REFERENCES


RESUMÉ. — On décrit une méthode statistique pour déterminer les heures en temps local où les effets de la variation géomagnétique diurne sont minimums. L'analyse de données provenant de plusieurs stations dans des zones de latitudes différentes montre que la période de minuit à l'aurore (0-6 h L.T.) sont les moins affectées par les variations diurnes pour presque toutes les composantes géomagnétiques. Les effets les plus importants sont observés pendant les heures de jour, ce qui indique une source principalement diurne pour de telles variations.

ABSTRACT. — A statistical method is described to determine the local time hours at which the geomagnetic daily variation effects are minimum. Analysis of data from several stations in different latitude zones shows that the midnight to dawn hours (0-6 hrs L.T.) are least affected by daily variations for almost all geomagnetic components. Largest effects are observed during daylight hours indicating a predominantly day-time source for such variations.

I. Introduction

Hourly data of geomagnetic variations observed at a worldwide network of magnetic observatories are generally used for estimating and studying the Sq field and the corresponding ionospheric and Earth current systems. A major difficulty in such studies is to decide the base line from which to measure the Sq. Usually, daily variations are studied by first evaluating the hourly deviations from the daily mean (mean of 24 consecutive hours) and subjecting these to harmonic analysis. However, this procedure presupposes a special property of the daily variation source viz. that it has components varying sinusoidally about the daily mean. This may or may not be true. For the geomagnetic variations, Price and Wilkins [1963] used the mean of several hours during night (21-3 hrs L.T.) as the base from which deviations at other hours were evaluated. Justifications for such a choice are given by Price and Stone [1964] viz that (a) the ionisation of the E region increases rapidly at sunrise and decays rapidly after sunset, (b) direct rocket measurements with magnetometers show ionospheric currents during the day but not during the night, (c) in magnetically quiet periods, changes during the night hours are much smaller than those during daylight hours, etc. However, they have also pointed out the possibility of the contribution to Sq from the induced earth currents which, though produced by the day-time ionospheric currents, may also have significant night-time values due to some harmonics. They have also shown that the fact that the true Sq field is derivable from a potential cannot be used to determine the true base-lines.
for the Sq variations by theoretical analysis. Thus, location of the exact hour at which the Sq field can be considered negligible remains largely a matter of speculation. Recently, Sarabhai and Nair [1969] have proposed an alternative hypothesis viz that the daily variation is caused not by a daytime increase but a night-time decrease due to magnetospheric effects. In a recent paper [Kane, 1976], some evidence has been presented to show that the daily geomagnetic variations are essentially a daytime effect. In the present paper a statistical method is described which can throw some light on this problem.

II. METHOD OF ANALYSIS

After removing the main field and its secular variation which arise due to sources within the earth, the field observed at any station shows long-term variations (periodicities exceeding one day as also irregular changes) and the daily variations, Sq as well as L (i.e. lunar). All these are of external origin. Amongst these, it is reasonable to assume that the long-term changes will be essentially similar at all stations. The daily variations are also roughly similar but vary so as compared to the long-term changes. The daily ranges at stations in different latitude zones do not seem to always correlate well with each other [Osborne, 1968]. Various other dissimilarities of daily variations at different latitudes are summarized by Hutton [1967]. It seems reasonable to assume, therefore, that the parallelism between the long-term changes at various stations will depend to some extent upon whether the daily variation has anyway affected the mean value used for studying the long-term changes. Usually, to eliminate the daily variation, daily means (means over 24 consecutive values) are used. In contrast, to study the effect of daily variation, long-term changes of values at various local times could be used. To illustrate, Fig. 1 (a) shows the monthly mean values of the horizontal component H for January-December 1958 for 4 stations, viz San Juan, Paramaribo, Tatuoca and Huancayo where each value is the average of the values centered at 00 Hr. local time for five local quiet days in each month (Pack & Stone, 1964). The month-to-month changes are roughly similar. Fig. 1 (b) shows a similar plot except that the values are now averages centered at 12 Hr. local time. The question asked is, which set shows better parallelism, the one in Fig. 1 (a) or the one in Fig. 1 (b)?

