On the geoeffectiveness of solar transients: characterization, trends and predictability

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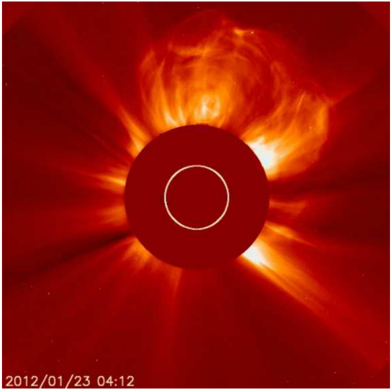
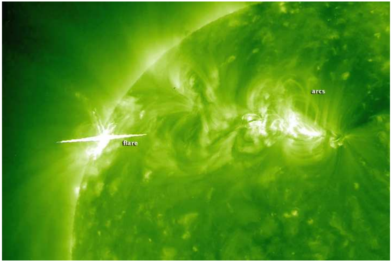
Outline

Solar transients: CMEs and Solar Flares





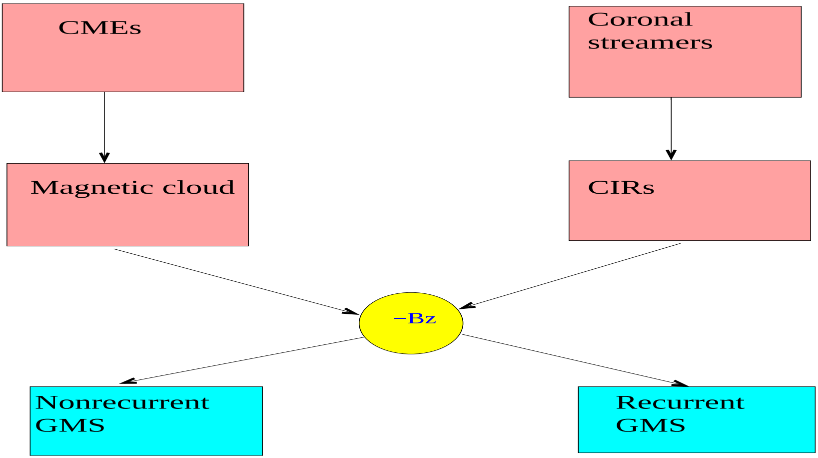
Coronal Mass Ejections, Geoeffective CMEs

- Transients expulsions of plasma and magnetic field from the Sun
- Produce disturbances in the IP medium leading to phenomena known as geomagnetic storms
- GMS are strong perturbations of the Earth atmosphere affecting space weather in various ways

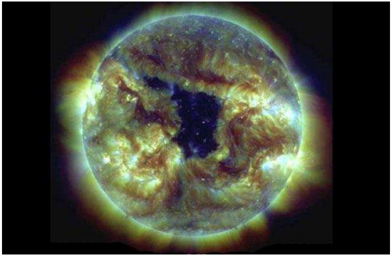
CMEs characteristics

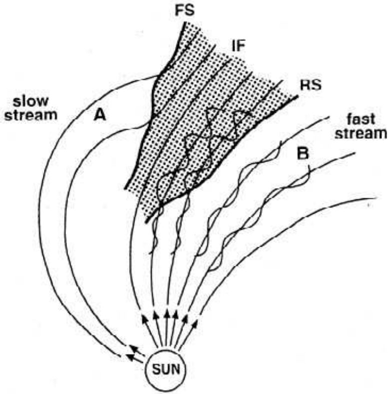
Property	range	average
Speed	$\sim$ 20 km/s to $>$ 3000 km/s	$\sim$ 470 km/s
Mass	$\sim 10^{12}$ g to $> 10^{16}$ g	$\sim 4 \times 10^{14}$ g
Kinetic energy	$\sim 10^{27}$ erg to 10^{33} erg	$\sim 5 \times 10^{29}$ erg
Angular width	$< 5^0$ to 360^0	$\sim 54^0$
Daily occurrence rate	$<$ 0.5 to $>$ 6 CMEs	Solar min - solar max

