RT Modelling of CMEs Using WSA-ENLIL Cone Model
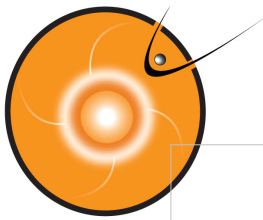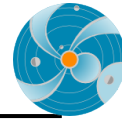
K. Muglach

(original presentation by A. Taktakishvili)

Space Weather Training at KSC

Feb.2015

1

In this presentation we will make an introduction to the
WSA-ENLIL Cone model, used at SWRC to model propagation
of coronal mass ejections (CMEs) in the heliosphere.

Outline

- Basic Principles behind cone modeling of CMEs.

- Brief description of the models

- Analyzing CME propagation and impact

- Operations

2

First, I will say few words about basic principles behind cone modeling of
CMEs.
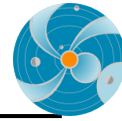Then, I will make a brief description of the WSA and ENLIL models.
After that I will describe how we analyze CME propagation and it's impact
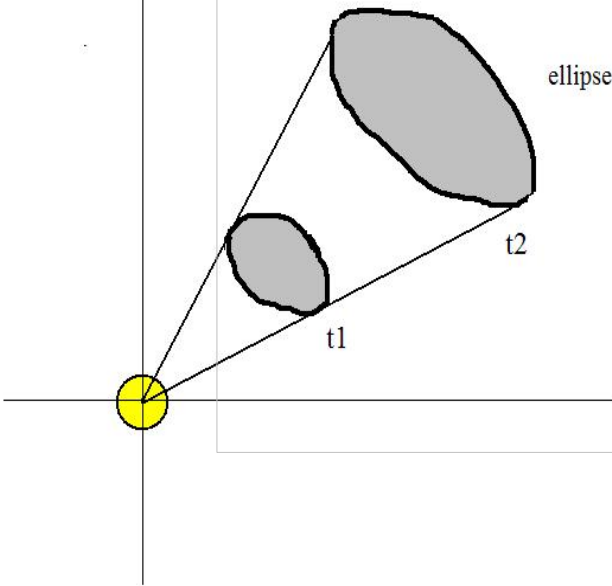Finally, I will demonstrate an example of forecasting in operations:
A collaboration with Air Force Weather Agency (AFWA)

Cone Model for CMEs

Plane of Sky (POS)

N

ellipse

t2

t1
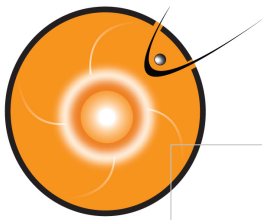
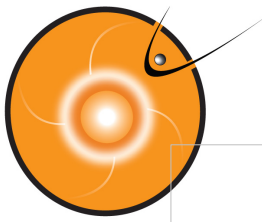Zhao was the first to come up with the Cone model of CME. The CME
cone model is based on observational evidence that CME has more
or less constant angular diameter in corona, being confined by the
external magnetic field, so that CME does not expand in latitude in the lower
corona, but expands in interplanetary space because of the weaker
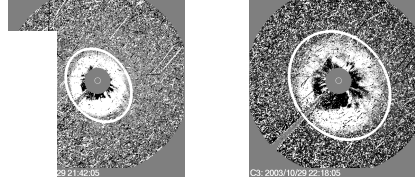external field. The assumptions are the following:
• CME propagates with nearly constant angular width in a radial direction
• CME bulk velocity is radial and the expansion is isotropic

Cone Modelling for Halo CMEs

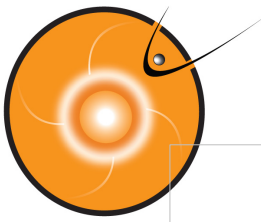SOHO LASCO C3 difference images

N | Plane of Sky (POS)

ellipse

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

t1

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

CME V and orientation

Input to WSA-ENLIL

4

artificial eclipse of the Sun. Eclipses allow corona
to be better viewed. But natural eclipses do not happen often. Occulting disk blocks
the bright sun so we can observe coronal features. Shown in this slide are difference
images.

