Interplanetary Magnetic-Sector Structure, 1926–1971

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The influence of the direction of the interplanetary magnetic field on the geomagnetic field at high latitudes is used to study the long-term behavior of the sector structure during nearly four solar cycles. It is found that the rotation period of the sector structure varies from about 28.5 days in the beginning of a solar cycle to 27.0 days in the end. Also it is shown that short-lived sectors rotate more slowly than long-lived ones.

Geomagnetic effects related to the interplanetary magnetic field. A relation between the polarity of the interplanetary magnetic field and the type of diurnal variation of the geomagnetic field inside the polar cap has been discovered independently by *Svalgaard* [1968], *Mansurov* [1969], and *Mansurov and Mansurova* [1970] and noted by *Iwasaki* [1971]. The relationship has been confirmed by *Friis-Christensen et al.* [1971]. The most pronounced effect, a broad perturbation of the geomagnetic field lasting for several hours, is found in the vertical component Z of the field on stations near the invariant poles. Figure 1 shows magnetograms from the near-conjugate stations Thule (86.8° invariant latitude) and Vostok (−84.9° invariant latitude). To increase readability, all magnetograms in this paper have been redrawn on the basis of hourly mean values. When the earth lies in a polarity sector of the interplanetary magnetic field away from the sun, the Z perturbation is directed away from the earth; in a sector toward the sun the perturbation is directed toward the earth in both hemispheres. As is seen from the magnetograms, it is easy by visual inspection to distinguish two types of disturbances. This is the basis of the following simple classification scheme.

A day is classified as type C if the Z magnetograms from the near-pole stations for that day show a broad positive perturbation between magnetic noon and local noon; a negative perturbation classifies the day as type A. An observer using magnetograms from a southern polar-cap station should adopt the definition that a positive Z perturbation is directed toward the earth. In general, the regularity of the magnetograms leaves little doubt about the type of perturbation. With very few exceptions it is possible to classify every day. Figure 2 shows some sequences of Z records from Resolute Bay (84.3° invariant latitude). It is clearly seen that the same type persists through several days. In some of the sequences a change of type is demonstrated.

This classification was actually developed be-

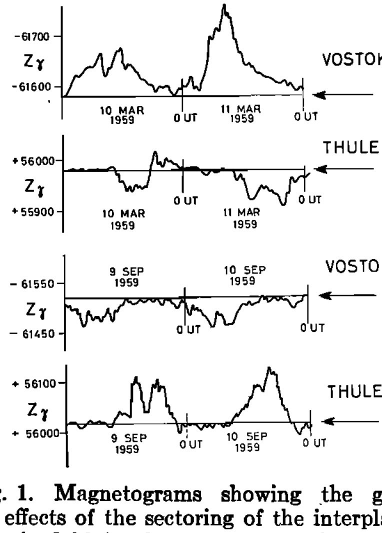

Fig. 1. Magnetograms showing the geomagnetic effects of the sectoring of the interplanetary magnetic field in the sector away from the sun (top) and in sector toward the sun (bottom) at Thule (86.8° invariant latitude) and Vostok (−84.9° invariant latitude). The quiet undisturbed fields are indicated by arrows.

