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Variability of equatorial ionosphere inferred from geomagnetic field measurements

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Abstract. The variability of equatorial ionosphere has been examined by using ground based geomagnetic field data of horizontal and vertical field intensities obtained at the isolated terrestrial equatorial station of Ibadan (07.22°N 03.58°E). The values of Sq daily variation rises from the early morning period to maximum at about local noon and falls to lower values towards evening. The ionospheric current responsible for the magnetic field variations is inferred to build up at the early morning periods and attain maximum intensity at about local noon. The daytime variation in resultant solar quiet daily variations Sq in horizontal and vertical field intensities Sq(H) and Sq(Z) respectively were generally greater than night time. The rising rate of the ionospheric Sq current is generally greater than the decay rate. The vertical daytime ExB drift velocity in the ionospheric F region and the daytime strength of the equatorial electrojet are inferred to have seasonal variation. The scattering of variation is more on the disturbed condition than the quiet condition. This is obviously due to the ionospheric disturbances originating from external drives, such as, space weather effects, storms, etc. The seasonal variation is attributed to seasonal shift in the mean position of the Sq current system of the ionospheric electroject and the electrodynamics effects of local winds. Magnitude of the annual means is greater in element H than Z at any given condition.

Keywords : equatorial ionosphere – currents – geomagnetic field

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1. Introduction

Characterizing the equatorial ionosphere is of utmost interest due to the numerous complexities associated with the region. An intense ionospheric current, the equatorial electrojet EEJ, flows in the region (Chapman 1951; Onwumechili 1997). This EEJ has various manifestations, ranging from transient variation to spatial variations and is surely responsible for various instabilities in the region. Using the POGO series satellite data, Kim & King (1999) confirmed the local time and longitudinal variations of the amplitude of the equatorial electrojet (EEJ). Jadhav et al. (2002) have used data from the Oesrted satellite to show the longitudinal variability of the EEJ intensities. Forbes et al. (2000) examined the variability of ionosphere and observed that the responsiveness of the ionosphere to increased magnetic activity increases as one progresses from lower to higher latitudes.

Recent studies had quantitatively established the relationships between the vertical daytime ExB drift velocity in the ionospheric F region and the daytime strength of the equatorial electrojet (Anderson et al. 2002, 2004). The drift vertical daytime ExB drift velocity in the ionospheric F region has been explained from geomagnetic observations (Anderson et al. 2004). For both perturbed and unperturbed conditions, Araujo-Pradere et al. (2004) discovered that the low latitude ionosphere shows higher variability than the high latitude ionosphere.

In the present paper we employ a set of geomagnetic data obtained at a low latitude observation point to examine the solar daily variations in geomagnetic horizontal and vertical field intensities under quiet and disturbed conditions.

2. Data analysis

The data set used in this study consists of the hourly values of the geomagnetic elements, horizontal intensity H, and vertical intensity Z, recorded at the geomagnetic observatory of the Department of Physics, University of Ibadan, Ibadan for all the months in the year 1970. However, the data of the horizontal intensity H for January 1970 was missing. The geographical coordinates of this observatory are 07.22°N, 03.58°E while the dip latitude is 6.0°S. The geomagnetic observatory at Ibadan benefited from the cooperation of the International Geophysical Year (IGY) and its cooperation IGY-C. The data were analysed for all the five international quiet days and five international disturbed days of each month of the year.

Evaluation of solar daily variation

The concept of local time (LT) was used throughout the analysis. The observatory is 1 hour ahead of the Greenwich Mean Time and thus, when it is 12 noon universal time

UT, the LT is 1.00 p.m. The baseline is defined as the average of the 4 hours flanking local midnight (23, 24, 1, 2, hours). The daily baseline values for the elements used in this research are:

$$H_0 = \frac{H_{23} + H_{24} + H_1 + H_2}{4} \tag{1}$$

$$Z_0 = \frac{Z_{23} + Z_{24} + Z_1 + Z_2}{4}. \tag{2}$$

Both H_0 and Z_0 were corrected to the nearest whole number, where (H_1, Z_1), (H_2, Z_2), (H_{23}, Z_{23}) and (H_{24}, Z_{24}) are the hourly values of H and Z at 01, 02, 23 and 24 hours LT respectively.

