STUDIES OF CMES CAUSING GEOMAGNETIC STORMS IN THE PERIOD 2007-2011

Daniela Adriana Lăcătuş[1,4], Alin Răzvan Paraschiv[1,4], Marilena Mierla[1,2,4], Luciano Rodriguez[2], Emilia Kilpua[3]

[1] Institute of Geodynamics, Romanian Academy, Bucharest, Romania

[2] Solar-Terrestrial Center of Excellence – SIDC, Royal Observatory of Belgium, Brussels, Belgium

[3] Department of Physics, Division of Geophysics and Astronomy, University of Helsinki, Helsinki, Finland

[4] Research Center for Atomic Physics and Astrophysics, Faculty of Physics, University of Bucharest, Romania

E-mail: lacatus.dana@gmail.com

ABSTRACT

We have selected the coronal mass ejections (CMEs) in the period 2007-2011 which were directed towards the Earth and produced geomagnetic storms (Dst < -30 nT). We used the data from the SECCHI-COR2 coronagraphs on-board the STEREO mission to derive the true speeds and direction of propagation of these CMEs. We applied the flux-rope like model introduced by Thernisien et al. 2006 on these events in order to derive their 3D parameters (direction of propagation, angular width, orientation etc.). We then compared the obtained values with in-situ data measured when the CME reached the spacecraft at Earth (ACE).

INTRODUCTION

Coronal Mass Ejections (CMEs) are huge eruptions of magnetized plasma from the Sun into interplanetary space and are of high importance to space weather, as they can be directed towards Earth, interact with its magnetosphere and give rise to severe magnetic disturbances. Such severe events can have a number of unwanted effects, such as hazards to orbiting spacecraft and astronauts, interference with radio and telecommunications, as well as current surges in extended power lines. In order to prepare for such events is of crucial importance to predict such phenomena before they reach Earth, therefore determining the CMEs parameters through reconstruction is a first step.

DATA ANALYSIS

All geomagnetic storms (with Dst<-30) in the period 2007-2011 were selected and a verification of whether the recorded disturbances were associated to the arrival of a CME or it was just due to an increase of solar wind flux was made. For the CMEs associated to storms, the polarized images from the COR2 data were acquired (taking one frame prior to the first appearance of the CME in the COR2 FOV) and forward modeling technique was applied. The data was downloaded using the form found at: http://secchi.nrl.navy.mil/cgi-bin/swdbi/secchi_flight/images/form.

Forward modeling technique (Thernisien, Howard, and Vourlidas, 2006)

This method can reproduce the large scale structure of the CME by using a flux rope model. In order to use this method we took the polarized images and through an IDL/SolarSoft routine obtained the total brightness difference images. On these images we then attempted to fit the CME outline by varying a set of 8 parameters (longitude, latitude, radius, tilt angle, ratio and half angle) on all the frames containing the CME. Knowing the time step between the images and the evolution of height with time the real speeds could be easily derived.

3D RECONSTRUCTION AND PROPAGATION

A total of 24 such storms were associated to CMEs in the period 2007-2011, with more than half being recorded in 2011, on the ascending phase of solar cycle 24. In order to obtain their propagation parameters a IDL/SolarSoft routine was used. The routine displays both views and requires manual fitting of the flux-rope model to the CME in both of them. (See Fig. 1).

