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John M. Wilcox and David S. Colburn

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THE RISING PORTION OF THE SUNSPOT CYCLE*

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Technical Report

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Interplanetary Sector Structure in the Rising Portion of the Sunspot Cycle

John M. Wilcox
Space Sciences Laboratory
University of California
Berkeley, California

and

David S. Colburn
Ames Research Center
Moffett Field, California

Abstract

The interplanetary sector structure during the rising portion of the sunspot cycle in 1966 and 1967 has been investigated. The sector pattern is often quasi-stationary for a few rotations, followed by an appreciable change in the next rotation. When a sector boundary passes the earth geomagnetic activity tends to increase, an effect rather similar to that observed near sunspot minimum. The recurrence period of the interplanetary field during the interval investigated was 27.5 $\pm$ 0.1 days.

The interplanetary sector structure during the rising portion of the present sunspot cycle has been investigated using observations obtained with the Ames Research Center magnetometers on Explorers 33 and 35, for which C. P. Sonett is the principal investigator. Descriptions of the magnetometer experiments have been given in Mihalov et al. (1968) and Sonett et al. (1968).

In the present study the determination of sector polarity has been made in a manner similar to that previously used by Wilcox and Ness (1965). Three-hour average values of the azimuthal direction of the observed interplanetary magnetic field component parallel to the ecliptic are used. Although the direction of the interplanetary magnetic field is usually variable, an averaging interval of three hours almost always results in a direction that can be associated with a basic Archimedes spiral field directed either toward or away from the sun.

The present results have been added to Figure 13 of Wilcox (1968) and are shown here as Figure 1, in which the observed sector structure of the interplanetary magnetic field is overlayed on the daily geomagnetic character index C9. This figure provides an overall view of the sector structure from midway in the decline of the last sunspot cycle to midway in the rise of the present sunspot cycle. The first point to observe is that even though we are approaching the maximum of the solar cycle, the interplanetary field retains the property that almost always several consecutive days have the same polarity, with field predominantly either toward the sun or away from the sun. The sector pattern is often quasi-stationary for a few rotations, followed by appreciable change in the next rotation. Many of the solar rotations have just two magnetic sectors, a situation similar to that observed by Mariner 2 in 1962 (Coleman et al., 1966). Near solar minimum, in approximately the year of 1964, there were four magnetic sectors per rotation in a pattern that appeared to be quasi-stationary for over a year (Wilcox and Ness, 1965). Each of these sectors appeared to be a coherent entity, in the sense that several observed parameters of the interplanetary plasma and field had smooth and reproducible variations as a function of position within the sector.

The interplanetary sectors observed during the rising portion of the sunspot cycle do not necessarily have all the same properties as the sectors observed near sunspot minimum. For example, it has been suggested by Wilcox and Howard (1968) that the mature, quasi-stationary sectors observed near sunspot minimum may have had an appreciable extent in latitude (from perhaps 40°N to 40°S heliographic latitude), while a newly-formed sector observed during the rise of the sunspot cycle has been related to a photospheric bipolar magnetic region by Schatten et al. (1968), so that the extent in latitude of this young sector would be much more limited. Nevertheless, it might still be interesting to see if the sectors studied in the present investigation are at all similar in their effects on geomagnetic activity to the sector structure observed near solar minimum (Wilcox and Ness, 1965).

Figure 2 shows the sector structure as determined in the present investigation overlayed on a chart of planetary magnetic three-hour-range indices Kp (after Bartels). The relation between sector structure and geomagnetic activity can be examined in more detail with this figure. On at least three occasions, namely January 13, 1967, February 7, 1967 and November 3, 1967, a sudden commencement occurs near a sector boundary. A similar case was previously observed on December 2, 1963 (Wilcox and

Ness, 1965). Thus we see that a sudden commencement is not necessarily associated with a flare-induced shock wave, but may also be caused by a corotating sector boundary.

During the quasi-stationary sector structure at solar minimum, geomagnetic activity was observed to reach a maximum about two days after a sector boundary had passed. In the present investigation there is a tendency for geomagnetic activity to increase after the passage of a sector boundary, although there are also some exceptions. The average structure of geomagnetic activity with respect to a sector boundary has been investigated using the superposed epoch technique. Boundaries were selected in which the field polarity was the same for at least four days on each side of the boundary, i.e. reasonably well-established sector boundaries were considered. Sixteen boundaries in the present investigation met this criteria; they are listed in Table I. Figure 3 shows the resulting average response of the geomagnetic activity index Kp to these boundaries. The solid line in Figure 3 is the result obtained from the boundaries of the quasi-stationary sector pattern near solar minimum (Wilcox and Ness, 1965, Figure 11). Both sets of boundaries show a tendency for geomagnetic activity to increase for a day or two after a boundary has passed the earth, and then to decrease more or less monotonically.

