FIDO Tutorial

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1 What is FIDO?

FIDO is the ForeCAT In situ Data Observer. This is a simple model that was designed to take the output of the CME deflection model, ForeCAT, and visualize the resulting in situ magnetic field based on the CME's modeled position and orientation. While the original intent was to pull the input parameters from ForeCAT, the model can certainly be used with other sources for the CME location and orientation.

The model uses the same torus shape as ForeCAT, shown in Figure 1, to represent the flux rope of the CME. FIDO uses a very simple algorithm to convert this to an in situ profile. The CME torus moves in the radial direction at a constant velocity and the spacecraft's distance from the toroidal axis is determined as a function of time. Using a simple flux rope model, typically the Lundquist force free flux rope model, the distance from the toroidal axis determines the relative magnitudes of the poloidal and toroidal magnetic field. Finally, FIDO uses the orientation of the CME and few rotation matrices to convert these components into Geocentric Solar Ecliptic (GSE) coordinates (positive x-axis is from Earth toward Sun, y-axis is trailing Earth's orbit, and z-axis is the ecliptic north pole).

The CME position, orientation, shape, and size are all set by the input parameters, as well as the magnetic field strength. The difficulty is in accurately determining these parameters, especially since there is often a degeneracy of inputs that yield similar in situ profiles.

2 Set Up

If you do not already have Python installed on the computer, find a distribution (such as Anaconda) and install it. Alternatively, Python and the individual packages can be installed by hand. FIDO uses fairly standard packages so installing a standard distrubution should take care of most of the dependencies. If doing things by hand, the major packages to download are numpy, scipy, matplotlib (including pylab), and Tkinter (easy to do with pip/pip3).

FIDO should work with either Python 2 or 3, but small changes must be made. It was developed in Python 2 but has been tested in Python 3, but not as thoroughly. In Python 2 line 11 is

```
from Tkinter import *
```

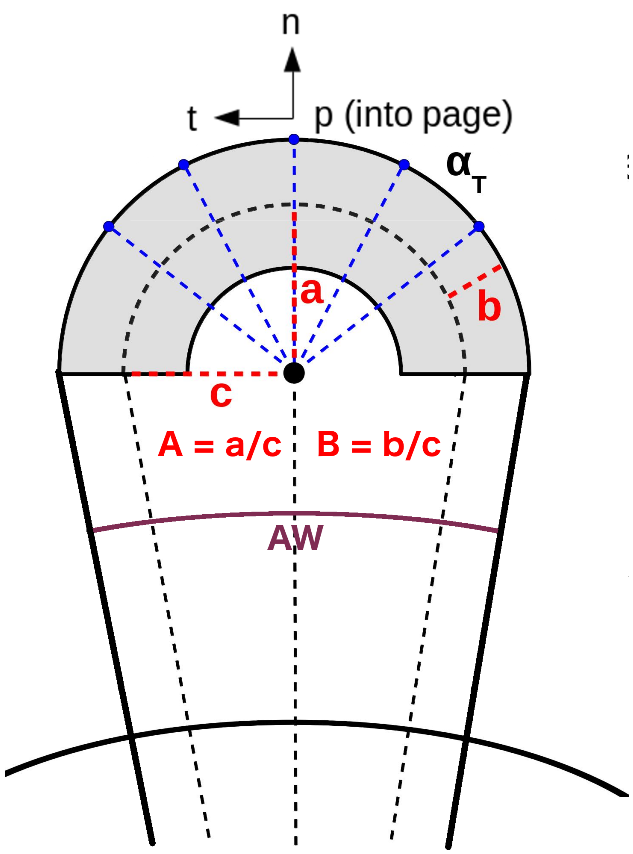

Figure 1: The torus shape used to represent the CME flux rope.

whereas in python3 it should be modified to

```
from tkinter import *
```

Obtain the FIDO python script `FIDO.py`, the sample input file `sampleinput.txt`, and the sample spacecraft data `ACE_CME7.txt` (odds are you were given them with this tutorial but they are also available from `github.com/ckay314/FIDO`).

3 Introduction to the FIDO GUI

To launch the FIDO GUI simply type

```
python FIDO.py
```

and a window that looks similar to Figure 2 should appear. If a window does not appear, check that the very bottom line `run_FIDO()` is not commented out. This makes the script actually run when the file is executed, but should be commented out when an external script is making use of FIDO functions. The exact display may vary with operating system and version of python. Any differences should be purely aesthetic and all the functionality should remain the same.

