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Rotation of the Photospheric Magnetic Fields: A North–South Asymmetry

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CSAA-ASTRO-89-14

August 1989

ABSTRACT

During most of solar cycle 21 the large-scale photospheric field rotated more rapidly in the northern hemisphere than in the southern. The large-scale northern field rotated with a 26.9 day period (synodic), was centered at 15° N, and covered a latitude zone about 24° wide. The large-scale southern field rotated with a periodicity of 28.1 days, was centered at 26° S, and covered a latitude zone about 32° wide. Our analysis showed rotational power at only a few discrete latitudes and frequencies in each hemisphere. The center of each peak lies near the sunspot differential rotation curve. The largest scale field contributes to the configuration of the coronal and interplanetary magnetic field (IMF). The strength of the first harmonic of the northern field suggests that this structure may be related to the 4-sector pattern observed in the IMF polarity. The southern field had much lower power at the first harmonic of the solar rotation rate and so would contribute only to a 2-sector structure in the IMF. These results were discovered in Fourier analysis of photospheric synoptic charts obtained at the Wilcox Solar Observatory from 1976 – 1986 and confirmed in higher resolution maps from the National Solar Observatory. Mt. Wilson magnetic field measurements from solar cycle 20 show a similar north–south asymmetry.

Subject headings: Sun: rotation – Sun: magnetic field – Sun: north-south asymmetry

I. INTRODUCTION

Many facts point to a relatively weak coupling between the photospheric magnetic fields in the northern and southern hemispheres. While the 22-year cycle remains in phase, characteristics such as the time of reversal of the polar fields and the level of activity differ significantly. Doppler observations of the photospheric plasma reveal a roughly constant differential rotation symmetric with respect to the equator (e.g. Howard and Harvey, 1970; Scherrer et al, 1980). Most previous Doppler analyses have not been sensitive to asymmetric rotation. Symmetry is also found in the rotation of short-lived photospheric magnetic fields (Snodgrass, 1983). However, recent work on the rotation of the computed and observed coronal magnetic field showed that the field patterns in the northern and southern hemispheres rotate at different rates during most of the cycle (Hoeksema and Scherrer, 1987; Parker, 1987). Even though the large-scale field contributes a relatively minor fraction of the total solar flux, the coronal field, and by extension the interplanetary magnetic field (IMF), results from the large-scale photospheric field. The IMF inferred at Earth during a 60 year interval shows two basic periodicities: 27 and 28.5 days. Where do these periods come from on the Sun? The answer may also reveal something of the internal workings of the solar cycle.

Does the photospheric field rotate symmetrically with respect to the solar equator? To answer this question we have analyzed synoptic charts of the photospheric magnetic field observed at the Wilcox Solar Observatory (WSO) at Stanford from 1976 to 1986 using the method of Hoeksema and Scherrer (1987) (Scherrer, Hoeksema, & Antonucci, 1987). Considering the field measured at a fixed latitude as a time series, power spectra were computed and a frequency interval including the nominal rotation rate was analyzed, as described in Section 2. Section 3 presents the investigation of the variation of the discovered rotational asymmetry during the solar cycle and Section 4 its confirmation in the higher resolution data from the National Solar Observatory (NSO) and in the previous cycle as observed at Mt. Wilson. The structure of the rotating pattern as revealed by the first harmonic amplitude is discussed in Section 5. In Section 6 we discuss the relation of the rotation properties of the photospheric field and of the coronal emission. The summary and discussion in Section 7 present some possible explanations for these observations.

II. ROTATION OF PHOTOSPHERIC MAGNETIC FIELDS

The rotation of photospheric magnetic fields has been determined using full-disk solar magnetograms obtained at the WSO. These data are obtained with low spatial resolution to be particularly sensitive to the net contribution of fields over a large-scale. The daily observations cover an interval lasting a little more than one solar cycle beginning in May 1976.

The 3 arc minute resolution observations are transformed into synoptic charts by combining the contributions of several daily magnetograms which include a given Carrington coordinate within 55° of central meridian. The field values are weighted for central meridian distance and image quality. The resulting maps have a resolution of 5° in Carrington longitude and 30 points north to south spaced equally in sine latitude. This is greater resolution than the observed points; higher spatial resolution is obtained by interpolating onto the Carrington coordinate system using a parabolic surface fitted to the nearest observed points.

The rotation rate of the photospheric fields is determined as a function of latitude by computing power spectra of the time series of the magnetic field values in each of the 30 latitude zones. Each time series covers a 10-year interval from May 1976 to November 1986. The spectral power is then plotted in latitude–frequency contour maps. This representation shows not only the values of frequency versus latitude, but also the power of the periodic signal in the time series. Figure 1 shows the contour map of spectral power for the whole solar cycle in the frequency window 300 to 500 nHz, where the frequency is predominantly determined by solar rotation. The power is not a continuous function in latitude–frequency space, but clusters in a few, well-defined regions. Large gaps are observed both in frequency and latitude where the spectral power is above the noise level.

This analysis measures the power of the effective dipole (or 2-sector) component of the net field. Most of the total power is actually found at higher harmonics (about 95%), but this component and the first harmonic determine the large scale structure of the coronal field.

