Predicting ICME Signatures at L1 with a Data-Constrained Physical Model

Phillip Hess and Jie Zhang

Department of Physics and Astronomy
George Mason University
4400 University Dr. Fairfax, VA

International Study of Earth-Affecting Solar Transients
Mexico City
10/26/2015

Motivation

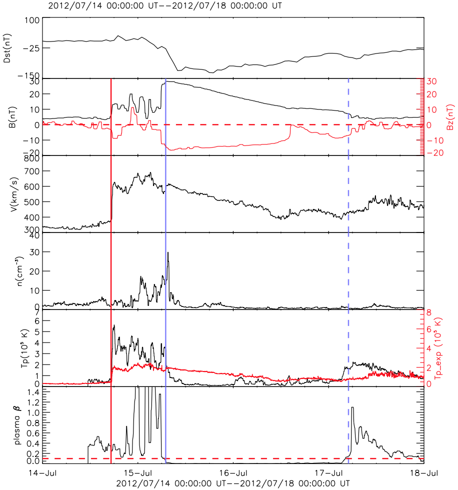
- Combine the Data from WG1, theoretical principles from WG2 and campaign events from WG4
- Combining these techniques can allow to study the physical processes of CME propagation
- It also forms the basis for a potential predictive tool
  We are careful to separate the sheath and ejecta observationally to study each front individually

Introduction

- We present a modified drag-based model to accurately predict the arrival of ICME structures at the L1 point
- For a 7 event sample, we are able to predict arrivals within 4 hours for separate ICME signatures
  - Ejecta- Eruptive material from the corona, likely a flux rope.
  - Sheath- Solar wind plasma accumulated as ejecta propagates. The front of the sheath may or may not be a shock
- For further detail, see Hess & Zhang (2015, 2014)

Event Selection

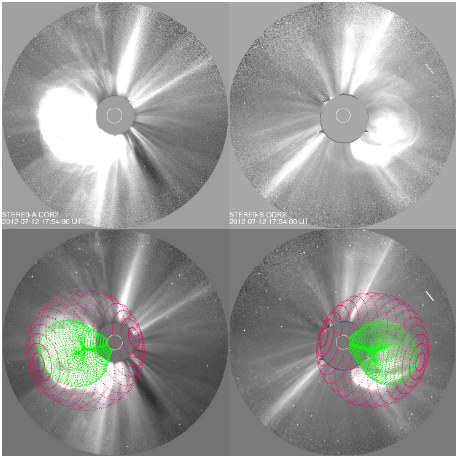
- Events were initially selected from ACE data
- An automatic detection algorithm identified potential ICMEs
- Manual conformation provided a larger list of events, 7 of which were picked based on quality of observations



Event List

First Measurement	SH Arrival	EJ Arrival	Direction	V_0	V_{sw}	R_0	R_f	AR	Flare	Flare Peak
04/03/2010 10:24	04/05 08:00	04/05 11:30	E06S26	854.7	512.4	5.5	62.8	11059	B7	04/03 09:54
05/24/2010 14:54	05/28 02:00	05/28 07:00	E28N03	605.7	362.3	4.6	45.0	-	-	-
09/14/2011 00:24	09/17 02:00	09/17 19:00	W20S16	519.5	396.9	5.3	28.1	11289	-	-
07/12/2012 16:54	07/14 17:00	07/15 07:15	W00S09	1492.0	353.7	4.3	76.6	11520	X1	07/12 15:36
09/28/2012 00:24	09/30 23:00	10/01 06:00	E28N17	1230.5	310.4	6.3	74.1	11577	C3	09/28 00:00
10/27/2012 17:24	10/31 15:00	11/01 00:00	E12N12	400.1	289.8	6.2	49.0	-	-	-
03/15/2013 07:24	03/17 15:30	03/18 00:00	W24S07	1220.2	429.3	7.4	37.0	11692	M1	03/15 05:46

Measuring the Fronts



- Height measurements were based on the raytrace method using SECCHI and LASCO observations (Thernisien et al., 2006, 2009)
- Each structure has a unique geometry (Hess & Zhang, 2014)
  - Ejecta- GCS
  - Sheath- Spheroid

Drag-Based Model

CME measurements are then fit with Drag-Based Model (Vršnak et al., 2013)

$$a(t) = -\Gamma(v(t) - v_{sw})|v(t) - v_{sw}|$$

$$v(t) = \frac{v_0 - v_{sw}}{1 + \Gamma(v_0 - v_{sw})t} + v_{sw}$$

$$R(t) = \frac{1}{\Gamma} ln[1 + \Gamma(v_0 - v_{sw})t] + v_{sw}t + R_0$$

Initial height (R_0) and velocity (v_0) can be determined reliably from the measurements. Upstream solar wind speed (v_{sw}), ACE data is used for now. This leaves the drag parameter (Γ) as the only true unknown