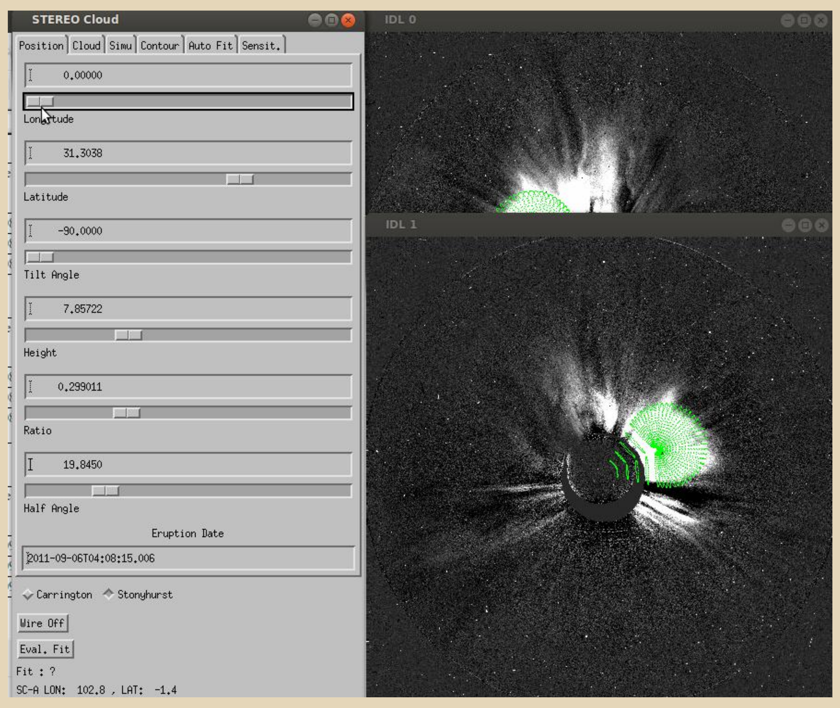

Figure 1: Fitting a CME with the forward modeling technique.

After obtaining the reconstruction parameters, using another IDL/SolarSoft routine was used in order to extend the CME to Earth and check if it hits Earth or one of the STEREO spacecraft. The routine used was developed by Rodriguez et al. 2011.

The table below presents the results of this extension, where the last 3 columns refer to weather the CME is heading to either one of the spacecraft or the L1(i.e. to Earth).

We found that from the total of 24 events analyzed, two headed to STEREO – B spacecraft, one was heading to STEREO – A, while 17 were directed to L1, and the remaining 6 were headed to neither of the directions. From the ACE data we know that all CMEs in this list reach Earth, however, using the routine to extend the fitting parameters some CME hit either A or B or miss all completely. For the 7 events that the model failed, there may be 2 explanations: either those CMEs were more complex than a flux-rope like events and the fit did not perform well, either the CMEs changed their direction while propagating into the interplanetary space.

Nr.	Date [1]	Hour[2]	Lon[3]	CMElon[4]	Lat[5]	CMElat[6]	Ang A[7]	Ang B[8]	Ang A lat[9]	Ang L1 lat[10]	Ang B lat[11]	Hit B[12]	Hit L1[13]	Hit A[14]
1	15-Oct-2007	23:52	1	10	4	13	19	-17	4	6	7	0	1	0
2	31-Aug-2008	03:07	2	24	-8	23	38	-33	6	7	5	0	1	0
3	29-Nov-2008	16:38	0	5	6	5	42	-43	-4	1	6	0	1	0
4	25-Aug-2009	17:24	-43	30	7	21	59	-52	5	7	3	1	0	0
5	12-Feb-2010	13:08	-11	21	3	25	65	-71	-5	-7	1	0	1	0
6	03-Apr-2010	11:24	7	19	-26	27	67	-71	1	-6	-5	0	1	0
7	08-Apr-2010	07:24	-1	28	-6	20	68	-71	1	-6	-6	0	1	0
8	08-Apr-2010	16:24	-83	28	20	21	68	-71	1	-6	-6	0	0	0
9	01-Aug-2010	09:24	-33	55	18	57	78	-71	5	6	-3	1	1	0
10	06-Oct-2010	09:08	-23	29	21	24	83	-78	-3	6	4	0	1	0
11	30-Jan-2011	16:08	-9	15	-17	20	86	-93	-5	-6	5	0	1	0
12	25-Feb-2011	22:08	43	15	13	12	87	-95	-1	-7	2	0	0	0
13	07-Mar-2011	16:08	-30	32	19	26	88	-95	0	-7	1	0	0	0
14	08-Mar-2011	06:08	44	0	-17	70	88	-95	0	-7	1	0	0	0
15	25-May-2011	14:08	15	14	12	15	94	-93	7	-1	-7	0	0	0
16	02-Jun-2011	09:08	-20	27	-9	29	94	-93	7	-1	-7	0	1	0
17	02-Aug-2011	07:24	-1	30	12	48	100	-93	3	6	-5	0	1	0
18	03-Aug-2011	15:08	-39	44	11	44	100	-93	3	6	-5	0	1	0
19	04-Aug-2011	04:24	-26	57	16	44	100	-93	3	6	-5	0	1	0
20	06-Sep-2011	04:08	1	19	31	41	103	-95	-1	7	-1	0	1	0
21	07-Sep-2011	00:08	30	86	27	72	103	-95	-1	7	-1	0	1	1
22	14-Sep-2011	02:09	21	27	21	29	103	-96	-2	7	0	0	1	0
23	24-Sep-2011	14:08	-30	36	18	52	104	-97	-4	7	1	0	1	0
24	22-Oct-2011	12:09	71	66	43	43	105	-100	-6	5	4	0	0	0

