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Organization of Solar Wind Plasma Properties in a Tilted, Heliomagnetic Coordinate System

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We have used a superposed epoch analysis to examine the variation in solar wind properties observed in 1974 in a 'heliomagnetic' coordinate system tilted with respect to the solar equator. A tilt of 30° ± 10° was found to produce the best 'organization' of these properties in such a coordinate system. The solar wind speed increased with heliomagnetic latitude, while the proton density and the proton flux density decreased. These variations are qualitatively consistent with those inferred from coronal hole and other interplanetary observations.

1. INTRODUCTION

The three-dimensional structure of interplanetary space has been a topic of interest since *Cortie* [1912] suggested a strong latitude dependence in solar particle emission as the explanation for semiannual variations in geomagnetic activity. Searches for such a dependence in the solar wind speed have been carried out using in situ observations [*Hundhausen et al.,* 1971; *Bame et al.,* 1977], radio scintillations [*Dennison and Hewish,* 1967; *Hewish and Symonds,* 1969; *Sime,* 1976], and comet observations [*Bertaux et al.,* 1973; *Brandt et al.,* 1975]. The limited nature of these observations and inconsistencies among the findings of these studies have left some doubt as to the existence of such an effect.

Recent studies of the role of coronal holes—vast regions of low density associated with rapidly diverging, open magnetic field lines—have also stimulated interest in the global structure of the solar corona and solar wind. Coronal holes have been identified as the sources of high-speed streams of solar wind and related to the interplanetary magnetic polarity (or sector) structure by numerous authors (see the references in the works by *Zirker* [1977] and *Hundhausen* [1979]). If coronal holes represent most of the magnetically open portion of the corona, their global pattern should be directly related to the spatial structure of both the interplanetary magnetic field and the flow of solar wind. At times when the observed global pattern of coronal holes is simple, a magnetic structure can be inferred [e.g., *Hundhausen,* 1979] that is closely related to a structure proposed earlier on largely hypothetical grounds [*Schultz,* 1973; *Svalgaard and Wilcox,* 1978] in which two hemispheres of nearly uniform magnetic polarity are separated by a neutral or current sheet. The distortions and warpings of this sheet, here referred to as the heliomagnetic equator, rotate with the sun to produce the changes in dominant magnetic polarity observed as 'sector boundaries' in near-equatorial interplanetary space. It has been further suggested that the speed of the solar wind increases with angular displacement from this heliomagnetic equator.

If such a heliomagnetic coordinate system dominates the spatial structure of interplanetary space, the detection of spatial variations in such parameters as the solar wind speed through the observation of a variation with heliographic latitudes becomes a difficult task. It is easily shown [*Hundhausen,* 1978] that very large spatial variations in a solar wind parameter can lead to small variations in average values of that parameter with heliographic latitude (near the heliographic equator) if the existing spatial structure is organized in a coordinate frame tilted with respect to heliographic coordinates. This effect, along with the influence of temporal variations, offers an explanation of the inconsistencies among different searches for heliographic latitude variations in the solar wind speed.

Our purpose here is to explore in detail the resolution of one particular example of this effect. In 1974 both the corona and the solar wind displayed extremely simple structure that evolved very slowly with time. The corona was dominated by two prominent polar holes; a single large equatorward extension of each polar hole existed, spaced by 180° in solar longitude. *Hundhausen* [1978] has suggested that this coronal structure was associated with a heliomagnetic equator tilted at 30° to the solar equator, with the rotation of this magnetic structure and the related fast flows from the two equatorward extensions producing the two–magnetic sector, two–high-speed stream solar wind pattern observed throughout most of 1974. It is our goal here to examine more carefully the organization of the solar wind flow in such a tilted coordinate system and compare any 'heliomagnetic coordinate' system that can be thus inferred from interplanetary observations with that suggested on the basis of coronal observations.

2. DESCRIPTION OF THE PRESENT WORK

We will use in this study solar wind properties from the tabulation of *King* [1977]; daily values have been read off of the graphs of solar wind speed, proton temperature, and proton density versus time. The top frame of Figure 1 shows the solar wind speed and magnetic polarity observed near the earth during Bartels solar rotation 1921 (January 14–February 10) in 1974. The daily values of the speed (derived from *King*'s [1977] data) and daily inferences of the polarity [*Svalgaard,* 1976; *King,* 1977] are plotted with time running backwards, or equivalently, as a function of longitude in a coordinate system rotating with a 27-day period. The two-stream, two-sector pattern prevalent through most of 1974 is evident in this display. During this 27-day interval the earth moved from heliographic latitude −3.2° to −5.6°; thus the solar wind observations are made at the heliographic coordinates (latitude and 'Bartels longitude') along the path shown in the center frame of Figure 1. During an entire year the earth (in the ecliptic plane) moves between ±7.3° in heliographic latitude. The limited extent of

