Effective local time hours for Sq and Sd

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RÉSUMÉ. — On emploie une méthode statistique pour déterminer les heures en temps local où les effets de la variation géomagnétique diurne sont importants. On trouve que, pendant les jours calmes, la variation diurne est limitée aux heures d'illumination tandis que, les jours perturbés, une perturbation supplémentaire est présente dans les heures qui précèdent l'aube ou en fin d'après-midi selon que les jours sont modérément ou extrêmement perturbés. Des courants sur une partie d'anneau dans la partie nocturne de la magnéosphère pourraient être une explication de la variation diurne des jours agités.

ABSTRACT. — A statistical method is employed to determine the local time hours at which geomagnetic daily variation effects are large. It is found that, during quiet days, the daily variation is confined to the day-light hours whereas, on disturbed days, additional disturbance occurs in the pre-dawn hours or later afternoon hours depending upon whether the days are moderately disturbed or highly disturbed. Partial ring currents in the night side magnetosphere could be a possible explanation for the disturbed day daily variation.

I. INTRODUCTION

In an earlier paper [Kane 1971], a method was suggested to determine the local time hours at which the geomagnetic daily variation effects are minimum. Briefly, the question asked is, for which hours (L.T.), do the values of any geomagnetic parameter at different observatories show better parallelism for long-term changes. Since daily variation effects at different stations are not always well correlated [Osborne, 1968], hours at which daily variation is predominant will show least long-term parallelism. From analysis of Sq variation data for several stations for 1958 [Price & Stone, 1964], it was concluded that daily variation on quiet days is confined mostly to the daytime (6 A.M. to 6 P.M.) hours.

In the present paper, the same method is applied to a longer period [1958-64] and for geomagnetic variations on both quiet and disturbed days.

II. EXPERIMENTAL DATA AND ANALYSIS

Data used are the hourly values for the horizontal component (Z) for two equatorial stations (Trivandrum and Anamalainagar) and two mid-latitude stations (Allag and Honolulu). Data for each station were first corrected for secular variation by polynomial fitting. Data for successive bi-monthly periods [January-February 1958, ... November-December 1964] were divided into three groups according to Ap values as:
a) Group 1 — Ap 0 to 8 (Quiet days).

b) Group 2 — Ap 9 to 15 (moderately disturbed days).

c) Group 3 — Ap exceeding 15 (highly disturbed days).

For each bi-monthly period and for each Ap group, the average daily variation (24 hourly values) for each station were obtained. For example, Figure 1 (a) shows the 00 Hr. (L.T.) average values from January-February 1958 to November-December 1964 (6 points per year for 7 years, 42 points in all) for the 4 stations. Figure 1 (b) shows a plot of similar values for 12 Hr. (L.T.). The question asked is, which set of curves is better correlated with each other, that is, Figure 1 (a) or that in Figure 1 (b). As a measure of parallelism, a variance factor \( V \) is calculated given by [Kane 1971]:

\[
V = \frac{1}{nm} \left[ \frac{\sum (D_{ij}^2)}{n} - \frac{1}{nm} \left( \frac{\sum D_{ij}}{n} \right)^2 \right]
\]

where \( D_{ij} \) represent the values of Figure 1 expressed as percentage deviations from the mean value for every station for the whole series, \( i \) representing the station (1 to 4) and \( j \) representing the particular value in the long series (1 to 42). In the present case, \( n = 4 \) and \( m = 42 \). Low values of \( V \) represent high degree of parallelism and, hence, low degree of pollution due to daily variation effects.

(\( a \)) 00 HR L.T.  (\( b \)) 12 HR L.T.

![Graphs showing horizontal components for different hours](image)

**FIG. 1**

Bimonthly average values of H component for 1958-64 for the stations Honolulu, Alibag, Anamalais, and Trivandrum for quiet days (Ap 0 to 8) for the solar hours (a) 00 Hrs. L.T. and (b) 12 Hrs. L.T.

\( V \) can be calculated for each hour (L.T.) separately and for the three Ap groups. Figure 2 shows a plot of \( V \) vs. hours (L.T.). Following may be noted:

a) The uppermost plot in Figure 2 refers to Ap 0-8 and hence represents \( S_0 \) in a general way. Here, one observes that \( V \) is minimum at about 18 Hours (L.T.). Thus, at this hour, the daily variation effects are the least. From 18 Hrs. to about 4 Hrs. there is a slight increase in \( V \). It is not certain whether this is significant but, if so, would represent small night-time effects. The major increase occurs during the day-time hours 6 A.M. to 6 P.M., with a maximum at about 11 A.M.

