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Forecasting the impact of an 1859-calibre superstorm on satellite resources

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Abstract

We have developed simple models to assess the economic impacts to the current satellite resource caused by the worst-case scenario of a hypothetical superstorm event occurring during the next sunspot cycle. Although the consequences may be severe, our worse-case scenario does not include the complete failure of the entire 937 operating satellites in the current population, which have a replacement value of ∼\$170–230 billion, and supporting a ∼\$90 billion/year industry. Our estimates suggest a potential economic loss of <\$70 billion for lost revenue (∼\$44 billion) and satellite replacement for GEO satellites (∼\$24 billion) caused by a 'once a century' single storm similar to the 1859 superstorm. We estimate that 80 satellites (LEO, MEO, and GEO) may be disabled as a consequence of a superstorm event. Additional impacts may include the failure of many of the GPS, GLONASS, and Galileo satellite systems in MEO. Approximately 97 LEO satellites, which normally would not have re-entered for many decades, may prematurely de-orbit by ca 2021 as a result of the temporarily increased atmospheric drag caused by a superstorm event occurring in ca. 2012. The \$100 billion International Space Station may lose significant altitude, placing it in critical need for re-boosting by an amount potentially outside the range of typical Space Shuttle operations, which are in any case scheduled to end in 2010. Currently, the ability to forecast extreme particle events and coronal mass ejections, or predict their fluences and geoseverity in the 24-h prior to the event, appears to be no better than 50/50. Our analysis of economic impacts is a first attempt at estimation whose approach will suggest ways in which better estimates may eventually be obtained.

Keywords: Space weather; Satellite anomalies; Satellite failures; Technology impacts; Superstorms; Radiation sickness; Economic impacts

1. Introduction

Considerable attention has been paid to the many ways in which space weather can compromise satellite operations. A general overview is provided by Odenwald (2000, 2005a). In addition, Baker (1986) and Allen and Wilkinson (1993) have assembled and analyzed satellite anomaly databases. Belov et al. (2004) and Iucci et al. (2005) have analyzed these, and other, anomaly databases in the context of various space weather drivers. Satellites appear to be remarkably robust against most space weather events encountered during the last 30 years, however, recent studies of historical events show that even more violent solar and geomagnetic storms are possible for which we have, as yet, no experience. During the current sunspot cycle (1996–2005), approximately 15 satellites have been damaged at a cost of ∼\$2 billion as a consequence of severe space weather events (Odenwald, 2000). Although the economic impacts have been minimal, and largely recovered through satellite insurance, a reasonable question to ask is, what is the upper bound to economic losses from a truly extreme space weather event?

The paper is organized as follows: Section 2 defines the physical scale of a hypothetical superstorm; Section 3 discusses the economic dimensions of the commercial satellite resource; Section 4 quantifies, so far as is possible, the likely space weather influences that can be expected to play a dominant role in satellite functioning following a worst-case superstorm event; Section 5 assesses the consequences

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of these influences through a series of simple models; and in Section 6 we will draw conclusions based on these models by providing a possible scenario for a superstorm.

2. Historic storms

A recent study of historical solar storms by Cliver and Svalgaard (2005) compared more than 50 major storms identified by their geomagnetic indices, Solar Proton Events (SPEs), and Coronal Mass Ejection (CME) speed. One storm stands out as the most impressive of all, namely the August–September 1859 Carrington-Hodgson event described in considerable detail by the Editors of the American Journal of Science (1859, 1860) and by Loomis (1860, 1861) and more recently by Green and Boardsen (2005), Green et al. (2005) and Tsurutani et al. (2003). It is often called a 'superstorm' because of its remarkable strength and global impact.

A study by Cliver and Svalgaard (2005) of the major space weather 'storms' since 1859 reveals a rather broad ranking of these events across the many physical parameters that characterize these events. Of these events, they have concluded that the Carrington-Hodgson 1859 storm appears as the most extreme event in nearly all categories.

