National Aeronautics and Space Administration

Headquarters
Washington, DC 20546-0001

APR 0 3 2014

Reply to Attn of: SMD/Heliophysics Division

TO: Associate Administrator for Science Mission Directorate
Deputy Associate Administrator for Programs

FROM: Director, SMD/Heliophysics Division

SUBJECT: Van Allen Probes Mission Success

The purpose of this memo is to document that the Van Allen Probes (formerly Radiation Belt Storm Probes, RBSP) mission has met its Mission Success Criteria as of March 26, 2014. Van Allen Probes is the second mission in NASA's Living With a Star (LWS) Program. It was successfully launched on August 30, 2012 on an Atlas V from Cape Canaveral.

The Van Allen Probes mission's primary science objective is to provide understanding, ideally to the point of predictability, of how populations of relativistic electrons and penetrating ions in space form or change in response to variable inputs of energy from the Sun. To this end four instrument suites, the Energetic particle Composition and Thermal plasma (ECT) Suite, the Electric and Magnetic Field Instrument Suite and Integrated Science (EMFISIS), the Electric Field and Waves (EFW) Instrument, and the Radiation Belt Storm Probes Ion Composition Experiment (RBSPICE), on two spacecraft simultaneously make ion, electron, and electromagnetic field measurements. These measurements are needed to address the mission objectives on a near-continual basis for extended periods of time, including both geomagnetically quiet and disturbed intervals. In addition, one spacecraft must lap the other at least three times during the first nine months of operations in order to provide simultaneous two-point observations of various phenomena over a range of inter-spacecraft separation distances.

For mission success, the average daily download of data from each spacecraft must meet or exceed 5.9 Gbits for the entire first year of operations. Additionally, processed data must be made available to the public within 60 days of the time the relevant measurements were taken.

The Van Allen Probes science team, led by the Mission Scientist, David Sibeck, has evaluated the Van Allen Probes flight data to date along with science results and EPO output, and concluded that the mission science criteria were successfully met on March 26, 2014. Their written report is attached.

Discipline scientists within the Heliophysics Division at NASA HQ evaluated the science team's report, and are in agreement with the mission scientist that Van Allen Probes has not only met, but significantly exceeded its mission success criteria. I concur with this finding, and formally certify that Van Allen Probes is successful.

David L. Chenette

cc:
SMD/Heliophysics/V. Elsbernd

- J. Hayes
- R. Kessel
- L. Guhathakurta
- D. Brewer

APR 0 2 2014

SMD/Heliophysics Division

TO: Division Director for Heliophysics Division

FROM: Ramona Kessel, Heliophysics Division

SUBJECT: Van Allen Probes Mission Success

Dear Dave,

I have reviewed the Van Allen Probes Mission Success memo from the Mission Scientist, David Sibeck. I concur with its conclusion that not only has Van Allen Probes met, but it has exceeded it's requirements for Mission Success as defined in the Level 1 Requirements Document signed August 30, 2011.

Regards,

Ramona J Kessel

Ramona Kessel
Van Allen Probes Program Scientist
Heliophysics Division

The Van Allen Probes Mission Achieves Minimum (or Threshold) Mission Success

D. G. Sibeck
Van Allen Probes Mission Scientist
March 26, 2014

As of March 26, 2014, the Van Allen Probes mission has met and surpassed the requirements for scientific instrument performance, mission operations, and scientific progress needed to achieve minimum (or 'threshold') success.

The primary science objective of the Van Allen Probes (formerly known as Radiation Belt Storm Probes or RBSP) mission is to provide understanding, ideally to the point of predictability, of how populations of relativistic electrons and penetrating ions in space form or change in response to variable inputs of energy from the Sun.

To achieve full (or 'baseline') success on the mission's objectives, the full suites of identical instruments on the two spacecraft comprising the Van Allen Probes mission must simultaneously make the ion, electron, and electromagnetic field measurements needed to address the mission objectives on a near-continual basis for extended periods of time, including both geomagnetically quiet and disturbed intervals. One spacecraft must repeatedly lap the other while traversing the ring current and radiation belts at near-equatorial latitudes.