The hourly departures, of H and Z from midnight baseline, (ΔH, ΔZ) were obtained by subtracting the midnight baseline values for a particular day from the hourly values for that particular day. Thus for 't' hour LT:

$$\Delta H_t = H_t - H_0 \tag{3}$$

$$\Delta Z_t = Z_t - Z_0 \tag{4}$$

where $t = 1$ to 24 hrs.

The hourly departure is further corrected for non-cyclic variation, a phenomenon in which the value at 01 LT is different from the value at 24 LT, after Vestine (1967) and Rabiu (2000). This is done by making linear adjustment in the daily hourly values of $(\Delta H, \Delta Z)$. A way of doing this is to consider the hourly departures $(\Delta H, \Delta Z)$ at 01 LT, 02 LT, 24 LT as $V_1, V_2, \ldots V_{24}$, and take

$$\Delta_c = \frac{V_1 - V_{24}}{23} \tag{5}$$

the linearly adjusted values at these hours are:

$$V_1 + 0\Delta_c, V_2 + 1\Delta_c, V_3 + 2\Delta_c \ldots V_{23} + 22\Delta_c, V_{24} + 23\Delta_c \tag{6}$$

In other words:

$$S_t(V) = V_t + (t-1)\Delta_c \tag{7}$$

where t is the local time ranging from 01 to 24.

The hourly departures corrected for non-cyclic variation gives the solar daily variation in H and Z. Sq(H) and Sq(Z) denote the solar quiet daily variation in H and Z respectively; while Sd(H) and Sd(Z) denote the solar disturbance daily variation in horizontal intensity and vertical intensity respectively. A set of hourly profiles of Sq(H), Sq(Z), Sd(H) and Sd(Z) was obtained for the 60 quiet and 60 disturbed days of the year 1970.

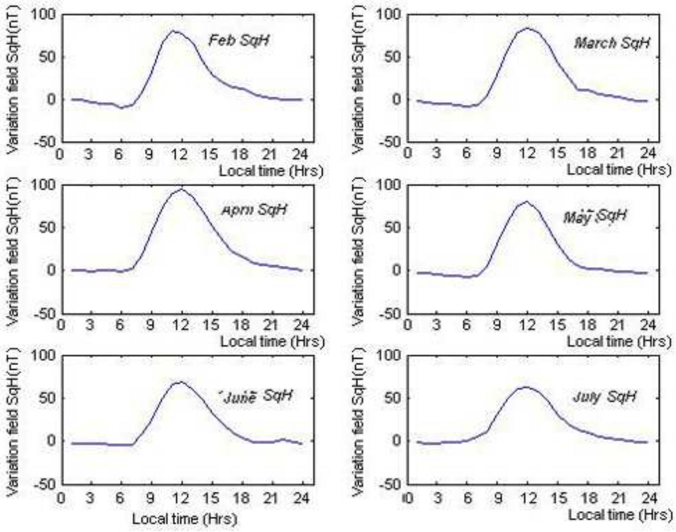

Figure 1(a)

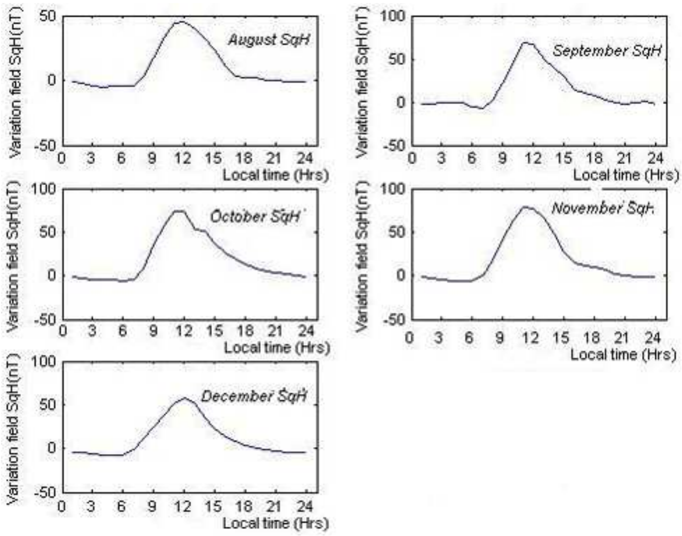

Figure 1(b)

Figure 1. (a) Diurnal variation of SqH Feb-July. (b) Diurnal variation of SqH August–December.