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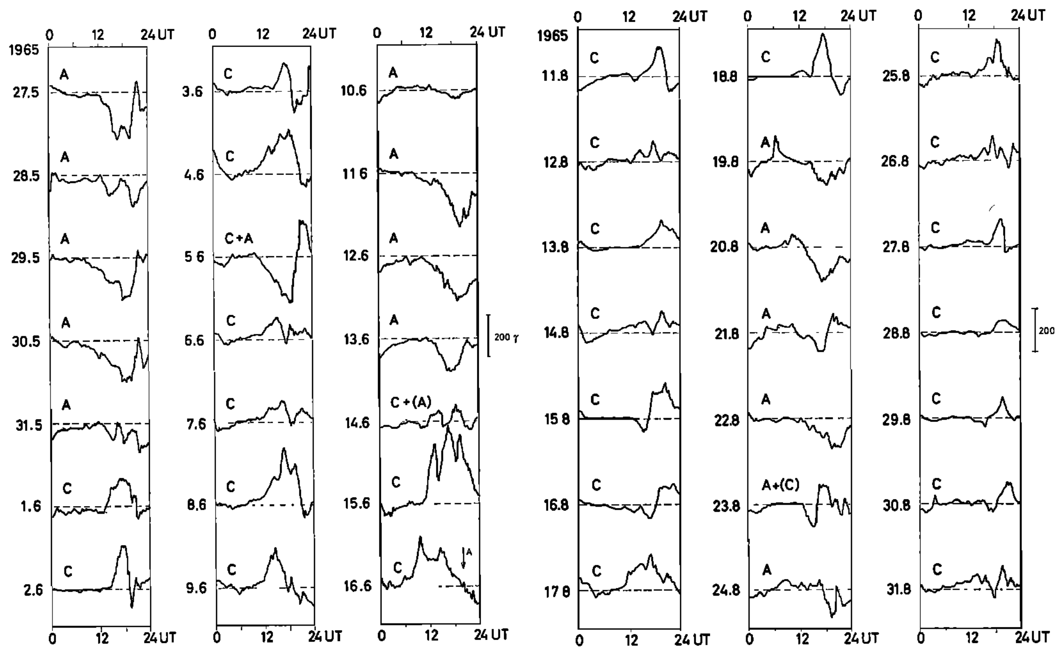

Fig. 2. Series of consecutive records of the vertical component Z of the geomagnetic field at Resolute Bay. The notation 27.5 means May 27, 28.5 is May 28, and so forth.

fore the relationship with the sector structure was discovered. When the sector structure of the interplanetary magnetic field was discovered [*Wilcox and Ness,* 1965], it became evident that A variations dominated during away sectors, whereas C variations were found during toward sectors.

Figure 3 compares the observed sector structure with the A-C classification as derived from Canadian IQSY stations for 1964–1965. This classification uses the Z records from stations with an invariant latitude of about 85°. The Z perturbations decrease with increasing distance from the invariant poles. Instead they turn into a perturbation of the horizontal component H. For a station such as Godhavn (77.5° invariant latitude) the H component increases on A days and decreases on C days. Figure 4 shows the relation between deviations of daily mean values from the monthly mean for Z at Thule and H at Godhavn. The relation is so close that the H magnetograms from Godhavn may as well be used to infer the type of day. As a matter of fact, during the winter months it is often easier to base the classification work on Godhavn H records than to base it on Thule Z records. The magnetic observatory at Godhavn has been operating continuously since 1926. This unique series of magnetograms is the basis of the investigation of the long-term behavior of the sector structure presented in the last part of this paper.

Sector polarity since 1926. A table presenting the result of an A-C classification of each day since February 1, 1926, has been prepared, but because of its great length only the last 10 years are given in this paper; the complete table may be obtained in machine readable form from the author. The full table is also published by *Svalgaard* [1972]. Several important conclusions may be drawn from this material. An autocorrelation analysis of the class of the day during the whole period 1926–1970 is illustrated by Figure 5. A recurrence property is clearly evident.

The recurrence peaks have been labeled with the number of recurrence periods that they represent. The recurrence period may be interpreted as the average rotation period of the sector structure. In Figure 6 it seems that the more stable the recurrence (high peak numbers) is, the faster the pattern rotates. In other words, short-lived sectors rotate more slowly than long-lived ones. A similar effect has been discovered in an analysis of the interplanetary magnetic field observed by spacecraft [*Wilcox and Tanen-*