Minimum, or 'threshold' (as it is termed by the Level 1 document), success places less stringent, but still strict, requirements on simultaneous observations from the two instrument suites and progress in at least one of the following science areas: (1) Global electrodynamics, (2) Wave-particle interaction physics, (3) Proton radiation belt characteristics and sources, and (4) The physics of shock-related radiation belt events.

This document sequentially assesses instrument, mission, and science performance relative to Level 1 requirements. Papers published in the volume by Fox and Burch [2014] provide details beyond those given below concerning instrument performance. This document concludes by summarizing efforts to engage the public.

Instrument Performance

To achieve both full and minimum mission success, the Level 1 document requires the instruments on the Van Allen Probes spacecraft to make the highly accurate observations of the particle and electromagnetic field environment with the Earth's ring current and Van Allen radiation belts detailed in Tables 1 and 2. As indicated in the tables and described in the text below, the mission has met all these requirements.

Table 1
Level 1 Particle Measurements

Req	Measurement	Cadence	Energy Range	Angular Resolution	Energy Resolution	Met?
1	High energy electrons	1 distribution/ minute	1-10 MeV	30°	30% at 3 MeV	✓
2	Medium energy electrons	1 distribution/ minute	0.05-1 MeV	20°	30% at 0.3 MeV	✓
3	High energy protons	1 distribution/ minute	20-75 MeV	30°	40% at 30 MeV	✓
4	Medium energy protons	1 distribution/ minute	0.1-1 MeV	20°	40% at 0.3 MeV	✓
5	Medium energy ion composition	1 distribution/ minute	0.02-0.3 MeV	30°	40% at 0.05 MeV	✓
6	Low-energy ion/electron composition	1 distribution/ minute	0.05 -50 keV	30°	40% at 10 keV	✓

High energy electron measurement #1 is satisfied by a combination of observations from the MagEIS and REPT instruments in the ECT suite. The MagEIS instrument measures electrons with energies from 20 keV to 4.8 MeV with angular resolutions of 16-20°, while the REPT instrument measures electrons with energies from 1.6 to >18.9 MeV with angular resolutions of 10°. REPT electron energy resolution at 3 MeV is 25%. Medium energy electron measurement #2 is satisfied by observations from the MagEIS instrument in the ECT suite. The MagEIS instrument measures electrons with energies from 20 keV to 4.8 MeV with angular resolutions of 16-20° depending on energy. MagEIS electron energy resolution at 0.3 MeV is 30%. Both MagEIS and REPT make measurements with a cadence of one distribution per ~12s spin period.

High energy proton measurement #4 is satisfied by observations from the REPT instrument in the ECT suite. The REPT instrument measures ions with energies from 17 to >100 MeV with angular resolution of 10°. REPT ion energy resolution at 30 MeV is 30%. Medium energy proton measurement #5 is satisfied by observations from the MagEIS instrument in the ECT suite. The MagEIS instrument measures protons with energies from 20 keV to 20 MeV with angular resolution of 16-20° depending on energy. MagEIS ion energy resolution at 0.3 MeV is 30%. Both MagEIS and REPT make measurements with a cadence of one distribution per ~12s spin period.

Medium energy ion composition measurement #5 is satisfied by observations from the RBSPICE instrument. The RBSPICE instrument measures ion composition over energies from 20 (H), 30 (He), and 50 (O) to 1000 keV with an angular resolution of 12°.

RBSPICE ion energy resolution at 0.05 MeV is 25%. Both HOPE and RBSPICE make measurements with a cadence of one distribution per ~12s spin period. Low energy ion/electron composition measurement #6 is satisfied by observations from the HOPE instrument in the ECT suite. The HOPE instrument measures H, He+, O+, and electrons with energies from 0.001 to 50 keV with an angular resolution of as little as 22.5°. HOPE ion and electron energy resolution ranges from 16% at 1 eV to 12% at 50 keV. Both HOPE and RBSPICE make measurements with a cadence of one distribution per ~12s spin period.

