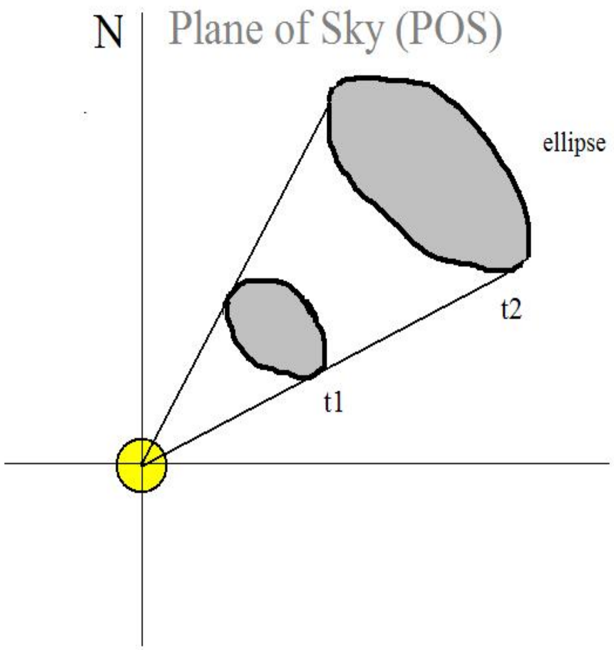
RT Modelling of CMEs Using WSA-ENLIL Cone Model

2014-06-04

Outline

- Basic Principles behind cone modeling of CMEs.
- Brief description of the models
- Analyzing CME propagation and impact
- Operations example: collaboration with AFWA

Cone Model for CMEs



The projection of the cone on the POS is an ellipse

Zhao et al, 2002, Cone Model:

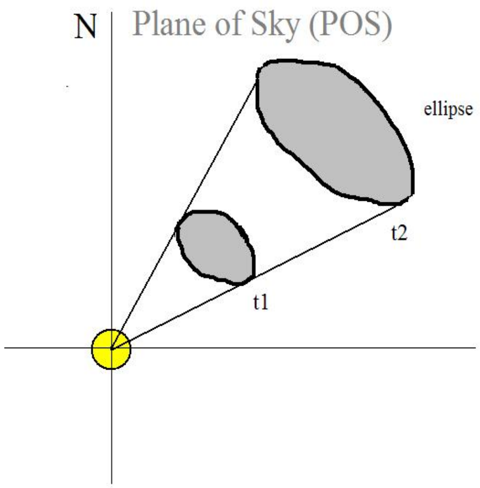
The CME cone model is based on observational evidence that CME has more or less constant angular diameter in corona, being confined by the external magnetic field, so that CME does not expand in latitude in the lower corona, but expands in interplanetary space because of the weaker external field

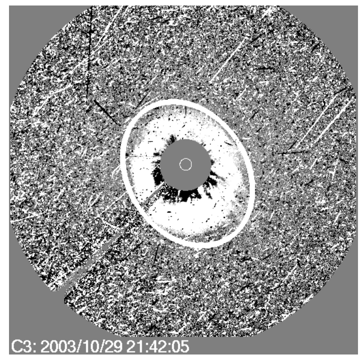
- CME propagates with nearly constant angular width in a radial direction
- CME bulk velocity is radial and the expansion is isotropic

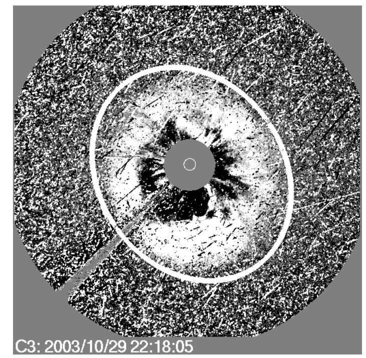
Overly simplistic approximation to describe halo CME

Cone Modelling for Halo CMEs

SOHO LASCO C3 difference images







Xie et al, 2004, Cone Model for Halo CMEs – analytical method

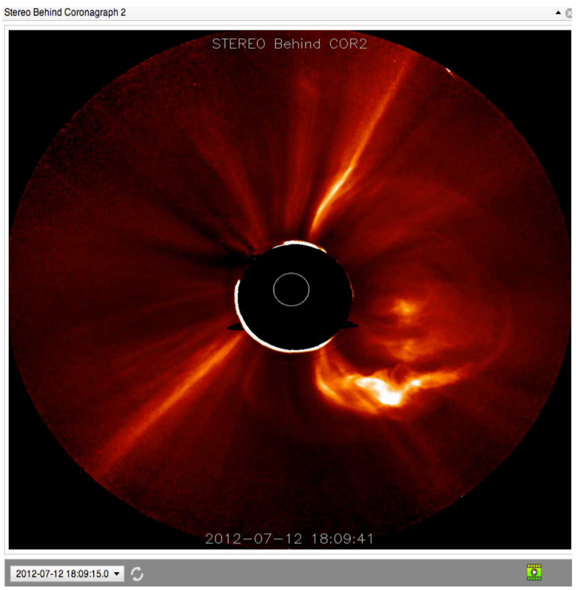
A. Pulkkinen, 2010, Cone Model for Halo CMEs – automatic method

