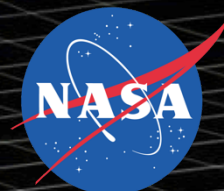


Drag-Based Ensemble Model (DBEM)

J. Čalogović¹, M. Dumbović², B. Vršnak¹,
M. Temmer², A. Veronig², T. Žic³, L. M.
Mays⁴, I. Piantschitsch²

1. Hvar Observatory, Faculty of Geodesy, University of Zagreb, Croatia
2. Institute of Physics, University of Graz, Austria
3. Faculty of Engineering, University of Rijeka, Croatia
4. NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA



DBEM with ensemble and synthetic measurements

Dumbović et al., ApJ, 2018

INPUT

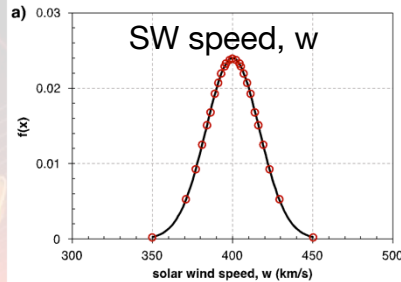
Ensemble of CME measurements:

$T_1, v_1, \phi_1, \lambda_1$
 $T_2, v_2, \phi_2, \lambda_2$
 ...

$T_n, v_n, \phi_n, \lambda_n$

n inputs

m x m inputs



Synthetic values for:

$w_1, \gamma_2 / w_2, \gamma_2$

w_m, γ_m

Ensemble modeling applied to Drag-based Model (DBM, Vršnak et al., 2013, SolPhys)

DBEM OUTPUT

Arrival time: 2013-09-01 12:48:17 < 2013-09-01 21:36:36 < 2013-09-02 03:45:54
 based on 10800 DBM runs, calculated in 13.46 seconds

a)

Input parameters (only first 8 shown)

	CME date&time	gamma	SW speed (w)
1	2013-08-30 06:21:00	0.05	300.0
2	2013-08-30 06:20:00	0.0756	325.6
3	2013-08-30 06:19:00	0.0822	332.2
4	2013-08-30 06:19:00	0.0868	336.8
5	2013-08-30 06:19:00	0.0906	340.6
6	2013-08-30 06:19:00	0.0939	343.9
7	2013-08-30 06:24:00	0.097	347.0
8	2013-08-30 06:22:00	0.1	350.0

	CME speed (v0)	CME h-w (lambda)	CME lon. (phi)
1	844	58	-49
2	848	58	-48
3	847	58	-46
4	854	58	-47
5	858	58	-49
6	889	59	-51
7	837	59	-49
8	835	59	-47

b)

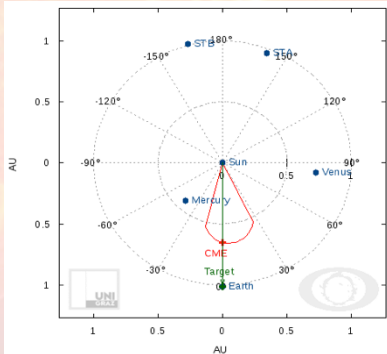
Hit target statistics



Fig. 4 Dumbovic et al. 2018

RUNS

nm^2 combinations (ensemble members)
 nm^2 DBM runs

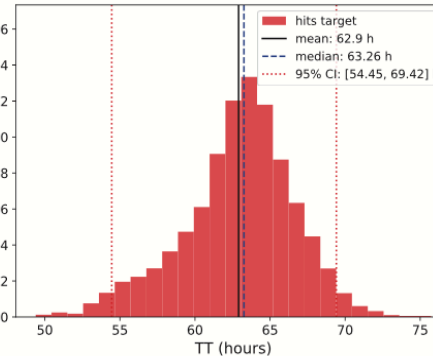


2D DBM (Žic et al., 2015, ApJ)

- hit or no hit
- transit time
- arrival time
- arrival speed

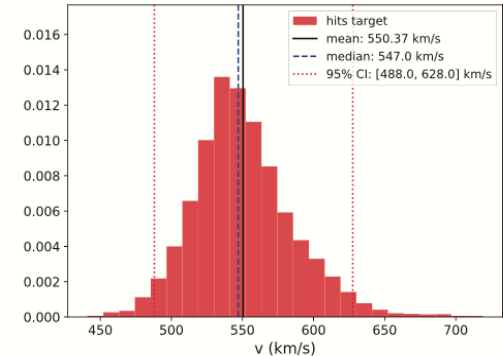
c)

CME Transit Time (TT)
 TT: 54.45 h < 63.26 h < 69.42 h



d)