Table 2
Level 1 Field and Wave Measurements

Req	Measurement	Cadence	Frequency Range	Frequency Resolution	Met?
1	3-D magnetic field	20 vectors/s	DC – 10 Hz	n/a	✓
2	3-D Wave magnetic field	6s	10 Hz-10 kHz	20 channels per decade	✓
3	3-D Wave electric field	6s	10 Hz-10 kHz	20 channels per decade	✓
4	3-D electric field	20 vectors/s	DC – 10 Hz	n/a	✓
5	Plasma Density	10s	n/a	n/a	✓

3-D magnetic field Requirement #1 is satisfied by observations from the EMFISIS fluxgate magnetometer, which samples the magnetic field at 64 vectors/second. 3-D Wave magnetic field Requirement #2 is satisfied by observations from the EMFISIS search coil magnetometer which are routinely processed to generate spectral matrices covering the frequency range from 2 Hz to 12 kHz in 65 logarithmically spaced bins at a cadence of 6s. 3-D Wave electric field Requirement #3 is satisfied by observations from the EFW electric field instrument that are processed by the EMFISIS instrument to produce spectral matrices from 2 Hz to 12 kHz in 65 logarithmically spaced bins at a cadence of 6s samples. 3-D electric field Requirement #4 is satisfied by observations from the EFW instrument, which samples the electric field at 32 vectors/second. Plasma density Requirement #5 is satisfied by both the EFW and EMFISIS instrument. The EFW instrument provides an algorithm that can be used to convert spacecraft potentials into densities and produces 16 samples of the potential per second. The EMFISIS instrument provides 6s samples of the density, when it can be obtained from the Upper Hybrid frequency.

Full mission success requires simultaneous observations from all the instruments in the ECT, EFW, EMFISIS, and RBSPICE suites on both spacecraft in the correct locations, for an extended period of time, a wide range of geomagnetic conditions, and for a range of inter-spacecraft separations.

Minimum success requires the Van Allen Probes mission to make substantial progress on at least one of the four science areas listed above. Table 3 lists the measurements required to achieve full and minimum success for each of these four science areas (numbered 1 to 4). Minimum success requires concurrent measurements from both spacecraft for nine months and single point measurements for an additional 3 months, for a total of one year. Since all instruments on both spacecraft have been fully functional since the end of the two-month commissioning phase on October 30, 2012, the mission met this aspect of minimum mission success at the end of October 2013.

Table 3
Minimum Success Table

		Science Area				
Measurement	Full Science	1	2	3	4	Level Met?
High energy Electrons	2	2^{A}	2^{A}	2^{A}	2	Full
Medium energy Electrons	2	2	2	2	2	Full
High energy protons	2	0	0	1	1	Full
Medium energy Protons	2	0	0	1	1 | 0	Full
Medium energy ion composition	2	1 | 2	0 | 1	0	0 | 1	Full
Low-energy ion/electron composition	2	1 | 0	1 | 0	0	0	Full
3-D magnetic field	2	2	2	2	2	Full
3-D wave magnetic field	2	0	1^{B}	0	1	Full
3-D wave electric field	2	1^{C}	1^{B}	1^{C}	1	Full
3-D electric field	2	1^{D}	1^{D}	1^{C}	2	Full
Plasma density	2	1	1	1	2	Full

[A] Either 1-4 MeV electrons or 3-10 MeV electrons are required to achieve Minimum Success.
[B] High resolution waveform data are required to achieve Minimum Success
[C] 2D will suffice to achieve Minimum Success
[D] For Minimum Success, the third axis can be derived instead of directly measured.

Minimum mission success places two additional requirements upon spacecraft operations. First, one spacecraft must lap the other at least three times during the first nine months of operations in order to provide simultaneous two-point observations of various phenomena over a range of inter-spacecraft separation distances. Since the orbits of the spacecraft cause one to lap another once each 90 days, this requirement has also been achieved.

