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

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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 are 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.

Fougere and Russell [1974] suggest that evaluation of the accuracy of the inferred interplanetary sector polarity [*Svalgaard*, 1972a] is difficult due to the subjective nature of the inferred index and also 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 this note to provide such a 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, 77.5° invariant latitude) was used in deriving the list.

The above statements should be qualified by noting that the recipe which will be presented is certainly 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 usefulness 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 showed a broad positive perturbation around local noon; a negative perturbation would classify the day as a type A day (associated with away polarity). It was found that the amplitude of these perturbations of the vertical Z component decreased with increasing distance from the invariant poles. Instead, perturbations are found in the horizontal H component. The sense of the H perturbations is opposite to 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 labeled A and C are the average variations during days classified by *Svalgaard* [1972b] as being of type A and of type C, respectively. The all-day average variation is also shown in the figure. A 6-hour interval around 1800 UT is delineated by the two dashed 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 1500–2100 UT, 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 ($\approx 10\%$ 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 the case of an isolated K disturbance the background reference level can normally be interpolated on the magnetogram by using the quieter intervals before and after the disturbance. Similar considerations apply for the determination of the A/C index, and, as is true for the K index, the difficulty in removing the background becomes most important when small disturbances are scaled.

A simple approach to the problem of removing the background level is as follows: In Figure 2, data for May 1968 are plotted such that during the interval 1500–2100 UT the actual variation of the horizontal component at Godhavn is shown for each day, while for all other times only 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 enhancement within the interval of interest (1500–2100 UT), a positive spike will result for that day on Figure 2, while a depression will show as a negative spike. Figure 2 displays just 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 plus sign (away) or a minus sign (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 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 are in good accordance with the result of *Friis-Christensen et al.* [1971], that the A/C signature may be used
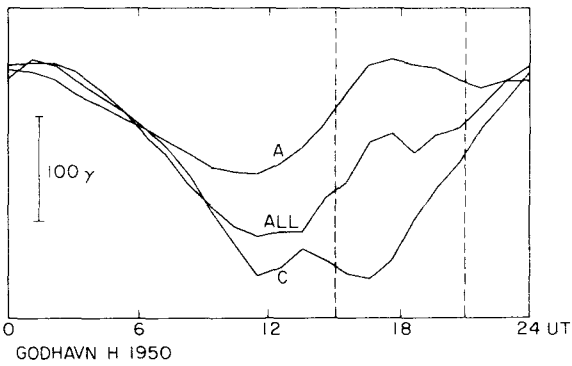
Fig. 1. Diurnal variation of the horizontal component at Godhavn during 1950. The curves labeled A and C are the average variations on days classified as being of type A and of type C, respectively. In the interval, shown by the dashed lines, the largest difference between the two types occurs.

to infer the second polarity with an accuracy exceeding 85%. Part of the remaining uncertainty 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 measured 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 H component 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 1500–2200 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 $HA \geq 0$ and $HC \leq 0$.
5. If $HA > -HC/2$, then classify the day as type A, and if $HC < -HA/2$, then classify the day as type C; otherwise classify the day as type B.

By using this recipe the A/C index has been redetermined 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 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 if only the Godhavn station and the simple recipe described above are used, 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 used 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 magnetosphere 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 inferred away polarity is dominant on type A days, while inferred toward polarity is predominant on type C days, as was originally suggested by *Svalgaard* [1968]. This correspondence is further

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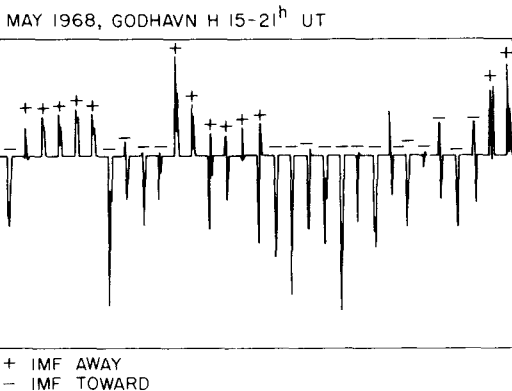
+ IMF AWAY
− IMF TOWARD

Fig. 2. Data for May 1968 plotted such that during the interval 1500–2100 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).

