On the nature of abnormal quiet days in $Sq(H)$

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Summary. It is well known that the time of occurrence of the minimum in the horizontal component of the Earth’s magnetic field ($H_{min}$) on quiet days at a mid-latitude station on the poleward side of the $Sq$ focus shows considerable variability from day to day. This variability has previously been discussed in terms of the incidence of so-called ‘abnormal quiet days’ (AQD), arbitrarily defined for the station Hartland as quiet days when $H_{min}$ occurred outside an interval of $\pm 2^{1/2}$ hr centred on the most common time of 1130 LT. AQDs have some interesting properties, which have been documented, but their precise nature and cause have not been elucidated. In this paper we report the results of a study of AQDs as identified at Hartland using a chain of Northern hemisphere stations situated approximately along the 0° longitude meridian and extending on both sides of the $Sq$ focus. It is found that there are two effects on AQDs: (i) a northward component field varying in LT is superposed at all latitudes throughout the day, so reducing the amplitude of the normal $Sq(H)$ variation at stations poleward of the focus and increasing it on the equatorward side, (ii) a southward perturbation field, of most probable magnitude 6.0 nT for the period studied, is imposed for about 4 hr at a fixed UT at all latitudes, so constituting an ‘AQD event’ which can lead to the occurrence of $H_{min}$ at an anomalous local time for a station poleward of the focus. It is shown that the AQD event may be of large geographical extent and that it is related to the interplanetary magnetic field. All the main properties of AQD occurrences are explained, and it is suggested that much of the day-to-day variability in the amplitude and phase of the normal $Sq(H)$ variation probably also arises from the occurrence of AQD events at times close to the diurnal turning points.

1 Introduction

It is well known that there is considerable variability in the phase of the daily variation in the horizontal component, $H$, of the Earth’s magnetic field on quiet days. Even restricting

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consideration to the five International Quiet Days (IQD) in any month the variation in phase of $Sq(H)$ may be quite extreme. For a mid-latitude station on the poleward side of the $Sq$ focus the most likely time of occurrence of $H_{\text{min}}$, the minimum in $Sq(H)$, is known to be near 1100 LT. Thus, Brown & Williams (1969) found that for the 27-yr period 1939–1965 over 50 per cent of the IQDs at Abinger (51° 11' N, 0° 23' W) and (since 1958) Hartland (51° 00' N, 4° 29' W) gave $H_{\text{min}}$ between 1000 and 1200 GMT, while 82 per cent of the quiet days had a minimum between 0830 and 1330 GMT. This leaves a significant proportion (18 per cent) of the days showing $H_{\text{min}}$ outside this time range. Brown & Williams arbitrarily defined those IQDs which had $H_{\text{min}}$ between 0830 and 1330 LT 'normal quiet days' (NQD); the others they termed 'abnormal quiet days' (AQD).

The initial analysis of Brown & Williams (1969) was extended by Brown (1975) to cover the 89-yr period 1884–1972 for $H$ observations at Greenwich, Abinger and Hartland. From these collective studies the following main properties of AQDs may be enumerated for a mid-latitude northern hemisphere station.

(i) There is a distinct pattern in the distribution of the times of $H_{\text{min}}$ on AQDs, with maximum occurrence around midnight or at times bordering the NQD interval, and a dearth of occurrences at intervening times (near 0400 and 1800 LT).

(ii) Overall, AQDs occur most frequently in local winter. The seasonal nature of this variation has been confirmed by an analysis of data for a southern hemisphere station.

(iii) Winter AQDs hardly ever exhibit $H_{\text{min}}$ at times bordering the morning NQD interval, but frequently occur with minima bordering the afternoon NQD interval and around midnight.

(iv) Summer AQDs have $H_{\text{min}}$ bordering both sides of the NQD interval (with some preference for the morning side) but very rarely show minima around midnight.

(v) Around the equinoxes there are very few AQDs; the limited number that occur tend to have $H_{\text{min}}$ bordering the afternoon NQD interval.

(vi) There is a clear solar cycle effect, further investigated by Brown (1974), with greatest occurrence of AQDs near sunspot minimum and least near sunspot maximum.

(vii) The 'normal' (local time) $Sq$ diurnal variation is usually also discernible on AQDs but with a reduced amplitude.