Figure 3 shows that in the present investigation the peak in geomagnetic activity after passage of a sector boundary is reached approximately a day earlier than in the investigation of Wilcox and Ness (1965). In the earlier investigation, during more than half of the sector boundary passages the IMP-1 satellite was within the geomagnetic field and therefore unable to observe the boundary. In the present investigation 13 of the 16 boundaries are directly observed. Thus the difference in the position of the peaks in Figure 3 could be partly caused by an uncertainty of a fraction of a day caused by the frequent presence of IMP-1 in the geomagnetic field during sector boundary crossings.

The recurrence period of a structure that is evolving with time is inherently somewhat ambiguous, but an approximation to the recurrence period can be obtained with an autocorrelation technique. Figure 4a shows an autocorrelation of the direction of the interplanetary field observed with Explorer 33 from October 24, 1966 to May 3, 1967. Figure 4b is the same for observations with Explorers 33 and 35 from July 23, 1967 to February 9, 1968, and Figure 4c is an autocorrelation of both observations, i.e. from October 24, 1966 to February 9, 1968. In each of the three cases the recurrence period (as computed from the position of the centroid of the peak) is 27.5 ± 0.1 days.

Inspection of Figure 1 shows that near solar minimum the interplanetary magnetic field had a recurrence time of 27.0 ± 0.1 days (Wilcox and Ness, 1965, Figure 6). During the rising portion of the new sunspot cycle in 1965 the interplanetary field had a recurrence time of 28.0 ± 0.1 days (Ness and Wilcox, 1967), and in the present investigation in 1966 and 1967 during the further rise of the sunspot cycle the recurrence period was 27.5 ± 0.1 days. Thus the average heliographic latitude of the solar source of the interplanetary field observed near earth may have changed from about 15°N during solar minimum (Wilcox and Ness, 1967) to a higher heliographic latitude near the start of the new sunspot cycle, and then declined as the cycle progressed. A more quantitative discussion will be given in a paper on the rotational characteristics of the large-scale photospheric magnetic field.

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Wilcox, J. M. and N. F. Ness, Solar source of the interplanetary sector structure, Solar Physics, 1, 437-445, 1967.

Figure Captions

Fig. 1. Observed sector structure of the interplanetary magnetic field, overlayed on the daily geomagnetic character index C9, as prepared by the Geophysikalisches Institut in Göttingen. Light shading indicates sectors with field predominantly away from the sun, and dark shading indicates sectors with field predominantly toward the sun. Diagonal bars indicate an assumed quasi-stationary structure during 1964.

Fig. 2. Interplanetary sector structure observed with Explorers 33 and 35 overlayed on a chart of planetary magnetic three-hour-range indices Kp (after Bartels). Dark shading is field polarity toward the sun and light shading is field polarity away from the sun. Most of the gaps are caused by the position of the satellite being within the geomagnetic field, but intervals of ambiguous polarity occurred on November 16-18, 1966, August 30-31, 1967, October 28-31, 1967 and December 16-18, 1967. The gap on January 1-2, 1968 is related to a complex sector boundary.

Fig. 3. Superposed epoch analysis of the magnitude of the planetary magnetic three-hour-range indices Kp as a function of position with respect to a sector boundary. The abscissa represents position with respect to a sector boundary, measured in days, as the sector pattern sweeps past the earth. The solid line represents similar results obtained near solar minimum (Wilcox and Ness, 1965, Figure 11).

Fig. 4. Autocorrelations of the interplanetary magnetic field direction. a) is for observations from October 24, 1966 to May 3, 1967; b) is for July 23, 1967 to February 9, 1968; and c) is for October 24, 1966 to February 9, 1968. For a), the top line represents an autocorrelation coefficient of 1.0, the second line represents 0.0, and the third line represents -1.0. b) and c) are displaced downward in a similar format.