Xie et al, 2004, developed analytical method of defining Cone Model CME
parameters for Halo CMEs based on series of coronograph image. A. Pulkkinen , 20010 developed automatic method

4

July 12, 2012CME Viewed by Coronagraph Imagers
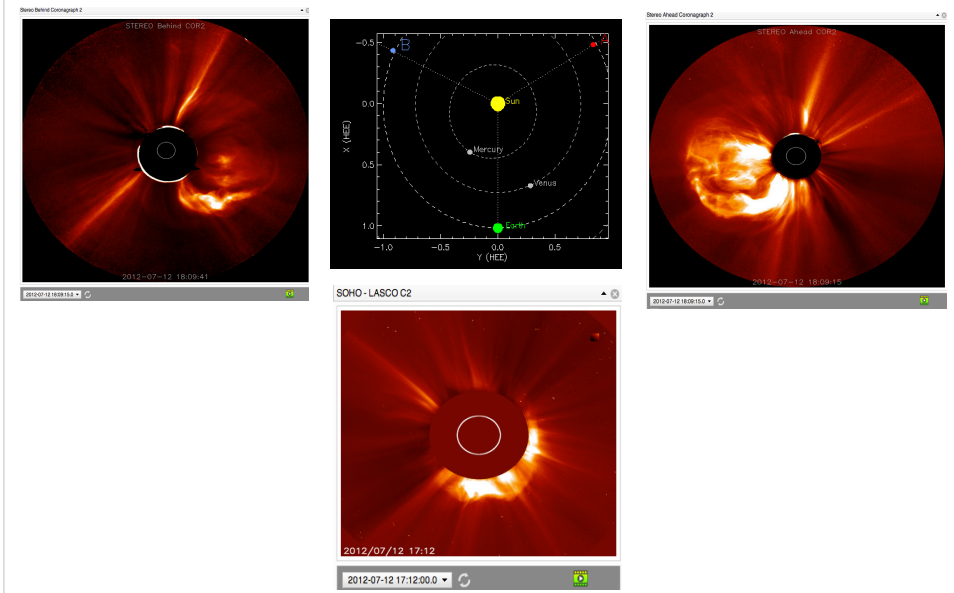
Another method to derive Cone model parameters is triangulation method.
This slide shows the a CME seen in 3 coronographs located on three
different satellites.
The schematic in the upper center shows the location of STEREO B,
SOHO and STEREO A satellites in the ecliptic plane at the time when the
CME occurred.
The CME was moving sort of towards the Earth, so STB sees it moving to
the right in its plane of sky, for STA it moves to the left and it's a halo
image for SOHO that is located on a sun-earth line.
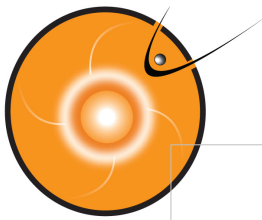
WSA-ENLIL Cone Model
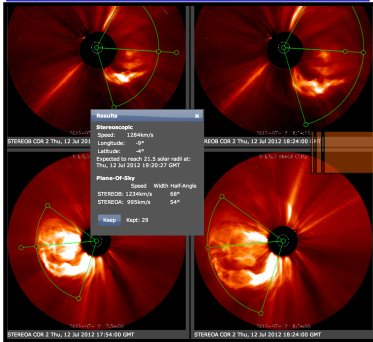
Parameters Defined with CCMC CME Triangulation Tool

CME Parameters: Input To WSA-ENLIL Cone Model

Parameters defined with CCMC CME
  Triangulation Tool
(CAT) or other tools are used as input
  CMEpParameters
to WSA-ENLIL Cone Model.
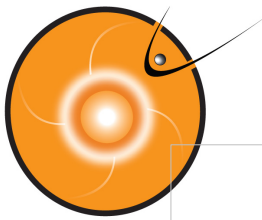
Cone model parameters
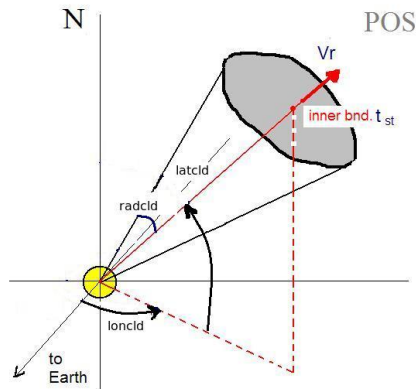
- tstart - when cloud at 21.5Rs
- Latitude
- Longitude
- Radius (angular width)
- Vr - radial velocity

