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USAGE OF THE DRAG-BASED MODEL

ESF HUMAN RESOURCES DEVELOPMENT
STRUKTURNI I INVESTICIJSKI FONDOVI

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Introduction

The drag-based model (DBM) is an analytical model which is usually used for calculating kinematics of coronal mass ejections (CMEs) in the interplanetary space, prediction of the CME arrival times and impact speeds at arbitrary "target" in the heliosphere. The main assumption of the model is that beyond a distance of about 20 solar radii from the Sun, the drag is dominant in the interplanetary space.

DBM extension

The previous version of DBM relied on the rough assumption of averaged, unperturbed and constant surrounding and CME properties during interplanetary CME propagation (Vršnak, 2001; Cargill, 2004; Owens et al., 2004; Vršnak et al., 2007; Borgazzi et al., 2009; Lara et al., 2009; Vršnak et al., 2010; Vršnak et al., 2013). The continuation of our work consists of enhancing the model into a form where is allowed a time-dependent and perturbed heliospheric environment and constraints on CME properties are lifted (Žic et al., 2015). Therefore, the further development leads to the extension of DBM which enables the DBM usage in perturbed and time-dependent surrounding without lower-limit constraint on the distances above 20 solar radii.

The CME acceleration, caused by the MHD "drag" is:

$$R''(t)=-\gamma(R)[R'(t)-w(R)]|R'(t)-w(R)|.$$

where the "drag parameter" γ is defined by:

$$\gamma(R)=\gamma_\infty\frac{w_\infty}{w(R)}.$$

The large distance limit is γ_∞ and $\Gamma = \gamma_\infty \times 10^7$ km.

The instantaneous acceleration and speed of the ejection are denoted by $R''(t)$ and $R'(t)$, whereas $w(R)$ represents the ambient solar-wind speed and its large distance limit is w_∞. The solar wind speed perturbation is defined in following form:

$$w(R)=\begin{cases} w_0(R)+w_p(R), R_1<R<R_2 \\ w_0(R), otherwise \end{cases}$$

where w_p is perturbed (valid between distances R_1 and R_2) and w_0 is unperturbed solar-wind speed term defined from Leblanc, Dulk, Bougeret density model (Leblanc et al., 1998).

The least-square fitting

The DBM extension provides the possibility of its application in various scenarios, such as automatic least-square fitting on initial CME kinematic data suitable for a real-time forecasting of CME kinematics. Basically, the least-square fitting (LSF) is based on a successive variation of DBM parameters in order to find minimal quadratic deviation of observational to DBM-calculated speeds. The minimal quadratic deviation recognizes the best suited DBM parameters for prediction of a CME propagation. The "goodness" of fit is represented by several statistical quantities:

- the standard deviation (SD): σ,
- the coefficient of variation: c_v,
- the coefficient of determination: $\Re^2$, as $\Re^2 \rightarrow 1$, fit gets better (Motulsky et al., 1987).

