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An IDL procedure to determine the inclination of loops in a solar image

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Abstract. The physics of solar loops is quite complex: there are several aspects, like their stability, heating and interaction, which have been deeply analyzed, but that still deserve further investigation. In this framework, the determination of loops geometric parameters in a coronal image can be very important. Therefore, in order to give a contribution to this question, we have elaborated an IDL procedure, based on a method developed by Loughhead et al. (1983), which allows us to determine in a TRACE image the loop orientation and inclination on the solar surface. The procedure is based on the following assumptions: 1) both loop footpoints can be determined; 2) the loop central axis lies in a plane; 3) the loop is symmetrical about its central axis.

Key words. Sun: loops – IDL procedure

1. Introduction

The observations of the Sun in X-ray and EUV wavelengths have shown that the solar corona is far from being uniform: it appears in fact highly structured, due to the interaction of the solar plasma with magnetic flux tubes emerging from subphotospheric layers. This interaction gives rise to the presence of magnetic structures, called loops, which can be considered the building blocks of the solar corona (Bray et al. (1991)).
In the last years, the huge amount of observational data obtained by YOHKOH, SOHO and TRACE satellites has allowed us to infer several information on the physical conditions in loops, by means of several diagnostic techniques (Aschwanden et al. (2000)).
In this respect, it is worthwhile to stress that, despite the undoubted progress in softwares devoted to the analysis of solar images, up to now these codes do not allow us to correctly determine the geometric configuration of these structures, especially as far as their inclination on the solar surface is concerned (Priest et al. (2000)).
Therefore, in order to give a contribution to this question, we have elaborated an IDL procedure, based on a method developed by Loughhead et al. (1983), which interactively allows us to select loops and to evaluate their azimuthal angle α, between the footpoints baseline and the circle of latitude, and their angle of inclination β between the loop plane and the plane vertical to the solar surface.

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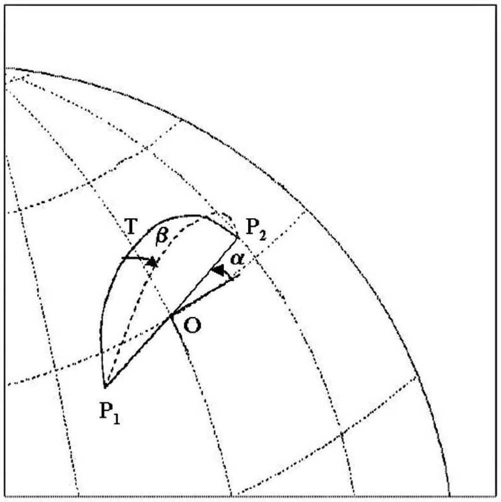

Fig. 1. Schematic drawing of a loop on the solar surface. The continuous line represents the observed loop: P_1 and P_2 are the footpoints, O is the midpoint of the line joining the footpoints and T is the top; the dotted line is an ideal vertical loop. Angle α gives the orientation of the loop about the circle of latitude; angle β gives the inclination of the plane of the observed loop about a vertical plane.

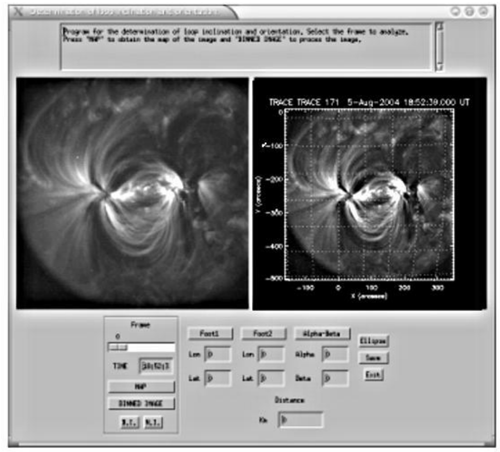

Fig. 2. Example of a pop-up window of the code. In the left box the original image is shown, while in the right box the map with the heliographic coordinates is reported. At the bottom of the pop-up window the values on angles α and β, obtained with the IDL procedure, are reported (see text).

2. Description of the methodology

In Fig. 1 a schematic drawing of a loop is reported. We indicate with P_1 and P_2 the loop footpoints, with O the midpoint of the line joining the footpoints, with T the loop top. The azimuthal angle α between the loop baseline and the circle of latitude (measured northward from the westerly direction) is called *loop orientation*, while the angle β between the plane containing the loop and a vertical plane (positive if clockwise) is called *loop inclination*.

