Source Regions of Broadside Coronal Mass Ejections Associated with Microwave Prominence Eruptions

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Abstract

The present work searches for source regions of the 134 broadside CMEs observed by LASCO/SOHO between August, 1996 and December, 2001 that are associated with microwave prominence eruptions observed by the Nobeyama Radioheliograph. We find that 47% of the 134 CMEs originated in bipolar closed field regions, 43% in unipolar closed field regions, and for 10% the origin is not clear. The mean speed of the CMEs originating in bipolar closed field regions is smaller than those in unipolar closed field regions; the mean angular width of the CMEs originating in bipolar closed field regions is greater than that in unipolar closed field regions. The differences may be understood by taking into consideration the different topology of the magnetic field between bipolar and unipolar closed field regions.

— **The SHINE 2003 Workshop, Working Group 1, July 7 – 11, 2003, Maui**

1. Introduction

Coronal mass ejections (CMEs) are large-scale dynamic phenomena believed to be driven by the magnetic free energy stored in closed field regions.

CMEs are usually associated with filament disappearances (prominence eruptions in the limbs) or/and flares. Both filament channels and active regions are located in coronal closed field regions. White-light helmet streamers observed in sunspot number minimum are sandwiched between polar coronal holes having opposite magnetic polarities. We call this kind of closed field region the bipolar closed field region due to the different magnetic polarities in adjacent open field regions. In addition to the bipolar closed field region there are closed field regions sandwiched between open field regions having like polarities. We call these the unipolar closed field regions (See Figure 1).

As sunspot number increases low-latitude coronal holes occur frequently and the occurrence of unipolar closed field regions increases. Near sunspot maximum, the area occupied by unipolar closed field regions is nearly the same as the area occupied by bipolar closed field regions (See top and middle panels of Figure 2). The bottom panel of Figure 2 displays two kinds of boundary layers on the source surface: the bipolar boundary layer lying above the bipolar closed field regions (i.e., the base of the heliospheric current sheet), and the unipolar boundary layer lying above unipolar closed field regions (i.e., the plasma sheet without current sheet.)

We have shown that most, if not all, of frontside full halo CMEs observed between 1996 and 2001 originate in bipolar closed field regions (Zhao and Webb, JGR-Space, in press, 2003). Gopalswamy et al (ApJ, 586, 562,2003) studied 134 broadside CMEs that are associated with microwave prominence eruptions observed by the Nobeyama Radioheliograph (see Table 1). The coronal mass motions involving CMEs and microwave prominence eruptions are found to be not random but organized by bundles of streamers that contain multiple plasma sheets emanating from active regions, arcades, trans-equatorial interconnecting loops, and polar crown filaments (Hori and Culhance (A&A, 382, 666, 2002).

This work searches for the source region of the 134 CMEs and their properties.

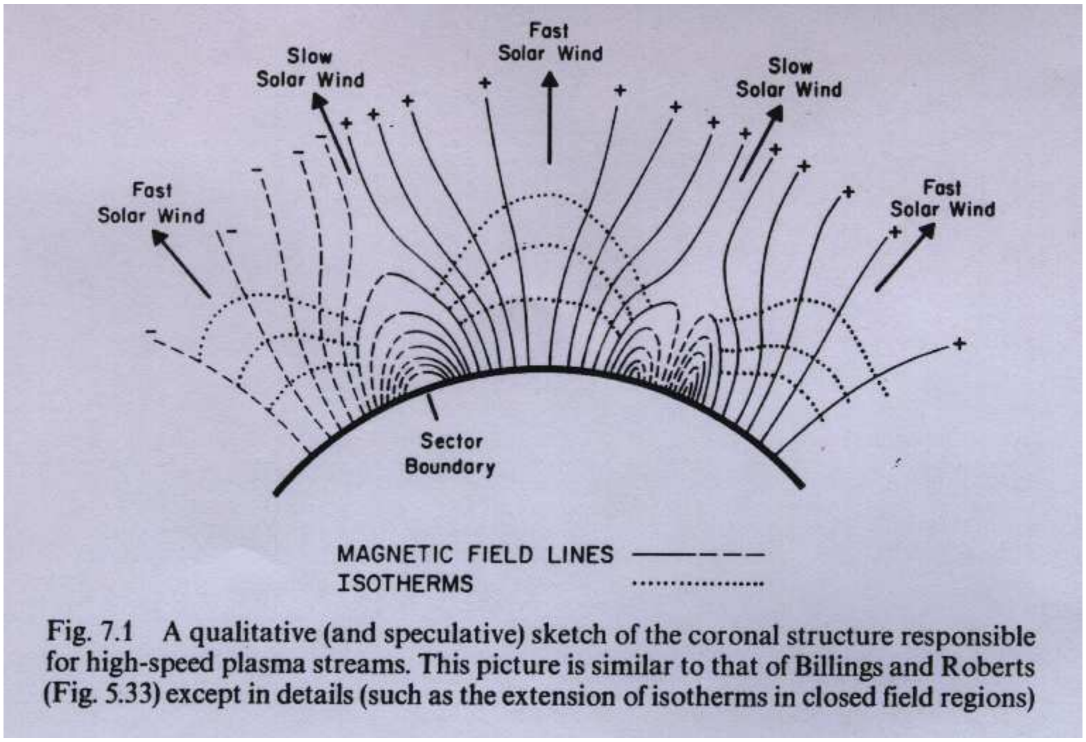

Fig. 7.1 A qualitative (and speculative) sketch of the coronal structure responsible for high-speed plasma streams. This picture is similar to that of Billings and Roberts (Fig. 5.33) except in details (such as the extension of isotherms in closed field regions)

Fig. 1.— The bipolar (left) and unipolar (right) closed field regions copied from A. J. Hundhausen's book (1972).

