3D CME Modeling Tool

User's manual
Version 0.4 (2013-03-14)

Contents:

1. General Description

Since launch of the STEREO twin spacecraft in October 2006 hundreds of CMEs were observed and analysed from different vantage points with the STEREO/SECCHI/COR2 coronagraphs onboard the STEREO-A and STEREO-B spacecraft. Pairs of coronagraph images reveal a stereoscopic view of the observed CME, and its 3D structure can be modeled with the Graduated Cylindrical Shell (GCS) model developed by Thernisien, Vourlidas and Howard in 2006 *(Thernisien,Vourlidas,Howard: **Forward Modeling of CMEs using STEREO/SECCHI Data**, Solar Phys. (2009), 256: 111-130).*
This documentation illustrates how the 3D structure of a typical flux-rope like CME can be parameterized in based on STEREO/SECCHI/COR2 beacon and/or science data. The obtained results can be used as an input for the forecast of space storms at Earth's orbit by ENLIL and other models to improve CME arrival time predictions.

2. Software Installation and Setup

The CME modeling tool is part of SolarSoft and requires the Interactive Data Language (IDL) installed on a Linux 32/64 bit or Mac system. The software is available at:

- IDL: www.exelisvis.com   (tested on IDL 6.3, 8.2)
- SSW: www.lmsal.com/solarsoft/ssw_install_howto.html
- SSWDB: www.lmsal.com/solarsoft/sswdb_install.html

The installation procedures are described in detail on the mentioned websites. For installing SolarSoft it is important to choose the packages "STEREO" and "SECCHI" and for SolarSoft Database the packages "SECCHI Background cal (Standard) stereo/secchi/backgrounds/a/ monthly_min" and   "SECCHI Background cal (Standard) stereo/secchi/backgrounds/b/ monthly_min" for correct data processing.
Before starting the modeling tool it is necessary to set up the environment with the following commands (www.lmsal.com/solarsoft/ssw_setup.html):

```
$ csh
$ setenv SSW /…/ssw
$ setenv SSW_INSTR "stereo secchi"
$ source $SSW/gen/setup/setup.ssw
```

This starts IDL with the SSW Environment and a demo mode of the GCS modeling tool:
```
$ sswidl
$ rtsccguicloud,/demo
```

3. CME Detection

To model a flux-rope like CME with GCS it is necessary to detect the CME in the coronagraphic data to determine timestamps for modeling. The STEREO/SECCHI/COR2 synoptic movies available on http://secchi.nrl.navy.mil/sccmovies allow to find quickly the time t_1 when the CME is best visible for fitting and the timestamp t_0 before the CME appears first time in the COR2 field of view. For both timestamps COR2 FITS-files are needed for image processing and running the modeling tool.

4. Data Acquisition and Processing

The required data are:
- 3 FITS-files for COR2-A at time t_0
- 3 FITS-files for COR2-B at time t_0
- 3 FITS-files for COR2-A at time t_1
- 3 FITS-files for COR2-B at time t_1
- 1 FITS-file for EUVI-A (at 195 or 304 Å) at time t_1
- 1 FITS-file for EUVI-B (at 195 or 304 Å) at time t_1

It is important that the COR2 files are chosen as triples captured in sequence by SECCHI. The wavelength of the EUVI files can be chosen depending on the source region of the CME. In general there are high-resolution science data available three days after recording onboard STEREO and low-resolution beacon data (for space weather forecast) which are available via internet within three hours after capturing. The data can be found on:

- SCC: STEREO Science Center @NASA   (Science Data for STEREO-A)
  http://stereosc.nascom.nasa.gov/data/ins_data/secchi/L0/a/seq/cor2/
- SCC: STEREO Science Center @NASA   (Beacon Data for STEREO-A)
  http://stereo-ssc.nascom.nasa.gov/data/beacon/ahead/secchi/cor2/
- NRL: Naval Research Laboratory   (Beacon and Science Data for STEREO)
  http://sharpp.nrl.navy.mil/cgi-bin/swdbi/secchi_flight/img_short/form

After downloading all files the data need to be processed with specific IDL routines for further usage with the CME modeling tool. A tutorial with a demo IDL script at http://secchi.nrl.navy.mil/synomaps/scraytrace/dobo/examples.html#tutrtsccguicloud   is available by the Naval Research Laboratory which can be used as basic approach.

