DISTORTION OF THE HELIOSPHERIC CURRENT SHEET DUE TO THE AZIMUTHAL GRADIENT OF SOLAR WIND VELOCITY ON IT – INITIAL RESULTS

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ABSTRACT

An azimuthal gradient of solar wind velocity in the range 300 to 840 km s^{-1} was inferred to be existing on the heliospheric current sheet using the interplanetary scintillation data of STELab, Nagoya, Japan. Taking this velocity gradient into account, the HCS was reconstructed at 1 AU using a simple kinematic approach. The HCS was found to be distorted considerably at 1 AU and the distortion was larger for larger gradients.

INTRODUCTION

The heliospheric current sheet (HCS) separates the heliospheric magnetic field into two opposite dominant polarities and is identified as the sector boundary (SB) crossings near the Earth's orbit where the solar wind velocity tends to be minimum. In an earlier study using the interplanetary scintillation (IPS) data of solar wind velocity (Bala and Nayar, 1993; 1995), we found an azimuthal gradient of velocity ($V_{azimuth}$) in the range 300 to 600 km s^{-1} existing on the HCS. The presence of such a large velocity gradient was found to distort the HCS at large distances from the Sun. In the present paper, a similar analysis is carried out using the data for solar cycle 23.

DATA AND RESULTS

The in situ measurement of solar wind by earth-orbiting spacecrafts are confined to the ecliptic plane but the HCS has a much larger latitudinal amplitude even during solar minimum. On the other hand, IPS can measure out-of-ecliptic solar wind velocity within a heliocentric distance of 0.1–1.0 AU and is better suited for studying the velocity distribution on the HCS. In the present work, the IPS data for 1997 obtained at the Solar-Terrestrial Environment Laboratory, Nagoya University, Japan, was used. The year 1997 is the ascending phase of the solar cycle 23 and being similar to the period in our earlier study (Bala and Nayar, 1995) was chosen for the present analysis. The synoptic maps of solar wind velocity (v-map) were constructed for individual Carrington rotations from CR1925 through CR1928 using the IPS data deconvolved using tomography. The HCS was taken as the neutral line (MNL) of the coronal magnetic field derived using the classical potential field model of Hoeksema, published in the Solar Geophysical data.

Figure 1 shows the v-map superposed with the corresponding HCS (thick solid line) and the velocity contours, at levels of 300, 350, 400 and 450 km s^{-1}. It is obvious from Figure 1 that the HCS has a much larger latitudinal extent than the slow solar wind except in CR1925 where the HCS lies within the slow solar wind most of the time. The difference is maximum near 100° in CR1926 and near 300° in CR1927, where the HCS extended beyond 30°. The spatial distribution of the slow solar wind in CR1925 is rather different from other rotations and the structure evolved slightly from one rotation to the other. Also, the overall shape and

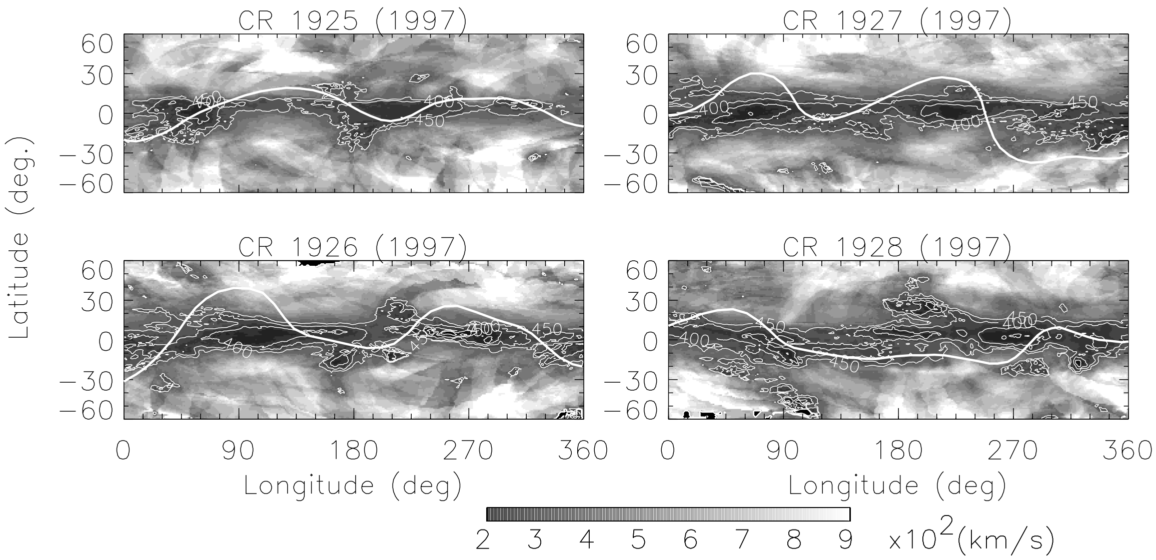

Figure 1: The v-map for CRs1925-1928 (1997). The thick solid line is the HCS for the corresponding rotation.

the latitudinal amplitude of the HCS and the size and number of sectors near the ecliptic differ from one rotation to another.