Table I Occurrence time of sixteen sector boundaries used in the superposed epoch investigation shown in Figure 3. (October 30, 1966, 5-6 means that in terms of the three-hour averages used in the present investigation, the sector boundary occurred between the fifth and the sixth three-hour intervals on October 30, 1966.)

Table I

Date	Interval	Date	Interval
October 30, 1966,	5-6	August 30, 1967,	6-7
December 4, 1966,	3-4	September 6, 1967,	6-7
January 1, 1967,	7-8	September 27, 1967,	3-4
January 13, 1967,	3-4	October 3, 1967,	1-2
January 18, 1967,	6-7	October 24, 1967,	2-3
February 7, 1967,	3-4	December 4, 1967,	5-6
March 22, 1967,	7-8	January 2, 1968,	2-3
August 4, 1967,	5-6	January 28, 1968,	8-1

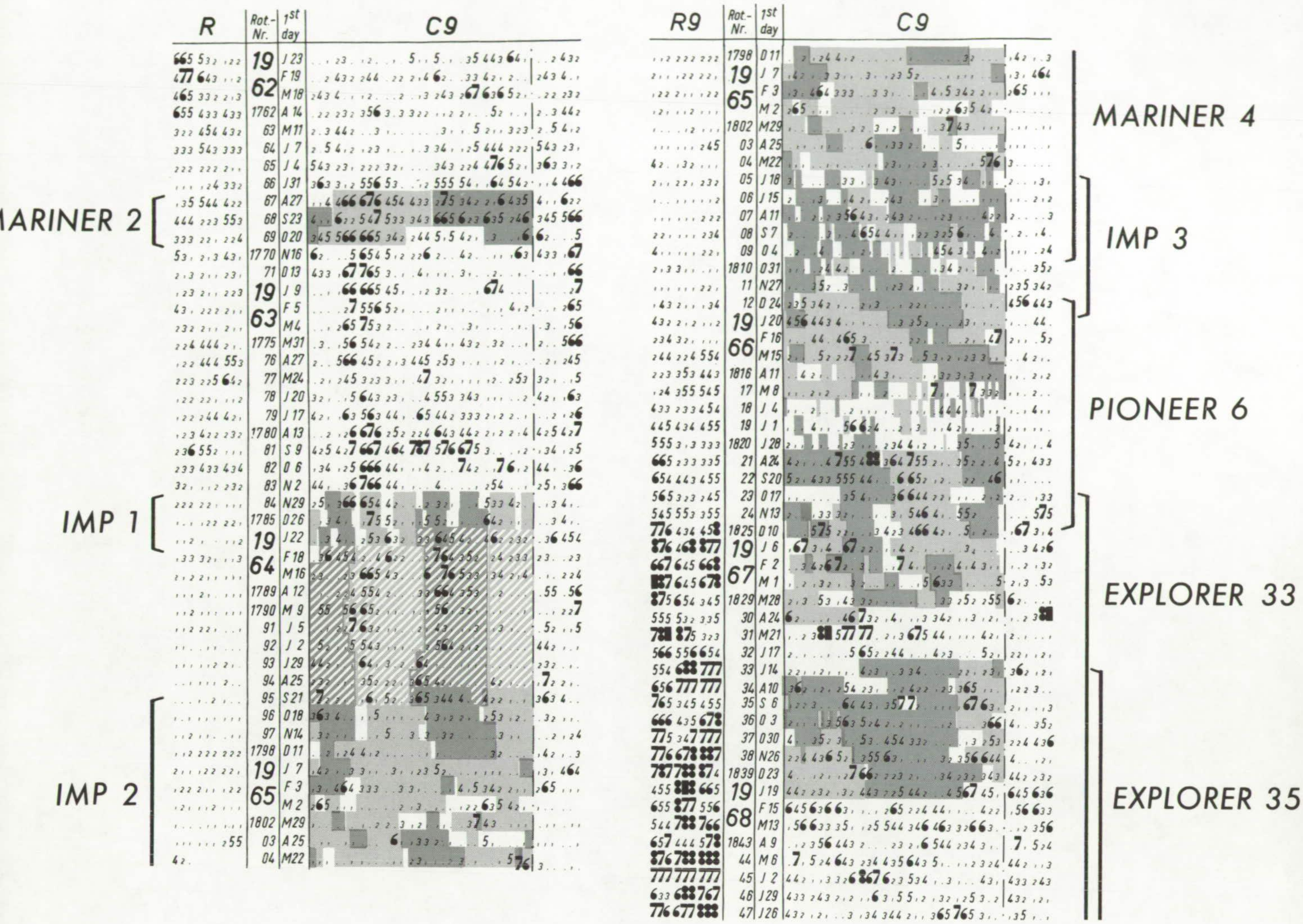

R
Rot.-Nr.
1st day
C9
R9
MARINER 2
IMP 1
IMP 2
MARINER 4
IMP 3
