On the Use of Godhavn
H-Component as an Indicator of
the Interplanetary Sector Polarity

by

Leif Svalgaard

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Abstract

An objective method of inferring the polarity of the interplanetary magnetic field using the H-component at Godhavn is presented. The objectively inferred polarities are compared with a subjective index inferred earlier (Svalgaard, 1972b). It is concluded that no significant difference exists between the two methods. The inferred polarities derived from Godhavn H is biased by the S_q^p signature in the sense that during summer prolonged intervals of geomagnetic calm will result in inferred Away polarity regardless of the actual sector polarity. This bias does not significantly alter the large-scale structure of the inferred sector structure.

ON THE USE OF GODHAVN H-COMPONENT AS AN INDICATOR OF
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Fougere and Russell (1974) suggest that evaluation of the accuracy
of the inferred interplanetary sector polarity (Svalgaard, 1972a) is dif-
ficult due to the subjective nature of the inferred index and further due
to the apparent lack of a detailed recipe on how to infer the sector polarity
from polar cap magnetograms. It is the purpose of the present note to pro-
vide one such recipe, and also to show that the quality of the published
list of inferred polarities going back to 1926 (Svalgaard, 1972b) is not
seriously affected by the fact that for most years before 1964 only one
station (Godhavn, $77.^{\circ}5$ invariant latitude) was used in deriving the list.

The above statements should be qualified by noting that the recipe
which will be presented certainly is not the perfect recipe, but it has the
virtue of belonging to a class of recipes which are very simple yet still
useful. Furthermore, the extent to which the inferred index (the so-called
A/C index) is useful depends somewhat on the purpose of the analysis. Just
as the Kp index does not give meaningful results when used for deriving the
diurnal variation of geomagnetic activity, there may well be (and apparently
are (Fougere, 1974)) limitations inherent in the present A/C index, which
may preclude its application to certain problems without affecting its use-
fulness in other areas.

In the original A/C classification, a day was classified as type C
(associated with Toward sector polarity) if the Z-magnetograms from near-
polar stations show a broad positive perturbation around local noon; a neg-
ative perturbation would classify the day as of type A (associated with Away
polarity). It was found that the amplitude of these perturbations of the
vertical component Z decreased with increasing distance from the invariant
poles. Instead, perturbations are found in the horizontal component H.
The sense of the H-perturbations is opposite of the sense of the near-pole
Z-perturbations. Figure 1 shows the average diurnal variation of the H-

component at Godhavn for 1950. The curves labelled A and C are the average variations during days classified by Svalgaard (1972b) as being of type A and of the type C, respectively. The all-day average variation is also shown in the figure. A six-hour interval around 18^hUT is delineated by two stippled lines. In this interval, the largest differences between the A- and the C- type variation occurs.

If a Godhavn H-magnetogram for a given day shows a definite local maximum within the interval 15^h - 21^hUT, the day is classified as type A, while a definite local minimum or depression will classify the day as type C. This recipe leaves room for a type B, when the variation is irregular during the interval of interest. It turns out that type B occurs rarely enough ($\approx$15% of the time) to make the A/C type classification meaningful. Originally a choice was made such that every day was classified only in terms of A or C.

The local maxima and minima (or enhancements and depressions) used to determine the type of the daily variation appear to be superposed on the normal diurnal variation, which is roughly sinusoidal. The amplitude of this background curve varies greatly with season and with disturbance level. To a certain degree, the quality of the A/C index is then dependent upon how well the background can be discerned and removed. This in turn demands some familiarity with the Godhavn magnetograms. The situation is analogous to the problem of determining Bartels' K-index. This index is basically a subjective index, because its determination requires recognition and subsequent removal of the normal, undisturbed diurnal Sq variation, which itself varies from day to day or even may change character during the day. In case of an isolated K-disturbance, the background reference level can normally be interpolated on the magnetogram using the quieter intervals before and after the disturbance. Similar considerations apply for the determination of the A/C index; and just as for the K-index, the difficulty in removing the background has the largest influence when scaling small disturbances.

A simple approach to the problem of removing the background level is as follows: In Figure 2, data for May 1968 is plotted such that during the interval 15^h- 21^hUT the actual variation of the horizontal component at Godhavn is shown for each day, while for all other times simply the monthly mean value of H is shown. The figure is then composed of a straight line interrupted each day by the (very time-compressed) actual H-trace. If H has a local enhance-

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ment within the interval of interest (15^h- 21^hUT), a positive spike will result for that day on Figure 2, while a depression will show as a negative spike. Figure 2 just displays a series of such spikes. The sector polarity as measured by spacecraft (Wilcox and Colburn, 1970) is indicated for each day on Figure 2 with a + (Away) or a - (Toward) placed near the spike for that day. Generally we see the familiar pattern, that a positive spike is associated with Away polarity and a negative spike is associated with Toward polarity. In a few cases a mixed signature is seen, but the data in Figure 2, as well as similar plots for other months of 1968 is in good accordance with the result of Friis-Christensen et al. (1971) that the A/C signature may be used to infer the sector polarity with a accuracy exceeding 85%. Part of the remaining uncertainity is related to the observation (Friis-Christensen et al. (1972)) that the sign of the azimuthal component of the interplanetary magnetic field rather than its polarity seems to determine the sign of the A/C perturbation.

The apparent success of the very simple procedure used in preparing Figure 2 in producing features (spikes) which correlate well with the interplanetary sector polarities as measued by spacecraft suggests the following formal recipe for assigning a character (A, B, or C) to a UT day characterizing the inferred IMF polarity.

1. Use the horizontal component, H, at Godhavn.

2. For each day within a given month, subtract the monthly mean value of H from the hourly means of H.

3. Set the reduced values of H equal to zero for all hours outside the interval 15^h- 22^h UT, thus simulating the base-line on Figure 2.

4. Determine the maximum value, HA, and the minimum value, HC, for each day. Due to the previous step we will generally have that HA≥0 and HC≤0.

5. If HA> -HC/2 then classify the day as type A, else if HC< -HA/2 then classify the day as type C, else classify the day as type B.

