SPACECRAFT SURFACE CHARGING RISK INDEX IN AURORAL REGION

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ABSTRACT

High level spacecraft surface charging, which is frequently observed in auroral region, may lead to electrostatic discharges and result in significant damage to the satellite. In this letter, we present preliminary results on the relationship between low Earth orbit (LEO) surface charging events and the geomagnetic activity indices. The surface charging events in the auroral regions are identified and listed based on precipitating ion/electron energy spectra and plasma density measured by the Defense Meteorological Satellite Program (DMSP) spacecrafts in the years 2011 and 2012. Furthermore, the charging features (i.e., duration, charging level, location, etc.) are investigated. The correlation coefficients (c.c.) for the four indices including Kp, Ap, Dst, AE and the average charging level are compared. It is found that AE is the best index due to the largest c.c. Besides, Kp is also a good charging proxy due to its simplicity. Since both the above indices can be forecasted through existing models which utilize the upstream solar wind parameters as input. Our results suggest that they can be used to predict the spacecraft surface charging likelihood in the auroral region.

1. INTRODUCTION

Spacecraft charging and the consequent electrostatic discharge (ESD) may lead to satellite anomalies and therefore they appear to be the primary causes of the mission terminations which are related to space environments [1]. For example, modification of environment electrostatic potential induced by surface charging may affect the accuracy of the scientific instruments onboard (i.e., the electrostatic analyser, electric field and wave instrument). The strong current and electromagnetic fluctuations associated with ESD could cause the payload and telemetry failure [2].

Spacecraft charging can be generally categorized as surface or deep dielectric charging. Surface charging is caused by electrons with energies range of several to several tens of keV, whereas electrons with greater energies may penetrate into materials and cause deep dielectric charging [3].

The surface charging of low earth orbit (LEO) satellite and its effects have continued to be the subject of active research since the first event of Defense Meteorological Satellite Program (DMSP) at 840 km is reported [4]. Due to the higher plasma density in LEO compared with geosynchronous orbit (GEO), spacecraft charging within this area is more likely to bring about ESD. In addition to the local plasma environment, surface charging is also affected by the material of the spacecraft and sunlit conditions.

Nine charging events were first documented with frame potential < -100V [4]. These events were found to occur more likely in the darkness when the spacecraft encountered an electron precipitation with the integral number flux of electrons over 14 keV exceeds 108 cm-2s-1sr-1 [4]. 184 charging events of DMSP are identified with frame potential ranging from -46 to -1430 V [5]. It was suggested that the frequency and severity of the surface charging are related to the ambient plasma density which depends on solar cycle. In addition, the ambient plasma density was observed to be less than 104 cm-3 for the event with a frame charging level < -100 V. Another statistical study has revealed over 1600 charging events with the potential exceeding -100 V during auroral region crossings [6]. The authors showed that most of events are located in 65° - 75° MLAT and 1800 - 0200 MLT. In certain cases, the charging level of DMSP were shown to reach an extreme value of -2000 V. Since the precipitating electrons flux in the auroral region is considerably larger during geomagnetic activities, it is believed that the charging events are more likely to occur during times of high geomagnetic activities. The statistical research using Freja data has shown that, as the Kp indices increase, the charging level also shows a slightly increasing trend. Besides, the events with large Kp values could occur in a broader local time sector on the night side [7].

For the purpose of mitigation, it is necessary to estimate the possibility and hazard for the surface charging in real-time or in advance. Therefore, the motivation of this study is to find a set of indices which can be used as proxies for determining the presence and risk of charging events. The geomagnetic indices (i.e., Kp, Ap, Dst, AE) can be forecasted through the existing models which utilize the upstream solar wind parameters, hence they might serve as the right proxies.

2. DATA AND METHOD

Based on two years' data provided by DMSP F16, F17, and F18, we examine the relationship between surface charging severity of DMSP satellites (including charging level and charging duration) and the above indices. Ion and electron energy flux recorded by SSJ/4 instrument onboard DMSP are used. Combining the measurements from F16, F17 and F18, we select 1894 days of data for the analysis.