PIONEER 6
EXPLORER 33
EXPLORER 35

Figure 1

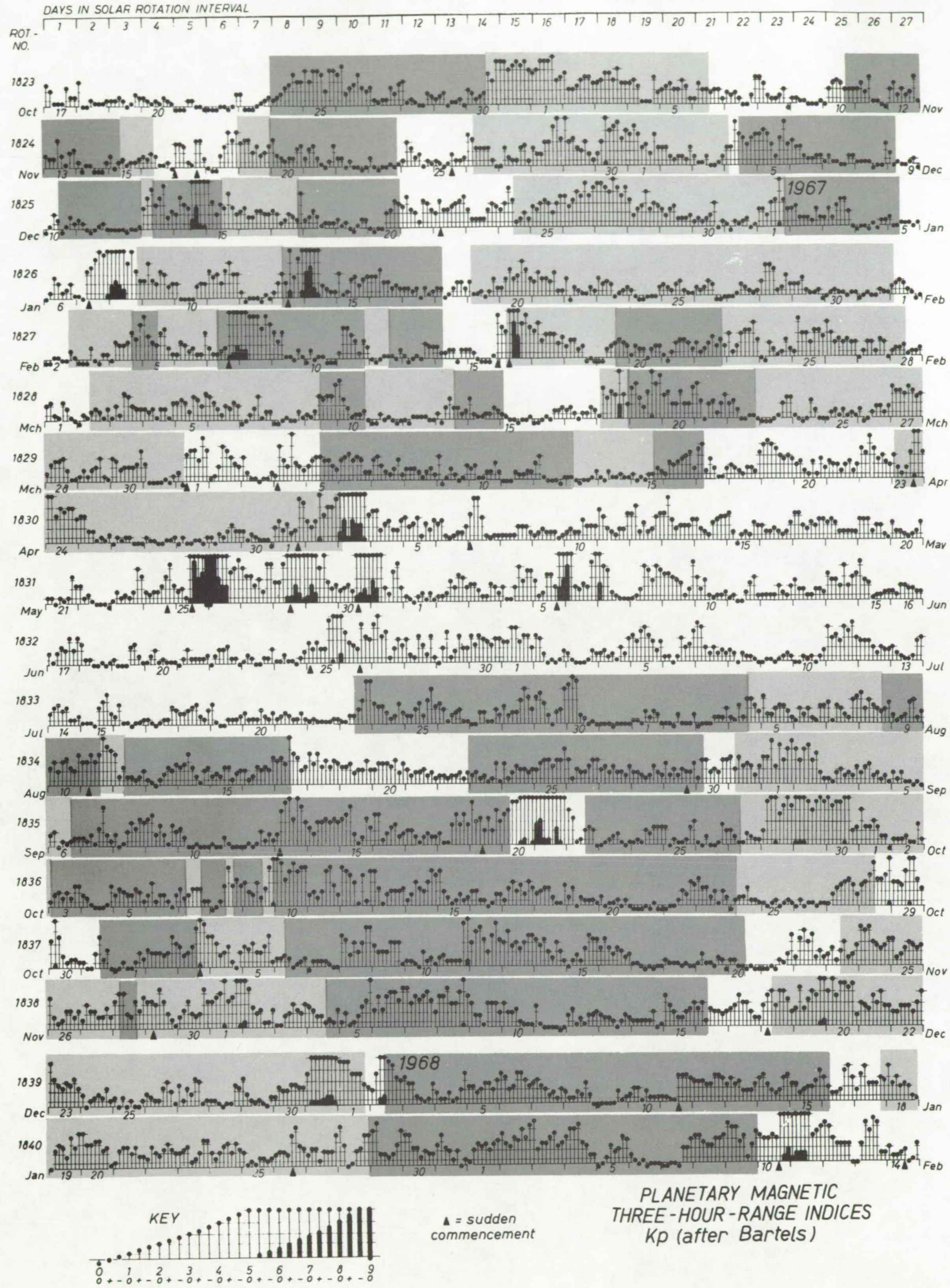
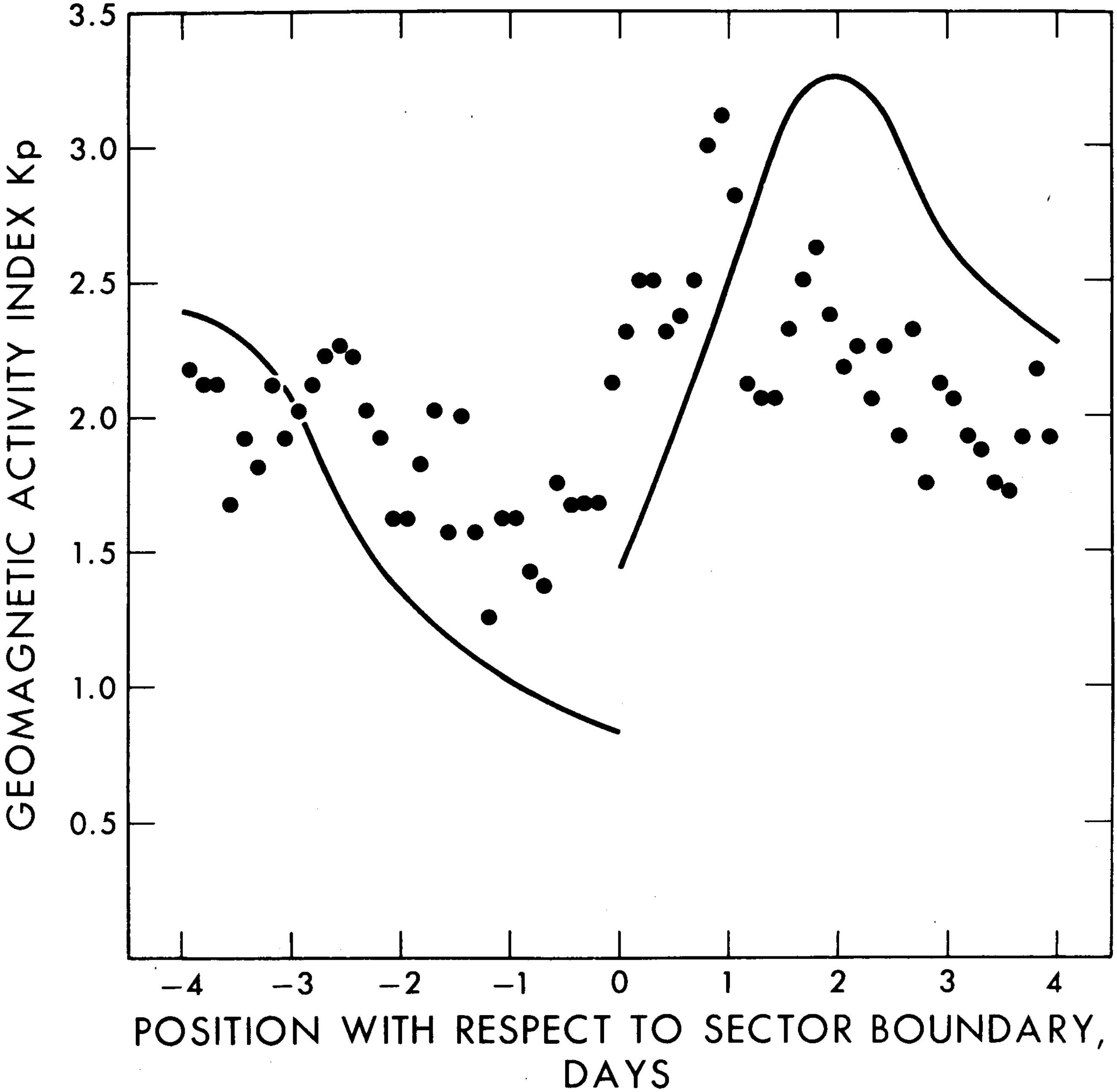

DAYS IN SOLAR ROTATION INTERVAL
ROT-NO.
1967
1968
KEY
▲ = sudden commencement
PLANETARY MAGNETIC
THREE-HOUR-RANGE INDICES
Kp (after Bartels)

Figure 2



3.5
3.0
2.5
2.0
1.5
1.0
0.5
GEOMAGNETIC ACTIVITY INDEX Kp
−4
−3
−2
−1
0
1
2
3
4
POSITION WITH RESPECT TO SECTOR BOUNDARY, DAYS