Modifying the DBM

- Most work using the DBM uses static, fixed parameters
- Making some physical and geometric assumptions about the flux rope, we simplify the form of Γ given by Cargill (2004)

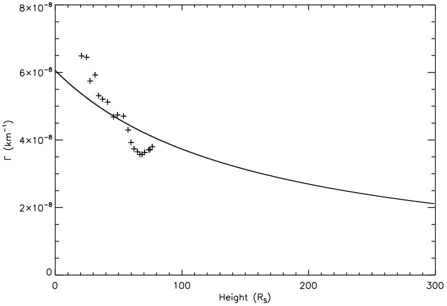
$$\Gamma = \frac{c_d A \rho_{sw}}{M + M_v} \rightarrow \Gamma(R) = \frac{c_d}{\frac{\rho_0 \kappa R_0}{\rho_{sw0}} + \frac{\kappa R}{2}}$$

- Using measurement and fittings, a height-dependent Γ can be determined, yielding an iterative drag model

$$R(t+1) = \frac{1}{\Gamma(R(t))} ln[1 + \Gamma(R(t))(v(t) - v_{sw})t] + v_{sw} t + R(t)$$

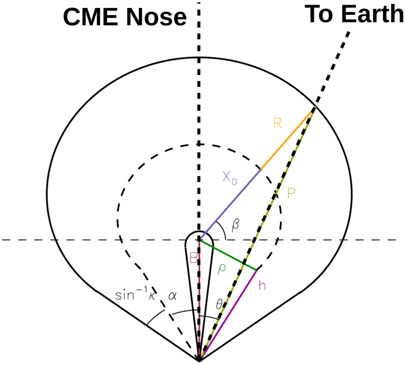
Fitting for Γ

- Γ is determined thoughout the heliosphere by getting a series of Γ values throughout the propagation
- This is done at each point by performing drag fittings on all the data up until that point (i.e. the first 4 points, then 5, etc.)
- The Γ values are not well fit by the Γ model, but do help at least constrain the amount of drag



Geometric Correction

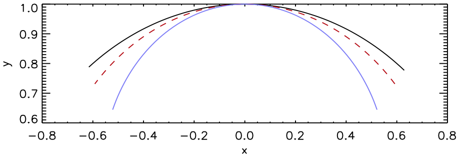
- Initially Predictions for CMEs far from Sun-Earth line were consistently early
- CME curvature effect
- Using the GCS geometry (right) a height correction was determined as a function of the deviation angle (θ)

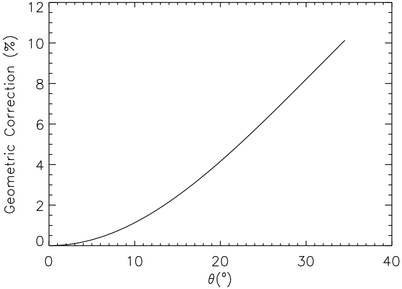


Geometric Correction Cont.

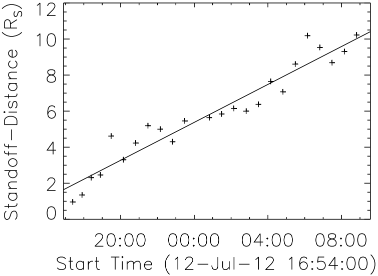
This led to an opposite effect with the GCS geometry causing late predictions, so a weighted average of the two is used

$$h_f = .645h_N + .355h_G$$



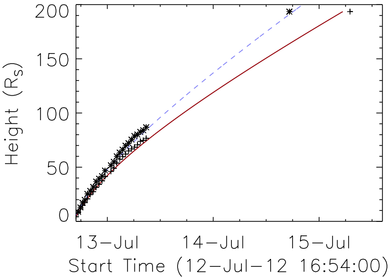


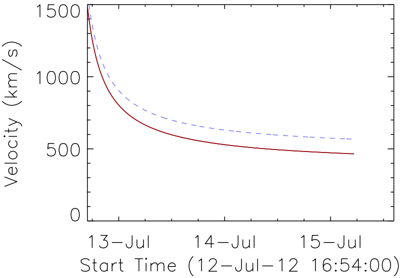
Fitting the Sheath Front



- The previous slides apply to the ejecta
- The method failed to predict the sheath
- By measuring both fronts, the standoff distance in the heliosphere can be known
- Combining the results of a SD fit with the flux rope model gives sheath height

