Forecasting Solar Storms in Solar Cycles 24 & 25

[Abstract] Solar storm data was analyzed revealing a sunspot cycle phase dependency. Solar cycle 24 is unlikely to spawn many solar storms that produce major geomagnetic storms having a Dst strength greater than -300 nT. Solar cycle 25 is likely to spawn several solar storms resulting in major geomagnetic storms with the highest concentrations between the years ~ 2022 and 2025. Great solar storms which produce great geomagnetic storms having a Dst strength greater than -400 nT are rare. They appear in equal numbers in either phase of the solar sunspot cycle. If a great solar storm materializes in solar cycle 24, it will most likely occur between the years ~ 2009 and 2011. If a great solar storm materializes in solar cycle 25, it will most likely occur between the years ~ 2022 and 2026.

Background

The sun undergoes a cyclical (~22 year) pattern of magnetic pole reversals observable in sunspot activity. This pattern is comprised of two ~11 year solar cycles phases. In the first phase, the sun's magnetic poles reverse polarity. In the second phase, the sun reverses the magnetic polarity again returning the poles back to its original polarity.

Sunspots are the site of origin for great solar storms that can produce solar flares, solar proton events (SPEs) and coronal mass ejections (CMEs). CMEs can generate geomagnetic storms on Earth. Great solar storms are a threat to Earth. The Earth is poised this year (2007) to enter Solar Cycle 24. This paper analyzes past cycles to provide an assessment and forecast for solar storm activity in cycles 24 & 25.

Analysis #1

Solar storm activity can be described by the intensity of the solar flares produced, the arrival time of SPEs, the solar proton fluence, the magnetic intensity of the disturbance on Earth, the arrival time of the CMEs and various other metrics. But measured data using these parameters have very limited timelines. This paper uses the intensity of the geomagnetic storm on Earth to assess the intensity of solar storms and the cycle of storms. This approach was selected because the geomagnetic effects are a major indicator of storm intensity and because the measured data timeline goes back the furthest in time to the year 1957.

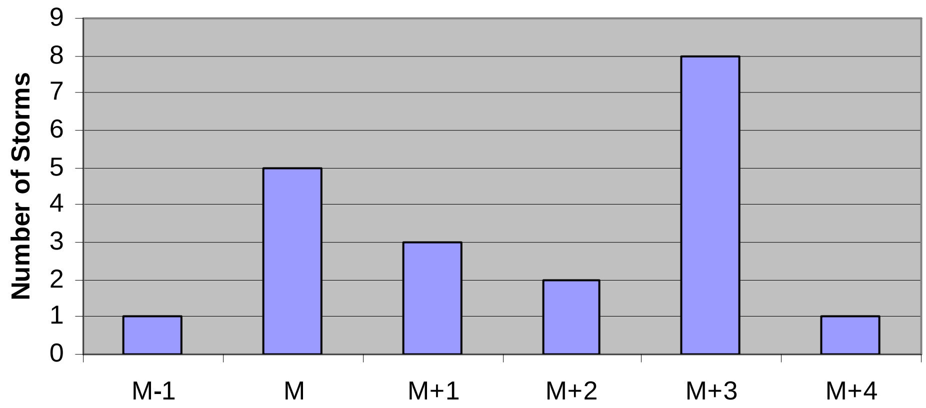
The Geomagnetic Storm database at the World Data Center for Geomagnetism, Kyoto was analyzed for major geomagnetic storms between January 1957 to April 2007.[1] This analysis identified 21 major geomagnetic storms with a Disturbance Storm Time (Dst) strength of - 300 nano-Tesla (nT) or greater. The Dst index is a measure of the variation in the horizontal component of Earth's magnetic field. Dst is a good indicator of the severity of a solar storm. The Dst metric is based on the peak hourly value of the Equatorial Dst Index. This listing is provided as Table 1. The storms were then correlated to their respective position within their respective solar cycles. The International Sunspot Number data at the National Geophysical Data Center was used to determine the sunspot cycle maximum (M) for each solar cycle. [2]