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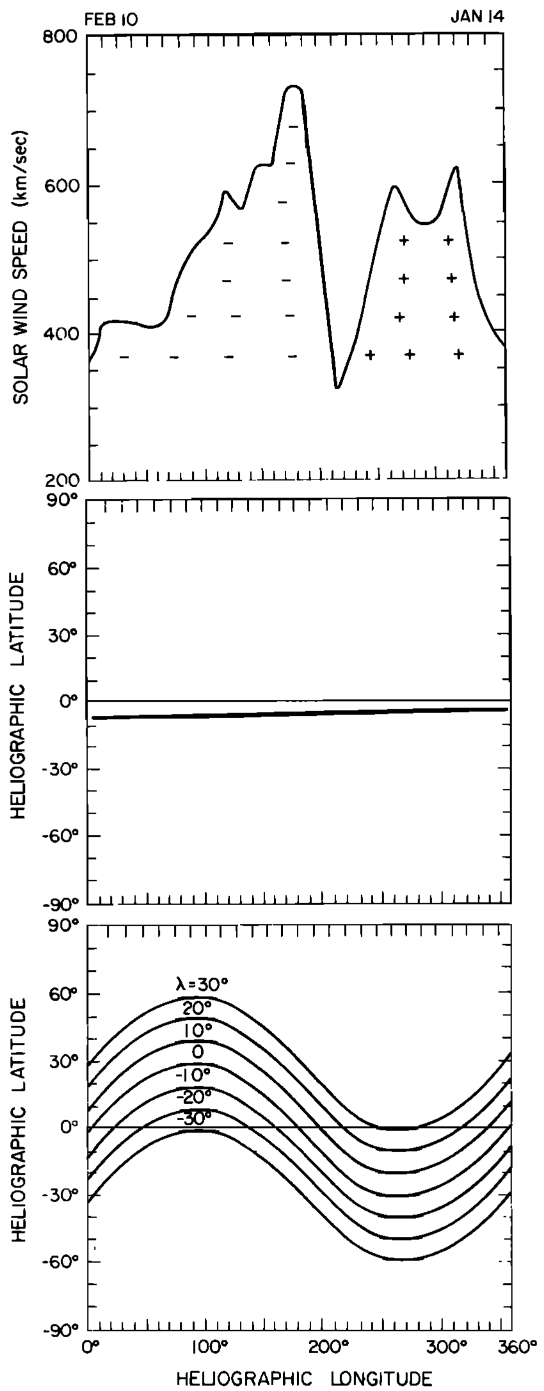

Fig. 1. Solar wind properties observed during Bartels rotation 1921. (Top) Daily values of the speed and daily inferences of the polarity versus time running backward, or 'Bartels longitude.' (Center) The heliographic position of the observations. (Bottom) The lines of constant heliomagnetic latitude λ for a 30° tilt angle.

this excursion is one of the major difficulties encountered in attempting to infer the global structure of the solar wind from ecliptic or terrestrial observations.

a. Display of Ecliptic Observations in a Tilted, Heliomagnetic Coordinate System

Let us now attempt to find a coordinate system that rotates with the Bartels period and in which the solar wind speed is, in some sense, simply organized. Following the suggestion based on coronal observations that the heliomagnetic equator is tilted at 30° to the solar equator during 1974, we will consider coordinate systems tilted at an angle α with respect to the rotation axis of the sun (the basis of the heliographic system) and identify the equator of the tilted system with the heliomagnetic equator. The 'organization' of observed solar wind properties will be judged on the basis of two criteria.

1. The intersections of the tilted heliomagnetic equator with the path of near-earth observations should match the observed sector boundaries. The simple tilt of the heliomagnetic coordinate system to be considered here will always yield the two-sector pattern observed in 1974. This criterion will thus serve to select the location of the two intersections of the heliomagnetic and heliographic equators, or the 'phase' (in longitude) of the two coordinate systems.

2. Following the suggestion that solar wind speed should increase with displacement from the heliomagnetic equator, we will hope to find a coordinate system in which the observed solar wind speed is a function of the latitude λ in the heliomagnetic system. The crux of our study will lie in the degree to which this criterion determines the tilt angle α of our proposed heliomagnetic coordinate system.

For example, the bottom frame of Figure 1 shows lines of constant heliomagnetic latitudes for a tilted coordinate system with (1) the intersections with the ecliptic chosen to reasonably match the observed sector boundaries and (2) the tilt angle arbitrarily chosen to be 30°.

In the new heliomagnetic coordinates the ecliptic observations span the latitude range from $\lambda = -35°$ to $\lambda = 25°$. Specifically, the heliomagnetic or tilted coordinate system latitude λ of an observation made at heliographic latitude θ, longitude ϕ, is given by

$$\sin \lambda = -\cos \theta[\sin \alpha \sin (\phi - \phi_0) - \cos \alpha \tan \theta]$$

where ϕ_0 is the longitude of intersection of the heliomagnetic and heliographic equators. For the case of Figure 1, $\phi_0 = 368.5°$ with respect to the longitude of intersection of the sector boundary with the 'path of observations' on January 14, and the variation of λ with longitude is shown in Figure 2. This transformation permits conversion of the speed versus longitude observations displayed in Figure 1 to the speed versus heliomagnetic latitude variation shown in Figure 3. The expected trend toward higher solar wind speed at larger heliomagnetic latitude is revealed in the top frame of Figure 3.

