MULTI-POINT MEASUREMENTS OF SOLAR ERUPTIONS AT LOCATIONS THROUGHOUT THE HELIOSPHERE

Elena García Broock[1] (elena.garcia.broock@gmail.com), Matthew J. West[2], Marilena Mierla[2], Elena Podladchikova[2] & Luciano Rodriguez[2].
[1]Universidad de La Laguna, [2]Royal Observatory of Belgium.

GOALS:

A kinematic study on Coronal Mass Ejections (CMEs) was made. The main goal was to calculate the arrival time to both the STEREO satellites[1] and near-Earth detectors, using single plane and triangulation methods. We assessed the accuracy of the methods by identifying, and comparing to, the in-situ signatures of the CMEs.

METHODOLOGY:

All CMEs associated with M- and X- class flares, occurring near the solar limb (between -20-20, and 70-100 and -110- -70 degrees longitude), observed between 15-Feb-2011 and 09-Aug-2011 were studied, a period when either STEREO-A or STEREO-B was in quadrature with the Sun-Earth line (~90 degrees of separation). The events were observed with various instruments (SDO-AIA[6], PROBA2-SWAP[9,10], STEREO-EUVI[1], SOHO-LASCO[2], STEREO-COR[1]) and processed using IDL, Python and JHelioViewer[5].

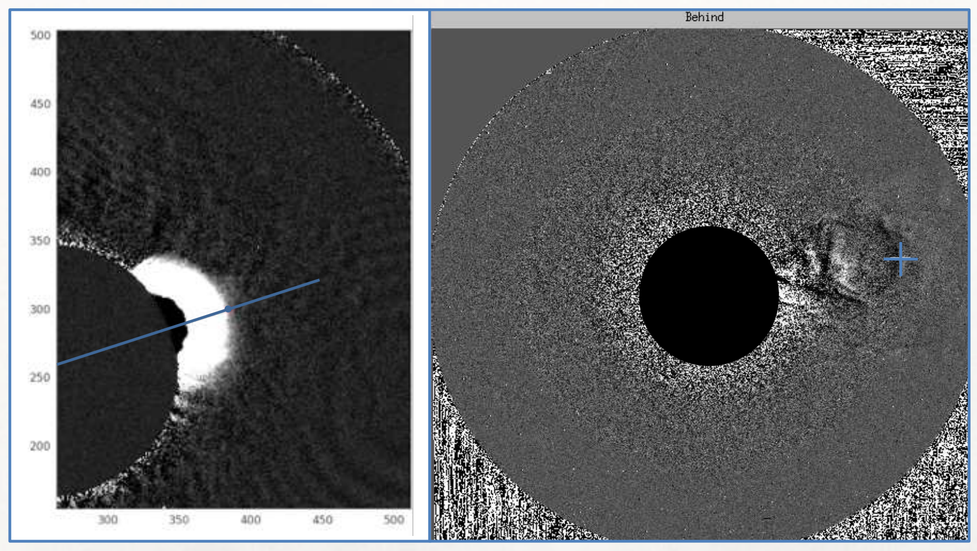

Figure 1 – Interactive screens from Python (left image) and IDL (right image) routines used to generate time-height files used to calculate CME speeds and arrival time to in-situ instrumentation.

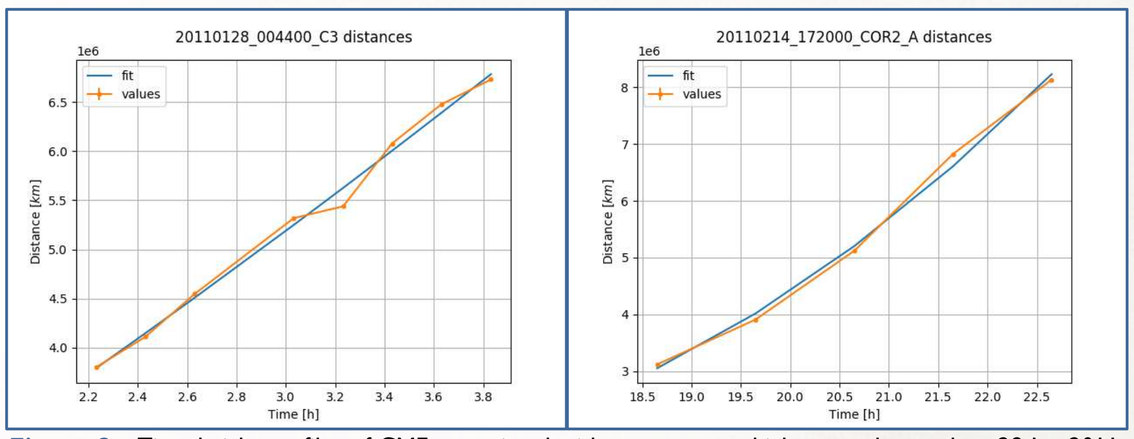

Figure 2 – Time-height profiles of CMEs associated with two events, which were observed on 28-Jan-2011 at 00:44 UT and 14-Feb-2011 at 17:20 UT (left and right respectively). The X axis shows the time from the beginning of the associated flare, until the CME left the field of view, and the Y axis shows the distance from Sun center. Measurements are shown in orange and a second degree fit is shown in blue. The left event points were extracted from LASCO-C3 data and right event points from STEREO A-COR2 data.