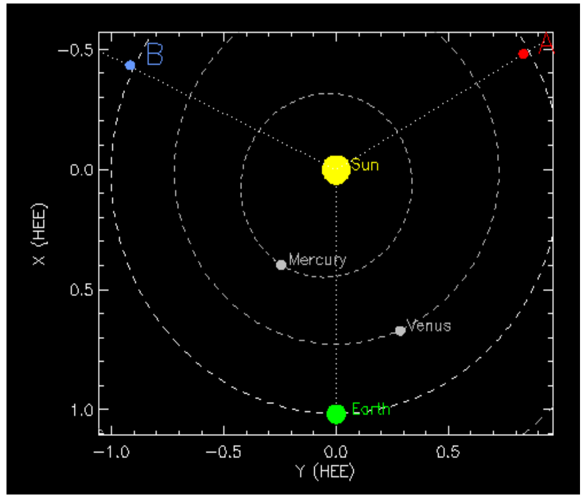
CME V and orientation

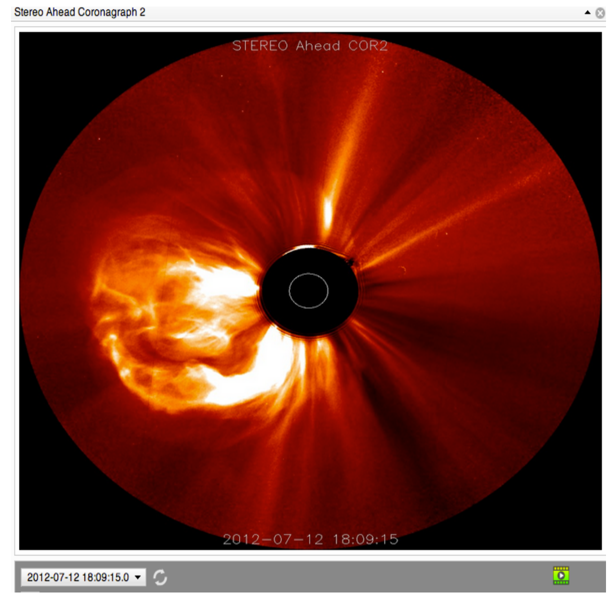
↓

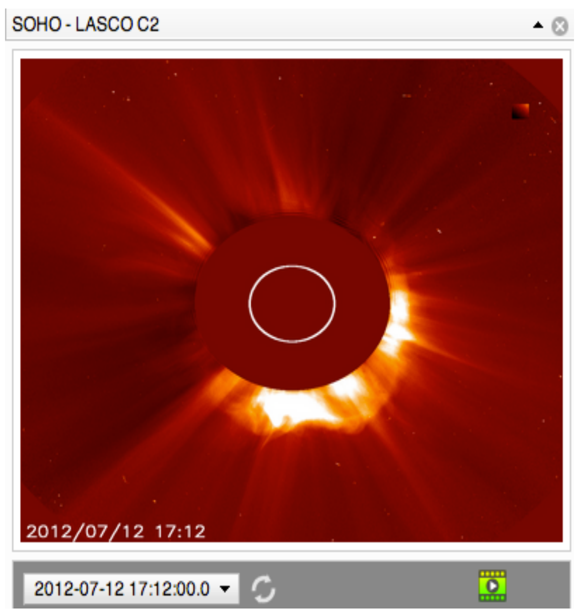
Input to WSA-ENLIL

July 12, 2012CME Viewed by Coronagraph Imagers