Figure 3

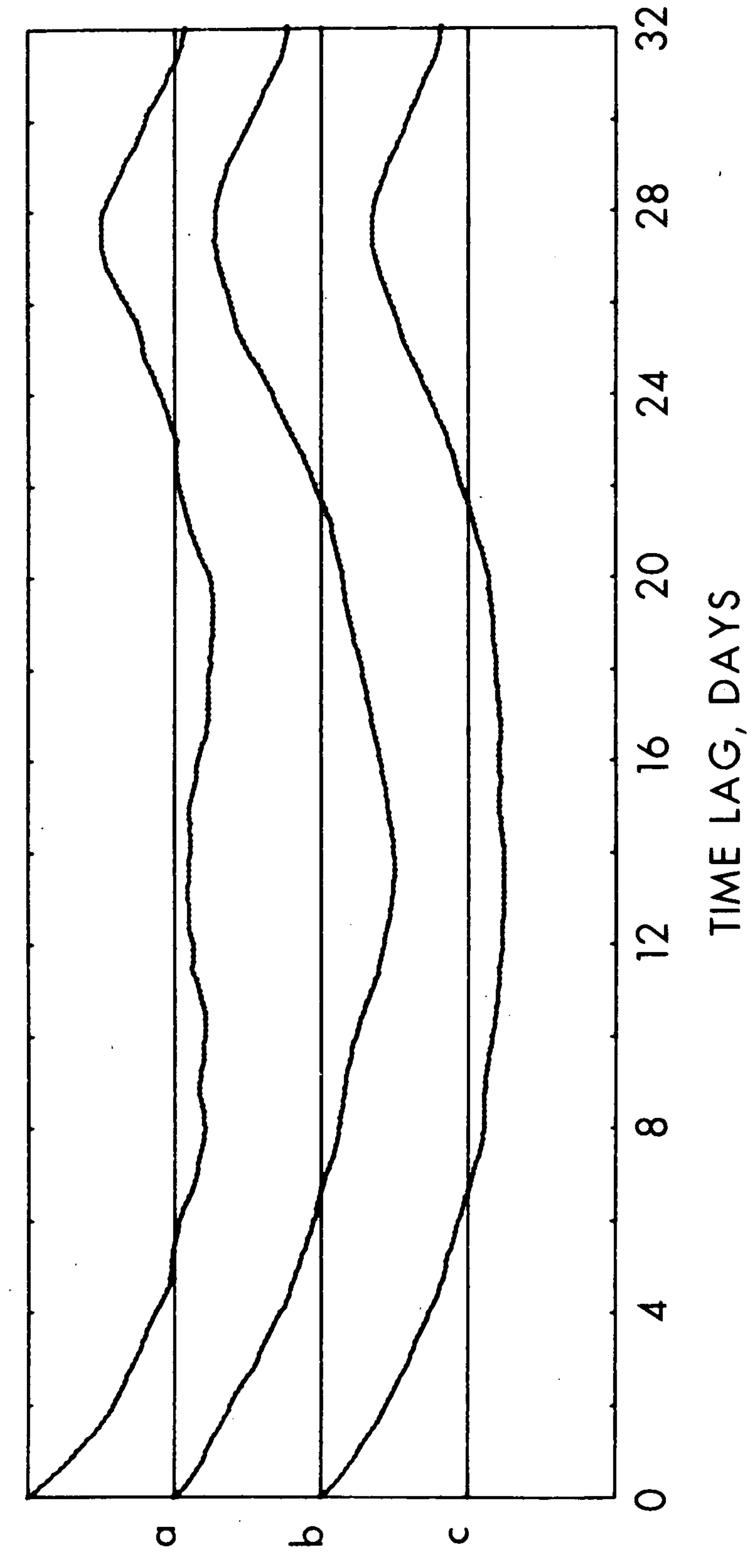


Figure 4

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13. ABSTRACT

The interplanetary sector structure during the rising portion of the sunspot cycle in 1966 and 1967 has been investigated. The sector pattern is often quasi-stationary for a few rotations, followed by an appreciable change in the next rotation. When a sector boundary passes the earth geomagnetic activity tends to increase, an effect rather similar to that observed near sunspot minimum. The recurrence period of the interplanetary field during the interval investigated was 27.5 ± 0.1 days. (U)