Correction to: Statistical Analysis of Solar Events Associated with Storm Sudden Commencements over One Year of Solar Maximum During Cycle 23: Propagation from the Sun to the Earth and Effects

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Abstract Taking the 32 storm sudden commencements (SSCs) listed by the International Service of Geomagnetic Indices (ISGI) of the Observatory de l'Ebre during 2002 (solar ac-

Earth-affecting Solar Transients

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tivity maximum in Cycle 23) as a starting point, we performed a multi-criterion analysis based on observations (propagation time, velocity comparisons, sense of the magnetic field rotation, radio waves) to associate them with solar sources, identified their effects in the interplanetary medium, and looked at the response of the terrestrial ionized and neutral environment. We find that 28 SSCs can be related to 44 coronal mass ejections (CMEs), 15 with a unique CME and 13 with a series of multiple CMEs, among which 19 (68%) involved halo CMEs. Twelve of the 19 fastest CMEs with speeds greater than 1000 km s^{-1} are halo CMEs. For the 44 CMEs, including 21 halo CMEs, the corresponding X-ray flare classes are: 4 X-class, 19 M-class, and 21 C-class flares. The probability for an SSC to occur is 75% if the CME is a halo CME. Among the 500, or even more, front-side, non-halo CMEs recorded in 2002, only 23 could be the source of an SSC, *i.e.* 5%. The complex interactions between two (or more) CMEs and the modification of their trajectories have been examined using joint white-light and multiple-wavelength radio observations. The detection of long-lasting type IV bursts observed at metric–hectometric wavelengths is a very useful criterion for the CME–SSC association. The events associated with the most depressed Dst values are also associated with type IV radio bursts. The four SSCs associated with a single shock at L1 correspond to four radio events exhibiting characteristics different from type IV radio bursts. The solar-wind structures at L1 after the 32 SSCs are 12 magnetic clouds (MCs), 6 interplanetary coronal mass ejections (ICMEs) without an MC structure, 4 miscellaneous structures, which cannot unambiguously be classified as ICMEs, 5 corotating or stream interaction regions (CIRs/SIRs), one CIR caused two SSCs, and 4 shock events; note that one CIR caused two SSCs. The 11 MCs listed in 3 or more MC catalogs covering the year 2002 are associated with SSCs. For the three most intense geomagnetic storms (based on Dst minima) related to MCs, we note two sudden increases of the Dst, at the arrival of the sheath and the arrival of the MC itself. In terms of geoeffectiveness, the relation between the CME speed and the magnetic-storm intensity, as characterized using the Dst magnetic index, is very complex, but generally CMEs with velocities at the Sun larger than 1000 km s^{-1} have larger probabilities to trigger moderate or intense storms. The most geoeffective events are MCs, since 92% of them trigger moderate or intense storms, followed by ICMEs (33%). At best, CIRs/SIRs only cause weak storms. We show that these geoeffective events (ICMEs or MCs) trigger an increased and combined auroral kilometric radiation (AKR) and non-thermal continuum (NTC) wave activity in the magnetosphere, an enhanced convection in the ionosphere, and a stronger response in the thermosphere. However, this trend does not appear clearly in the coupling functions, which exhibit relatively weak correlations between the solar-wind energy input and the amplitude of various geomagnetic indices, whereas the role of the southward component of the solar-wind magnetic field is confirmed. Some saturation appears for Dst values $< -100 \text{ nT}$ on the integrated values of the polar and auroral indices.

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Table 3 The 44 CMEs associated with the 32 SSCs mentioned in Table 2: 21 halo CMEs (CMEH), 9 partial-halo CMEs (CMEP), and 14 non-halos CMEs (CMEN), detected in 2002 with an identified source at the Sun. Starting from the second column on, we list the date and time of the beginning of the solar event at the origin of the CME as seen in SOHO/EIT images at 30.4 nm or 19.5 nm, source coordinates in seconds of arc from Sun center ([0, 0]) with positive to the west and north, and nature of the source seen in SOHO/EIT (AR = active region, Fi = filament, FL = flare, CH = coronal hole), the final height (h) in units of solar radii in the SOHO/LASCO FOV at which the CME is observed, the corresponding velocity ($V_{\odot}$) [km s^{-1}], the acceleration (a) [m s^{-2}], the exit time from LASCO FOV, and the flare class (GOES).