The cause of AQDs has not been fully explained. Brown & Williams (1969) considered initially that changes in the dynamo region of the ionosphere may be responsible for such changes in $Sq(H)$. However, they found no support for this possibility in the $E$-region data that they examined. Indeed, the fact that the maximum occurrence of AQDs occurs at sunspot minimum, in winter, near midnight, when the $E$-region electron density is at its lowest must cast serious doubts on an $E$-region dynamo source of AQDs, although subsequent work by Brown (1975) seemed to indicate some relationship between the less extreme winter AQDs (i.e. those where $H_{\text{min}}$ occurred near the NQD range) and planetary wave penetration to the dynamo region. Brown & Williams concluded that the most likely source would be one of extra-terrestrial origin. This conclusion was supported by Mizzi & Schlapp (1971) who considered five stations spread over a longitude range of nearly 115°, situated in the latitude range 52°–56° N. Their analysis showed that the 'AQD event' could occur at all stations over the longitude range considered (although it may not necessarily be large enough to result in the day being classed as an AQD at all stations), and that its time of occurrence depended on UT (whereas the normal $Sq(H)$ minimum is, of course, controlled by LT). Recent work by Butcher & Brown (1980) suggesting a connection between AQD occurrences and the interplanetary magnetic field also favours an extra-terrestrial or magnetospheric origin.
Thus, although much is known about the temporal properties of AQDs, an explanation of these properties and the basic cause of them have not been forthcoming. The phenomenon certainly warrants further study, especially in view of a potentially powerful application to the prediction of forthcoming solar activity discussed by Brown (1980). Further, very little is known on the extent of the AQD phenomenon, since most analyses have been based on one or two stations only. In this paper we report the results of a detailed study of AQDs by considering the variation in $Sq(H)$ for a set of stations situated approximately along a fixed meridian of longitude but separated over a latitude range sufficient to cover both sides of the $Sq$ focus. Since the ionospheric current, as indicated by the amplitude and phase of $Sq(H)$ on NQDs, is in opposite directions each side of the focus, such a study may be expected to yield valuable information on the roles of dynamo currents and extra-terrestrial (or magnetospheric) influences in producing AQDs. It will also be shown that once the nature of an AQD is established the main properties listed above may be understood.

2 The nature of the AQD event

In order to study the AQD events an analysis was made of $Sq(H)$ on IQDs using the tabulated hourly $H$ values for the line of stations shown in Table 1. In view of property (vi) mentioned in the Introduction, the analysis was confined to the sunspot minimum years 1963–1965. AQDs were selected on the basis of the magnetic variation at Hartland, since this has been the station used in almost all previous work on the phenomenon. It is recognised that the individual $Sq(H)$ variations may not necessarily confirm every such day as an AQD at each station separately, but at those stations where the main minimum in $H$ occurs at the normal time subsidiary minima invariably occur simultaneously with the AQD minimum.

In order to determine the magnitude and direction of the AQD effect, the following procedure was adopted for each station separately. The average variation of $Sq(H)$ for the NQDs in the month in which the AQD occurred, together with that for the NQDs in the preceding and following months (i.e. a possible total of 14 days) was considered to represent the average NQD $Sq(H)$ variation. This NQD variation was then subtracted from the corresponding AQD variation. The direction of the AQD event was then evident as a positive or negative value in these differences and the amplitude was determined by measuring the maximum deviation from the average trend each side of the AQD event. The amplitude and direction were measured in this way for 17 AQDs and the following features emerged from this analysis:

(1) The amplitude of the AQD event was always found to be a negative-going (southward) magnetic field change in $H$ at all the stations considered. Fig. 1 shows an example: the difference curve exhibits a negative departure for the AQD event at 1730 UT at all four