Main sources of geomagnetic storms

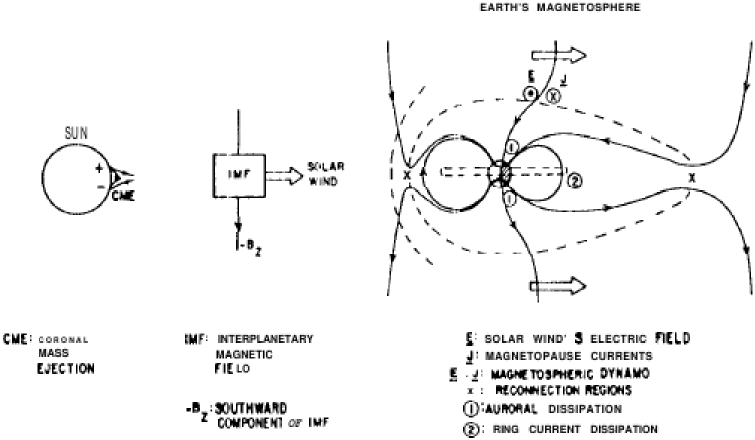


CIRs as sources of recurrent GMS

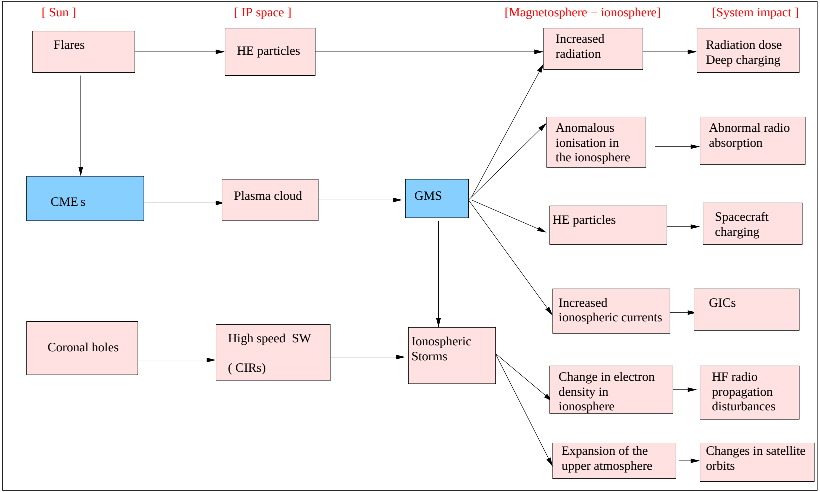




Magnetic storms generation



Space Weather impact



Properties of Geoeffective CMEs

1. Geoeffectivity: Their ability to produce geomagnetic storms: In this study, $Dst \leq -50$ nT.
2. halo CMEs: appear to surround the occulting disk of the observing coronagraphs
3. Generally fast and wide and mostly associated with powerful flares (Class X and M)
4. Full halo CMEs: apparent width (W) of 360^0
5. partial halo CMEs: apparent width (W) of $120^0 \leq W \leq 360^0$.
6. But still not very clear what kind of CMEs produce GMS, some halo and front-sided CMEs may not have a geomagnetic impact

Objectives

- Recent decades, intensive research focusing on estimating the geoeffectiveness of solar phenomena

Objectives

- A statistical investigation of CMEs and associated solar and IP properties that were probable causes of 229 magnetic storms covering 1996-2006; a full average 11-year solar cycle.