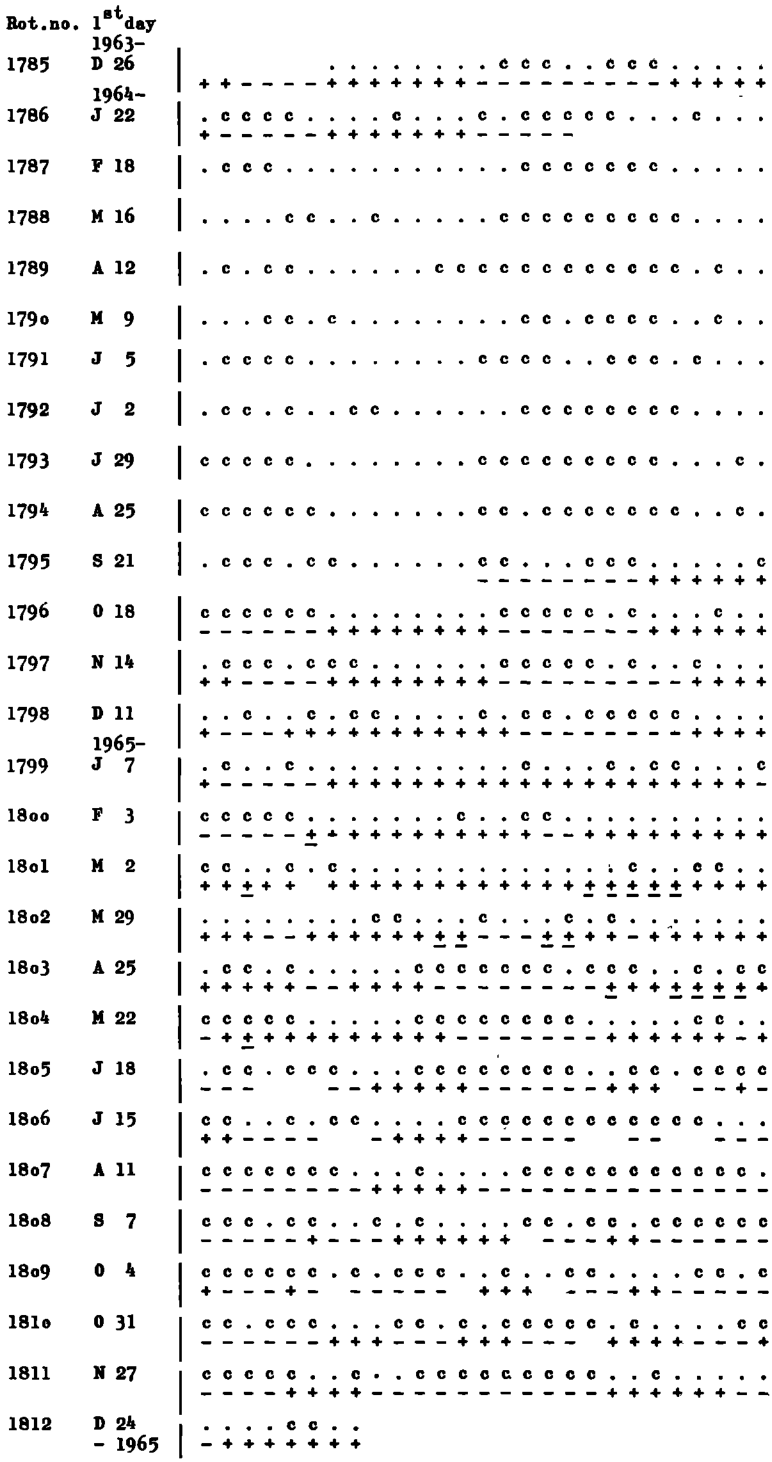

Fig. 3. Comparison of the observed sector structure with the A-C classification. Plus indicates interplanetary magnetic field directed away from the sun, minus indicates field directed toward the sun, dots indicate type A daily variations, and *c* indicates type C variations of the vertical component *Z*. The data are ordered in sun rotation periods. (Reproduced from *Svalgaard* [1968].)

