THE MEAN PHOTOSPHERIC MAGNETIC FIELD FROM SOLAR MAGNETOGRAMS: COMPARISONS WITH THE INTERPLANETARY MAGNETIC FIELD

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Abstract. Large-scale averages of daily solar magnetograms have been compared by cross-correlation with the interplanetary magnetic sector pattern during a $2\frac{1}{2}$ yr interval. A significant correlation was found at a lag of about $4\frac{1}{2}$ days, with the amplitude of the correlation depending on the area included in the magnetogram averages. The highest correlation was found when an area of one quarter of the solar disk was used, which is consistent with the idea that the photospheric features which are to be associated with the interplanetary sector pattern are large scale features.

1. Introduction

By viewing the Sun as a star, Severny *et al.* (1970) found a correlation between the photospheric magnetic field averaged over the visible disk and the interplanetary magnetic field sector structure. This average field was measured by letting light from all parts of the solar disk fall on the entrance aperture of the magnetograph and measuring the Zeeman splitting of the iron line $\lambda 5250$ Å in the resulting integrated light. One would expect to obtain similar results by measuring the field with the magnetograph operating in the normal method and averaging over large portions of the disk. We have compared large-scale averages of Mount Wilson Observatory daily magnetograms with the interplanetary sector structure for a $2\frac{1}{2}$ yr interval beginning in July 1967, and have seen that if one averages over the proper area of the disk, significant correlation results.

2. Observations

The photospheric field averages which we used in this analysis were available for the interval July 1967 through June 1970. Ten averages were found for each day's magnetogram by averaging the photospheric field included in ten concentric circles with radii 0.1, 0.2,..., 1.0 $R_\odot$. We have labeled both the circles and the resulting averages Disk 1 through Disk 10 with Disk 10 being the whole solar disk. Figure 1 is a schematic drawing of these disks with Disk 5 shown cross-hatched as an example. These

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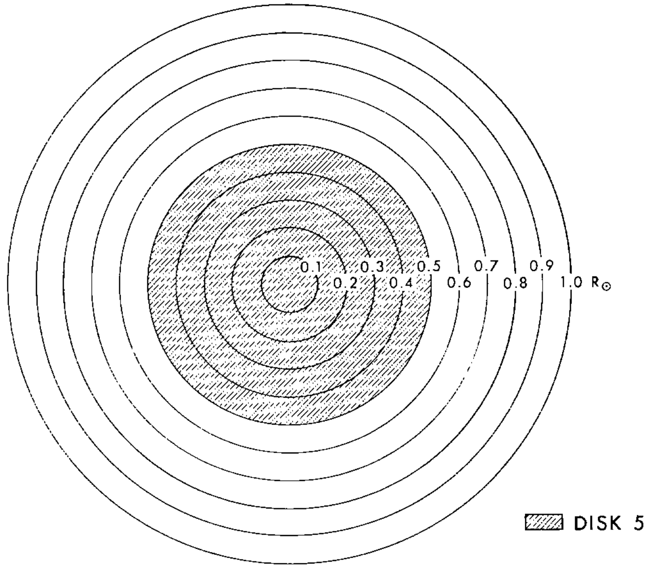

Fig. 1. Schematic drawing showing areas of disk averages of the photospheric magnetic field.