Second, the spacecraft must operate through both active and quiet geomagnetic times. Active times can be identified as those during which intense fluxes of energetic electrons are observed and the disturbed storm time index reaches large negative values indicating intense ring currents encircling the Earth. Figure 1 shows weekly averages of the data returned by each spacecraft as a function of time from the end of the commissioning period to March 2014, electron fluxes at 2.3 MeV, and the Dst index. As can be seen, the spacecraft continued to return data throughout the mission, without interruption during active times.

Mission Operations

To obtain observations of the radiation belts, the Van Allen Probes spacecraft must pass through them. The Level 1 documents requires the spacecraft apogees to lie between 5.2 and 6.0 R_E geocentric distance from Earth, and spacecraft perigees to lie below 1000 km above the surface of the Earth. The orbital inclination must be less than 18°. Finally, the apogees of the spacecraft were required to pass through local times beginning prior to from 0600, through midnight, and beyond 1800 LT during the first year of operations after commissioning. These requirements are met by the 5.8 R_E apogees of the Van Allen Probe spacecraft, 600 km perigees, 10° inclinations, initial apogee at 0615 LT immediately following the commissioning phase, and apogee of 1645 LT one year after the end of the commissioning phase.

The average daily download of data from each spacecraft must meet or exceed 5.9 Gbits for the entire first year of operations. As indicated by the top panel of Figure 1, this requirement has been met and (since September 2013) greatly exceeded following the release of the RF margin and the enabling of data compression.

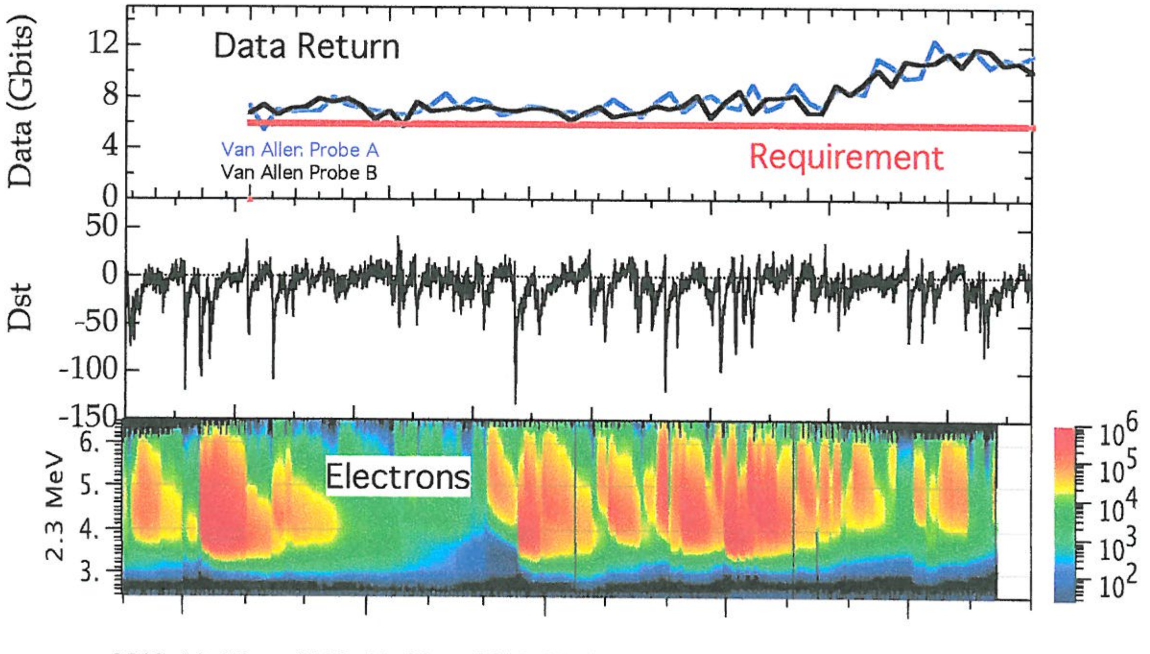

Figure 1. Weekly averages of the date returned daily by both Van Allen Probe spacecraft have exceeded requirements throughout the mission, regardless of geomagnetic activity as measured by enhanced negative values of Dst or enhanced fluxes of 2.3 MeV electrons measured by the Van Allen Probe spacecraft themselves.

