Solar Physics
DOI: 10.1007/•••••-•••-•••-••••-•

THE HELIO 100 CME CHALLENGE

**J. P. Byrne[1] · B. Cecconi[2] ·
D. Pérez-Suárez[3] · E. Carley[3] ·
S. A. Maloney[4] · G. Pierantoni[5] ·
N. Bourrel[6] · A. Lynnyk[6] · F. Mayer[7] · & the
HELIO team.**

Abstract

Studying the propagation and impact of solar eruptive events and their various manifestations is of great importance for understanding and predicting space weather conditions in the heliosphere. The Heliophysics Integrated Observatory (HELIO) was generated out of a need to robustly link the detections of solar-driven events at different locations in space, via remote-sensing and in-situ instruments onboard various spacecrafts. Under development since 2009, HELIO is now at a stage of great scientific benefit for large-scale studies of solar and heliospheric phenomena, through the generation of workflows that use HELIO to access and cross-correlate event lists and their measured properties.

The fourth HELIO coordinated data analysis workshop (HELIO CDAW-4) held in Trinity College Dublin in September 2012 outlined three challenges to be addressed by working groups comprising solar physicists and computer scientists. The challenges were titled: (1) “Heliospheric variability over the solar cycle”; (2) “The 100 CME challenge”; and (3) “HELIO as a tool for space weather”. In this paper we outline the success of challenge (2), that focused on using HELIO to study the origin, propagation and impacts of a large number of coronal mass ejections (CMEs) in the heliosphere. HELIO provides an interface that allows researchers to track active regions as they evolve and produce solar flares and CMEs. Once launched, CMEs can be tracked in coronagraph and heliospheric images. Their impacts throughout the heliosphere can then be measured using in-situ instruments from a number of spacecraft throughout the solar system. The aim of this challenge was to use HELIO to track a large number of CMEs

[1] Institute for Astronomy, University of Hawaii, Honolulu, USA. email: jbyrne@ifa.hawaii.edu
[2] LESIA, Observatoire de Paris, Meudon, France.
[3] School of Physics, Trinity College Dublin, Dublin, Ireland.
[4] Skytek Ltd., Dublin, Ireland.
[5] School of Computer Science and Statistics, Trinity College Dublin, Dublin, Ireland.
[6] Research Institute in Astrophysics and Planetology (IRAP) - CNRS/UPS, Toulouse, France.
[7] Technische Universitt Wien, Austria.

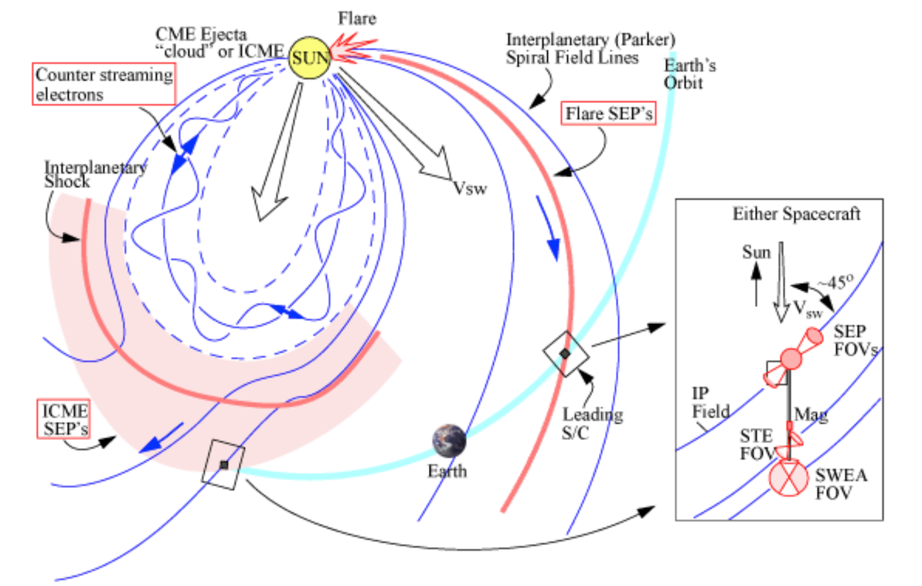

Figure 1.