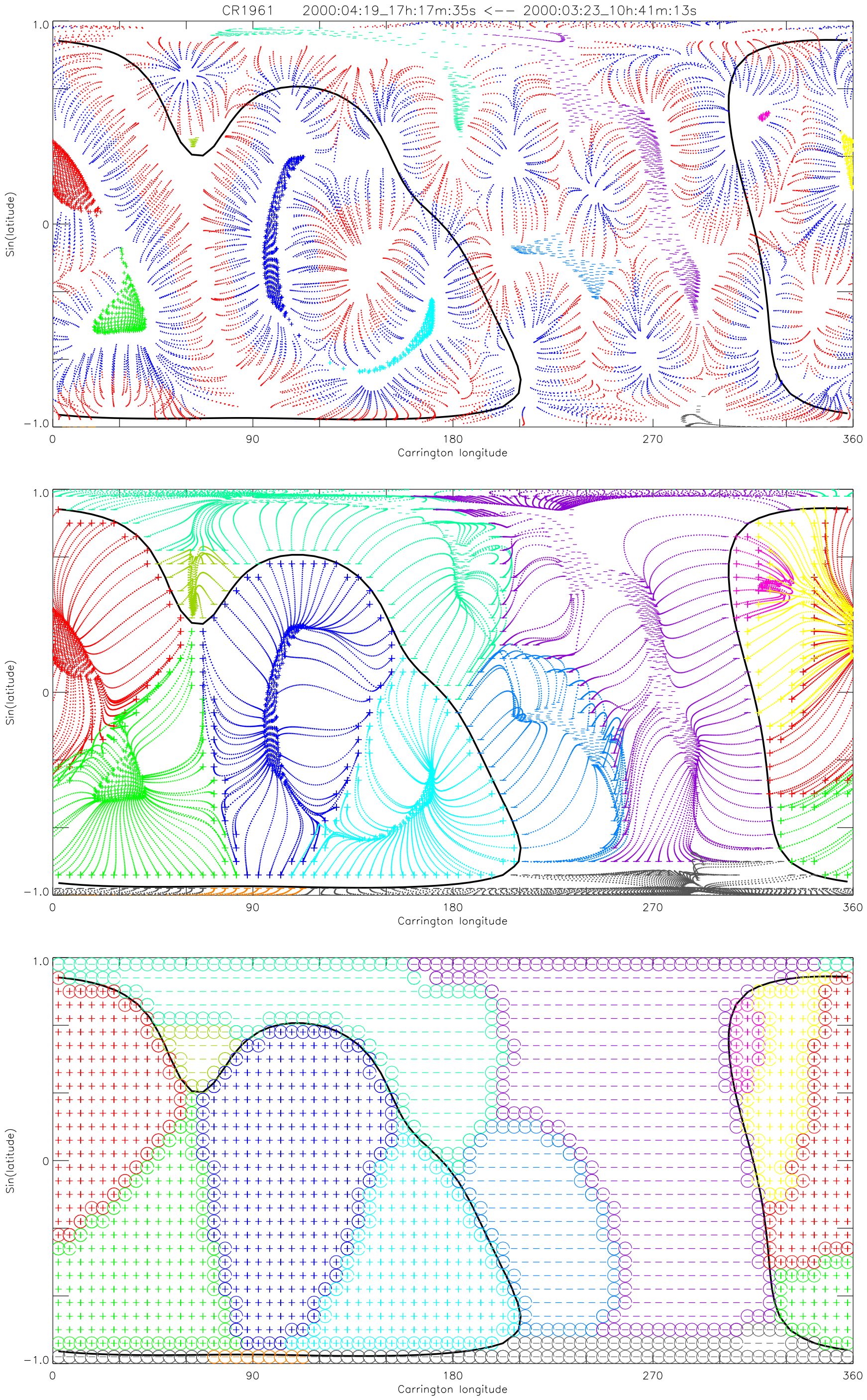

Fig. 2.— Two kinds of closed field regions and two kinds of boundary layers on the source surface. Top panel shows 11 open field regions (the areas of symbol + and − with different color) and closed field regions sandwiched between open field regions. The curves consisting of blue (upward) and red (downward) segments denote closed field lines. The dark thick curve is the neutral line on the source surface. The middle panel shows the radial variation of the boundary of open field regions. The bottom panel shows the bipolar and unipolar boundary layers on the source surface.

2. The magnetic configuration in closed field regions

The three-dimensional structure of the magnetic field in the source region of CMEs is the key to understanding how the stored magnetic energy eventually causes an eruption.

In the classical model of bipolar closed field regions or helmet streamers, (Pneumann and Kopp, 1971) there is only one bipole within the closed field regions, as shown in Figure 1. But sometimes there are three bipoles (see the top panel of Figure 2). Figure 3 shows the 26–27 Feb. 2000 CME and filament eruption observed by EIT, LASCO and SXT, and the schematic drawing of magnetic structures in the CME source region before, during, and after the eruption (Hanaoka, IAU Symposium, Vol. 203, 2001). The coronal loop structure shows that this event was an eruption of a part of a quadrupolar magnetic field structure consisting of two active regions. The event originated in a bipolar closed field region including three bipoles (see the schematic drawing). The outermost closed field lines that confine the underlying plasma were opened up during the eruption.

Contrary to this, unipolar closed field regions usually contain two bipoles, and there are no outermost field lines that confine the inner plasma which need to be opened up during the eruption. It means that if the CME source region stored the same magnetic energy between the two closed field regions, the CME originating in the unipolar closed field region may have higher speed than that in the bipolar closed field region since in the bipolar regions some magnetic energy must be consumed for opening up the outermost field lines there.

