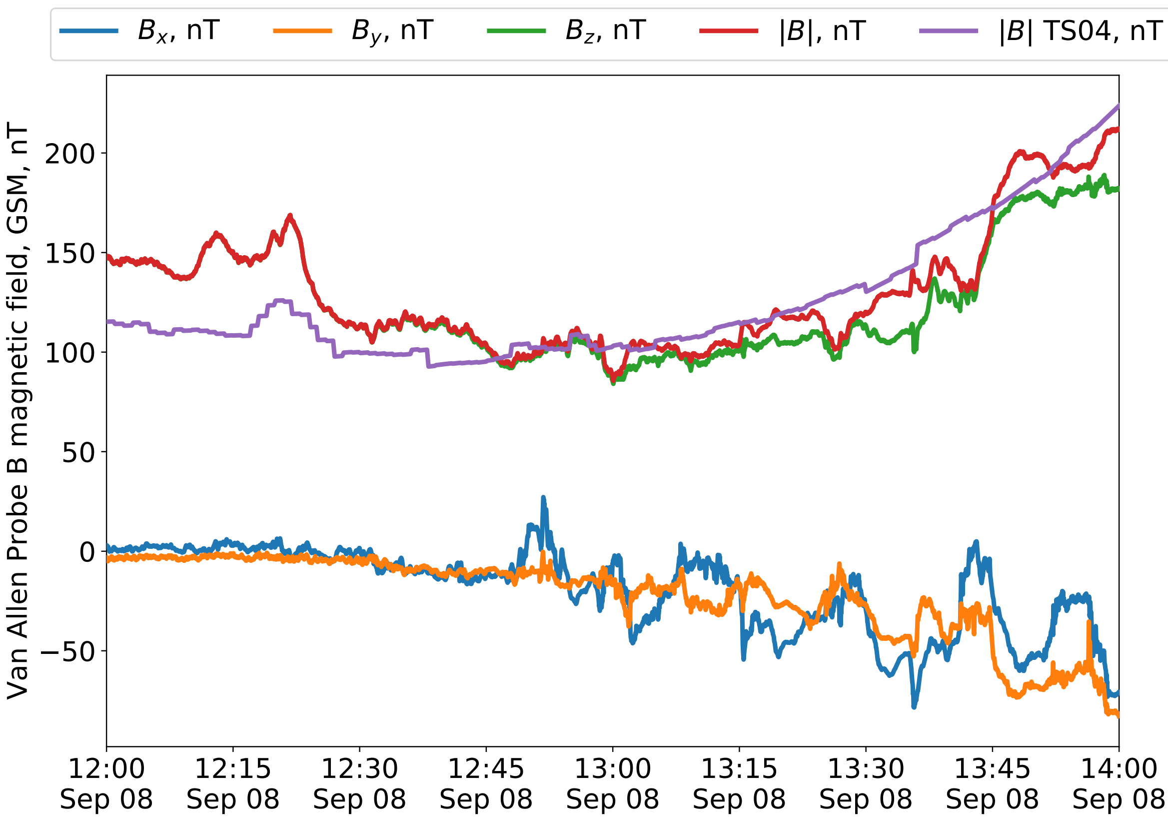

Figure S2. Van Allen Probe B model and measured magnetic field data in the same format as Figure S1.