Regions having significant power are not symmetric about the equator. The non-uniform distribution of spectral power can be compared with the differential rotation curve derived by Newton and Nunn (1951). If this component of the field rotated as sunspots, the power would lie on a curved ridge along the line shown in Figure 1. Although power is not continuously and uniformly distributed along this curve, the peaks of the regions of enhanced power lie near the sunspot rotation curve. The regions of enhanced power extend significantly in latitude, while the frequency width is only about twice the frequency resolution, which for the interval considered is about 3 nHz. Hence, a specific frequency for each enhanced region can be defined. This relation can be described as follows: for a given area of enhanced power, the maximum in the spectral power occurs at the latitude defined by the sunspot curve. The large latitudinal extent of the enhanced power regions is an interesting observational property. It indicates that the rotation rate of the magnetic fields, determined by the peak value in the region, is common to the adjacent latitudes over a broad latitude zone.

Three dominant frequencies are apparent in Figure 1 during Cycle 21: 431 nHz (26.9 day period) in the northern hemisphere and 412 and 395 nHz (28.1 and 29.3 days) in the southern hemisphere. Of those, the 26.9 day period is the strongest in the northern hemisphere over a latitude zone 24° wide, centered near 15° N; while the 28.1 day period predominates in the southern hemisphere in a latitude zone 32° wide, centered near 26° S. The rotational properties of large-scale photospheric field pattern manifest a strong asymmetry with respect to the equator which has not been found by studying other photospheric or chromospheric tracers or by directly measuring velocity signals at the photospheric level.

Rotation Power vs. Frequency and Latitude

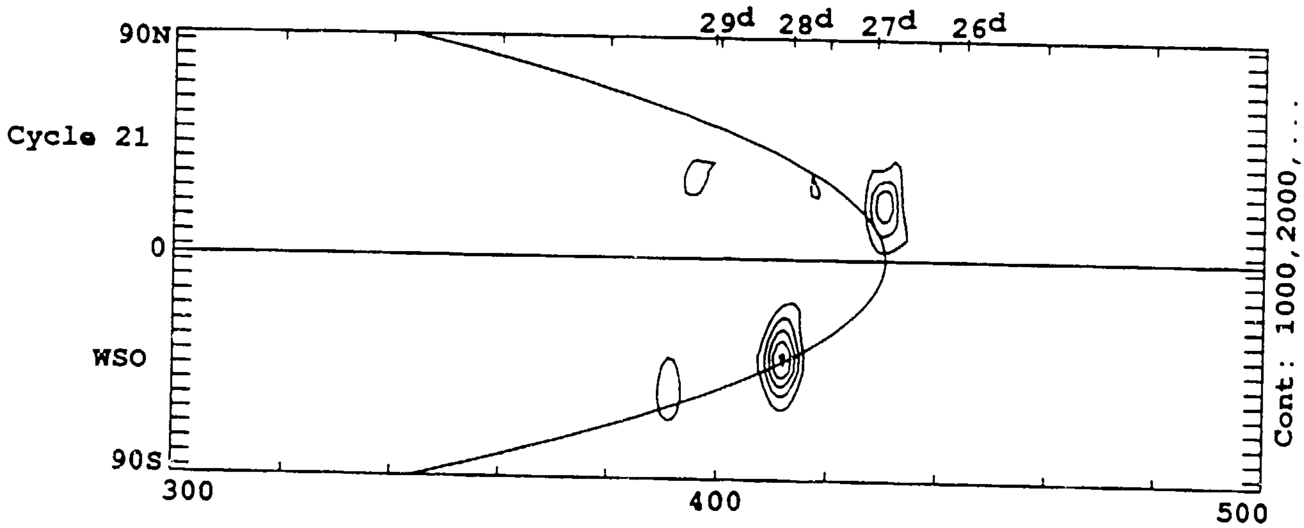

Fig. 1.– For each of 30 strips in sine latitude the power spectrum of the photospheric field observed at the Wilcox Solar Observatory between May 1976 and November 1986 has been calculated. A contour map of the power in the 300–500 nHz range is shown. From north to south power is concentrated at frequencies of 431, 412, and 395 nHz, corresponding to synodic rotation periods of 26.9, 28.1, and 29.3 days. The dominant northern peak is about 20° wide, centered at 15° N. The dominant southern peak is centered at 26° S with a width of about 30°. For comparison the Newton and Nunn differential rotation curve is superposed. Frequencies of relevant whole day periods are shown on the upper axis. Contour levels are indicated at the right.

III. NORTH - SOUTH ASYMMETRY OF THE ROTATIONAL PROPERTIES THROUGH THE CYCLE

Figure 1 shows a strong asymmetry over the whole cycle, but it is easy to imagine that most of the signal might come from the period around maximum when the fields are strong. What happens in different parts of the cycle? Four consecutive intervals, each 35 Carrington Rotations long, are considered. The latitude–frequency maps of the spectral power are shown in Figure 2. We find that the characteristic north-south asymmetry persists through most of the cycle. However, the latitudes and frequencies of the peaks do vary with time. As expected, most of the power comes from the time near solar maximum. But the 27-day rotation is present at mid-latitudes in the north in all but the late declining phase (Interval 4) and the southern structures rotate more slowly than 27 days throughout the cycle. Table 1 reports the latitudes and frequencies of the peaks in each interval.

