

# MODELING THE RADIAL VARIATION OF CORONAL STREAMER BELTS DURING SUNSPOT ASCENDING PHASE

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## ABSTRACT

The coronal streamer belts and their radial variation between 2.5 and 20.0 solar radii in the ascending phase of the solar cycle can be well reproduced using the horizontal current-current sheet-source surface magnetic field model with the set of model parameters determined based on MDI and LASCO Carrington maps during 1996 minimum activity phase.

## INTRODUCTION

Using SOHO/LASCO Carrington maps of the corona, SOHO/MDI synoptic charts of the photospheric magnetic field and the horizontal current-current sheet-source surface (HCCSSS) model for the coronal magnetic field (Zhao and Hoeksema, 1995) we have shown (Zhao and Hoeksema, 1999) that 1) The well-defined coronal streamer belts in 1996 become flatter as the heliocentric distance increases from 2.5 solar radii to 14 solar radii, 2) This radial variation in the shape of the coronal streamer belts may be used to determine the 3 free parameters in the HCCSSS model. The computed magnetic neutral lines match the corresponding coronal streamer belts at various heights very well.

The radial variation in the shape of the coronal streamer belt between 2.5 and 14.0  $R_{\odot}$  is associated with non-radial coronal streamers at mid-latitudes and is governed by the stronger large-scale magnetic field in polar coronal holes. Is there any radial variation in coronal streamer belts during the ascending activity phase? Can the radial variation be in this interval reproduced using the set of optimum parameter values inferred in minimum activity phase?

## COMPUTATIONS and OBSERVATIONS

The HCCSSS model contains three free parameters. “ $a$ ” parameterizes the height distribution of the horizontal current; the  $R_{cp}$  parameter denotes the heliocentric distance of the spherical surface (the cusp surface) located near the cusp point of coronal streamers where all field lines are open but not necessary radial; and the  $R_{ss}$  parameter is the heliocentric distance of the so called source surface located near Alfvén critical point where all field lines must be radial. Zhao and Hoeksema (1999) found that with a set of optimum parameter values, viz,  $a = 0.2R_{\odot}$ ,  $R_{cp} = 2.5R_{\odot}$  and  $R_{ss} = 14.0R_{\odot}$ , the coronal streamer belts observed at various heights between 2.5 and 30 solar radii by SOHO/LASCO in 1996 can be well matched by the magnetic neutral lines computed using the HCCSSS model and the photospheric magnetic field observed by SOHO/MDI. It turned out that the coronal streamer belts’ location remained unchanged beyond 14 solar radii. This implies that the Alfvén critical point is located near 14 solar radii, consistent with earlier estimates (Pizzo, 1994).

We examine the radial variation of coronal streamer belts using the LASCO Carrington maps for Carrington Rotations (CR) 1922 (April 24 – May 21, 1997), 1936 (May 11 – June 7, 1998) and 1947 (March 7 – April 3, 1999). Figure 1 displays the CR1922 LASCO Carrington maps for  $r = 2.5, 3.0, 4.5 R_{\odot}$  from the C2 coronagraph and  $r = 5.0, 10.0, 20.0 R_{\odot}$  from the C3 coronagraph (Brueckner et al., 1995). The panels

in left (right) column are constructed using East (West) limb observations. As in 1996, the topology of the streamer belts show slight variation between 2.5 and 20 solar radii, gradually flattening toward the equator. Note the wispy, arc-like features around Carrington longitude  $270^\circ$  curve away from the equator. Wang et al. (1997) found that the bright streamers seen in the coronagraph images were the result of line-of-sight viewing of a convoluted or "folded" uniform density heliospheric plasma sheet centered at the magnetic neutral line; the arc-like features represent a projection effect, whereby individual structures move to higher (lower) apparent latitudes as they rotate away from (toward) the plane of the sky. Because of the tilt of the Sun's rotation axis relative to the sky plane, the arcs exhibit a left-right asymmetry with opposing directions in the northern and southern hemisphere and in the east and west limb maps. Superposed on Figure 1 are magnetic neutral lines (solid dark lines) computed using the HCCSSS model with the set of optimum parameter values. '+' and '-' symbols show the daily IMF polarity observed near Earth.