Table 1. Major Geomagnetic Storms
January 1957 – April 2007

Date of Storm	Strength of Geomagnetic Storm - Disturbance Storm Time (Dst) (nano-Teslas) [1]	Position of Geomagnetic Storm in Relationship to Solar Sunspot Cycle [2]
September 5, 1957	- 324 nT	M
September 13, 1957	- 427 nT	M
September 23, 1957	- 303 nT	M
February 11, 1958	- 426 nT	M+1 year
July 8, 1958	- 330 nT	M+1 year
July 15, 1959	- 429 nT	M+2 years
April 1, 1960	- 327 nT	M+3 years
April 30, 1960	- 325 nT	M+3 years
November 13, 1960	- 339 nT	M+3 years
May 25/26, 1967	- 387 nT	M-1 year
April 13, 1981	- 311 nT	M+2 years
July 14, 1982	- 325 nT	M+3 years
February 9, 1986	- 307 nT	Outside
March 13/14, 1989	- 589 nT	M
November 9, 1991	- 354 nT	M+3 years
July 16, 2000	- 301 nT	M
March 31, 2001	- 387 nT	M+1 year
October 29/30, 2003	- 353 nT	M+3 years
October 30/31, 2003	- 383 nT	M+3 years
November 20/21, 2003	- 422 nT	M+3 years
November 8, 2004	- 373 nT	M+4 years

The number of major geomagnetic storm was then plotted as a function of their relationship to the solar sunspot cycle. This produced Figure 1. The results show that solar storm activity is concentrated in the period from one year before solar sunspot maximum to four years after solar sunspot maximum. The peak years for major geomagnetic storms occur at M and M+3 years. [The solar storm of February 9, 1986 was excluded from this graph as an outlier. This storm occurred during a solar minimum].

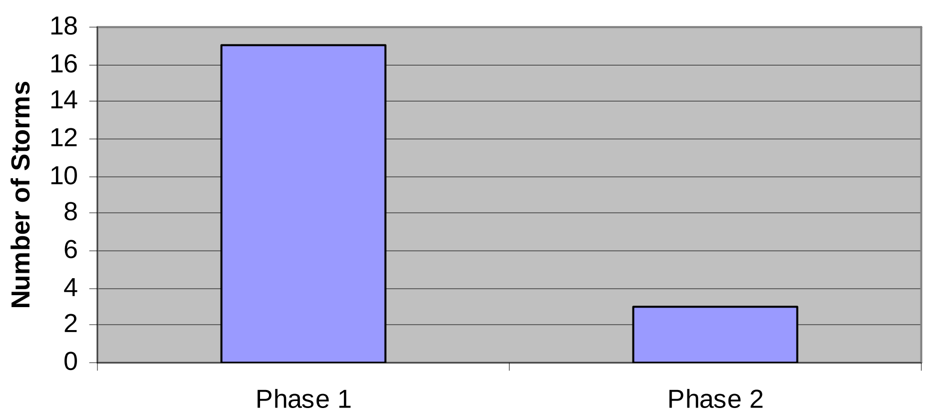
Figure 1. Geomagnetic Storm Distribution over Sunspot Cycle



The full sunspot cycle is divided into two phases, each approximately 11 years in length. It has been suggested that the intensity of the solar storms may not be equal between the two phases. The Phase 1 solar cycle was arbitrarily selected beginning with the sunspot maximum year 1870 and the Phase 2 solar cycle beginning in 1860. Phase 1 solar cycle was associated with sunspot maximum years: 1870, 1893, 1917, 1937, 1957, 1979 and 2000. Phase 2 solar cycle was associated with sunspot maximum years: 1860, 1883, 1905, 1928, 1947, 1968 and 1989.

The geomagnetic storms from 1957-2007 with Dst strength greater than - 300 nT were coded as either Phase 1 or Phase 2 geomagnetic storms. The result is displayed in Figure 2. The graph shows that geomagnetic storms are concentrated in far greater numbers during Phase 1 than during Phase 2.

Figure 2. Geomagnetic Storms by Sunspot Cycle Phase



The International Sunspot Number data at the National Geophysical Data Center was analyzed from the solar maximum of 1848 to the solar maximum of 2000.[2] On average there is 3.79

years from a solar sunspot minimum to the next solar sunspot maximum. There is 7.07 years between a solar sunspot maximum to the next solar sunspot minimum. There is approximately 10.86 years between solar sunspot maximums.

Based on the average length of solar cycles, the next Phase 2 (Solar Cycle 24) sunspot maximum (M) is estimated to occur in the year 2011. The next Phase 1 (Solar Cycle 25) sunspot maximum (M) is estimated to occur in the year 2022. The peak of sunspot activity (M) has some variability between consecutive cycles. In general, this variability has an order of magnitude of approximately ± 1 year. Since the actual value of next Phase 1 & 2 M is unknown at this time. This forecast will define the next Phase 2 Solar Sunspot Maximum as the year *2011 ± 1 year* and the next Phase 1 Solar Sunspot Maximum as the year *2022 ± 1 year*.