CME speed (v) at target
 v: 488 km/s < 547 km/s < 628 km/s

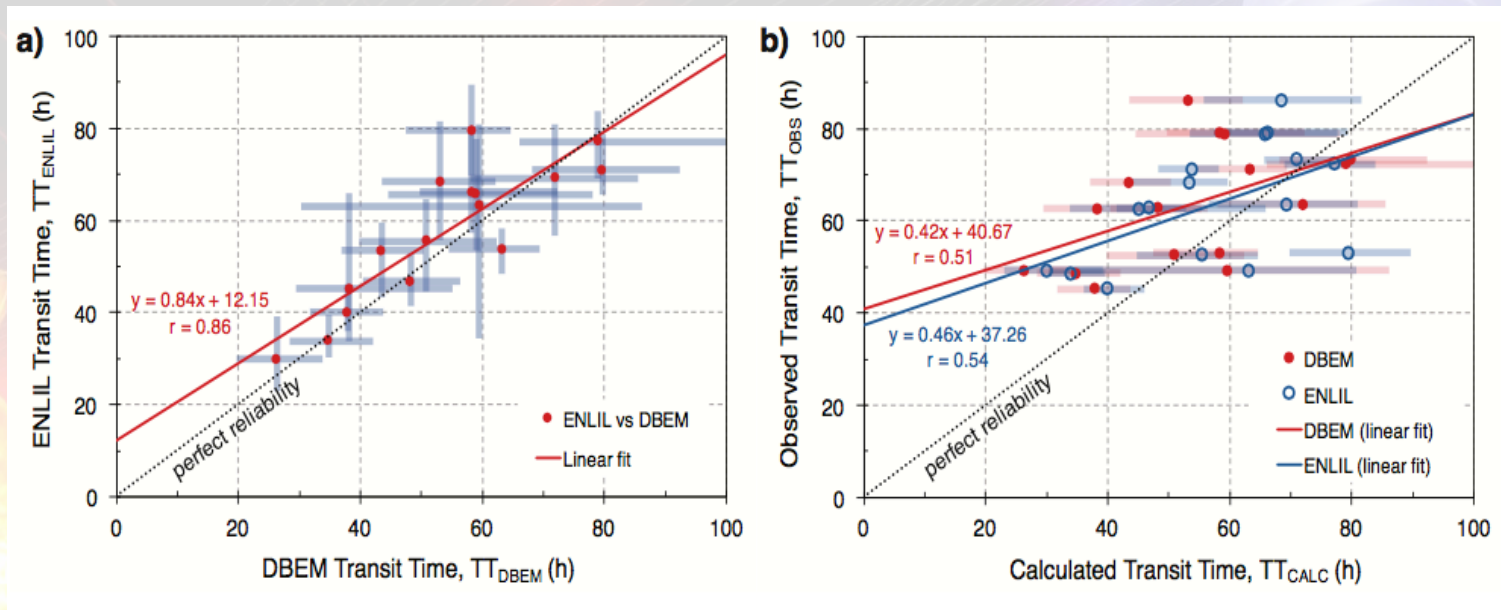


Performance and comparison with ENLIL

- Based on sample: *Mays et al., 2015, SolPhys*

TRANSIT TIME

Fig. 7 from Dumbović et al., 2018



- Both ENLIL and DBEM are not far away from the line of perfect reliability

RELIABILITY DIAGRAM

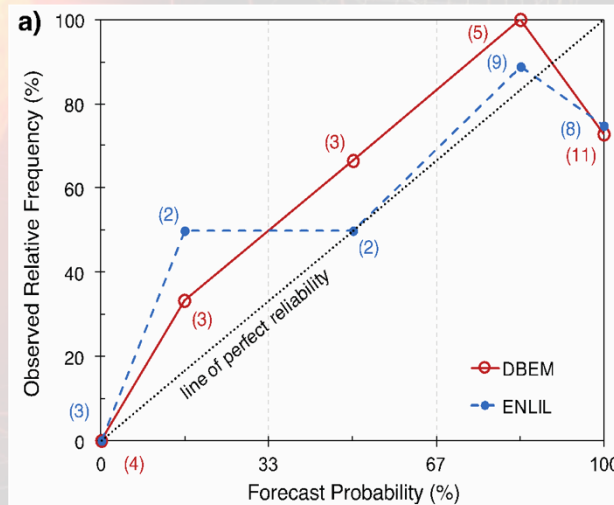


Fig. 5 from Dumbovic et al., 2018

ARRIVAL SPEED

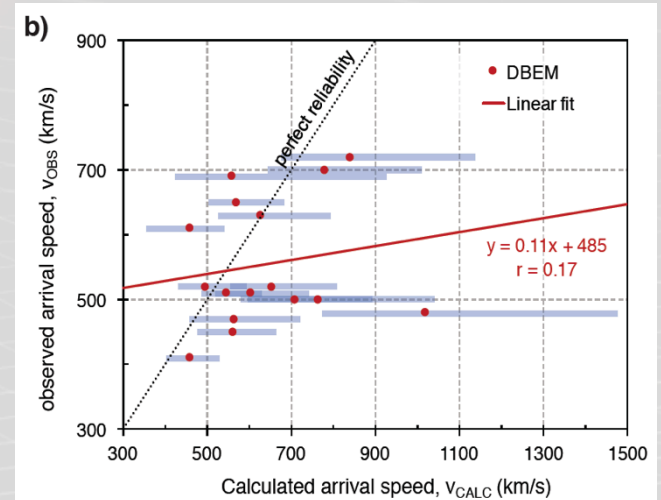


Fig. 8 from Dumbovic et al., 2018

Main points - DBEM

Dumbović et al., ApJ, 2018

- Offers probabilistic forecasting of **CME hit chance**, **transit time** and **arrival speed** for different targets in solar system
- Reliable and simple model
- Runs **very fast** (more than 1000 DBM runs per sec on a single CPU)
- ENLIL and DBEM perform similarly
- Fast CMEs predicted to arrive too early for both DBEM and ENLIL
- Suitable for implementation as on-line (web) forecasting tool:
DBEMv1 and **DBEMv2** - ESA Expert Service Group for Solar & Heliospheric Weather (swe.uni-graz.at)

c) prediction errors for TT (h)	DBEM	ENLIL
mean error (ME)	-9.7	-6.1
mean absolute error (MAE)	14.3	12.8
root mean square error ($RMSE$)	16.7	14.4

On-line DBEMv1 tool with synthetic measurements

- Needs as input only one CME measurement with estimated uncertainties
- Uses **synthetic measurements for all 6 input parameters** (T , v , ϕ , λ , w , γ)
- Needs certain number of synthetic measurements ($m > 9$) to perform reliably - large number of DBM calculations (slow)
- DBEMv2** is faster and more reliable than DBEMv1

- oh.geof.unizg.hr/DBEM
- phyk039240.uni-graz.at:8080/DBEM

Drag-Based Ensemble Model (DBEM):
probabilistic model for heliospheric propagation of CMEs

Input Uncertainties Documentation