5. GCS CME Modeling Tool

The CME modeling tool uses the geometry of the Graduated Cylindrical Shell (GCS) model to fit a flux-rope like CME to STEREO/SECCHI/COR2 data. The shape of the GCS Model shown in Figure 1 is reminiscent of a hollow croissant and can be parameterized with 6 parameters:

- Carrington Longitude Φ [deg]
- Heliospheric Latitude θ [deg]
- Tilt Angle γ [deg]
- Height h_{front} [r_{sun}]
- Half Angle 2α [deg]
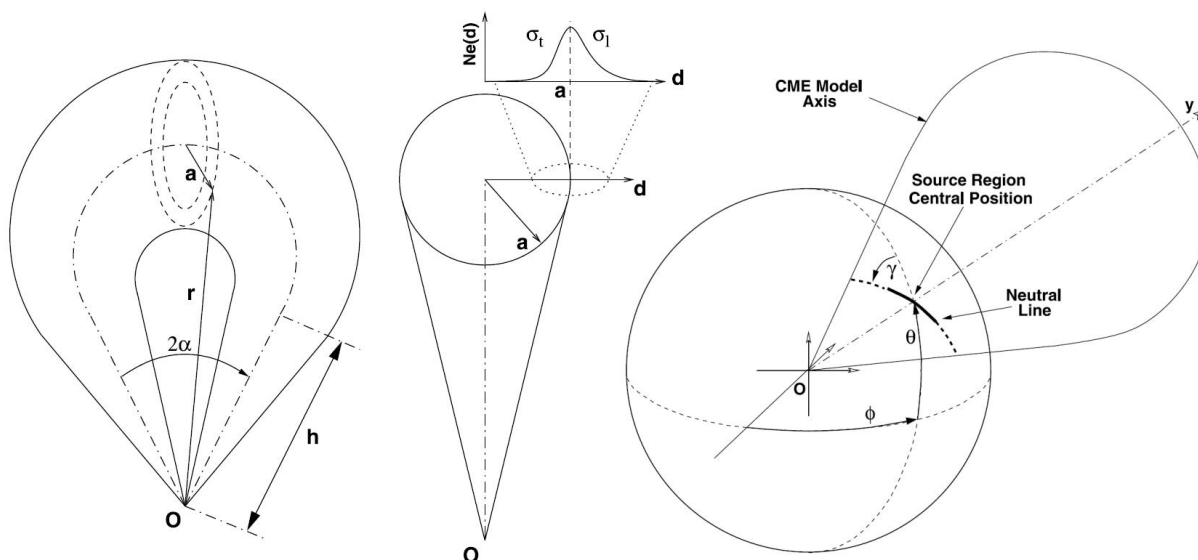- Aspect Ratio $\kappa = a/r$ --

Figure 1: Geometry of the Graduated Cylindrical Shell (GCS) Model developed by Thernisien, Howard and Vourlidas: **Modeling of Flux Rope Coronal Mass Ejections**, *The Astrophysical Journal*, 652: 763-773, 2006.