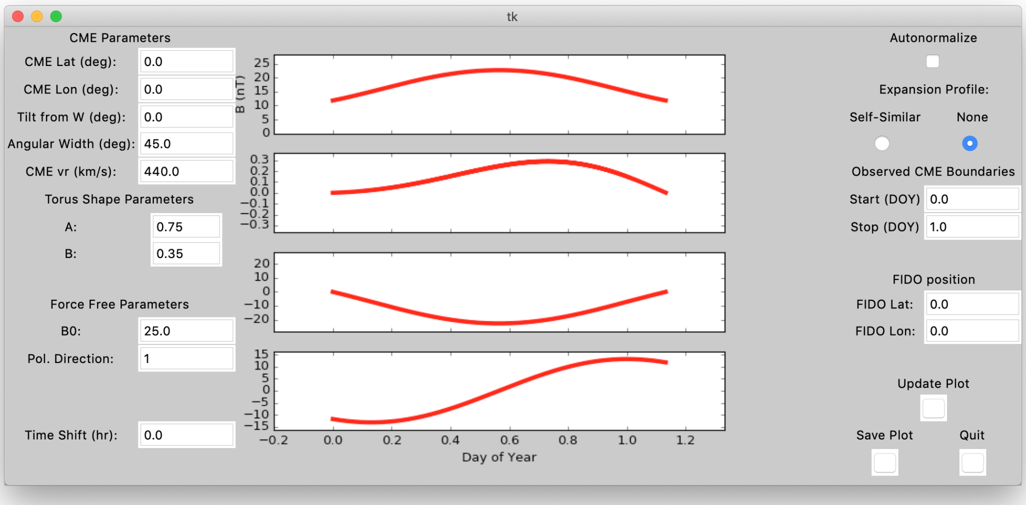

Figure 2: The FIDO GUI when no input file is included.

The GUI shows the path of a spacecraft through the CME torus. We haven't given any parameters to FIDO, so it is currently using default values. We also haven't given it a file with any in situ data to compare to so the GUI only shows the model results in red. From top to bottom the figure shows the total magnitude and B_x, B_y, and B_z in GSE coordinates. FIDO will output several lines to the terminal warning that the various inputs required for comparison cases are missing.

In the bottom right corner there are three buttons used to control the GUI. "Update Plot" will take the current values from the input parameter boxes, recalculate the profile, and update the figure. "Save Plot" will save the current results, the format of which we will discuss later. Finally, "Quit" should be used to exit the GUI, rather than simply clicking the exit button built into the window. This often just kills the window but leaves the script running so one cannot return to the command line until python is also stopped (typically ctrl+c works).

Let's run through each set of parameters to understand how they affect the results before we start comparing with observations. Try modifying each value beyond the behavior described below to get a better feel how the profile depends on each one.

3.1 CME Position

The top left set of parameters describe the CME position, orientation, and shape. The first two are the CME latitude and longitude, which correspond to the location of the CME nose (the center of the front of the torus in Figure 1, which is always the farthest point radially in FIDO.) These two positions should be given in degrees with positive latitude corresponding to northward from the equator. The longitude can be in Carrington or Stonyhurst coordinates so long as the same coordinate system is used for the FIDO (satellite) location (middle to bottom of right column). It is not the magnitude of the CME latitude and longitude that are important for determining profiles, rather the relative difference between the CME position and the FIDO position. Try moving both longitudes to 10°, the profile will remain the same. Now move the CME longitude back to 0°, the profile will change since the separation is now 10°. We now have a much larger, positive B_x. Finally, try a CME longitude of 10° and a FIDO longitude of 20°. Since the separation is still 10° this matches the previous result.

Now try changing the CME latitude or longitude to 60°. The red line will disappear and "No impact expected" will be printed in the terminal. We have moved the CME sufficiently far away that we no longer expect the satellite to encounter it at all. This results from not only the position parameters that we have already described, but also the size and shape parameters that we will discuss later.

3.2 CME Orientation

The next parameter is the tilt or orientation of the CME. This is measured as the orientation of the toridal axis (curved dashed line in Figure 1) measured counterclockwise from solar west (right from the Earth's perspective). The default is set to 0°, which corresponds to a perfectly horizontal CME. This means that the toroidal axis is in the xy-plane and the poloidal axis is in the xz-plane (in a heliocentric coordinate system, though with the Earth at 0° latitude and longitude it is also true for GSE coordinates). When the spacecraft is precisely at the nose the x-component becomes negligible, which we see in the B_x panel, within the computational limits. B_y shows the toroidal component, which starts at a minimum at the edge of the CME, increases as the spacecraft approaches the center/toroidal axis, then decreases back toward the trailing edge but maintains the same sign. B_z shows the poloidal component, which has the largest magnitude near the edges. The poloidal component slowly decreases, reaching zero at the exact center, and reversing sign as it increases in magnitude as it approaches the back edge.