TABLE 1. Negative (A) and Positive (C) Perturbations for 1962–1971

Month	Classification by Day						
1962							
January	AAAAA	ACCCC	CAACC	CAACA	AAAAA	AAAAA	A
February	AAACC	CCAAA	CCCCC	CAAAA	AAACA	CAA	
March	ACCAC	CAAAC	CCAAA	AAAAC	CAACC	AAAAC	A
April	AACAA	CCCCC	CCAAA	AAAAA	ACAAC	ACCCC	
May	CCAAA	CAAAA	CAAAC	CAAAA	AAAAA	ACCAA	C
June	ACCCC	CAAAA	AAAAA	AAAAA	CACCC	CCCCC	
July	AAAAA	ACAAA	AACAC	AAAAC	CAACA	CCCCA	A
August	AAAAA	ACAAA	AAACC	CCCCA	ACCCC	AAAAA	C
September	AAACC	AAACC	CCCCC	AAACA	CCACC	AAAAA	
October	CCAAA	AACCC	CCCCA	CACCC	ACCCA	CACCC	A
November	ACACA	CCCAA	CAACC	CAAAA	CCCAC	AAAAA	
December	AAACC	ACCCC	CCCCC	ACCCC	CCAAA	CAAAA	C
1963							
January	CAACC	CCCCC	CCCAA	CAACA	AAAAA	AAAAC	C
February	CCAAA	CCCAA	ACCAC	AAAAA	AAAAA	AAA	
March	ACACC	CCCCA	CAAAC	ACCCC	ACAAC	AAACA	A
April	CAAAA	AAAAC	CCCCC	CCCAA	ACCCA	ACAAC	
May	AACCA	AACCC	CCACA	AAAAC	CACAC	CCAAA	A
June	AAAAC	ACCCC	ACCAA	CCCAC	AAACA	AAAAC	
July	AAACC	CCACC	ACACC	ACACC	AAAAA	AAAAC	C
August	CCCAC	ACACA	ACCCC	CCAAA	ACAAC	CCCCA	A
September	CACCC	ACCCC	ACCAA	AAAAA	CCACC	CCACC	
October	AAACC	ACCAA	AAAAA	AAAAA	ACCCA	CAAAC	C
November	CCCCA	CCAAA	AAAAA	ACCCA	CCACC	CAAAC	
December	CCCCC	AAAAA	AAACC	CCCCC	ACCCA	AACCC	C
1964							
January	AAAAA	AAACC	CAACC	CAAAA	AACCC	CAAAA	C
February	AAACA	CCCCC	AAACA	AAACC	CAAAA	AAAA	
March	AAACC	CCCCC	AAAAA	AAAAC	CAACA	AAAAC	C
April	CCCCC	CCAAA	AACAC	CAAAA	AACCC	CCCCC	
May	CCCCA	CAAAA	ACCAC	AAAAA	AAACC	ACCCC	A
June	ACAAA	CCCCA	AAAAA	AACCC	CAACC	CACAA	
July	AACCA	CAACC	AAAAA	ACCCC	CCCCA	AAACC	C
August	CCAAA	AAAAA	CCCCC	CCCCA	AACAC	CCCCC	A
September	AAAAA	ACCAC	CCCCC	CAACA	ACCCA	CCAAA	
October	AAACC	AAACC	CAAAA	ACCCC	CCCAA	AAAAA	A
November	CCCCC	ACAAA	CAAAC	CCACC	CAAAA	AACCC	
December	CCACA	ACAAA	AACAA	CACCA	AAACA	CCACC	C
1965							
January	CCAAA	AACAA	CAAAA	AAAAA	ACAAA	CACCA	A
February	ACCCC	CCAAA	AAAAC	AACCA	AAAAA	AAA	
March	ACCAA	CACAA	AAAAA	AAAAA	ACAAC	CAAAA	A
April	AAAAA	CCAAA	CAAAC	ACAAA	AAAAA	CCACA	
May	AAAAC	CCCCC	CACCC	AACAC	CCCCC	CAAAA	A
June	CCCCC	CCCAA	AAACC	AAACC	ACCCA	AACCC	
July	CCCCC	AACCA	CCCCC	CAACA	CCAAA	ACCCC	C
August	CCCCC	CCAAA	CCCCC	CCAAA	CAAAA	CCCCC	C
September	CCCCC	ACCCA	CCAAC	ACAAA	ACCAC	CACCC	
October	CCCCC	CCCCA	CACCC	AACAA	CCAAA	ACCAC	C
November	CACCC	AAACC	ACACC	CCCAC	AAAAC	CCCCC	
December	CAACA	ACCCC	CCCCC	AACAA	AAAAA	AACCA	A
1966							
January	AAAAA	AACAC	ACAAA	AACCC	CCCCC	AAAAA	A
February	AAAAC	AAAAC	CCCAA	AAAAA	CAAAA	AAA	
March	AAACC	CCAAA	CACCA	ACAAA	CACCA	AAAAC	C
April	CCACC	CCAAA	AAACA	CAAAA	CAACC	AAACA	
May	CCCCA	AAAAC	AAAAA	CCCCC	AAAAA	ACACC	C
June	CCCAA	AACCC	CCCAC	AAACA	CACCC	CCCCC	
July	CCCCA	AACAC	CCAAC	CAAAC	CCCCA	CCACC	C
August	AAAAC	CACCA	AAAAA	AACCC	CCCAC	CCCCC	C
September	ACCAC	AAAAA	AAACC	CCCCA	CCCCC	CCCCA	
October	AACAA	AAAAA	CCCCC	ACCCC	CACCC	CCCCC	A