Previous method of surface charging identification is to find the ion line structures in the spectrogram [4-6]. This method is based on the assumption that when the spacecraft surface is charged, the ambient thermal ions (< 1 keV) tend to be accelerated by the potential difference Φ between the frame and the ambient plasma. As a result, the SSJ/4 instrument grounded to the spacecraft frame may observe a distinct ion flux with energy -qΦ. Following the similar idea, the DMSP charging event is identified by a set of criterions in our study:

(1) Ion line structure in ion spectrogram can be distinguished.
(2) An intense, energetic electron (> 14 keV population) precipitation occurs (flux > 10^8electrons cm -2s -1sr -1).
(3) The spacecraft charging level ranges from -2000 V to -100 V.
(4) The duration of the event is larger than 3 seconds. Multiple charging events with time difference less than 3 seconds are considered as one event.

Fig. 1 shows the ion and electron spectrograms associated with two charging events of DMSP F16 satellite on 2 May 2011. The first event begins at 18:45:17 when the satellite encountering an intense flux of prepetition electrons with a distinguishable ion line structure in the ion spectrogram. The second event shows up at 18:45:33 with its charging level reaching the maximum value of -440 V.

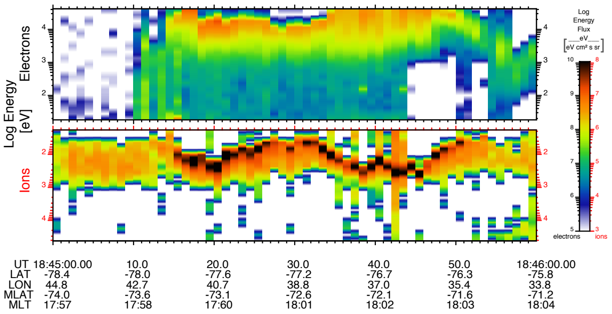

Figure 1. Overview of the F16 surface charging event from 18:45 UT to 18:46 UT on 2 May 2011.

The ion and electron energy flux spectra at 18:45:20 are shown in Fig. 2. The significant flux of ions in the 300 V energy channel is due to the corresponding charging level at about -300 V.

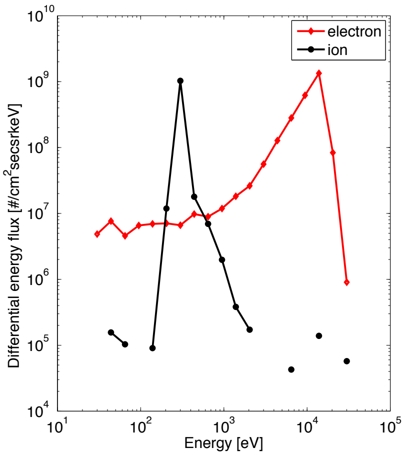

Figure 2. Ion and electron energy flux spectra measured at 18:45:20, 2 May 2011.

3. STATISTICAL RESUTLS

Based on the above criterions, 195 events are identified from the database. The detailed characteristics of these events are listed in Tab. 1.

Table 1. Charging features of the events

	F16	F17	F18
Number of available days	537	630	727
Number of charging Events	72	66	57
Longest Duration (s)	33	38	20
Average Duration (s)	8.3	8.5	7.9
Average Voltage (V)	473	365	521

Fig. 3 illustrates the locations of the 195 charging events of three satellites. Due to the hemispherical asymmetry of the ambient plasma density on DMSP orbits, there is an asymmetry in the charging occurrence frequency of the satellites [6]. The magnetic local time (MLT) and magnetic latitude distribution (MLT) of the events are reflected in Fig 4. They are mainly located in 1800 – 0000 MLT and 65° -75°MLT, which is in agreement with the intense precipitation region of the energetic elections associated with auroral arcs.