Using this recipe, the A/C index has been redeterimined for an interval in 1968 and compared with spacecraft measurements of the interplanetary magnetic field polarity. The result is shown in Figure 3. Even with this very crude recipe, which certainly is inferior to the visual judgement of the experienced observer, we obtain almost 80% agreement between the A/C index and

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the sector polarity. The larger scale features of the sector structure are well defined by the A/C index, and this seems to be the case independent of season. The point we are trying to make is that as long as we concentrate on the interval of the day where the A/C effects are largest, we obtain very reasonable agreement between the A/C index and the sector polarity, even if the classification procedure is as rough as the one discussed above.

We shall not at this point discuss how much better one could do by using other stations at even higher latitudes such as Thule or Resolute Bay or by using more elaborate (and possibly more subjective or shrewd) techniques for removing the background level. Instead, we will note that by using only the Godhavn station and the simple recipe described above it seems possible to determine the large scale features of the sector structure exhibited by the interplanetary magnetic field.

Figure 4 shows Godhavn H plotted in the same format as in Figure 2, but for April 1950 when no spacecraft measurements of the interplanetary medium were available. Unless we assume that the response of the magneto-sphere to the interplanetary magnetic field has changed between 1968 and 1950, we may again associate positive spikes with Away polarity and negative spikes with Toward polarity. Also shown in Figure 4 are the original visual estimates of the A/C index by Svalgaard (1972b). Generally we find that in-ferred Away polarity is dominant on days of type A, while inferred Toward polarity is predominant on days of type C as originally suggested by Svalgaard (1968). This correspondence is further evidenced by Figure 5, where the original visual estimates are compared with the inferred polarities determined using the algorithm given above for each day of 1950. In all the cases we have examined here, the agreement between the various estimates and determi-nations is of the order 80% or better.

Having established that the A/C index most of the time is well cor-related with the polarity of the interplanetary magnetic field, the few cases with obvious disagreements command particular attention. If the dis-agreements depend systematically on other properties of the disturbance pat-tern, which is a very reasonable assumption, it may have a strong influence on some of the statistical properties of the A/C index. Let us assume that the five international quiet days in a month always (for some reason) are classified as being of type A, while the five disturbed days always are classified as type C. The remaining twenty days are classified correctly.

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If geomagnetic activity were independent of the sector polarity, $2\frac{1}{2}$ inter-
national quiet days and $2\frac{1}{2}$ international disturbed days would be classified
wrongly, meaning that out of the 30-day month, 25 days were classified cor-
rectly corresponding to 83% agreement. We now assume that the quiet days
have a C_i character figure of 0, the disturbed days a C_i character figure
of 2, and that the remaining days are moderately active with a C_i character
figure of 1. The average C_i figure for type A days then becomes $(10 * 1 +
5 * 0)/15 = 0.67$, while the average C_i figure for type C days becomes $(10 *
1 + 5 * 2)/15 = 1.33$, or twice as high.

This idealized example shows that the A/C index well can have a high
information content (83% agreement) yet be systematically contaminated such
that C days appear much more active than A days. How serious this particular
systematic error will be depends of course on to what research problem the
A/C index is applied. One such application was the confirmation by Wilcox and
Scherrer (1972) of a finding by Rosenberg and Coleman (1969), that the
polarity of the interplanetary magnetic field measured out of the solar equa-
torial plane should be biased by the polarity of the magnetic pole of the sun
that is on the same side of the equator as the interplanetary probe.

When the interplanetary sector structure was first discovered (Wilcox
and Ness, 1965) during the decending phase of sunspot cycle #19 there were
four stable sectors. Analyses of the inferred field using the A/C index
(Svalgaard, 1973) show that this four-sector pattern is a persistent feature
of at least the last five sunspot cycles. The main conclusion from the
analysis of the A/C index was that the solar sector structure evolves through
rather similar patterns in each sunspot cycle. During most of the cycle a
four sector structure with synodic recurrence period near 27 days is apparent.
Near sunspot maximum there emerges a superposed structure having polarity in-
to the sun with a width in longitude of about 100° and a synodic recurrence
period between 28 and 29 days. This "$28\frac{1}{2}$ day feature" co-exists with the
basic underlying four sectors for extended periods of time. It may at these
times be difficult to discern the four-sector structure clearly, but when the
$28\frac{1}{2}$ day structure disappears or weakens some time after sunspot maximum, the
four-sector structure becomes very prominent as the cycle progresses toward
sunspot minimum. This evolutionary scheme has been observed directly by
spacecraft during the present cycle and the A/C index seems to indicate that
the sunpot cycle variation of the sector structure is rather similar also in

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the previous four cycles.

If would seem that the A/C index, even in its present form, can be used to study the large-scale evolution of the sector structure through the sunspot cycle. For other kinds of study, such as the average disturbance level for the two polarities separately, it seems equally certain that a revised A/C index will be needed. A dilemma arises between conflicting views on how this index should be constructed. Should it be a homogeneous index derived from the Godhavn station only, but covering the full interval from 1926 to the present? Or should it be the "best possible" index in the sense that whenever additional stations are available, they should be utilized to improve the index? A case can be made for both points of view. The list published by Svalgaard (1972b) is not a homogeneous list because additional data from other polar cap stations (mostly Thule) was used when available (mostly after 1963).

Using published yearbooks from the Godhavn Geophysical Observatory and the recipe given above, a homogeneous A/C index could be produced. Analysis of statistical properties of this index may show various differences between polarities, seasons or sunspot cycles. It would not be possible to establish which of these differences were due to artifacts in the index or due to real physical changes. A more constructive approach would be to intensify the study of polar cap geomagnetic variations, because it seems to the present author that a purely mechanical recipe based on a few initial observations is not the proper solution to the very important problem of inferring the interplanetary magnetic field.