Processed data must be made available to the public within 60 days of the time the relevant measurements were taken following the first three months of the operational phase of the mission. This requirement has also been met. Not only are data available within 60 days of the time they are taken, they have been archived at NASA within the same period at cdaweb.gsfc.nasa.gov. Inspection on March 10, 2014 revealed lag times ranging from 2 to 33 days for Level 2 data products, with the latency for most products ranging from 2-5 days.

To further their utility, the Van Allen Probes were required to generate and broadcast near real-time space weather data. To this end agreements are in place with Charles University in Prague, Czech Republic and KASI in Daejeon, South Korea to receive space weather data, while additional agreements are being work with Argentina and Brazil. Near real-time space weather data appear on the Project's WWW site at http://athena.jhuapl.edu/space_weather_data_plots within 15 minutes of reception.

Scientific progress

The Level 1 document calls out a set of specific science objectives that must be achieved in order for the Van Allen Probes mission to achieve either full or minimum success. Table 4 lists these objectives. As indicated by the references, substantial progress has been made on all these objectives.

Table 4
Overall Science Objectives

Topic	References
Quantify electron energization, loss, transport, source populations, and their effects. Understand how they work together. Improve models.	1, 7, 10, 11, 19, 23, 25, 28
Determine spatial and temporal variations of electron radial phase space density profiles to distinguish between candidate processes	2, 21, 29
Convective and impulsive flows, shock-generated fronts, plasma densities	7, 8, 32
Constrain global electric and magnetic fields, model their effects on particle distributions	15, 33
Determine the importance of ELF, VLF, ULF, random and quasi-periodic waves and their effects on particle distributions, diffusion rates, energization, loss, transport	4, 5, 6, 12, 13, 14, 17, 20, 24, 26, 27, 31

In addition, minimum success requires the Van Allen Probes mission to make substantial progress in at least one of the following science areas: (1) Global electrodynamics, (2) the details of wave-particle interaction, (3) Proton radiation belt characteristics and sources, and (4) The physics of shock-related radiation belts. Of these topics, the Van Allen Probes mission has made the most substantial progress on science area (2). Chaston et al. [2014] employ Van Allen Probe observations to define the properties of Doppler-shifted kinetic Alfvenic field line resonances during energetic plasma injections. Santolik et al. [2014] describe the fine structure of large-amplitude chorus wave packets. Fennell et al. [2014] present observations of electrons interacting with chorus wave bursts, while

Paulson et al. [2014] discuss in situ observations of Pc1 pearl pulsations. Mann et al. [2014] make use of Van Allen Probe and ground-based observations to define the ducting of EMIC waves.

Beyond these topics, the mission has made several unexpected discoveries that have gained considerable attention. Baker et al. [2013] reported the existence of a persistent storage ring of extremely high-energy electrons just inside the plasmapause. Ukhorskiy et al. [2014] reported that global diurnal variations in electric and magnetic fields organize electron into multiple stripes of enhanced and diminished fluxes whose energy depends on radial distance from Earth. Mozer et al. [2014] presented evidence for the presence of multiple double layers, which in sum could energize electrons to high energies.

Education and Public Outreach

The Van Allen Probes Education and Public Outreach (E/PO) program inspires and educates a broad audience about Heliophysics and the Sun-Earth system, specifically the Van Allen Radiation Belts. The program comprises a variety of formal, informal and public outreach activities aligned with the NASA Education Portfolio Strategic Framework outcomes. Instrument teams also implement their own E/PO activities in collaboration with the mission E/PO program.