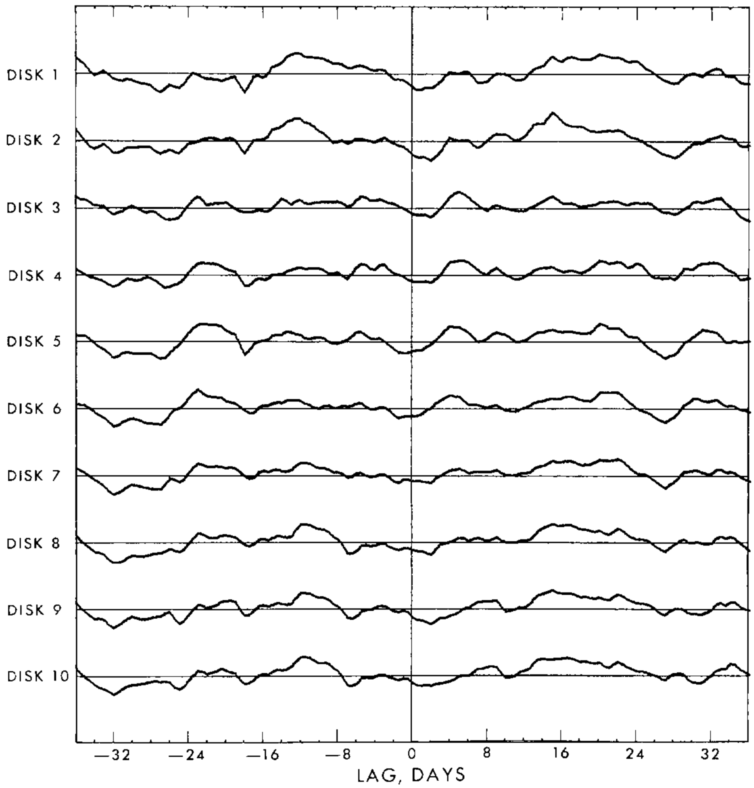

Fig. 2. Cross-correlation of disk averages of the photospheric magnetic field with interplanetary magnetic field polarity for the six months, July through December 1967. The curve near the line labeled 'disk 5' represents the cross-correlation of the disk 5 data for lags −36 to +36 days. The line labeled 'disk 5' represents a correlation coefficient of zero. The line labeled 'disk 4' represents a correlation coefficient of 1.0 for disk 5, and similarly the line labeled 'disk 6' represents a correlation coefficient of −1.0. All the other disk and ring correlations are in the same format.

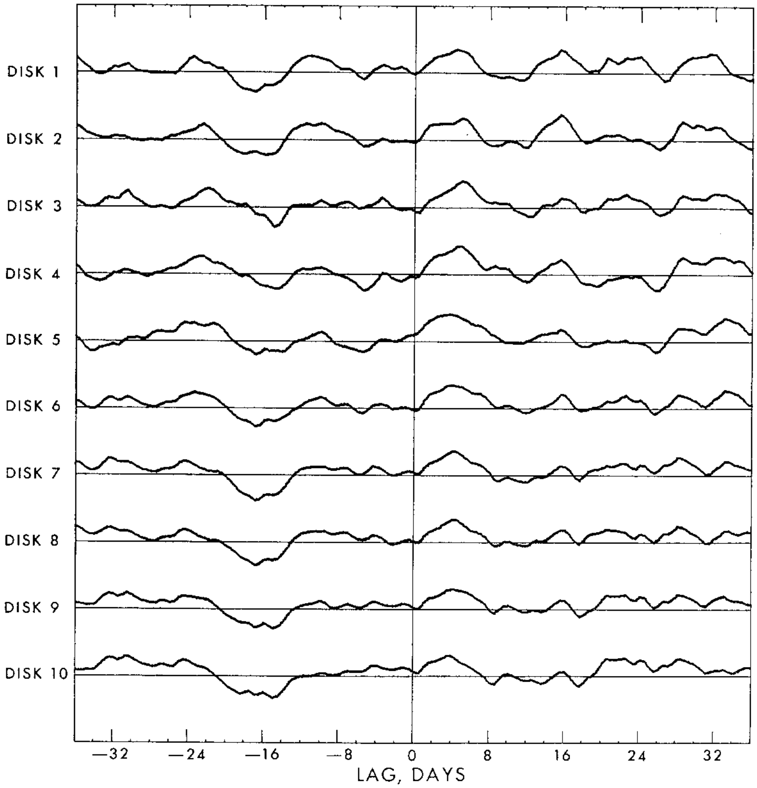

Fig. 3. Same as Figure 2, but for January through June 1968.

averages are simple averages of the magnetic signal from the magnetograph, correcting only for brigthness. No correction has been made for geometrical foreshortening or possible inclination of the lines of force to the line of sight. While averages over circular regions cannot show the existence of a north-south sector boundary in the photosphere, they do reveal how large an area on the Sun must be examined to see the interplanetary sector pattern.

The interplanetary sector pattern for 1967 through 1969 which was used for comparison with the solar averages was obtained from the Ames Research Center magnetometer experiments on Explorer 33, Explorer 35 and Pioneer 6 as reported by Wilcox and Colburn (1969, 1970, 1971). Only the polarity of the interplanetary field was used in this analysis.

