Long-Term Datasets for the Understanding of Solar and Stellar Magnetic Cycles
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Geoeffective events through solar cycles

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Abstract. Extreme solar storms are well known in the historical databases. Since the modern era, it has been possible to associate clearly geomagnetic disturbances with solar events (flares, SEP, CMEs). In the recent solar cycles the geoeffective events (number and strength) are decreasing. As an example, in the 2002 maximum activity year, we present how many flares, and CMEs were geoeffective. Based on observations and simulations, we discuss on the size of sunspots and the field strength to get more energetic flares ($> 10^{32}$ ergs) in the near future.

Keywords. Sun: Coronal Mass Ejections (CMEs), Sun: flares, Solar-terrestrial Relations

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Historical observations of Meudon collection (BASS2000) corresponding to the dates of the largest geoeffective events (Table 1) are presented in Figure 1 (a, b, c) showing that sunspot groups never exceed 0.6 % of the solar visible surface. Besides large sunspot groups could also never lead to geoeffective events (*e.g.* April 1947, October 2014).

Solar flares in the past have likely not substantially exceeded the level of the largest flares observed in the space era, and that there is at most about a 10% chance of a flare larger than about X 30 in the next 30 years (Schrijver *et al.* 2012). The previous authors argued that flares with a magnitude well above the observational maximum of about 10^{33} ergs are unlikely to occur. Kepler satellite showed that a great number of high energetic flares occurred in stars having large sunspot areas some with similar class as the sun (Maehara *et al.* 2012). Besides a recent study by Bocchialini *et al.* (2018) studying all the *Storm Sudden commencement* (SSC) registered in Dst variations during 2002 showed that the 37 largest SSCs were mainly related to 44 CMEs. 52% CMEs have a velocity larger than 900 km/s, 75% are halo CMEs. The association with GOES flares is: 22 CMEs with a C-class flare (among 2000), 19 CMEs with a M-class flare (among 200) and three with an X-class (among 12). 25 % of the X-class flares are related to geoeffective and fast CMEs.

The OHM simulation was used as an experiment with parameters varying in a large space (Aulanier *et al.* 2013). In the simulations high twist or free energy are the trigger of the CMEs. The OHM simulations demonstrated that considering the largest sunspot area ever reported (6000 MSH) with a magnetic field of 3.5 kGauss the maximum energy of a flare could reach at least 6×10^{33} ergs, already 5 to 10 times more than the highest energetic flares of Halloween (X17-X40). To reach the flare energy of the Kepler stars (10^{36} ergs) the spot area should increase by a factor 100 to reach 60000 MSH (Figure 1 d, e, f). Let us conclude like Schrijver *et al.* (2012): "Flare energies for the present-day Sun have either a true upper cutoff or at least a rapid drop in frequency by several orders of magnitude below the scaled stellar frequency spectrum for energy fluences above X40. Based on direct solar observations and indirect way (the OHM simulation) solar flares with energy fluences above X40 are very unlikely for the modern Holocene-era Sun."

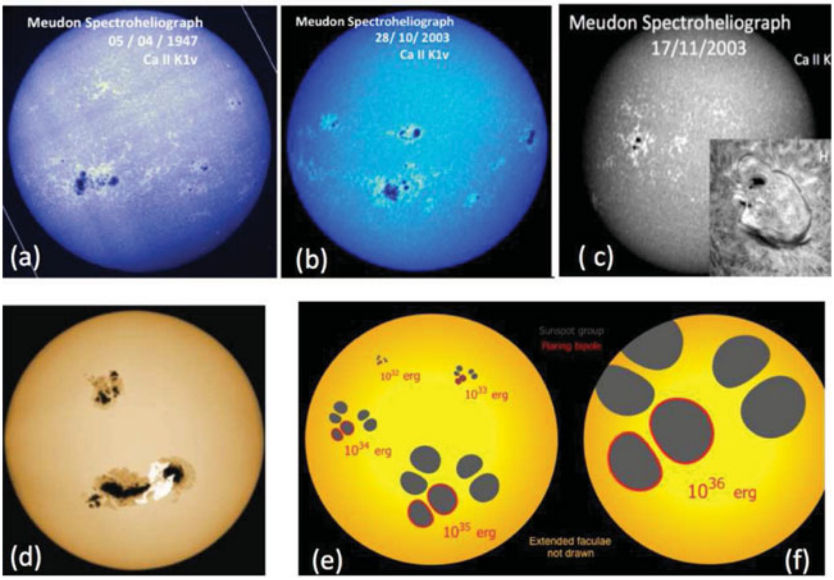

Figure 1. Spots on the sun and stars: (a), (b), (c) Historical Ca II K1v spectroheliograms from Meudon (*BASS2000.obspm.fr*): The largest sunspot groups ever reported (5400 to 6000 MSH or 0.54 to 0.6 % of solar hemisphere): (a) on April 4, 1947 with no geoeffective effect, (b) on October 28, 2003. The AR 10486 in the south hemisphere led to a X17 flare and consequently a geomagnetic disturbance with a Dst = -350 nT, (c): AR 10501 on November 17, 2003 with an inserted Hα image of the active region. The huge eruptive filament surrounding the AR initiated the largest Dst of the 23th solar cycle (Dst = - 472 nT) (Chandra *et al.*2011), (d) Sketch from Kyoto Univ. (e), and (f) Results of the OHM simulation (adapted from Aulanier *et al.* (2013))

Table 1. List of geomagnetic storms from 1859 to 1954 from Greenwich/Abinger (*left*) and different estimations for historical events, *e.g.* using the recovering phase method (Cid *et al.* 2013) and recent measurements of Dst (*right*)

Year	Month	Declination (')	Horizontal force (nT)	Vertical force (nT)	Year	Month	References or Stations	Dst (nT)
1859	01 Sept.	>> 92	>>625	1500	1859	1-2 Sept.	Lakhhina 2005	-1760
1872	04 Fev.	125	800	> 950	1859	"	Siscoe 2006	-685
1882	17 Nov.	115	>1090	>1060	1859	"	Tsurutani 2003	-1600
1903	31 Oct.	119	1175	1440	1859	"	Cid 2013	-1560
1909	25 Sept.	193	1710	>1080	1859	"	Cliver and Dietrich 2013	-900
1921	14 May.	110	>> 740	>>460	1921	13-15 May	Alibag (Cid etal. 2013)	-713
1938	25 Jan	126	1055	570	1928	7 July	Alibag (")	-506
1938	16 Apr	307	1375	500	1938	16 Apr.	Alibag (")	-263
1940	24 Mar.	131	1370	1000	1957	13 Sept.	Alibag (")	-532
1941	01 Mar.	186	1650	1310	1958	11Feb.	Alibag (")	-475
1941	18 Sept.	123	1250	1115	1989	13 Mar.	Kakioka (")	-674
1946	28 Mar.	162	1660	920	2003	20 Nov.	largest Dst of cycle 23	-472
1946	21 Sep.	136	925	450	2015	17 Mar.	largest Dst of cycle 24	-223

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