Figures 2 and 3 show CR1936 and CR1947. The bright structures become more complicated than CR1922. Almost all arc-like features are matched by the segments of neutral lines that lie nearly parallel to solar equator, though there appears to be no single, stable current sheet being viewed alternately edge-on and then flat-on. The match suggests the existence of the neutral lines. The vertical bright structures in the maps are caused by coronal mass ejections.

Figure 4 shows the radial variation in the shape of computed neutral lines. The solid, dotted and dashed lines denote, respectively, the neutral lines at  $r = 2.5, 5.0$ , and  $14.0 R_\odot$ , showing that radial variation occurs mainly in the latitudinal direction in both minimum and ascending activity phases.

## SUMMARY

The topology of the coronal streamer belt during the ascending activity phase shows slight variations between 2.5 and 14.0 solar radii, gradually flattening toward the equator, though the bright structures are more complicated than during the minimum activity phase.

The coronal streamer belts and their radial variations during the ascending phase of the solar cycle can be well reproduced using the HCCSSS model with the set of model parameters determined using MDI and LASCO Carrington maps during the year 1996, viz,  $a = 0.2R_\odot$ ,  $R_{cp} = 2.5R_\odot$  and  $R_{ss} = 14.0R_\odot$ .

The magnetic neutral line computed at 14 solar radii (near the Alfvén critical point) should be more representative of the heliospheric current sheet if the coronal streamer belt extends radially into interplanetary space. *In situ* observations of the heliospheric magnetic field should be compared with the magnetic neutral line near the Alfvén critical point.

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## REFERENCES

- Bruuckner, G. E., R. A. Howard, M. J. Koomen, C. M. Korendyke, D. J. Michels, J. D. Moses, D. G. Socker, K. P. Dere, P. L. Lamy, A. Llebaria, M. V. Bout, R. Schwenn, G. M. Simnett, D. K. Beford, and C. J. Eyles, The large angle spectroscopic coronagraph (LASCO), *Solar Phys.*, **162**, 357-402, 1995.
- Pizzo, V. J., Global, quasi-steady dynamics of the distant solar wind. 2. Deformation of the heliospheric current sheet, *J. Geophys. Res.*, **99**, 4185, 1994.
- Wang, Y.-M., N. R. Sheeley, Jr., R. A. Howard, J. R. Kraemer, N. B. Rich, M. D. Andrews, G. E. Bruuckner, K. P. Dere, M. J. Koomen, C. M. Korendyke, D. J. Michels, J. D. Moses, S. E. Paswaters, D. G. Socker, D. Wang, P. L. Lamy, A. Llebaria, D. Vibert, R. Schwenn and G. M. Simnett, Origin and Evolution of Coronal Streamer Structure During the 1996 Minimum Activity Phase, *Astrophys. J.*, **485**, 875-889, 1997.
- Zhao, X. P. and J. T. Hoeksema, Prediction of the Interplanetary magnetic Field Strength, *J. Geophys. Res.*, **100**, 19-33, 1995.
- Zhao, X. P. and J. T. Hoeksema, Modeling Magnetic Polarity Structures of the Heliosphere, *EOS*, **80**, 46, 1999.