As Rostoker (1974) points out, the study of polar cap disturbances is still on unsure ground and large arrays of observatories need to be set up to allow researchers to separate out the magnetic effects of many contributing current systems. The observed magnetic perturbation pattern in the polar cap may stem from (1) the distant effect of the auroral electrojets, (2) the high-latitude Sq current flow, (3) cross polar cap ionosphere currents associated with magnetospheric convection, (4) the effects of distant field-aligned currents penetrating the auroral oval and (5) the special vortex-like currents associated with variations in the azimuthal components of the interplanetary magnetic field. Varying degrees of activity produce dramatically different mixtures of all these effects, and much work remains to be done before those possible contributions can be separated out. A mechanical

procedure which is not based on physical understanding can only provide a crude
first approximation to the physical reality under study. But even an approx-
imation can be very useful if applied within its limitations.

Returning to the discussion of interplanetary signatures in the geo-
magnetic field we shall study the reason why some quiet days appear to show
the A-signature at Godhavn irrespective of the actual sign of the azimuthal
component of the interplanetary field. Figure 6 shows the typical variation
of Thule Z and Godhavn H for a few days around the sector boundary passing
on July 25, 1968. These days are moderately to weakly disturbed. At Godhavn,
we note the normal night maximum - indicated by T on the Figure - and the
morning mimimum - indicated by S. These features occur regularly every day
independent of sector polarity. Both features invariably appear enhanced
during magnetically active intervals. In addition, we note the characteristic
signatures associated with the interplanetary field. A noon and afternoon
positive perturbation indicated by A -correlated with Eastward-pointing inter-
planetary magnetic field, and the negative perturbation -indicated by C-
associated with a Westward interplanetary field. The Thule records also show
dramatic change of the diurnal variation as the sector boundary passes. We
emphasize that the typical signatures are reversed at the two stations, maxi-
mum at one corresponds to mimimum at the other and visa versa.

However, this is not always the case. During intervals of prolonged
geomagnetic calm, Thule Z still shows the correct signature corresponding to
the interplanetary field, while Godhavn H develops a peculiar perturbation
resembling very much the A-signature. This happens even if the interplanetary
magnetic field is Westward - which should produce a C-signature. Figure 7
shows a good example of this phenomenon. During four consecutive days, the
interplanetary magnetic field is steady Westward and geomagnetic activity is
very low. Thule Z shows a clear C-signature on each day. All of what is left
of a C-signature in Godhavn H is a minor depression around 21^h UT. Other-
wise a positive perturbation - denoted with a P on the records - in the after-
noon is prominent in the diurnal variation. Without knowledge of the Thule
magnetograms, these four days would be classified as being of type A because
the P-perturbation has a strong resemblence with the A-signature. In fact,
Figure 3 shows that these four days actually are classified as type A.

What we are seeing here are examples of the S_q^p variation, which may
be observed on quiet days in the polar regions (e.g. Kawasaki and Akasofu (1973)).

Figure 8 shows the average S_q^p variation at Godhavn and it is now clear that many quiet days may have been classified as type A due to the similarity of the A-signature with the S_q^p variation. With increasing activity the P-maximum in Figure 8 decreases and the S-minimum gets deeper which may cause the day to be classified as a type C. The S_q^p variation thus introduces a bias in the A/C classification (when based on Godhavn H) in the sense that quiet days have a greater possibility of being classified as type A, while disturbed days have a greater possibility of being classified as type C. This systematic bias is expected to be most effective if the interplanetary signature is weak i.e. if the interplanetary magnetic field strength is small. Furthermore, the bias reflects the changing size of the polar cap. On an internationally quiet day the polar cap is small and Godhavn is heavily in-fluenced by the S_q^p currents flowing near the day-side polar cap boundary. With increasing activity the polar cap expands, and Godhavn becomes a true polar cap station situated well within the polar cap boundary and the in-fluence of the S_q^p currents is weaker. Since the size of the polar cap is determined by the North-South component of the interplanetary magnetic field (Akasofu et al, 1973) it seems reasonable to fit the observed values of H to an expression of the form:

$$H = H_o + a \cdot BY + b \cdot BZ \qquad (1)$$

where BY and BZ are the East-West and the North-South components of the interplanetary magnetic field, and H_o is a slowly varying background field. It is well known that H_o has a yearly variation of the order of 30γ. It is not known why. Furthermore, H_o has a roughly sinusoidal daily variation of the order of 80γ. The coefficients a and b change during the day as shown in Figure 9, and also change with the seasons being larger during summer. The values plotted are averages of the twelve monthly values obtained by fitting (1) separately for each month of 1968. Figure 10 gives some in-dication of the kind of fit which may be obtained using the very simple ex-pression (1). In computing the least-square fits hourly averages were used; due to the fact that on time-scales of an hour or more BY is generally greater than BZ and because a>b we see that the effects of BY are generally greater than those of BZ during the day-hours, while the opposite is true during the night-hours where a approaches zero. Roughly speaking then we might say that normally BY-related variations dominate during the day while BZ-related vari-ations dominate during the night. The same conclusion was also reached by

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Kawasaki et al, (1973).

Then, to the extent that fluctuations of BZ average out over a time scale of a few hours, Godhavn H is a fair indicator of the East-West component of the interplanetary magnetic field. Only when BZ has constant sign for extended time intervals does its influences dominate over that of BY and systematic errors are introduced into an index of sector polarity based exclusively on Godhavn H. These systematic errors will have large importance in a study of the average disturbance properties of the two different polarities, but will be of minor or no importance in a study of the long-term evolution of the interplanetary sector structure.

Acknowledgements

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Fig. 1. Diurnal variation of the horizontal component at Godhavn during 1950. The curves labelled A and C are the average variations on days classified as being og type A and of type C, respectively. In the interval delineated by stippled lines, the largest difference between the two types occurs.

Fig. 2. Data for May 1968 plotted such that during the interval $15^h- 21^h$ UT the actual variation of the horizontal component at Godhavn is shown for each day, while for all other times the monthly mean value is shown as straight line segments. (see text)

Fig. 3. Comparison between the polarity of the interplanetary magnetic field (Toward the sun, or Away from the sun) as measured by spacecraft (Wilcox and Colburn, 1970) and the polarity inferred using the recipe described in the text. The data is displayed in 27-day Bartels' rotations, with the data of the starting day of each rotation shown at the left.

Fig. 4. Data for April 1950 plotted in the same format as used in Figure 2.