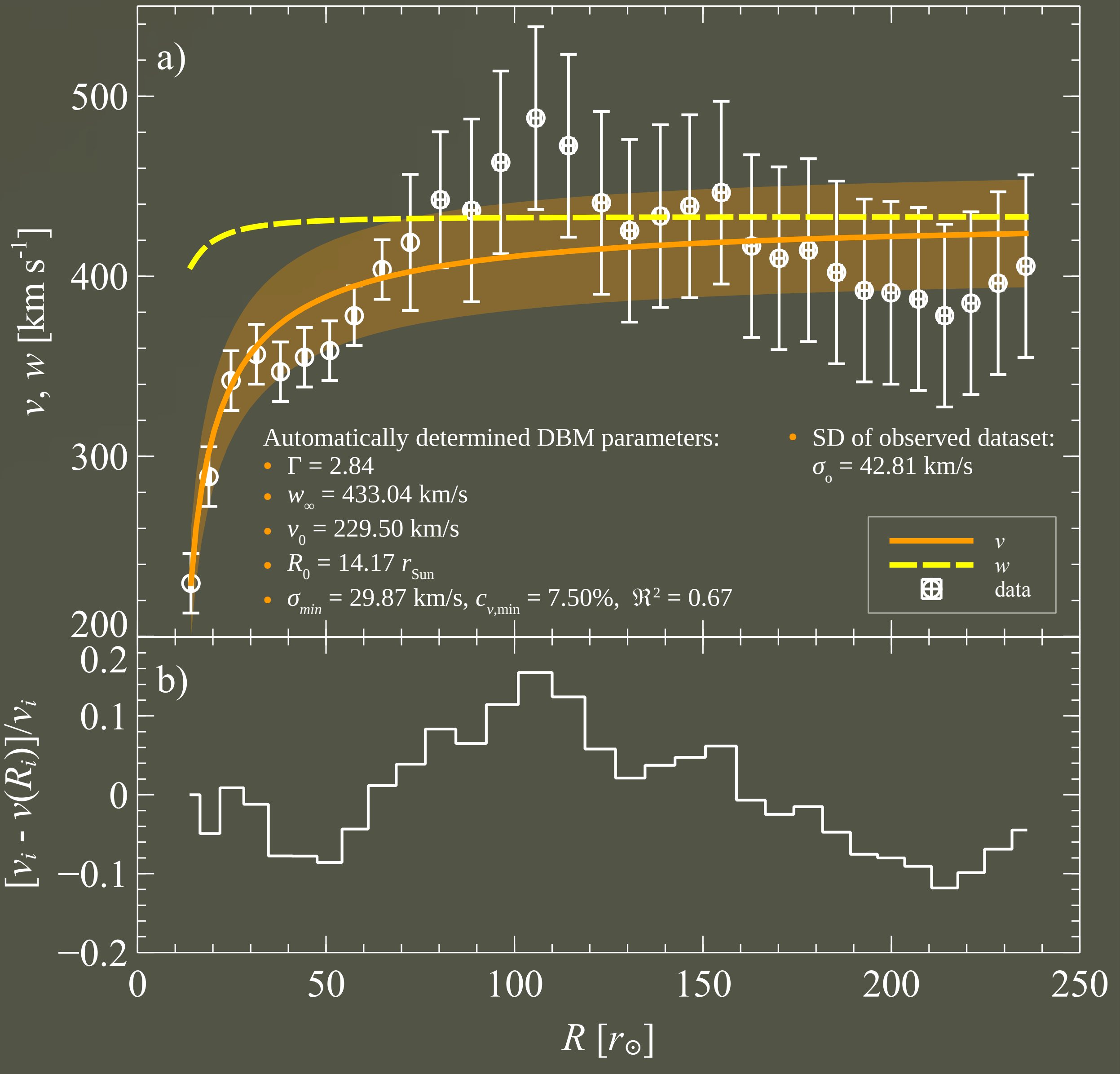

Fig. 1. LSF is applied on the Event 1 data from the paper by Temmer et al. (2011). The event started on 2008 June 1 at ~21 UT, while standard deviation of the observed dataset is $\sigma_o = 42.81$ km/s.

a) The estimated kinematic $v(R)$ curve is presented by solid orange line and error is shown as orange shaded area. The white circles (and error bars) present observed CME speed.
Numerically calculated solar-wind speed w is plotted by dashed yellow line. Orange shaded area is the "average" error of the fit, defined in range from $v(R) - \sigma_{min}$ to $v(R) + \sigma_{min}$.

b) The relative residuals between observational speed, v_i, and DBM-calculated, $v(R_i)$, speed of CME.

The fitted standard deviation σ_{min} is smaller than the observed σ_o!