Now switch the tilt to 90°, which corresponds to a perfectly vertical CME. We are still directly at the CME nose, but now have the toroidal component in the xz-plane and the poloidal component in the xy-plane. The B_x component is still essentially zero but B_y now smoothly varies between extremes of opposite signs at the edges and B_z peaks in the center. As the relative geometry of the CME and spacecraft change it becomes more difficult to conceptualize the division of poloidal and toroidal components into GSE coordinates so it is important to understand these simple cases so one can try and extrapolate from here. What happens as one moves away from the nose in the toroidal direction? In the poloidal direction? What about when the orientation deviates from perfectly vertical or horizontal? Try using the torus figure and GUI and see if you can rationalize small changes in each of the first three parameters. It quickly becomes quite difficult, which is why we have FIDO to quickly visualize profiles for us.

3.3 Angular Width

The next parameter is the angular width of the CME, which is measured as the angle in degrees between the outermost part of the torus, as shown in Figure 1. When our impact is near the CME nose changing the angular width will not cause a change in the shape of the profile, but it will affect the duration. If the impact is near to the flank then an increase in the angular width will move the impact toward the nose and a decrease toward the flank. If you decrease the angular width sufficiently then what was previously an impact can become a miss.

3.4 CME Radial Velocity

The next parameter is the radial velocity of the CME. This does not have an effect on the shape of the magnetic field profile but, combined with the CME size and shape, deterimines the duration. If the velocity increases the profile becomes shorter.

3.5 Torus Shape Parameters

The final set of CME parameters are a pair of shape ratios A and B that fully determine the torus shape as shown in Figure 1. A is ratio of the height to width of the toroidal axis and B is the ratio of the cross-sectional width to the toroidal axis width. Similar to the angular width changing these primarily affects the duration when the impact is near the nose but near the flanks the shape of the profiles can be affected.

Increasing B typically causes an increase in the duration, but the dependencies can be a little complex based on our definition of A, B, and the angular width. The CME's nose is at a fixed distance R but the maximum width is not measured at R but at the radial distance corresponding to the black dot in Figure 1. Expressing the distances a and b using the shape ratios the angular width (AW) is then

$$\tan AW = \frac{(B+1)c}{R-(A-B)c} \tag{1}$$

which can be solved for c if the shape parameters and angular width are known. The CME duration is the cross-sectional width $2Bc$ divided by the velocity. The math is relatively simple, but the resulting equation is sufficiently complicated to make an intuitive understanding of the scaling with A and B slightly complicated.

3.6 Flux Rope Parameters

The middle part of the left column shows the parameters related to the flux rope model. B_0 scales the total magnetic field strength. The total magnitude will equal B_0 when the spacecraft intersects the toroidal axis. Note that many cases pass through the torus either above or below the axis so that the maximum magnitude may be less than B_0.

Both the magnitude and sign of B_0 matter with the sign indicating the direction of the magnetic field along the toroidal axis. A note of caution here, FIDO has been designed to be flexible so any angle can be used for the tilt. A tilt of +90° or -90° is the exact same for the torus *shape*, but will cause different magnetic profiles. The same is true for 135° and -45°. Think of the tilt as setting the orientation of a vector, it tells you where the tip points. If you switch the sign of B_0 to negative then this sets the tip to the other end of the vector. Compare the profiles with a tilt of +90° and positive B_0 and -90° and negative B_0.

If you only use tilts between 0° and 180° then positive B_0 corresponds to northward field at the toroidal axis (at least partially, it will also have an eastward or westward component depending on how horizontal it is) and negative corresponds to southward field. If you only use tilts between ±90° then positive B_0 means westward field at the toroidal axis (with some north or southward component) and negative B_0 means eastward. It is recommended to stick to one of these conventions to reduce confusion with redundant solutions.

The other parameter is the poloidal direction - whether the flux rope is left or right handed. This determines the direction the poloidal magnetic field rotates around the toroidal field. Positive (1) is counterclockwise and negative (-1) is clockwise. No values other than 1/-1 are accepted as inputs.

Consider the vertical CME with the impact at the nose (CME and spacecraft position equal and a tilt of 90°). With positive B_0 we will have purely northward field at the center (toroidal axis) and poloidal field pointing to the west on the front and east on the back. FIDO shows negligible B_x, B_y that rotates from negative to positive, and a peak in positive B_z at the center. Now switch the poloidal sign to negative, B_z will remain the same as the toroidal field is unaffected but B_x and B_y will switch signs. Now switch B_0 to negative. This time all three components flip. The toroidal axis changes and the handedness remains the same but now clockwise (assuming the poloidal sign is still negative) corresponds to westward field on the front and eastward field at the back. Things become more complicated as one moves away from the nose or away from a perfectly vertical or horizontal orientation, but try and build up a little bit of intuition before comparing FIDO results with a real case.

