MOSWOC's Coronal Mass Ejection (CME) Ensemble Prediction System

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Motivation and Status Quo

MOSWOC was founded in 2014 and started providing CME arrival time forecasts for the Earth. To this date CME forecasting remains one of the cornerstones in MOSWOC. The CME parameters that are input to the heliospheric model are inferred with the help of a CME Analysis Tool (CAT). An example of CAT in action is shown in Figure 1. Deriving CME parameters this way is state-of-the art but it comes with errors. For that reason, MOSWOC developed a CME ensemble forecasting system. The inferred CME parameters (Figure 1) are perturbed, and a 24-member ensemble system is thus created. This ensemble system is of great use for MOSWOC forecasters [1]. But it is built upon ad-hoc assumptions and to address this we researched a new ensemble system. In Table 1 we show the existing ensemble perturbation configuration as used by MOSWOC.

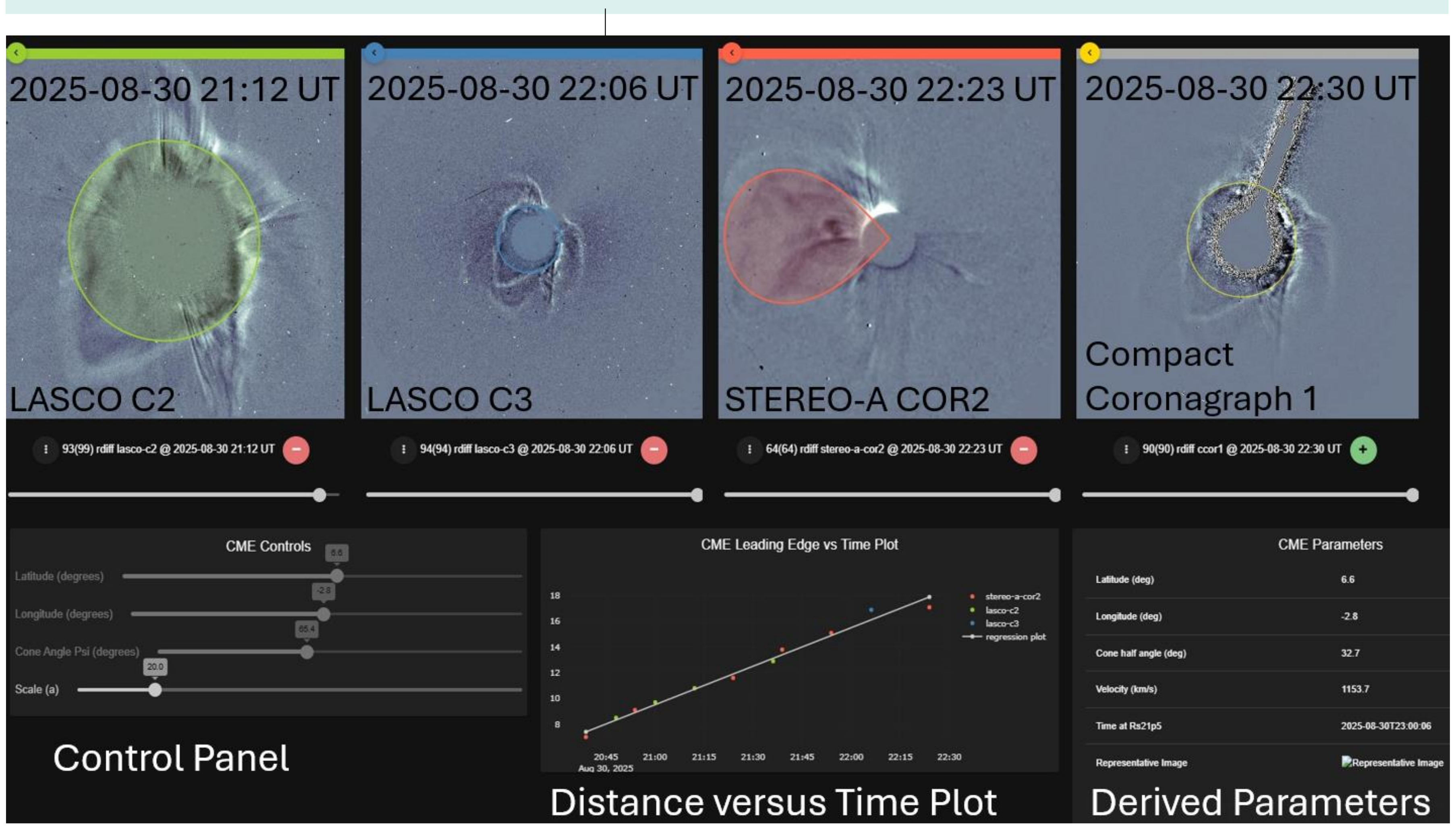

Figure 1: MOSWOC forecasters use CAT to infer 5 parameters (valid at 21.5 solar radii): longitude, latitude, cone angle, CME speed and date. In order to reduce the fitting errors 2 viewpoints are needed, ideally spaced apart wide enough. The current CAT tool uses coronagraph images from the SOHO (Large Angle and Spectrometric Coronagraph instrument on the Solar and Heliospheric Observatory), at Lagrange Point 1, and the STEREO-A (Coronagraph 2 instrument on the Solar TErrestrial RElations Observatory) spacecraft in the ecliptic. A new version of CAT also allows to include coronagraph images (Compact Coronagraph 1) from the GOES-U satellite at a geostationary height.

Parameter	Δ longitude (°)	Δ latitude (°)	Δ cone angle (°)	CME speed Δ vcld (%)
Perturbation Range	-5 … +5	-5 … +5	-15 … +15	-20 … +20

Table 1: The range of perturbations that are applied to the inferred parameters (see Figure 1). A random number is drawn from these ranges and added to the nominal values. This is repeated 23 times for an ensemble set of 24 members (the unperturbed CAT fit is also a member):

- Longitude (°) = longitude + Δ longitude
- Latitude (°) = latitude + Δ latitude
- cone angle (°) = cone angle + Δ cone angle
- vcld (km/s) = vcld * (1 + Δ vcld/100)

The New CME Ensemble Forecasting System