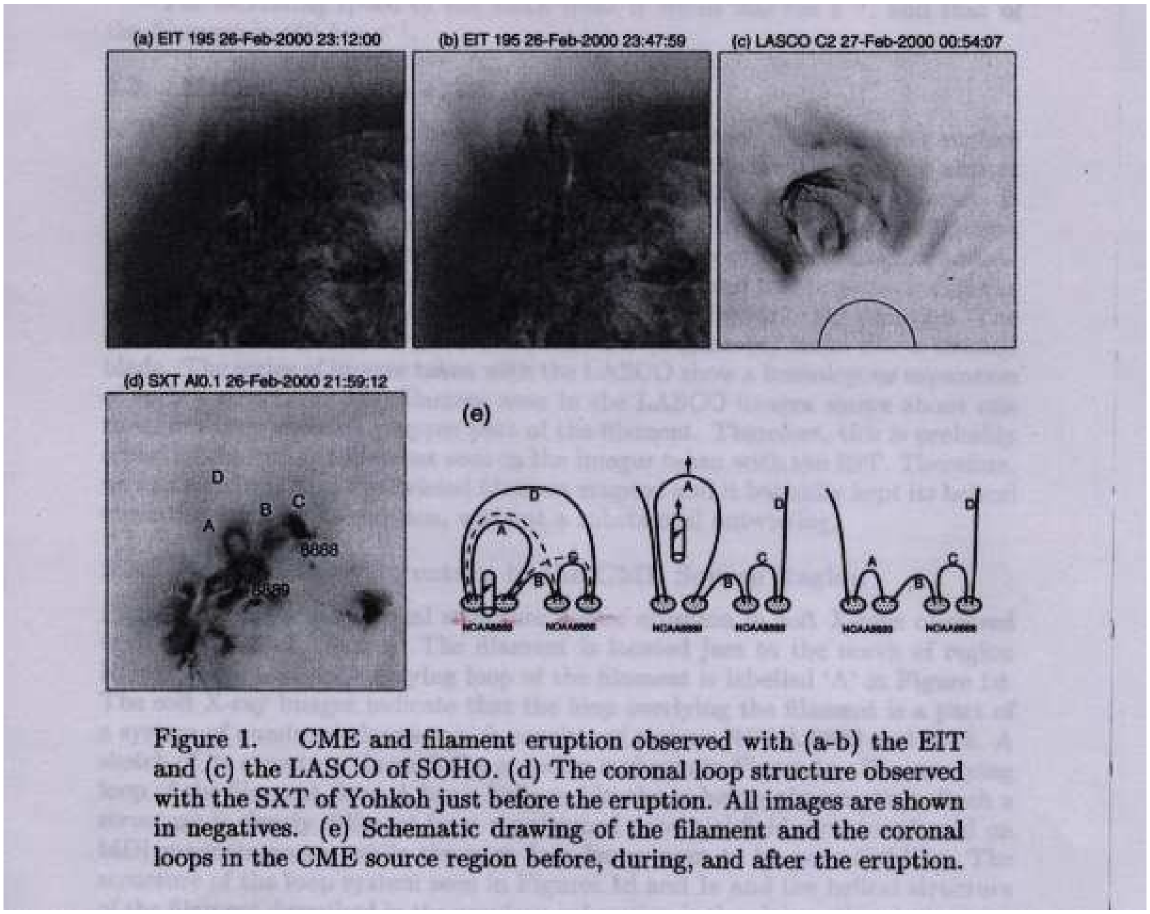

Figure 1. CME and filament eruption observed with (a-b) the EIT and (c) the LASCO of SOHO. (d) The coronal loop structure observed with the SXT of Yohkoh just before the eruption. All images are shown in negatives. (e) Schematic drawing of the filament and the coronal loops in the CME source region before, during, and after the eruption.

Fig. 3.— The three-dimensional magnetic structure of a bipolar closed field region with three bipoles. (from Hanaoka (2001)).

3. The source region of prominence-eruption-associated CMEs

Figure 4 displays the source regions of 6 prominence-eruption-associated CMEs. Dark dots in each panel denote the central position of the CMEs. The Carrington longitude of the central position, ϕ, is determined as $\phi = cmd \pm 90^\circ$ where cmd denotes the Carrington longitude corresponding to the onset time of the CMEs, and the selection of $+$ or $-$ depends on whether the broadside CMEs occurred in the right or left limb. The heliographic latitude of the central position, λ, is inferred from the measured position angle of the CMEs, P, $\lambda = 90 - P$ when $P \leq 180$ and $\lambda = P - 270$ when $P > 180$. The vertical lines centered at the dots denote the angular width of the CMEs. The number above the dots is the index number of the CMEs (see Table 1 of Gopalswamy et al. (2003)) Blue and red areas in each panel represent positive and negative open field regions computed using WSO synoptic charts of the photospheric magnetic field and the potential field source surface model. The blank areas between blue and red areas are bipolar closed field regions, and those between two red or two blue areas are unipolar closed field regions. The curves consisting of blue and red points denote the bipolar boundary layer, i.e., the magnetic neutral line or the base of the heliospheric current sheet. The curves between open field regions with identical color denote the unipolar boundary layer. Figure 4 indicates that the central positions of CMEs 18, 20 and 107 are located near the bipolar boundary layer or the HCS, originating in bipolar closed field regions, and the central positions of CMEs 102, 103 and 106 are located near unipolar boundary layer, originated in unipolar closed field regions.

Figures 5a, 5b and 5c display the source regions of the 134 CMEs associated with microwave prominence eruptions. 47% of events occurred in bipolar closed field regions, 43% in unipolar closed field regions, and for 10% the source region is not clear.