TABLE 1. (continued)

Month	Classification by Day					
November	CAAAA	CACCA	CCCCA	CCCCA	CCCAA	CCAAA
December	AAACA	CACCC	ACCCA	CAAAC	CAAAA	ACAAA C
1967						
January	CCCAA	AACAC	CCCCC	CCAAA	CAAAA	AACCC A
February	AAAAC	ACCCC	CCCAC	AAAAA	ACAAA	AAC
March	AAAAA	ACCCC	CAACA	AAAAC	CCAAA	AACAA A
April	AACCA	ACACC	CCAAA	CCCCC	CCAAA	AAAAA
May	AACCC	AAACC	CCCCC	CCACC	ACAAA	CCACC C
June	CCAAA	CCCAC	AACCC	ACCAC	CCCAC	CCCCA
July	ACAAA	AACCC	CCCCC	ACCAC	ACCCC	CCCAA A
August	ACCCC	AAACC	CCCCA	CCCCC	CCAAC	CAACC A
September	AAAAA	CCCCC	CCCCA	CCCAA	CCCCC	AAAAA
October	ACCCA	ACAAC	CCCCC	CACCC	CAAAA	ACCAC C
November	AACAA	AACCC	CCACA	CCCCA	CCCCA	ACCAA
December	CCAAC	AACCC	AAACA	CCCCC	AAAAC	CAAAC C
1968						
January	CAACC	CACCC	CAAAC	AAAAA	AAACC	AAACA C
February	CCCAC	CAAAA	AAAAA	CCCCC	AAAAA	ACCC
March	CCCCC	CCCAA	AAAAC	AAACC	ACCCC	CCAAC C
April	CCACA	AAACC	AAAAC	ACAAC	CCCCA	CCCAC
May	AAAAA	CCAAA	AACCC	CCCCC	CCCCC	CCAAA C
June	CCAAC	AAACA	CACCC	CCCCA	CCAAA	ACCCC
July	CAAAA	AAACC	CCCCC	AAAAA	AAACC	CACCC A
August	AAACC	CCAAA	CAACA	AAACC	CCCCA	CCCCA A
September	CCACC	CAAAA	AAAAA	AAACC	CCCCA	AAAAC
October	AACCC	AAAAC	AAAAA	ACACC	CCCCC	AAACC C
November	CACAA	AAAAA	ACACC	CCCCC	CACAA	ACCAC
December	CCCCA	AAAAC	AAAAC	CCCCA	CAAAA	AAAAA C
1969						
January	CCCCC	CCCCC	CCCAC	CCAAA	AAAAA	CAAAA A
February	CCCCC	CCACC	CCCCA	AAAAA	AAAAA	AAA
March	AAACC	CCCCC	CCCCC	CACCC	CCCCA	AAAAA A
April	ACCCC	CCCCA	ACCAC	CCACA	AACAA	AACCC
May	CCCCC	CAAAA	ACCCA	CCAAA	AAAAA	ACACC C