BASED ON GODHAVN H, 1968

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

UPPER ROW: SPACECRAFT MEASUREMENTS
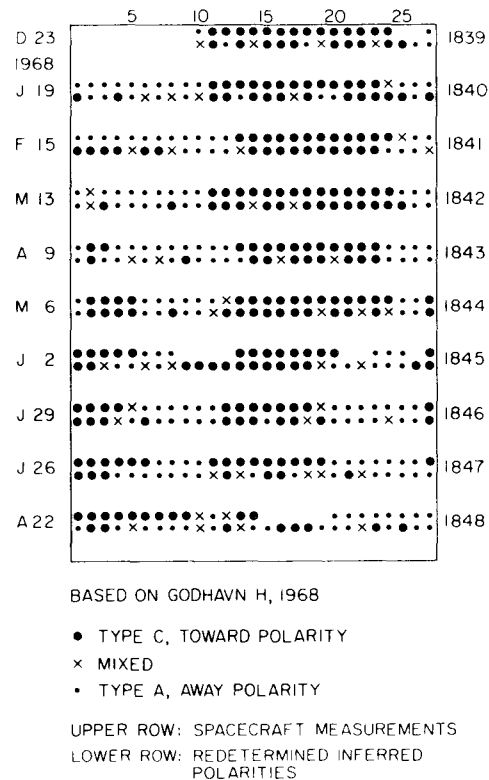LOWER ROW: REDETERMINED INFERRED POLARITIES

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 by using the recipe described in the text. The data are displayed in 27-day Bartels' rotations, with the date of the starting day of each rotation shown at the left.

APRIL 1950, GODHAVN H 15-21^h UT

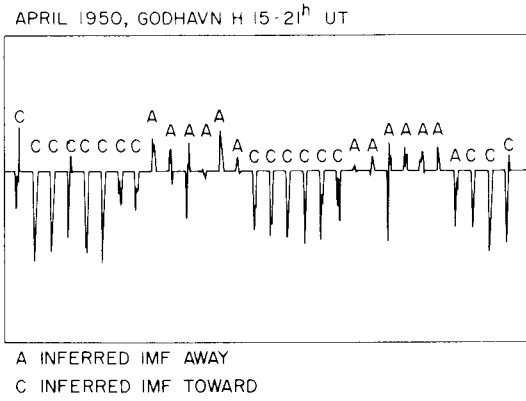A INFERRED IMF AWAY
C INFERRED IMF TOWARD

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

evidenced by Figure 5, where the original visual estimates are compared with the inferred polarities determined by 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 determinations is of the order of 80% or better.

After it has been established that the A/C index is well correlated with the polarity of the interplanetary magnetic field most of the time, the few cases with obvious disagreements command particular attention. If the disagreements depend systematically on other properties of the disturbance pattern, 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 (for some reason) are always classified as being of type A, while the five disturbed days are always classified as being of type C. The remaining twenty days are classified correctly. If geomagnetic activity were independent of the sector polarity, 2½ international quiet days and 2½ international disturbed days would be classified wrongly, meaning that out of the 30-day month, 25 days were classified correctly, corresponding to 83% agreement. We now assume that the quiet days have a C_i character figure of 0, that the disturbed days have 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 can well have a high information content (83% agreement) yet can 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 what research problem the A/C index is applied to. 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 equatorial plane should be biased by the polarity of the magnetic pole of the sun, which 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 descending 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 into the sun with a width of about 100° in longitude and a synodic recurrence period between 28 and 29 days. This '28½-day feature' coexists with the basic underlying four sectors for extended periods of time. At these times it may be difficult to discern the four-sector structure clearly, but when the 28½-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 sunspot cycle variation of the sector structure is rather similar also in the previous four cycles.

It 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 study of 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 im-
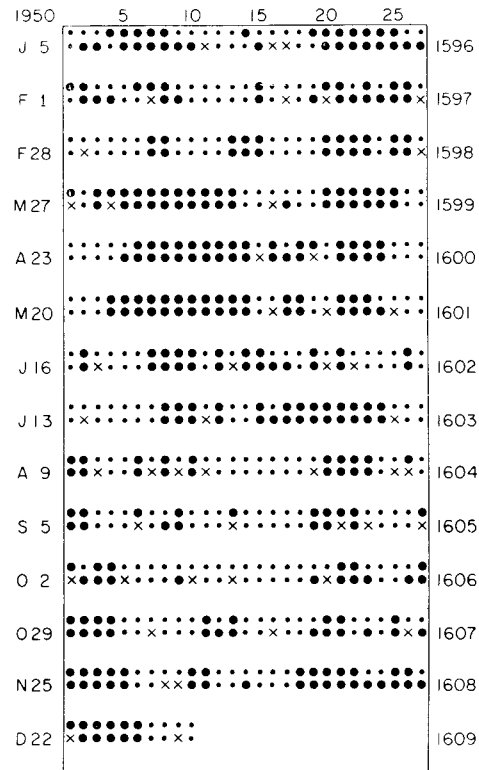
BASED ON GODHAVN H, 1950

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

UPPER ROW: ORIGINAL VISUAL ESTIMATES
LOWER ROW: REDETERMINED POLARITIES

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

prove 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) were used when available (mostly after 1963).