We implement and test this system [2] on real data and compare it against MOSWOC's operational model for the years 2016-2021 on 80 CME events [3]. This new system also uses the CAT derived parameters but how the perturbations are applied differs. Table 2 shows the perturbation values and permutation scheme which creates 81 ensemble members.

Parameter xi	Δ longitude (°)	Δ latitude (°)	Δ cone angle (°)	speed Δ vcld (km/s)
Perturbation Range	±10	±10	±10	±100 and ±200

Table 2: The perturbation scheme is as follows: $x_i = x_i - \Delta x_i$, $x_i = x_i$, $x_i = x_i + \Delta x_i$. Where x_i is one of the parameters. These permutations when combined give 81 members (3^4). For the CME speed we test it with 2 different perturbations. The magnitude of perturbations follows from [2].

Results

We calculate boundary conditions for ENLIL [4] from synoptic maps [5] with Wang-Sheely-Arge code v4.5 [6]. Table 3 shows a contingency table of the arrival time error of the ensemble mean. We chose an error window of ±24 hours [1]. We see from that Table that the new candidate (P81 v1 and v2) is similar to the operational model MO24. Although the new model is similar to the old one, we would still prefer the new ensemble system because it is built on a more solid mathematical foundation.

MO24	$Y_{predicted}$	$N_{predicted}$
$Y_{observed}$	37	25
$N_{observed}$	14	4
MO81	$Y_{predicted}$	$N_{predicted}$
$Y_{observed}$	37	25
$N_{observed}$	14	4
P81v1	$Y_{predicted}$	$N_{predicted}$
$Y_{observed}$	36	26
$N_{observed}$	16	2
P81v2	$Y_{predicted}$	$N_{predicted}$
$Y_{observed}$	3	29
$N_{observed}$	17	1

Table 3: A *hit* (observed $Y_{observed}$ and predicted $Y_{predicted}$ are both true) is defined when the median arrival time from the ensemble for an event falls within the observed arrival time [3] ±24 hours. A *miss* ($Y_{observed}$ and $N_{predicted}$ is true) is when it falls outside of that window. A *false alarm* ($N_{observed}$ and $Y_{predicted}$ are true) means the CME did not hit Earth. A *correct rejection* ($N_{observed}$ and $N_{predicted}$ are true) denotes a case when a CME was not observed at Earth and no ensemble member had an arrival time. The sum of the 4x4 matrix gives 80 events. MO24 is the operational model with 24 ensemble members; MO81 is the operational model with 81 members; P81 is the new model with 81 ensemble members.

References:

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