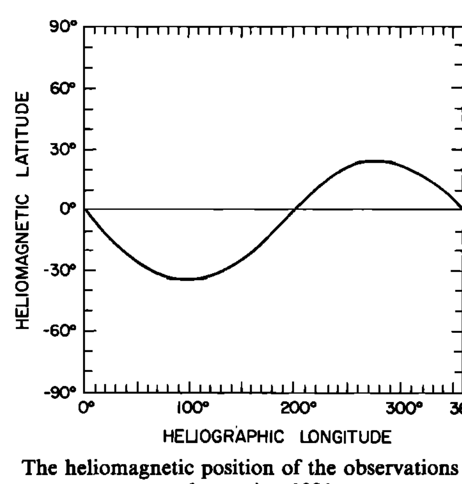

Fig. 2. The heliomagnetic position of the observations during Bartels rotation 1921.

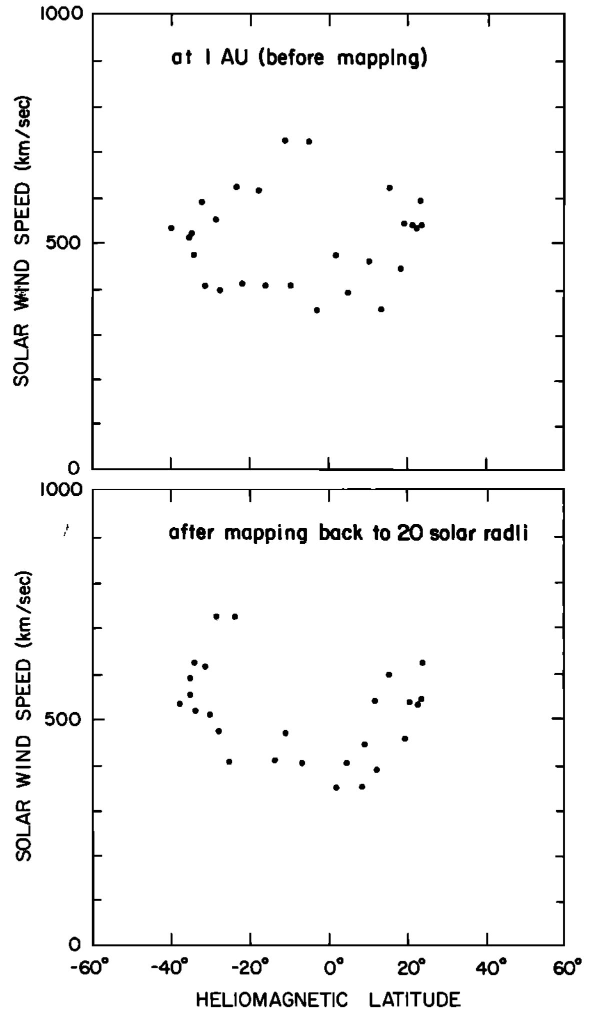

Fig. 3. Solar wind speed during Bartels rotation 1921, with a tilt angle of 30°, versus heliomagnetic latitude. (Top) For the observation at 1 AU. (Bottom) At 20 R_S.

In any more detailed examination of this variation the effects of stream steepening and interaction must be considered. For example, if the solar wind speed increased symmetrically with latitude on both sides of the heliomagnetic equator at some heliocentric distance near the sun, the overtaking of slow wind by fast wind would be expected to lead to an asymmetric profile at larger heliocentric distances. The same 'steepening' of a solar wind stream profile should lead to compression and rarefaction of material (with an accompanying heating or cooling) ahead of and behind the maximum in expansion speed, respectively—the phenomenon usually described as the 'stream interaction.' In the present discussion we will attempt to remove the effects of steepening by extrapolating the observations made near 1 AU to a heliocentric distance near the sun by assuming propagation with a constant, radial velocity. The relative error made in the longitude identifications made on the basis of this extrapolating to 20 R_S will be less than or equal to 10° [*Sime,* 1976; *Pizzo,* 1981]. Application of this simple technique to the observations of Figure 1 yields the speed versus the observational date (or the heliographic longitude) curve at 0.4 AU and 20 R_S shown in Figure 4; some of the steep rise–gradual fall character of observed solar wind streams is removed. The speed versus heliomagnetic latitude variation obtained from the 'unsteepened' profile is also shown in the bottom frame of Figure 3; it is (not surprisingly) more symmetric about the heliomagnetic equator. It should be emphasized that this simple correction for the effects of stream steepening does nothing to eliminate stream interaction effects (compression or rarefaction of the plasma, heating or cooling) and neglects the acceleration of plasma (including its deflection from radial flow) associated with stream interactions. In addition, the low-speed noncompressive density-enhanced flows, which might be associated with some of coronal mass ejection events [*Gosling,* 1976; *MacQueen,* 1980], can also not be eliminated by this correction.

