DMSP Auroral Charging at Solar Cycle 24 Maximum

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Abstract

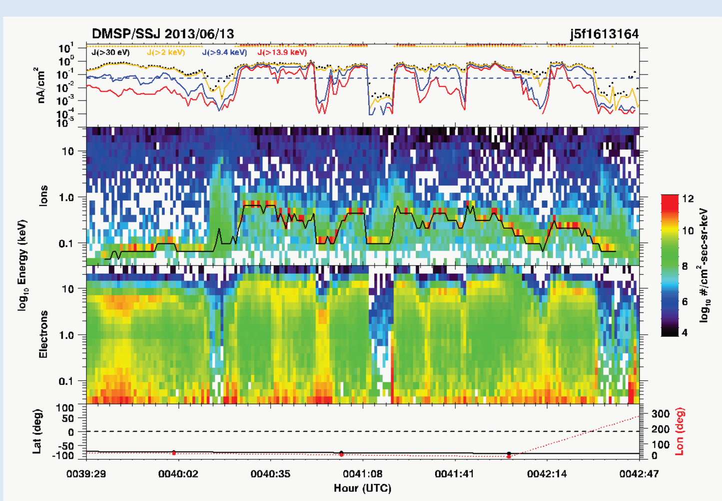
It has been well established that polar orbiting satellites can experience mild to severe auroral charging levels (on the order of a few hundred volts to few kilovolts negative frame potentials) during solar minimum conditions (Frooninckx and Sojka, 1992; Anderson and Koons, 1996; Anderson, 2012). These same studies have shown a strong reduction in charging during the rising and declining phases of the past few solar cycles with a nearly complete suppression of auroral charging at solar maximum. Recently, we have observed examples of high level charging during the recent approach to Solar Cycle 24 solar maximum conditions not unlike those reported by Frooninckx and Sojka (1992). These observations demonstrate that spacecraft operations during solar maximum cannot be considered safe from auroral charging when solar activity is low. We present a survey of auroral charging events experienced by the Defense Meteorological Satellite Program (DMSP) F16 satellite during Solar Cycle 24 maximum conditions. We summarize the auroral energetic particle environment and the conditions necessary for charging to occur in this environment, we describe how the lower than normal solar activity levels for Solar Cycle 24 maximum conditions are conducive to charging in polar orbits, and we show examples of the more extreme charging events, sometimes exceeding 1 kV, during this time period.

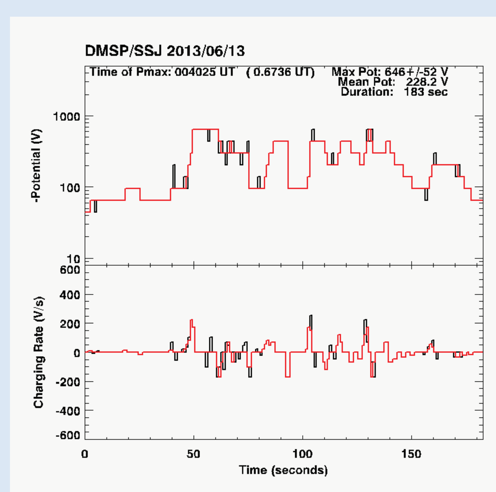
Conditions Required for Auroral Charging

1. Satellite is in darkness
2. An intense, energetic electron (> 14 keV population) precipitation event is required (flux > 10^8 electrons cm^{-2} s^{-1} sr^{-1})
3. Locally depleted (< 10^4 cm^{-3}) ambient plasma density

Surface charging is the result of a current balance on the surface of a spacecraft. The currents of importance to surface charging are: *Incident ions, incident electrons, backscattered electrons, conduction currents, secondary electrons, photoelectrons, and active current sources (beams, thrusters).*