Fig. 5. Comparison between the polarity of the interplanetary magnetic field inferred using the method described in the text and as originally classified by Svalgaard (1972b).

Fig. 6. Typical changes of the characteristics of the magnetic variations at Thule and at Godhavn as response to the passage of an interplanetary magnetic sector boundary on July 25, 1968. The upper panel shows the 3-hour planetary activity index ap. The next panel gives the azimuthal component of the interplanetary field in solar magnetospheric coordinates. The lower two panels display Z-magnetograms from Thule and H-magnetograms from Godhavn. The variations related to the sector polarity are shared.

Fig. 7. Same format as in Figure 6, but showing an atypical response at Godhavn as discussed in the text.

Fig. 8. Diurnal variation of the horizontal component, H, at Godhavn on internationally quiet days during 1965-69.

Fig. 9. Diurnal variation of the coefficients (a and b) of a fit $H = H_O + a \cdot BY + b \cdot BZ$ of the horizontal component H at Godhavn to the East-West component, BY, and the North-South component, BZ, of the interplanetary magnetic field.

Fig. 10. Comparison between the observed values of H at Godhavn and the values computed from $H = H_O + a \cdot BY + b \cdot BZ$ for four hourly intervals as indicated at the left side of each curve. The figure shows the values for each day during June 1968 for which interplanetary data was available.

GODHAVN H 1950

Figure 1

14
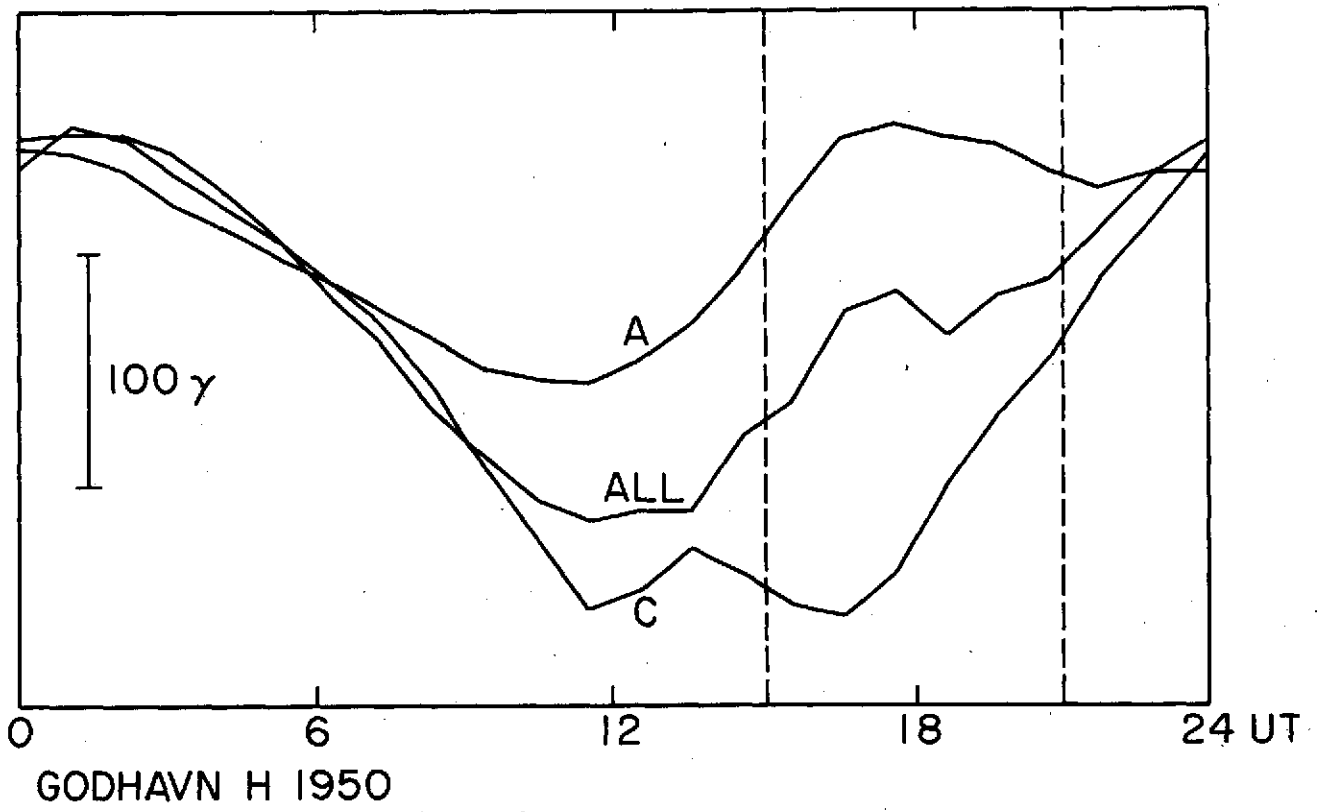
MAY 1968, GODHAVN H 15-21^h UT
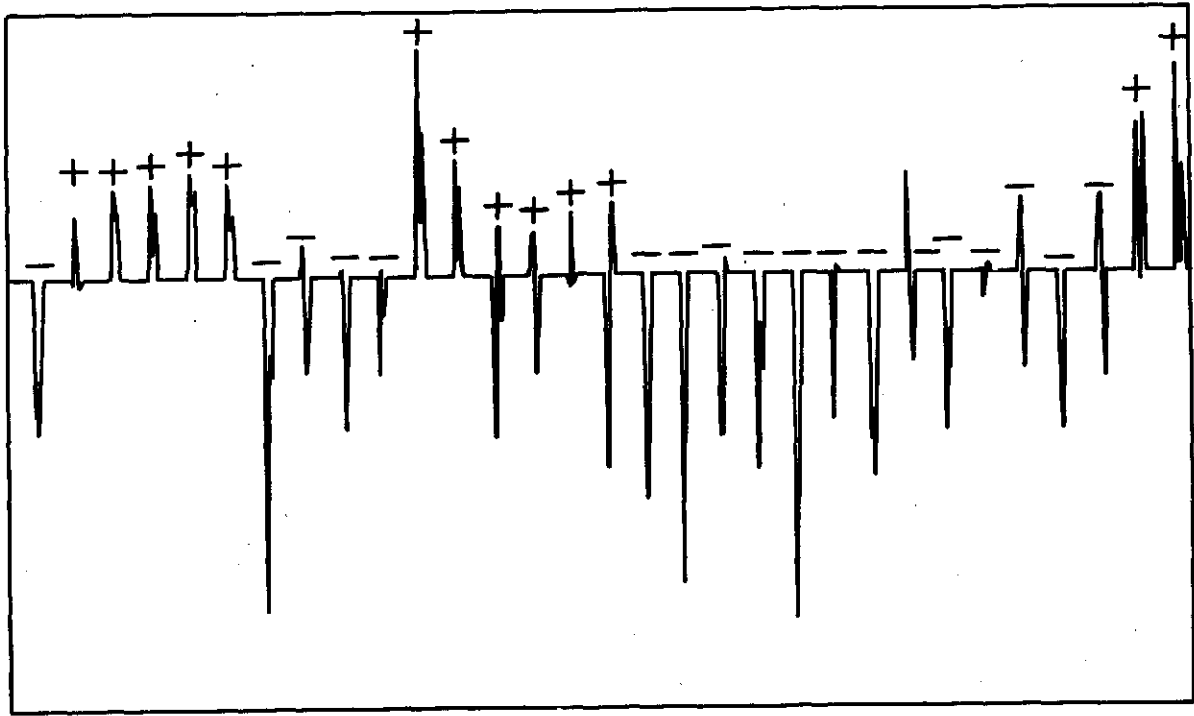
+ IMF AWAY
− IMF TOWARD