Important note: This version of DBEM is mainly for testing purposes. Method with the synthetic measurements may produce the unreliable results in the case of hit/miss ratio, if the number of synthetic measurements is small ($m < 15$) resulting in bad representation of the normal distribution. For this purpose, we developed **DBEM version 2** with slightly different method that uses the randomly generated samples determined by normal (Gauss) distribution as input.

CME date (at R_0): Aug 30 2013

CME time in UTC (at R_0): 06 h 21 min

Drag parameter, γ (depending on CME speed): 0.1 (fast CME) $\times 10^{-7} \text{ km}^{-1}$

Solar wind speed, w = 350 km/s (current: 326 km/s)

CME starting radial distance, R_0 = 21.5 r_{Sun}

Starting speed of CME, v_0 (at R_0) = 861 km/s

CME's angular half-width, Δ = 59 deg

Longitude of CME source region, Φ_{CME} = -48 deg

Select target: Earth

Proceed with model uncertainties Reset

Drag-Based Ensemble Model (DBEM):
probabilistic model for heliospheric propagation of CMEs

Input Uncertainties Results Documentation

Probability of CME arrival at Earth (1.009 AU): **82.72 %**

CME arrival time at Earth (lower 95% Confidence Interval, CI < median < upper 95% CI):
2013-09-01 09:42:52 < **2013-09-01 20:49:59** < 2013-09-02 11:07:30

CME speed at Earth (lower 95% CI < median < upper 95% CI):
466.41 < **549.45** < 655.08 km/s

DBEM plot:

Arrival time: **2013-09-01 09:42:52 < 2013-09-01 20:49:59 < 2013-09-02 11:07:30**
based on 601425 DBM runs, calculated in 31.98 seconds

Input parameters (only first 8 shown)

	CME date&time	gamma	SW speed (w)
1	2013-08-30 05:51:00	0.05	300.0
2	2013-08-30 06:14:15	0.0756	328.6
3	2013-08-30 06:21:00	0.0822	336.0
4	2013-08-30 06:27:44	0.0868	341.3
5	2013-08-30 06:51:00	0.0906	345.8
6		0.0939	350.0
7		0.097	354.2
8		0.1	358.7

	CME speed (v0)	CME h-w (lambda)	CME lon (phi)
1	694.0	41.0	-63.0
2	797.0	52.1	-53.8
3	823.5	55.0	-51.4
4	843.3	57.1	-49.6
5	861.0	59.0	-48.0
6	878.7	60.9	-46.4
7	898.5	63.0	-44.6
8	923.0	65.9	-42.2

