Real-Time Modeling of CMEs Using the WSA-ENLIL+Cone Model

Christina Kay

M. Leila Mays
Aleksandre Taktakishvili
CCMC at NASA GSFC
Modeling CMEs with WSA-ENLIL+Cone

- WSA-ENLIL is a global 3D MHD model which provides a time-dependent description of the background solar wind plasma and magnetic field into which a spherical or ellipsoid shaped CME can be inserted.

- A CME-like hydrodynamic structure is launched into the solar wind and magnetic field computed from the WSA coronal model at 21.5 R\textsubscript{s}.

- WSA coronal maps generated from synoptic magnetograms provide the magnetic field and solar wind speed at the boundary between coronal PFSS and heliospheric models.

- Other coronal models can also be coupled with ENLIL (e.g. MAS, heliospheric tomography).

Model References: Arge and Pizzo, 2000; Arge et al., 2004; Odstrcil et al. 1996; Odstrcil and Pizzo, 1990a,b; Odstrcil, 2003.
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ENLIL - Schematic Description

ENLIL — Sumerian God of Winds and Storms
Dusan Odstrcil, GMU & GSFC

Input: WSA (coronal maps of Br and Vr updated 4 times a day). For toroidal components at the inner boundary- Parker spiral.

ENLIL’s inner radial boundary is located beyond the sonic point: the solar wind flow is supersonic in ENLIL.

Computes a time evolution of the global solar wind for the inner heliosphere, driven by corotating background structure and transient disturbances (CMEs) at it’s inner radial boundary at 21.5 Rs.

Solves ideal fully ionized plasma MHD equations in 3D with two additional continuity equations: for density of transient and polarity of the radial component of B.
ENLIL model does not take into account the realistic complex magnetic field structure of the CME magnetic cloud and the CME as a plasma cloud has a uniform velocity.

It is assumed that the CME density is 4 times larger than the ambient fast solar wind density, the temperature is the same.

Thus, the CME has about four times larger pressure than the ambient fast wind. Launching of an over pressured plasma cloud at 21.5 \( \text{Rs} \), roughly represents CME eruption scenario

**Output:**

3D distribution of the SW parameters at spacecraft and planets and topology of IMF.
Cone Model for CMEs

CME measuring technique that assumes:
• CME propagates with nearly constant angular width in a radial direction
• CME bulk velocity is radial and the expansion is isotropic

Zhao et al, 2002, Cone Model:

The projection of the cone on the coronagraph image is an ellipse.
Cone model parameters

- time the CME reaches the inner boundary of 21.5 Solar Radii
- Latitude (in HEEQ coordinates)
- Longitude (in HEEQ coordinates)
- Half-width (deg)
- Radial velocity (km/s)
Parameters Defined with CCMC CME Triangulation Tool: StereoCAT

CME Parameters: Input To WSA-ENLIL Cone Model
SWPC CME Analysis Tool (SWPC_CAT)
Determining CME Arrival Time

WSA-ENLIL+Cone at Earth

2017-09-04T00:00

“direct” arrival
“flank” arrival

2018–05–06T18:00

2018–05–03T00 +3.75 days

Ecliptic Plane

LAT = −3.5°
2017–11–24T00:00

2017–11–24T00 +0.00 day

WSA–ENLIL+Cone at Earth

2017–11–24T00:00

glancing
CME Impact: Arrival time, duration of passage, magnetopause standoff distance

CME shock arrival – a sharp jump in the dynamic pressure

\[ n m_p V^2 \]

Duration of the disturbance – duration of the dynamic pressure hump

Magnetic field required to stop SW

\[ \frac{B_{\text{stop}}^2}{2 \mu_0} = Kn m_p V^2 \]

Magnetopause standoff distance

\[ \frac{r_{mp}}{R_e} = \left( \frac{B_0}{B_{\text{stop}}} \right)^{1/3} \]
Kp Index Prediction – Newell Coupling Function

Kp is predicted using a relationship between the solar wind speed, magnetic field, and magnetic field clock angle. ($\Theta_C = 90^\circ, 135^\circ, \text{and } 180^\circ$)

Magnetic flux opening rate at the magnetopause

\[ \frac{d\Phi_{MP}}{dt} = \frac{v}{3} B_T^{2/3} \sin^{8/3} (\theta_c / 2) \]

\[ Kp = 9.5 - \exp \left( 2.17676 - 0.000052001 \frac{d\Phi_{MP}}{dt} \right) \]
E-mail/text file with CME impact estimate at Earth

Arrival time(year/month/day, hr:min UT) =2012-07-31T15:02Z
(confidence level +7 hours)

Duration of the disturbance (hr) = 10.3
(confidence level +8 hours)

Minimum magnetopause standoff distance: Rmin(Re)=5.6
(under quiet conditions: Rmin(Re)=10;
R_geosynch(Re)=6.6)

Kp index for three possible IMF clock angles
(angle 180 gives the maximum possible estimated Kp):
(Kp)_90=4
(Kp)_135=6
(Kp)_180=7

Here are the links to the movies of the modeled event


Inner Planets

Timelines
http://iswa2.ccmc.gsfc.nasa.gov/downloads/20120729_014700_ENLIL_CONE_timeline.gif
Impact estimate at NASA mission locations

Mars

CME did not hit the Mars.
or
CME impact is very weak.

Stereo A

CME did not hit the StereoA.
or
CME impact is very weak.

Stereo B

CME did not hit the StereoB.
or
CME impact is very weak.

Spitzer

Arrival time (year/month/day, hr:min UT) = 2015-05-11T20:49Z

Inner Planets

http://iowa.gsfc.nasa.gov/downloads/20150509_071500_2_0_anim_tim-den.gif
http://iowa.gsfc.nasa.gov/downloads/20150509_071500_2_0_anim_tim-vel.gif
http://iowa.gsfc.nasa.gov/downloads/20150509_071500_2_0.anim.tim-den-Stereo_A.gif
http://iowa.gsfc.nasa.gov/downloads/20150509_071500_2_0.anim.tim-vel-Stereo_A.gif
http://iowa.gsfc.nasa.gov/downloads/20150509_071500_2_0.anim.tim-den-Stereo_B.gif
http://iowa.gsfc.nasa.gov/downloads/20150509_071500_2_0.anim.tim-vel-Stereo_B.gif

Inner Planet Timelines

http://iowa.gsfc.nasa.gov/downloads/20150509_071500_2_0_ENLIL_CONE_Mars_timeline.gif
http://iowa.gsfc.nasa.gov/downloads/20150509_071500_2_0_ENLIL_CONE_STA_timeline.gif
http://iowa.gsfc.nasa.gov/downloads/20150509_071500_2_0_ENLIL_CONE_STB_timeline.gif
http://iowa.gsfc.nasa.gov/downloads/20150509_071500_2_0_ENLIL_CONE_Spitz_timeline.gif
http://iowa.gsfc.nasa.gov/downloads/20150509_071500_2_0_ENLIL_CONE_Merc_timeline.gif
http://iowa.gsfc.nasa.gov/downloads/20150509_071500_2_0_ENLIL_CONE_Venus_timeline.gif