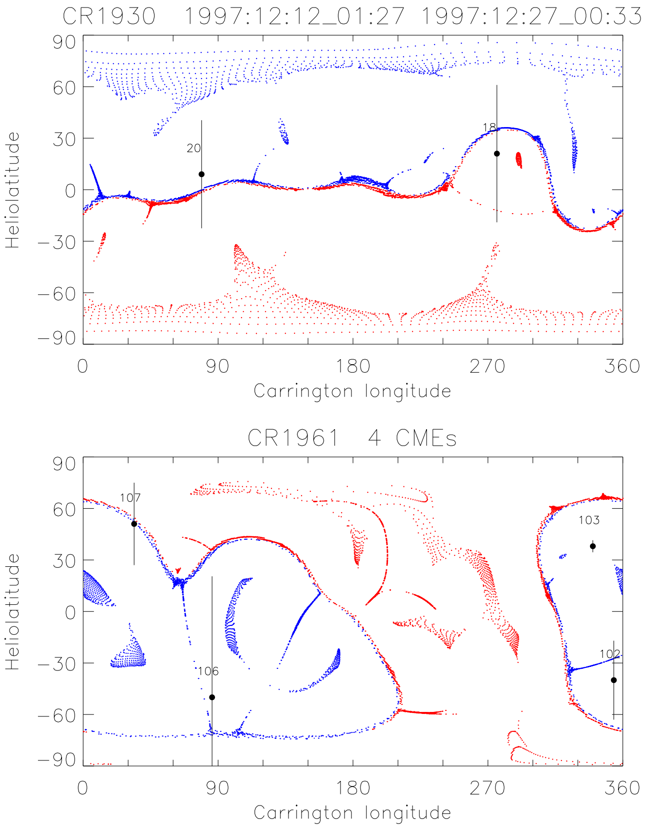

Fig. 4.— The central positions of CMEs in Carrington synoptic maps of CR1930 and CR1961. Blue and red dot areas denote positive and negative open field regions. The curves consisting of blue and red dots are the bipolar boundary layer or the neutral line on the source surface. The curves consisting of blue or red dots are the unipolar boundary layer. The dark dots denote the central position of CMEs, and the vertical line is the angular width of the CMEs. The number corresponds to the index of CMEs in Table 1 of Gopalswamy et al (2003).

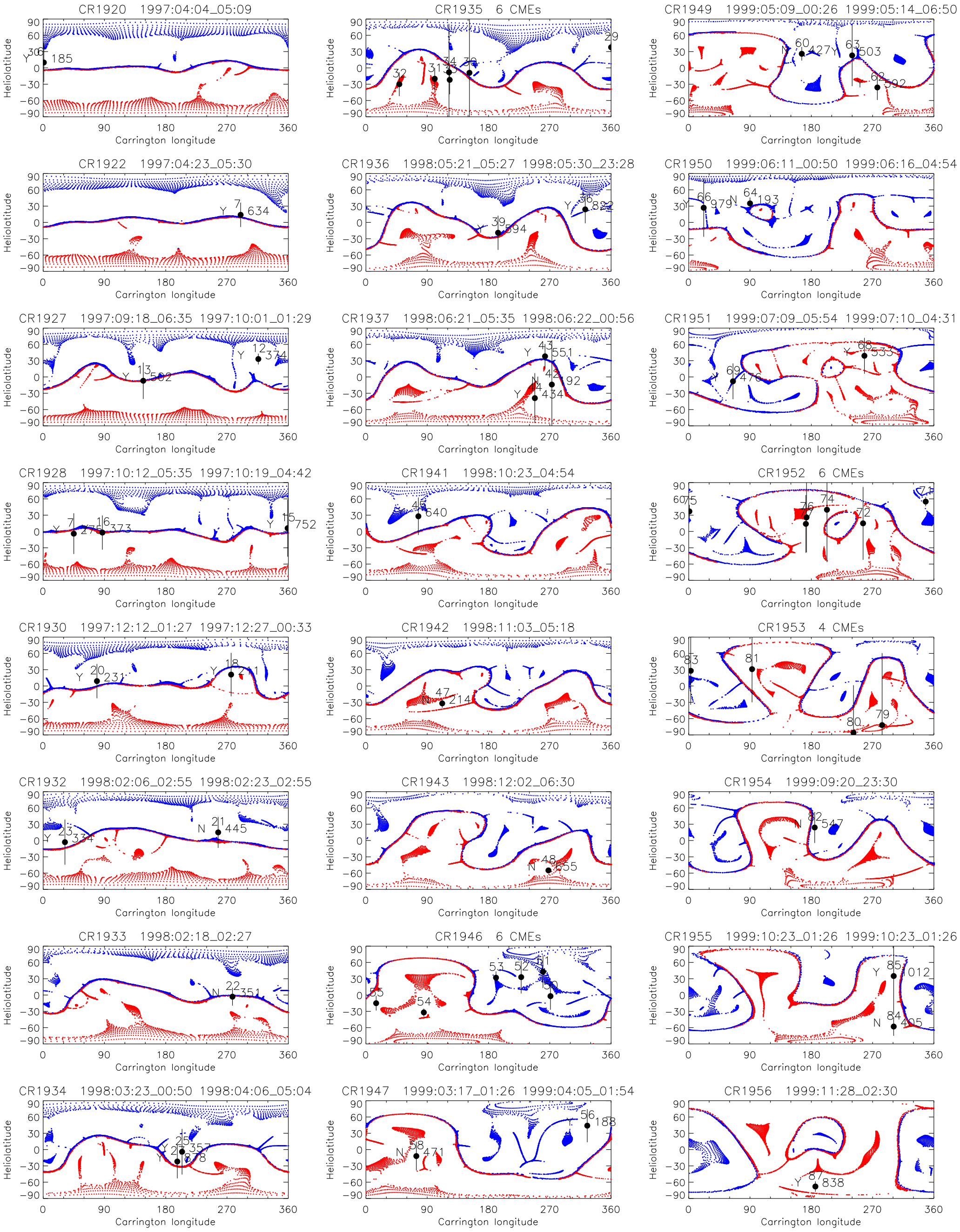

Fig. 5a.— The same as Figure 4 but for 24 solar rotations between Apr. 1997 and Nov. 1999