TABLE 1

ROTATION RATES OF THE MAJOR FEATURES AT VARIOUS TIMES

Interval	Rotations	Time	Frequency	Period	Latitude
1	CT 1642 - 1677	Jun 76 - Jan 79	426	27.2	30 N
			426	27.2	26 S
			406	28.5	30 S
2	CT 1677 - 1712	Jan 79 - Sep 81	432	26.8	13 N
			412	28.1	26 S
			394	29.4	39 S
3	CT 1712 - 1747	Sep 81 - Apr 84	391	29.6	30 N
			433	26.7	17 N
			416	27.8	30 S
4	CT 1747 - 1782	Apr 84 - Nov 86	431	26.9	10 S
			427	27.1	17 S

The dominant region of enhanced power observed in the southern hemisphere drifts in latitude and frequency during the solar cycle, while the northern feature retains approximately the same latitude - frequency values. The variations observed in latitude for the power peak in the southern hemisphere are consistent with the frequency variations along the sunspot differential rotation curve. The power at the two dominant frequencies increases and decreases with the general activity level. During Intervals 1, 2, and 4 there is more power in the southern hemisphere.

Beginning in the third and continuing in the fourth interval the frequencies found in each hemisphere begin to change. There is a slowly rotating feature in the northern hemisphere in Interval 3 as well as the more characteristic 26.7 day power. During the latest part of the Solar Cycle, Interval 4, the frequencies observed in the two hemispheres are more similar. There is a strong asymmetry in total power that favors the southern hemisphere, but much of that power is concentrated at 27 days. The strongest peak in the northern hemisphere (though at a very low level) is at a rotation period longer than 28 days. This may suggest a reversal for the next solar cycle.

IV. CONFIRMATION IN HIGHER RESOLUTION DATA

To test the validity of these results we performed the same analysis using the higher resolution synoptic charts obtained at the National Solar Observatory at Kitt Peak. We were concerned that the latitudinal extent of the dominant frequency peaks might be influenced by the interpolation procedures used to obtain a higher spatial resolution in the WSO synoptic charts. To determine the average values of the dominant frequencies the spectral analysis was performed over the entire period 1976 to 1986. The latitude-frequency map including all of Solar Cycle 21 derived from WSO data, as discussed in the previous section, is shown again in the top panel of Figure 3. The center panel shows the result of using

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Fig. 2.– Spectral power maps similar to Figure 1 are shown for four consecutive intervals, each 35 Carrington Rotations long. Periods in days are shown for reference. The power is asymmetric throughout Cycle 21, but the frequencies begin to change during the later part of the cycle. The total power changes with the envelope of the cycle. The contour levels are indicated for each panel.