Thus the source of \( S_0 \) seems to be confined mainly to day-light hours with a small possible contribution during night hours.

b) The middle curve in Figure 2 refers to moderately disturbed days (Ap 9 to 15). Here, the major increase in \( V \) is again in the day-light hours (maximum at 10-11 A.M.). But, even before dawn, there is a substantial rise from 02 Hrs. to 06 Hrs. Also, the minimum is not at 18 Hrs. but later, at about midnight.

Since this curve refers to \( S_0 + S_{10} \) on moderately disturbed days, it would seem that the \( S_{10} \) is contributed by extra disturbance mostly in the pre-dawn period and to a smaller extent in the post-dusk period.

c) The bottom curve of Figure 2 refers to highly disturbed days (Ap exceeding 15). Here, the major increase is again during day-light hours. But there is a noticeable fine structure. Thus, after attaining a maximum at about 11 A.M., followed by a drop up to 2 P.M., there is a rise again up to 4 P.M. and the subsequent fall continues not only beyond 6 P.M. but even beyond midnight to reach a minimum only at about 3 A.M. Thus, there is substantial disturbance in the post-dusk period and to a lesser extent in the pre-dawn period.

**III. CONCLUSION**

In conclusion, the results may be summarised as follows:

a) During quiet periods, the geomagnetic daily variation (particularly of the horizontal component \( H \)) is confined mainly to daylight hours with a possible small contribution during night hours. This is consistent with an overhead ionospheric current system with possible small induced earth currents persisting into night hours [Parks and Stone, 1964]. However, possible daytime effects of non-ionospheric origin cannot be ruled out [Kane 1970].

b) During magnetically disturbed days, the source of disturbance, on moderately disturbed days is mostly in the pre-dawn period with a smaller contribution in the post-dusk period. However, on highly disturbed days the conditions seem to be reversed, a predominant contribution coming from the late afternoon hours, continuing up to hours later than midnight. Thus, the disturbed day variations \( S_0 \) is an extra disturbance during pre-dawn hours for small disturbances and during late afternoon to post-dusk hours for large disturbances.

From the ATS1 satellite magnetometer data, Cummings and Coleman [1968] have demonstrated that some magnetic field variations occur simultaneously at the earth's surface and at distances of about 6.6 earth radii. Cummings et al [1968] have discussed the relationship between magnetospheric substorms and field variations of ground based magnetometers and have evoked a model involving formation and disruption of partial ring currents [Frank 1961, Cummings 1966] in the dusk-midnight quadrant. It is possible that such partial ring current systems, presumably formed by the inward convection of particles near the midnight meridian (through the geomagnetic tail) offer a satisfactory explanation of the main features of disturbed day variation (\( S_0 \)) referred to above. Details need to be worked out to see whether the \( S_0 \) variation can be explained completely on the basis of such a non-ionospheric source or a significant ionospheric contribution is still needed.

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a) Group 1 — Ap 0 to 8 (quiet days).

b) Group 2 — Ap 9 to 15 (moderately disturbed days).

c) Group 3 — Ap exceeding 15 (highly disturbed days).

For each bi-monthly period and for each Ap group, the average daily variation (24 hourly values) for each station were obtained. For example, Figure 1(a) shows the 00 Hr. (L.T.) average values from January-February 1958 to November-December 1964 (6 points per year for 7 years, 42 points in all) for the 4 stations. Figure 1(b) shows a plot of similar values for 12 Hr. (L.T.). The question asked is, which set of curves is better correlated with each other, that in Figure 1(a) or that in Figure 1(b). As a measure of parallelism, a variance factor \( V \) is calculated given by [Kane 1971]:

\[
V = \frac{1}{nm} \sum_{i=1}^{n} \left( \frac{D_{ij}}{\langle D \rangle} \right)^2 - \left( \frac{1}{n} \sum_{i=1}^{n} \frac{D_{ij}}{\langle D \rangle} \right)^2
\]

where \( D_{ij} \) represent the values of Figure 1 expressed as percentage deviations from the mean value for every station for the whole series, \( i \) representing the station (1 to 4) and \( j \) representing the particular value in the long series (1 to 42). In the present case, \( n = 4 \) and \( m = 42 \). Low values of \( V \) represent high degree of parallelism and, hence, low degree of pollution due to daily variation effects.

\[ (a) \quad 00 \text{ HR L.T.} \\
(b) \quad 12 \text{ HR L.T.} \]

**Fig. 1**
Bimonthly average values of \( H \) component for 1958-64 for the stations Honolulu, Abha, Ammannaltpuram and Trivandrum for quiet days (Ap 0 to 8) for the solar hours (a) 00 Hrs. L.T. and (b) 12 Hrs. L.T.