Figure 2

15

BASED ON GODHAVN H, 1968

● TYPE C, TOWARD POLARITY

× MIXED

• TYPE A, AWAY POLARITY

UPPER ROW: SPACECRAFT MEASUREMENTS

LOWER ROW: REDETERMINED INFERRED
POLARITIES

Figure 3

APRIL 1950, GODHAVN H 15-21^h UT
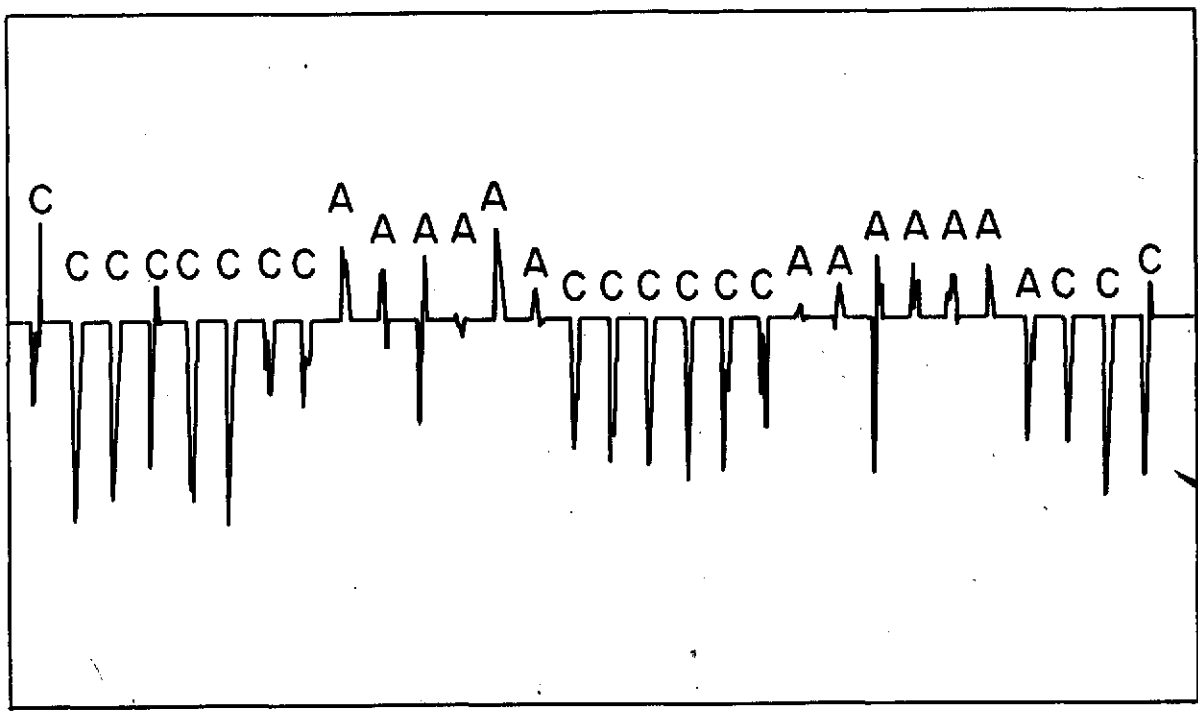
A INFERRED IMF AWAY