Diurnal variation of solar daily variation

The mean of the hourly values for each individual hour for all the days of a month is called the mean hourly value for the month. Similarly, here we have obtained the mean

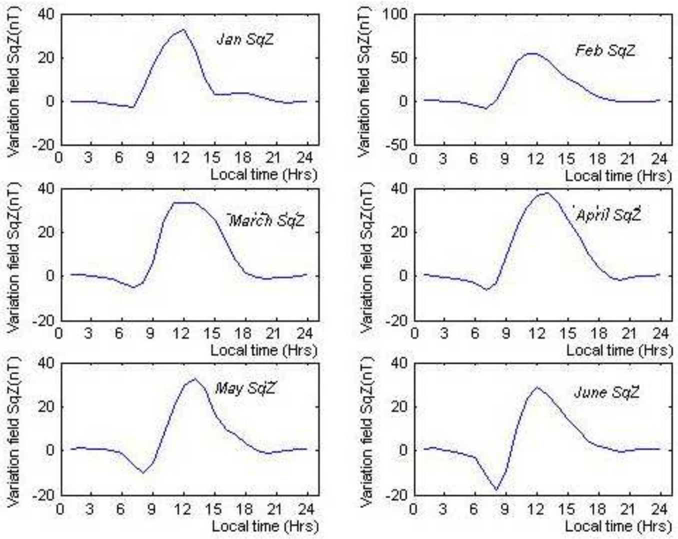

Figure 2(a)

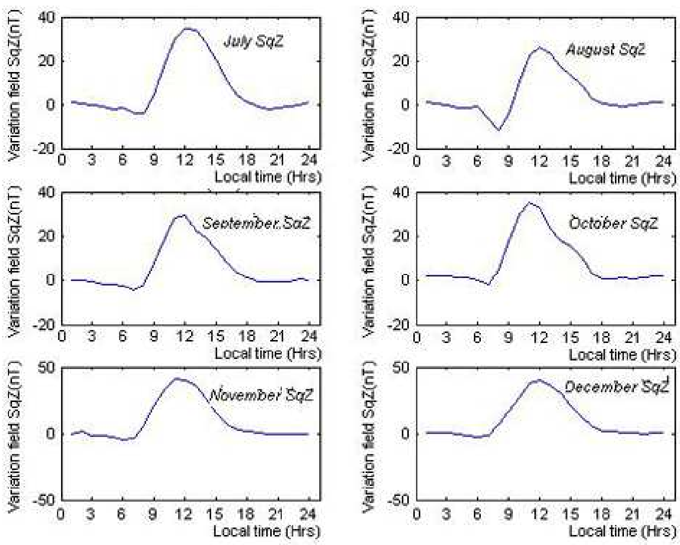

Figure 2(b)

Figure 2. (a) Diurnal variation of SqZ Jan-June. (b) Diurnal variation of SqZ July-December.

hourly values from a selected group of days of a month. Such selected groups are usually the five international quiet days and five disturbed days of the month.