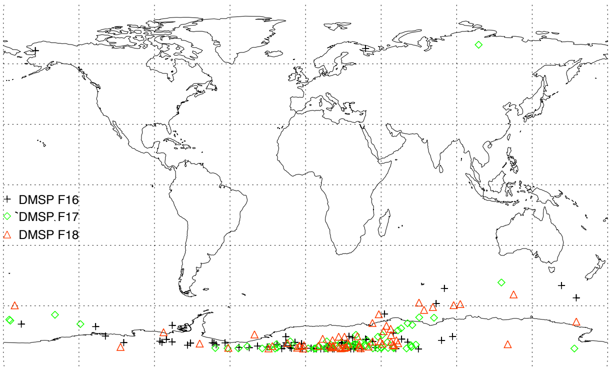

Figure 3. Locations of the charging events.

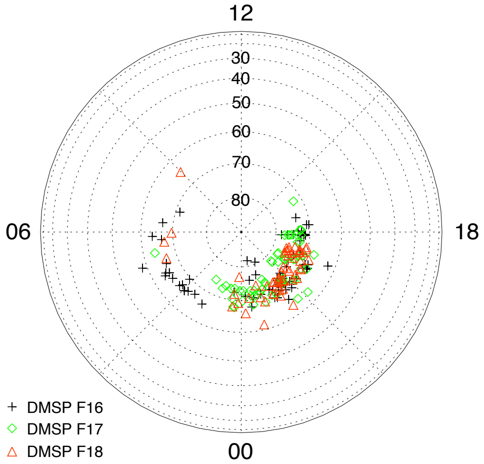

Figure 4. Distribution of the charging events in MLT and MLAT.

Fig. 5 shows the histograms of geomagnetic indices distribution of charging events. It can be seen that the charging events are primarily located near the rages 2<Kp<3, Ap <10, -20<Dst<0, AE <600. To account for the distribution of these indices in the dataset, we have divided the number of events by the number of indices in each bin. Fig. 6 shows the normalized charging frequencies as a function these geomagnetic indices. It is clear that the normalized charging frequency shows an increasing trend as Kp, AE increase.

As the severity of an event can be represented by the maximum charging level of the event, the relationship between the levels of frame charging and value of geomagnetic indices Kp and AE are examined. By excluding the most severe cases of AE (>1100), we have divided the values of AE index into 11 bins with the interval of 100. Similarly, the value of Kp index ranging from 0 to 7 are divided into 8 bins. The index value and event charging levels of every bin are also averaged to compute the correlation coefficient.

Fig. 7 shows the scatter plot of average charging level as a function of index value, together with the corresponding cc. It is found that the average charging levels are strongly correlated with Kp and AE indices, with their coefficients equals to 0.8 and 0.85, respectively.