<table>
<thead>
<tr>
<th>Station</th>
<th>Geographic coordinates</th>
<th>Geomagnetic coordinates</th>
</tr>
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<tbody>
<tr>
<td>Lerwick</td>
<td>60° 08' N 1° 11' W</td>
<td>62° 30' N 88° 36' E</td>
</tr>
<tr>
<td>Eskdalemuir</td>
<td>55° 19' N 3° 12' W</td>
<td>58° 30' N 82° 54' E</td>
</tr>
<tr>
<td>Hartland</td>
<td>51° 0' N 4° 29' W</td>
<td>54° 36' N 79° 0' E</td>
</tr>
<tr>
<td>Logrono</td>
<td>42° 27' N 2° 30' W</td>
<td>46° 0' N 77° 0' E</td>
</tr>
<tr>
<td>Toledo</td>
<td>39° 53' N 4° 3' W</td>
<td>43° 36' N 75° 42' E</td>
</tr>
<tr>
<td>Almeria</td>
<td>36° 51' N 2° 28' W</td>
<td>40° 36' N 75° 18' E</td>
</tr>
<tr>
<td>Tenerife</td>
<td>28° 29' N 16° 17' W</td>
<td>35° 0' N 58° 36' E</td>
</tr>
<tr>
<td>M'Bour</td>
<td>14° 24' N 16° 57' W</td>
<td>21° 13' N 55° 0' E</td>
</tr>
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</table>
stations (two on each side of the Sq focus). The approximate 4 hr duration of the event is typical. The significance of the large positive departure in Fig. 1, centred at noon, will be discussed in (4) below. It is worth noting that although this effect is usually evident in the 'raw' magnetogram for stations poleward of the focus it is rarely detectable in such data for stations on the equatorward side of the focus, where the normal Sq(H) change is positive (northward) near 1100 LT (for an example see Fig. 1 of Butcher & Brown 1980).

(2) Excluding two AQDs (1963 June 4 and 1964 February 18) which showed exceptionally large field deviations and which will be discussed separately later, out of 100 determinations of the amplitude of the magnetic deviation for the other 15 days at all the stations, only

Figure 1. Plot of the difference between the $H$ variation for the AQD on 1964 October 11 and the average NQD $H$ variation for 1964 September, October and November, normalized to zero at 0030 UT. (---•) Toledo, (+-.-.-+) Logrono, (οοοοο) Lerwick, (x-----x) Hartland.

Figure 2. The distribution of AQD event amplitudes determined from 15 events at seven stations.
seven were greater than 10 nT. The distribution of the amplitudes is shown in Fig. 2. It is seen that for the period 1963–1965 studied, the most probable value of the amplitude is 6.0 nT and the average value of the 100 determinations was found to be 6.5 nT, with an rms error of 3.2 nT.

(3) Although on any given AQD there could be a variation of amplitude amongst the stations, no consistent variation from station to station was apparent. This is illustrated in Fig. 3 which shows the average AQD amplitude determined over the 15 days for each station plotted as a function of latitude. Although there is some spread, the maximum departure is only 1.5 nT from the all-station average and there is no evidence for any systematic variation with latitude.

(4) On AQDs for stations on the poleward side of the focus the 'normal' minimum in $Sq(H)$ between 0830 and 1330 LT is often still discernible in the magnetograms, especially if the main (AQD) minimum occurs well away from the NQD time range. If the main minimum occurs close to the NQD time range the subsidiary 'normal' $Sq(H)$ minimum is not resolved. As mentioned in the Introduction (property viii) Brown & Williams (1969) noted that for Hartland the normal minimum was reduced in amplitude on AQDs and this result has been essentially confirmed here. In fact it appears from the present analysis that with nearly all AQDs there was a reduction in the amplitude of the normal variation at all stations on the poleward side of the focus and, additionally, an increase in amplitude on the equatorward side of the focus. This effect is illustrated in Fig. 4 which shows mean winter magnetograms for one station on each side of the $Sq$ focus. Another example is contained in Fig. 1, where all four stations (two on either side of the focus) show a positive difference (AQD–NQD) at the time of normal diurnal inequality preceding the AQD event. The effect is equivalent to the superposition of a northward component field at all latitudes; alternatively it may be described in terms of a poleward movement of the inferred $Sq$ focus on AQDs (Butcher & Brown 1981). In order to bring out the changes in the normal $Sq(H)$ amplitude on AQDs relative to NQDs the magnetograms in Fig. 4 have all been normalized to zero at 0030 UT, but in fact the midnight levels of $H$ tend to be consistently about 2 nT larger on AQDs than NQDs. The superposed northward field is therefore present throughout the whole day, but with reduced amplitude at night.

To summarize, we may conclude that for the stations and epoch used in this study an average AQD event consists of the 'intrusion' of a southward field for a period of the order...
of 4 hr simultaneously at all latitudes with a roughly constant amplitude of about $-6$ nT. Associated with the days on which this event occurs is an increase in the northward component field at all latitudes resulting in changes in the amplitude of the normal $Sq(H)$ variation.