CME No.	Source (EIT)				CME (LASCO)				Flare class
	Date	Time [UT]	Coord.	Source type	h	$V_{\odot}$	a	Exit time [UT]	
CMEH01	27 Jan	12:24	(375, 850)	AR	26	1000	-19.2	16:30	C
CMEN02	28 Jan	9:35	(-200, -500)	AR, Fi	12	738	35.0	13:00	C
CMEN03	24 Feb	14:45	(650, -400)	AR, Fi	6	258	5.2	17:50	C
CMEH04	15 Mar	21:48	(113, -48)	AR, Fi, CH	30	784	-17.4	4:30 (+1)	M
CMEP05	17 Mar	10:28	(-273, -233)	AR, Fi	30	931	-6.0	15:45	M
CMEH06	18 Mar	1:48	(410, -240)	AR, Fi	20	971	-2.9	6:30	M
CMEP07	19 Mar	9:24	(770, -70)	AR, Fi	28	711	-0.9	16:10	M
CMEP08	19 Mar	11:12	(770, -70)	AR, Fi	12	1030	46.4	13:45	M
CMEP09	20 Mar	23:24	(870, -270)	AR, Fi	30	1075	-0.2	4:50 (+1)	C
CMEH10	22 Mar	10:36	(980, -160)	AR, Fi	18	1685	-22.5	12:40	C
CMEH11	22 Mar	11:36	(980, -160)	AR, Fi	36	1027	14.6	18:30	M
CMEN12	11 Apr	16:24	(420, -200)	AR, Fi	20	497	-3.4	23:30	C
CMEH13	15 Apr	3:12	(252, -159)	AR	26	742	2.1	9:45	M
CMEN14	16 Apr	11:00	(910, -216)	AR, Fi	15	421	-9.1	15:45	C
CMEH15	17 Apr	7:50	(550, -130)	AR, Fi	28	1103	-19.7	12:20	M
CMEH16	21 Apr	00:48	(916, -229)	AR	25	2,388	-1.4	3:20	X
CMEN17	06 May	23:47	(800, 400)	AR	28	1266	5.6	4:10 (+1)	C
CMEH18	07 May	3:36	(-214, -109)	AR, Fi	6	926	158.1	4:50	C
CMEH19	08 May	13:13	(130, -150)	AR, Fi	5	697	78.9	14:30	C
CMEH20	15 May	23:47	(-197, -316)	AR	28	506	-6.6	8:45 (+1)	C
CMEN21	17 May	00:47	(-100, -350)	Fi	20	532	5.5	8:30	C
CMEN22	17 May	7:48	(-900, 200)	AR	15	616	-7.5	11:40	M
CMEN23	18 May	11:50	(-388, -455)	AR	6	614	45.6	14:00	C
CMEP24	21 May	23:24	(881, -319)	AR, Fi	28	1341	14.2	3:45 (+1)	C
CMEH25	22 May	03:12	(881, -319)	AR, Fi	28	1504	-10.4	6:50	C
CMEP26	27 May	12:23	(-250, 400)	Fi	18	1122	3.8	15:50	C
CMEH27	15 Jul	19:59	(15, 239)	AR, Fi	28	973	-25.6	0:20 (+1)	X
CMEP28	15 Jul	21:00	(15, 239)	AR, Fi	23	1264	-7.3	0:20 (+1)	M
CMEH29	18 Jul	7:59	(500, 250)	AR, FL	22	919	-30.1	11:20	X
CMEP30	18 Jul	11:30	(-730, 200)	AR	23	680	-14.0	16:20	C
CMEH31	18 Jul	18:26	(-730, 200)	AR	28	1788	-	21:20	C
CMEH32	26 Jul	21:12	(-400, -370)	AR, Fi	30	816	-0.1	4:20 (+1)	M
CMEN33	29 Jul	02:30	(150, -350)	AR	25	409	3.8	15:00	M
CMEN34	29 Jul	10:59	(150, -350)	AR	11	301	-3.8	16:00	M
CMEN35	30 Jul	00:30	(700, -700)	Fi	15	998	32	4:20	C
CMEH36	16 Aug	11:24	(-250, -200)	AR, Fi	23	1239	-67.1	15:20	M

Table 3 (Continued)