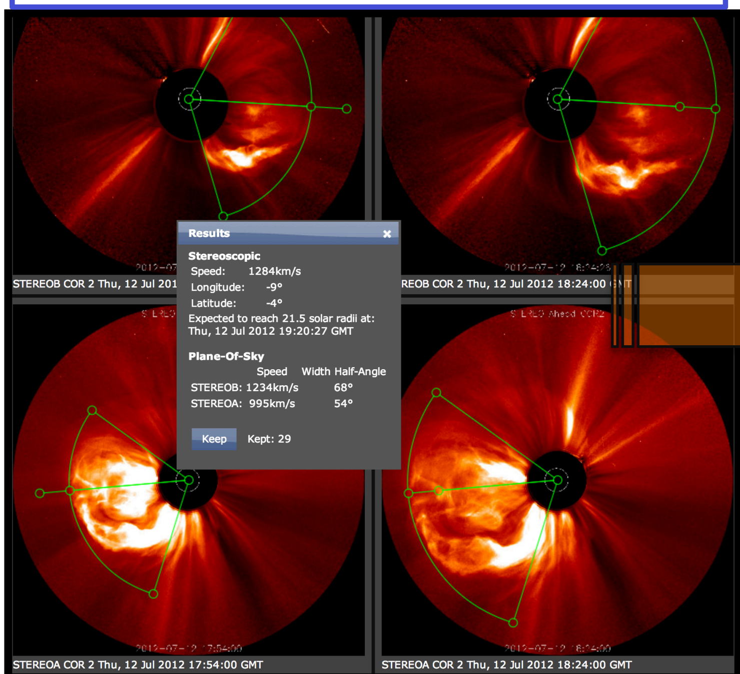




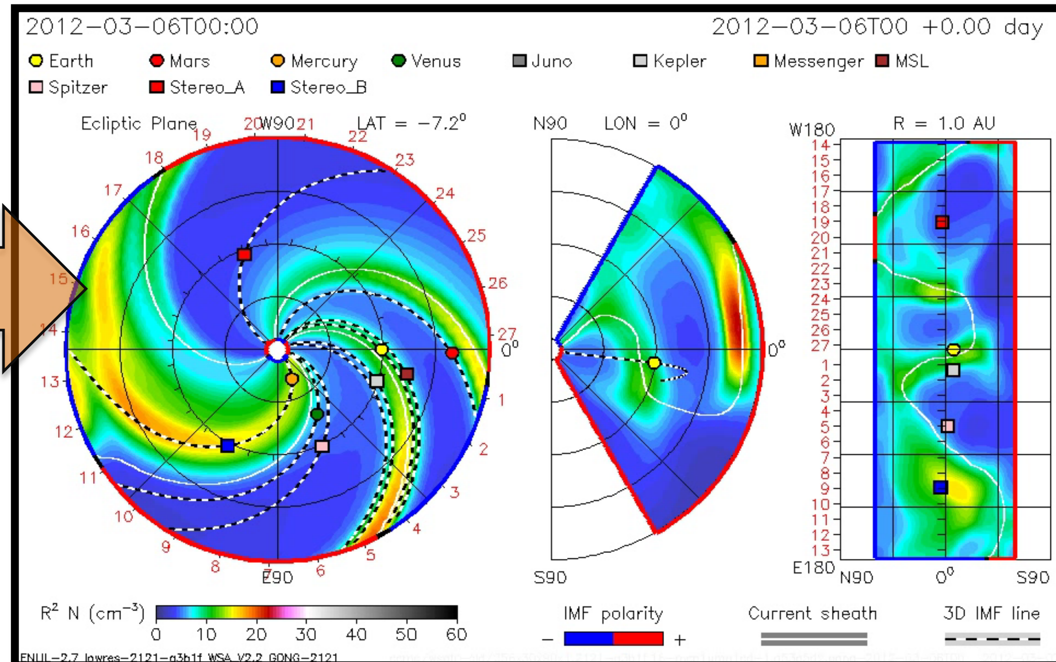


WSA-ENLIL Cone Model

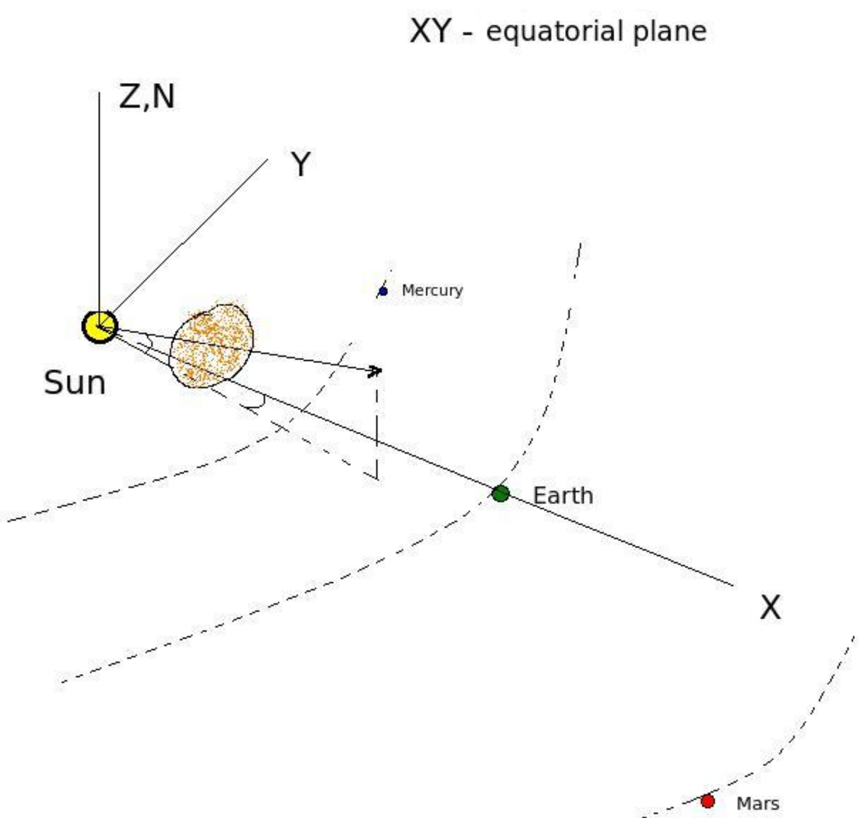
Parameters Defined with CCMC CME Triangulation Tool