Table 1: Extension of the reconstructed CME to ICME at STEREO – A & B and L1.
(Complete explanation of parameters found in Rodriguez et al. 2011)

SPEEDS COMPARISON

Using the results from forward modeling the real speeds were also computed by plotting the height of the leading edge of the reconstructed CME versus the time. A linear fit was then applied and the slope of the fit and its error was taken as real 3D speed.

In the table below we made a comparison between the reconstructed speed computed from forward modeling, the speed from SOHO data at 20 solar radii taken from the SOHO LASCO CME CATALOG (found at: http://cdaw.gsfc.nasa.gov/CME_list/) and the speeds recorded in Richardson and Cane list of Near-Earth Interplanetary Coronal Mass Ejections Since January 1996 (list found at: http://www.srl.caltech.edu/ACE/ASC/DATA/level3/icmetable2.htm) where available or if the event was not included in the list, the ACE speeds obtained using the OMNIWeb tool (http://omniweb.gsfc.nasa.gov/form/omni_min.html).

The sometime great difference between the reconstructed speed and the speed from the LASCO catalog can be mainly explained by the fact that the speed at LASCO is a projected one while from forward modeling we got the real propagation speed. Also most of the events were seen as full halo from SOHO or there were not enough images for a more accurate measurement. The ICME speed measured at ACE could also differ from the speed of the CME when it left the Sun as on its way to Earth it can interact with previous CMEs or it can be accelerated or decelerated by interactions with the solar wind.

Nr.	Date DD.MM.YYYY	Time	V SOHO 20 km/sec*	V 3D km/sec	Vmax ICME km/sec	Geomagnetic storm	Dst min (nT)
1	15.11.2007	18:50	263	226.24 ± 41.73	480	19-20.11.2007	-40
2	30.08.2008	17:30	390	469.46 ± 7.8	593	03-04.09.2008	-51
3	29.11.2008	11:54	273	780.5 ± 243.15	443	04-05.12.2008	-39
4	25.08.2009	06:30	439	338.64 ± 20.55	471	30.08.2009	-33
5	12.02.2010	13:42	437	768.91 ± 69.15	345	16.02.2010	-47
6	03.04.2010	10:33	661	718.13 ± 10.52	790	05-06.04.2010	-73
7	08.04.2010	01:31	362	404.60 ± 32.50	460	11-12.04.2010	-56
8	08.04.2010	04:54	179	369.55 ± 119.98	460	11-12.04.2010	-56
9	01.08.2010	13:42	1309	1238.37 ± 63.57	590	03-04.08.2010	-65
10	06.10.2010	07:12	441	365.08 ± 85.04	451	11.10.2010	-79
11	30.01.2011	12:36	289	223.62 ± 18.68	470	4-5.02.2011	-36
12	25.02.2011	20:24	390	221.21 ± 37.37	672	1-2.03.2011	-61
13	07.03.2011	14:48	632	540.94 ± 78.08	561	10-12.03.2011	-59
14	08.03.2011	04:11	669	560.26 ± 22.30	561	10-12.03.2011	-59
15	25.05.2011	13:25	523	707.09 ± 11.15	540	27-29.05.2011	-80
16	02.06.2011	08:12	996	916.71 ± 81.98	556	05.06.2011	-38
17	02.08.2011	06:36	596	989.15 ± 109.31	440	04-06.08.2011	-113
18	03.08.2011	14:00	480	869.38 ± 167.31	610	04-06.08.2011	-113
19	04.08.2011	04:12	1208	1892.45 ± 74.87	610	04-06.08.2011	-113
20	06.09.2011	02:24	1662	307.18 ± 10.04	530	09-11.09.2011	-64
21	06.09.2011	23:05	582	792.09 ± 11.15	530	09-11.09.2011	-64
22	14.09.2011	00:02	457	515.82 ± 9.26	590	17-18.09.2011	-63
23	24.09.2011	12:48	2089	1188.14 ± 128.27	698	26-28.09.2011	-103
24	22.10.2011	10:24	1074	1023.93 ± 66.92	510	24-26.10.2011	-137