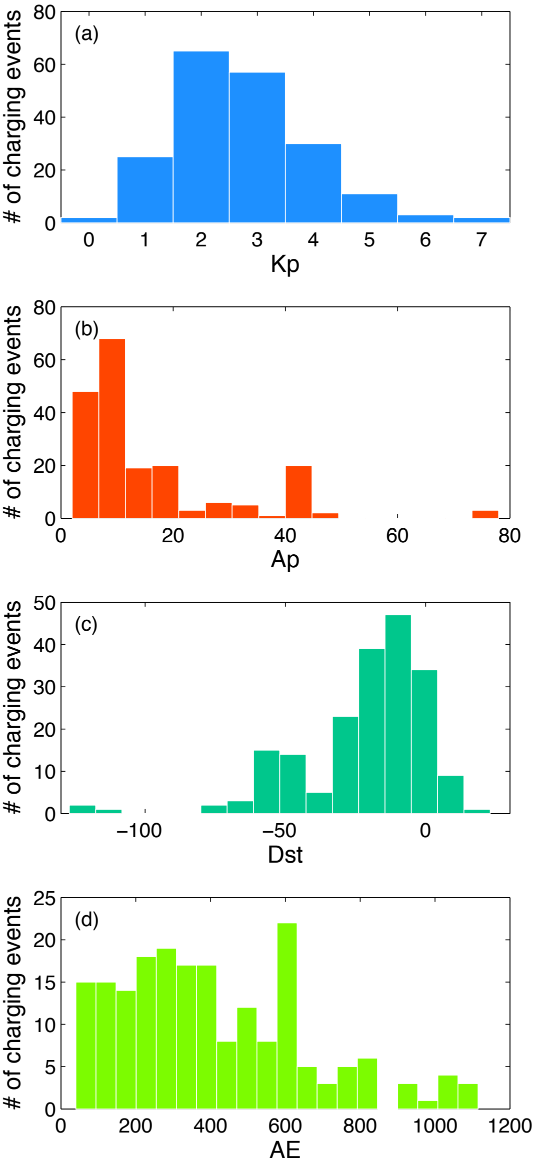

Figure 5. Histograms of the number of charging events as a function of the geomagnetic Kp, AP, Dst, and AE indices.

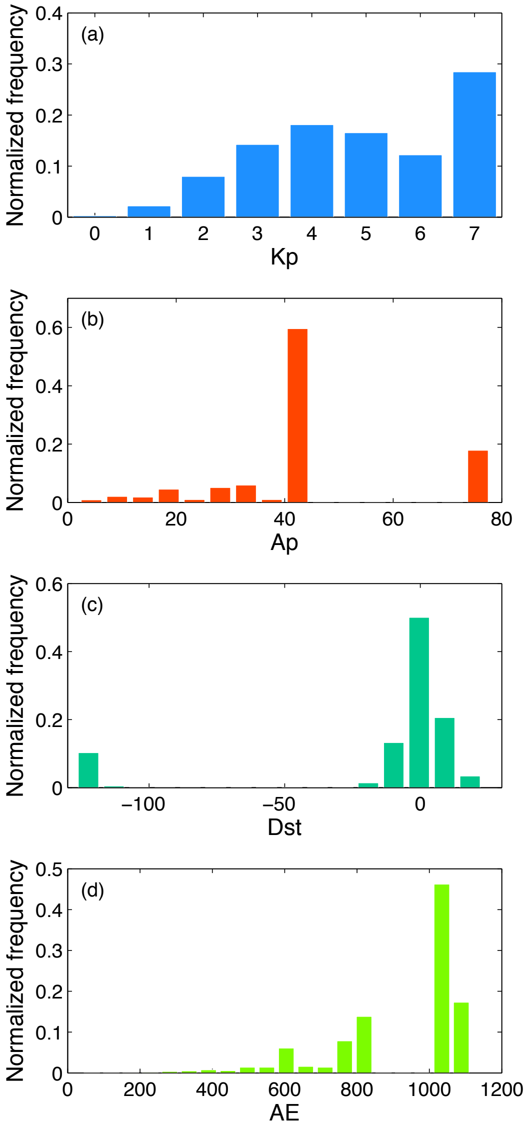

Figure 6. Histograms of the normalized charging frequency as a function of the geomagnetic Kp, AP, Dst, and AE indices.

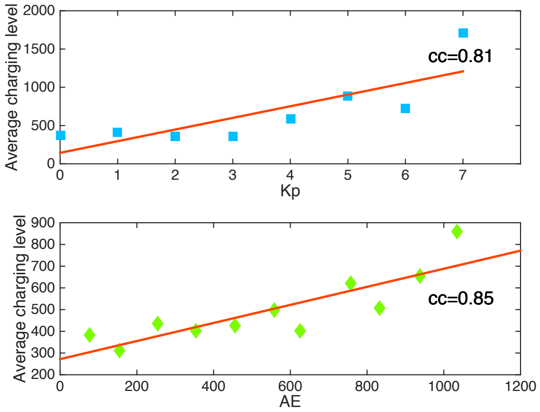

Figure 7. Scatter plot of average charging level as a function of Kp and AE indices.

4. SUMMARY AND DISCUSSION

The spacecraft surface charging risk index in auroral region is searched by statistically investigating the relationship between the charging features and the geomagnetic indices distributions. A better correlation was obtained for Kp and AE, indicating that they could be used in the estimation of DMSP surface charging level. However, the dataset in this letter covers only the maximum of the solar cycle. In the near future, we are planning to build a larger database (i.e., using multi satellite measurements) to better evaluate and quantify the relation between the surface charging process and the space environment effects.

5. REFERENCES

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