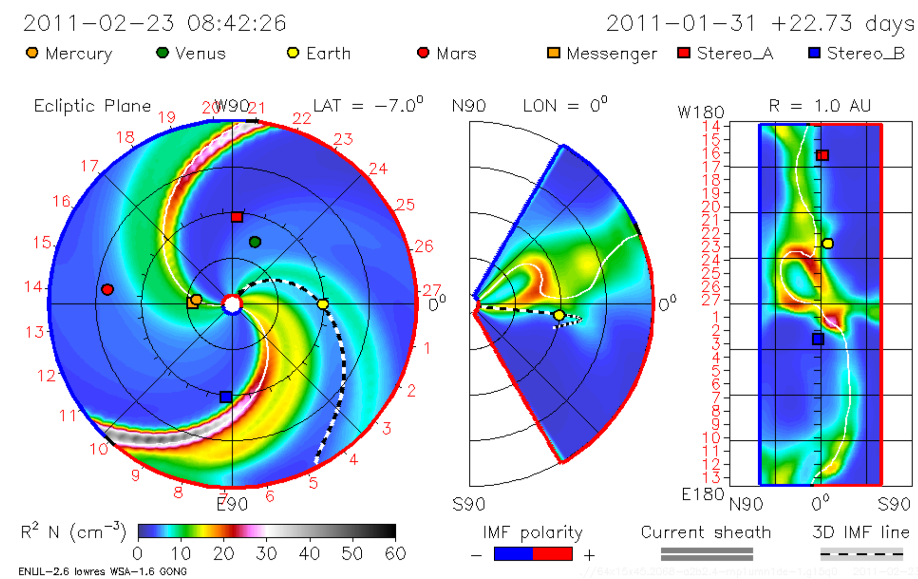
CME Parameters: Input To WSA-ENLIL Cone Model