Objectives

- Comparison of the magnetic storm effectiveness between full and partial halo CMEs

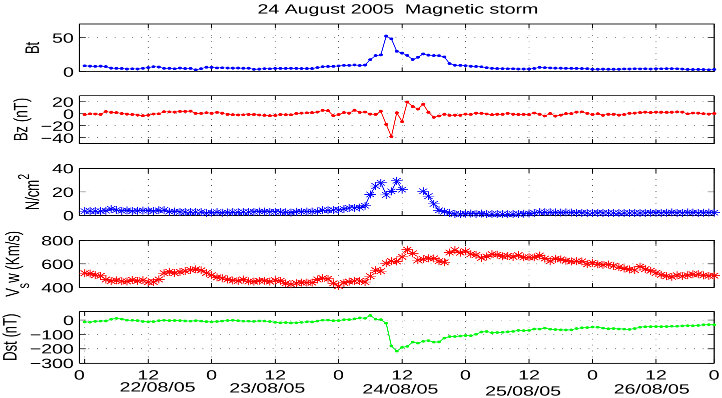
Selection of geomagnetic storms events

- Selection based on the Dst index
- A measure of the H-component of the Earth's MF at low to mid latitude
- A good measure of the ring current
  1. Moderate storms (with -100 nT $\leq$ *Dst* $\leq$ -50 nT)
  2. Intense storms with *Dst* ≤ -100 nT
  3. Minor storms (*Dst* > -50 nT) not considered.
- In total, 244 storm events identified (Jan 1996- Dec 2006).
- Data source on : http://www.ngdc.noaa.gov/stp/geomag/dst.html.

IP signatures of geoeffective solar events

- Transport of solar disturbances to near Earth via Solar wind (SW).
- CME structures at 1 AU are known as ICMEs.
- ICMEs are geoeffective when associated with negative Z-component of IMF(Bs).
- A table of ICMEs with associated properties and geomagnetic effect by (Richardson and Cane, 2010). (see:http://www.srl.caltech.edu/ACE/ASC/DATA/level3/icme
- We produced a similar table based on GMS events (no minor storms involved) which shows additional 92 storm events
- Data source on OMNIWEB: http://www.nssdc.gsfc.nasa/omniweb.html.

Geoeffective SW structures associated with the passage of an ICME in IP medium



Geoeffective properties associated with halo CMEs

- Angular Width (AW) of CMEs as appear in solar coronagraphs: large AW implies higher probability of Earth's impact
- CME speed and association with powerful solar flares
- Surface location of a long duration flare can be considered as the source region of the associated CME
- Considered a range of $\pm$0.5 hours to decide the association of halo CME eruption with flare occurrence

Data source

Solar data from..

1. LASCO/CME data: http://cdaw.gsfc.nasa.gov/CME_list
2. GOES data on: http://www.ngdc.noaa.gov/stp/solar/solarflares.html.

Methods of investigation

- Identified solar and IP parameters (AW_{cmes}, V_{cmes}, B_s, V_{sw}, SF_s) suitable enough for analysis of storm efficiency.
- Prediction of storm occurrence at 86% when used in an empirical model, Uwamahoro et al., 2012.

Method

"A 5-day time window prior to the occurrence of a storm was used to explore probable halo CMEs (and associated solar and IP properties) causes of the subsequent storm."

- But one storm event may follow from more than one halo CME; Consider frontside CMEs with other associated geoeffective properties.

Selected examples from a Table of 244 storm events

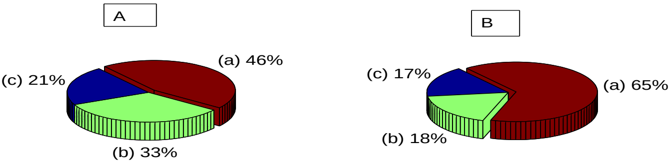
Event/ parameters	Event 232	Event 187	Event 195
Date of event	24/08/2005	20/11/2003	04/04/04
Dst(nT)	-216	-422	-112
B_S(nT)	-38.3	-50.9	-7.9
$V_{sw}(km/h)$	620	553	506
Halo CME	$FH : 22/08[01 : 31; 17 : 30]$	$FH : 18/11[08 : 50]$	CIR or SOHO stealth CME..??
$V_{cme}(km/h)$	1194; 2378	1668	-
Flare/Location	$M2.6; S11W54$	$M3.9; N03E18$	-
ICME/Time	24/08 [14;00]	20/11 [10:00]	03/04 [14:00]