b. Application to Observations From Six Bartels Rotations During 1974

Given these preliminaries, we have applied the mapping of ecliptic measurements to heliomagnetic latitude for solar wind observations from six solar rotations from 1974 spaced almost symmetrically with respect to heliographic latitude in the earth's orbit, during which two magnetic sectors of approximately equal duration were present. During Bartels rotations 1921, 1922, and 1923 the average heliographic latitude of the ecliptic plane was −4.9°, −7.3°, and −4.9°, respectively. The observations from the southernmost excursion in heliographic latitude are balanced by those from Bartels rotations 1927, 1928, and 1929, when the average latitudes were +2.4°, +4.9°, and +7,3°. The top frame of Figure 5 shows all of the daily speeds derived from the data tabulated by *King* [1977] transformed to a heliomagnetic latitude with an assumed tilt angle $\alpha = 30°$ and with the simple correction for stream steepening described above used to extrapolate the data to a heliocentric distance of 20 R_S. There is, again, a strong tendency for low solar wind speeds near the heliomagnetic equator and high solar wind speeds at high heliomagnetic latitudes (on both sides of the equator). The bottom frame of Figure 5 shows the average values of the solar wind speed observations in 10° intervals of latitude. The average speed increases from near 400 km s^{-1} within ±10° of the heliomagnetic equator to 700 km s^{-1} in the 30°–40° interval and to 640 km s^{-1} in the −30°–−40° interval. This change in average values is as great as the range of observed solar wind speeds from this epoch. Also shown in this figure is a simple functional variation of speed with latitude (see the discussion in section 3) and the 95% confidence intervals

$$(u - u_\alpha s_1/\sqrt{N},\ u + u_\alpha s_1/\sqrt{N})$$

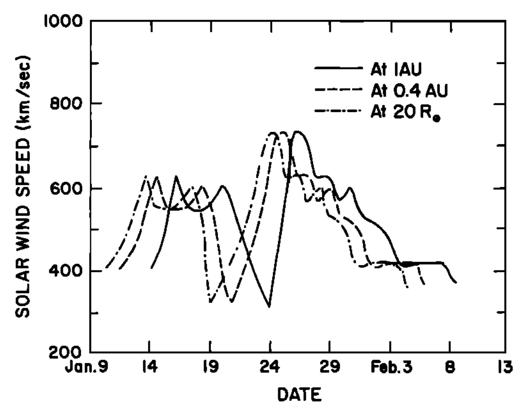

Fig. 4. Temporal plot of solar wind speed during Bartels rotation 1921; included are three associated heliocentric distances, 1, 0.4, and 0.1 AU (20 R_S).

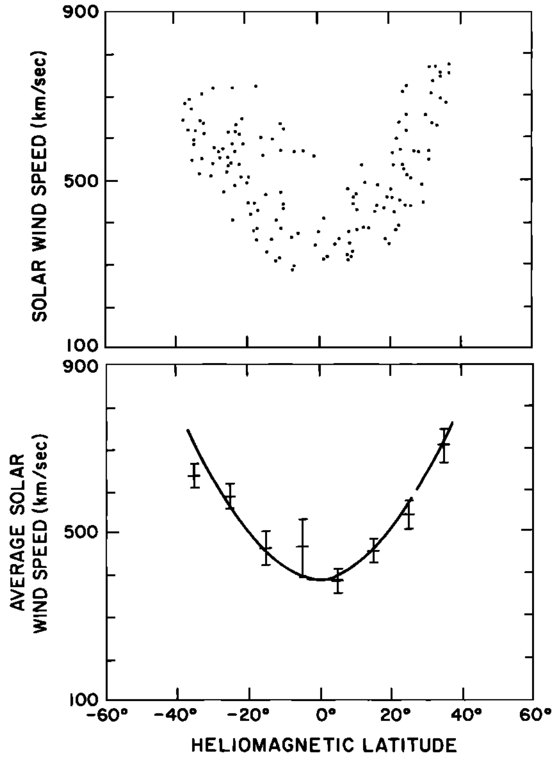

Fig. 5. (Top) Heliomagnetic latitude distribution of wind speed at 20 R_S for the six Bartels rotations 1921–1923 and 1927–1929, with the tilt angle at 30°. (Bottom) Heliomagnetic latitude variation of average wind speed over the above-mentioned six rotations, the 95% confidence intervals, and the simulated curve.

of the population mean of wind speed in the 10° latitude intervals; here

$$s_1 = \left[\frac{1}{N-1}\sum^{N}(v-u)^2\right]^{1/2}$$

is the standard error of the sample mean u of the wind speed v, N is the sample size in 10° latitude interval. The value of u_α comes from the table of t distribution under a given confidence coefficient. The method used here for estimating the confidence interval is appropriate to small samples, where the population variance is unknown. It follows that the confidence level for the displayed curve is also 95% and that the confidence intervals about the average are appreciably smaller than the trend described by the curve. It should be noted that the measurements of the solar wind speed are not completely independent unless separated in time by about 3 days or more [*Gosling and Bame,* 1972]; thus some data points in each 10° latitude interval are also not independent, and the distribution of speed is probably not normal in each latitude interval. The distribution of sample mean of speed will tend to be normally distributed as sample size N is increased [*Edwards,* 1974]; however, some of the N are very small in the present discussion, and so the estimates here and later may be poor in these cases.