Sun, Planets, CME



Heliocentric Earth Equatorial Coordinates - Heliographic

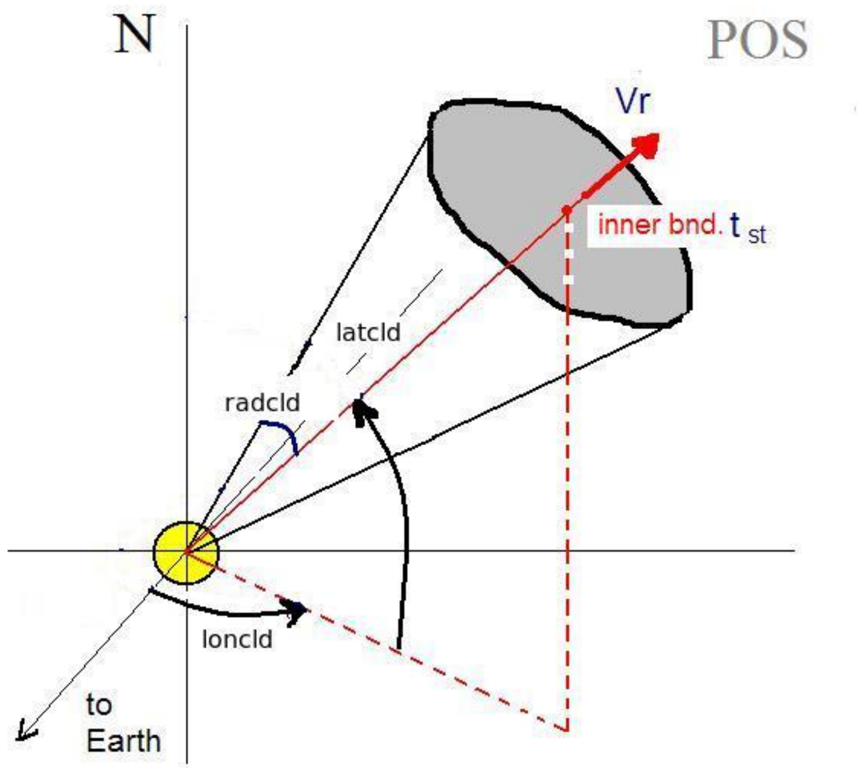


Constant Latitude Plane passing through Earth

Meridional Plane

1AU quasi-sphere

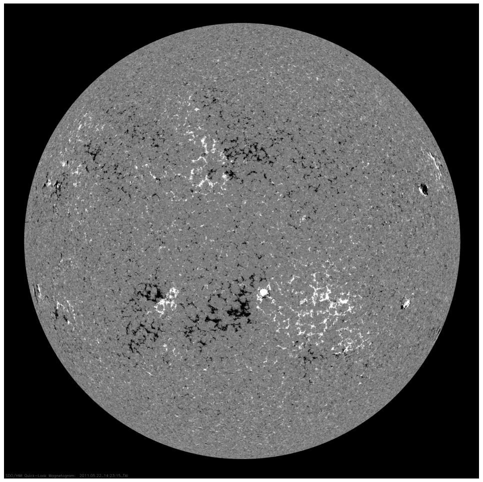
Cone model parameters

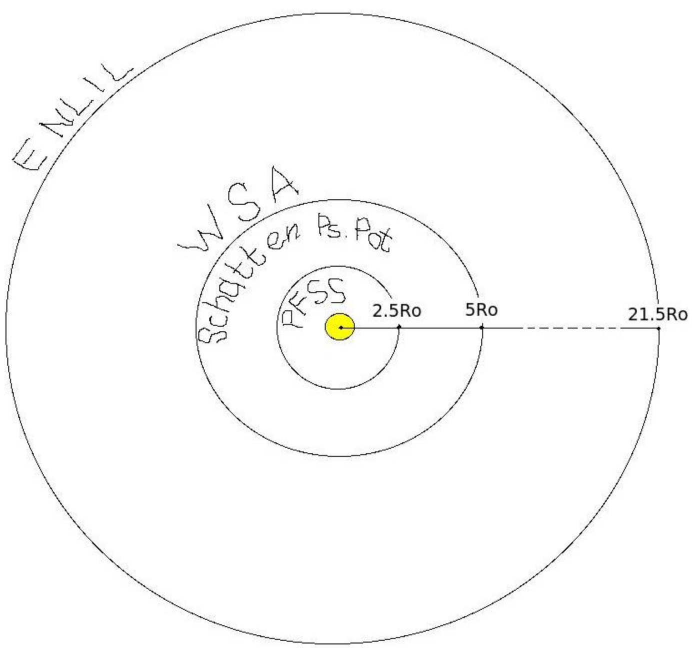


- tstart - when cloud at 21.5Rs
- Latitude
- Longitude
- Radius (angular width)
- Vr - radial velocity

Input to ENLIL cone model run

WSA- Input to ENLIL

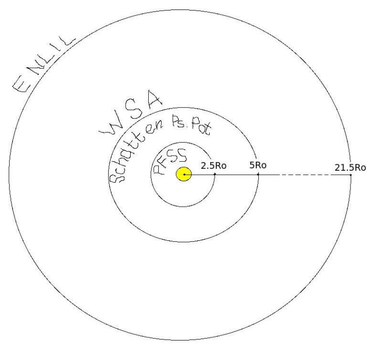


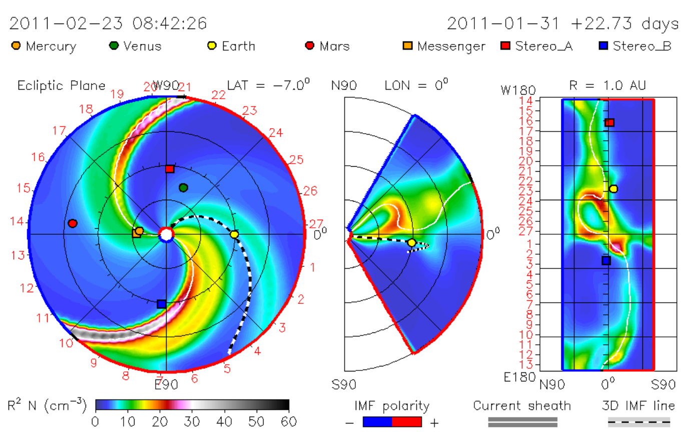


WSA (Wang-Sheeley-Arge, AFRL):

- **PFSS** (Potential Field Source Surface)**.**
  Input: synoptic map photospheric magnetogram.
  Force free (even current free) solution with radial field at 2.5 Ro.
- **Schatten Current Sheet**.
  Input: PFSS.
  Modifies the sign of radial field to positive to prevent reconnection, creates potential solution with radial boundary conditions, restores the sign in the new solution at 5 Ro.
- **WSA.**
  Input: Schatten CS.
  Assuming radial constant speed flow at 5 Ro uses empirical formula for speed, determined by the rate of divergence of the magnetic field at 5 Ro and proximity of the given field line to the coronal hole boundary.