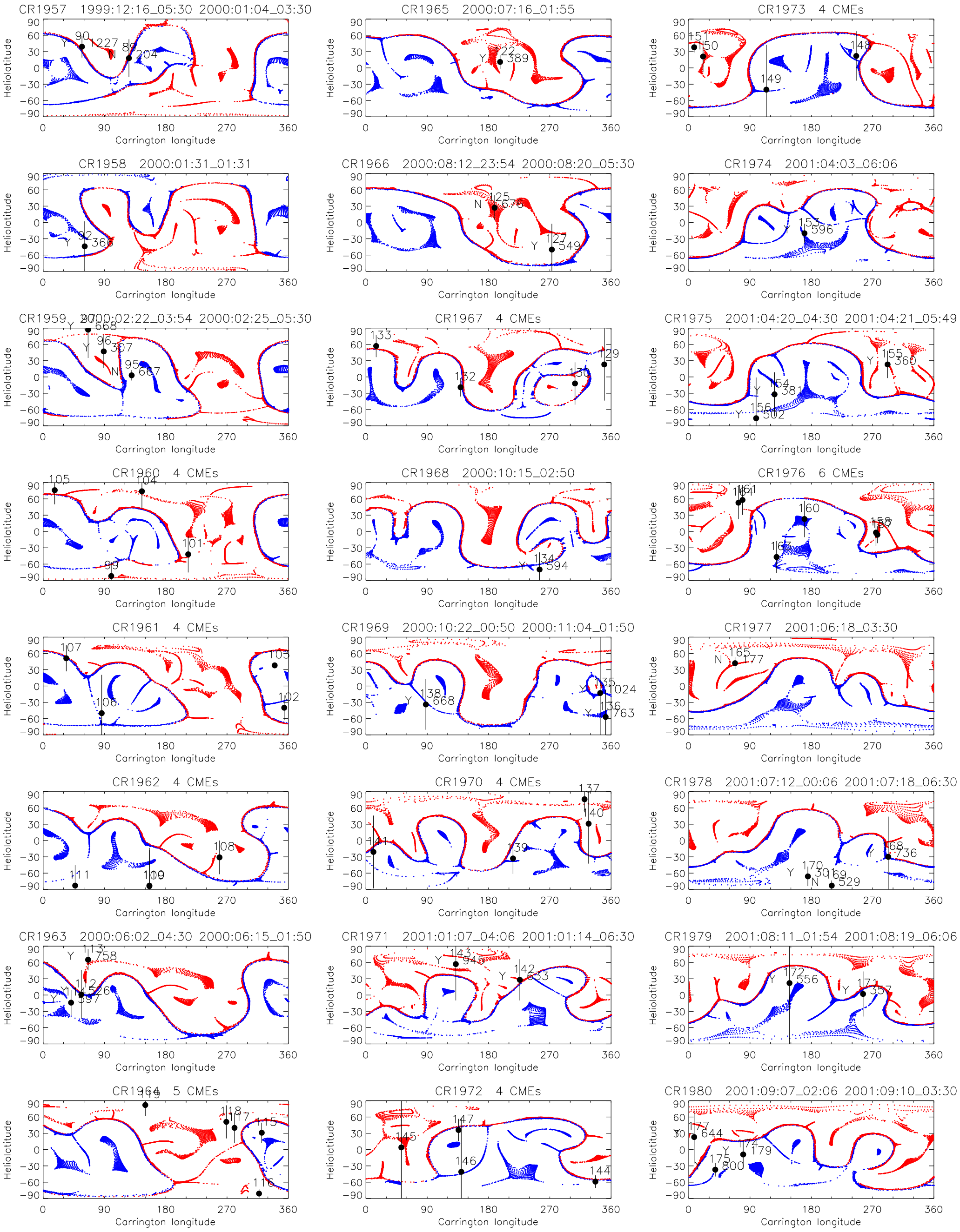

Fig. 5b.— The same as Figure 4 but for 24 solar rotations between Dec. 1999 and Sept. 2001

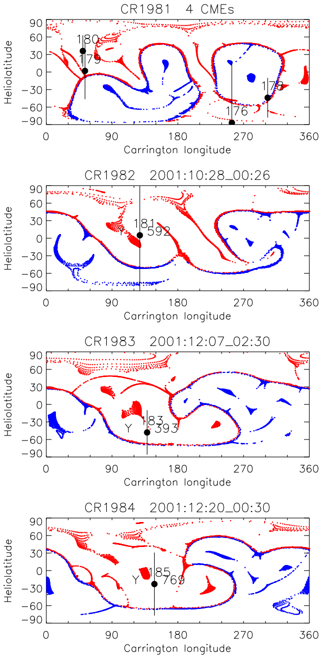

Fig. 5c.— The same as Figure 4 but for 4 solar rotations between Sept. and Dec. 2001

4. The difference between CMEs originating in different closed field regions

Figures 6a and 6b show the histograms for the CME speed, angular width and latitude for the 134 CMEs. The mean speed of CMEs originating from unipolar regions is higher than those from bipolar regions, whereas the mean angular width is lower than those from bipolar regions. In addition, the latitude distribution of central positions for the CMEs originating in unipolar closed field regions is much wider than those in bipolar closed field regions.