Data from the various instruments were downloaded and prepped with Python and IDL routines. Routines were developed to calculate the CME distances, speeds and accelerations. The routines allowed us to identify the leading edge of the CME at different times to generate Time-Height profiles, later used to calculate the leading edge speeds. Figure 1, shows an example CME with leading edge identified and Figure 2 shows an example height-time profile.

The calculated speeds were used with the Drag Based Model[11], to estimate arrival times at in-situ detectors, from which data was extracted and ICMEs (Interplanetary Coronal Mass Ejections) were identified.

Indicators of ICME arrival included material expansion, declining speed profiles, low temperatures, enhanced and rotation of magnetic fields, and low plasma betas[4,7].

RESULTS:

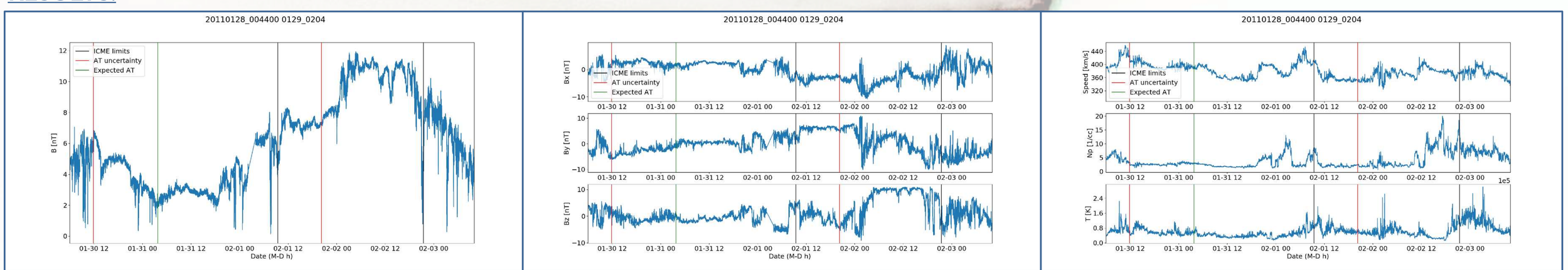

Figure 3 – In-situ data from the 28-Jan-2011 event, obtained with the IMPACT and PLASTIC instruments on STEREO-A. The Green line represents the estimated arrival time, the red lines the uncertainty gap and the black lines the beginning and the end of a possible ICME.

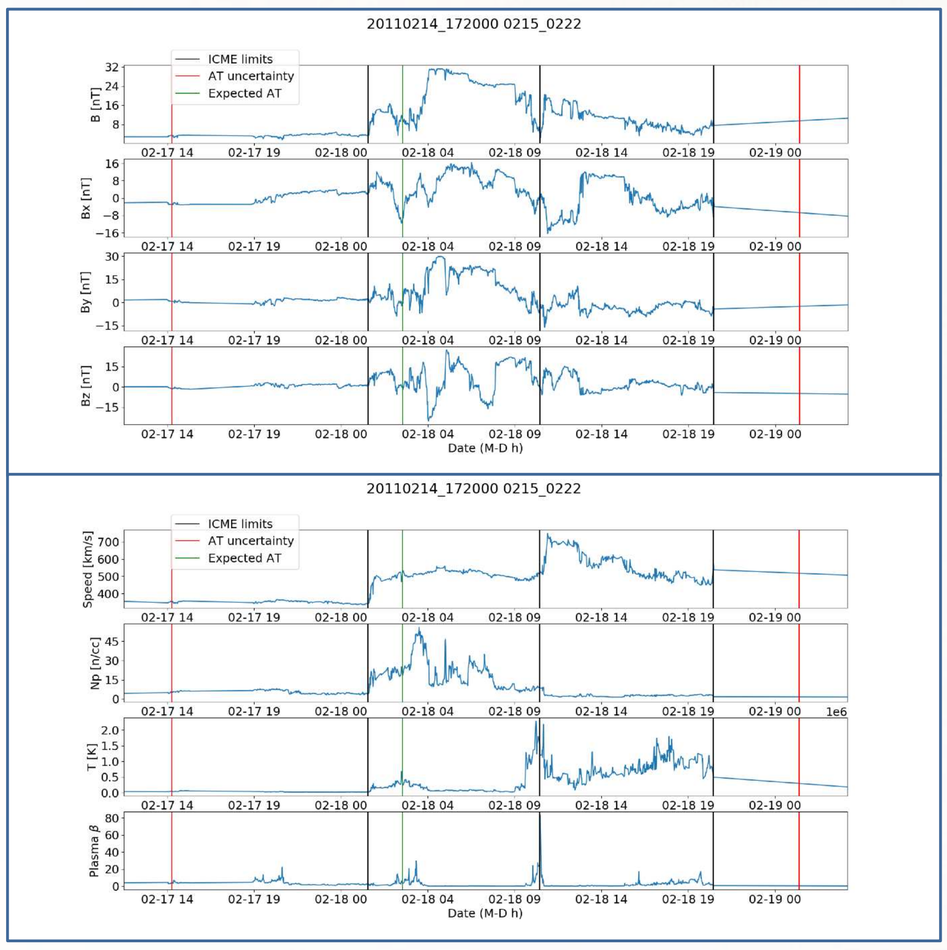

Figure 4 – In-situ data from 14-Feb-2011 event. Taken from the WIND and ACE instruments, in the OMNI data-sets[2]. The color code is the same as in Figure 3. There is evidence of two interacting ICMEs, which can be separated around the central black line. The interaction could be the result of a superposition of 14-Feb-2011 and 15-Feb-2011 events.