C INFERRED IMF TOWARD

Figure 4
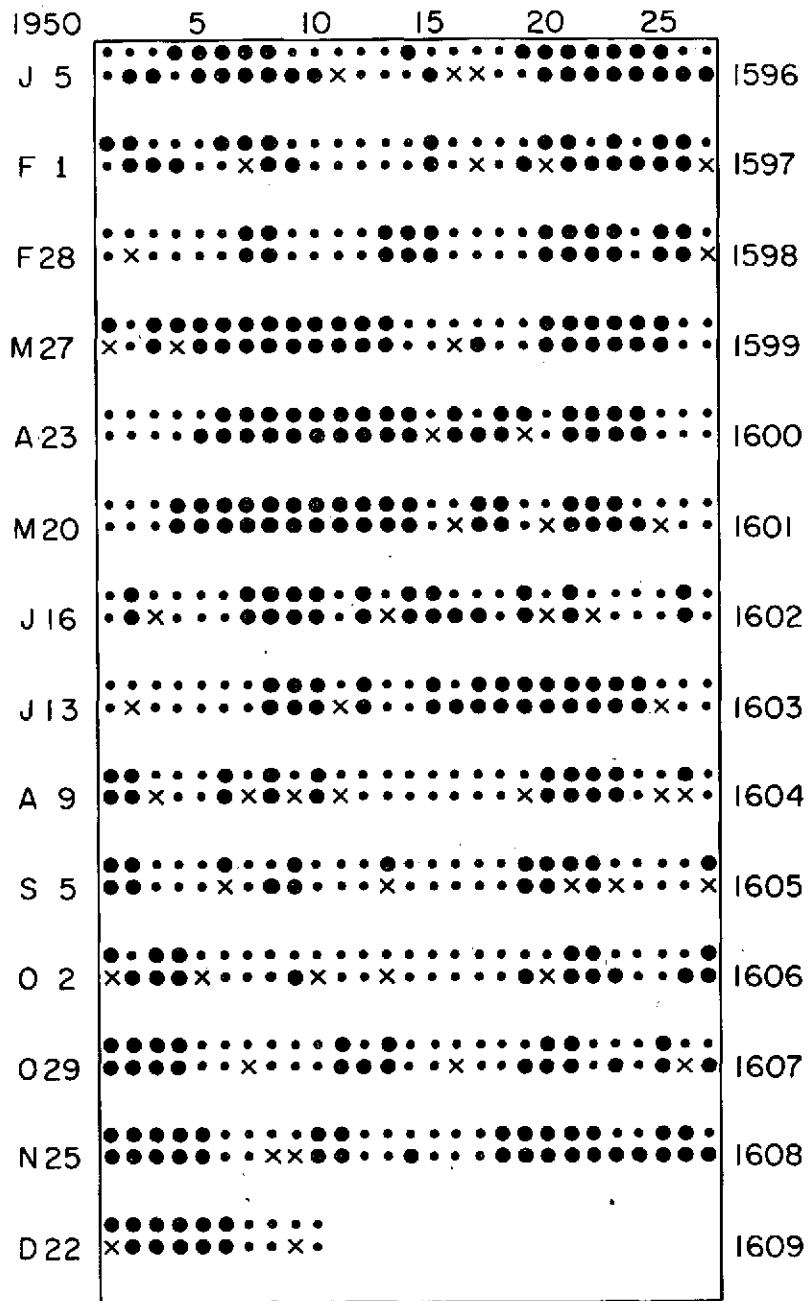
BASED ON GODHAVN H, 1950

● TYPE C, INFERRED TOWARD POLARITY
× MIXED
• TYPE A, INFERRED AWAY POLARITY

UPPER ROW: ORIGINAL VISUAL ESTIMATES
