ANALYSIS OF MEO PLASMA ENVIRONMENT FOR SPACECRAFT SURFACE CHARGING

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ABSTRACT

Analysis of plasma environment for spacecraft surface charging in the medium Earth orbits (MEO) is important for spacecraft designs and operations, because surface charging with resultant discharging could cause spacecraft anomalies. We use the data from the Helium Oxygen Proton Electron (HOPE) instrument of the Van Allen Probes (VAP) to calculate their spacecraft potential and the density and temperature of ions and electrons. For the significant charging events, we simulate surface potentials of a simple VAP model in the measured plasma environmental parameters using the Spacecraft Plasma Interaction System (SPIS) software and compare the results with the measured potentials.

1. INTRODUCTION

Spacecraft surface charging not only affects plasma and electric field measurements but also could cause spacecraft anomalies in the medium Earth orbits (MEO). Analysis of plasma environment for spacecraft charging and spacecraft charging simulations in the charging environments improve our understanding of spacecraft charging to prevent and mitigate spacecraft charging effects

The Van Allen Probes (VAP), formerly known as the Radiation Belt Storm Probes (RBSP), are a pair of twin probes (A and B) launched on 30 Aug. 2012 in a highly elliptical orbit with a perigee of ~600 km, an apogee of ~30,000 km, an inclination of ~10 degrees, and a period of ~9 hours. The Van Allen Probes are designed for scientific missions to limit the differential surface charging for measurements of low-energy plasma and electric fields which are particularly sensitive to charging of spacecraft surfaces. The cover glasses of the solar panels have an Indium Tin Oxide (ITO) conductive coating with each cover glass. Most other surfaces are covered with conductive black Kapton as thermal blankets or are coated ITO coatings. All conductive surfaces are conductively tied together with the chassis.

The Van Allen Probes contain two instruments which provide the MEO data to study spacecraft charging. One is the Electric Fields and Waves (EFW) instrument (Wygant et al. [1]). The other is Helium Oxygen Proton Electron (HOPE) instrument (Funsten et al. [2]). The EFW instrument has double-probe electric field sensors. The spacecraft potential is measured in calculating on the ground by averaging the probe potentials from the double-probe electric field sensors on opposite sides of the spacecraft in the spin plane. However the EFW potential measurements saturate at −200 V due to voltage limitations and are unreliable during eclipse times when the spacecraft is in Earth's shadow. The HOPE instrument consists of an electrostatic analyzer that measures 1 eV to 50 keV Helium, Oxygen, Hydrogen ions and 15 eV to 50 keV electrons. To measure the spacecraft potential, we extract charging lines in ion spectrograms from the HOPE instrument. The charging line occurs when the spacecraft charges negative and all ions are accelerated by the spacecraft potential. The bulk ion acceleration manifests in the counts spectra as a peak of high counts and appears at the level of charging. For −1000 V of charging, there would be a line of high counts in the 1000 eV measurement bin. In this situation, the detector should observe no ions below 1000 eV. The lowest energy of the charging line is called a cutoff energy. Therefore we can measure the spacecraft potentials during the EFW saturation times and the eclipse times when the Van Allen Probes are charged significantly. Recently, Sarno-Smith et al. [3] studied the Van Allen Probes surface charging and presented their statistical distributions using the EWF data. They also compared the EWF and HOPE results and examined the relationship between the surface charging potential and the ambient plasma environments

We study the significant surface charging events recorded in the HOPE data and show their orbital distributions in the Geocentric Solar Ecliptic (GSE) coordinate. We calculate the density and temperature of ions and electrons from the HOPE flux spectra. For the maximum charging event, we simulate surface charging potentials of a simple Van Allen Probe model using a spacecraft charging analysis software and compare the simulated results and the measured potential.