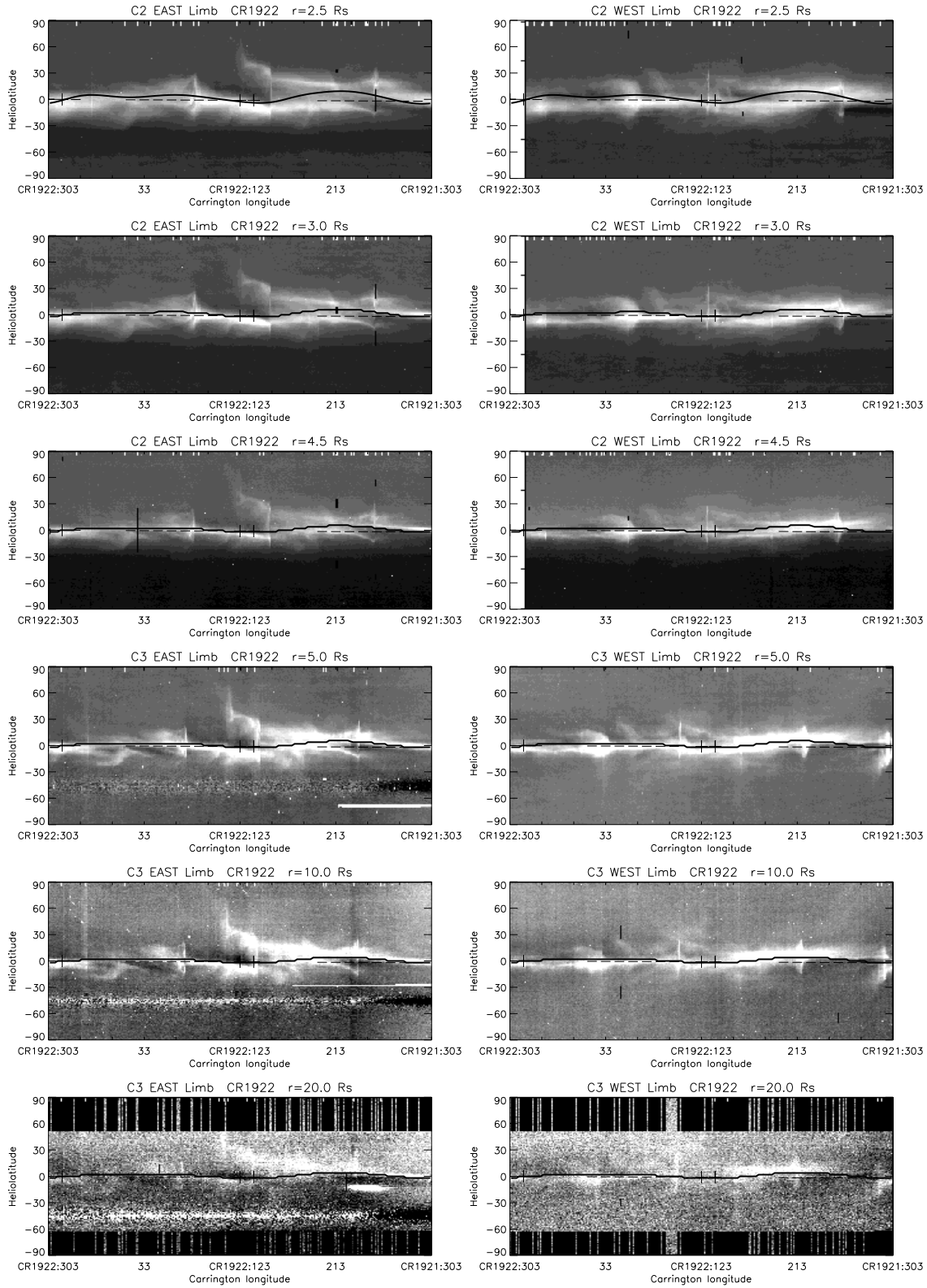


Fig. 1. The coronal streamer belts observed by LASCO and magnetic neutral lines (dark lines) computed using MDI data and HCCSSS model at various heights for Carrington Rotation 1922 in May 1997. Symbols '+' and '-' denote positive and negative daily IMF polarities observed at 1 AU.