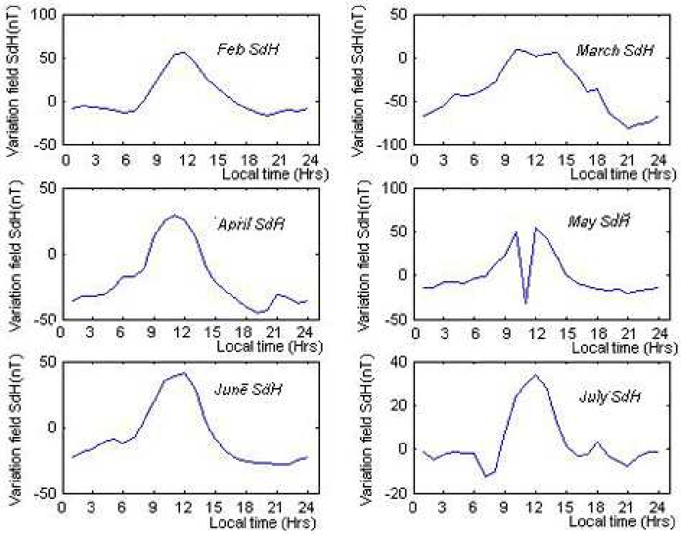

Figure 3(a)

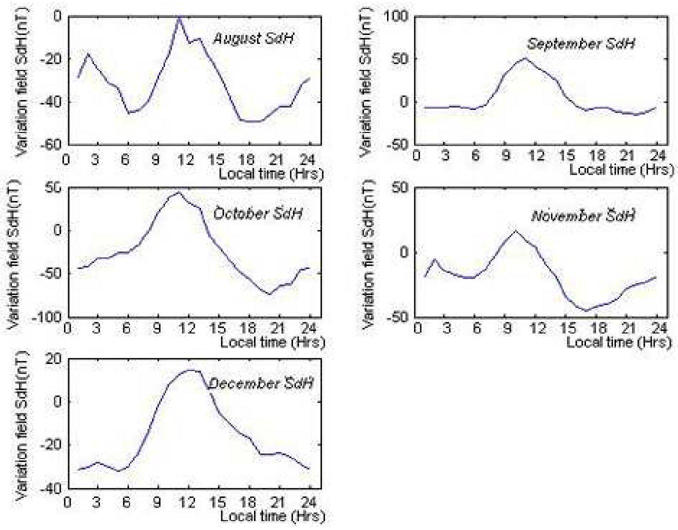

Figure 3(b)

Figure 3. (a) Diurnal variation of SdH Feb-July. (b) Diurnal variation of SdH August-December.

The mean monthly hourly variations of solar quiet variation were then found by finding the mean of the hourly solar quiet variation in horizontal intensity, Sq(H) and in vertical intensity, Sq(Z) for each set of the five international quiet days of each month for

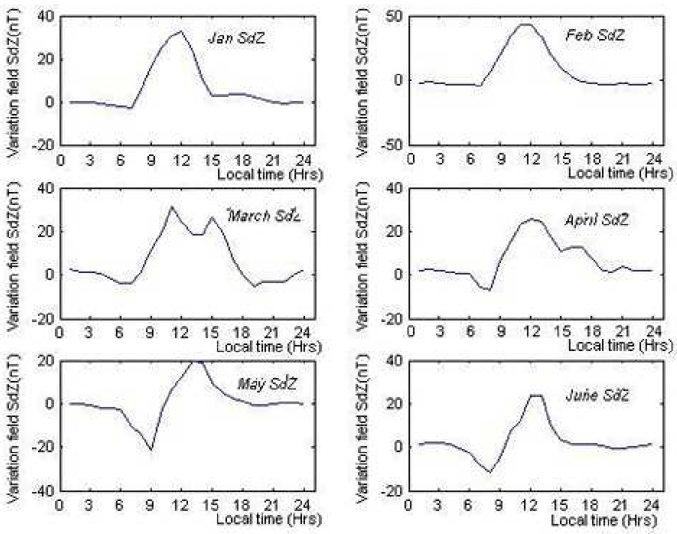

Figure 4(a)