3.7 Time Shift

The final CME parameter is a "time shift" that allows the FIDO results to be shifted along the temporal axis. Note that the input is in hours but the GUI's x-axis displays in days. This parameter is not necessary for the most part, but might be relevant in cases that are compared to observations. The FIDO results are defined to start at the CME start in the right column, which would likely be a number chosen for some specific reason (analyzing in situ properites, either yourself or from someone's list). This allows us to keep the CME start the same for quality-of-fit purposes (discussed later) but see if we get a better fit to the rest of the CME if we make a small change in the FIDO start.

4 Expansion

So far we have only considered a case with no CME expansion. The torus maintains the exact same physical size as it passes over the spacecraft. FIDO also includes an option for self-similar expansion where the CME maintains a constant angular width. This means that the CME is physically larger when it is at farther distances. The toggle near the top of the right column allows one to change between the two expansion modes.

Note that when there is no expansion the profiles are symmetric in time. When we include expansion we account for conservation of magnetic flux so that the total magnetic field will weaken over time and have a longer extended tail.

5 Comparison with Observations

Now that we have a feeling for the different parameters we can compare with an observed CME. For all the previous cases FIDO was initiated with default input parameters. We can use a text file to pass specific values to it, including the in situ data with which we want to compare. Run

```
python FIDO.py sampleinput.txt
```

and the GUI should look like Figure 3. Note that all the text boxes now have numbers in them, the FIDO results (red) are compared with observations (black), and all the command line warnings have been replaced with “Files will be saved as sample input” and a score. Note that FIDO will use the name of the input file (minus the “.txt”) for all its output files.

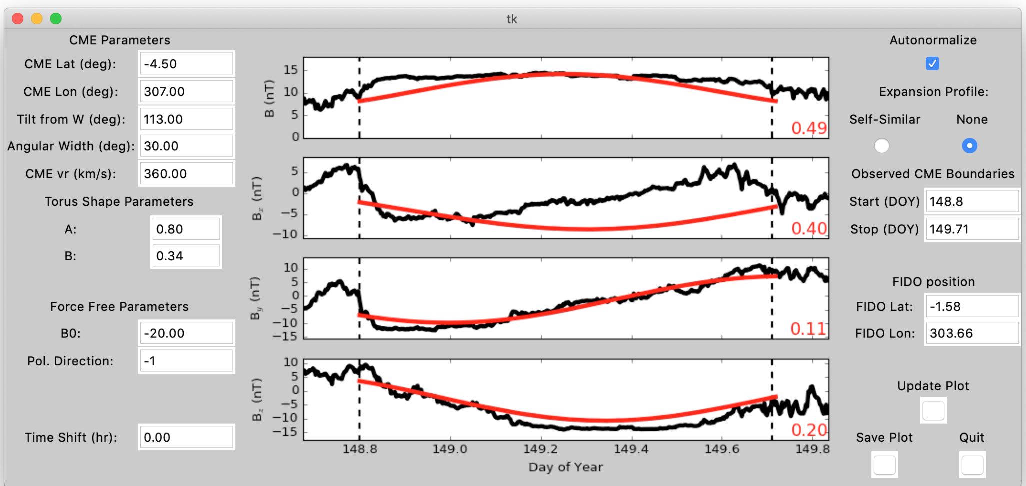

Figure 3: The FIDO GUI using the sample file.

5.1 Input File

First open `sampleinput.txt`. There are two columns: a list of variable names and their associated values. FIDO will scan through the file, identify the appropriate variables by the specific names, then assign the given value. The order of the names does not matter but the only names accepeted are insitufile, CME_lat, CME_lon, CME_tilt, CME_AW, CME_Ashape, CME_Bshape, CME_vr, CME_B0, CME_pol, tshift, Sat_lat, Sat_lon, CME_start, CME_stop, Launch_GUI, No_Plot, Autonormalize, Save_Profile, Expansion_Model, Silent, and Indices. The “:” must be included after the variable name. It is not necessary to include every value in the text file, FIDO will revert to defaults for any missing parameters. All the CME_ and Sat_ labels correspond to the variables discussed in Section 3 and the new parameters are discussed below.

insitufile is the the name of the text file containing the in situ data. We will discuss the format of the in situ data in Section 5.2.

When the "Save Plot" button is selected in the GUI, FIDO will save a png with the image currently in the figure and a .txt file with the corresponding parameters, making it easy to reload cases. If Save_profile is set to True then it will also save a .dat file with the model results as columns of day of year, B_x, B_y, and B_z. This can be used to output results that can easily be compared elsewhere outside the FIDO GUI.