The velocity on the HCS at every one degree longitude was taken from the v-map and plotted against the Carrington longitude (Figure 2) for all the rotations CR1925-1928. In general, the velocity on the HCS varied between 300 and 840 km s^{-1} . The highest values $\sim$ 800 km s^{-1} were obtained in CR1926 and CR1927 where the HCS extended beyond 30°, but velocities as high as 700 km s^{-1} were found in the other two rotations as well. The author is of the opinion that the existence of such a large range of velocity which in turn introduces large and non-uniform azimuthal gradients (not shown here) has to be taken into account in constructing the HCS at 1 AU and predicting the SB crossings. Therefore, a simple kinematic approach described by Eq.1 was adopted which includes the $V_{azimuth}$, for constructing the HCS at 1 AU.

$$\phi = \phi_{ss} - \omega R_{\odot}/V_{azimuth} \tag{1}$$

where, $R_{\odot}$ is the heliocentric distance at which the HCS position is calculated, ω, the angular rotation of the Sun, 2.5 μrad/s, ϕ_{ss} and ϕ, the longitudes on the source surface and at a distance $R_{\odot}$ from the Sun, respectively and $V_{azimuth}$ is the velocity on the HCS obtined in Figure 2. The solid line in Figure 3 depicts the HCS at 1 AU constructed with $V_{azimuth}$ (HCS-1) and the dashed line with a constant speed of 400 km s^{-1} (HCS- 2). The solid lines parallel to the X-axis at $\pm 10°$ serves as a reference for the ecliptic.

DISCUSSION AND CONCLUDING REMARKS

A remarkable feature of Figure 3 is the multiple warps in HCS- 1 in all the rotations except CR1925, in addition to those present in HCS- 2. Note that the additional warps were introduced near longitudes with $V_{azimuth}$ larger than 500 km s^{-1} where the velocity gradient is larger. On the other hand, HCS- 2 retains its simple sinusoidal structure. The two HCS are different from each other in many respects and the SB crossings near the ecliptic will not be

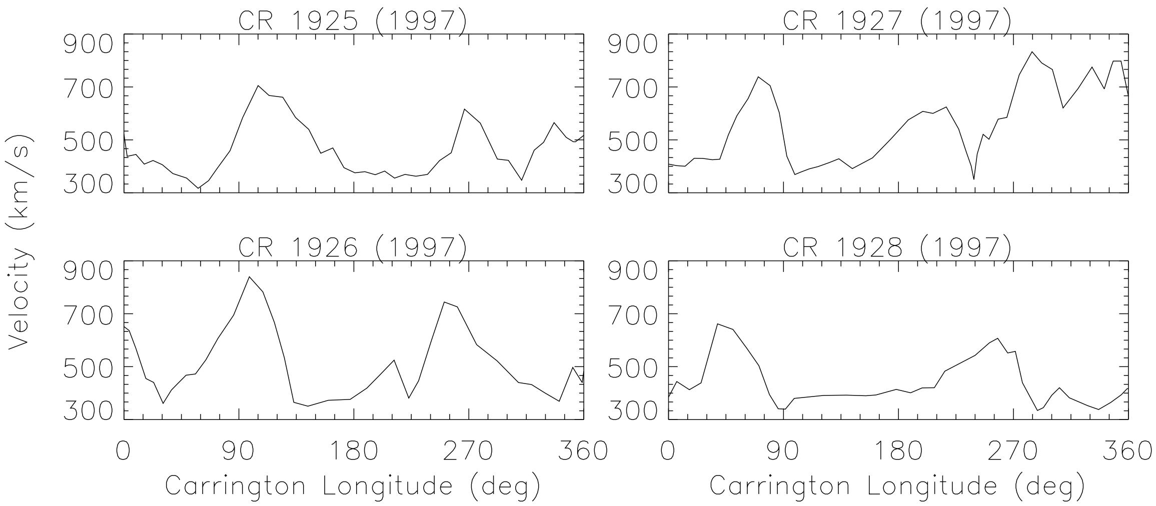

Figure 2: The solar wind velocity distribution on the HCS at source surface for the rotations 1925-1928 (1997) deduced using Fig.1