LOWER ROW: REDETERMINED POLARITIES

Figure 5

18
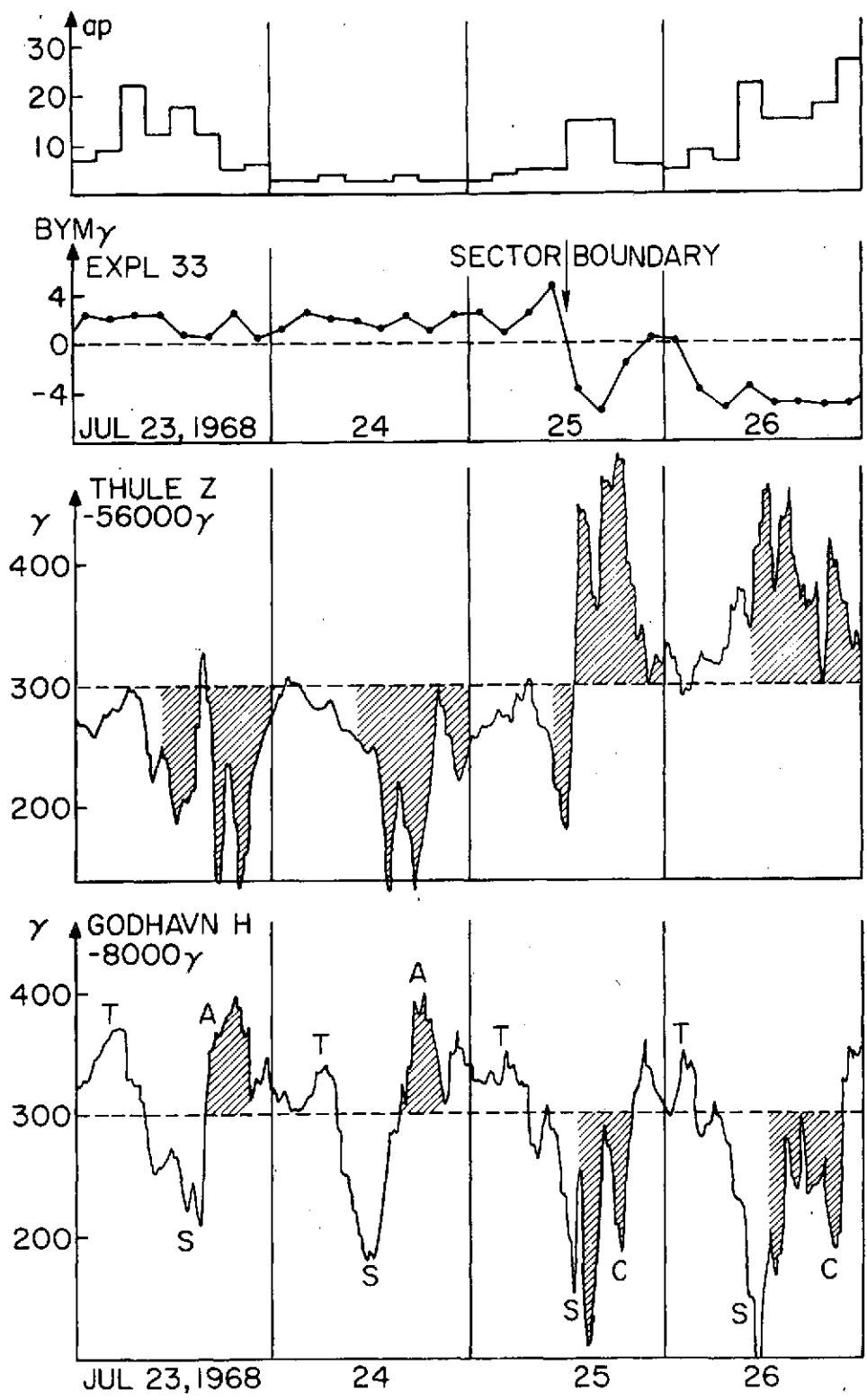
Figure 6

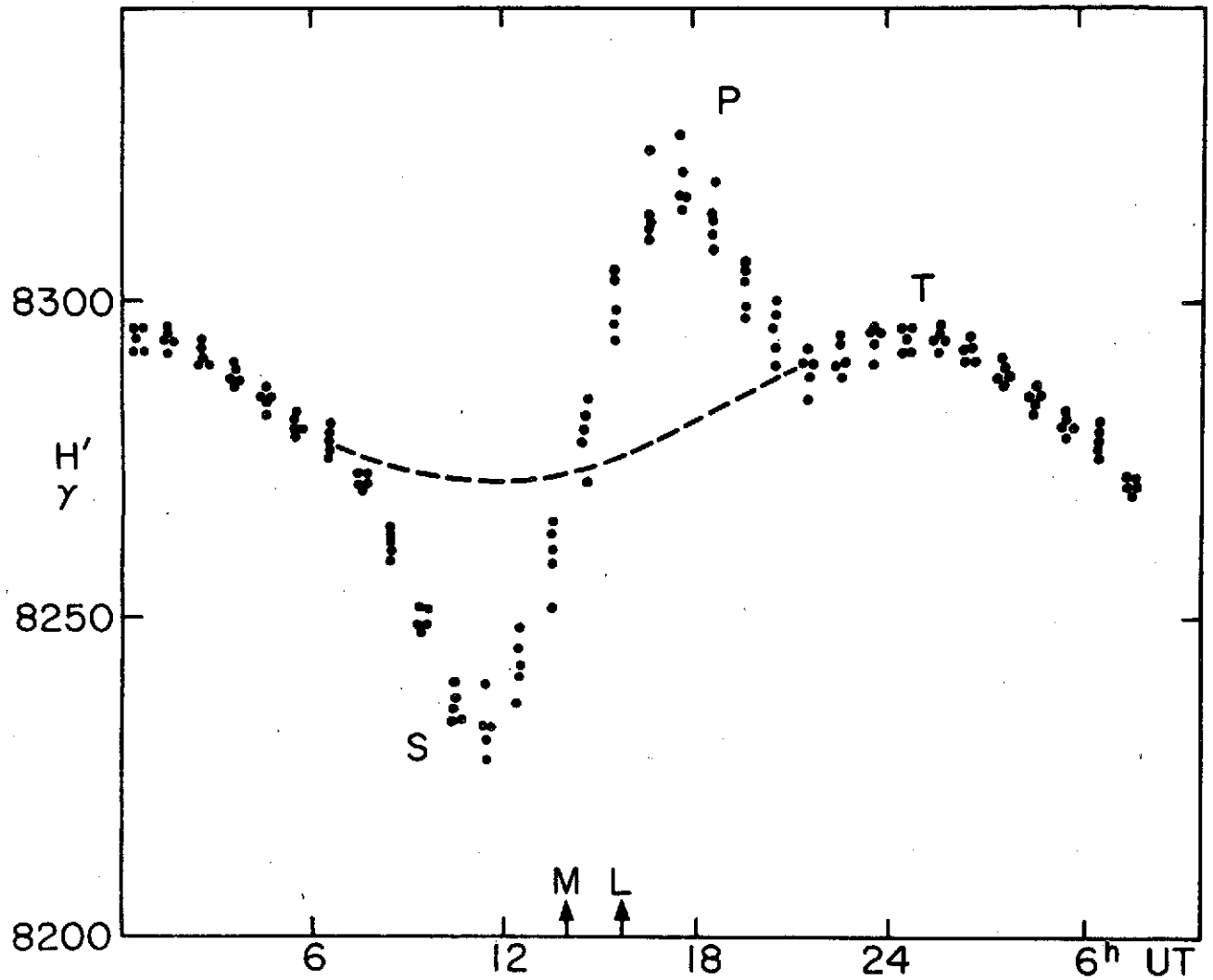19
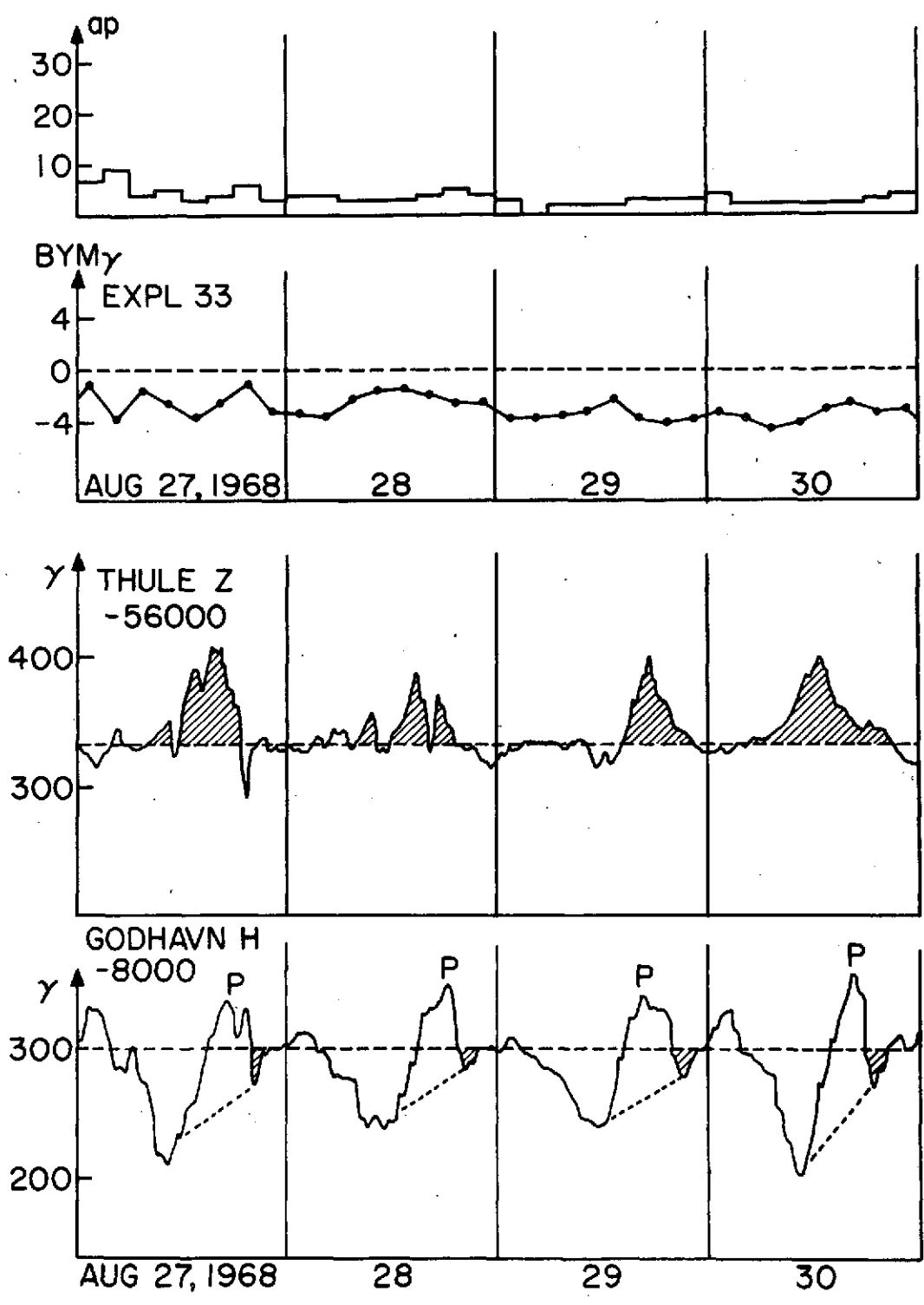
Figure 7