Rotation - Frequency Maps During Cycle 21

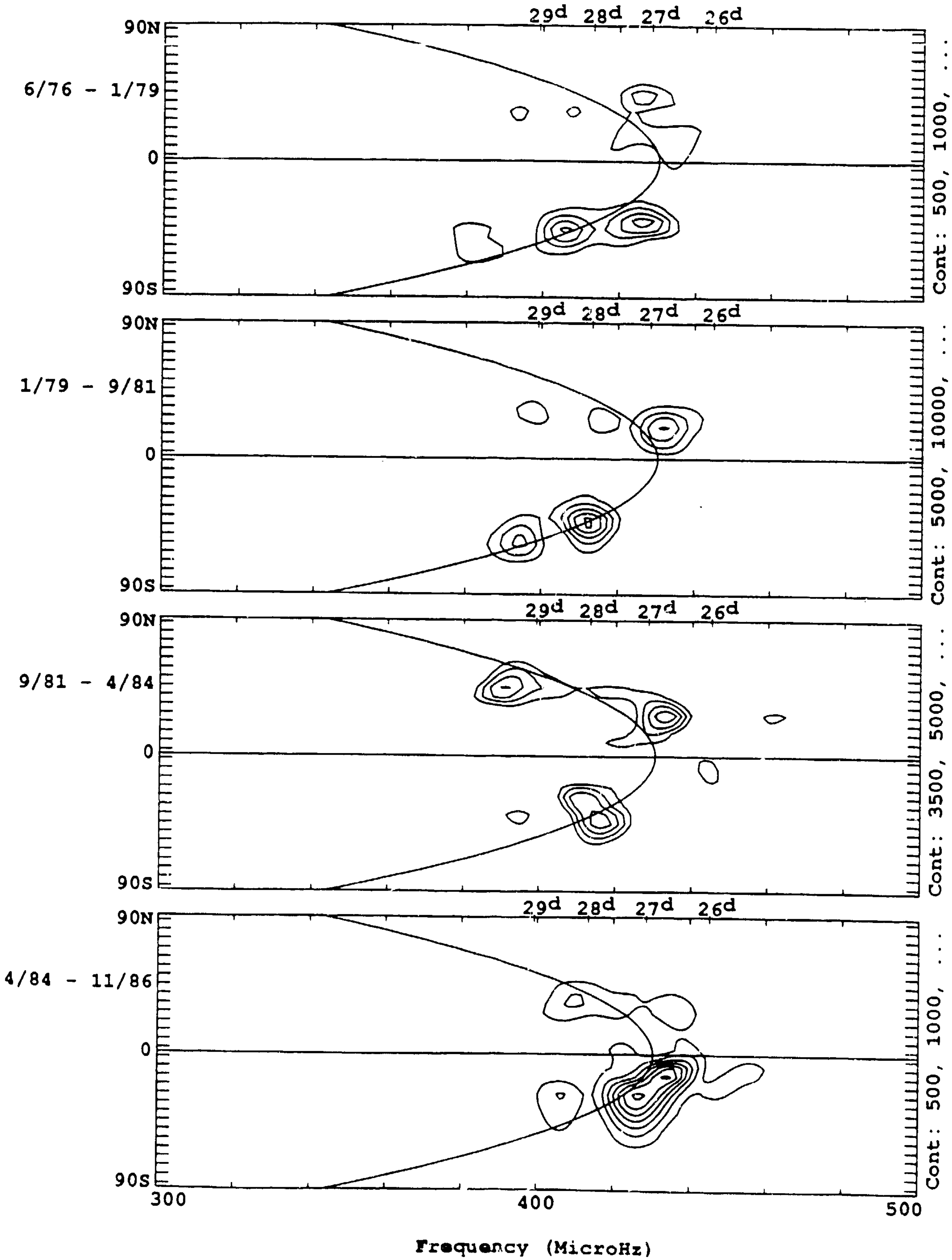

Figure 2

the NSO data for roughly the same time interval. We *averaged* (rather than interpolated) the NSO data into the 30 latitude bins. The results obtained with the high resolution data confirm both the latitudinal extent and peak frequency of the two predominant regions of enhanced power.

The consistency of the results obtained with synoptic charts of different spatial resolutions indicates that the result is not an artifact of the aperture size or the normal data reduction process.

The position of the power peaks in the latitude-frequency maps appears to be a characteristic not only of the recent solar cycle. The bottom panel of Figure 3 displays the results obtained by analyzing the Mt. Wilson Synoptic charts during cycle 20 in the period 1965 to 1975. In this case the coincidence of enhanced regions is less complete, but it is still possible to find excess power around 24° S with a period of 27.8 days and at 13° N with a period of 27.0 days. These are not the only prominent features, since the highest absolute power peak occurs at 15° S at shorter periods, 26.4 - 26.6 days.

Table 2 summarizes the results shown in Figure 3. We can conclude that two different dominant rotation periods (26.9 and 28.1 days) are observed in the photospheric magnetic fields in opposite hemispheres. The dominant periodicities have maximum amplitudes at two preferential latitudes located asymmetrically with respect to the equator (15 ° N, 26 ° S respectively) and they are related to the preferential latitude by the sunspot differential rotation law. The same dominant frequencies and relative preferential latitudes can be identified for two consecutive solar cycles, with slight variations in values.

TABLE 2
ROTATION RATES OF MAJOR FEATURES OBSERVED AT THREE OBSERVATORIES

Observatory	Time	Frequency	Period	Latitude
WSO	1976 - 1986	431	26.9	15 N
		412	28.1	26 S
		395	29.3	37 S
NSO	1976 - 1984	430	26.9	16 N
		413	28.0	22 S
MtWSO	1965 - 1975	429	27.0	15 N
		437	26.5	15 S
		416	27.8	24 S

V. STRUCTURE OF THE STRONGEST ROTATING PATTERNS

The power in the fundamental accounts for less than 5% of the total variance in the photospheric field. In fact, the greatest power is in the 4th harmonic. However, the corona and IMF are primarily influenced by only the fundamental and first harmonic. This is apparent from considering the relative strengths of the harmonics higher in the corona and can be inferred from the characteristic patterns

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Fig. 3.– Spectral power maps for WSO, NSO, and Mt. Wilson. The upper panel is the same as Figure 1. the center shows the results of the same analysis procedure using the higher resolution synoptic charts from the National Solar Observatory at Kitt Peak for the interval August 1976 to December 1984. The largest concentrations of power occur at the same locations and have the same latitude and frequency widths. Panel C shows the results of the analysis of Mt. Wilson data for the interval 1965 - 1975, Cycle 20. The signal is noisier, but an asymmetry between north and south persists.