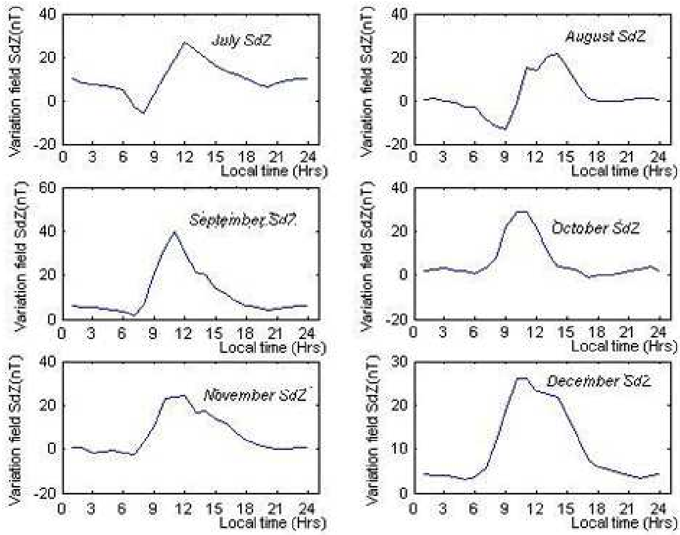

Figure 4(b)

Figure 4. (a) Diurnal variation of SdZ January – June. (b) Diurnal variation of SdZ July–December.

the year 1970. The values of Sq (H) and Sq(Z) were then plotted against local time to examine the hourly variation (diurnal) on quiet days. The diurnal variations of the solar

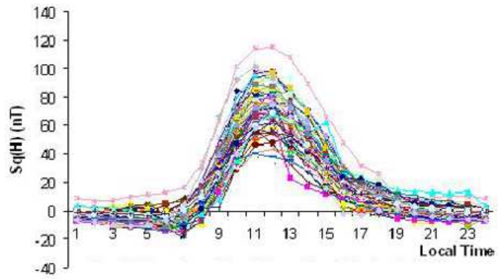

Figure 5. Mass plots of the daily profiles of the hourly SqH.

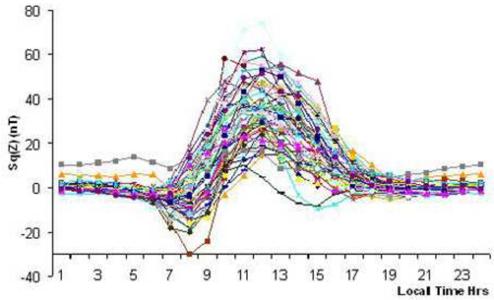

Figure 6. Mass plots of the daily profiles of the hourly SqZ.

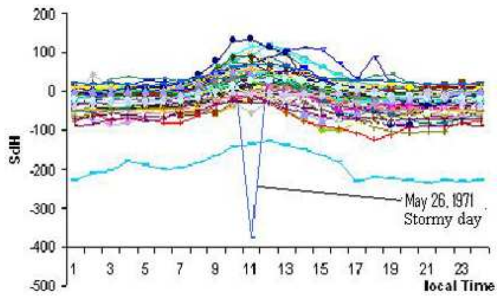

Figure 7. Mass plots of the daily profiles of the hourly SdH.

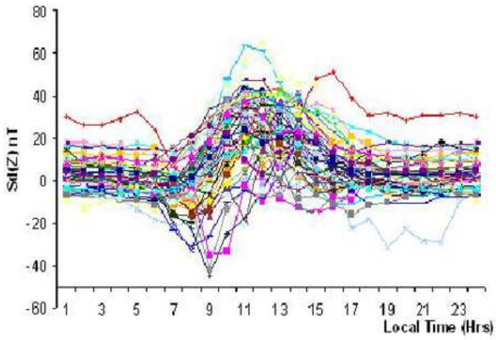

Figure 8. Mass plots of the daily profiles of the hourly SdZ.

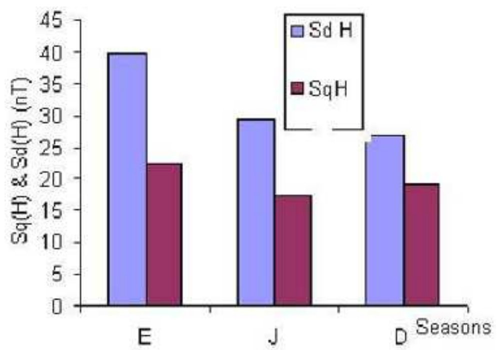

Figure 9. Seasonal variation of SqH and SdH.