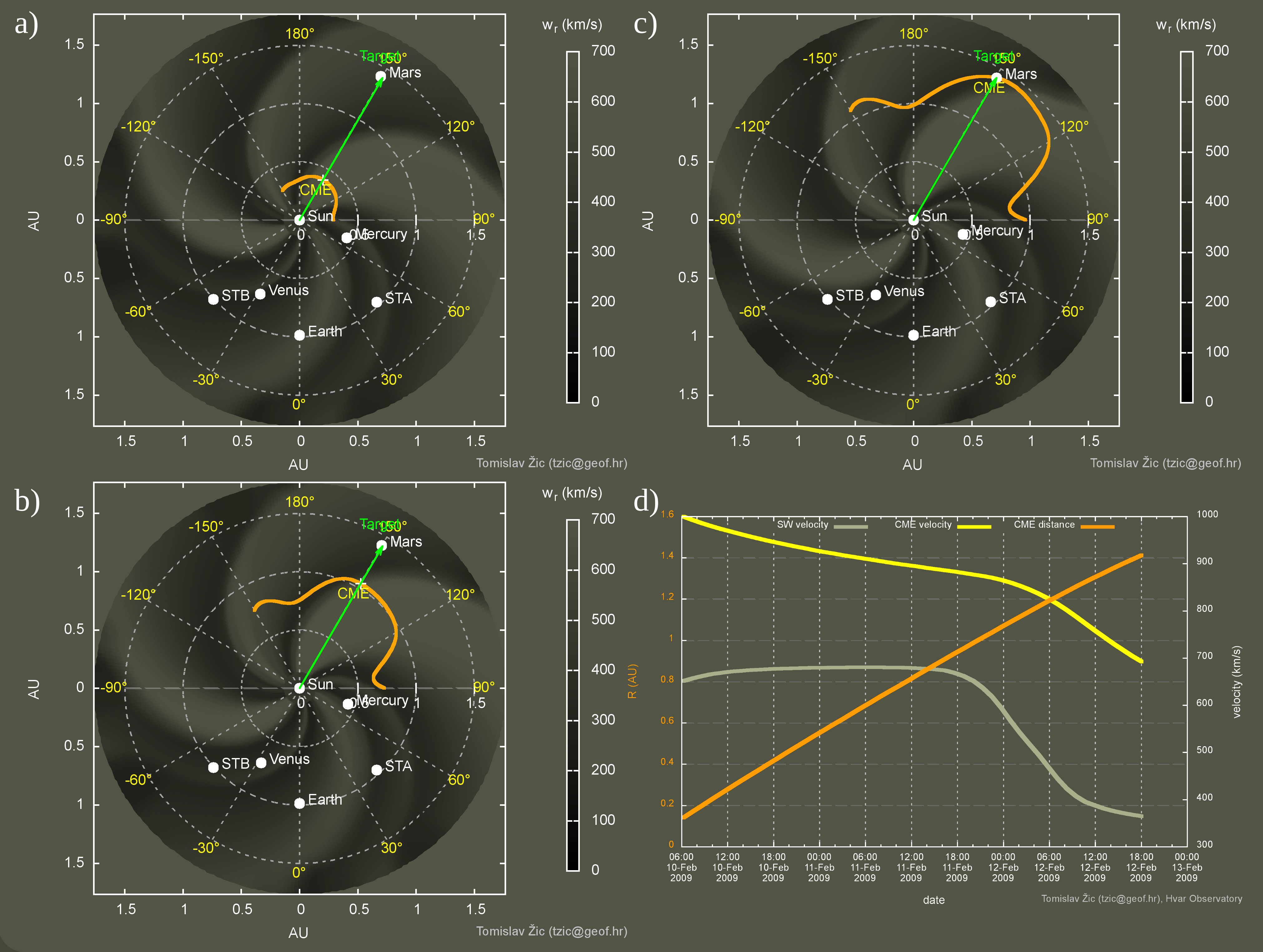

Fig. 2. a), b) and c) Example of CME propagation in the ecliptic plane from CME initial position (a) to the target – Mars (c). The background ENLIL solar-wind speed w_r rotates in time and it is calculated for heliospheric condition on February the 10th, 2009 at 06:13 UT. The CME leading edge (in orange color) deforms as its segments travel in fast or slow environment. The kinematic curves on subfigure d) describe the travel of CME segment presented by „+“ sign on subfigures a), b) and c).
d) CME kinematic curves toward target position (Mars). Gray, yellow and orange lines represent ambient solar-wind velocity, CME velocity and CME distance, respectively.

Example of DBM and ENLIL integration

We have chosen a demonstration of possible embedding of DBM to more sophisticated numerical models. In this example DBM is integrated into the WSA-ENLIL+Cone model (Odstrcil et al., 2004) from the Community Coordinated Modeling Center at the NASA Goddard Space Flight Center.

The background solar wind w is numerically calculated from ENLIL dataset and is valid for date:

10th of February 2009 at 6h 12min 57sec (UT).

In this example the common „average“ DBM parameters are employed:

- drag parameter: $\Gamma = 0.2$
- initial CME distance: $R_0 = 31\ r_{Sun}$
- initial CME speed: $v_0 = 1000$ km/s
- CME half-width: $\lambda = 60°$
- launching CME meridian distance $\varphi = 150°$

and Mars is selected as target for this example.

Conclusion

The presented demonstration opens an opportunity for LSF implementation in real-time space-weather forecasting tools and alerting systems for CME impacts on Earth (or any heliospheric "target" of interest). The novel approach is based on real-time data-driven DBM-parameter optimization that iteratively improves the accuracy of CME kinematics in the heliosphere. Furthermore, the integration with other advanced numerical codes gives an availability for employment in practical and fast online CME prediction tools.

The existing and versions under development of DBM are freely available on web-site:

http://www.geof.unizg.hr/~tzic/dbm.html

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