Launch_GUI can be set to either True or False. When set to True (the default) it causes the GUI to pop up when the script is run. When set as False no window will open but the "Save Plot" command will be executed and save a figure, as well as a .dat file if desired. The option No_Plot allows one to just save the .dat without a figure. If No_Plot is set to True when Launch_GUI is also True then it is ignored. These parameters are meant to be used when FIDO is being called repeatedly by wrapper scripts, such as for creating ensemble results. Silent can also be set to prevent any noncritical messages from being displayed on the command line.

Autonormalize also can only be True or False (default is True when comparing with in situ data) and corresponds to the toggle box in the top right of the GUI. When True, FIDO ignores the magnitude of B_0 and automatically scales the modeled magnetic field to match the average total observed magnetic field strength in the middle four hours of the CME. This can cause issues if the CME is shorter than four hours (which should not apply for any reasonable case) or if there is missing data in the middle of the CME. The sign of B_0 is still used when autonormalize is selected.

Expansion_model allows one to select between "None" and "Self-Similar" corresponding to the two expansion models described above. The default is none.

Setting Indices to true includes a extra panel with the Kp index generated from the magnetic field profile and CME velocity. The blue lines in the B_y and B_z show the model results in GSM coordinates, a slight rotation from GSE, which are used to determine the Kp indices. The Kp values will be included in the saved .dat file. This feature has been less extensively tested than the rest of FIDO.

The CME start and stop time should also be provided if comparing with in situ data. If no start is provided then the CME is assumed to start at the first in situ data time (or zero without in situ data). If no stop time is provide then an arbitrary duration of one day is assumed to allow the code to function and visualize the results, but the scores should not be used. The black, dashed, vertical lines in the figure show the start and stop times.

5.2 In Situ File

FIDO was designed to read in ACE data. The expected input format is columns of fractional day of year, B_x, B_y, and B_z. Data can be accessed through a web interface at the ACE website `http://www.srl.caltech.edu/ACE/ASC/level2/lvl2DATA_MAG.html`. The four minute-averages are recommended as they show the small scale features within the observations (which FIDO cannot reproduce, but are worth visualizing). The appropriate date range must be chosen, after which one can pick the parameters to export. Occasionly, CMEs extend over multiple time intervals if the split date falls in the middle. In this case, multiple files must be downloaded and stitched together.

Alternatively ACE provides a direct link to downloads (information at `http://www.srl.caltech.edu/ACE/ASC/level2/new/hint.html`). The following example has been modified to produce the desired output for FIDO, only the start date and time (sd and st) and end date and end time (ed and et) need to be modified. Make sure to allow for padding around the precise CME start and stop (at least three hours) as this is needed for the visualization. The data is likely output as `mag_level2_dat_4min.txt` in the Downloads folder, but this may vary from computer to computer.

`http://www.srl.caltech.edu/ACE/ASC/level2/new/ACEL2Server.cgi?datasetID=mag_level2_data_4min&TPARAM=fp_doy&PARAM=Bgse_x&PARAM=Bgse_y&PARAM=Bgse_z&sd=2010-05-27&st=00:00:00&ed=2010-05-30&et=23:59:59&dataformat=TEXT&nonint=1`

Clicking on the link should download a file with the same content as `ACE_CME7.dat`. If you try to copy and paste directly from the pdf you may have issues, which may also occur if you copy it to a text file to edit the start and stop times. When the link is copied it often adds in either spaces or return symbols at the line breaks in the pdf (between "mag_" and "level" and between "&" and "st"). Delete these so that the link is one continuous line or the website will generate an error file.

Any other data source can be used instead of ACE data with minor changes. If the data is formatted in DOY, B_x, B_y, B_z then the only change should be the number of lines in the header, currently `skip_header` is set to 44 for the ACE output (line 829) within the function `setupObsData`.

```
data = np.genfromtxt(ISfilename, dtype=np.float, skip_header=44)
```

5.3 Score

As a metric of the quality of fit, we include a score for the fit as a whole, as well as the individual vector components. These are shown in red in the bottom right of each panel. Note that the top score is a measure for the whole CME, not for the fit of the total magnitude, and is what is printed to the terminal.

For the fit as a whole FIDO uses the vector magnitude of the average absolute error in each of the hourly-averaged individual components, weighted by the average total observed magnetic field strength. While that is a nice, succinct description, it is bit difficult to conceptualize immediately.

We first consider a single component, say B_x. When then convert the modeled and observed B_x profiles into a series of hourly averages. We determine the absolute difference between the modeled and observed averages for each hour then take the average of all the hourly differences to get a single value for the error in B_x, which we call σ_x. We repeat the process for B_y and B_z yielding two more errors σ_y and σ_z.