Forecast (1): Solar cycle 24 is <u>unlikely</u> to spawn many solar storms that produce major geomagnetic storms having a Dst strength greater than - 300 nT. Solar cycle 25 is <u>likely</u> to spawn several solar storms resulting in major geomagnetic storms with the highest concentrations between the years ~2022 and 2025 (M and M+3).

<u>Analysis #2</u>

On rare occasions Great Solar Storms can materialize. The storm of September 1859 is an example. It is the only observed solar storm to produce a white light flare on the sun. Analysis of nitrate spikes in polar ice indicated this solar storm produced the largest SEP event recorded during the years 1561 to 1992 with an omni-directional solar proton fluence of 2×10^{10} cm^{-2}.[3] The storm had the fastest CME arrival time ever measured of 17 hours and 40 minutes.[4] The CME produced the greatest geomagnetic disturbance observed on the planet with a Dst of - 1,760 nt.[4] If this solar storm were to reoccurred today, it would produce significant infrastructure damage around the world dramatically effecting our highly technological society. For this reason, a second analysis was conducted to evaluate the probability of a Great Solar Storm within Solar Cycle 24 & 25.

Lakhina et al. analyzed great solar storms of the past. They identified 14 great geomagnetic storms that occurred over the past 150 years.[4] These storms are listed in Table 2. In general, they included storms producing a geomagnetic disturbance Dst greater than - 400 nT. Because Dst metrics did not go back further than the year 1957, they used “H Range” data and “Geographic location of the measuring site” to identify the great geomagnetic storms between 1859 and 1956. One solar storm on their list (October 30, 2003) was originally identified with a Dst of - 406 nT which was subsequently reassessed downward to - 383 nT and should therefore drop off the list. I retained this storm on the list because on November 4 the storm produced the largest measured solar flare, X45 ever observed.[5]

I correlated these great storms to the phase and position within the solar sunspot cycles. The great geomagnetic storms do not appear to favor one phase over the other. The frequency of storms was plotted for each phase. These are provided as Figures 3 & 4. These graphs show that frequency is localized differently within each phase.

Forecast (2): Great solar storms that produce great geomagnetic storms having a Dst strength greater than - 400 nT are rare. They appear in equal numbers in either phase of the solar sunspot cycle. If a great solar storm materializes in solar cycle 24, it will most likely occur between the years ~ 2009 and 2011 (M-2 to M). If a great solar storm materializes in solar cycle 25, it will most likely occur between the years ~ 2022 and 2026 (M and M+4).

Table 2. Great Solar Storms

Date	Solar Flare Intensity	Omni-Directional Solar Proton Fluence	Main CME Arrival Time	Magnetic Intensity Disturbance Storm Time (Dst) (nano-Teslas)	Position of Geomagnetic Storm in Relationship to Solar Sunspot Cycle
1-2 September 1859	Sept 1 Carrington White Light Flare [6]	2 x 10^{10} cm^{-2}	17 hours 40 minutes [4]	Sept 2 - 1,760 nT [4]	Phase 2 M-1 year
12 October 1859					Phase 2 M-1 year
4 February 1872					Phase 1 M+2 years
17-18 November 1882					Phase 2 M-1 year
31 October 1903					Phase 2 M-2 years
25 September 1909					Phase 2 M+4 years
13-16 May 1921					Phase 1 M+4 years
7 July 1928					Phase 2 M
16 April 1938					Phase 1 M+1 year
13 September 1957				Sept 13 - 427 nT [1]	Phase 1 M
11 February 1958				Feb 11 - 426 nT [1]	Phase 1 M+1 year
13 March 1989	X15			Mar 13/14 - 589 nT [1]	Phase 2 M
29 October - 5 November 2003	Oct 28 X17.2 Oct 29 X10 Nov 4 X45 [5]		19 hours	Oct 29 -353 nT [1] Oct 30 -383 nT [1] Nov 5 (missed Earth)	Phase 1 M+3 years
18-21 November 2003	Nov 18 M3.2 [4]			Nov 20/21 - 422 nT [1]	Phase 1 M+3 years