DIURNAL VARIATION OF GODHAVN H ON QUIET DAYS
DURING THE YEARS 1965-1969

Figure   8

Figure 9

22

GODHAVN H, JUNE 1968

11-12 UT

500γ

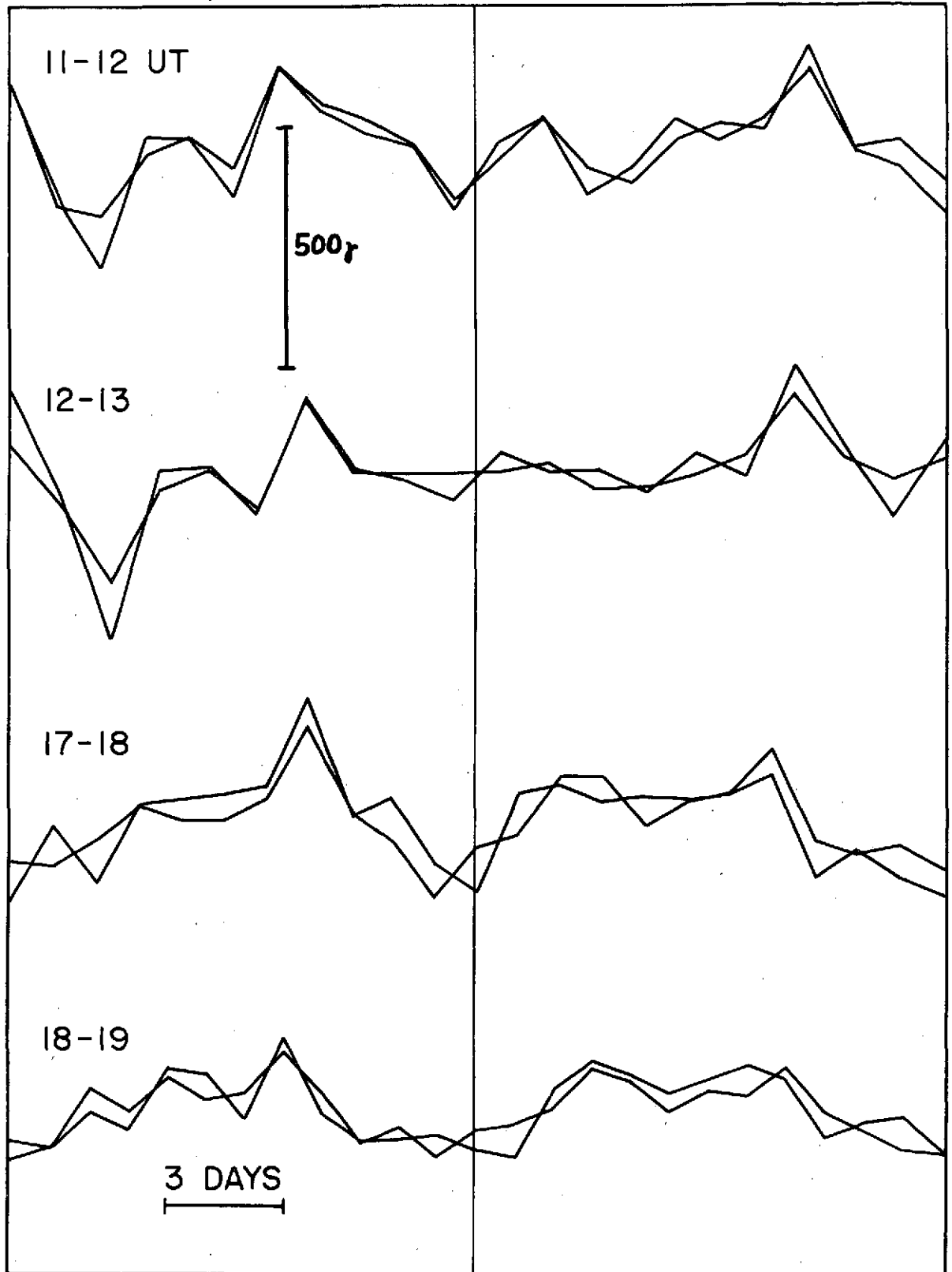12-13

17-18

18-19

3 DAYS

Figure 10