3 The occurrence of AQDs

We are now in a position to discuss the main features of AQDs outlined in the Introduction. At the outset it is apparent from the fact that the AQD event is associated with a reduction in $H$ at all latitudes that it cannot be attributed to a sudden augmentation of the $Sq$ current system, since this would lead to an increase in $H$ on the equatorial side of the $Sq$ focus. We thus consider the event to consist of the superposition of a magnetic perturbation of most probable magnitude $-6.0$ nT at any time on the normal $Sq(H)$ variation. Clearly, whether or not such a perturbation reduces the value of $H$ below the normal diurnal minimum value (for stations on the poleward side of the $Sq$ focus), and therefore whether or not such a day becomes classed as an AQD, depends on two factors: (i) the local time of occurrence of the perturbation; and (ii) the amplitude of the normal $Sq(H)$ variation. It will now be shown that consideration of these two factors results in a natural explanation of all the main properties listed in the Introduction.

In addition to the well-known variation in the amplitude of the $Sq(H)$ variation with season, there is also a distinct difference in the 'shape' of the average $Sq(H)$ curve with a tendency for a morning maximum in winter and an evening maximum in summer. These two
Figure 5. The average $Sq(H)$ variation at Hartland for the sunspot minimum years 1963–1965. (a) Winter months, (b) summer months, (c) equinoxial months. (X-X) NQDs, (●-●) AQDs. The thickened parts on the AQD variation indicate those times when $Sq(H)$ is $\leq 6$ nT from $H_{\text{min}}$. The magnetograms have been normalized to zero at 0030 UT.

features markedly influence the effect of an AQD event on the resultant magnetic variation. To illustrate, Fig. 5 shows the average $Sq(H)$ variation for Hartland for the years 1963–1965 for the three seasonal groups of months. The NQD and AQD data have been considered separately. As a general guide to the most likely times when the onset of a characteristic magnetic perturbation might lead to the day being designated an AQD, the portions of the AQD magnetograms which are within 6 nT of the 'normal' minimum value are drawn in heavy line. It is recognized that this procedure can only give a broad indication of possibilities since the AQD magnetogram used may itself be untypical by being influenced by a non-uniformly distributed set of perturbation onset times. Further, as is clear from Fig. 2, there is the possibility of perturbations of amplitude significantly greater than 6 nT. However, taking the heavy-line sections in Fig. 5 as indicating the most likely times of $H_{\text{min}}$ on AQDs it is immediately clear how they match up to each of the properties denoted (i)–(v) in the Introduction. Thus, collectively the heavy line sections in Fig. 5 conform to the preferred
times of $H_{\text{min}}$ given in property (i); the fact that in Fig. 5(a) the whole AQD magnetogram apart from the time interval 0700–0830 GMT is in heavy line explains the preponderance of AQDs in winter (property ii), with $H_{\text{min}}$ probable at any time other than that bordering the morning NQD interval (property iii); Fig. 5(b) shows that in summer AQDs will be less prevalent and are likely to have $H_{\text{min}}$ bordering both sides of the NQD interval (property iv); Fig. 5(c) shows that in the equinoxes the most likely time for $H_{\text{min}}$ will be in the early afternoon period (property v). Property (vi) follows from the fact that the $Sq(H)$ range on AQDs is considerably larger in sunspot maximum years than in sunspot minimum years, as illustrated for Hartland by comparing Fig. 6 for the winter months of 1958–1959 with the winter curve in Fig. 5 for 1963–1965. The incidence of the heavy-line sections shows that AQDs are much less likely to occur around solar maxima (and when they do, the most probable time of occurrence of $H_{\text{min}}$ would be in the afternoon bordering the NQD interval). This conclusion will remain valid even if the typical AQD event amplitude at sunspot maximum epoch is considerably greater (or less) than the value of 6 nT assumed here.

To substantiate the above interpretations we have carried out a further test. It is well known that the amplitude of $Sq(H)$ increases with latitude poleward of the focus, and accordingly on our AQD model it is anticipated that there should be a corresponding decrease in the occurrence of AQDs with latitude. This is confirmed in Fig. 7, which shows the

Figure 6. The average $Sq(H)$ variation at Hartland, winter months, for the sunspot maximum years 1958–1959, (××××) NQDs, (●●●●) AQDs. The thickened part on the AQD variation indicates those times when $Sq(H)$ is ≤ 6 nT from $H_{\text{min}}$. The magnetograms have been normalized to zero at 0030 UT.