Following the Tutorial mentioned in Section 4 the GCS CME Modeling Tool is started and provides a graphical user interface (Figure 2) for fitting the CME. The Control Panel on the left shows sliders to change all six parameters of the GCS visualized with a green wireframe shown in the COR2 images on the right side. In their publication from 2006 Thernisien et al. describe step by step how to adjust all parameters to get an appropriate fit matching the CME observation in STEREO/SECCHI/COR2 data:

1. Set all parameters to zero and *Height* to ≈10 r_{sun}
2. Adjust *Longitude*, *Latitude* and *Height* until a good visual match is achieved.
3. Fit *Aspect Ratio* to describe the spatial extension of the CME.
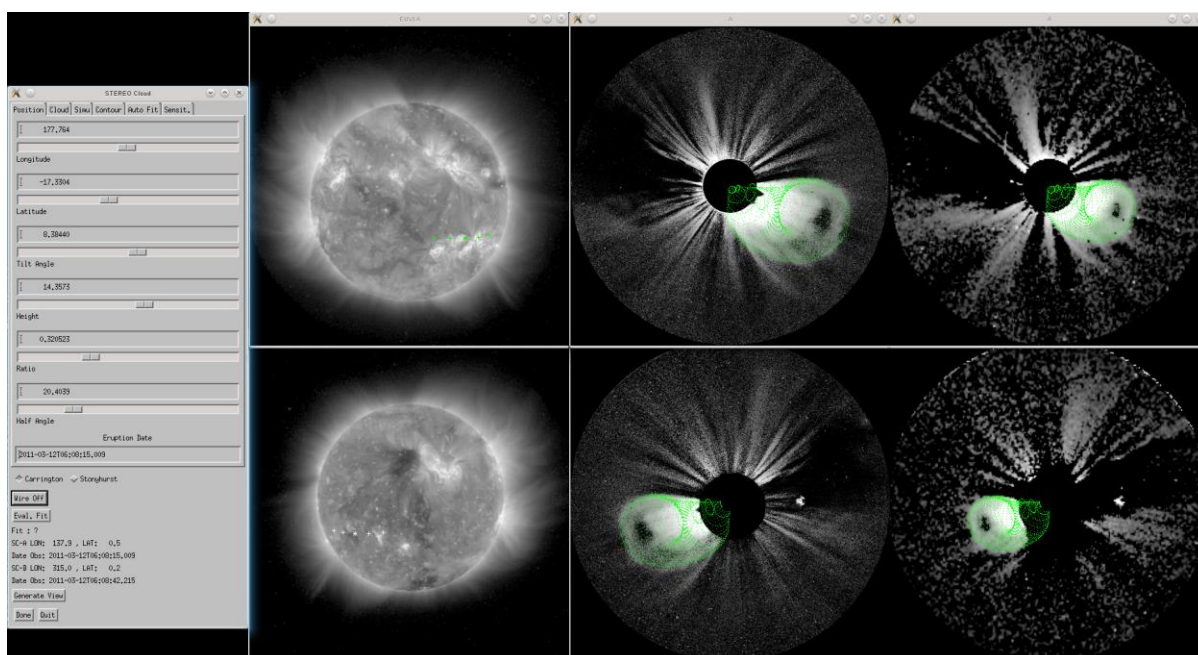4. Then adjust the *Half Angle* and *Tilt Angle* to complete the Fit.

Figure 2: Graphical User Interface of the GCS Modeling Tool. From left to right is shown the Control Panel, EUVI Observations of the Sun at 195 Å, COR2-A/B Observations from science data with a green wireframe representing the GCS fit and COR2-A/B Observations from beacon data with a green wireframe representing the GCS fit. STEREO-A and -B images are shown in the top and bottom row, respectively.

6. Results

The GCS modeling technique yields a parameterization of a CME observed in the STEREO /SECCHI/COR2 field of view. The results provide - amongst others - information about CME propagation direction, spatial expansion and orientation. Generating several fits in a time sequence make it possible to determine CME speed and temporal evolution. Since the fits are done by hand they exhibit the modelers' subjective perception of the CME's shape and orientation and need some experience. A set of 51 CMEs observed in 2010 has been modeled by Bosman, E., Bothmer, V., Nistico, G., Vourlidas, A., Howard, R., Davies, J.A.: 2012, Three-Dimensional Properties of Coronal Mass Ejections from STEREO/SECCHI Observations, *Solar Phys.*, **281**, 167-185.

7. Acknowledgements

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