These σ will increase as the total magnetic field strength increases so we want to normalize so we can compare the quality of fit between different CMEs. We could do this using the average observed magnetic field strength of each component. The magnetic field is likely not evenly distributed between the three components, however, so if we normalize using the average observed field of each component we risk overemphazing a small error in the weakest component. To avoid this we use the average of the total observed magnetic field. The number in red in each of the component panels shows the σ weighted by the average total observed magnetic field.

The total score for the CME equals the root mean square (vector magnitude) of the three individual component scores. We add in an extra component to reflect any difference in length between the observed and modeled CMEs. If the modeled CME ends more than 30 minutes before the observed end we add 5 to the score to flag the quality of fit. If the CME extends more than an hour beyond the observed end then we penalize by adding 0.1 for every additional hour. These precise values are somewhat arbitrary but can be modified in lines 361 and 363 in the `calc_score` function if desired.

Assuming the model has appropriate duration, a perfect fit corresponds to a score of zero and the worst fit possible, assuming autonormalization or at least comparable total magnitudes, is two, which occurs when each vector component has the correct magnitude but opposite sign for the CME duration. A score of one is a somewhat arbitrary but reasonable cutoff for a "good" fit. This corresponds to the error in each of the components being roughly less than or equal to the magnitude of that component, which can only occur if the model has the correct sign for each component for the majority of the CME.

6 Sample Case

Now that we have seen what changes with an input file, we can explore the sample case. This corresponds to the CME that erupted on May 24, 2010 at 13:55 UT. This corresponds to CME number 7 in the Kay & Gopalswamy (2017) paper. The CME arrived at Earth on May 28 at 19:00 (start of the flux rope) and ended on May 29 at 17:00 according to the Richardson and Cane ICME list[1].

The numbers used for the inputs are rounded versions of the values determined using the ForeCAT CME deflection model (rounded only for the sake of exploration in this tutorial, the precise values are in Kay & Gopalswamy (2017)). ForeCAT gives a final latitude of -4.5°, a longitude of 307°, and a tilt of 113°. We use the same angular width as the the end of the ForeCAT simulation, 30°, but assume there is no continued expansion when the CME arrives at 1 AU. The radial velocity comes also from the Richardson and Cane list, where it is derived from the in situ observations.

The sign of B_0 and the handedness come from observations of solar magnetic field orientation at the surface. Typically we use the relation from Bothmer and Schwenn (1998). This is statistically valid for most active region CMEs, but counterexamples exist, particularly for non-Hale's law regions. The hemisphere determines the handedness with northern eruptions being left-handed and southern being right-handed. The direction of B_0 is determined by the relative signs of the leading and trailing polarities. Since we are comparing with a measured case rather than predicting we make things simple and use the autonormalize feature rather than trying to determine B_0 using the photospheric magnetic field and approximating conservation of flux within the CME en route to 1 AU.

Since we have the CME longitude in Carrington coordinates we use the same for the satellite longitude[2]. The Carrington coordinate system continues to rotate due to the Sun's

[1] `http://www.srl.caltech.edu/ACE/ASC/DATA/level3/icmetable2.htm`

[2] Information on calculating the Earth's Carrington longitude at `http://umtof.umd.edu/pm/crn/`

rotation. Both the CME's and Earth's Carrington longitude will change by about 25-50° as the CME spends approximately 2-4 days propagating to Earth, simply due to the rotation of the coordinate system itself. If we use the Earth's Carrington longitude at the time of arrival then we need to incorporate the change in the CME's Carrington longitude during propagation to 1 AU. Alternatively, we can just use the Earth's Carrington longitude at the from the same time as the final modeled/measured CME longitude. It is often less confusing to just use Stonyhurst coordinates with the Earth located at longitude zero.

Using either Carrington and Stonyhurst, we do need to explicitly account for the orbit of the Earth around the Sun during the transit, which will cause a change in the relative longitudes of 0.9856° per day. This can either be added to the Earth's longitude or subtracted from the CME's longitude. The Earth's latitude is typically nonzero due to its inclined orbit. The latitude should be for the time of impact, but typically the change is negligible over the few days spent in transit.

The only parameters we do not have well-defined values for are the shape parameters A and B. We use certain values in ForeCAT, but the CME shape can certainly change during propagation to 1 AU. We almost always use either 0.7, 0.75, or 0.8 for A in FIDO. These values seem "reasonable" and match the average observed aspect ratio determined by Janvier et al (2015). B shows a much wider range between cases, anywhere from 0.01 to 0.6 or even larger. For comparison cases (not predictions) we can make use of the observed transit time. The angular width and speed are relatively constrained, so we can simply pick the value of B that makes the modeled duration match the observed. For predictions, the evolution of B must be modeled or the default value can be used.