The formal education program includes educator training and support, educational product creation and dissemination, and direct student engagement. Highlights include teacher and pre-service educator training through Van Allen Probes workshops and SMD partnership opportunities such as the Heliophysics Educator Ambassador Program and the Heliophysics Community of Practice, a workshop that trained 77 pre-service educators from Historically Black Colleges and Universities in MD and DC on how to apply heliophysics science to a variety of classroom disciplines, and a partnership with National Geographic and Cengage Learning to develop a digital curriculum module highlighting the Van Allen Probes mission in a chapter focusing on magnetism in space. Five Space Academies at APL focused on the Van Allen Probes, engaging over 700 regional middle school students with the engineers and scientists who work on the mission, while the NASA/APL internship program provided 19 undergraduate and graduate students the opportunity to work on the mission.

Informal education activities include museum and science center partnerships to advance heliophysics mission science awareness and understanding among a wide variety of audiences. The E/PO campaign coinciding with the launch of the twin spacecraft reached nearly 16,000 visitors at the Kennedy Space Center Visitors Complex in July 2012. Figure 2 shows the Van Allen Probes exhibit at the visitors complex.

Figure 2. Over 4,000 people visited the Van Allen Probes exhibit at the Kennedy Space Center Visitors Complex during the launch campaign. Many more were engaged through other exhibits and interactive activities at KSC.

Summary

The Van Allen Probes mission has met all the requirements for minimum mission success and is well along the route towards achieving full mission success. All instruments on both spacecraft are fully functional, the required data products are being routinely produced and delivered to a NASA-designated archive, where they are provided promptly to researchers and the general public. As documented by a series of papers published in high impact journals, researchers within and outside the Van Allen Probes mission are accessing and interpreting the data to make fundamental discoveries concerning the processes that accelerate, transport, and cause the loss of particles within the Earth's Van Allen Belt radiation environment.

References

[1] Baker, D. N., et al., A long-lived relativistic electron storage ring embedded in Earth's outer radiation belt, Science, 340, 186-190, 2013.

[2] Baker, D. N., et al., Gradual diffusion and punctuated phase space density enhancements of highly relativistic electrons: Van Allen Probes observations, Geophys. Res. Lett., 41, doi:10.1002/2013GL058942, 2014.

[3] Chaston, C. C., et al., Observations of kinetic scale field line resonances, Geophys. Res. Lett., 41, 209-215, 2014.

[4] Claudepierre, S. G., et al., Van Allen Probes observation of localized drift resonane between poloidal mode ultra-low frequency waves and 60 keV electrons, Geophys. Res. Lett., 40, 4491-4497, 2013.

[5] Dai, L., et al., Excitation of poloidal standing Alfven waves through drift resonance wave-particle interaction, Geophys. Res. Lett., 40, 4127-4132, 2013.

[6] Fennell, J. F., et al. Van Allen Probes observations of possible direct wave particle interactions, Geophys. Res. Lett., 10.1002/2013GL059165, 2014.

[7] Foster, J. C., et al., Prompt energization of relativistic and highly relativistic electrons during a substorm interval: Van Allen Probes observations, Geophys. Res. Lett., 41, 20-25, 2014a.

[8] Foster, J. C., et al., Storm time observations of plasmasphere erosion flux in the magnetosphere and ionosphere, Geophys. Res. Lett., 41, 762-768, 2014.

[9] Fox, N. and J. L. Burch, The Van Allen Probes Mission, Springer, New York, , pp. 1-646, 2014.

[10] Hudson, M. K., et al., Simulated magnetopause losses and Van Allen Probe flux dropouts, Geophys. Res. Lett., 41, doi:10.1022/2014GL059222, 2014.

[11] Li, X., et al., First results from CSSWE CubeSat: Characteristics of relativistic electrons in the near-Earth environment during the October 2012 magnetic storms, J. Geophys. Res., 118, 6489-6499, 2013.