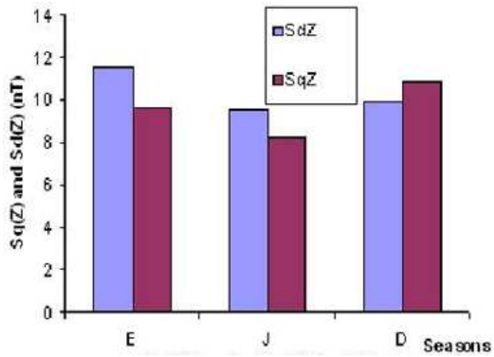

Figure 10. Seasonal variation of SqZ and SdZ.

quiet daily variation Sq are illustrated in Figs 1 (a & b) for Sq (H) and Figs 2 (a & b) for Sq(Z).

Similarly, the mean monthly hourly variation of solar disturbed variation were also

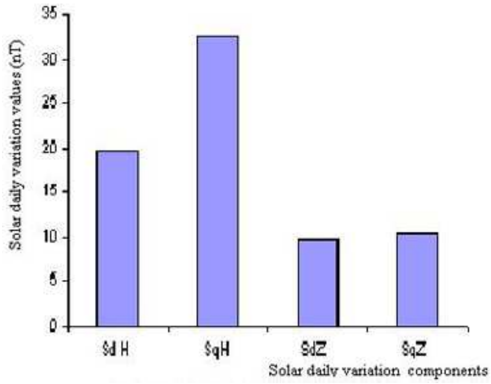

Figure 11. Annual means of SdH, SqH, SdZ and SqZ.

found by finding the mean of the hourly solar disturbed daily variation in horizontal intensity, Sd(H), and vertical intensity, Sd(Z), for each set of the five international disturbed days of each month for the year 1970. The values of Sd(H) and Sd(Z) were then plotted against local time to examine the hourly variation (diurnal) on disturbed days as shown in Figs 3 (a & b) for Sd(H) and Figs 4 (a & b) for Sd(Z).

Figures 5, 6, 7, and 8 give the graphs of the daily Sq(H), Sq(Z), Sd(H) and Sd(Z) respectively for all the days studied, between January to December, 1970.

Seasonal variation of H and Z elements

Following Lloyd's seasons (Eleman 1973), the months of the year are classified into three seasons; December or D-Season (January, February, November, December), Equinox or E – season (March, April, September, October), June Solstice or J-Season (May, June, July, August).

The seasonal means were evaluated by finding the average of the monthly means under a particular season. Fig. 9 presents the seasonal variation of the Sq(H) and Sd (H) while Fig. 10 presents the seasonal variation of Sq(Z) and Sd(Z). The annual means of Sq(H), Sq(Z), Sd(H) and Sd(Z) are illustrated in Fig. 11.

3. Discussion

Diurnal variation

It is clear from Figs 1–4 that, the diurnal variations of solar quiet daily variation, Sq, and solar disturbance daily variation, Sd, exist in both elements on quiet and disturbed days throughout the year. Sq(H) has diurnal variations on quiet days (see Figs 1 and 5) throughout the year. The absolute value of Sq (H) daily variation rises from 0006 hrs LT, reaches the peak at about 12 noon, and reclines to low level at 0018 hrs LT. In general, the daytime magnitudes are much greater than the night time magnitudes for all the months of the year. This variation pattern is due to the diurnal variation of the ionospheric conductivity. (Onwumechili 1997).

It can also be seen that the daytime variation of Sq(Z) are generally regular and smooth for all the months of the year. The absolute value of the Sq(Z) daily variation is consistent and reaches its maximum at about local noon. The diurnal variation of solar daily variation on both conditions followed the variation pattern of solar daily variation in earlier works (for examples Onwumechili 1960; and Matsushita 1969), and can be attributed to the variability of the ionospheric processes and physical structures such as conductivity and winds structures.