Whether using ForeCAT results or values from some sort of visual fit to coronagraph images, it is important to remember that these values are estimates with some uncertainty, not direct, precise measurements. We give our best guess to FIDO, but should explore if we can get a better in situ fit with small changes in any (or all) of the numerical free parameters (one can check what happens with different polarities, but you should be relatively confident in their values from near-Sun observables). Try changing things and see if you can improve the score. Notice that sometimes you may be optimizing the fit to one component, but this ends up making the other fits worse. Also, be caution of large simultaneous changes in multiple parameters, this can lead to no impact and it may be difficult to diagnose why. Instead, by changing things slowly, and even one at a time, you can tell why FIDO may predict no impact when the previous case was fine. If you are near the flanks, a change to miss by from a small change in position can be balance by a small increase in the angular width or shape parameter B.

7 Additional Cases

The in situ data for the sample case shows a relatively well defined flux rope and we are able to reproduce it reasonably well with FIDO. However, most cases will not work so well. Often the flux rope is distorted and/or we see variations on short time scales. FIDO is designed to reproduce a very idealized flux rope, though we can still represent flank cases that end up

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`CARRTIME.HTML` and a useful webtool for both Carrington longitude (L0) and heliographic latitude (B0) `http://bass2000.obspm.fr/ephem.php` appearing less than ideal. The more chaotic and less structured the in situ flux rope is, the worse we expect the FIDO fit to be, but hopefully we can still describe the general behavior.

Try getting fits for some or all of these additional cases, which represent a variety of in situ cases. You will need to obtain the in situ data for each case. Note that these start and stop times correspond to a mix of values from the Richardson and Cane list and the Wind ICME list[3].

If you have a preferred method of measuring CME position/orientation try starting with those measurements. Otherwise, the ForeCAT results are included below (with some heavy rounding to give room to explore and improve the fit). Your numbers may differ slightly from the ForeCAT values, but probably should be similar (within about 10°). These are cases from the ensembles study in Kay & Gopalswamy (2018), which were selected to represent a wide range of deflections and rotations. Like any model, ForeCAT is sensitive to the inputs and there are degeneracies in the output, but these CMEs have been thoroughly studied to develop a consistent story from the Sun to the Earth, which should minimize the uncertainty in the CME's position and orientation. Try getting the Earth's position on your own and determining the magnetic field signs, but values have also been provided. Each test case has a rough value of the score we found previously to give an idea of the quality of fit you should expect.

Test Case 1 (score 0.95)

- LASCO Date: September 6, 2011 22:25 (249.93)
- 1 AU Start (DOY): September 10, 2011 03:00 (253.13)
- 1 AU Stop (DOY): September 10, 2011 15:00 (253.63)
- Latitude: 31
- Longitude: 219
- Orientation: 70
- Angular Width: 45
- Speed: 470
- B0/Poloidal Sign: +/+
- Earth Latitude: 7.25
- Earth Longitude: 212.51 (Car Lon at LASCO date + 0.9856*(1 AU Start - LASCO))

Test Case 2 (score 0.55)

- LASCO Date: July 12, 2012 16:48 (194.70)
- 1 AU Start (DOY): July 15, 2012 00:00 (197.30)
- 1 AU Stop (DOY): July 17, 2012 05:00 (199.14)
- Latitude: -15

[3] https://wind.nasa.gov/ICMEindex.php

- Longitude: 84
- Orientation: 50
- Angular Width: 45
- Speed: 490
- B0/Poloidal Sign: -/+
- Earth Latitude: 4.36
- Earth Longitude: 83.63

Test Case 3 (score 0.70)

- LASCO Date: September 28, 2012 00:12 (272.01)
- 1 AU Start (DOY): October 1, 2012 00:00 (275.00)
- 1 AU Stop (DOY): October 2, 2012 00:00 (276.00)
- Latitude: 15
- Longitude: 147
- Orientation: 105
- Angular Width: 50
- Speed: 370
- B0/Poloidal Sign: +/-
- Earth Latitude: 6.71
- Earth Longitude: 142.36

Test Case 4 (score 0.45)

- LASCO Date: September 29, 2013 21:45 (272.91)
- 1 AU Start (DOY): October 2, 2013 23:00 (275.96)
- 1 AU Stop (DOY): October 2, 2013 22:00 (276.92)
- Latitude: 20
- Longitude: 353
- Orientation: 75
- Angular Width: 60
- Speed: 470
- B0/Poloidal Sign: -+
- Earth Latitude: 6.62
- Earth Longitude: 339.82