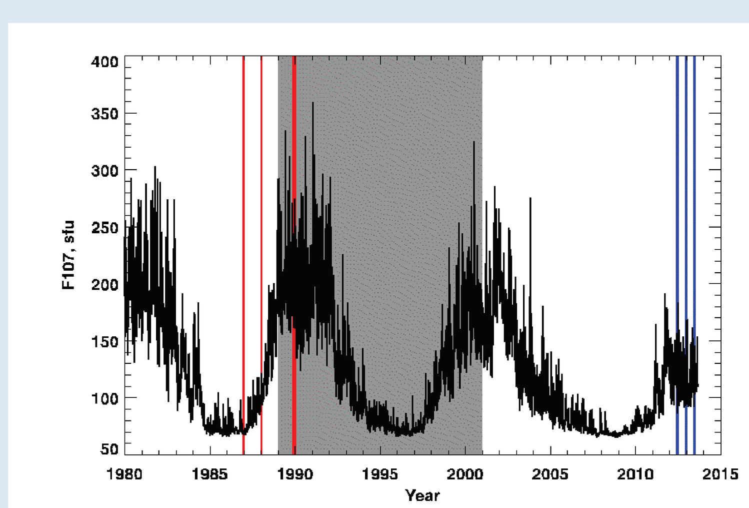
Auroral charging is readily identified from the "ion line" signature that appears in ion electrostatic analyzer records. The ion line is the result of ambient low energy ions accelerated by the spacecraft potential from an initial energy E_0 to a final energy $E = E_0 + q\phi$ where q is the charge of the ion and ϕ the spacecraft surface potential in volts.





Solar Cycle

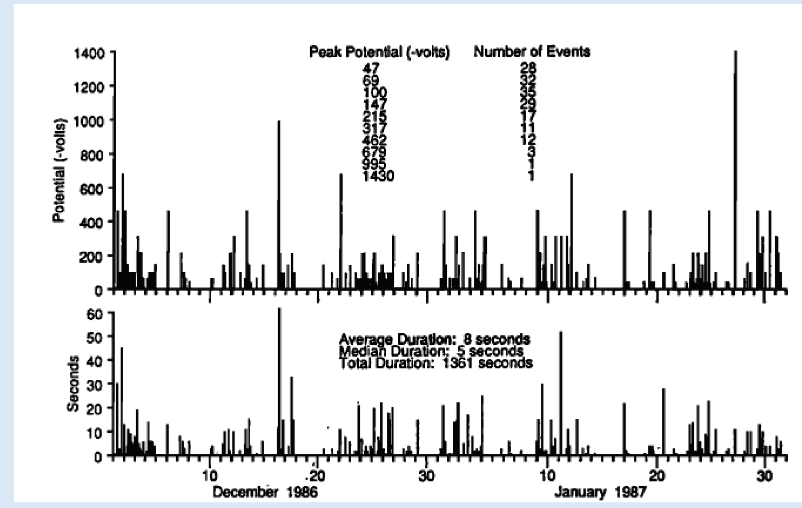
The F10.7 index as a function of time showing solar variability over the current and recent solar cycles. Depleted electron densities resulting in stronger auroral charging is typically expected during solar minimum when solar EUV levels are low.



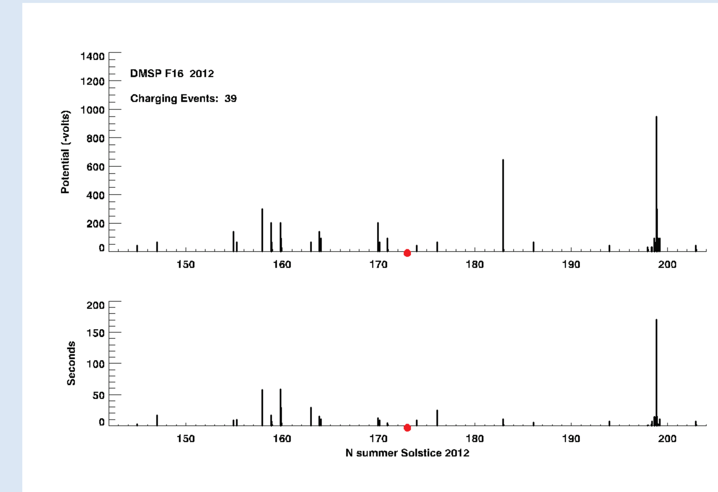
Auroral Charging Study Periods

Red	Frooninckx and Sojka, 1992
Grey	Anderson, 2012
Blue	current study

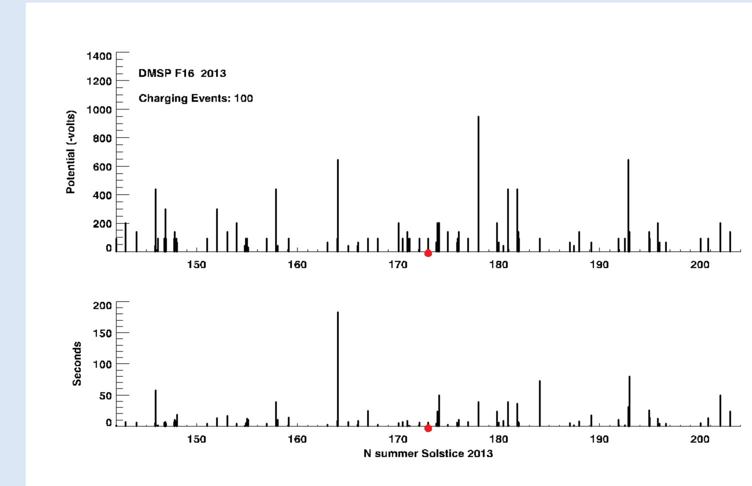
Frequency and Distribution of Auroral Charging