2. SPACECRAFT POTENTIAL

Fig. 1 shows the hydrogen ion and electron spectrograms on 20 Feb. 2013 from the HOPE instrument of the Van Allen Probes A. The horizontal

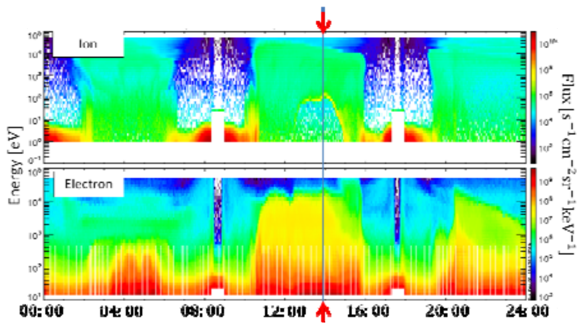

Figure 1. (Upper panel) the hydrogen ion and (lower panel) electron flux spectrograms of the Van Allen Probe A on the 20 Feb. 2013. The ion charging lines are observed from ~13:00 to ~15:00 UT.

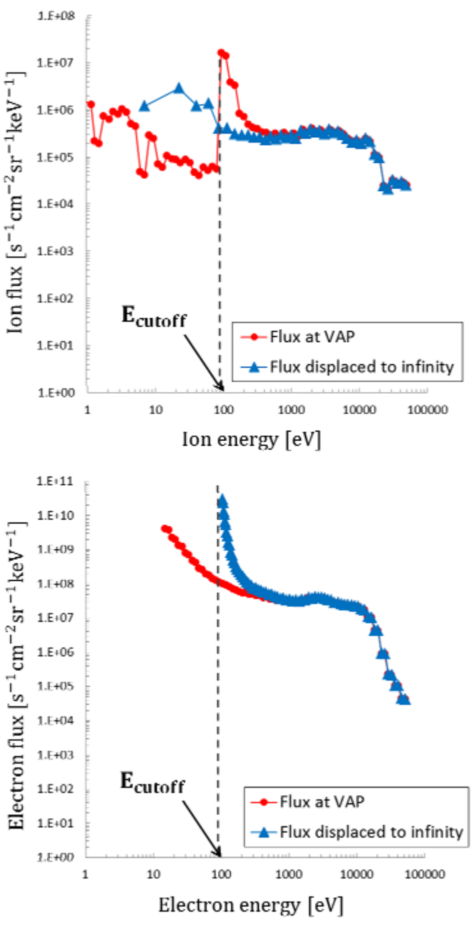

Figure 2. (Upper panel) The hydrogen ion and (lower panel) electron energy flux spectra of Van Allen Probe A at 13:52(UT) on 20 Feb. 2013. The red data points labelled "Flux at VAP" indicate the measured spin-averaged flux spectra. The blue data points labelled "Flux displaced to infinity" indicate the flux spectra shifted to infinity.

axis is for the time in UT and the vertical axis is for the energy of the particle, the color scale is for the differential flux. The charging lines are seen in the ion spectrogram from ~13:00 to ~15:00 UT. The Van Allen Probe A is not in eclipse during this charging event.

Fig. 2 shows the hydrogen ion and electron energy flux spectra at 13:52(UT) on 20 Feb. 2013 as shown by the vertical line in fig. 1. The red data points labelled "Flux at VAP" indicate the measured spin-averaged flux spectra. We can calculate the spacecraft potential, density and temperature of ions and electrons from these spectra in the same manner as the Los Alamos National Laboratory geosynchronous satellite data analysis (e.g. Davis et al. [4]). In the ion spectra, the lowest-energy channel with a significant count rate is 84.2 to 98.1 eV, which is the cutoff energy. Therefore the absolute potential is taken to be the geometric mean of the energy channel edges, −90.9 V. Cold ions with nearly zero energy at infinity are accelerated to 90.9 eV by the