In total 64 flare events where studied, of which 44 were found to have associated CMEs. From those, 15 fell into desirable longitude gaps. ICME signatures were found for 10 of the events, see Table 1. Figure 2 (left) shows the Time-Height plot associated with the ICMEs in Figure 3. These results highlight the inaccuracies in estimating CME arrival time based on events emerging near the solar limb (approximately plane-of-sky), where our estimates are expected to be most accurate.

Table 1 – Data from events with ICME evidences. Positions taken from Earth perspective. LE = Leading Edge. Estimations on the Arrival Time are not always exact because, given the FOV of the instruments or the diffusion of the CME at great heights, the LE distance taken is sometimes too close to the Sun for the calculation to be optimal.

Flare date	Position	Longitude	Flare class	Flare Start Time (UT)	CME LE Speed (km/s)	Speed Error (km/s)	CME LE Detector	LE Distance (Solar R)	Estimated Arrival Date	Estimated Arrival Time (UT)
14-Feb-2011	Center	5	M2.2	17:20	480.845	127.162	SA-COR2	11.680	18-Feb-2011	03:25
15-Frb-2011	Center	10	X2.2	01:44	653.225	68.518	SA-COR2	13.431	17-Feb-2011	19:27
02-Aug-2011	Center	15	M1.4	05:19	989.323	22.067	SA-COR2	10.484	04-Aug-2011	10:11
06-Sep-2011	Center	5	M5.3	01:35	603.924	36.367	SA-COR2	9.737	08-Sep-2011	23:53
06-Sep-2011	Center	20	X2.1	22:12	884.132	94.281	SA-COR2	8.282	09-Sep-2011	07:18
28-Jan-2011	Limb	90	M1.3	00:44	546.979	269.012	LASCO-C3	9.665	01-Feb-2011	20:16
08-Mar-2011	Limb	95	M1.4	19:46	525.547	27.207	LASCO-C3	8.883	12-Mar-2011	04:34
08-Mar-2011	Limb	90	M4.4	18:08	373.859	29.237	LASCO-C2	4.732	13-Mar-2011	06:57
09-Aug-2011	Limb	70	X6.9	07:48	609.951	238.512	LASCO-C3	16.109	13-Aug-2011	10:53
04-Sep-2011	Limb	85	M3.2	11:21	492.791	198.466	LASCO-C3	11.364	09-Sep-2011	03:56

References:

[1] M. L. Kaiser et al (2008) The STEREO Mission: An Introduction. Space Science Review. 136. 1-4. 5-16.
[2] J. H. King et al. (2005) Solar wind spatial scales in and comparisons of hourly Wind and ACE plasma and magnetic field data. Journal of Geophysical Research: Space Physics. 110. A2.
[3] G. E. Brueckner et al. (1995) The Large Angle Spectroscopic Coronograph (LASCO) Solar Physics. 162. 1-2. 357-402.
[4] H. Z. Thomas et al. (2006) In-situ solar wind and magnetic field signatures of interplanetary coronal mass ejections. Space Science Reviews 123. 31-43.
[5] D. Müller et al. (2009) Jhelioviewer: Visualizing Large Sets of Solar Images Using JPEG 2000. IEEE.
[6] J. R. Lemen et al. (2012) The Atmospheric Imaging Assembly (AIA) on the Solar Dynamics Observatory (SDO). Solar Physics. 275. 1-2. 17-40.
[7] T. Mulligan et al. (1998) Solar cycle evolution of the structure of magnetic clouds in the inner heliosphere. Geophysical Research Letters. 25. 15. 2959-2962.
[8] E. Palmerio et al. (2019) Multipoint Study of Successive Coronal Mass Ejections Driving Moderate Disturbances at 1 au. The American Astronomical Society.
[9] D. B. Seaton et al. (2013) The SWAP EUV Imaging Telescope Part I: Instrument Overview and Pre-Flight Testing. Solar Physics. 286. 1. 43-65.
[10] J. P. Halain et al. (2013) The SWAP EUV Imaging Telescope. Part II: In-flight Performance and Calibration. Solar Physics. 286. 1. 67-91.
[11] B. Vršnak et al (2007) Transit times of interplanetary coronal mass ejections and the solar wind speed. A&A. 472. 3. 937-943.

STARS4ALL J.C. Casado STARRYEARTH

Royal Observatory of Belgium

Universidad de La Laguna