June	CCCCC	AACCA	ACAAA	AAAAA	ACCCC	CCCAC
July	CCACA	CCCCA	AAAAA	AACAA	CCCCC	CCCAA A
August	CCCAC	CAAAA	AAAAA	CCCCC	CCCCC	AACAC C
September	CCCAA	ACCAA	AAAAA	AACCC	CACCC	CCCCA
October	AAAAA	AAAAA	AAAAC	CCCCC	CCCCC	CCAAA A
November	AAAAA	ACAAC	CCCCC	CCACC	CCCCC	ACACC
December	AAAAA	CCCCA	CCCCC	CCCCA	CACAC	CAAAA A
1970						
January	ACAAC	CCCCA	ACCCC	CCCAA	AAACA	AACCC A
February	AACCC	CAACA	ACCCA	CCAAA	AACAA	AAC
March	CCCAC	AACAA	CCACA	AAAAA	ACAAA	AAAAC C
April	AAACA	ACAAA	AAACA	CCCAA	ACCCC	CCCCA
May	AAAAA	AAAAC	ACCCC	CAAAC	CCCCC	CCAAA A
June	CCAAC	AACCC	CCCCC	CCACC	CACAA	ACAAC
July	AAAAC	CCCAA	CCCCC	CCAAC	ACAAA	ACCAC C
August	CCCCA	ACCCC	CCCCC	ACAAC	AAAAA	AAAAA A
September	CCCAC	CCCCC	CAAAA	AAAAA	AAAAA	AAACC
October	CCCAC	CCCCC	AAAAA	AAAAA	CAACA	ACACC C
November	CCCCA	ACCAA	AAAAA	ACCAA	AACCC	AACAC
December	CCCCA	CAAAC	AAACC	AAAAA	AACCC	CCCCA A
1971						
January	AAAAA	ACCCC	AAAAA	AACAC	CCCCC	AAACC C
February	CACCC	CAAAA	AAACC	CCCCA	CCACA	CAA
March	ACACC	CAAAA	AACCC	ACCCC	CCAAA	CAAAA C
April	CAAAC	AAACC	CCCCA	ACAAA	AACAA	ACCAA
May	AAACA	CACCC	CCCCC	AAAAA	ACACC	CCCAA A
June	CCCCC	CACCC	CACAC	AAACA	AAACA	AAACC

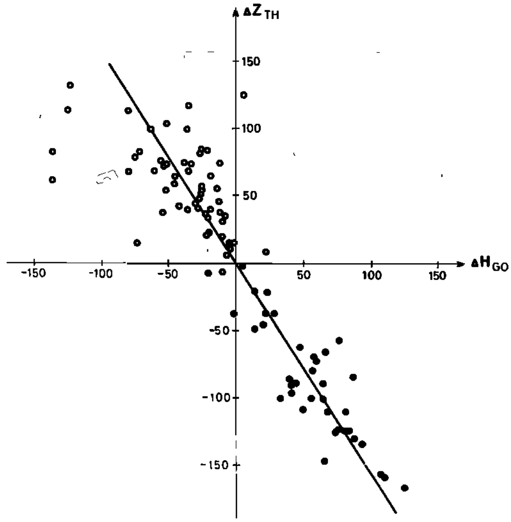

Fig. 4. Relationship between deviations of daily mean values from the monthly mean for Z at Thule and H at Godhavn. Data points are from June to August 1959. Solid circles denote days within inferred sectors away from the sun, and open circles days within inferred sectors toward the sun.