Observed values of the solar wind proton density and temperature can be handled in a similar manner. In these cases, extrapolation to 20 R_S involves both modification of the solar longitude of observation and changes in the values of observed parameters. If the solar wind speed is again assumed to be constant, as justified by in situ observations between 0.7 and 1.0 AU [*Intriligator and Neugebauer,* 1975] and radio scintillation observations between 0.4 and 1.1 AU [*Coles and Rickett,* 1976], the proton density would vary as r^{-2}. Figure 6 shows the resulting values of density as functions of heliomagnetic latitude, for a tilt $\alpha = 30°$ and with extrapolation to 20 R_S, and the averages, the 95% confidence intervals of the averages, and a possible functional dependence on latitude (see section 3). A decline in density with heliomagnetic latitude is suggested by Figure 6. The radial variation of proton temperature is not well known. A polytropic relation of the form

$$\frac{T}{T_0} = \left(\frac{n}{n_0}\right)^{p-1}$$

with the value $p = 1.175$ has been empirically determined by *Sittler and Scudder* [1980] from electron observations between 0.45 and 4.76 AU. We will assume that the radial variation of proton temperature also follows a polytropic relation, but the polytropic index is not given. It is thus easily shown that the effect of altering the polytropic index on the proton temperatures which is mapped back to a heliocentric distance close to the sun is only the change in the value of the temperatures themselves. The form of the heliomagnetic latitude dependence of the proton temperature is independent of the choice of polytropic index. Figure 7 shows the resulting values of temperature (a quantization produced by rounding off the temperature in reading from King is present on the figure) as functions of heliomagnetic latitude, again for a tilt $\alpha = 30°$ but reextrapolation to 1 AU. An increase in proton temperature with latitude may be visible in Figure 7; this effect is, however, much smaller than the fluctuations and of question-

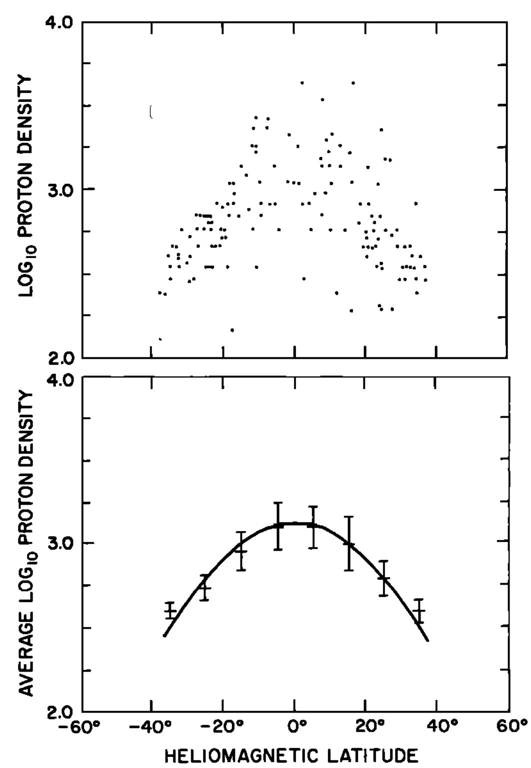

Fig. 6. (Top) Heliomagnetic latitude distribution of proton density at 20 R_S for the six Bartels rotations, 1921–1923 and 1927–1929, with the tilt angle at 30°. (Bottom) Heliomagnetic latitude variation of average proton density over the above-mentioned six rotations, the 95% confidence intervals, and the simulated curve.

able statistical significance. It should be noted that both the density and the proton temperature are expected to be strongly affected by stream interactions and that our extrapolations take no account of these effects.