ENLIL - Schematic Description





ENLIL – *Sumerian God of Winds and Storms*

Dusan Odstrcil, GMU & GSFC

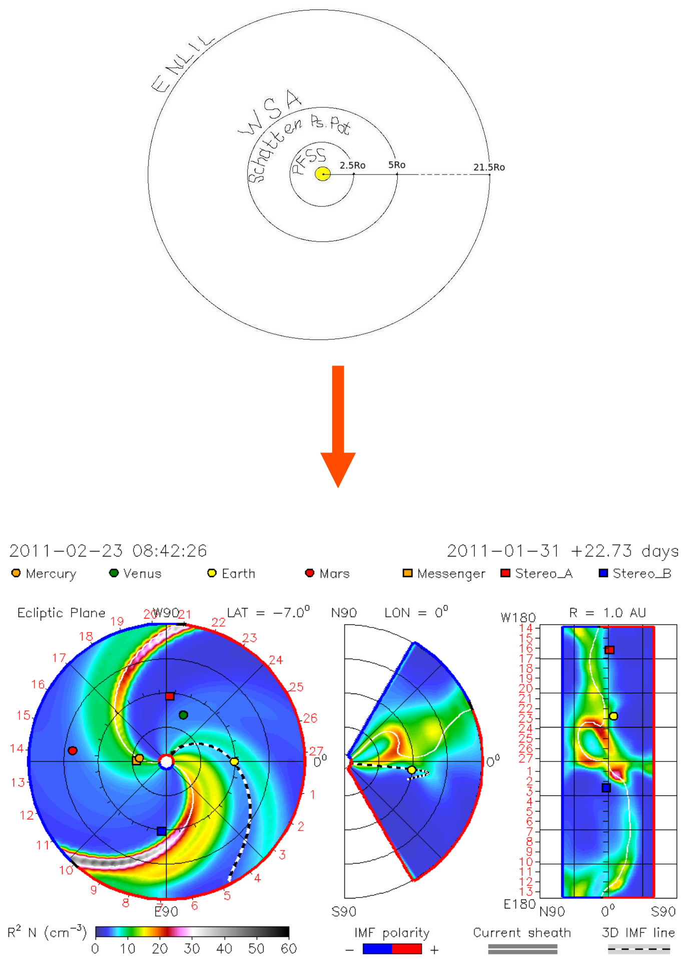
Input: WSA (coronal maps of Br and Vr updated 4 times a day). For toroidal components at the inner boundary- Parker spiral.

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 Ro.

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 Schematic Description (cont.)



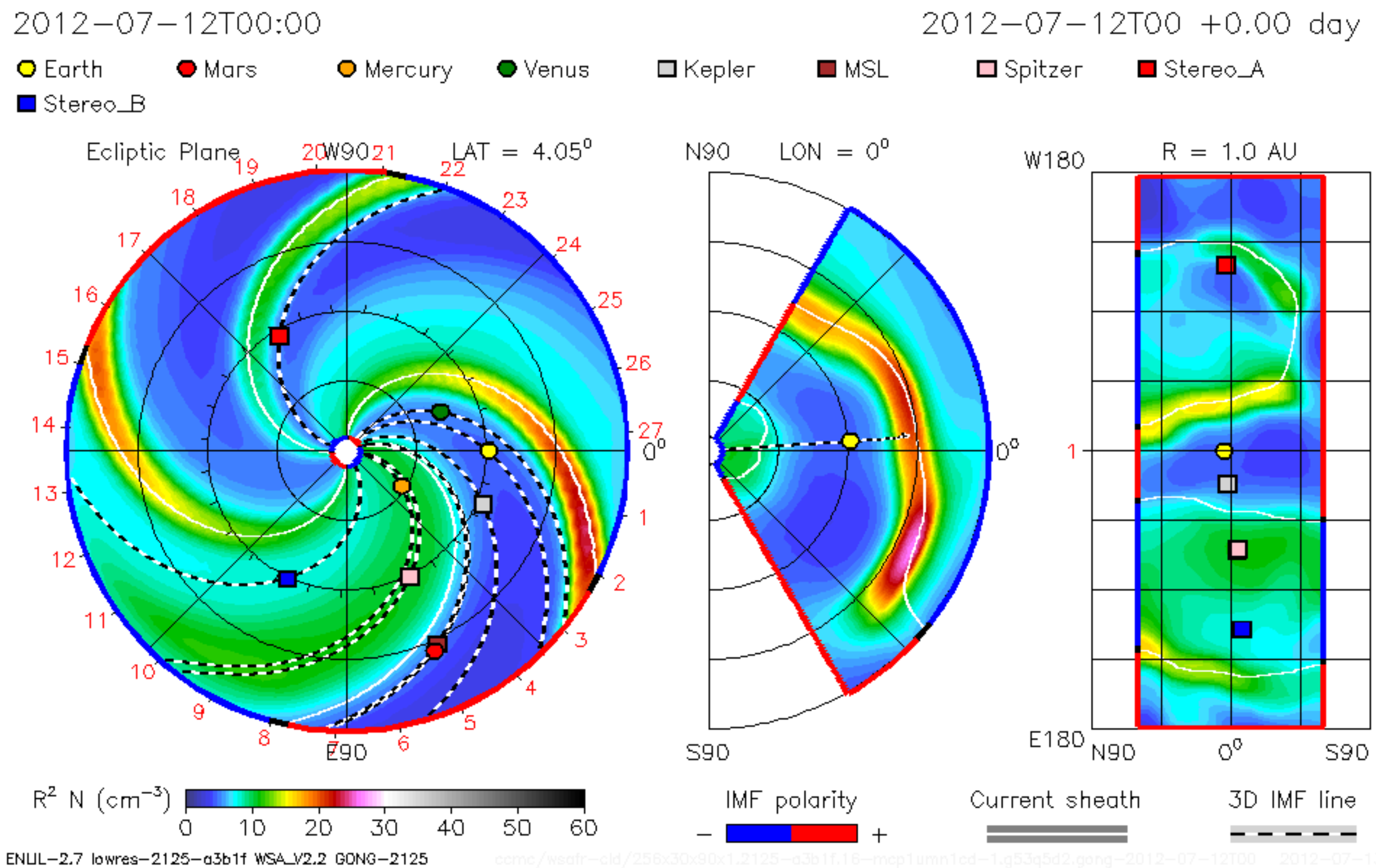
ENLIL model does not take into account the realistic complex magnetic field structure of the CME magnetic cloud and the CME as a plasma cloud has a uniform velocity.