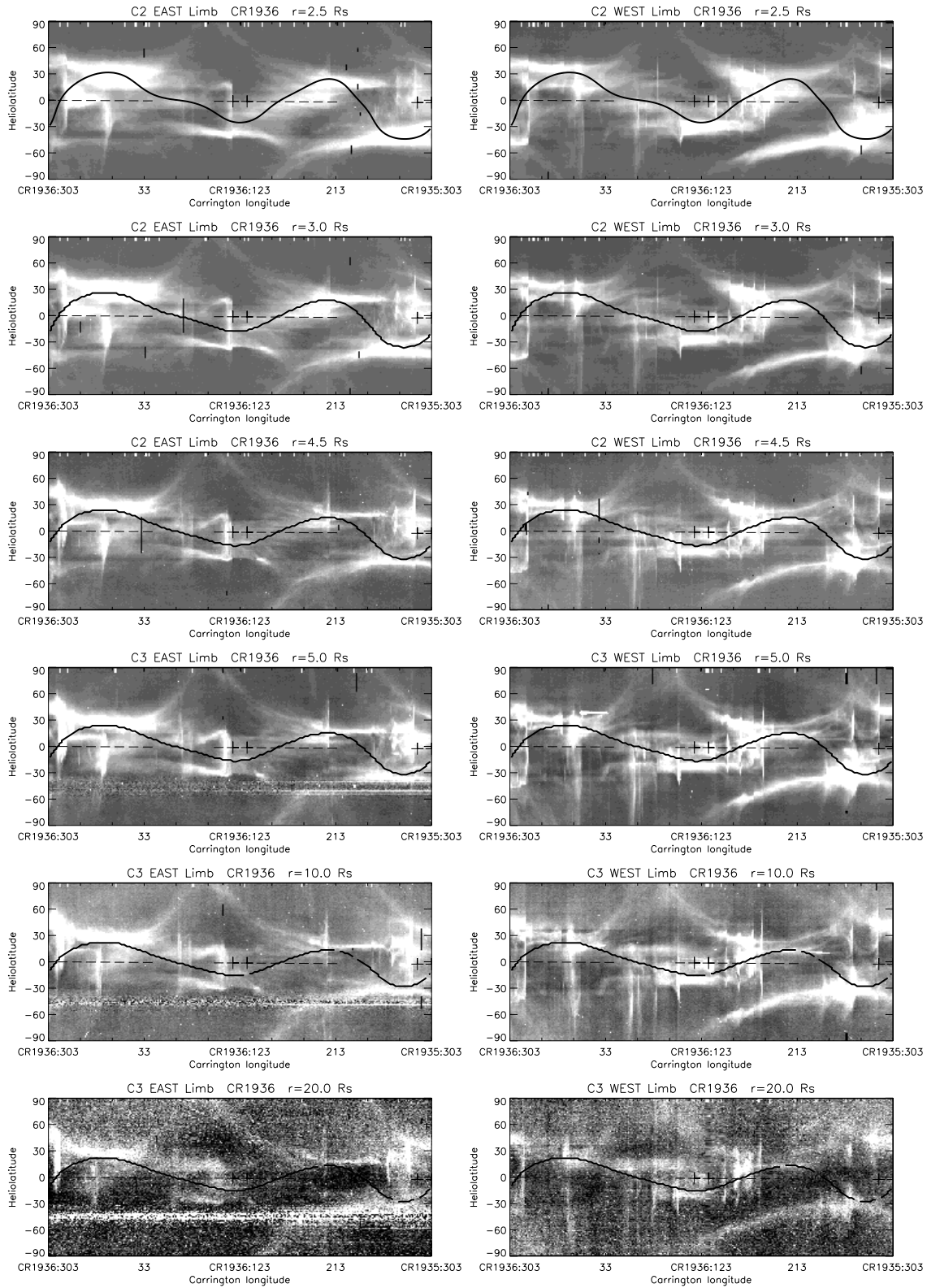


Fig. 2. The coronal streamer belts observed by LASCO and magnetic neutral lines (dark lines) computed using MDI data and HCCSSS model at various heights for Carrington Rotation 1936 in May 1998. Symbol '+' ('-') denotes positive (negative) daily IMF polarity observed at 1 AU.