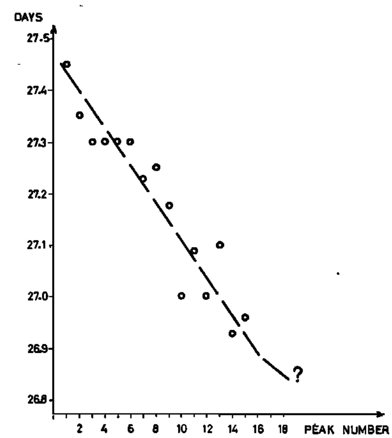

Fig. 6. Recurrence period for the direction of the interplanetary magnetic field compared with the number of the recurrence peak.

baum, 1971] and in an analysis of the photospheric magnetic field [*Wilcox et al.,* 1970].

To examine the variation of the average period of the sector structure through the sunspot cycle, autocorrelations were computed for each year from 1926 to 1970. The observation that years with the same phase within the solar cycle have very similar autocorrelation curves then justifies computing an average autocorrelation curve for all years having the same relative position within the sunspot cycle. This set

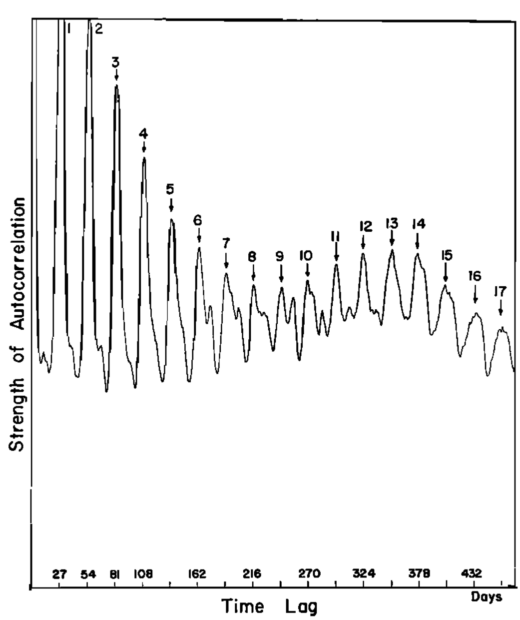

Fig. 5. Autocorrelation of the direction of the inferred interplanetary magnetic field, 1926–1971.

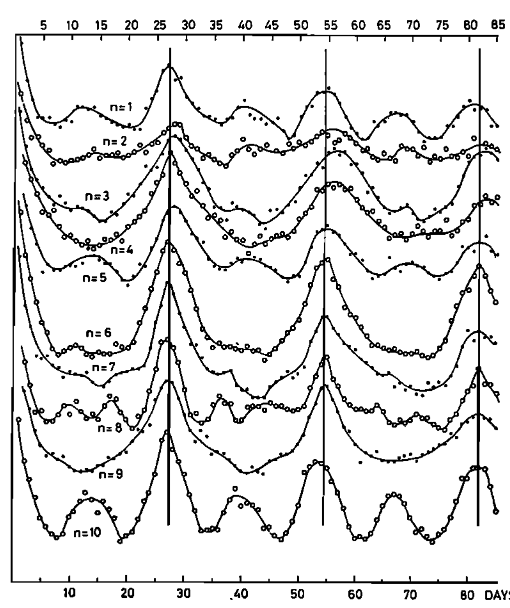

Fig. 7. Autocorrelations of the direction of the inferred interplanetary magnetic field for different years in the sunspot cycle. The number n denotes years following sunspot minimum.