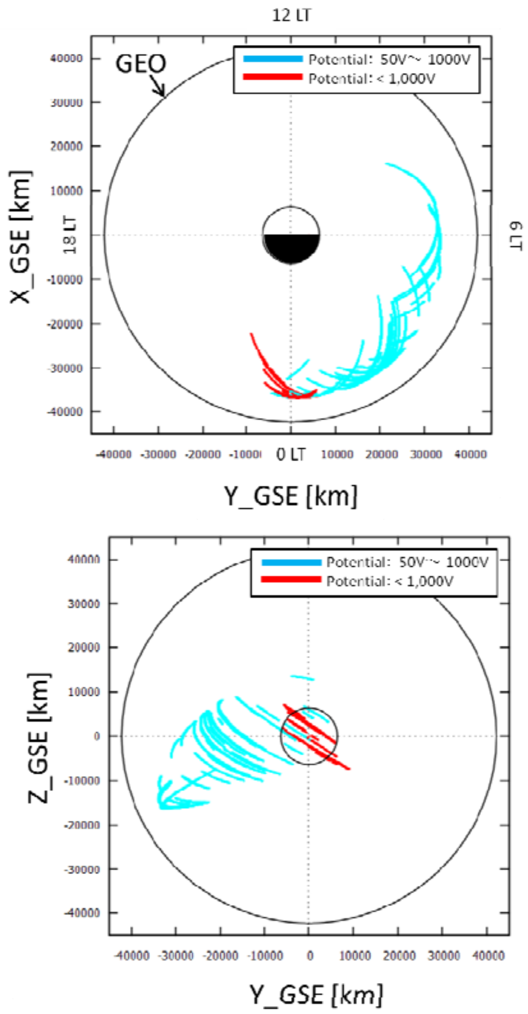

Figure 3. The significant charging orbits of the Van Allen Probes A and B plotted in the GSE coordinate from 18 Oct. 2012 to 23 March 2014. The pale blue lines indicate −50 V ~ −1000 V charging orbits and the red lines indicate < −1000 V charging orbits.

time they reach the HOPE instrument, which is why few ions are seen in the energy channels below 90.9 eV. On the other hand, the negatively charged spacecraft repels electrons. An electron with energy of 90.9 eV at infinity reaches the detector with zero energy, and lower-energy electrons do not reach the detector at all. The intense fluxes of electrons that are seen below 90.9 eV are photo electrons and secondary electrons ejected from the spacecraft surface and trapped by electric fields due to differential charging.

We calculate the spacecraft potentials of the Van Allen Probes A and B from 18 Oct. 2012 to 23 March 2014. Fig. 3 shows < −50 V charging orbits plotted in the GSE coordinate. They are located ~25,000 km further away from the center of the Earth and in the mid-night to dawn sector. The pale blue lines indicate the −50 to −1000 V charging orbits. The number of the orbits is 41. The red lines indicate the orbits in which the minimum charging potential negatively exceeds −1000 V. The number of the orbits is 22 and the < −1000 V charging events are measured only in the eclipse.

3. PLASMA ENVIRONMENT PARAMETERS

To gain some general insight into the flux spectra, we calculate the density and temperature of ions and electrons assuming isotropic distributions. We use Liouville's theorem, which states that the phase space density is conserved along a dynamical trajectory to map the measured fluxes to their values at infinity. In fig.2, the blue data points labelled "Flux displaced to infinity" indicate the flux spectra shifted to infinity. We calculate the density and temperature of ions and electrons in three methods. One is a moment method that calculates the moments of the ion and electron flux spectra shifted to infinity. In the electron calculation, the minimum energy is chosen to filter out the photo electrons and secondary electrons accelerated by local electric fields. The others are the common practice of fitting the shifted flux spectra to single and double Maxwellian distribution functions using the logarithmic least squares fitting method. Table 1 shows the calculated plasma environmental parameters at 06:39(UT) on 21 March 2013, when the maximum charging event of the Van Allen Probes B is measured. At the time, the Van Allen Probes B is in eclipse and its minimum potential is −8,923 V. The same minimum potential is also once detected by of the Van Allen Probes A at 22:20(UT) on 17 March 2013.

4. CHARGING SIMULAION

To simulate the Van Allen Probes surface charging, we use the spacecraft charging analysis software of Spacecraft Plasma Interaction System (SPIS) [5, 6]. The SPIS project aims at developing a software toolkit for spacecraft-plasma interactions modelling. The software is distributed as open source code on the SPIS home page [5].