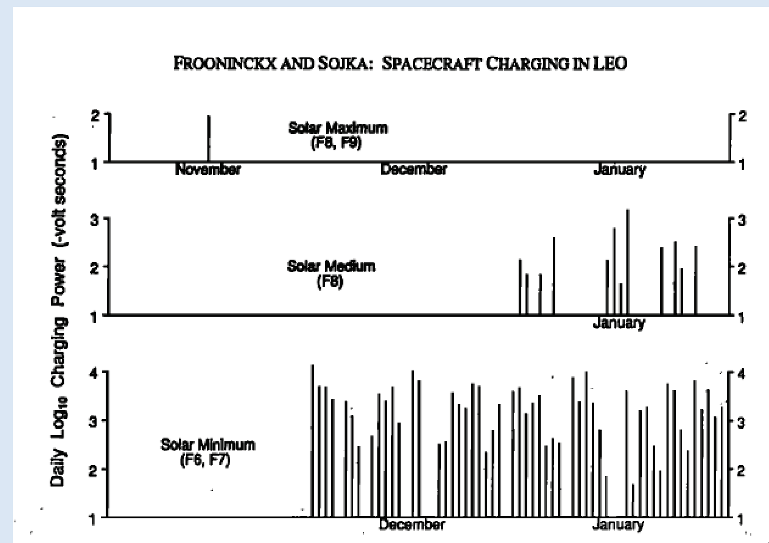
(a) DMSP Charging Frequency
December 1986 – January 1987



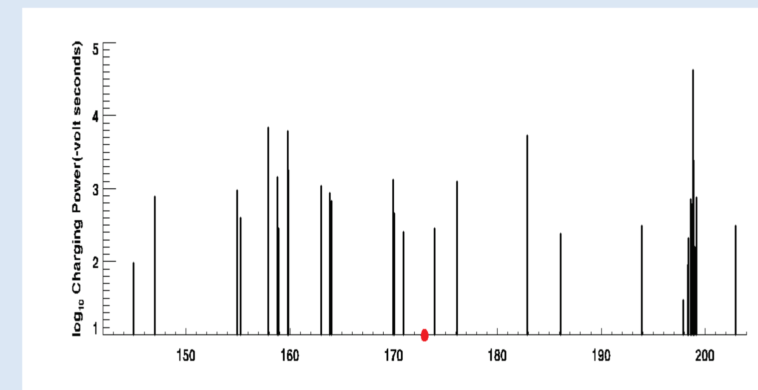
(b) DMSP Charging Frequency
May 21 – July 21, 2012



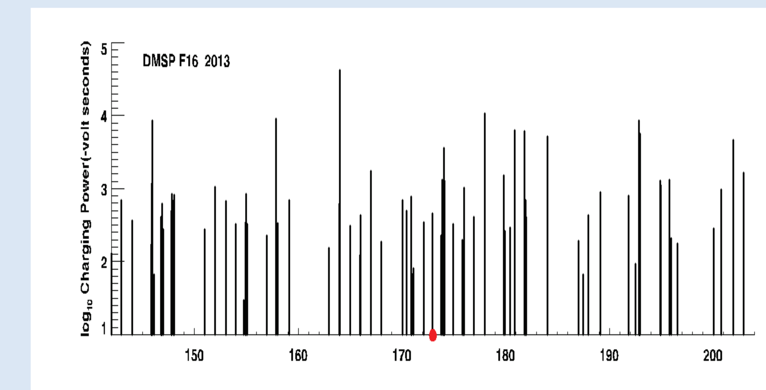
(c) DMSP Charging Frequency
May 21 – July 21, 2013