CME No.	Source (EIT)				CME (LASCO)				Flare class
	Date	Time [UT]	Coord.	Source type	h	$V_{\odot}$	a	Exit time [UT]	
CMEP37	23 Aug	05:47	(−243, −279)	AR	8	622	36.6	8:20	M
CMEH38	24 Aug	01:13	(950, −100)	AR	26	2,066	43.7	3:20	X
CMEH39	05 Sep	16:30	(−400, 23)	AR	17	1855	43.0	18:20	M
CMEN40	27 Sep	01:36	(900, −200)	AR	21	1300	−61	3:40	M
CMEN41	27 Sep	13:13	(−650, 150)	AR	20	510	−10	18:45	M
CMEN42	06 Nov	05:24	(−49, −280)	AR	16	485	−6.3	11:00	C
CMEH43	09 Nov	12:54	(624, −205)	AR, Fi	26	1977	35.3	15:40	M
CMEH44	24 Nov	19:13	(−750, 280)	Fi	20	1179	20.5	23:20	C

3.1. Statistical Considerations on the Listed CMEs

As mentioned in the previous section, we identify one or more possible solar sources for each SSC-led event. The probability for an SSC to occur is some 75% if the CME is a halo (21/28). According to the CDAW list, more than 500 non-halo, front-side CME were observed in 2002 (1.5 *per* day on average). Only 23 CMEs (see Table 3) could be the sources of an SSC, *i.e.* about 5% (23/500).

For the 44 CMEs associated with an SSC (as Leading or Contrib.) in Table 2,

- 18 have their source only in an AR (in one case, EIT detected the accompanying flare), 4 have their source only in a filament, and 22 have their source in an AR and a filament (including one case near a coronal hole (CH)). Thus 91% (40/44) of the CMEs have their source in an AR (with or without a filament), 60% (26/44) in a filament (in or out of an AR).
- 73% (32/44) come from the southern hemisphere of the Sun, and 27 % (12/44) from the northern hemisphere of the Sun.
- 39% (17/44) come from the eastern side of the Sun, 61% (27/44) from the western side of the Sun, which is not surprising.
- 13.5% (6/44) have a velocity less than 500 km s^{-1} (non-halo CME), 43% (19/44) a velocity ranging from 500 km s^{-1} to 999 km s^{-1} , 38.5% (17/44) a velocity between 1000 km s^{-1} and 2000 km s^{-1} (10/17 are halo CME), and 4% (2/44) a velocity greater than 2000 km s^{-1} (2 halo CME),
- 21 CMEs are associated with GOES C-class events, 19 with M-class events, and 4 with X-class events. All but one are linked to an AR. In 2002, around 2000 C-class flares, around 200 M-class flares, and 12 X-class flares were seen by GOES.

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Table 12 Characterization of the geoeffectiveness of the events associated with the SSC, classified first by their category at L1 (MC, ICME, Misc., Shock, and CIR/SIR) and then by increasing values of the min(Dst) value. Shown from left to right for the SSCs: No., date, time, amplitude value (A in nT), and amplitude rank (by decreasing amplitude). For the geomagnetic activity: min(Dst) value and geomagnetic-storm intensity (C, S+ means strong for min(Dst) ≤ -100 nT, S means moderate for $-100 < \text{min(Dst)} \leq -50$ nT, and nothing otherwise), max(AE) value, and AE activity intensity characterization (C, S for strong max(AE) > 1000 nT, W for weak max(AE) < 350 nT, nothing otherwise). For the thermosphere neutral density response (A means strong if > 2 , B means moderate if between 1.5 and 2, and C means weak if < 1.5 , – means not noticeable, and n/a not available). For the ionosphere, PCP maximum value (S for strong, i.e. PCP ≥ 95 kV, M for moderate, i.e. PCP < 75 kV). For the magnetosphere: AKR and NTC (Y for yes, – for no signature, and n/a if not available). Category of event at L1. Solar event: CMEH, CMEN, or CMEP shown as H, N, and P, respectively. Flare class in GOES. Radio signatures marked as y if present or – if absent in the following order: A, B, interaction, type II, type IV.