Table 2: 3D speed and measured speeds

GEOMAGNETIC SIGNATURES

An example from 26-28 September 2011 geomagnetic storm that marks the arrival of the 24.09.2011 CME to Earth is shown in Figure 2. The arrival is marked by perturbations of the Bz component of the geomagnetic magnetic field (top graph of Figure 2) and a drop in the Dst index (bottom graph contains the evolution of the sub-hour equivalent of the Dst index). The middle graph depicts the evolution of the speed of the incoming flux of particles at ACE. The values stabilize after the ICME passes.

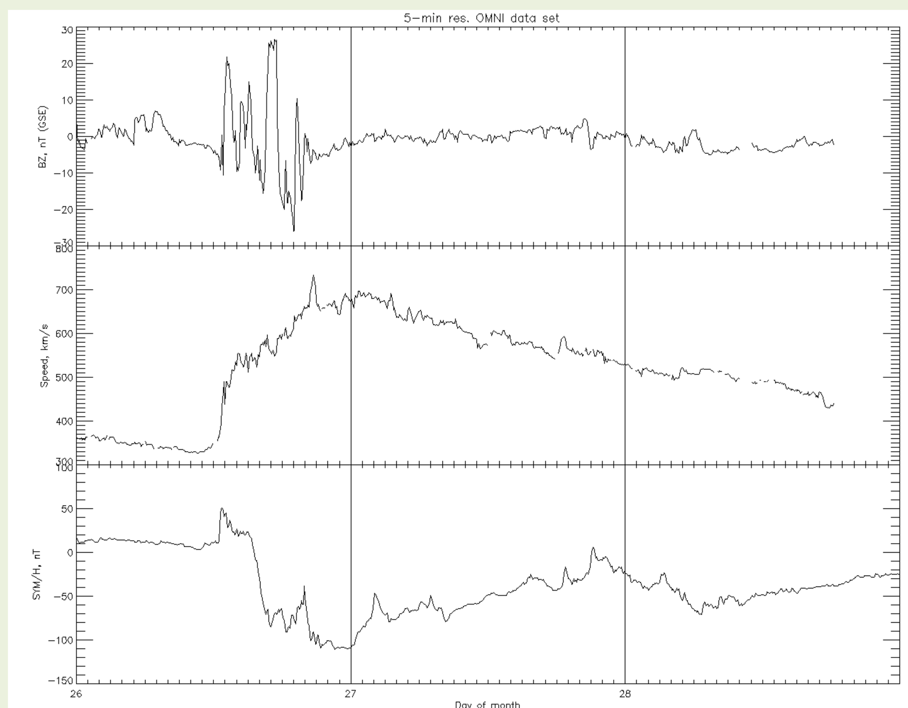

Figure 2: Arrival of a CME to ACE

SUMMARY:

- A total of 24 events were reconstructed using the forward modeling technique;
- By extending the reconstructed parameters, 17 were confirmed to reach Earth;
- The 3D speeds were computed and compared to the speed of the CME as seen from LASCO and with the speed of the ICME when it reached ACE.

ACKNOWLEDGEMENTS

A.R.P and D.A.L would like to thank SIDC and ROB for the facilities and funding granted to carry out this work. The authors would like to acknowledge the using of the data from Solar Weather Browser. We thank the STEREO/SECCHI consortium for providing the data.

REFERRENCES:

- Mierla, M. , Inhester, B., Marque, C., Rodriguez, L., Gissot, S., Zhukov, A., Berghmans, D.and Davila, J.: 2009, Sol.Phys., Vol. 259, Issue 1-2, pp. 123-141.
- Rodriguez, L.; Mierla, M.; Zhukov, A. N.; West, M.; Kilpua, E.: 2011, Sol.Phys., Vol. 270, Issue 2, pp.561-573.
- Thernisien, A.F.R., Howard, R.A., Vourlidas, A.: 2006, Astrophys. J. 652, 763.