that had an associated type II radio burst from their source region on the surface of the Sun, and possible flare occurrence, to their effects through interplanetary space. This was achieved through the generation of a workflow that accessed the corresponding event lists and used a ballistic CME propagation model to predict each event’s arrival time at Earth and elsewhere in the solar system. This provides a timeframe for determining the in-situ parameters measured at the different spacecraft locations where a CME impact was detected, and thus allows us to combine the data across multiple spacecrafts on a per-event basis for comprehensive analysis of the physics of their propagation and evolution.

1. Introduction

2. Building a workflow

The challenge group began by choosing a *test case* CME for tracking through the HELIO interface, and building a model workflow to be ultimately extended for a large scale study of many events. The CME chosen was a fast event associated with a flare and type II radio burst, as listed in the ‘Wind/WAVES type II bursts and CMEs list[1]. The radio burst was detected at 04:20 UT on 11 April 2004, with an associated NOAA C 9.6 flare at disk location S 14 W 47, and CME observed

[1] http://cdaw.gsfc.nasa.gov/CME_list/radio/waves_type2.html

in LASCO at 04:30 UT with central position angle 203°, angular width 314°, and speed 1645 $\mathrm{km\,s^{-1}}$.

The workflow was built in the following manner, with the *test case* inputs/outputs as specified:

i) A time interval is specified and input to the 'Wind/WAVES type II bursts and CMEs list[1] to retrieve a list of events within the given time-range of interest.
Time range: 2004/04/01 00:00:00 – 2004/04/30 00:00:00

ii) The list of candidate events were ranked in order of decreasing CME speed, with the intent that the top 100 across a large time-range be chosen for the purposes of this challenge. (The single fastest event in the *test case* sample was chosen, as described above.)

Type II burst	*Time range: 2004/04/11 04:20 – 05:35*
	Frequency: 14000 – 500 kHz
Flare	*Location: S14W47*
	NOAA: 10588
	Class: C9.6
CME	*Start time: 2004/04/11 04:30*
	Central position angle: 203°
	Angular width: 314°
	Speed: 1645 km s^{-1}

iii) The GOES Soft X-ray Flare List[2] was then inspected for any associated flaring activity of the relevant class, within a specified window of ±1 hour on the start time of the type II burst, to obtain the catalogued source longitude on disk.
Time range: 2004/04/11 03:20 – 05:20
Peak flare time (t_{start}): 04:19
Longitude (λ_{lon}): 46°

iv) The SOHO LASCO CME Catalogue[3] is inspected in order to associate CME parameters from the relevant detection in the time range of the type II burst. In this case the necessary parameters are the CME initial and final speeds, and angular width. The choice of catalogue can be changed, for example to call one of the automated CME catalogues such as CACTus.

v_{init} :	*1953 km s^{-1}*
v_{final} :	*1340 km s^{-1}*
θ_{width} :	*314°*

v) The CME speed is determined as $v_{cme} = v_{final} \pm \sigma_v$ where an initial estimate of the uncertainty on the CME speed is calculated as $\sigma_v = \frac{|v_{final} - v_{init}|}{2}$. A clause is put on the angular width that if it is greater than 180°, i.e., a halo

[2]http://www.ngdc.noaa.gov/stp/solar/solarflares.html
[3]http://cdaw.gsfc.nasa.gov/CME_list/

CME where $\theta_{width} > 180°$, its true width is calculated as half the plane-of-sky width $\theta_{cme} = \theta_{width}/2$.

v_{cme} : *1340 ± 306.5 km s^{-1}*

θ_{cme} : *157°*

vi) The HELIO ballistic CME model is run with the following input parameters: CME start time from the peak time of the associated flare t_{start}; trajectory from the associated flare longitude λ_{lon}; speed v_{cme}, and angular width θ_{cme}.

vii) From the ballistic CME model, an expected timeframe of arrival at the L1 point (the first Lagrangian point, near Earth) is determined. If an event is not deemed Earth-directed it is flagged as so. The in-situ data from the ACE spacecraft is queried via the Automated Multi Dataset Analysis web service[4], and an average speed of the solar wind $\bar{v}_{sw}$ during this timeframe is calculated.