Rotation - Frequency Maps From 3 Observatories

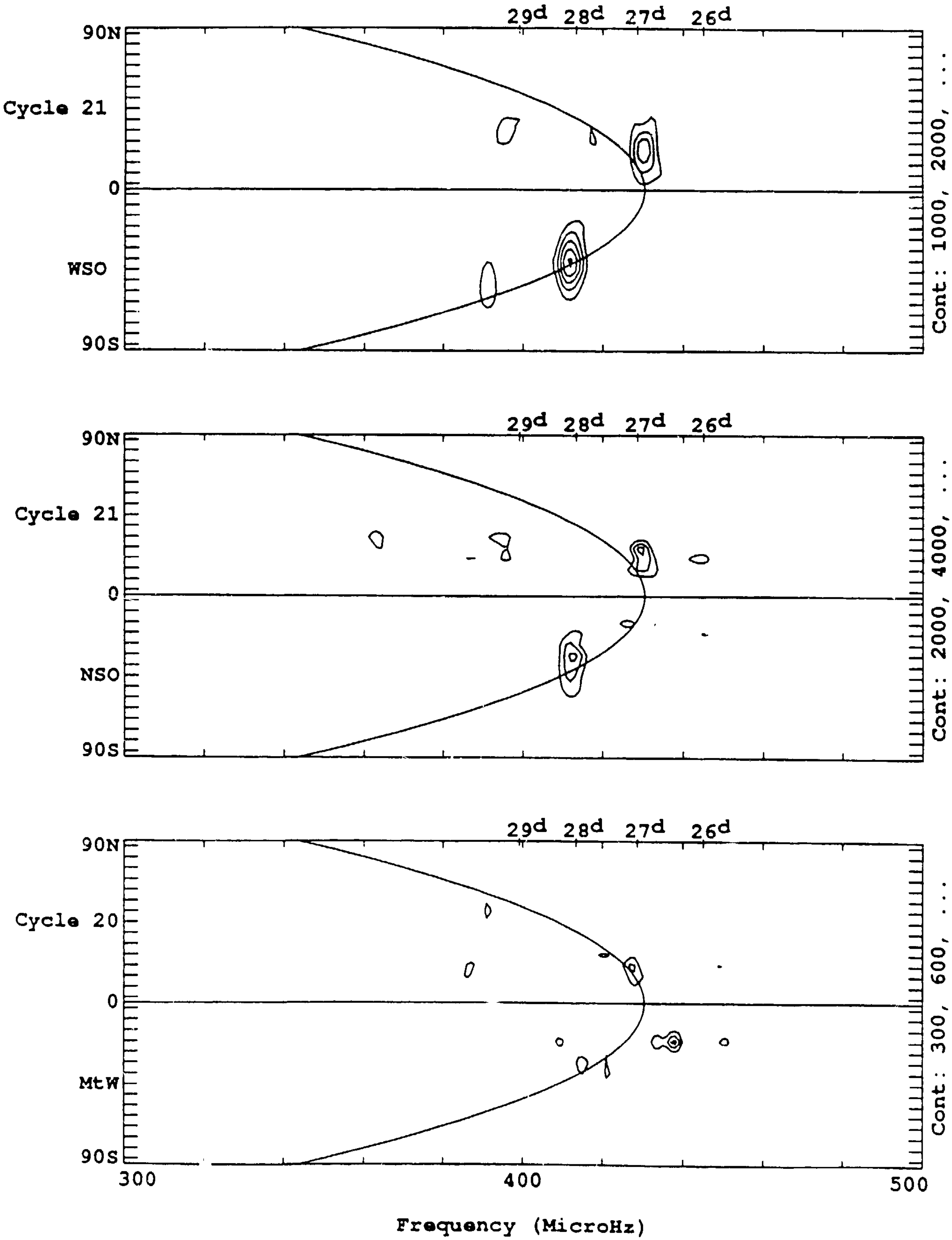

Figure 3

observed in the IMF polarity structure. There are basically two modes: the Earth experiences either two or four sectors of alternating IMF polarity during the course of one solar rotation. To find the source of the coronal rotation signal we analyze only the frequency ranges corresponding to rotation and [illegible] harmonic. At the photosphere the first harmonic has about twice the power of the fundame[illegible] translates into roughly equal power at the source surface located at 2.5 solar radii (not including [illegible] dipole.)

Figure 4 is like Figure 3 except that it shows the power at twice the rotation frequency; the [illegible] panel shows the WSO results. The two strongest peaks in the latitude-frequency map of Figure 4 are found at frequencies not related to the strongest peaks in the fundamental frequency range. The strongest peak in the northern hemisphere appears at 836 nHz (half 27.7 days) and is present throughout the cycle; the strongest southern peak corresponds to rotation period of half 27.27 days, the Carrington rate, and is seen during all but the first couple years of Cycle 21. A cluster of slightly weaker peaks occurs in the northern hemisphere at 854, 860, and 868 nHz (half 27.1, 26.9, and 26.7 days, respectively.) These frequencies are strong during different phases of the cycle. The total power near 27/2 days exceeds the power at the other frequencies, but the shorter lifetimes and variable frequencies of the field patterns scatter the power into several smaller peaks. Of the largest peaks, only the 836 nHz northern peak is present during each part of the cycle.

Comparing the fundamental and first harmonic, the only common peak is the one near 27 days in the north. The existence of a significant first harmonic suggests that the 27-day periodicity results from the rotation of a photospheric field pattern with four longitudinal sectors. Changes in the first harmonic structure are aliased down to the fundamental frequency. Therefore we associate the 27-day rotation with a four sector pattern that arises primarily in the northern hemisphere during Cycle 21. On the other hand, the pattern at 28.1 days has no associated first harmonic and cannot be related to a rotating pattern with a 90° spatial recurrence. Hence we conclude this periodicity arises from a predominantly dipolar (two-sector) pattern.

Each of these peaks appear in both the WSO and NSO data for Cycle 21. The power peaks are clustered about the Newton and Nunn rate and are discrete, as they were in the earlier analysis. The two strongest peaks in Cycle 20 derived from Mt. Wilson data match the Cycle 21 results from WSO and NSO, though the frequencies, particularly in the northern hemisphere, are slightly greater. Interestingly, the 27-day northern peak is virtually absent.