Test Case 5 (score 0.65)

- LASCO Date: February 12, 2014 06:12 (43.26)
- 1 AU Start (DOY): February 16, 2014 00:42 (47.03)
- 1 AU Stop (DOY): February 16, 2014 16:00 (47.60)
- Latitude: -5
- Longitude: 359
- Orientation: 95
- Angular Width: 35
- Speed: 380
- B0/Poloidal Sign: +/-
- Earth Latitude: -6.89
- Earth Longitude: 356.85

A Input File Cheat Sheet

Here is a list of the parameters that can be passed to FIDO via the input text file, as well as a brief description of each. The value in brackets indicates the default value when the parameter is not include in the input file.

- `CME_lat`: The latitude of the nose of the CME, which is the center grid point and farthest point radially, given in degrees in Heliocentric coordinates. [0°]

- `CME_lon`: The longitude of the nose of the CME, given in degrees. Any Heliocentric longitude system can be use (Carrington or Stonyhurst) but it should be the same as used for the Earth's longitude. [0°]

- `CME_tilt`: The orientation (in degrees) of the CME torus ranging between ±180°. This is measured by the angle between the toroidal axis and the solar equator, with positive values measured counterclockwise from the west direction (i.e. pointing north is 90°). This direction corresponds to the direction typically used in the literature, but different authors may have different conventions. [0°]

- `CME_AW`: The angular width of the CME in degrees, measured from nose to flank. Technically this is half of the full angular width (i.e. from flank to flank), but is what is typically reported and matches the GCS reconstructions. FIDO cannot use angular widths greater than 90°. [45°]

- `CME_Ashape`: The ratio of the CME height to the CME width (a/c in Figure 1). Reasonable values would be between about 0.5 and 1.5, but there is no strict limit. [0.75]

- `CME_Bshape`: The ratio of the CME cross-sectional width to the CME width (b/c in Figure 1). This must be lower than 1. [0.35]

- `CME_vr`: The radial speed of the CME in km/s. This is equivalent to the speed of the CME nose, not the average speed over the full CME, which would vary depending on the trajectory through the CME. Caution should be applied when pulling values from observations to make sure that the appropriate value is used. [440 km/s]

- `CME_B0`: The magnitude used in the Lundquist flux rope model, in nT. The sign indicates the toroidal magnetic field direction, either parallel or antiparallel to the toroidal direction. If `Autonormalize` is selected then the magnitude is ignored but the direction still affects the results. [25 nT]

- `CME_pol`: The handedness of the flux rope with 1 indicating right-handed and -1 indicating left-handed. [1]

- `tshift`: An offset used to adjust the start time of the modeled CME. FIDO is set to automatically align the front of the modeled results with the value given in `CME_start`. This parameter shifts the modeled CME by the given number of hours. This parameter is typically not needed or used, but is still included. [0 hours]

- `Earth_lat`: The latitude of the Earth in Heliocentric coordinates. If considering a target other than a near-Earth satellite then the latitude of that satellite. [0°]

- `Earth_lon`: The longitude of the Earth (or other target) in Heliocentric coordinates. As with the CME longitude, any reference point can be used for zero longitude, the important factor is the relative difference between the two longitudes. [0°]

- `CME_start`: Day of year corresponding to the start of the in situ CME. This can be updated from the initial value, the range of the plot window will not change but the vertical line will move and the calculations will reflect the change. FIDO will not run if it is set outside the plot range. FIDO automatically sets the plot range as three hours on either side of the initial start/stop times so if these values need to change more than this the initial text file should be updated. [none]

- `CME_stop`: Day of year corresponding to the end of the in situ CME. Same behavior as `CME_start` [none]

- `Autonormalize`: Option to scale the total magnetic field strength to automatically match the observed magnetic field strength. The autonormalize value is chosen to match the average of the observed and simulated total magnetic field strength during the four hours in the center of the CME. This can be set to True or False. [False]

- `Launch_GUI`: An option not to launch the GUI and simply save the results automatically instead. This can be useful for running multiple simulations from a bash script. [True]

- `Save_Profile`: Only a text file option, there is no corresponding button in the GUI. When set to True it will output a simple text file with FIDO results. [False]

- `No_Plot:` Set to True to not plot/save a figure when not launching a GUI. This prevents unneccessary portions from running if FIDO is being used to generate an ensemble. [False]

- `Silent:` Can be used to prevent unneccesarry information to the command line. Critical errors, either from Python itself or related to input issues, will still be displayed [False]

- `Expansion_Model:` The mode of expansion, this can be set only to “Self-Similar” or “None”. FIDO defaults to none. [None]