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 **Rs,** roughly represents CME eruption scenario

Output:

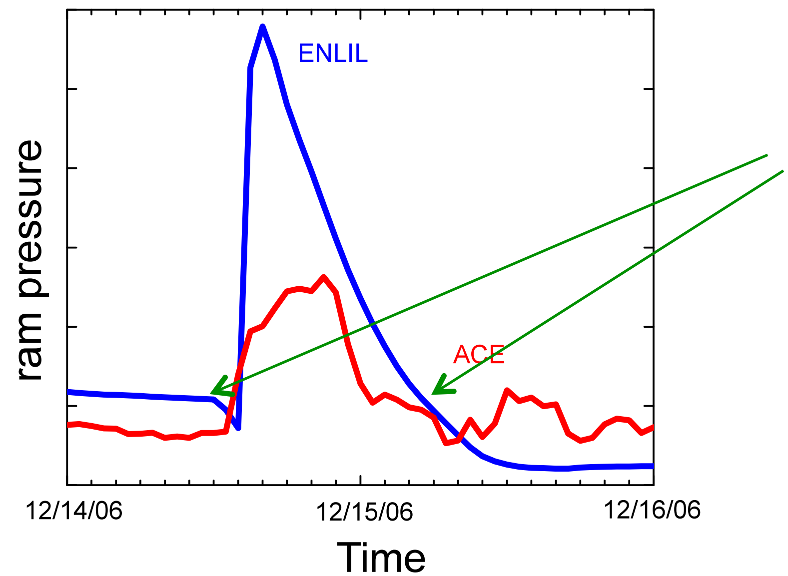
3D distribution of the SW parameters at spacecrafts and planets and topology of IMF.

CME modeling



CME Impact – arrival, duration, MP standoff distance

CME shock arrival – a sharp jump in the dynamic pressure



Duration of the disturbance – duration of the dynamic pressure hump

Magnetic field required to stop SW

$$\frac{B_{stop}^2}{2\mu_0} = Knm_p V^2$$

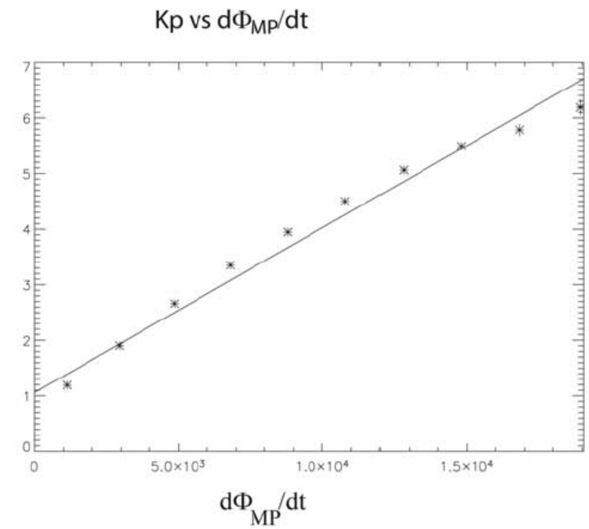
Magnetopause standoff distance

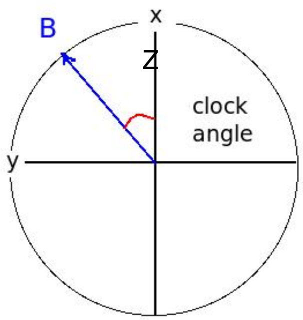
$$\frac{r_{mp}}{R_e} = \left(\frac{B_0}{B_{stop}}\right)^{1/3}$$

Kp Index – P. Newel's Empirical Expression

Magnetic flux opening
rate at the magnetopause

$$\frac{d\Phi_{MP}}{dt} = V^{4/3} B^{2/3} \sin^{8/3}(cl\ ang/2)$$





$$Kp = 1 + 0.0002947 \frac{d\Phi}{dt}$$

$$Kp = 9.5 - \exp\left(2.17676 - 0.000052001 \frac{d\Phi_{MP}}{dt}\right)$$

AFWA Collaboration

AFWA
CME alert e-mail based on CCMC iSWA LASCO C3 difference image analysis

From: Space Weather <spaceweather@offutt.af.mil>
Subject: **AFWA-CCMC collaboration**
Date: February 19, 2010 4:16:00 PM EST
To: Pulkkinen, Antti A. (GSFC-674.0)[UNIVERSITY OF MARYLAND BALTIMORE CO] <antti.a.pulkkinen@nasa.gov>
Cc: Reich, Joseph P III Capt USAF AFWA 16 WS/WXN <Joseph.Reich@offutt.af.mil>, Holland, Donald E CTR USAF AFWA 16 WS/WXN <Donald.Holland.Ctr@offutt.af.mil>, Jones, James C LtCol USAF AFWA 2WS/CC <James.Jones2@offutt.af.mil>, Michael Hesse and 6 more...