(d) Distribution of DMSP Charging Events



(e) DMSP Charging Power
May 21 – July 21, 2012



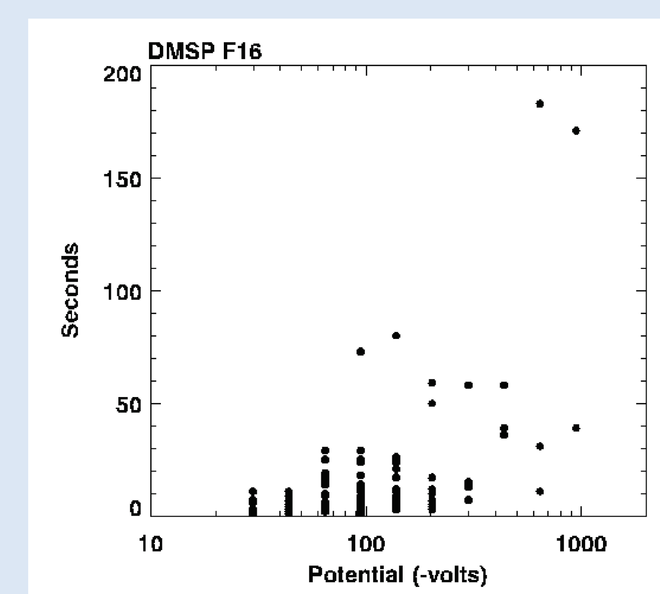
(f) DMSP Charging Power
May 21 – July 21, 2013

Figures (a), (b), and (c) are the maximum charging potential (top panel) and charging duration (lower panel). Figures (d), (e), and (f) are the charging power for each event. Figures (a) and (d) are from Frooninckx and Sojka, 1992. Charging events were observed for the June, 2012 solstice in southern hemisphere winter conditions, but no charging events were observed for the December, 2011 northern hemisphere winter solstice.

Auroral charging is most common during solar minimum conditions and most commonly encountered in the midnight sector of the auroral oval (Frooninckx and Sojka,1992; Wahlund et al. 1999; Ericksson and Wahlund, 2005; Anderson 2000, 2001,2012). However, we find that auroral charging events continue to occur on DMSP F16 for the current near solar maximum conditions of Solar Cycle 24. The relatively low activity of Cycle 24 compared to the recent cycles included in the previous studies results in sufficiently low ambient plasma densities to allow auroral charging to persist through the current solar maximum.

Conclusions

- Examples shown here result from an effort to characterize extreme auroral charging events. These events are encountered infrequently by spacecraft in polar low Earth orbit but are the kind of event that drive spacecraft design. We focus on the extreme potentials, duration the potentials exceed a threshold value, and mean potentials because the information is needed by spacecraft designers for evaluating the response of the spacecraft to the charging environment.
- Past studies have reported auroral charging events predominantly during solar minimum conditions. However, we have observed charging events on DMSP F16 of nearly -1000 V during the approach to solar maximum conditions due to the lower than average solar activity in Solar Cycle 24. We focus this study on the solstices (Nov, 2011 - Jan, 2012, May - July, 2012, and May - July, 2013) due to the larger likelihood of encountering charging events in order to document auroral charging for Solar Cycle 24 solar maximum conditions.
- Temporal variations of the spacecraft potential through a charging event are important since extreme potentials are generally only a subset of the charging event.
- Frame potentials may reach kilovolt levels in auroral charging environments, but the duration of charging at these most extreme levels are limited to periods of a few seconds to perhaps ten to fifteen seconds
- Mean potentials over the period of a charging event never exceed a few hundred volts
- No charging events were seen in the northern hemisphere winter months for periods included in this study



May 21 – July 21, 2012; 2013

Future work will include time periods from Solar Cycle 24 not included in this study to more fully characterize the auroral charging environment for this solar maximum period. A paper to Geophysical Research Letters is in work.