Given data from any two stations, the question can be answered very simply by finding out the correlation coefficient between the two traces in Fig. 1 (a & b) separately. Larger correlation would indicate better parallelism. However, for more than 2 stations, one would get two correlation matrices which are difficult to inter-compare. Alternatively, following method could be adopted.

\[ V = \frac{1}{nm} \sum_{i=1}^{n} \left( \frac{1}{m} \sum_{j=1}^{m} (D_i^j) - \frac{1}{n} \sum_{i=1}^{n} (D_i^j) \right)^2 \]  

Let us see the implication of this for the example in Fig. 1 (a), here number of stations n = 4 and number of values m = 12.

1. Case I: If all the traces are perfectly parallel to each other, the percentage deviations would be alike at all stations for the same value of j (say January or February, etc.). Hence: \( D_1 = D_2 = D_3 = D_4 \) for any value of j.

Hence

\[ V = \frac{1}{4 \times 12} \left[ \sum_{j=1}^{12} (D_1^j) - \frac{1}{4} \sum_{j=1}^{12} (D_1^j) \right] = 0 \]  

Thus, the value of V in (1) will range between zero and \( \sum_{j=1}^{n} (D_i^j)^2/nm \) depending upon the degree of parallelism, lower values corresponding to better parallelism.

III. EXPERIMENTAL DATA AND ANALYSIS

The method outlined above could be utilized for any set of stations and the value of V obtained for every hour (L.T.) of the day. A plot of V against L.T. would show the hours at which V was minimum i.e. the parallelism was utmost i.e. effect of daily variation was least.

Price and Stone [1964] have given the quiet-day magnetic variations for several stations for January-December 1958 for the geomagnetic components X, Y, Z. From these, values of H and T defined as

\[ H = X^2 + Y^2 + Z^2 \]  

\[ T = (X^2 + Y^2 + Z^2)^{1/2} \]  

Thus, in contrast to the correlation method where highest correlation coefficient was equivalent to perfect parallelism, here, minimum V corresponds to best parallelism.

For the purpose of this study, the data given by Price and Stone [1964] have been used and the following parallelism for a number of stations and the value of V obtained for every hour (L.T.) of the day. A plot of V against L.T. would show the hours at which V was minimum i.e. the parallelism was utmost i.e. effect of daily variation was least.

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Thus, in contrast to the correlation method where highest correlation coefficient was equivalent to perfect parallelism, here, minimum $V$ corresponds to best parallelism.

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The method outlined above could be utilised for any set of stations and the value of $V$ obtained for every hour (L.T.) of the day. A plot of $V$ against L.T. would show the hours at which $V$ was minimum i.e. the parallelism was utmost i.e. effect of daily variation was least.

Price and Stone [1964] have given the quiet-day magnetic variations for several stations for January-December 1958 for the geomagnetic components $X$, $Y$, $Z$. From these, values of $H$ and $T$ defined as

$$H = (X^2 + Y^2)^{1/2}$$
$$T = (X^2 + Y^2 + Z^2)^{1/2}$$
were also evaluated. Thus, for every station, five parameters \( T, H, X, Y, Z \) were studied.

Fig. 2 shows a plot of \( V \) versus L.T. for the five components \( T, H, X, Y, Z \) for all 67 stations (see Table I) taken together. Following may be noted:

2. For the \( Y \) and \( Z \) components, the hours of maximum disturbance are somewhat earlier viz 6-12 hrs. L.T. in contrast to about noon for \( T, H \) and \( X \).

Thus, if there is a common source of diurnal variation of geomagnetic field at all locations, its strength is least during the midnight-dawn period. Hence, the average value for these hours may be considered as the best base-line for \( fg \) studies.

To see whether different longitude zones show similar results, the stations were grouped into five longitude zones as shown in Table I. The \( V \) vs. L.T. plots are shown in Figure 3. Whereas there are differences, it is doubtful whether these are meaningful in view of the fact that the latitude distributions of the stations in the various longitude zones are not similar (see Table I). However, the main conclusion viz that the quietest hours are 0-6 hrs. L.T. is true in almost all cases depicted in Figure 2.

To see whether different latitude zones showed similar results, the stations were divided into six latitude groups (see Table I), according to their “dip latitudes” (Price & Strom, 1964) which is defined as

\[ \tan \theta = \frac{Z}{2H} \]

The plots of \( V \) versus L.T. for the equatorial and mid-latitude region (Groups 3, 4, 5) are shown in Figure 4. Similar plots for high latitude regions (Groups 1, 2, 6) are shown in Figure 5.

