Drag-based Forecast for CME Arrival

E. Yordanova\textsuperscript{1*}, S. Jaklovsky\textsuperscript{2}, M. Dumbović\textsuperscript{3}, M. Temmer\textsuperscript{4},
A. P. Dimmock\textsuperscript{1}, and L. Rosenqvist\textsuperscript{5}

(*) eya@irfu.se

1 Swedish Institute of Space Physics, Uppsala, Sweden
2 Uppsala University, Uppsala, Sweden
3 Hvar Observatory, Faculty of Geodesy, University of Zagreb, Croatia
4 Institute of Physics, University of Graz, Graz, Austria
5 Swedish Defense Research Agency, Sweden
Motivation

DBEM Model

Dataset

Results

Summary
Front-sided halo CMEs are propagating directly in the Sun-Earth line and therefore cause most of the large geomagnetic storms.

Forecasting their arrival at Earth is a challenging issue due to:

- 2D projection effects in the plane-of-sky affecting the accurate estimation of the halo CME kinematics from coronagraph images
- ever-changing properties of the background solar wind affecting the CME propagation

Here, we test the performance of the Drag-Based Ensemble Model (DBEM) for halo CME arrival prediction, focusing explicitly on the effect of background solar wind speed and exerted drag.
Drag-based Model (DBM)

[Žic et al., 2015; Vršnak et al. 2013; Dumbović et al., 2018]

Model assumptions:

- CME with cone geometry
- CME cross section: \( A \propto r^{-2} \), \((r\text{-heliospheric distance})\)
- CME mass: \( M = \text{const.} \)
- Solar wind density: \( \rho_w \propto r^{-2} \)
- Constant: \( w_{SW} \) cone half-width \((\lambda)\), drag \((\gamma)\)

\[ \gamma = \frac{c_d A \rho_w}{M}, \quad [10^{-7} \text{ km}^{-1}] \]

\[ c_d = \text{const.} \]

CME propagation eq: \( a = \gamma(v - \omega)|v - \omega| \)

http://swe.ssa.esa.int
Dataset: 12 geoeffective Earth-directed fast halo CMEs (Scolini et al. 2018)

Input:

- CME kinematics from Scolini et al., 2018
- CMEs’ shock speed $V_{sh}$ and the velocity of the respective preceding solar wind $V_{sw}$ observed by WIND (example shown in the figure)
Overall, the model produced a wide distribution of arrival times both being under- and overestimated.

Larger uncertainty comes from the variation of the CME initial speed, solar wind speed and drag parameter.

DBEM is less sensitive from half-width and solar source longitude.

**Figure.** Predicted CME arrival time in 95% confidence intervals (colors) obtained from ensemble DBM runs when only one input parameter at a time is varied, while the rest have zero uncertainties.
Results II

Figure. DBEM (predicted) CME speeds versus the observed in-situ speed by WIND spacecraft at L1 for different drag values (the colors correspond to three input $\gamma$ values with dashed lines of the median, correlation coefficients $cc$ and gray dotted line, giving the perfect match between predicted and observed speeds).

- All three input values of the drag parameter $\gamma$ produce overestimated arrival speed
- The best correlation between prediction and observation is achieved for $\gamma = 0.3$ which is higher than the recommended value for fast CMEs
On average, drag parameters $\gamma = 0.1$ and $\gamma = 0.2$ yield to earlier arrival times, while $\gamma = 0.3$ results in later CME arrival.

The higher drag values ($\gamma = 0.2$ and $\gamma = 0.3$) fall in the interval of $\pm 10h$, considered in general as the mean error for CME arrival times.
In this work, we have tested the performance of DBEM model for twelve geoeffective Earth-directed fast halo CMEs, using as inputs the CMEs’ shock speed and the velocity of the preceding solar wind measured at L1.

The results show that:

❖ The solar source longitude and CME cone half-width have insignificant effects on the DBEM predicted arrival time and speed. Note, however that they have a large role in determining if the CME will hit Earth or not.

❖ Solar wind speed, drag and initial CME speed input parameters have greater impact on predicted CME arrival time and speed.
DBEM performance regarding arrival times for this set of CMEs and their associated shocks, is best for $\gamma = 0.2$, \textit{(in agreement with Vršnak et al., 2014, where $\gamma$ ranging between 0.1 and 0.2 was found to be a good proxy for shock arrival predictions).}

DBEM predictions regarding the match between predicted and observed CME impact speed, result from runs with higher drag $\gamma = 0.3$, meaning that there is a \textit{trade-off in achieving both better arrival time and speed prediction.}

The variability in the results points to some aspects not being taken into consideration in the forecast, e.g. preconditioning of the interplanetary space from preceding CMEs, coronal holes, and streamers, therefore \textit{the drag value probably needs to be adjusted on an event to event basis.}