By 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, and 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 this 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 vortexlike currents associated with variations in the azimuthal component 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 these 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 approximation can be very useful if it is applied within its limitations.

Returning to the discussion of interplanetary signatures in the geomagnetic 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 minimum, 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, is correlated with eastward-pointing interplanetary magnetic field, and the negative perturbation, indicated by C, is 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, maximum at one corresponds to minimum at the other and vice 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
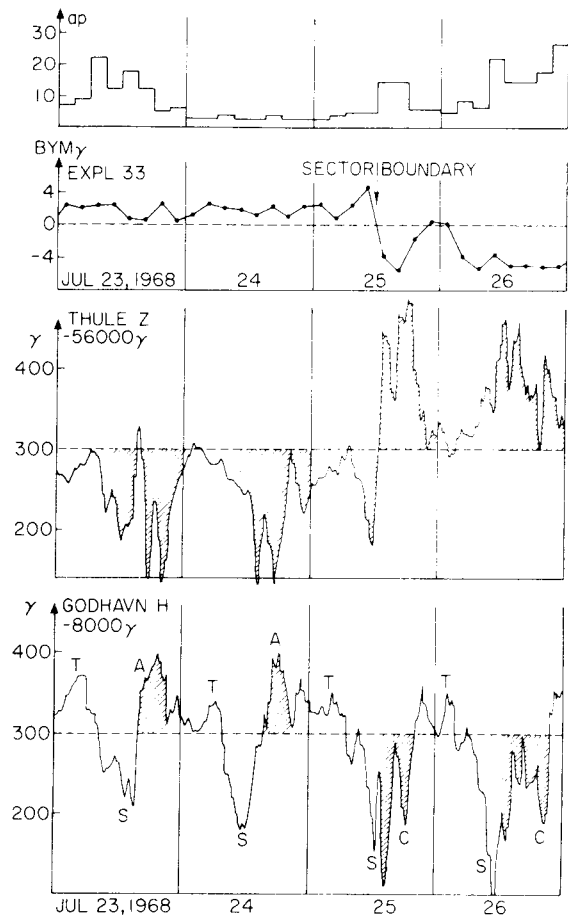

Fig. 6. Typical changes of the characteristics of the magnetic variations at Thule and at Godhavn as response to the passage of an interplanetary magnetic sector boundary on July 25, 1968. The upper panel shows the 3-hour planetary activity index *ap*. The next panel gives the azimuthal component of 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.

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 2100 UT. Otherwise a positive perturbation, denoted by a P on the records, in the afternoon 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 resemblance to 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 to 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 day. 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
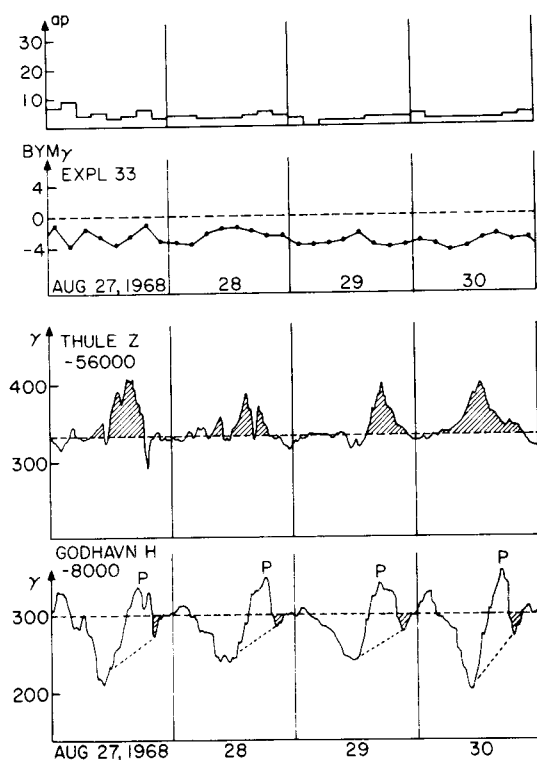
Fig. 7. Same format as used in Figure 6 but showing an atypical response at Godhavn as discussed in the text.

Fig. 9. Diurnal variation of the coefficients (a and b) of a fit $H = H_0 + a \cdot BY + b \cdot BZ$ of the horizontal H component at Godhavn to the east-west component BY and the north-south component BZ of the interplanetary magnetic field.