In all of the displays described above, the observations made near 1 AU have been extrapolated to a heliocentric distance of 20 R_S during the correction for the effects of stream steepening. Extrapolation to different radii near the sun would be expected to produce small changes in the longitude assigned the observations and thus small changes in the final display in terms of heliomagnetic latitude. We have confirmed this expectation by carrying out a similar analysis with extrapolation to 0.4 AU or 86 R_S. Even with this major change, the conclusions drawn form the analogs of Figures 4 and 5 are unchanged. We will thus continue to extrapolate to 20 R_S in the remainder of this study.

c. *Variation of the Tilt Angle* α

Consider next tilt angles α other than the 30° value assumed for illustrative purposes in section 2*b*. Figure 8 shows plots of average solar wind speed in 10° latitude intervals and the 95% confidence intervals (as defined in section 2*b*) about the averages, based on interplanetary observations from Bartels rotations 1921–1923, 1927–1929 (as in Figure 5), for α = 0°, 10°, 20°, $\cdots$, 90°. For the small tilt angles, α = 0° and α = 10°, very little of the observed variation in solar wind speed is 'organized' in these plots; the averages in 10° latitude intervals are 525 km s^{-1}, which is larger than that in the 'slow-stream' solar wind, and the systematic variations identified as high-speed streams in the temporal plots (Figure 4) produce fluctuations about that average. For $\alpha \geqq$ 20° the averages in latitude intervals vary from 400 km s^{-1} near the heliomagnetic equator to about 700 km s^{-1} well away from the heliomagnetic equator. Thus the speed variations associated with streams are 'organized' as a heliomagnetic latitude effect for these cases. As α is increased toward 90°, the implied variation of average speed with latitude becomes weaker, as the observations are 'spread out' over a wider latitude range.

The interpretation of the observed solar wind streams in 1974 as comprising a spatial structure organized about a tilted heliomagnetic equator can thus be maintained if tilt angles α greater than 20° are assumed. The value α = 30°, suggested by some studies of coronal structure, leads to an interpretation of streams in terms of an average solar wind speed that varies from 400 km s^{-1} near the equator to 700 km s^{-1} at 30°–40° heliomagnetic latitude. Larger values of α spread the same variation in solar wind speed over larger ranges of heliomagnetic latitudes. Is there any a priori criterion for choosing any of the values of $\alpha \geqq$ 20° above any other?

Let us examine the confidence intervals about the average speeds determined in Figure 8. These intervals tend to increase with tilt angle α due both to the level of fluctuations about the average and to the smaller numbers of samples in each interval, as the same number of daily observations is spread over a wider range of heliomagnetic latitudes as α is increased. Thus the variation in solar wind speed with heliomagnetic latitude is less well demonstrated (in a statistical sense) for large values of α.

The same argument can be stated in more physical terms by examining the fluctuations (as measured by standard deviations about the mean in each 10° interval) as α is changed. For example, both the fluctuation in the 10° latitude interval with the largest number of observations and the largest fluctuation in any 10° interval are minimized for tilt angles between 20° and 40°.

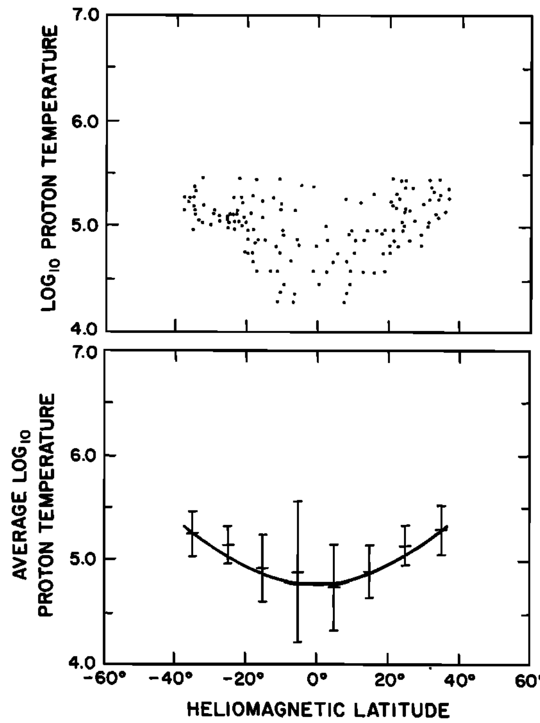

Fig. 7. (Top) Heliomagnetic latitude distribution of proton temperature reextrapolated at 1 AU for the six Bartels rotations, 1921–1923 and 1927–1929, with the tilt angle at 30°, and (bottom) heliomagnetic latitude variation of average proton temperature over the six above-mentioned rotations, the 95% confidence intervals, and the simulated curve drawn from $\log_{10} T = [1 - P_2(\cos\lambda)] + 4.82$.

We are thus led to conclude that a value of the tilt angle α = 30° ± 10°, consistent with the other studies cited above, produces the best organization of solar wind speed observations on the basis of two criteria: (1) the 400 to 700 km s^{-1} systematic variation in solar wind speed so clearly associated with the recurrent stream-sector structure in 1974 emerges as a heliomagnetic effect, and (2) the fluctuations and statistical confidence intervals about the mean variation of speed with heliomagnetic latitude are, in some sense, minimized.

Finally, we would like to point out that the method used above is just one possible method for the deduction of the tilt angle and the deduction may not be unequivocal. As a supplement to the above deduction, other in situ data such as the latitude variation of the stream-associated magnetic sector structure [*Schultz*, 1973; *Svalgaard and Wilcox*, 1978; *Villante et al.*, 1979] can also be used to determine the tilt angle α, although, again, the deduction may not be unequivocal. For example, by use of the percentages of field lines of an assigned polarity during Bartels rotations of 1921–1923 we have estimated the tilt angle to be 25°.