CMEs with angular width greater than 120° are often classified as halo CMEs. For halo CMEs it is not easy to determine whether the events occurred in the front or back. To make more conservative estimate, we exclude the events with angular width greater than 100°. Figures 7a and 7b show the results. The same inferences as from Figures 6 can be made but with a significant difference in mean speed and mean angular width between the two groups of CMEs.

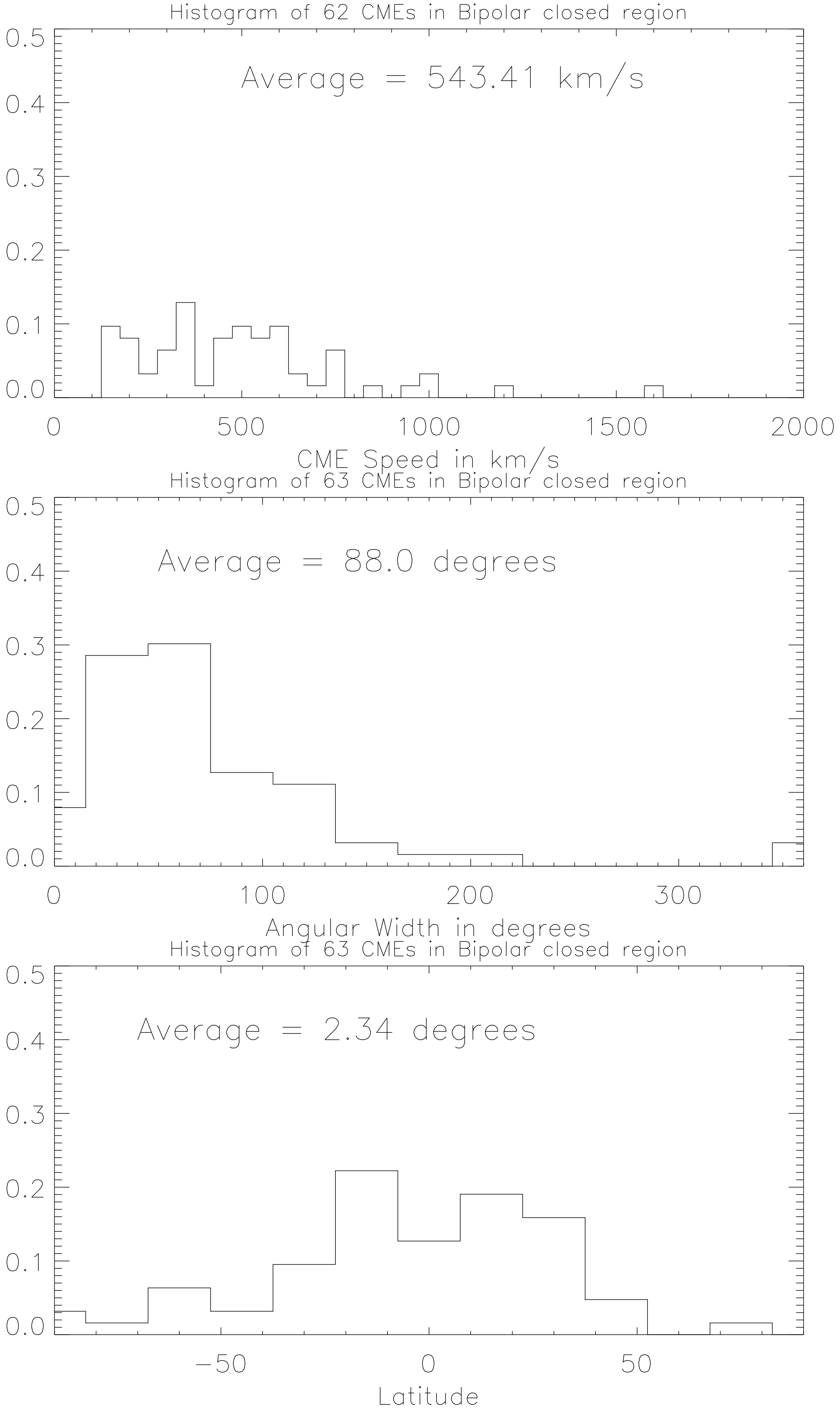

Fig. 6a.— The histogram of speed, angular width and latitude for CMEs in bipolar closed field regions.