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===HEADER===

Air Force Coronal Mass Ejection (CME) notice to the Community Coordinated Modeling Center.

Issued 2010-02-07T06:45:SSZ

NOTE:  Below key "c3_diff" is used to indicate timestamps of the LASCO C3 difference images where the halo CME is visible. Key
"type_II_shock_speed" is used to indicate Type II-based estimates of the CME shock speed. All shock speeds are given in km/s and time in
UT.

===END_HEADER===

===DATA===
c3_diff         2010-02-07T04:18:SSZ
c3_diff         2010-02-07T05:18:SSZ
c3_diff         2010-02-07T05:42:SSZ
type_II_shock_speed     N/A
type_II_shock_speed     N/A
===END_DATA===
```

CCMC
RT WSA/ENLIL Cone Model run using the most recently updated GONG magnetogram

Re: 28 July 2012/22Z CME — Inbox

Delete Junk Reply Reply All Forward Print To Do

From: Lee, Hyesook (GSFC-674.0)[UNIVERSITY OF MARYLAND BALTIMORE COUNTY] <hyesook.lee@nasa.gov>
Subject: **Re: 28 July 2012/22Z CME**
Date: July 28, 2012 10:12:33 PM EDT
To: Westlund, John SSgt USAF AFWA 2WS/WXZ <john.westlund@offutt.af.mil>
Cc: Space Weather, Mickus, Laura M SSgt USAF AFWA 2 WS/WXZ <laura.mickus@offutt.af.mil>, Taktakishvili, Aleksandre (GSFC-674.0)[UNIVERSITY OF MARYLAND BALTIMORE COUNTY] <aleksandre.taktakishvili-1@nasa.gov>, Chulaki, Anna (GSFC-674.0)[SIGMA SPACE CORP] <anna.chulaki-1@nasa.gov> Kuznetsova, Maria M. (GSFC-6740) <maria.m.kuznetsova@nasa.gov>, ccmc-swx@ccmc.gsfc.nasa.gov and 10 more...
Reply-To: Lee, Hyesook (GSFC-674.0)[UNIVERSITY OF MARYLAND BALTIMORE COUNTY] <hyesook.lee@nasa.gov>

Dear All,

Plese see below for the simulation results of the attached request.

All the best,
Hyesook

Attached please find a text file with an experimental Interplanetary Coronal Mass Ejection estimate at 1 AU produced by the Community Coordinated Modeling Center at NASA/GSFC.

The estimate is based on heliospheric MHD simulations using the WSA/ENLIL cone model combination.

The estimate is performed solely for research purposes with no attached warranties, direct or implied.

CCMC team.

Experimental ICME estimate at 1AU
based on heliospheric MHD simulations.
Produced by the Community Coordinated
Modeling Center at NASA/GSFC
for the Air Force Weather Agency.
For more information please contact:
Aleksandre.Taktakishvili-1@nasa.gov
****
Estimate issued on 2012/07/28, 18:34:29 EST
****

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_geosynchr(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

AFWA

AFWA Collaboration 2

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Cc: Reich, Joseph P III Capt USAF AFWA 16 WS/WXN <Joseph.Reich@offutt.af.mil> , Holland, Donald E CTR USAF AFWA 16 WS/WXN <Donald.Holland.Ctr@offutt.af.mil> , Jones, James C LtCol USAF AFWA 2WS/CC <James.Jones2@offutt.af.mil> , Michael Hesse and 6 more...

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type_II_shock_speed     N/A

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AFWA Collaboration

Estimate e-mail

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(angle 180 gives the maximum possible estimated Kp):
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(Kp)_135=6
(Kp)_180=7

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Here are the links to the movies of the modeled event

http://iswa.gsfc.nasa.gov/downloads/20120729_014700_afwa_anim.tim-den.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_afwa_anim.tim-vel.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_afwa_anim.tim-pdyn.gif

Inner Planets
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_anim.tim-den.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_anim.tim-vel.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_anim.tim-den-Stereo_A.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_anim.tim-vel-Stereo_A.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_anim.tim-den-Stereo_B.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_anim.tim-vel-Stereo_B.gif

Timelines
http://iswa2.ccmc.gsfc.nasa.gov/downloads/20120729_014700_ENLIL_CONE_timeline.gif
http://iswa2.ccmc.gsfc.nasa.gov/downloads/20120729_014700_ENLIL_CONE_Kp_timeline.gif

e-mail for NASA missions

Estimate e-mail

Messenger
****

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

****

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
****
CME did not hit the Spitzer.
or
CME impact is very weak.

****

MSL
****
CME did not hit the MSL.
or
CME impact is very weak.

****

Inner Planets
http://iswa.gsfc.nasa.gov/downloads/20120813_150000_anim.tim-den.gif
http://iswa.gsfc.nasa.gov/downloads/20120813_150000_anim.tim-vel.gif
http://iswa.gsfc.nasa.gov/downloads/20120813_150000_anim.tim-den-Stereo_A.gif
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