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 influenced 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 influence 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
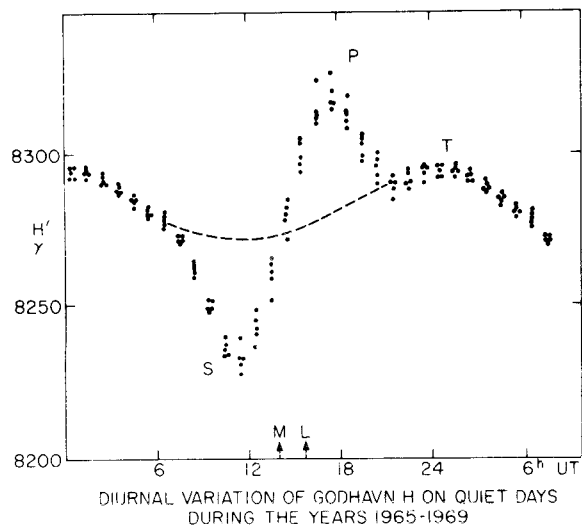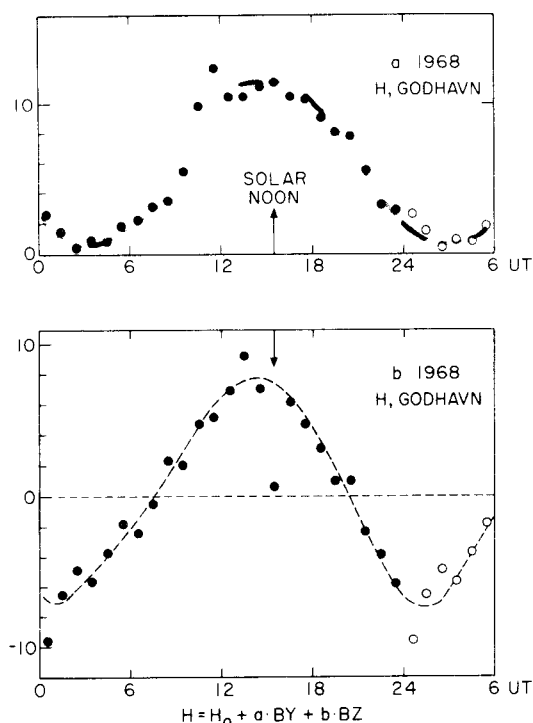
$$H = H_0 + a \cdot BY + b \cdot BZ \qquad (1)$$

where BY and BZ are the east-west and the north-south components of the interplanetary magnetic field and H_0 is a slowly varying background field. It is well known that H_0 has a yearly variation of the order of 30 γ. It is not known why. Further-

Fig. 8. Diurnal variation of the horizontal H component at Godhavn on internationally quiet days during 1965–1969.
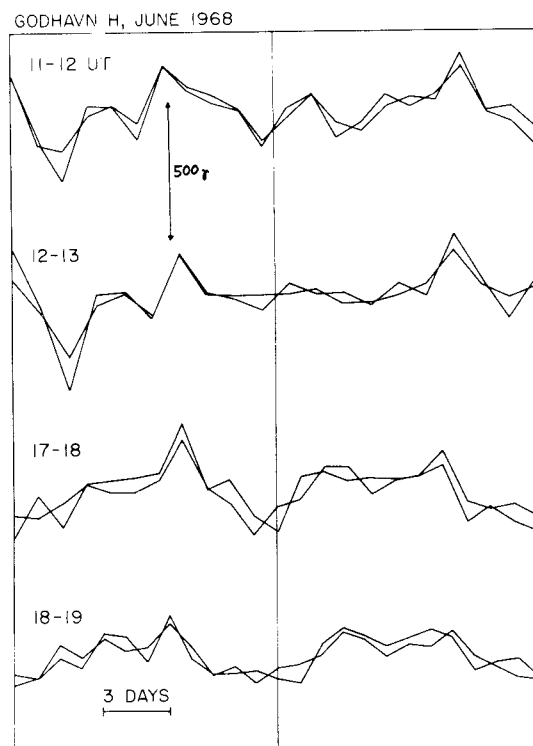
Fig. 10. Comparison between the observed values of H at Godhavn and the values computed from $H = H_0 + a \cdot BY + b \cdot BZ$ for four hourly intervals as indicated on the left side of each curve. The figure shows the values for each day during June 1968 for which interplanetary data were available.

more, H_0 has a roughly sinusoidal daily variation of the order of 80 γ. 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 12 monthly values obtained by fitting (1) separately for each month of 1968. Figure 10 gives some indication of the kind of fit which may be obtained by using the very simple expression (1). In computing the least squares fits, hourly averages were used. Since on time scales of an hour or more BY is generally greater than BZ and since $a > b$, we see that the effects of BY are generally greater than those of BZ during the day hours, whereas 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 variations dominate during the night. The same conclusion was also reached by *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 a constant sign for extended time intervals do its influences dominate over the influence of BY, and systematic errors are introduced into an index of sector polarity based exclusively on Godhavn H. These systematic errors will be of great 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.

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