Figure 3. Great Geomagnetic Storm - Phase 1

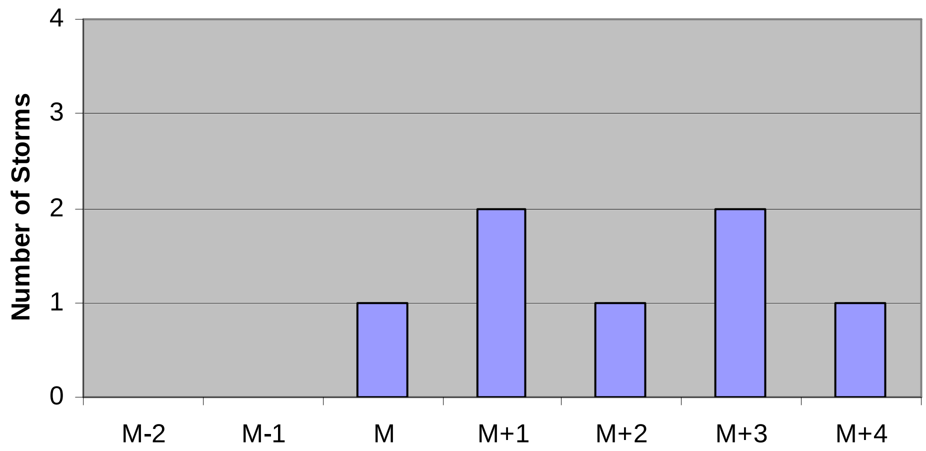
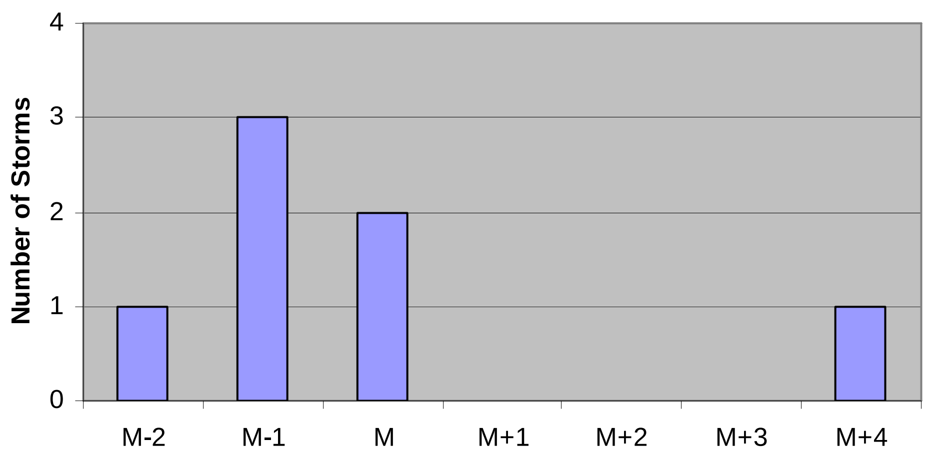


Figure 4. Great Geomagnetic Storm - Phase 2



<u>Summary</u>

Geomagnetic storm metrics associated with major solar storms was analyzed. The data shows a strong frequency association with the phase of the solar sunspot cycle and an association with the position within the solar cycle. From this analysis a forecast of major solar storms within solar cycle 24 & 25 was developed.

Solar cycle 24 is <u>unlikely</u> to spawn many solar storms that produce major geomagnetic storms having a Dst strength greater than - 300 nT. Solar cycle 25 is <u>likely</u> to spawn several solar storms resulting in major geomagnetic storms with the highest concentrations between the years ~ 2022 and 2025 (M and M+3).

Great solar storms that produce great geomagnetic storms having a Dst strength greater than - 400 nT are rare. They appear in equal numbers in either phase of the solar sunspot cycle. If a great solar storm materializes in solar cycle 24, it will most likely occur between the years ~ 2009 and 2011 (M-2 to M). If a great solar storm materializes in solar cycle 25, it will most likely occur between the years ~2022 and 2026 (M and M+4).

References

1. Geomagnetic Storm database at the World Data Center for Geomagnetism, Kyoto available at http://swdcwww.kugi.kyoto-u.ac.jp/dstdir/finalprov.html
2. International Sunspot Number data at the National Geophysical Data Center available at http://www.ngdc.noaa.gov/stp/SOLAR/ftpsunspotnumber.html
3. Smart, D.F., M.A. Shea, G.A.M. Dreschhoff, H.E. Spence, and L. Kepko, (2005) The frequency distribution of solar proton events: 5 solar cycles and 45 solar cycles, *Solar and Space Physics and the Vision of Space Exploration Conference*, 16-20 October 2005.
4. Lakhina, G.S., S. Alex, B.T. Tsurutani and W.D. Gonzalez, (2005) Research on historical records of geomagnetic storms, *Coronal and Stellar Mass Ejections Proceedings IAU Symposium*, No. 226, doi 10.1017S1743921305000074.
5. Thomson, N.R., C. J. Rodger, and R. L. Dowden (2004) Ionosphere gives size of greatest solar flare, *Geophys Res. Lett.*, *31*, L06803, doi:10.1029/2003GL 019345.
6. Stuart Clark, "The Sun Kings", Princeton University Press, Oxford, 2007