Night-time variation

Night-time was taken as the time from 0018 hrs LT to 0006 hrs LT through 0024 hrs LT. Figs 1-4 also indicate that there is a visible night-time variation of solar disturbance daily variation in both elements. Various reasons have been given to explain these night-time variations, which include convective drift currents in the magnetosphere and the asymmetric ring currents in the magnetospheric currents, magnetospheric effects like the westward ring current even during fairly quiet periods, variation due to disturbances indicating possible non-ionospheric origin and a partial ring current in the right side magnetosphere (Rabiu 1996).

Day-to-day variability

Figs 5–8 show the mass plots of daily hourly variation of the solar daily variation of horizontal and vertical intensities on both conditions. It gives a measure of day-to-day variability of the solar quiet daily variation, Sq, and solar disturbance daily variation Sd in both elements. Obviously, it is clear that the Sq and the Sd on one day are clearly different from Sq and Sd of another day even at the same hour. This implies that, there is day-to-day variability in the ionospheric conditions in the region of interest, i.e. low latitude.

Also, as expected, the scattering of the day-to-day variation is more on the disturbed condition than the quiet condition. This is due to the ionospheric disturbances originating from external drives such as space weather effects, storms etc. For example, a day noted for a very pronounced daytime disturbance is marked as May 26, 1970 and confirmed to be a stormy day with Dst value −45.7917. Generally the magnitude of the variation on disturbed days are always greater than those of quiet condition and this should be due to extra input of energy into the ionosphere during storms and other ionospheric phenomena.

Seasonal variation of Sq and Sd

Figs 9 and 10 show a clear indication that solar quiet daily variation Sq and solar disturbed variation Sd exhibit seasonal variation which varies with the magnetic components and prevailing ionospheric condition.

On quiet condition, Sq(H) maximizes in equinox while Sq(Z) maximizes in December solstice; both components have least variation in June solstice. While on perturbed condition, Solar daily variation in both components maximize in equinox, Sd(H) has least variation in December solstice; Sd(Z) has least variation in June solstice.

Forbes (1981) noted that the seasonal variability could be partially explained by the seasonal variation of lunar semi-diurnal tide. Seasonal change in the Sq variation is attributed to a seasonal shift in the mean position of the Sq current system of the ionospheric electroject (Hutton 1962). The electrodynamics effects of local winds can also account for seasonal variability, since the winds are subject to day-to-day and seasonal variability. This seasonal variability of the Sq and Sd implies that the vertical daytime ExB drift velocity in the ionospheric F region can be inferred to have seasonal variation.

Fig. 11 clearly indicates that on disturbed days, the annual mean of solar daily variation is generally greater than those on quiet days for same elements. The annual mean is greater in element, H, than element Z, at any given condition, which is in agreement with the experience at Muntilupa (Rabiu 1992). This implies that element H suffers much variation for similar effect than Z at location of study.

4. Conclusions

The main conclusions include the following:

1. The equatorial electrojet exhibits diurnal variations on both quiet and disturbed days throughout the year. The daytime magnitude of the solar daily variation in magnetic field is greater than the night-time magnitudes for all the months in the two elements, H and Z. The diurnal variation of solar daily variation on both conditions followed the variation pattern of solar daily variation in earlier works (Onwumechili & Ezema 1977; Emilia & Last 1977) and can be attributed to the variability of the ionospheric processes and physical structures such as conductivity and winds structures.
2. The rate of building up of ionospheric Sq current is faster than its rate of decay after noon time maximum.
3. The scattering of variation is more in disturbed conditions than in quiet conditions. This is obviously due to the ionospheric disturbances originating from external drives, such as, space weather effects and storms.
4. The variation of the night-time may be as a result of the variability of the night-time distant current.

5. The seasonal variation is attributed to seasonal shift in the mean position of the Sq current system and the electrodynamics effects of local winds. The vertical daytime ExB drift velocity in the ionospheric F region is inferred to have seasonal variation.
6. The magnitude of annual means is greater in element H than Z at any given condition.

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