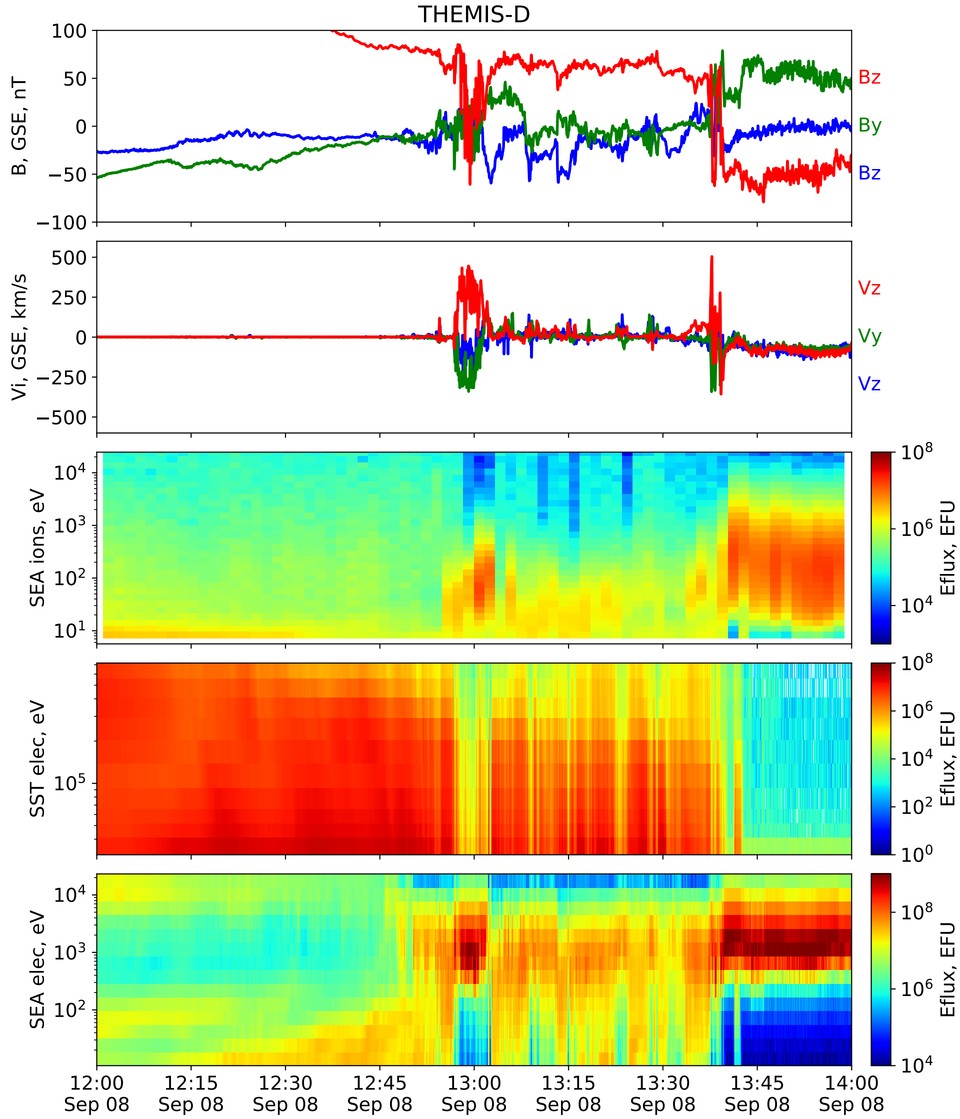

Figure S3. A summary plot of THEMIS-D magnetic field and particle measurements. From top to bottom, the panels show magnetic field components in the GSE coordinate system, ion plasma flow velocity in the GSE coordinate system, and ion energy flux from the electrostatic analyzer (ESA), solid-state telescope (SST) electron energy flux, ESA electron energy flux. THEMIS-D briefly crosses the magnetopause at 12:57 UT, which corresponds to a sharp decrease in B_z component of the magnetic field, an increase in the ion drift velocity measurement of the warm sheath plasma populations, and a rapid drop in the electron measurements above 10 keV. THEMIS-D then enters the boundary layer, before crossing into the clean magnetosheath around 13:40 UT.