Figure 7. The percentage occurrence of AQDs as a function of geographic latitude (●) and geomagnetic latitude (●). (●) and (+) are the percentages for Meanook for geographic and geomagnetic latitudes respectively.
occurrence of AQDs (expressed as a percentage of the total number of IQDs) over the period 1963-1965 plotted as a function of latitude (both geographic and geomagnetic) for the stations Lerwick, Eskdalemuir, Hartland and Logrono together with an additional station Meanook. Since Logrono is close to the $S_4$ focus, only days when it was on the poleward side of the focus were used in this analysis. The difference between the geographic and geomagnetic latitudes is similar for the first four stations, so use of either coordinate gives essentially the same trend, which is linear over this range. However, the data for Meanook, with a geographic latitude ($54^\circ 37' N$) similar to that of Eskdalemuir and geomagnetic latitude ($61^\circ 48' N$) close to that of Lerwick (see Table 1), conform to the geographic latitude plot better than the geomagnetic latitude plot. It may be inferred that the amplitude of $S_q(H)$ on AQDs is probably more closely linked to geographic than geomagnetic latitude.

4 AQDs and the Interplanetary Magnetic Field (IMF)

As mentioned in Section 2, on AQDs the ‘normal’ $S_q(H)$ amplitude is changed at all stations down the $0^\circ$ longitude meridian such that the northward component in $H$ is increased. This phenomenon has been discussed by Butcher & Brown (1981) in relation to the apparent poleward motion of the $S_4$ focus and it has been shown to be related to the direction, but not the magnitude, of the interplanetary magnetic field, particularly when the IMF is directed away from the Sun (A-days). A smaller change is observed on AQDs when the IMF is directed towards the Sun (T-days). Additionally, there is no difference between the $S_q(H)$ amplitudes on A-days and on T-days if analysis is restricted to NQDs.

The above results have been demonstrated only for the stations on the $0^\circ$ meridian in the northern hemisphere, but it is likely that they are generally valid. Evidence for the reduction in amplitude of the $S_q(H)$ variations on A-day AQDs compared with A-day NQDs at two other stations on the poleward side of the focus (one in the southern hemisphere) and at different epochs is given in Table 2. In each case the selection of the AQDs was made on the basis of the magnetograms at the individual station concerned. In both cases the difference in amplitude is significant at the 2.5 per cent level, using the Student t-test. It proved impossible to obtain corresponding figures for T-days because, apart from the 1963-1965 Meanook NQDs (when it was verified that an amplitude of $-10.9$ nT also held for T-days), it was found that the number of T-days available was far too small to give meaningful results. For example, 83 per cent of the Meanook AQDs in 1963-1965 occurred on A-days. For Amberley, over the extended period 1953-1958, 87 per cent of the AQDs and 86 per cent of the NQDs occurred on A-days which suggests that over this period there is a marked tendency for all IQDs to be A-days. It was decided to investigate this feature as fully as possible using all available IMF polarity data and Hartland magnetic data. The direction of the IMF was taken from the polarities inferred from Z-magnetograms at Thule by Svalgaard (1972) supplemented, for the more recent years, by data published in Solar Geophysical Data (NOAA) obtained in the same way from the Thule Z-magnetograms, or by satellite measurements given by King (1975).

<table>
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<th>Station</th>
<th>Geographic coordinates</th>
<th>Period analysed</th>
<th>NQD</th>
<th>AQD</th>
</tr>
</thead>
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<tr>
<td>Meanook</td>
<td>$54^\circ 37' N, 113^\circ 26' W$</td>
<td>Winter 1963-1965</td>
<td>$-10.9$</td>
<td>$-5.8$</td>
</tr>
<tr>
<td>Amberley</td>
<td>$43^\circ 09' S, 172^\circ 43' E$</td>
<td>Winter 1953-1954</td>
<td>$-10.7$</td>
<td>$-6.2$</td>
</tr>
</tbody>
</table>
Over the whole period 1926–1978 with 3141 IQDs, 75 per cent occurred on A-days; 536 of these IQDs were designated AQDs at Hartland, and virtually the same proportion (76 per cent) of them occurred on A-days. More detail is given in Fig. 8, where 3-yr running means are plotted of the percentage of IQDs that are A-days and the percentage of AQDs that are A-days. It is seen that although there has been a considerable variation in the proportions over the whole period, the percentage of AQDs that occur on A-days follows the percentage of IQDs that occur on A-days remarkably well. It may therefore be concluded that there is no preferential occurrence of AQDs on A-days: the high correlation between these events is just a reflection of the fact that over the period examined most of the IQDs are A-days.