3. DISCUSSION

We have examined in detail earlier suggestions that properties of the solar wind observed in 1974 could be simply organized with respect to a 'heliomagnetic equator' tilted with respect to the solar equator. A superposed epoch analysis of measured solar wind speed, density, and temperature reveals a high degree of such organization when the intersections of a tilted, planar heliomagnetic equator with the path of near-

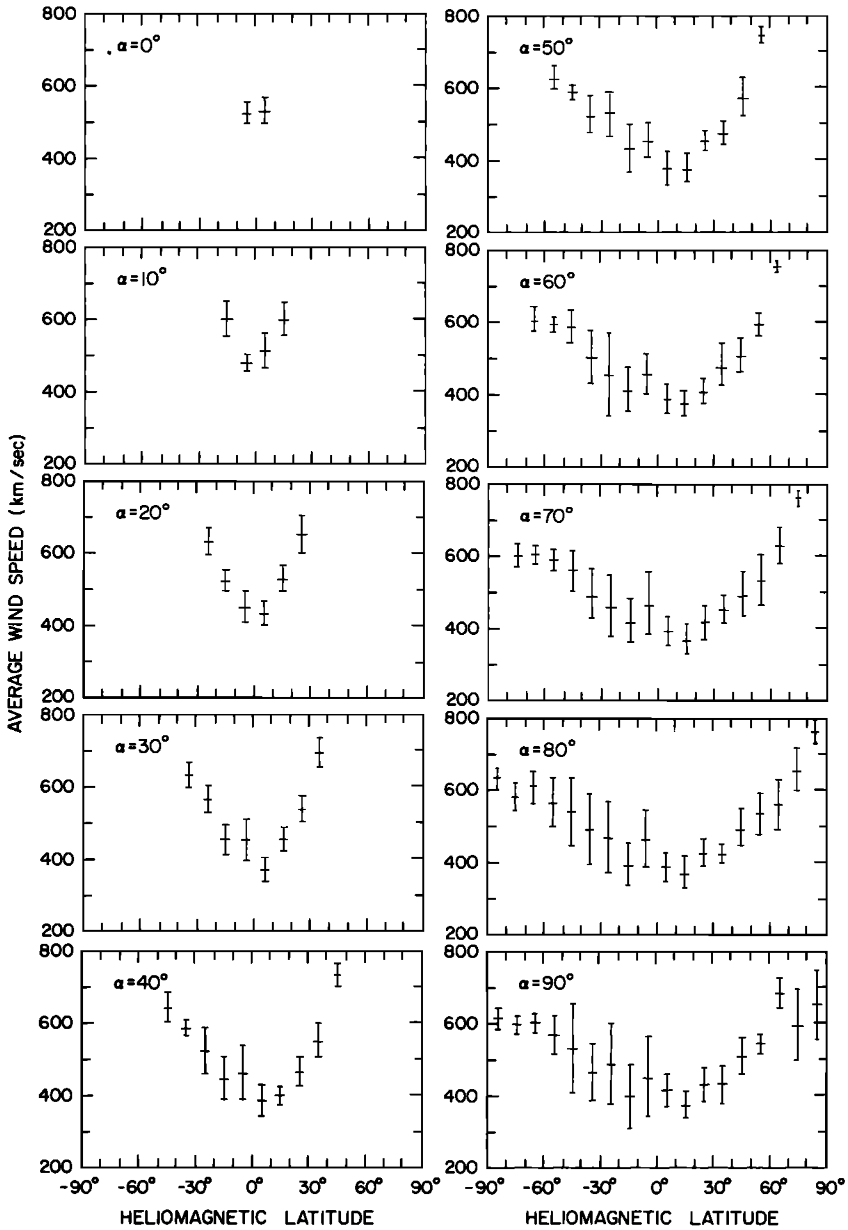

Fig. 8. Heliomagnetic latitude variation of average wind speed at 20 R_S over six rotations with the tilt angle at 0°, 10°, 20°, · · · , 90°.

earth observations are chosen to match the sector boundaries observed at this time. In particular, much of the variation in solar wind speed that occurred during this epoch and that is associated with a highly recurrent stream structure can be explained as a pure spatial dependence with heliomagnetic latitude if a tilt angle of 20° or greater is used. The level of fluctuations about this average spatial dependence is minimized for tilt angles near 30° and increases appreciably for angles greater than 40°. We are thus led to a value near 30°, with an uncertainty of ±10°, as the tilt of the heliomagnetic coordinate system that best organizes solar wind observations from 1974.