[12] Li, W., et al., Constructing the global distribution of chorus wave intensity using measurements of electrons by the POES satellites and waves by the Van Allen Probes, Geophys. Res. Lett., 40, 4526-4532, 2013a.

[13] Li, W., et al., An unusual enhancement of low-frequency plasmaspheric hiss in the outer plasmasphere associated with substorm-injected electrons, Geophys. Res. Lett., 40, 3798-3803, 2013b.

[14] Mann, I., et al., Discovery of the action of a geophysical synchrotron in the Earth's Van Allen radiation belts, Nature Communications, 4, doi:10.1029/ncomms3795, 2013.

[15] Morley, S. K., et al., Phase space density matching of relativistic electrons using the Van Allen Probes: REPT results, Geophys. Res. Lett., 40, 4798-4802, 2013.

[16]Mozer, F. S., et al., Megavolt parallel potentials arising from double-layer streams in the Earth's outer radiation belt, Phys. Rev. Lett., 111, doi:10.1103/PhysRevLett.111.235002, 2013.

[17]Ni, B., et al., Resonant scattering and resultant pitch angle evolution of relativistic electrons by plasmaspheric hiss, J. Geophys. Res., 118, 7740-7751, 2013.

[19]O'Brien, T. P., et al., An empirically observed pitch-angle diffusion eigenmode in the Earth's electron belt near L*=5.0, Geophys. Res. Lett., 41, 251-258, 2014.

[20]Paulson, K. W., et al., In-situ observations of Pc1 pearl pulsations by the Van Allen Probes, Geophys. Res. Lett., doi:10.1002/2013GL059187, 2014.

[21]Reeves, G., et al., Electron acceleration in the heart of the Van Allen radiation belts, Science, 341, 991-994, 2013.

[22]Santolik, O., Fine structure of large-amplitude chorus wave packets, Geophys. Res. Lett., 41, 293-299, 2014.

[23]Schiller, Q., et al., A nonstorm time enhancement of relativistic electrons in the outer radiation belt, Geophys. Res. Lett., 41, 7-12, 2014.

[24]Shprits, Y. Y., et al., Unusual stable trapping of the ultrarelativistic electrons in the Van Allen radiation belts, Nature Phys., 9, doi:10.1038/nphys2760, 2013.

[25]Su, Z., Nonstorm time dynamics of electron radiation belts observed by the Van Allen Probes, Geophys. Res. Lett., 41, 229-235, 2014.

[26]Thorne, R. M., et al., Evolution and slow decay of an unusual narrow ring of relativistic electrons near L ~ 3.2 following the September 2012 magnetic storm, Geophys. Res. Lett., 40, 3507-3511, 2013a.

[27]Thorne, R. M., et al., Rapid local acceleration of radiation belt electrons by magnetospheric chorus, Nature, 504, 411-413, 2013b.

[28]Tu, W., et al., Event-specific chorus wave and electron seed population models in DREAM3D using the Van Allen Probes, Geophys. Res. Lett., 41, doi:10.1002/2013GL058819, 2014.

[29]Turner, D. L., On the storm-time evolution of relatistic electron phase space density in Earth's outer radiation belt, J. Geophys. Res., 118, 2196-2212, 2013.

[30]Ukhorskiy, A. Y., et al., Enhanced radial transport and energization of radiation belt electrons due to drift orbit bifurcations, J. Geophys. Res., 119, 163-170, 2014.

[31] Usanova, M. E., et al., Effect of EMIC waves on relativistic and ultrarelativistic electron populations: Ground-based and Van Allen Probes observations, Geophys. Res. Lett., doi:10.1002/2013GL059024, 2014.

[32] Yu, Y., et al., The role of ring current particle injections: Global simulations and Van Allen Probes observations during 17 March 2013 storm, Geophys. Res. Lett., 41, doi:10.1002/2014GL059322, 2014a.

[33] Yu, Y., et al., Application and testing of the L* neutral network with the self-consistent magnetic field model of RAM-SCB, J. Geophys. Res., doi:10.1002/2013JA019350, 2014b.