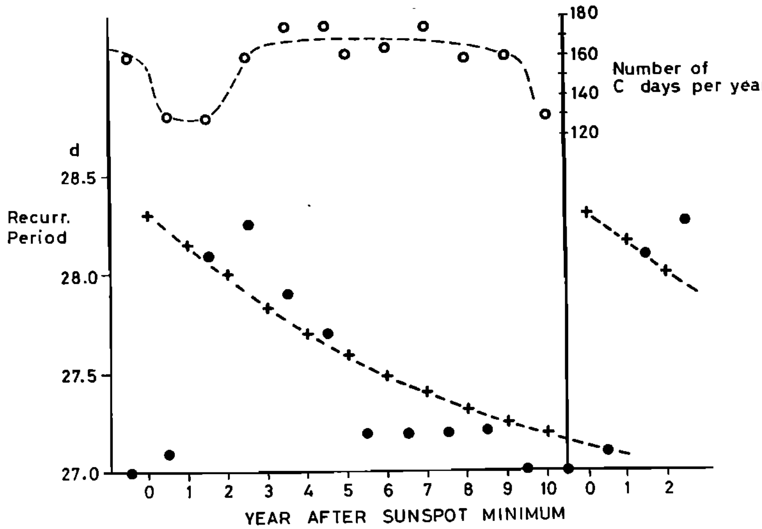

Fig. 8. Average recurrence period for the sector structure (solid circles) during the solar cycle. Also shown are the average rotation period for sunspots (crosses) and the number of C days, or polarity toward the sun, per year (open circles).

of curves is shown in Figure 7. The recurrence period shows a systematic variation through the cycle (Figure 8). Near sunspot minimum the period is 27.1 days. With the rise of the new high-latitude solar activity the recurrence period increases sharply to 28.3 days; with the progress of the cycle the period decreases and remains rather constant at about 27.2 days during the last half of the cycle. The variation of the recurrence period resembles the variation of the rotation period of sunspots through the solar cycle.

Just around sunspot minimum the number of C days per year (days with the probability of a sector toward the sun) is significantly smaller than that during the rest of the cycle. Often it seems as if the C sectors are dying away just at minimum. When the new activity starts, it begins rather erratically with no well-developed sector structure. After sunspot maximum the sector structure is usually well defined before it disappears again near the next minimum. The disappearance usually happens within one or two solar rotations and may provide an independent way of determining the time of the beginning of the next cycle. Also near minimum there is a high probability for the occurrence of a four-sector structure, as is seen from the secondary peaks in Figure 7 for $n = 1$ and $n = 10$.

Table 1 includes a prediction of the sector polarity during 1970 and the first half of 1971. This prediction will make possible a strong test of the connection between the A-C effects and the sector polarity in the sense that the structure predicted is not just an extrapolation of that of 1969 but includes the disappearance of a sector and the creation of a new one having a different phase.

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REFERENCES

Friis-Christensen, E., K. Lassen, J. M. Wilcox, W. Gonzalez, and D. S. Colburn, Interplanetary magnetic sector polarity from polar geomagnetic field observations, *Nature, 233,* 48, 1971.

Iwasaki, N., Localized abnormal geomagnetic disturbance near the geomagnetic pole and simultaneous ionospheric variations, *Rep. Ionos. Res. Space Res. Jap., 25,* 163, 1971.

Mansurov, S. M., New evidence of a relationship between magnetic fields in space and on earth, *Geomagn. Aeron., 9,* 622, 1969.

Mansurov, S. M., and L. G. Mansurova, The relationship between the magnetic fields in space and at the earth's surface, *Ann. Geophys., 26,* 397, 1970.

Svalgaard, L., Sector structure of the interplanetary magnetic field and daily variation of the geomagnetic field at high latitudes, *Pap. 6,* Dan. Meteorol. Inst. Geophys., Charlottenlund, Denmark, 1968.

Svalgaard, L., Interplanetary magnetic sector structure 1926–1971, *Pap. 29,* Dan. Meteorol. Inst. Geophys., Charlottenlund, Denmark, 1972.

Wilcox, J. M., and N. F. Ness, Quasi-stationary corotating structure in the interplanetary medium, *J. Geophys. Res., 70,* 5793, 1965.

Wilcox, J. M., and A. S. Tanenbaum, The influence of solar differential and rigid rotation on the interplanetary magnetic field, *Space Sci. Lab. Rep., Ser. 12,* issue 45, Univ. of Calif., Berkeley, June 1971.

Wilcox, J. M., K. H. Schatten, and A. S. Tanenbaum, Photospheric magnetic field rotation: Rigid and differential, *Solar Phys., 14,* 255, 1970.

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