VI. PHOTOSPHERIC MAGNETIC FIELDS AND CORONAL ROTATION

The tendency of large-scale photospheric magnetic field patterns to rotate rigidly in latitude belts of considerable width around the preferential latitudes influences the rotation of the corona. As discussed in Sections 2 and 3, photospheric magnetic fields rotate at approximately the same rate up to relatively high latitudes and there is no strong coupling of rotation in the two hemispheres for most of the solar cycle, as shown by the average latitude-frequency maps of Figure 2. In fact, the dominant rotation rates in the two hemispheres differ and the latitudes where the rotation signals predominate are not symmetric with respect to the equator. A tendency of the solar photospheric magnetic fields to rotate rigidly within 25° of the equator was found by Wilcox et al. (1970) in an autocorrelation study of the Mount Wilson magnetic

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Fig. 4.– The spectral map of the WSO data from cycle 21 for the spectral interval 600–1000 nHz, double the frequency of solar rotation. Power is concentrated at 27.7 and 26.9 days in the north (the 26.9 day peak is split) and at the Carrington rate in the south. The two lower panels show the results for the Kitt Peak and Mt. Wilson data.

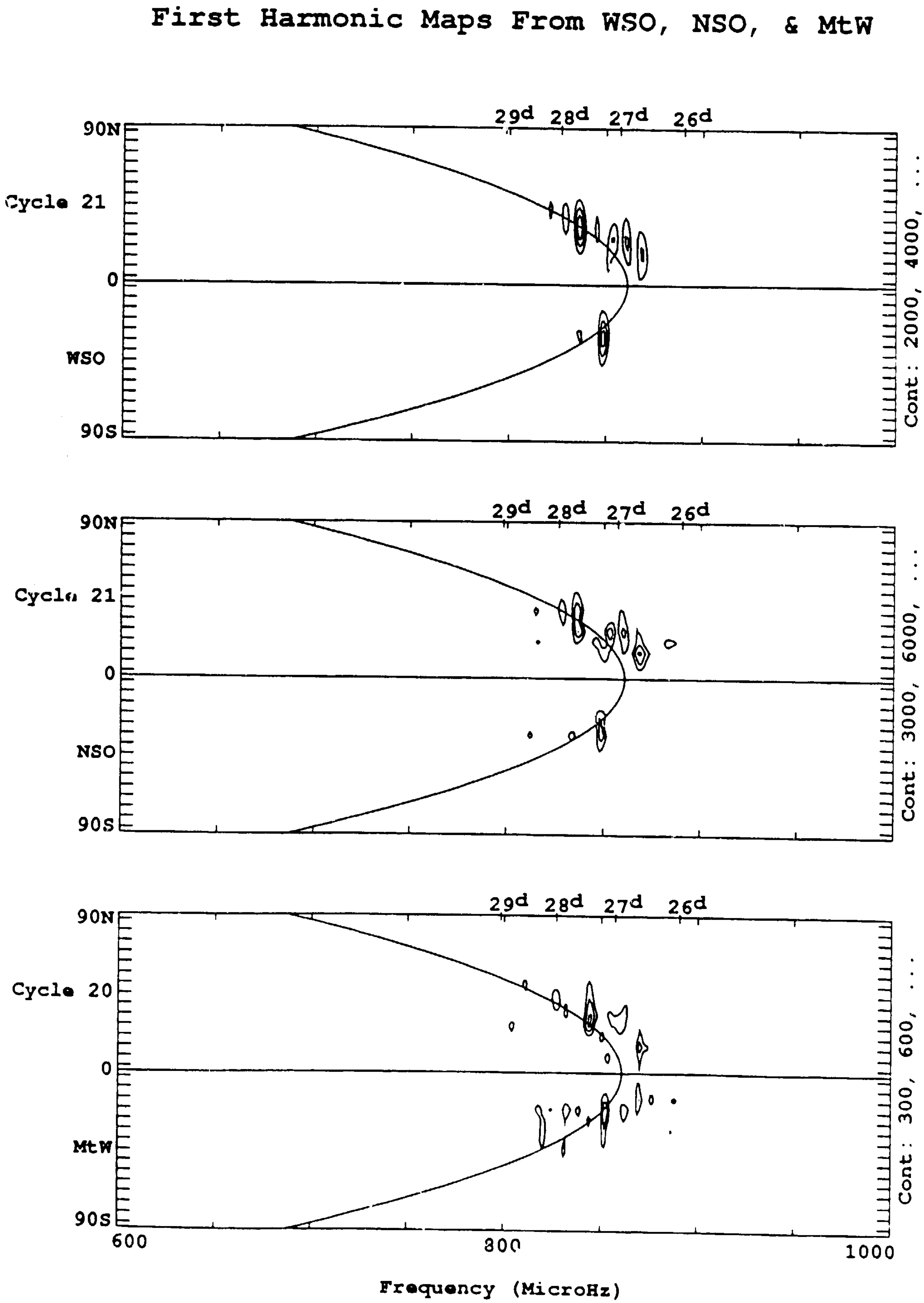
First Harmonic Maps From WSO, NSO, & MtW
29d 28d 27d 26d
90N
Cycle 21
0
WSO
90S
Cont: 2000, 4000, ...
Cycle 21
NSO
Cont: 3000, 6000, ...
Cycle 20
MtW
Cont: 300, 600, ...
600
800
1000
Frequency (MicroHz)

Figure 4

field data. Stenflo (1977), in an analysis of measurements from the same observatory, demonstrated the existence of a solar cycle dependence of the degree of the differential rotation for the photospheric fields. However, no north-south asymmetry in the rotational behavior of the photospheric field was discussed in previous studies. Comparison with the study by Hoeksema and Scherrer (1987) on the rotation of the coronal field, which was extrapolated from the same photospheric measurements used in this analysis, shows that the dominant frequencies present at the photospheric level appear in the corona at 2.5 solar radii as well. However, comparing photospheric and coronal rotation of the magnetic fields, we note an increase with height of the extent of the rigidly rotating latitude zones.