On the other hand, the results of Butcher & Brown (1980) mentioned at the beginning of this section suggest that there is some relation between AQDs and the IMF. It is, perhaps, suggestive in this context to note that the distribution of hourly averaged values of the IMF, covering 71 431 values over the period 1965–1973, given by Burlaga & King (1979) is remarkably similar to our distribution of field deviations on AQDs given in Fig. 2. These authors find the average value of the IMF to be 6.09 nT, and the most probable value 5.0–6.0 nT, which numerically compare directly with our values of 6.5 nT and 5.5–6.5 nT respectively for the AQD perturbations.

Although an AQD event is similar in form to a long period negative bay, examination of the listed bays (IAGA Bulletin) reveals no clear relationship between the two events. However, the relationship between magnetic bays and the IMF is now well established (see, e.g. Mishin 1977). Thus Arnoldy (1971) has reported a correlation between the AE index (which measures the total range of $H$ for auroral stations and may therefore be used as an indicator of bay activity) and the $z$-component, $B_z$, of the IMF, such that $B_z$ reached a maximum negative (i.e. southward) value 1 hr before a maximum of AE. We have therefore examined the behaviour of the parameters AE, AL (which indicates the magnitude of negative depressions in $H$ for auroral stations) and $B_z$ in relation to the Hartland AQD events to see if these events show a similar relationship. Fig. 9 shows a superposed epoch analysis of these parameters for A- and T-days separately, where the zero time corresponds to the time of minimum $H$ for AQD events (also shown). For this analysis data were used for the period 1966–1973 for which satellite IMF, and AE and AL data were available and only those AQDs were used where the event occurred before 0530 and after 1530 LT to avoid any undue influence of the normal $Sq(H)$ on the analysis of the $H$ data. It is seen that AE and AL vary in a similar
manner to $\Delta H$ and $B_z$ reaches a minimum 1 hr earlier. This result suggests that AQD events as well as being similar in form to mid-latitude negative bays, but of smaller amplitude, may well arise from a similar cause linked to the IMF.

5 Discussion

Our analysis has shown that over the sunspot minimum period analysed for a series of northern hemisphere stations situated roughly along the Greenwich meridian an AQD is caused by a small negative-going (southward) magnetic perturbation, of typical magnitude 6 nT, that adds to the normal $Sq(H)$ variation to reduce the magnitude of $H$ over a period of about 4 hr. For a station on the poleward side of the $Sq$ focus whether the $-6$ nT perturbation actually forms a minimum in $H$ depends not only on the time at which it occurs but also on the amplitude of the $Sq(H)$ variation. There is therefore some difficulty in obtaining a consistent universal definition of an AQD. At stations where the $Sq(H)$ amplitude is larger, the $-6$ nT perturbation may only form a secondary minimum in $H$ whereas at another station it may form the main minimum. Thus the definition of an AQD is somewhat arbitrary since it depends on the station considered. Also, an AQD may only be defined in this way for a station on the poleward side of the focus.

However, acknowledging the problem of an absolute definition, considering AQDs as
determined from the Hartland data some interesting results are found, and in particular most of the main properties relating to the temporal occurrence of AQDs are explained. It is also shown that there is strong evidence to link AQDs to the IMF. This relationship appears in two different ways.

First, the change in the normal $Sq(H)$ amplitude which occurs on AQDs (reduction poleward of the focus, augmentation equatorward of the focus) is more marked on A-days than on T-days, so making it easier for the $-6 \text{nT}$ perturbation to form a minimum in $H$ on the poleward side of the focus on A-days. This phenomenon may also be expressed in terms of an apparent poleward motion of the $Sq$ focus on AQDs for A-days relative to AQDs for T-days (and also NQDs, be they A- or T-days). This effect is equivalent to the superposition of a northward magnetic field at all latitudes on AQDs and from Figs 1, 4, 5 and 6 it is clear that this field has a LT dependence which is suggestive of a control by ionospheric conductivity. The parameter which distinguishes A- and T- sectors of the IMF is the azimuthal component $B_y$, A- sectors being associated with positive (dawn to dusk) values of $B_y$, T- sectors with negative $B_y$. So far as possible interaction with the ionosphere is concerned it is the induced electric field that is physically important, i.e. in this context the component perpendicular to the ecliptic plane $E_z = -V_x B_y$, where $V_x$ is the (radial) velocity of the solar wind. In principle, such meridional electric fields, if they map into the ionosphere, can give rise to zonal Hall currents.