**Fig. 2**
Variation \( V \) vs. local time for component \( H \) for various Ap groups viz. Ap = 0 to 8; 9 to 15; exceeding 15.

\( V \) can be calculated for each hour (L.T.) separately and for the three Ap groups. Figure 2 shows a plot of \( V \) vs. hours (L.T.). Following may be noted:

a) The uppermost plot in Figure 2 refers to Ap 0-8 and hence represents \( S_q \) in a general way. Here, one observes that \( V \) is minimum at about 18 Hours (L.T.). Thus, at this hour, the daily variation effects are the least. From 18 Hrs. to about 4 Hrs. there is a slight increase in \( V \). It is not certain whether this is significant but, if so, would represent small night-time effects. The major increase occurs during the day-time hours 6 A.M. to 6 P.M., with a maximum at about 11 A.M.

Thus the source of \( S_q \) seems to be confined mainly to day-light hours with a small possible contribution during night hours.

b) The middle curve in Figure 2 refers to moderately disturbed days (Ap 9 to 15). Here, the major increase in \( V \) is again in the day-light hours (maximum at 10-11 A.M.). But, even before dawn, there is a substantial rise from 02 Hrs. to 06 Hrs. Also, the minimum is not at 18 Hrs. but later, at about midnight.

Since this curve refers to \( S_q + S_p \) on moderately disturbed days, it would seem that the \( S_p \) is contributed by extra disturbance mostly in the pre-dawn period and to a smaller extent in the post-dusk period.

c) The bottom curve of Figure 2 refers to highly disturbed days (Ap exceeding 15). Here, the major increase is again during day-light hours. But there is a noticeable fine structure. Thus, after attaining a maximum at about 11 A.M., followed by a drop upto 2 P.M., there is a rise again upto 4 P.M. and the subsequent fall continues not only beyond 6 P.M. but even beyond midnight to reach a minimum only at about 3 A.M. Thus, there is substantial disturbance in the post-dusk period and to a lesser extent in the pre-dawn period.

### III. Conclusion

In conclusion, the results may be summarised as follows:

- a) During quiet periods, the geomagnetic daily variation (particular of the horizontal component \( H \)) is confined mainly to daylight hours with a possible small contribution during night hours. This is consistent with an overview ionospheric current system with possible small induced earth currents persisting into night hours [Pratt and Stone, 1964]. However, possible daytime effects of non-ionospheric origin cannot be ruled out [Kane 1970].

- b) During magnetically disturbed days, the source of disturbance on moderately disturbed days is mostly in the pre-dawn period with a smaller contribution in the post-dusk period. However, on highly disturbed days the conditions seem to be reversed, a predominant contribution coming from the late afternoon hours, continuing upto hours later than midnight.

Thus, the disturbed day variation \( S_p \) is an extra disturbance during pre-dawn hours for small disturbances and during late afternoon to post-dusk hours for large disturbances.

From the ATS1 satellite magnetometer data, Cummings and Coleman [1968] have demonstrated that some magnetic field variations occur simultaneously at the earth's surface and at distances of about 6.6 earth radii. Cummings et al. [1968] have discussed the relationship between magnetospheric substorms and field variations of ground based magnetometers and have evolved a model involving formation and disruption of partial ring currents [Frazin 1961, Cummings 1966] in the dusk-midnight quadrant. It is possible that such partial ring current systems, presumably formed by the inward convective motion of particles near the midnight meridian (through the geomagnetic tail) offer a satisfactory explanation of the main feature of disturbed day variation \( S_q \) referred to above. Details need to be worked out to see whether the SS \( S_q \) variation can be explained completely on the basis of such a non-ionospheric source or a significant ionospheric contribution is still needed.

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