The rigid rotation of the photospheric field in more or less extended latitude belts, depending on the phase of the cycle, can explain the tendency of the corona to rotate rigidly found in many earlier studies. On the average, the corona rotates more rigidly than the photosphere and chromosphere (Hansen, Hansen and Loomis, 1969; Antonucci and Svalgaard, 1974; Parker, Hansen and Hansen, 1982; Fisher and Sime, 1984). The degree of differential rotation in the inner corona is a function of the solar cycle phase and decreases in the declining part of the cycle. This result comes from a study of the coronal green line (5303 A) and included a time interval of almost three solar cycles, from 1947 to 1974 (Antonucci and Svalgaard 1974, Antonucci and Dodero 1979). Coronal features, such as coronal holes, can have the same rotation rate over quite large latitudinal zones of the solar disk (Wagner 1975, Timothy, Krieger and Vaiana, 1975). The rotation rate of the white light corona at 1.5 solar radii also shows a general dependence on the solar cycle during the period 1965-1983 (Fisher and Sime, 1984). Parker (1987) showed that the degree of coronal differential rotation decreases with height.

These properties of coronal rotation can be better understood in the light of the importance of the photospheric magnetic fields in controlling the coronal structure and its evolution. Solar cycle dependence in the behavior of the magnetic field rotation can be found at the coronal level as well. At the end of cycle 18, in the years 1950-1952, the green corona showed rigid rotation with a 27 day period in the latitude interval #+-# 57.5° (Antonucci and Svalgaard, 1974). Rigid rotation is not always observed in the corona during the declining phase of a cycle, but the degree of differential rotation was significantly reduced in cycle 19 and 20. The extension of rigid rotation as far as the polar zones, characteristic of coronal magnetic fields in the declining phase of the cycle (Hoeksema and Scherrer, 1987) was also observed in coronal holes before the last solar minimum (Timothy, Krieger, Vaiana, 1975).

The rotational properties found here, particularly the reduction in the degree of differential rotation for large-scale fields, are consistent with the reported properties of the photospheric and coronal fields in the last two solar cycles, 20 and 21. The north-south asymmetry has been briefly noted by Parker (1987) who found that high-latitude coronal structures in the northern hemisphere rotate more slowly than those in the south during Cycle 20. Sheeley and Harvey (1981) studied coronal holes during the ascending phase of cycle 21 and found the existence of two persistent rotation rates. A negative polarity coronal hole pattern present during the years 1977-1979, rotating at 28.5 days, was generated by a sequence of mid-latitude coronal holes in the southern hemisphere; two long-lived 27-day patterns during 1977 and during 1979 were generated by low-latitude, northern hemisphere coronal holes. The authors attributed these periodicities to a non-stationary migratory process leading to a recurrence of the long-lived coronal hole pattern with the local rotation period. However, the same observations can also be explained in terms of coronal hole locations controlled by large-scale fields having different rotation periods in the two hemispheres. It is interesting that the 27-day coronal hole pattern is formed at low northern latitudes, while the 28.5 day pattern originates at mid-latitudes at south. These latitudes show approximately the same north-south asymmetry of the latitudes (15° N and 30° S) which we observe in the peak of enhanced rotation of the photospheric magnetic field, averaging the observations over the entire cycle. Of course the bimodal rotation in the IMF has long been known and has persisted over at least the past 6 sunspot cycles.

There is, of course, a question as to which phenomenon is ultimately responsible for the pattern: is it an underlying organization of the large scale field patterns, possibly produced by the organized emergence of new flux, or is it primarily a surface phenomenon produced by migratory processes acting on more-or-less random flux patterns?

VII. INTERPRETATION, DISCUSSION, AND SUMMARY

The study of the rotational properties of photospheric field has yielded five principal results:

- Power in the rotation rate of the largest scale fields appears at only a few discrete latitudes and frequencies. The latitude zones over which these frequencies appear are very wide.
- The centers of the peaks lie near the sunspot differential rotation curve.
- A strong asymmetry exists between the rotation rates of the northern and southern hemispheres during most of the cycle. This is consistent with a difference in the latitude of the strongest peaks.
- The ~28-day structure observed near the ecliptic in the interplanetary medium comes from relatively high southern latitude in Cycle 21. The structure is predominantly 2-sector in the photosphere and in the IMF.
- The ~27-day structure in the IMF arises in the northern hemisphere at lower latitudes and is a combination of fundamental (2-sector) and first harmonic (4-sector). Most of the first harmonic power comes from the northern hemisphere

The peaks in spectral power observed at 15° N and 30° S may result either because the lifetimes of photospheric tracers are longer at such latitudes or because fields emerge according to large scale patterns rotating at the frequency dominant in the given hemisphere.

The most powerful rotation peaks lie near the differential rotation curve; however, the extent of the latitude zones at the dominant periods clearly indicates that the frequency is not consistent with the standard differential rotation curve in the zones adjacent to the central latitude. This fact tends to exclude the first hypothesis; i.e. the observation of dominant frequencies is probably *not* due to the presence of zones with longer lived tracers.