IV. DISCUSSION AND CONCLUSIONS

From Figures 4 & 5, it seems that, in general, Variances \( V \) are low for night hours and high for daytime hours. Table II gives the hours (L.T.) at which Variances start increasing and also hours at which the increases end. Following may be concluded:

a) In general, Variances are low and constant in the midnight-dawn period (0-6 Hrs.), start rising by about 6 A.M. to about noon and then fall to low values by about 6 P.M. There is a further but slight decrease from 6 P.M. to 12 midnight, indicating that dusk-midnight period is not as quiet as the midnight-dawn period.

b) In high latitudes and auroral regions, the Variances are not always maximum near noon. Morning and/or afternoon maxima are observed especially in the \( Y \) component. Nights are, however, quiet.

c) In equatorial region, maximum variances are mostly within an hour or two of noon except for \( Y \) for which morning maxima are observed. Also, variances persist to remain somewhat high even after sunset but are invariably low by midnight.

Thus, the source of daily variation is definitely confined to the daytime hours, though some effect persists for a few hours after sunset. But the midnight-dawn period is invariably quietest and values at these hours could be safely taken as base values.
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Fig. 2 shows a plot of $V$ versus L.T. for the five components $T$, $H$, $X$, $Y$, $Z$ for all 67 stations (see Table 1) taken together. Following may be noted:

1. The variances $V$ are lowest during the midnight-dawn period (0-6 hrs. L.T.). However, these values are not zero, indicating either that the current systems may not be altogether absent during the night hours or that, even at night, the long-term changes at all stations may not be exactly alike in magnitude for all latitudes and for all the components. The latter seems to be more likely.

2. For the $Y$ and $Z$ components, the hours of maximum disturbance are somewhat earlier viz 6-12 hrs. L.T. in contrast to about noon for $T$, $H$ and $X$.

Thus, if there is a common source of diurnal variation of geomagnetic field at all locations, its strength is least during the midnight-dawn period. Hence, the average value for these hours may be considered as the best base-line for $S_y$ studies.

To see whether different longitude zones show similar results, the stations were grouped into five longitude zones as shown in Table 1. The $V$ vs. L.T. plots are shown in Figure 3. Whereas there are differences, it is doubtful whether these are meaningful in view of the fact that the latitude distributions of the stations in the various longitude zones are not similar (see Table 1). However, the main conclusion viz that the quietest hours are 0-6 hrs. L.T. is true in almost all cases depicted in Figure 2.

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Thus, the source of daily variation is definitely confined to the daylight hours, though some effect persists for a few hours after sunset. But the midnight-dawn period is invariably quietest and values at these hours could be safely taken as base values.
These results are consistent with the present theories of ionospheric current systems both at equator (electrojet) and at higher latitudes. However, daytime magnetospheric effects are not ruled out. What seems certain is the absence of night-time sources to any appreciable degree. This applies to night-time components of induced earth currents also. These remarks apply in general and to quiet days.

On individual days (specially disturbed ones) and at individual stations, deviations from this general pattern may be observed.

Thanks are due to the Department of Atomic Energy, Govt. of India for financial support.

**REFERENCES**


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**TABLE II**

Local time hours at which Variance $V$ starts increasing and recovers to low values (end) as seen from Fig. 4 & 5.

<table>
<thead>
<tr>
<th>Group No. and Dip lat. range</th>
<th>$T$</th>
<th>$H$</th>
<th>$X$</th>
<th>$Y$</th>
<th>$Z$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start Hr.</td>
<td>End Hr.</td>
<td>Start Hr.</td>
<td>End Hr.</td>
<td>Start Hr.</td>
</tr>
<tr>
<td>Group 1 50°N to 60°N</td>
<td>?</td>
<td>?</td>
<td>7</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td>Group 2 40°N to 50°N</td>
<td>8</td>
<td>18</td>
<td>6</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Group 3 5°N to 40°N</td>
<td>6</td>
<td>21</td>
<td>6</td>
<td>24</td>
<td>7</td>
</tr>
<tr>
<td>Group 4 4°N to 4°S</td>
<td>5</td>
<td>23</td>
<td>5</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>Group 5 5°S to 40°S</td>
<td>6</td>
<td>17</td>
<td>9</td>
<td>16</td>
<td>9</td>
</tr>
<tr>
<td>Group 6 40°S to 60°S</td>
<td>6</td>
<td>13</td>
<td>6</td>
<td>13</td>
<td>6</td>
</tr>
</tbody>
</table>
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