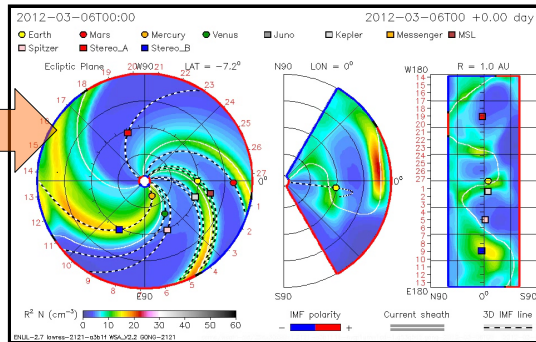Input to ENLIL cone model run

7

Parameters defined with CCMC CME
   Triangulation or other Tools yield CME
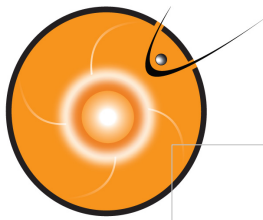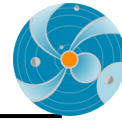Parameters: Input To WSA-ENLIL Cone Model.
   These parameters are:

1- start time of CME at 21.5 Rs (inner boundary
   of the ENLIL model)
2- Cone axis latitude
3- Cone axis longitude
5- Cone Radius – half angle of the cone angular
   width
6- Radial Velocity

Sun, Planets, CME

Heliocentric Earth Equatorial Coordinates - Heliographic

2011-02-23 08:42:26   2011-01-31 +22.73 days

○ Mercury   ● Venus   ○ Earth   ● Mars   ■ Messenger   ■ Stereo_A   ■ Stereo_B

XY - equatorial plane

Z,N

Y

Sun

Mercury

Earth

X

Mars
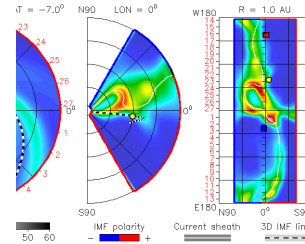
Meridional Plane ('side' view)

1AU quasi-sphere
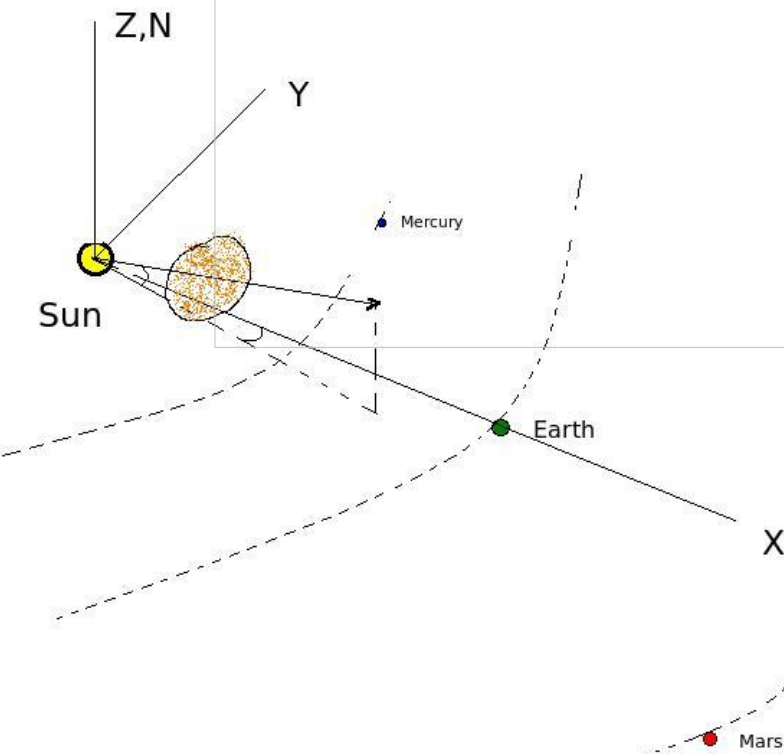
...e of the Sun

...ocated in the

...uatorial plane (changes from -7.5 deg to 7.5 deg).

The first panel in WSA-ENLIL plot shows a plane passing through the
Earth and is parallel to equatorial plane. The second panel is a meridianal cut passing
through the Earth. The latitude goes from -60 to 60 degrees.
 The third panel shows Longitude-Latitude map of a quasi sphere at 1 AU and with
The cut off for Latitude > |60 deg|

8

WSA- Input to ENLIL

WSA (Wang-Sheeley-Arge, AFRL):

NISP SOLIS Near Real Time Magnetic Flux Synoptic Map
630.2 nm

...tial Field Source Surface)**.**

...nap photospheric magnetogram.