The second hypothesis implies instead that the emergence of photospheric field tracers is organized in a persistent large-scale pattern with different rotation periods in the two hemispheres. How this interacts with the evolution of field patterns once the flux reaches the surface is a subject for further study building on the models of Sheeley, Nash and Wang (1987).

The weak coupling of the rotation in the two hemispheres could be associated with a weak interdependence of the magnetic field systems originating in the two hemispheres. Such conditions are, for instance, expected in the model of the solar cycle driven by the dynamo action of the global-scale convective motions developed by Yoshimura (1975). The dynamo waves formed in the two hemispheres are independent in this model and only diffusion processes can make the entire magnetic field system to be coherent. Thus, the field systems generated in the two hemispheres can indeed have different characteristics.

One possible interpretation of the north-south asymmetry in the dominant periods and of the rigid rotation of the photospheric magnetic fields would be that the magnetic patterns of the surface magnetic flux observed in the two hemispheres originate at different depths of a solar convection zone whose rotation rate varies with depth. This hypothesis would imply that the subsurface patterns rotate rigidly over latitude zones 30° or 40° wide; these would correspond to zones of intense toroidal field in the convective shell. The variation of the strongest periodicity in the southern hemisphere would then be ascribed to a variation in depth of the level of the source of the surface fields during the cycle. This hypothesis is suggested by the difficulty of explaining the difference in rotation rate of the surface fields in terms of a difference in the latitude of the subsurface sources, due to the intrinsic symmetry of the pattern of the zonal magnetic flux with respect to the equator (Howard and LaBonte, 1981). The hypothesis of magnetic field rotating differently at different depths would also explain the coexistence of regions of enhanced rotation power in partially overlapping latitude zones. If this were the case, the rotation rate would indicate the depth of the layer where the emerging magnetic field originated.

Unfortunately results on the rotation of the convection zone from helioseismology analysis, indicate that the rotation rate is virtually constant with depth down to at least the base of the convection zone (Brown & Morrow, 1987; Harvey, 1988.)

The preferred frequencies could also be explained as a reinforcement of the periodic signal at the latitudes where the rotation rate of the rigid pattern matches the rate of the differentially rotating surface plasma. The rigid pattern would simply be different in the two hemispheres.

Alternatively, rigid rotation can also result as an effect of expansion of the field appearing at the surface from confined subsurface sources located at different latitudes in the two hemispheres. In this case, the magnetic flux originates from differentially rotating sources. The flux spreads in latitude while maintaining the original rotation rate. In this way surface flux over a wide latitude range has the same rotation rate as the source. The width of the rigid rotation latitude zone reveals the degree to which the field spread before its appearance at the surface of the sun. This may relate to the work of Hoeksema, *et al.* (1987) who found a very high meridional motion implied by the shape of large scale field patterns. It is more likely that local sources have a large latitudinal extent rather than that there is such a large meridional transport. The rotation rates of the two predominant sources of the field have to be approximately constant through the cycle, with latitude asymmetric with respect to the equator. The preferred latitudes and rotation rates would in this case be those of the confined subsurface sources. This may relate to the work of Bai (1988) who finds a very long lived periodicity in the occurrence of super-active regions and flares. Since the rotation belts are asymmetric with respect to the equator, we find a certain degree of difficulty in explaining why two asymmetric subsurface sources should generate a symmetric total magnetic flux pattern (Howard and LaBonte, 1981).

The analysis of the first harmonic of the dominant rotation frequencies indicates that the northern sources of photospheric field are organized according to a four sector configuration, while the southern source is probably organized in 2 sectors. The higher harmonics do not contribute significantly to structure of the coronal field or to the IMF. On the basis of the present results, it is possible to localize the sources of the two predominant periods of rotation, 27 and 28.5 days, found in the IMF by Svalgaard and Wilcox (1975) in a study of the long-term evolution of the IMF polarity. These periodicities are quite close to those of the photospheric magnetic field and, in addition, there is a correspondence in the longitudinal sector pattern associated with the dominant periodicities. In the IMF a 4 sector longitudinal structure is associated with the faster rotation of 27 days and a 2 sector structure with the slower one of 28.5 days. Therefore, we surmise that the sources of the two predominant periodicities present in the IMF are localized, at least in the last solar cycle, in different solar hemispheres: the source of the 27 day in the northern hemisphere, and of the 28.5 days in the southern hemisphere. Considering the results on coronal hole rotation obtained by Sheeley and Harvey (1981), we can conclude the correspondence in rotation rate and preferred latitudes suggests that coronal hole locations are organized according to the magnetic patterns which contribute to the dominant rotation signal in the photosphere. Furthermore, the IMF polarity, which is influenced by the large-scale coronal polarity patterns, has demonstrated approximately the same dominant periodicities for the last six cycles.

ACKNOWLEDGMENTS

The work at Stanford was supported in part by the Office of Naval Research under Contract NOO014-86-K-0085, by the National Aeronautics and Space Administration under Grant NGR 05-020-559, and by the Atmospheric Sciences Section of the National Science Foundation under Grant ATM 86-18263. J.T.H. and P.H.S. are grateful for several visits of E.A. to Stanford over an extended period that were instrumental in completing this study.

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