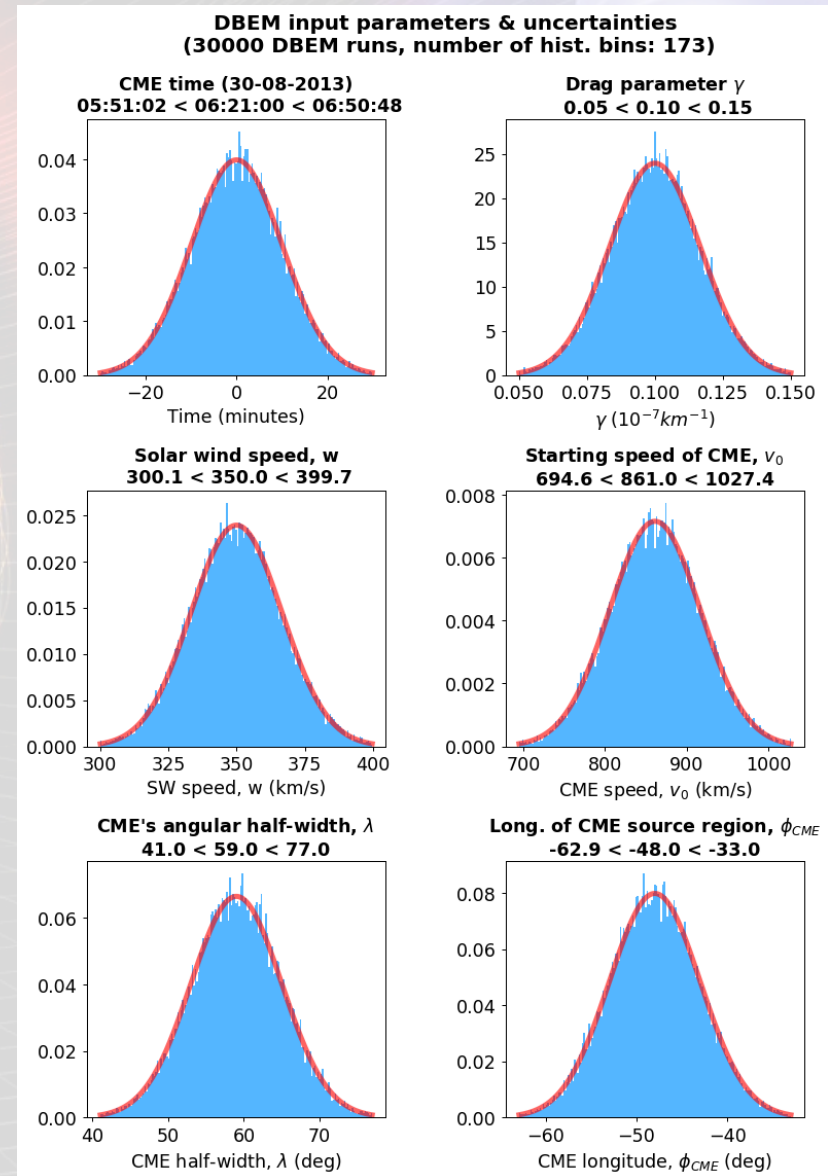
Hit target statistics

Hits target: 82.7%
Misses target: 17.3%

DBEMv2 (version 2) input parameters

Čalogović et al., in preparation

- Same engine (software) as DBEMv1 with synthetic measurements, however different method is used for input uncertainties
- For all 6 input parameters (T , v , ϕ , λ , w , γ) random values are generated in a range input \pm uncertainty (3σ) following a normal (Gaussian) distribution
- Advantages:
 - input distributions are better represented than with DBEMv1
 - converges to stable results much faster than method with syn. measurements
 - allows lower number of DBM runs - **faster**
 - user can choose the exact number of DBEM runs
- Disadvantages:
 - due to random input, it produces every time slightly different results - differences converge with increasing nr. of runs (differences are negligible at $>10\,000$ runs)



DBEMv2 results

- More accurate hit/miss ratio due to better representation of normal distribution in uncertainty range
- Provides statistics (mean, min, max, StDev, CI) for all calculated parameters
- User can download all results in a zip file
- Will be soon integrated in

ESA SSA portal as operational forecasting tool in the frame of the **ESA Expert Service Group for Solar & Heliospheric Weather**

(
swe.ssa.esa.int/heliospheric-weather) -

DBEMv2 on-line tool



1. <http://oh.geof.unizg.hr/DBEMv2>
2. <http://phyk039240.uni-graz.at:8080/DBEMv2>