...ven current free) solution with
... 2.5 Ro.

...urrent Sheet.

...sign of radial field to positive to
...nnection, creates potential solution
...oundary conditions, restores the
...ew solution at 5 Ro.

...n CS.

...dial constant speed flow at 5 Ro
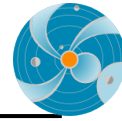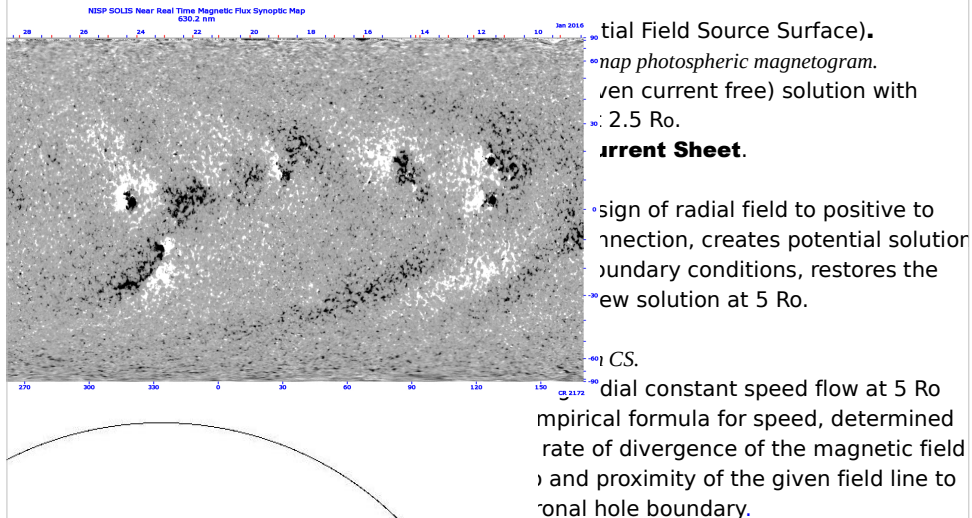...mpirical formula for speed, determined
...rate of divergence of the magnetic field
...o and proximity of the given field line to
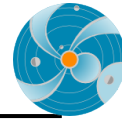...onal hole boundary.

Wang-Sheeley-Arge model WSA (Wang-Sheeley-Arge, AFRL)
is the input model to the ENLIL at it's inner boundary of 21.5Rs.
The input to the WSA is daily magnetograms of the solar surface,
that describe the magnetic field of the photosphere.

WSA model itself consists of different models

- **PFSS** (Potential Field Source Surface)**.**

    Input: synoptic map photospheric magnetogram.
    Force free (even current free) solution with radial
    field at 2.5 R_o.

- **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
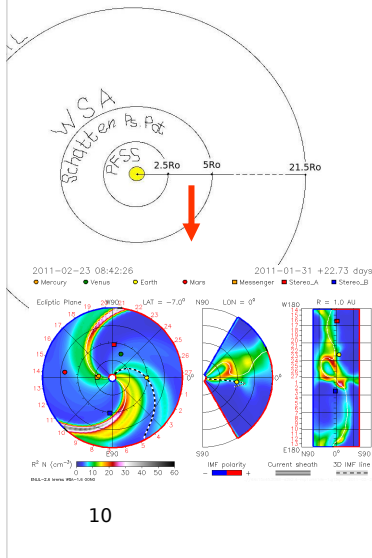   and proximity of the given field line to the coronal
    hole boundary.

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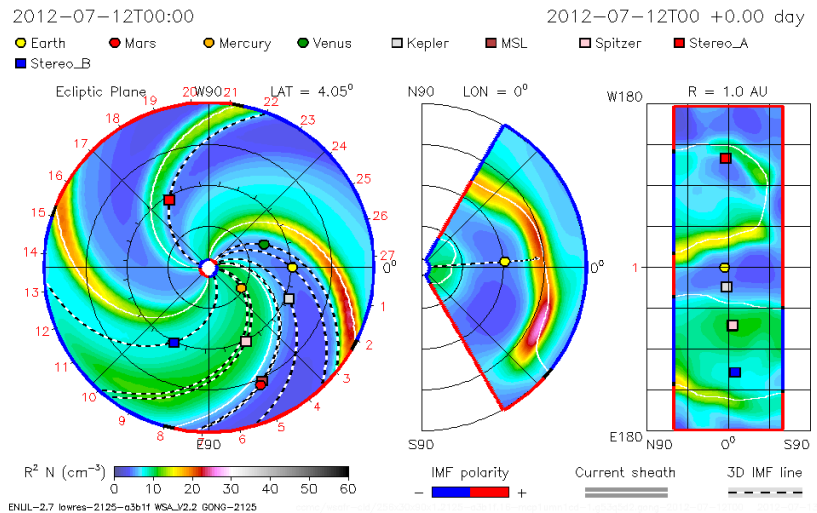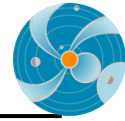
ENLIL model does not take into account the realistic complex magnetic field structure of the CME magnetic cloud and the CME as a plasma cloud has a uniform velocity.