3. Results

The cross-correlation functions between these disks and the interplanetary field polarity were found as a function of lag for various time intervals. Figures 2 through 6 show the results of these calculations for the disks for the five six-month intervals from July 1967 through December 1969. The main region of interest in these figures is the

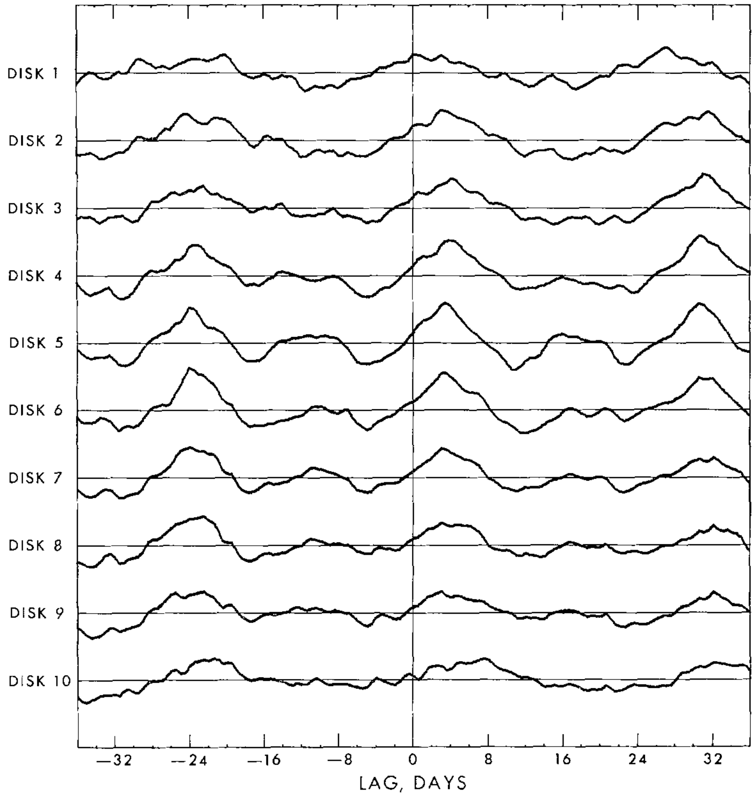

Fig. 4. Same as Figure 2, but for July through December 1968.

correlation at a lag of about $4\frac{1}{2}$ days corresponding to the transit time of the solar wind plasma from the Sun to the Earth, and the following discussion refers to this region.

Figure 2 shows that there is a significant correlation for Disk 3 through Disk 6 but no correlation for smaller or larger disks. This pattern of greater correlation for the middle size disks was also found when the $2\frac{1}{2}$ yr interval as a whole was correlated with the sector pattern. There are differences however in the results with individual six-month intervals. Figure 3 shows quite different results for the first half of 1968. In this interval there are similar peaks for all the disks. The next three six-month intervals also show that the amount of correlation at different disks fluctuates in time. In the last half of 1968 (Figure 4) there is correlation for all disks, but the peak at Disk 5 is the largest. In the first half of 1969 (Figure 5) the seven larger disks each have similar peaks. Finally, the last half of 1969 (Figure 6) shows good correlation only for the middle disks and is similar to the last half of 1967.

The pattern of correlation which we find for the disks, that is, small for small disks, increasing to disk 5, then decreasing for the larger disks, is consistent with the results of Schatten (1970). Our interpretation of these results follows.

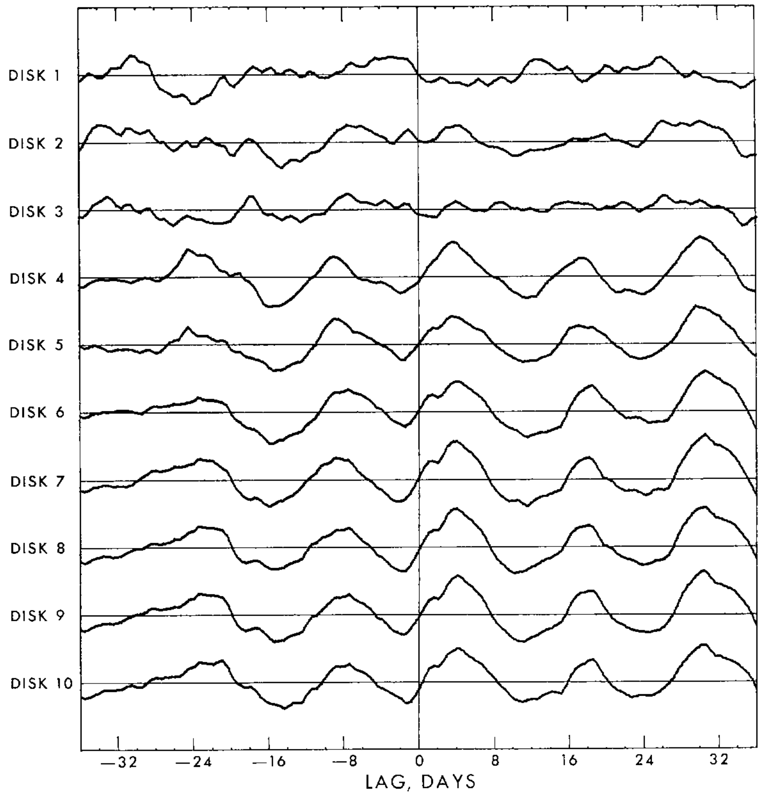

Fig. 5. Same as Figure 2, but for January through June 1969.