the same at all. A few of the additional warps in HCS- 1 appear near the ecliptic which introduces additional sectors in the heliospheric magnetic field. Note that the HCS- 1 in CR1925 is not so distorted as in the other three rotations. Referring to the v-map in Figure 1 one can immediatly find the reason for this as the better agreement between the HCS and the slow solar wind and hence a slightly smaller velocity gradient. In other words, the magnitude of distortion depends on the magnitude of the velocity gradient; the larger the gradient the larger the distortion.

The HCS corresponds to closed magnetic field regions of the corona where the slow solar wind emanate from. Therefore, the HCS is expected to be embedded in the slow solar wind (similar to CR1925 in Figure 1). However, the HCS deviates from the slow solar wind very often as seen in CRs1926-1928, which has been pointed out in earlier works also (Kojima and Kakinuma, 1990; Crooker *et al.,* 1998). This deviation is the main cause of the existence of $V_{azimuth}$ on the HCS, though the fast solar wind crossing the solar equator can also be the cause (Bala and Nayar, 1995). Erdös and Balogh (1998) have pointed out that two of the SB crossings predicted by the classical potential field model of the corona were not detected by Ulysses and two of the Ulysses crossings were not predicted by the model. The results of the present analysis suggest how the prediction of the SB crossings at 1 AU can be altered by $V_{azimuth}$. The sector boundary crossings at 1 AU predicted by HCS- 1 and HCS- 2 in the present model is to be compared with the in situ data of solar wind to test the model. And such a study is currently underway. Moreover, the latitudinal amplitude of the MNL of the classical potential field model (PFM) appears larger than the actual HCS can have and therefore, an analysis using the MNL using a PFM with a radial boundary condition is planned. Recently, mapping the very-low-speed solar windback to the Sun, Kojima *et al.,* (1998) have shown that they emanate from outside one of the foot-points of the active regions. This observation suggests an origin of the slow solar wind different from the helmet streamers, contrary to the general belief questioning the relation between the HCS and the slow solar wind. A more detailed analysis of the slow solar wind as well as $V_{azimuth}$ is planned for the future.

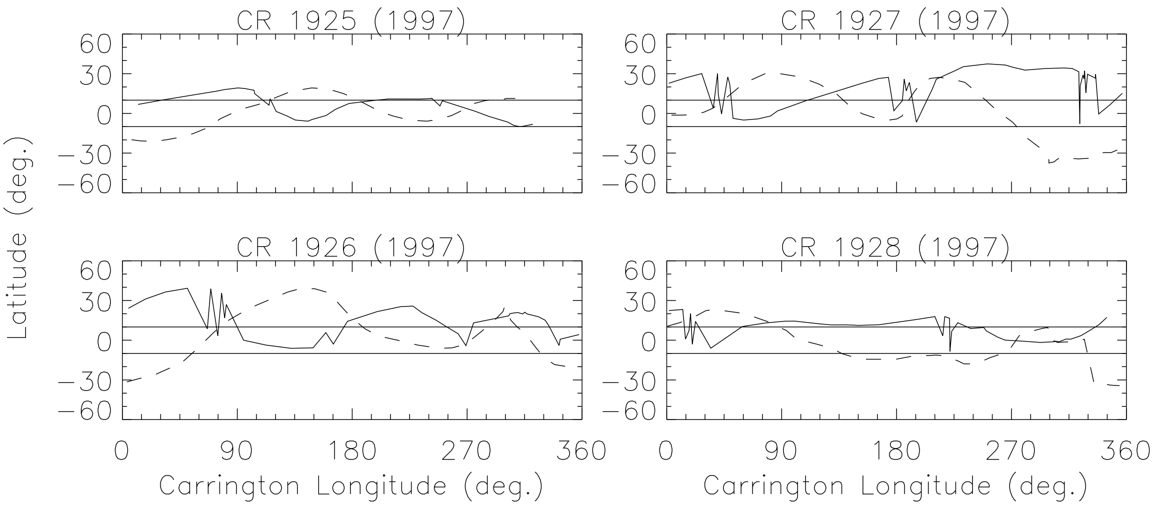

Figure 3: The HCS at 1 AU constructed using $V_{azimuth}$ shown in Fig.2 (solid line) and a constant velocity of 400 km s^{-1} (dashed line)

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