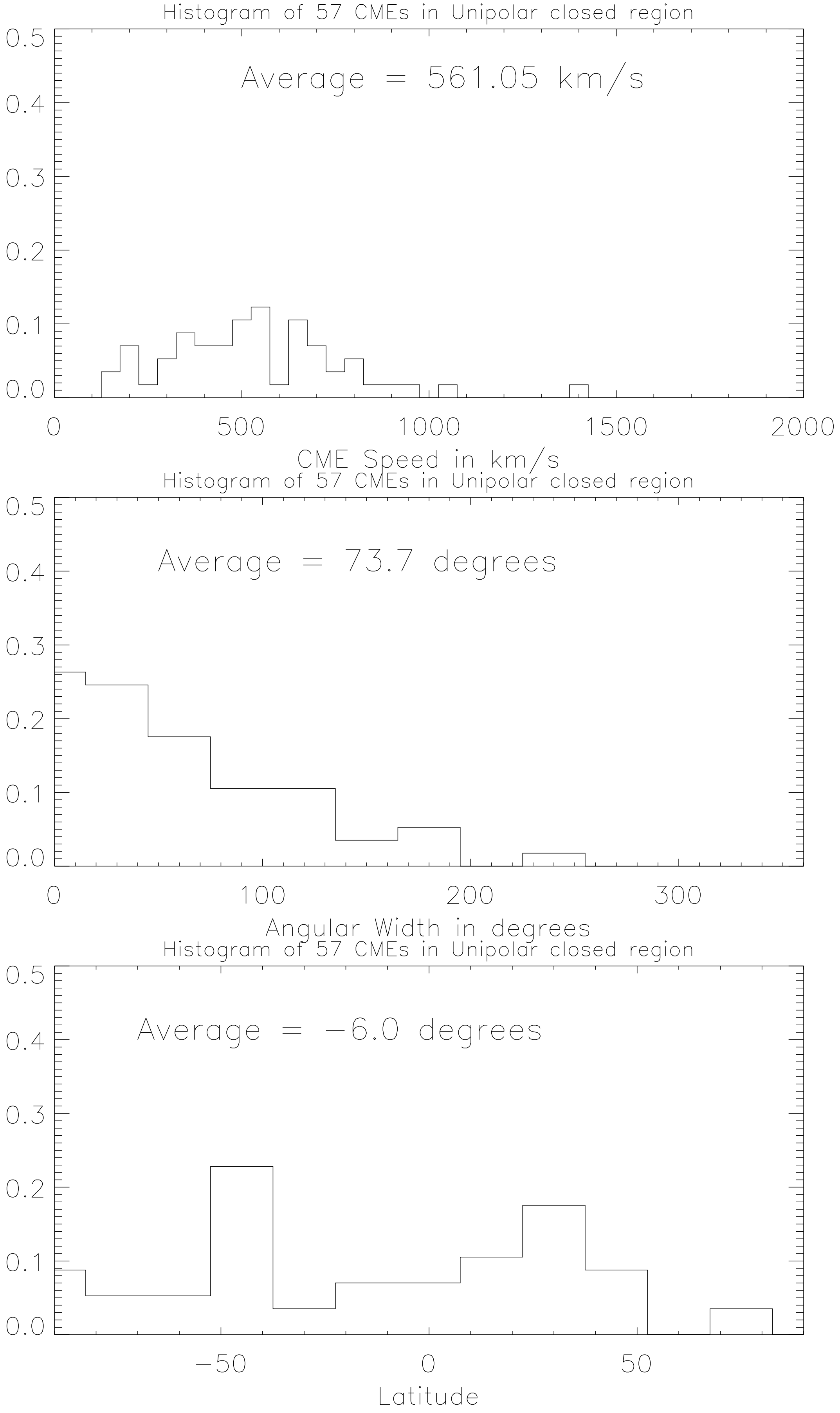

Fig. 6b.— The histogram of speed, angular width and latitude for CMEs in unipolar closed field regions.

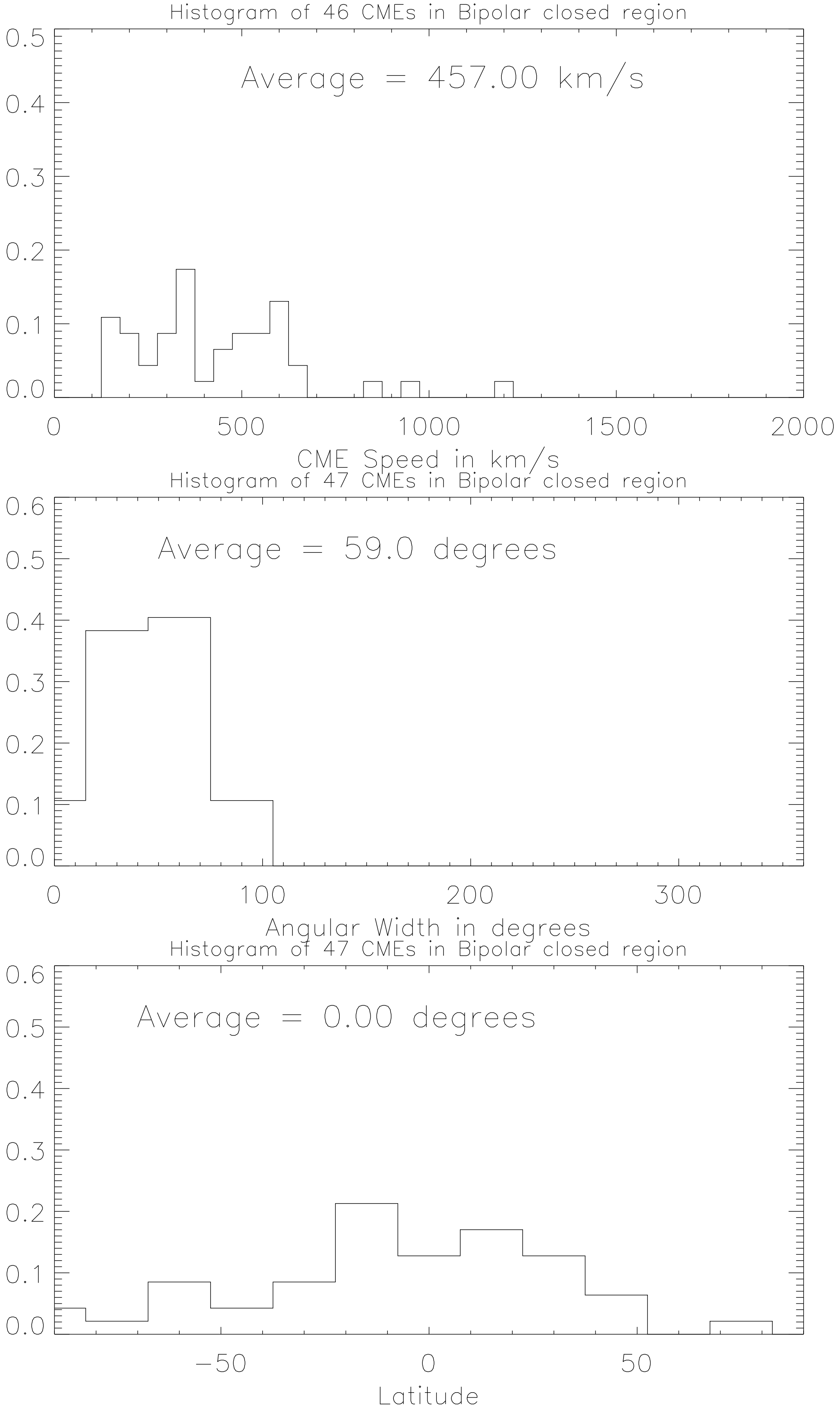

Fig. 7a.— The histogram of speed, angular width and latitude for bipolar-region CMEs with angular width less than 100 degrees