L1 timeframe: *2004/04/12 05:57:54 – 21:10:41*

$\bar{v}_{sw}$: *442.33 km s^{-1}*

viii) From the average solar wind speed, a new velocity of the CME is calculated to essentially account somewhat for the influence of drag. The average solar wind speed is used to modify the input CME speed by lowering the uncertainty interval to match it as the lower bound (or raise it to the upper bound as the case may be, though unlikely for these candidate 100 fastest CMEs chosen). While the upper bound is kept fixed, the modified CME speed between the bounds is calculated as $v'_{cme} = \frac{1}{2}\left(\bar{v}_{sw} + \frac{v_{final}+v_{init}}{2}\right)$ with new uncertainty $\sigma'_v = \frac{1}{2}\left(\sigma_v + v_{final} - \bar{v}_{sw}\right)$. These are used to rerun the ballistic CME propagation model.

v'_{cme} : *1044 ± 602 km s^{-1}*

ix) The predicted impact timeframes of the CME at the relevant locations throughout the heliosphere are output from the workflow, e.g., in this case Mercury, Earth, and Voyager 1 & 2 at the edge of the heliosphere.

Mercury arrival timeframe:	*2004/04/11 16:04:54 – 2004/04/13 00:06:36*
Earth arrival timeframe:	*2004/04/12 05:57:54 – 2004/04/15 03:47:20*
Voyager 2 arrival timeframe:	*2004/06/28 00:00:00 – 2005/02/02 00:00:00*
Voyager 1 arrival timeframe:	*2004/07/18 00:00:00 – 2005/02/05 00:00:00*

[4] http://manunja.cesr.fr/Amda-Helio/

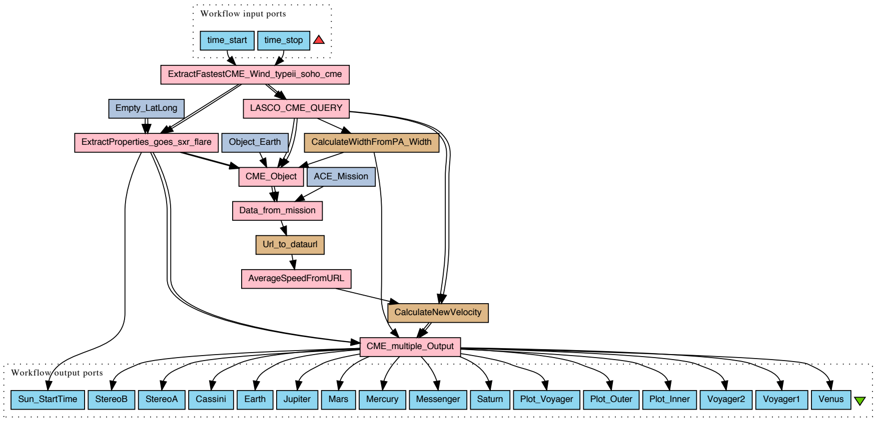
Workflow input ports
time_start
time_stop
ExtractFastestCME_Wind_typeii_soho_cme
Empty_LatLong
LASCO_CME_QUERY
ExtractProperties_goes_sxr_flare
Object_Earth
CalculateWidthFromPA_Width
CME_Object
ACE_Mission
Data_from_mission
Url_to_dataurl
AverageSpeedFromURL
CalculateNewVelocity
CME_multiple_Output
Workflow output ports
Sun_StartTime
StereoB
StereoA
Cassini
Earth
Jupiter
Mars
Mercury
Messenger
Saturn
Plot_Voyager
Plot_Outer
Plot_Inner
Voyager2
Voyager1
Venus

Figure 2.