Results and discussion

Main results

1. In total, 244 events [1996-2006]; excluding 15 events of missing SOHO/LASCO data
2. July, August, September 1998 and January 1999], hence analysis of 229 storm events
3. Identified 84 intense GMS and 145 moderate storms

Solar and IP precursors of intense vs moderate storms



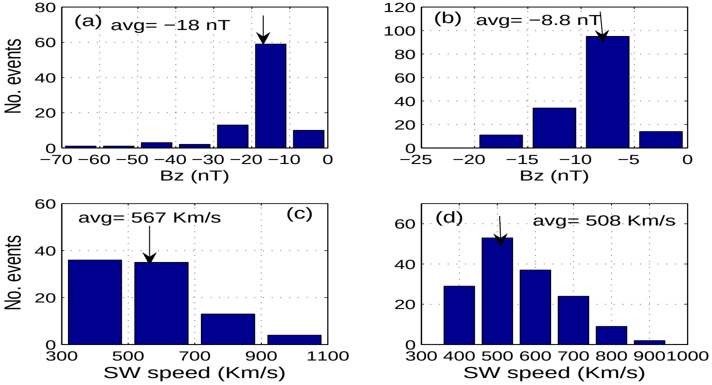
A= Distribution of sources for moderate storms: (a) CIRs, (b) FH CMEs; (c) PH CMEs.

B= Distribution for intense storms: (a) FH CMEs, (b) PH CMEs (c) CIRs

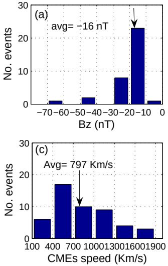
Solar and IP precursors of intense vs moderate storms

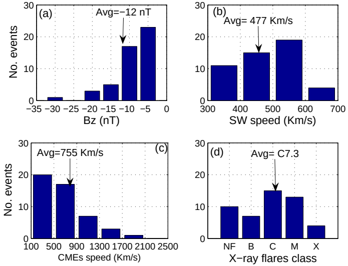
Storm category	No.of GMS	FH-CME	PH-CME	No CMEs	ICMEs
Intense storms	84	55 [65%]	15 [18%]	14 [17%]	72[86%]
Moderate storms	145	48 [33%]	31 [21%]	66 [46%]	64 [44%]
Total	229	103 [45%]	46 [20%]	80[35%]	136 [59%]

IP properties for intense vs moderate storms



Intense vs moderate storms associated properties



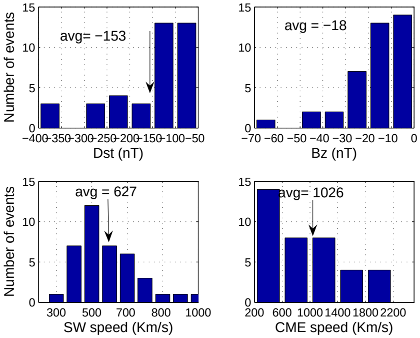


On magnetic storms association with solar flares

Flare class	B-class	C-class	M-class	X-class
Number	9	46	48	23
Percentage	7%	37%	38%	18%