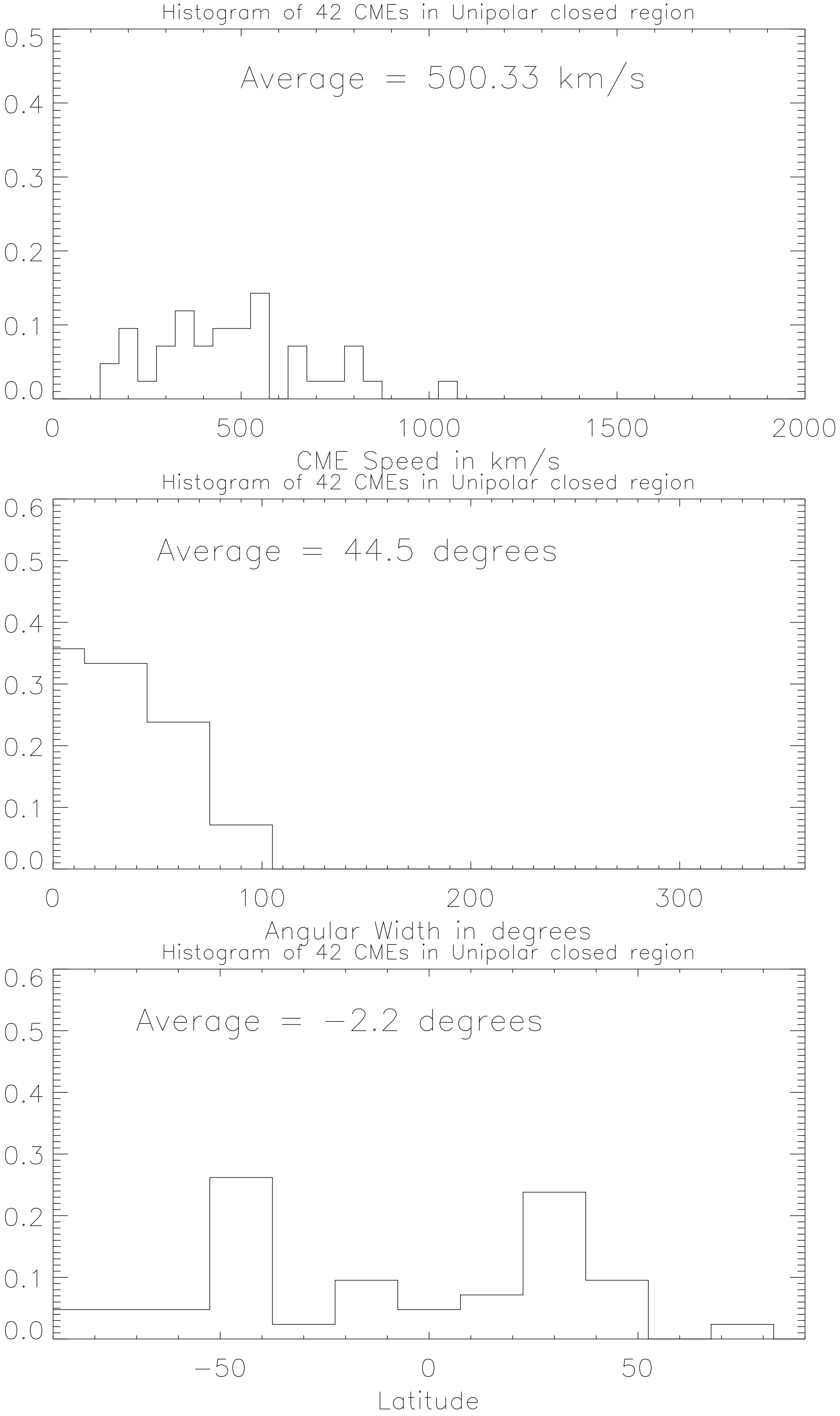

Fig. 7b.— The histogram of speed, angular width and latitude for unipolar-region CMEs with angular width less than 100 degrees

5. Summary and discussion

- Among the 134 CMEs associated with microwave prominence eruptions observed between August 1996 and December 2001 , 47% originated in bipolar closed field regions and 43% in unipolar closed field regions. For 10% the origin is not clear.

- The CMEs originating in bipolar closed field regions tend to have lower speed, greater angular width and narrower latitude distribution than those in unipolar closed field regions.

- The smaller speed for the events originating in bipolar closed field regions may be understood because the outermost closed field lines within bipolar closed field regions need to be opened up before the eruption for which part of the free magnetic energy is consumed. The fact that the angular width for bipolar region events is greater than for unipolar region events may suggest that the CMEs associated with microwave prominence eruptions mostly occurred in closed field regions with multiple bipoles. The angular width of the CMEs from bipolar regions with three bipoles may be greater than those from unipolar regions with two bipoles if the elemental bipoles are nearly of same size. The different latitude distribution of central positions for the two groups of the CMEs is associated with the different latitude distribution of the two kinds of boundary layers.