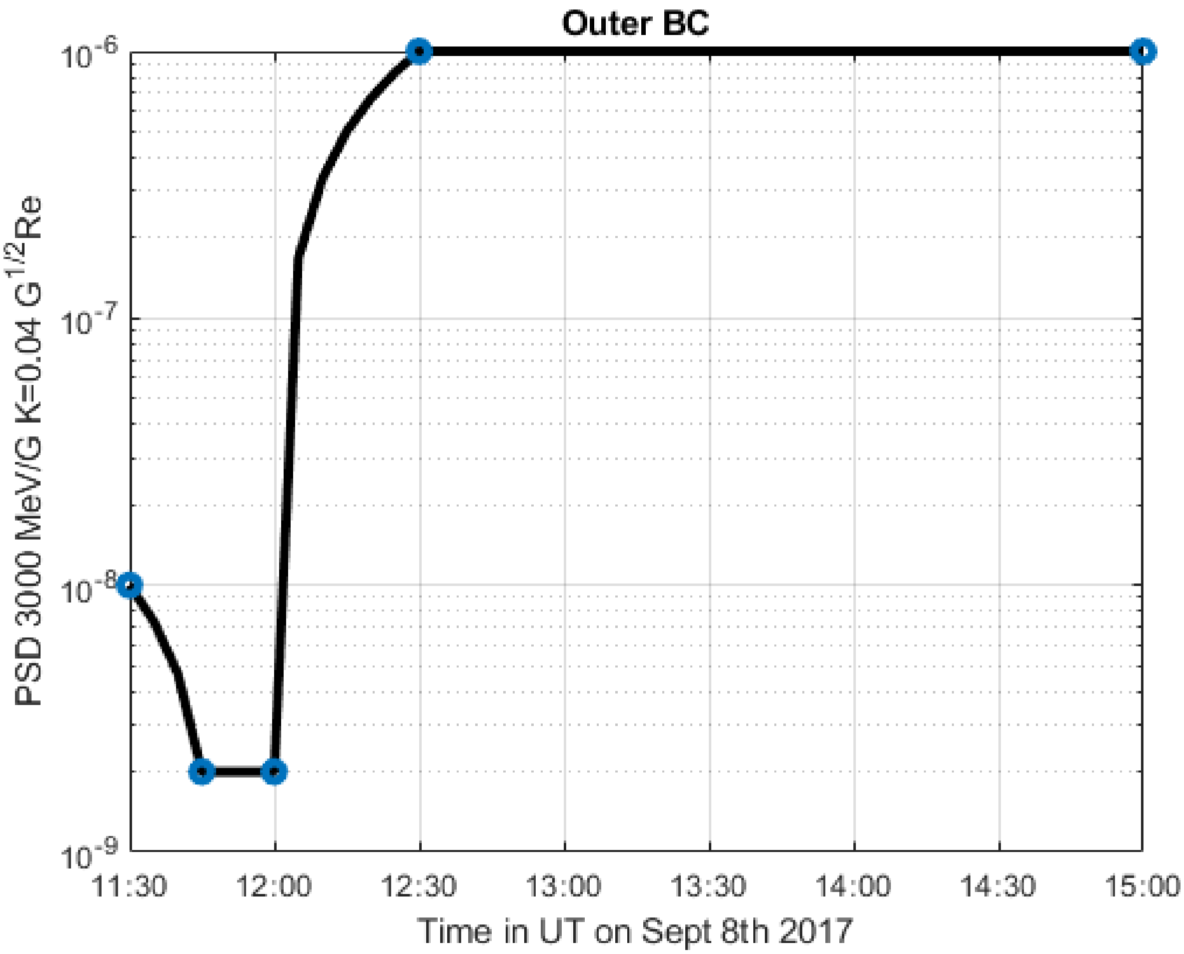

Figure S4. Outer boundary conditions used in the radial diffusion simulation. The figure represents a short loss period, observed by Van Allen Probe B from 11:30 UT until 12:00 UT, which coincides with the inward motion of the last closed drift shell (LCDS), followed by a sharp assumed enhancement of the outer boundary electron population which acts as a source for the subsequent inwards radial diffusion. Note that these data were inferred from the observed electron phase space density data at fixed μ=3000 MeV/G and K=0.04 $R_E G^{0.5}$. However, such dynamics are representative of the relativistic electron population at other μ and K values as explained in the main text of the paper.