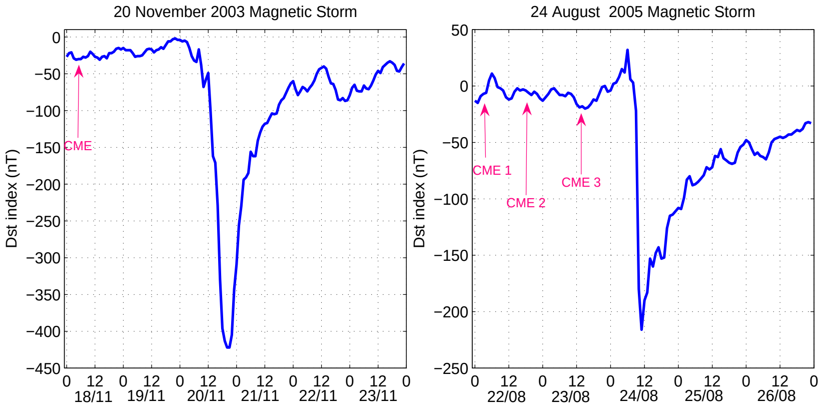
Multiple halo CME associated storms

- 39 cases identified; mostly lead to intense storms (up to 69%).
- Generally associated with higher average values of B_s, V_{sw} accompanied by ICME at 92%



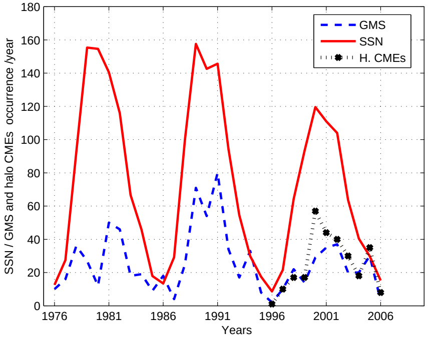
Multiple CME storms precursors properties

Multiple vs one CME driven storm



Trends in SC 23

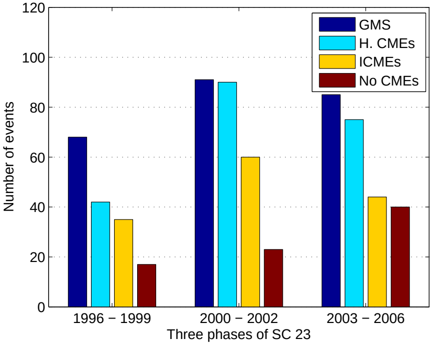
- Observed correlation between solar activity (in terms of SSN) and the occurrence of storms.
- Notice a triple peak in both CME and GMS occurrence



SC trends in CMEs and associated GMS.

Trends in SC 23

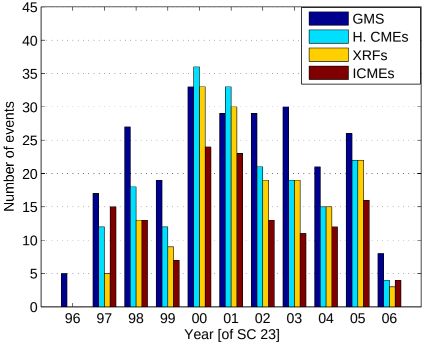
- Observed trends by SC phase in terms of GMS, halo CMEs, ICMEs and CIRs.
- Half of all nonhalo CME associated storms accured in the declining phase



Frequency by SC phase.

Trends in SC 23

- Frequency occurrence per year in SC 23of 244 GMS and associated properties.
- Peaks in 1998, 200-2002 and 2005. Exceptional peak in 2003 due to Halloween storms.



Frequency per year.

Main results

Summary of main results

1. During an average 11-year SC, 83% of intense storms were found to be caused by halo CMEs
2. CIRs and / or undetected CMEs mostly moderate storms at 46%.
3. Up to 84% of full halo CME driving storms originated close to the disck center; but only partial halo CMEs from outside $\pm 45^0$ of the CMD were geoeffective.
4. Storms associated with FH CMEs were mostly intense storms(Mean $Dst = -128$ nT); those associated with PH CMEs were moderate with avg $Dst = -92$ nT.

Main results

Summary of main results

1. Geoeffective parameters (B_s, V_{sw}, V_{cmes}) were of higher values for FH CMEs compared to those following PH CMEs.
2. FH CMEs were associated with class M flares on *avg*, class C on *avg* for PH CMEs.
3. 26% of identified GMS were possibly driven by multiple (interacting) CMEs of which up to 69% were intense storms.
4. About half of all non-halo CME-driven storms were found in the declining phase of SC23

Conclusion

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1. Thanks for your attention!