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 solar wind parameters at spacecrafts and planets and topology of the interplanetary magnetic field.

11

Limitation of the ENLIL model:

It 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:
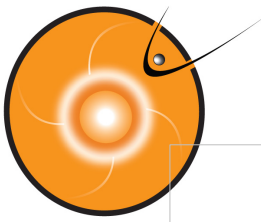3D distribution of the SW parameters at spacecrafts and planets and topology of IMF.
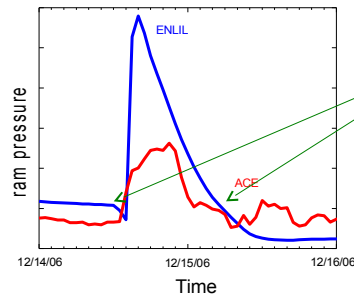
CME modeling

After we define the CME parameters we run the WSA-ENLIL cone model.

CME Impact – arrival, duration, MP standoff distance, Kp index

CME shock arrival – a sharp jump in the dynamic pressure

ENLIL

ram pressure

ACE

12/14/06   12/15/06   12/16/06

Time

Duration of the disturbance – duration of the dynamic pressure hump

Empirical equations for:

- Magnetopause standoff distance

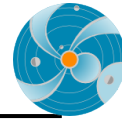**- Kp Index (measure for the strength of the geomagnetic storm)**

13

After the run is done, we estimate the CME impact on planets, satellites.

1. CME shock arrival – a sharp jump in the dynamic pressure.
2. Duration of the disturbance – duration of the dynamic pressure hump.
3. In case of the Earth we estimate also the degree of compressing of the magnetosphere: when the CME mass reaches the magnetosphere it pushes it inward and the magnetic field of the Earth is stressed like a spring to stop the CME motion.
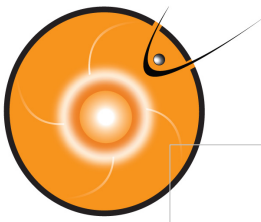
e-mail with CME impact estimate at Earth

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_geosynchr(Re)=6.6)

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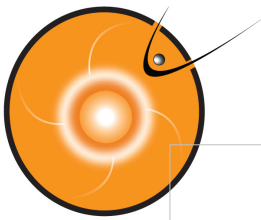(angle 180 gives the maximum possible estimated Kp):
(Kp)_90=4
(Kp)_135=6
(Kp)_180=7

****

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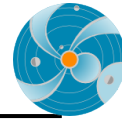http://iswa.gsfc.nasa.gov/downloads/20120729_014700_afwa_anim.tim-pdyn.gif

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

And here is our response e-mail the them in details.
It contains the CME impact estimate for the Earth
(arrival time, magnetopause standoff distance,
Kp estimate for three possible clock angles of the IMF),
and links to the modeling animation and timelines.

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://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_anim.tim-den.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_anim.tim-vel.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_anim.tim-den-Stereo_A.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_anim.tim-vel-Stereo_A.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_anim.tim-den-Stereo_B.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_anim.tim-vel-Stereo_B.gif

Inner Planet Timelines
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_ENLIL_CONE_Mars_timeline.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_ENLIL_CONE_STA_timeline.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_ENLIL_CONE_STB_timeline.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_ENLIL_CONE_Spitz_timeline.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_ENLIL_CONE_Merc_timeline.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_ENLIL_CONE_Venus_timeline.gif

16

But we are not monitoring only Earth impact. Being responsible for
providing space weather assessment to NASA robotic mission operators,
we are monitoring possible impact of the CME on NASA missions.
So we send out another e-mail, that shows this estimate.