Summary

Date	Time (UT)	Φmax (volts)	<Φ > (volts)	Duration (s)
23-May-12	22.6881	44±4	33.5	3
25-May	23.9258	65±5	45.2	17
2-Jun	22.225	139±11	101.5	9
	22.235	95±8	58.4	3
3-Jun	6.7517	65±5	39.5	10
5-Jun	21.5981	300 ± 24	115.1	58
6-Jun	19.7069	204±16	81.9	17
	21.3517	44±4	39.3	7
	21.3972	65±5	44	6
7-Jun	19.4814	204±16	102.4	59
	21.1367	95±8	60	29
10-Jun	23.8917	65±5	37.7	29
11-Jun	20.305	139±11	86.2	9
	20.3161	65±5	48	5
	20.3253	65±5	57.1	15
	20.3342	65±5	50.1	14
	23.7486	95±8	60.1	11
17-Jun	22.4333	204±16	101	12
	22.4569	65±5	42.3	3
18-Jun	1.7456	65±5	50.3	9
	22.1944	95±8	61	4
21-Jun	23.2086	44±4	31.3	9
24-Jun	2.2047	65±5	49.4	25
30-Jun	21.3475	646±52	451.7	11
4-Jul	1.7736	65±5	47	5
11-Jul	22.3686	44±4	44	7
15-Jul	21.5672	30±2	30	1
16-Jul	7.8097	30±2	30	3
	9.5275	30±2	30	7
	14.585	95±8	51.1	14
	14.5931	95±8	71.9	8
	16.2336	65±5	44.9	14
	19.5694	949±76	243.8	171
	21.2844	95±8	67.3	3
	21.2903	300±24	147.6	15
17-Jul	0.5656	95±8	57	3
	4.1678	95±8	66.4	11
20-Jul	22.1242	44±4	44	7
22-May-13	1901	95±8	53.3	3
22-May	222900	65±5	53.8	3
	222917	204±16	94.8	7
	222942	44±4	41.2	3
23-May	235546	95±8	68	4
	235705	139±11	56.6	6
25-May	201017	44±4	34	5
	214729	139±11	74.4	9
	214832	95±8	63.8	18
	214932	440±35	145.5	58
26-May	25735	95±8	49.8	2
	180505	30±2	30	6
	181535	95±8	68.4	6
	195650	65±5	50	6
	213727	300±24	75.8	7
	231203	95±8	60.7	4
27-May	180313	95±8	67	7
	194357	139±11	75.9	11
	230633	95±8	74	9
28-May	4531	65±5	50.4	10
	4556	65±5	44	19
31-May	628	95±8	66.8	4
	235649	300±24	78.4	13
2-Jun	12700	139±11	38.3	17
	232345	204±16	69.8	4
3-Jun	181310	44±4	34.7	1
	212648	95±8	64.5	5
	230858	95±8	70.1	12
4-Jun	23759	30±2	30	11
5-Jun	224451	95±8	50.2	4
6-Jun	205809	440±35	221	39
7-Jun	2243	44±4	31.2	11
8-Jun	32645	95±8	49.7	14
11-Jun	231030	65±5	48.2	3
12-Jun	225401	95±8	72.9	9
13-Jun	4025	646±52	228.2	183
	4446	65±5	59	5
14-Jun	2945	44±4	44	7
	222738	44±4	40.5	3
15-Jun	1033	65±5	46.8	9
	1747	65±5	60.8	4
16-Jun	220	95±8	68	25
	234943	95±8	52.8	3
19-Jun	10246	204±16	120.9	5
	10731	139±11	81.6	4
	10750	44±4	44	2
	111726	95±8	72.5	7
	111745	95±8	95	1
	213114	139±11	80.7	9
	231233	95±8	68	1
20-Jun	23421	95±8	68	1
21-Jun	22040	95±8	52.1	6
	224654	95±8	68.4	6
22-Jun	191231	65±5	54.5	4
	205344	65±5	45.4	4
	205404	204±16	93.6	3
	205414	95±8	54	24
23-Jun	1329	44±4	40	5
	1408	204±16	68.8	10
	15344	204±16	73.8	50
	20019	139±11	60.3	21
	221859	139±11	92.2	3
24-Jun	202601	65±5	35	6
	202649	65±5	42.3	3
	220728	95±8	55	3
	234913	139±11	89.4	11
25-Jun	215530	95±8	58.3	7
26-Jun	232446	949±76	267.8	39
28-Jun	193757	204±16	102	3
	193815	139±11	62.9	24
	225920	65±5	43.1	6
29-Jun	104745	44±4	33.8	9
	210128	440±35	160.3	39
	210207	65±5	56.3	3
30-Jun	190948	440±35	168.8	36
	223242	139±11	90.7	7
	223307	139±11	87.6	4
1-Jul	1117	95±8	80	5
3-Jul	12808	95±8	71.4	73
6-Jul	5208	65±5	41.7	2
	5228	44±4	37	5
	111327	44±4	34.7	2
	225701	139±11	52.1	8
8-Jul	35208	65±5	49.3	18
10-Jul	202517	95±8	70.3	11
11-Jul	114926	95±8	51.7	2
	201138	646±52	261.2	31
	215140	44±4	41.7	4
	233234	139±11	71.4	80
13-Jul	212551	139±11	48.6	26
	230638	65±5	49.6	3
	230751	95±8	75.5	14
14-Jul	192108	204±16	103.4	12
	224823	65±5	48.2	4
	225543	65±5	49.6	4
15-Jul	140805	65±5	47.5	4
19-Jul	12806	95±8	53.3	5
	182747	95±8	74.2	13
20-Jul	231750	204±16	91.7	50
21-Jul	230005	139±11	66.9	24