The study of the record of historic solar proton events (SPEs) during the last 500 years by McCracken et al. (2001a,b) reveals over 125 such events that have left their traces in the nitrite abundances of polar ice cores from Antarctica, Greenland, and the Arctic Region. The strongest of these, once again, coincided with the 1859 Carrington-Hodgson storm and white-light flare, and produced an equivalent fluence of 1.88×10^{10} particles/cm^2. The July 14, 2000 Bastille Day solar proton event (SPE) by comparison had a fluence of 6.3×10^9 particles/cm^2 for protons with $E > 30$ MeV, and was observed to cause a 2% power decline in the SOHO satellite (Brekke et al., 2004).

McCracken et al. (2001b) have identified the solar activity cycles during the satellite era as being uncharacteristically weak in SPE events and fluences compared to the historical record of these events since the year 1567. The frequency of large events with >30 MeV fluences> 2×10^9 particles/cm^2 between 1964 and 1996 averages one event per sunspot cycle, while 6–8 such events occurred for sunspot cycles near the years 1605 and 1893. The integrated fluence of the largest five SPEs between 1830 and 1910 was 5.49×10^{10} particles/cm^2 compared with only 6.7×10^9 particles/cm^2 during the years 1910–1985. In particular, the satellite era (1967–1994) ranks sixth lowest in the integrated fluences of the strongest 6–8 SPEs. The implication is that, during the last 400 years, the sun is most certainly capable of producing a substantially more active satellite environment than what we have come to accept in recent decades. Depending on the assumptions made about the spectral hardness of the Carrington-Hodgson event, the fluence for >30 MeV protons may have reached levels near 3.6×10^{10} particles/cm^2. Currently, this is considered to be a worst-case event (Townsend, 2003), but are even stronger events possible?

Reedy (1998) examined isotopic abundances in lunar rock surface layers to estimate the SPE fluence distributions for the last few million years. Apparently, the upper limits suggest that there have been no flares with fluences more than what has resulted from 10-times the average of flares seen during the last few decades. The 1859 flare is only three-times more luminous than flares seen in recent decades, suggesting that the distribution of SPE fluences has a sharp turnover at levels just above the 1859-level. We can then assume that a storm more than three times as intense as the 1859 event is a reasonable upper limit 'worst case' event. This means the brightest SPE may have a fluence of about 5.6×10^{10} particles/cm^2. Once again, these events averaged over several million years are substantially less common than the 1859 event. Nevertheless, they represent an upper limit on the true worst case superstorm event, and so we will use this flux in the discussions to follow as an upper bound to what we could expect from a single, extreme space weather event.

A list of SPEs and their fluxes between 1976 and 2004 was obtained from NOAA (2004). Table 1 summarizes this SPE history in terms of the peak proton fluxes of the strongest events each year, along with its date and associated flare, if any. We note that SPE events and, for example, X-class solar flares are not always correlated. The SPE

Table 1
SPE fluxes for 1976–2004

Year	Peak	Date	X-flare
1976	12 pfu	May 1	X2
1977	200	September 19	X2
1978	2200	September 23	X1
1979	950	June 7	X2
1980	100	July 19	M3
1981	2000	October 13	X3
1982	2900	July 13	X9
1983	340	February 4	X4
1984	2500	April 26	X13
1985	160	April 26	X1
1986	130	February 14	X1
1987	120	November 8	M1
1988	92	January 3	X1
1989	40,000	October 20	X13
1990	950	March 19	X1
1991	43,000	March 24	X9
1992	4600	May 9	M7
1993	44	March 13	M7
1994	10,000	February 21	M4
1995	63	October 20	M1
1996	0	—	—
1997	490	November 7	X9
1998	1700	April 21	M1
1999	64	June 4	M3
2000	24,000	July 15	X5
2001	31,700	November 6	X1
2002	2520	April 21	X1
2003	29,500	October 29	X17
2004	2086	July 26	M1