The IDL interactive procedure Diverging_loop.pro is based on the assumptions that the loop footpoints can be determined in the image, that the loop central axis lies in a plane and that the loop is symmetrical about an axis perpendicular to its baseline (see Loughhead et al. (1983)).

Before determining the values of α and β angles, the IDL procedure processes the image and creates a two levels image (binned image), using an algorithm which evaluates two dynamic threshold values. Initially the minimum and the maximum values of the image are read and a first threshold is computed so that all data values lower than this threshold are set to zero; then, considering a box of 20×20 pixel on the lower left corner of the image, the mean M and the standard deviation sd inside the box are evaluated and a second threshold is fixed as $M + sd \times 0.5$. If the value of the outer pixel of the box is greater than this threshold, it is set to one, otherwise it is set to zero. Then the box is shifted of one pixel and the calculations are repeated.

3. Description of the IDL procedure

This IDL procedure analyzes TRACE coronal images already corrected for instrumental effects by means of standard IDL Solar SoftWare routines.
Diverging_loop.pro can be divided into the following steps:

- The file to analyze is selected by the user and a single frame from the 3D data array is chosen and shown on the left side of the pop-up window (see Fig. 2, left image);
- The button MAP is selected and the map image with the heliographic coordinates is

shown in the right side of the pop-up window (see Fig. 2);
- The button BINNED IMAGE is selected in order to process the image and evidence the loops (Fig. 3 (b)).
- Using the cursor, the footoints and a point near the apparent top of the loop are selected; the values of the angles α and β are then calculated and shown in the main window (Fig. 2, bottom)
- By selecting ELLIPSE, the ellipse which better approximates the loop is plotted (Fig. 3 (a)).
- By simply repeating steps 4-5 it is possible to determine the geometry of another loop in the same frame.

The output of the procedure are a jpeg file containing the drawn arches of ellipse and a text file containing both α and β values and the distance between the footpoints for each loop (see Table 1)

Table 1. Loop Parameters. In the first raw the number which identifies the loops in Fig. 3 (a) is reported. In the last column the footpoint distance is shown.

Loop number		α (degrees)	β (degrees)	Distance (km)
1		2.7	-34.1	90500
2		2.7	-23.0	90500
3		6.6	-27.3	78000
4		1.5	5.0	65000
5		1.5	19.6	65000
6		5.3	82.3	80800

4. Discussion and conclusions

Comparing the shape of the arches of ellipses drawn in Fig. 3 (a) with the TRACE image shown in Fig. 2, we can see that the IDL procedure is able to correctly reconstruct the observed shape of the loops in the plane of the solar image.

Moreover, the values of the azimuthal angles α reported in Table 1 result positive: this is in agreement with the loop orientation in the image (see the map in Fig. 2).

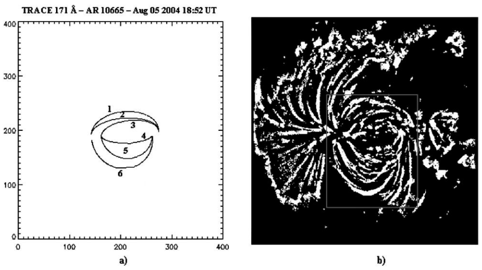

Fig. 3. (a) The curves correspond to arches of the ellipses which better approximate the loops selected by the user; the numbers on each curve allow the user to compare the shape of the arches with the values of the angles reported in Table I. (b) Binned map obtained from TRACE 171 Å image of NOAA 10655, acquired on August 05, 2005. The rectangle indicates the area analyzed by the user.

Finally, the most important result concerns the angle of inclination β: we can see in Table 1 that the loops No. 1-3 have negative β values, according to the fact that they are inclined counterclockwise with respect to the vertical plane and, more importantly, at decreasing β angles (compare Fig. 2 with Fig. 3 (a)). The same good agreement is found for loops No. 4-6, characterized by increasing positive (i.e. clockwise) angles.

In conclusion, we believe that this procedure might give an important contribution to the study of solar phenomena occurring in the upper solar atmosphere, like for instance those related to loop dynamics, flares and CME.

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