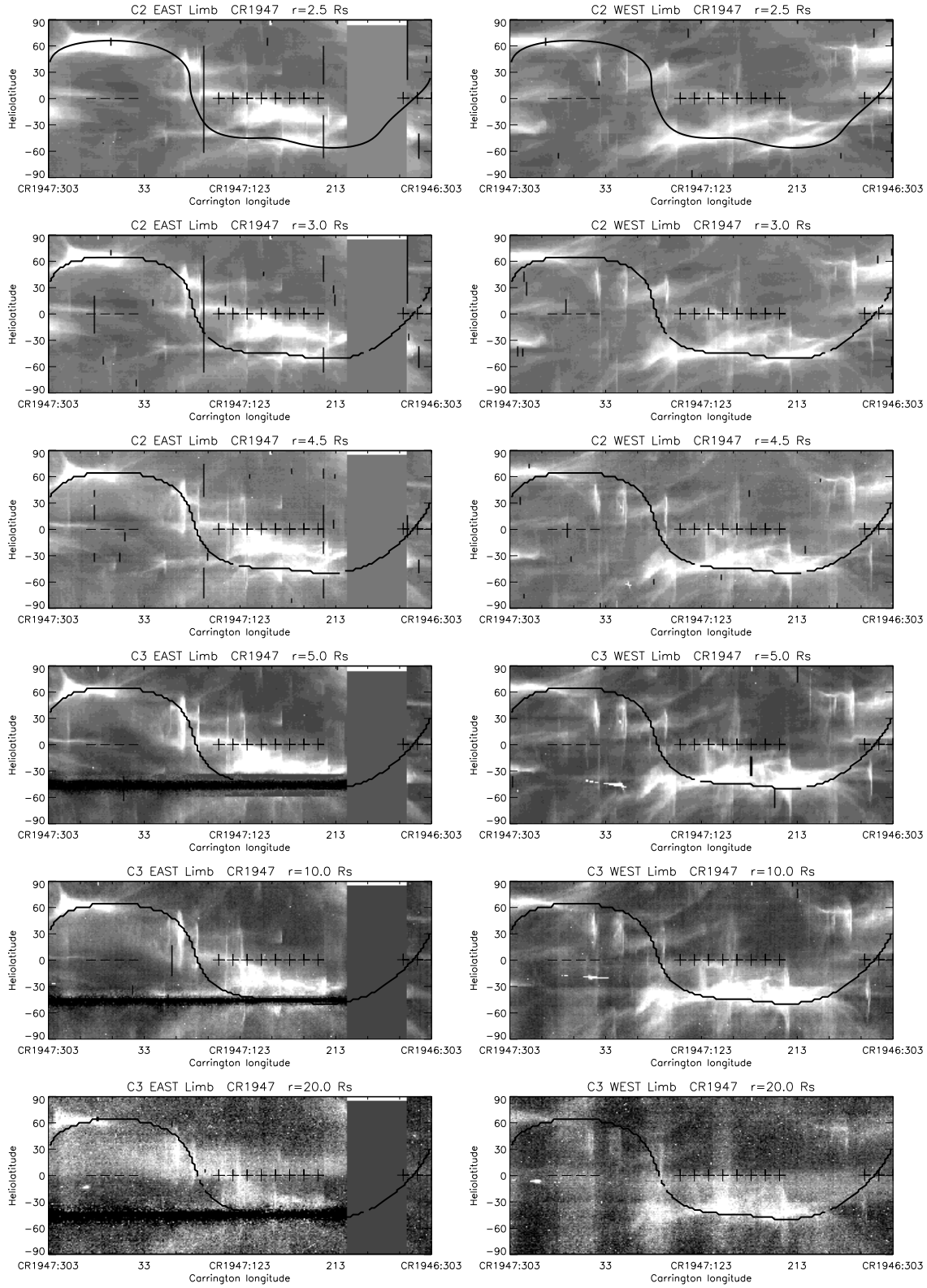


Fig. 3. The coronal streamer belts observed by LASCO and magnetic neutral lines (dark lines) computed using MDI data and HCCSSS model at various heights for Carrington Rotation 1947 in March 1999. Symbols '+' ('-') denotes positive (negative) daily IMF polarity observed at 1 AU.