Several other estimates of the degree of tilting or warping of the coronal or interplanetary neutral sheet pertinent to 1974 have been published. *Svalgaard and Wilcox* [1976] give an 'extent in heliographic latitude of extended sector structure magnetic fields' of 30°–40° for similar epochs in earlier sunspot cycles, based on the variation in sector durations produced by the ±7.3° excursion of the ecliptic plane in solar latitude. *Sime and Rickett* [1978] deduced a tilt of 40° from interplanetary radio scintillations observed in 1974. *Hundhausen* [1977] suggested a tilt of 30° based on the 1974 coronal brightness pattern observed at 1.5 R_S. Estimates for other epochs have been given by *Svalgaard and Wilcox* [1976], *Smith and Wolfe* [1979], and *Villante et al.* [1979]. Our inference of a tilt angle of 30° ± 10° for 1974 is consistent with, but somewhat smaller than, the values favored by Svalgaard and Wilcox and by Sime and Rickett, based on interplanetary observations, and agrees with the 30° value suggested by Hundhausen for the outer corona. This latter agreement implies that to the ±10° accuracy of these deductions, the neutral sheet separating the north and south magnetic 'hemispheres' of the sun does not undergo displacement in latitude between the outer corona and the orbit of earth. This conclusion is consistent with that which comes from the direct comparison of Helios 1 and 2 observations of the interplanetary sector pattern in early 1976 with the maximum brightness in the K-coronameter data at 1.5 R_S [*Burlaga et al.*, 1981]. All of these values must, of course, be read as estimates; as pointed out by Villante et al., each method is compromised by any temporal changes in the actual coronal and interplanetary structure that occurred during the period of analysis.

Given the estimated tilt angle of 30°, the solar wind speed and density variations with 'latitude' in the tilted coordinate system can be approximated in the ±40° latitude range by

$$u = 1000 \sin^2 \lambda + 400$$

$$\log_{10} n = P_2 (\cos \lambda) + 2.28$$

where λ denotes the heliomagnetic latitude and u (km s^{-1}) and n (cm^{-3}) denote the solar wind speed and proton number density, respectively, at 20 R_S. $P_2 (\cos \lambda)$ is the second-order Legendre polynomial. These functional dependences were used to draw the curves in Figures 5 and 6 and give a reasonable fit to the observed averages. It is evident that at the heliomagnetic equator the wind speed is the lowest, increasing towards the heliomagnetic poles, and that the proton density is maximum at the heliomagnetic equator, decreasing towards the heliomagnetic poles. *Schwenn et al.* [1978] found a steeper dependence of solar wind speed on heliographic latitude from multiple spacecraft observations of a single solar wind stream in 1975. Our result may differ from theirs, as it is an average over about 6 months of observations. Extrapolating these dependences back to the polar magnetic open regions or coronal holes, it could easily be imagined that the plasma velocity and proton density in polar coronal holes are not homogeneous, increasing for plasma velocity and decreasing for proton density towards the hole center. Although there is no a priori justification for extrapolating in this manner from 40° to the poles, these conclusions are qualitatively consistent with density observations in a coronal hole [*Munro and Jackson*, 1977] and support the theoretical predictions in coronal holes [*Suess*, 1976] and in interplanetary space [*Yeh and Pneuman*, 1977]. In fact, the second-order Legendre polynomial relation determined here for the heliomagnetic latitude dependence of plasma properties is just that derived from coronal hole observations and used in their theoretical analysis.

We can also deduce a dependence of the proton flux density on the heliomagnetic latitude, as shown in Table 1. It is evident that the proton flux density near the heliomagnetic equator, which should correspond to low-speed flow, is highest and decreases towards the heliomagnetic poles. The observed values of the proton flux density near 1 AU are 3.9×10^8 cm^{-2} s^{-1} for the low-speed flow and 2.7×10^8 cm^{-2} s^{-1} for the high-speed flow [*Feldman et al.*, 1977]. Obviously, our inference here is consistent with in situ observations. It also implies that the proton flux density, which comes from the regions well away from the edge of coronal holes, is lower than that which comes from the edge of coronal holes.

Some of the inferences deduced from this study are consistent with the observations. However, since we have scanty out-of-the-ecliptic data and outer coronal data, many of the inferences mentioned above need further testing in future coronal observations and in situ observations of out-of-the-ecliptic extension.

This study confirms the simple nature of the three-dimensional solar wind structure suggested by interplanetary observations from 1974. The interpretation of these observations in terms of variations in solar wind properties with displacement from a heliomagnetic equator is strengthened by our findings. Nonetheless, this interpretation is far from unique; many of these inferences demand further examination using additional coronal observations and, ultimately, in situ interplanetary observations from well out of the ecliptic plane.

TABLE 1. Dependence of Proton Flux Density on Heliomagnetic Latitude

Heliomagnetic Latitude, deg	Average Proton Number Flux Density at 20 R_S, cm^{-2} s^{-1}	Average Proton Number Flux Density at 1 AU, cm^{-2} s^{-1}
±35	3.4×10^{10}	2.9×10^8
±25	4.0×10^{10}	3.4×10^8
±15	4.6×10^{10}	4.0×10^8
±5	4.8×10^{10}	4.2×10^8

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