Table 1. The plasma environmental parameters calculated for the Van Allen Probes B maximum charging event at 06:39 (UT) on 21 March 2013.

		density [cm^{-3}]	temperature [keV]	density [cm^{-3}]	temperature [keV]
Moments	Electron	0.71	15		
	Ion	4.1	11		
Single Maxwellian	Electron	0.24	21		
	Ion	0.32	20		
Double Maxwellian	Electron	0.79	6.4	0.17	25
	Ion	0.23	5.9	0.22	38

Table 2. The spacecraft chassis potential in the NASA worst case environment.

	Model A	Model B	Nascap-2k
Sunlit chassis potential (V)	-6.13	-38.5	3.5
Ecliptic chassis potential (V)	-22.5×10^{3}	-17.3×10^{3}	-22×10^{3}

Table 3. The spacecraft chassis potential in the double Maxwellian plasma environment in table 1.

	Model A	Model B	VAP
Ecliptic chassis potential (V)	-1.2×10^{4}	-8.9×10^{3}	-8.9×10^{3}

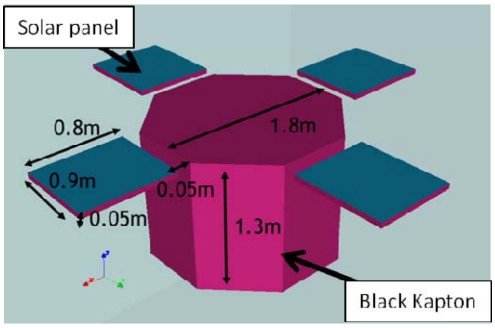

Figure 4. The charging simulation model of the Van Allen Probes.

Fig. 4 shows a charging simulation model of the Van Allen Probes used in this study. The model is a simple one and does not have axial booms and surface instruments, which the Van Allen Probes have. We made two models with different material properties of the solar panel surface. Model A has conductive ITO coating surfaces such as the Van Allen Probes. Model B has nonconductive solar cell surfaces for comparison. All other surfaces are conductive black Kapton conductively tied together with the chassis. Previously, Davis et al. [7] present a surface charging analysis of the Van Allen Probes (Radiation Belt Storm Probe (RBSP)) by Nascap-2k to estimate charging effects on the measurements. Their model has three axial long booms as Van Allen Probes have and is more similar to the Van Allen Probes than our model. They presented the simulated chassis potentials in the NASA Worst Case environment [8] (n_i=1.12 cm^{-3}, T_i=12 keV, n_e=0.236 cm^{-3}, T_e=29.5 keV). We also simulate the chassis potentials of our models in the NASA Worst Case environment. Table 2 shows these potentials. The results of Model A almost agree with the Nascap-2k results and demonstrate the certain validity of our simulation.

Table 3 shows the simulation results in the double Maxwellian plasma environmental parameters in table 1. The ecliptic chassis potential of Model A is deeper than the measured potential but that of Model B is unexpectedly coincident with the measured potential. We think that this discrepancy is caused by the lack of reproducibility of the ambient plasma flux spectra in the double Maxwellian distribution and/or the setting of the surface material parameters.

5. SUMMARY

We study the significant surface charging (< −50 V) events of the Van Allen Probes recorded in the HOPE data. We present that the significant charging orbits are located ~25,000 km further away from the center of the Earth and in the mid-night to dawn region. The significant deep charging (< −1000 V) events are only detected in the eclipse. For the maximum charging event, we simulate the chassis potentials of the VAP models in the calculated plasma environmental parameters using the SPIS software and compare the results with the observed potentials.

Acknowledgments

The authors acknowledge the Radiation Belt Storm Probes ECT Science Operations and Data Center and Van Allen Probes Science Gateway for the use of Van Allen Probes data. The authors acknowledge Spacecraft Plasma Interaction System (SPIS) project. This work was partially supported by the NICT Science Cloud at National Institute of Information and Communications Technology.

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