Model Example

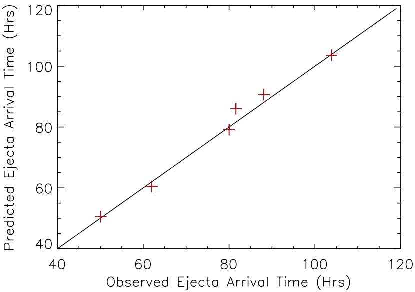


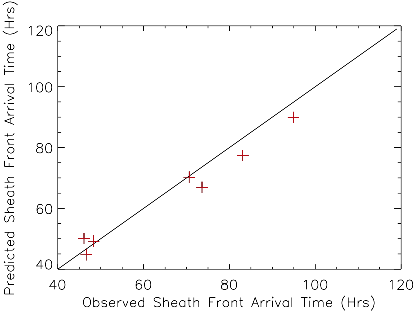


Results Table

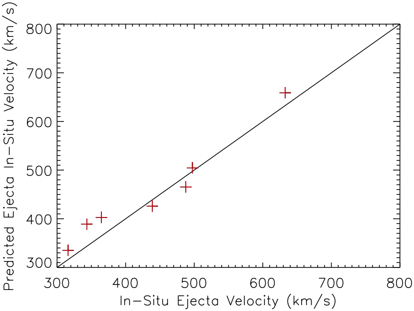
ICME Date	ΔT_{SF}	ΔT_{EJ}	ΔV_{SF}	ΔV_{EJ}	$\rho_{ratio}(R(0))$	$\rho_{ratio}(L1)$	$\rho_{ratio}(ACE)$
04/05/2010	1.89	0.38	23.3	26.4	32.17	0.91	0.41
05/24/2010	5.69	2.52	96.3	38.1	6.70	0.15	1.21
09/14/2011	6.68	4.39	15.8	13.0	3.24	0.09	0.71
07/12/2012	0.84	1.51	24.8	22.4	18.61	0.41	0.61
09/28/2012	0.34	0.9	61.6	45.6	10.31	0.31	0.97
10/27/2012	4.99	0.28	24.5	19.0	14.78	0.47	0.67
03/15/2013	3.91	0.26	22.9	7.2	5.98	0.21	0.38
Average	3.47	1.46	38.5	24.5	13.11	0.36	0.80
RMS	1.58	0.76	17.9	12.9	-	-	-

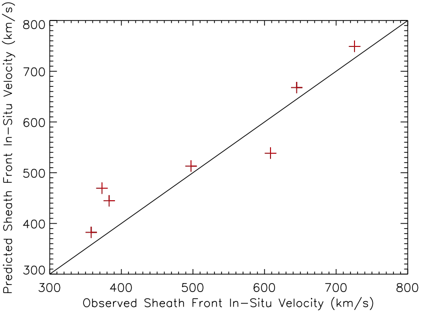
Arrival Comparisons



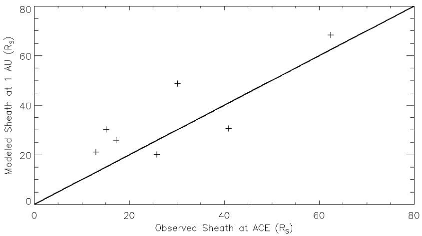


Velocity Comparison



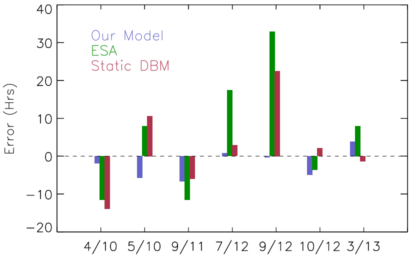


Sheath Comparison



- The majority of the sheath sizes are over estimated
- This is not surprising given the linear propagation assumption for the sheath
- This explains why the many of the sheath arrival predictions were too early

Comparison with Other Models



ICME Date	Our Model	ESA[a]	Static[b] DBM
04/05/2010	-1.9	-11.6	-14.0
05/24/2010	-5.7	7.9	10.6
09/14/2011	-6.7	-11.5	-6.0
07/12/2012	0.8	17.4	2.9
09/28/2012	-0.3	32.9	22.5
10/27/2012	-5.0	-3.7	2.1
03/15/2013	3.9	8.0	-1.4
Abs. Average	3.5	13.3	8.5
RMS	1.6	6.0	4.2

a-Gopalswamy et al. (2013) b-Vršnak et al. (2014)

Limitations for Real-Time Operational Forecasting

- Real-time measurements
- Current Lack of STEREO/L5 observer
- Solar Wind Prediction
- Test for false positives

Conclusions

- Despite the obstacles, we demonstrate an effective proof of concept
- While there is much to do to make this model operational, it does show two keys to making accurate predictions
    - The CME and the heliospheric environment in which it propagates must be uniquely considered for each event
    - The separate structures of the CME should be considered.

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