SSC No.	Date	Time [UT]	A [nT]	R	Geomag. activity		max(AE) [nT]	max(AE) C	Th. N.	Iono. PCP max	Magnetosphere		L1 Ev. type	$B_{z=0}^*$ [nT]	Solar event		Radio leading
					min(Dst) [nT]	min(Dst) C					AKR	NTC			CME	Flare class	
SSC28 – SSE28	30 Sep	08:16	16	26	–176	S+	1088	S	A	S	Y	Y	MC	–6.7	N	M	y- - - -
SSC10 – SSE10	19 Apr	08:34	25	14	–149	S+	1639	S	B	S	Y	Y	MC	–6.8	H,N	M,C	yy-yy
SSC09 – SSE09	17 Apr	11:06	53	3	–127	S+	1356	S	B	M	Y	Y	MC	–7.4	H	M	yy-yy
SSC17	23 May	10:49	78	1	–109	S+	1480	S	A	S	n/a	n/a	MC	–6.6	H,P	C,C	-yyyy
SSC25	18 Aug	18:45	37	8	–106	S+	1095	S	B	S	Y	Y	MC	–3.6	H	M	yy-yy
SSC24	01 Aug	23:10	28	11	–102	S+	1125	S	B	M	Y	Y	MC	–10.1	N,N	./; C	- - - - -
SSC06	23 Mar	11:35	22	17	–100	S+	1025	S	B	S	Y	Y	MC	–5.7	H,P,H	C,M,./	yy-yy
SSC01	31 Jan	21:26	13	29	–86	S	570		C	S	–	Y	MC	–7.8	N,H	./,C	-y- - -
SSC03	28 Feb	04:50	37	7	–71	S	1015	S	C	M	Y	Y	MC	–4.8	N	C	-yyy-
SSC14	18 May	20:08	41	5	–58	S	701		B	S	Y	n/a	MC	–3.3	H	C	yy-yy
SSC23	1 Aug	05:10	17	23	–51	S	989		C	M	Y	Y	MC	–6.2	N,N	M,M	y-y-
SSC04	18 Mar	13:21	61	2	–37		692		B	W	–	Y	MC	–2.4	H,P	C,M	yy-y-
SSC27	7 Sep	16:36	23	16	–181	S+	1413	S	A	S	Y	Y	ICME	–12.1	H	M	yyyyy
SSC13	11 May	10:13	26	12	–110	S+	1287	S	B	S	Y	Y	ICME	–11.7	H	./	yy- -y
SSC15	20 May	03:39	14	28	–36		661		–	M	Y	Y	ICME	–1.0	N	C,./	- - - - -
SSC21	19 Jul	10:08	19	20	–36		972		C	S	Y	Y	ICME	–1.7	H,H,P	C,C,X	- - - - -
SSC20	17 Jul	16:02	40	6	–17		503		–	M	Y	Y	ICME	–1.1	H,P	X,M	y-y-
SSC05	20 Mar	13:27	15	27	–13		713		–	M	–	Y	ICME	–0.4	H,P,P	M,M	yy-y-

Table 12 (Continued)

SSC No.	Date	Time [UT]	A [nT]	R	Geomag. activity			Th. N.	Iono.		Magnet.		L1 Ev. type	Solar event		Radio leading
					min(Dst) [nT]	min(Dst) C	max(AE) [nT]		PCP max	AKR	NTC	$B_{z<0}^*$ [nT]		CME	Flare class	
SSC32	26 Nov	21:50	25	13	-64	S	990	n/a	S	Y	Y	-3.3	Misc.	H		--y-
SSC11	23 Apr	04:48	43	4	-57	S	1136	B	M	Y	Y	-2.5	Misc.	H	X	yy-yy
SSC26	26 Aug	11:30	21	19	-45		1166	C	M	Y	Y	-4.2	Misc.	H,P	X,M	yy-yy
SSC12	10 May	11:22	29	10	-14		886	-	M	Y	Y	-1.3	Misc.	N,H	/,C	--- --
SSC08	14 Apr	12:34	10	30	-23		940	-	S	Y	Y	-4.4	Shock	N?	C	y-y-
SSC18	30 May	02:04	9	31	-13		335	-	W	Y	Y	-0.9	Shock	P	/,	-y-y-
SSC16	21 May	22:02	18	21	-12		681	-	M	-	Y	-1.2	Shock	N	C	y-y-
SSC22	29 Jul	13:21	25	15	0		198	-	W	-	-	-0.3	Shock	H	M	y-y-
SSC07	29 Mar	22:36	31	9	-38		780	C	M	-	Y	-1.2	CIR	/,		
SSC31	11 Nov	12:30	16	25	-32		171	-	M	Y	-	-1.5	CIR	H	M	yy-yy
SSC29-30	9 Nov	51:00	17	32	-28		673	n/a	M	-	Y	-2.0	CIR	N?	C	
SSC02	17 Feb	02:54	21	18	-21		331	-	M	Y	Y	-2.0	SIR	/,		
SSC19	6 Jun	11:39	17	22	-16		581	C	M	Y	n/a	-2.6	CIR	/,		