Secondly, the AQD event itself is also linked to the IMF, being well correlated with negative values of the $B_z$ component and the auroral indices AE and AL in a way suggestive of a negative bay-like disturbance, though of significantly smaller amplitude than a conventional bay. Although bays occur mostly during the main and recovery phases of magnetic storms, they may also occur at quiet times (Ratcliffe 1972). In considering the transfer of energy to the near-Earth environment from the solar wind the azimuthal interplanetary electric field $E_y = V_x B_z$ is the key parameter, which depends on the north–south magnetic field $B_z$. The energy associated with bay activity is transferred from the solar wind into the tail of the magnetosphere, a process that is enhanced when $E_y$ is positive, i.e. the IMF is directed southward, although the mechanisms of the energy, momentum and mass transfer are, as yet, not clear (Mishin 1977). At some stage in the build-up of energy in the magnetospheric tail current flows down the field lines from the magnetosphere into the auroral ionosphere producing an intense auroral electrojet, polar substorms and bays. The magnetic variation associated with long period bays (> 1 hr duration) may be described by a two cell equivalent current system (Rostoker 1969) where a return current flows through the mid- and low-latitude regions. It is tempting to suggest that it is this return current that causes the AQD event, but since AQD events occur mostly at night, when the ionospheric conductivity is at its lowest, it is unlikely that they could be caused by ionospheric currents. However Rostoker (1969) stresses that this equivalent current does not necessarily flow in the ionosphere and he suggests that the long period bay variations could be produced by an asymmetric ring current configuration.

Finally, as mentioned previously, the amplitude of the AQD event on two days in the period analysed was exceptionally large at all stations. The $H$ magnetograms for a number of stations (including Surlari $44^\circ 41'N, 26^\circ 15'E$ geographic, $42^\circ 30'N, 106^\circ E$ geomagnetic; Agincourt $43^\circ 47'N, 79^\circ 26'W$ geographic, $55^\circ N, 13^\circ W$ geomagnetic; and Memambetsu $43^\circ 55'N, 144^\circ 12'E$ geographic, $34^\circ N, 151^\circ 36'W$ geomagnetic) for these two days are shown in Fig. 10. The event centred on 0730 UT on 1963 June 4 had an average amplitude of 15 nT; that at 1630–1730 UT on 1964 February 18 had an average amplitude of 23 nT. In both cases it is clear that the effect of the AQD event was experienced over a wide geographical extent.
Moreover, study of the magnetograms for 1964 February 18 shows that, although not evident at Hartland, a second AQD event occurred on the same day at 1030 UT; it does not show at Hartland because it occurred at a time near that of the normal minimum in \(Sq(H)\). This example raises the question of the effect of an AQD event when it occurs within the so-called NQD interval.

In general, an AQD event occurring at, say, 1030 UT if large enough could cause the minimum in \(H\) at a station on the poleward side of the focus to occur somewhat earlier than the minimum produced solely from an ionospheric current having its maximum east–west component near 1130 UT and could also result in an increased apparent amplitude of the \(Sq(H)\) variation. For a station on the equatorward side of the focus on the same line of longitude such an event could similarly cause the maximum in \(H\) to be reduced, and to occur somewhat later than that caused by the ionospheric current. In fact, the event at 10.30 UT...
on 1964 February 2 shows both these influences. The minima at Hartland and Surlari occur at the same UT even though they are separated by 26° of longitude (and therefore the minimum at Surlari would be expected to occur nearly 2 hr earlier in UT than that at Hartland), while the 'bite-out' in the variation at Tenerife causes the maximum in $H$ to occur later. Similarly, an event occurring at, say, 1230 UT could cause the time of maximum in $H$ to occur earlier at stations on the equatorward side of the focus and the time of minimum to occur later at stations on the poleward side. Such influences could contribute to the apparent skew effects of the $Sq$ current system discussed by Brown (1975) and also to the well-known day-to-day variability in the phase and amplitude of $Sq(H)$ on NQDs. This variability will be discussed in a subsequent paper.

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References