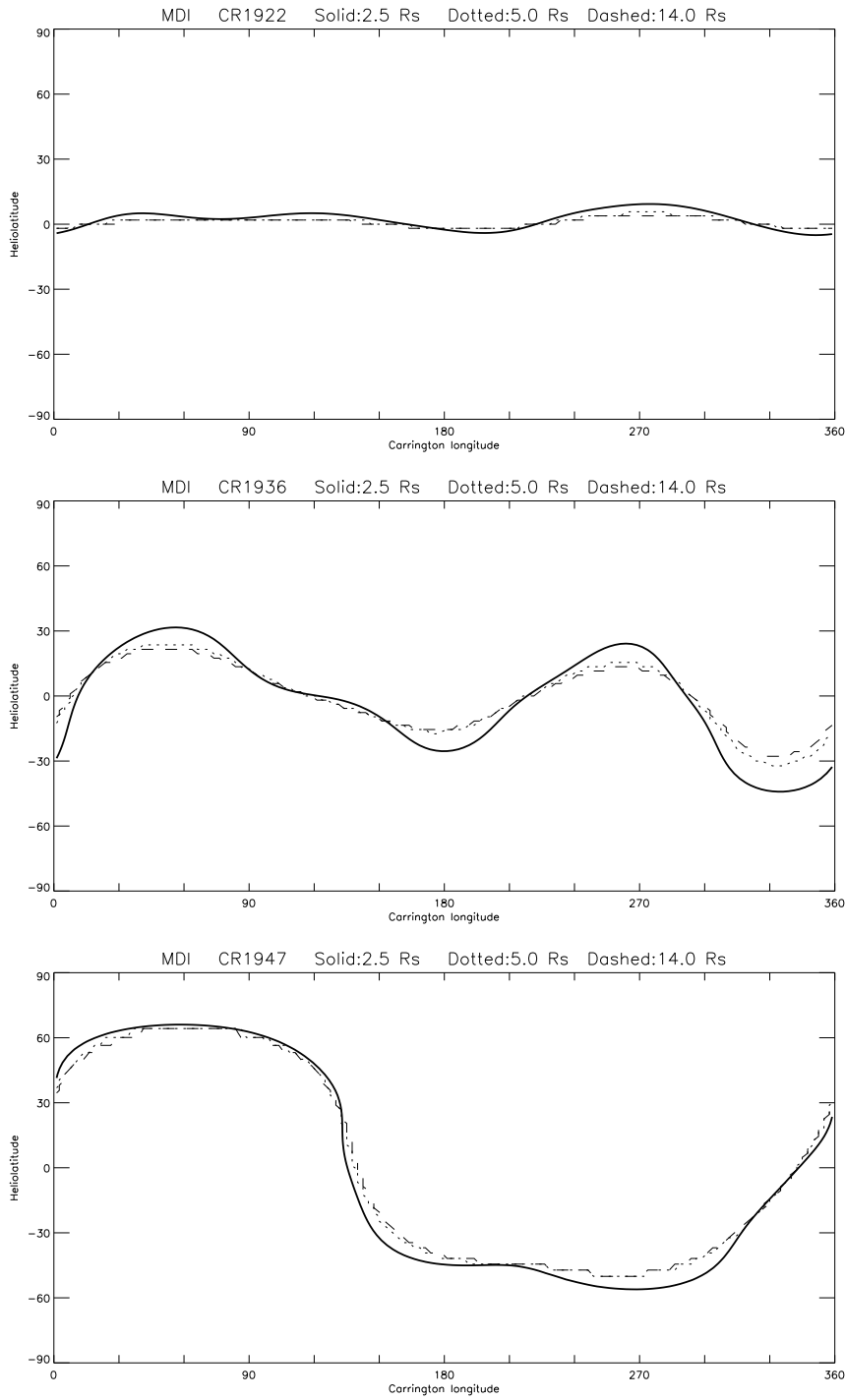


Fig. 4. The radial variation in the shape of the computed magnetic neutral lines for CR1922, CR1936 and CR1947. The solid, dotted and dashed lines denote, respectively, the neutral line at 2.5, 5.0 and 14.0 solar radii.