4. Discussion

The first conclusion that one draws from these results is that the most consistent correlation between daily magnetograms and the interplanetary field is found when the magnetograms are averaged over an area about equal to disk 5. If too small an area is used, no correlation results; and if the whole disk is used, sometimes lower correlation results.

It is our interpretation that the interplanetary sector pattern has its source in a large scale photospheric field pattern. This large scale pattern is understood to consist of weak background fields with large areas having predominately one polarity. Superimposed on this weak large scale field pattern are the bipolar fields of active regions (Wilcox, 1971). When the photospheric field is averaged over a 'small' area such as disk 1 or 2, there is a good chance that only half of some bipolar regions are included in the average, thus masking the weaker background fields. This is probably the reason that the smaller disks do not show significant correlations with the sector pattern. In order to see large scale patterns, one must look at large regions.

Since the interplanetary sector structure can usually be described as a pattern of

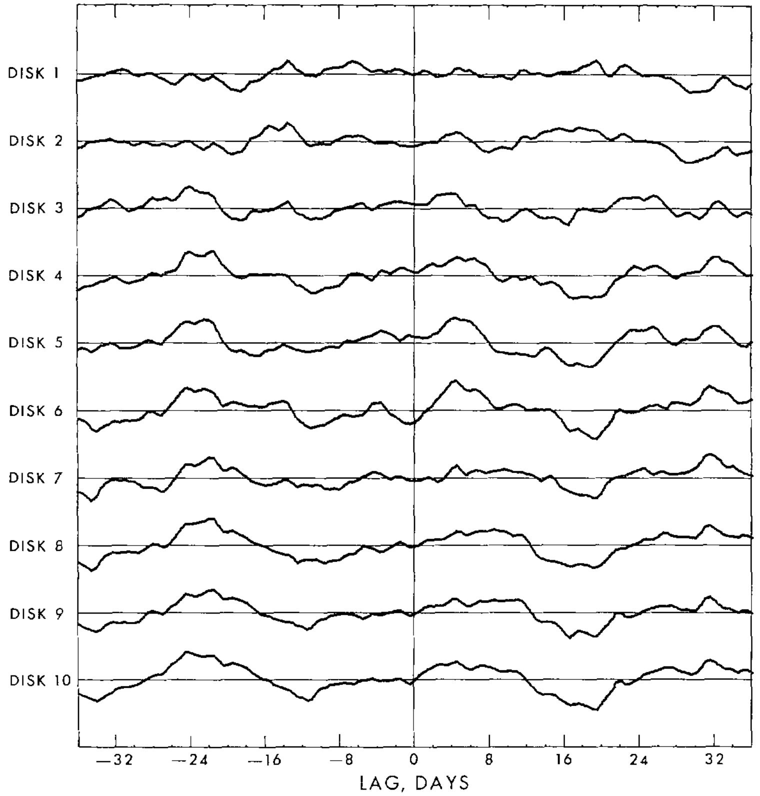

Fig. 6. Same as Figure 2, but for July through December 1969.

either two or four sectors per solar rotation, one might expect the underlying photospheric field pattern to show similar structure. In this case, as progressively larger areas are included in a photospheric field average, the probability increases that regions from several sectors with opposite polarity will be included in the average. In addition, radial magnetic fields near the limb are not as well measured as those near the disk center. We believe this explains the smaller correlation with the interplanetary field shown by the larger disks as compared to the mid-sized disks. Thus there seems to be an optimum area to be used for photospheric field averages if the object is to find the large scale field pattern.

Some comments should be made at this point concerning comparison of the disk type averages described here to the integrated light type of mean field measurements as described by Severny *et al.* (1970). It is possible that there may be different weighting of fields from different parts of the Sun in the two kinds of observations, because of limb darkening, changes in the line profile due to solar rotation, and possibly other causes. It turns out however that during the period for which integrated light observations are available (roughly half the period represented in Figure 3), the significant result in the comparison of correlations with different disks is that all the disks showed approximately the same correlation with the interplanetary field, just as in Figure 3. Thus no information about such a possible weighting could be found in this analysis.

The primary result that we have seen is that the interplanetary sector pattern can be seen in large-scale averages of the photospheric magnetic field and that, at least for the interval examined, an area equal to about one-fourth the area of the disk, centered on the disk, may be an optimum size for such averages.

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