The Asymmetrical Behaviour of the $S_qH$ Current System during the Prenoon-Postnoon Epochs at African Longitudes

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Abstract: This study examines the prenoon-postnoon asymmetrical behaviour and latitudinal dependence of $S_q$ (solar quiet) current system using data of quiet-time daily variations of the geomagnetic field intensity from twelve geomagnetic observatories along the African Meridian. The dataset of each month during 2009 (noted for empirically low solar activity with average sunspot number $R_z = 3.1$) was treated for non-cyclic correction. From a blend of spatial contour maps and graphical analyses, our results show that $S_q$ current system exhibits in the daytime unstable tendency. A consistent diurnal variation of solar quiet variation in the horizontal component of earth magnetic field ($S_qH$) was observed which exhibits synoptic pre-noon and post-noon mean values of 59 nT and 33 nT with ranges of 33 nT and 24 nT, respectively. The centre of circulation of overhead electric current is observed to exhibit both pre-noon and post-noon epoch’s asymmetric variations. This is noted to indicate the dynamic heterogeneous genesis of the mechanism responsible for the observation. The spatial contour mapping result depicts $S_qH$ behaviour switch twice a year around March and September with similar spatial distribution in January up to March and then October up to December. A similar distribution was noted for the months of April to September. Prenoon values of $S_qH$ have higher magnitudes across the latitudes in comparison with the post noon values just as is the case at noontime.

Key words: solar quiet variation, pre-noon epoch, ionospheric current system, variability.

1. Introduction

Daily variations in the Earth’s magnetic field arising from the Sun’s effect on the ionized region of the upper atmosphere during the geomagnetic quiet condition has long been a proven fact and the cause has been known as the dynamo action in the upper atmosphere, at altitudes ranging 100~130 km above Earth’s surface [1]. At these altitudes the atmosphere is significantly ionized by the Sun’s ultraviolet and X-radiation and the ions are moved by winds and tides arising from the heating effects of the Sun and the gravitational pull of the Sun and the Moon [2]. This creates the required conditions for a dynamo to operate, and two current cells are formed, one in the sun-lit northern hemisphere going counter clockwise, the other in the sun-lit southern hemisphere going clockwise. The magnetic effect of these current systems is observed on the ground at observatories as solar quiet-day variation [3-5]. The geomagnetic field has a regular variation with a fundamental period of 24 h. This regular variation is dependent on local time, latitude, season, and solar cycle. The ionospheric current system is responsible for these variations on $S_q$ (solar quiet) days. The wind and the conductivity of the ionosphere vary seasonally due to their dependence on the solar zenith angle [6, 7]. Schlapp [8] studied the day-to-day variability of $S_q$ based on the
IGY (international geophysical year) data obtained from a global network and he suggested that the day-to-day variability of $S_q$ is due to the variations in dynamo driving force rather than variations in conductivity [9, 10]. Zhao et al. [11] concluded that the correlation between the $S_q$ amplitude and solar zenith was higher in high latitude than in low latitude regions due to the effect of the prenoon-postnoon asymmetry of $S_q$. The $S_q$ field variation has a main spatial dependence on latitude and is affected by other factors including epoch of the year and level of solar activity. This paper presents comprehensive morphology about the asymmetrical variation of solar quiet variation in the horizontal component of earth magnetic field ($S_qH$) over Africa, during the low solar activity year. In view of this, the results from this work will update the prior results of the prenoon/postnoon variation of $S_q$ over the African region.

2. Data and Method of Analysis

This research uses data obtained from ground based magnetometer from 12 stations of MAGDAS (magnetic data acquisition system) covering both the northern and the southern hemispheres, distributed along east with geographic longitudes between 0° to 40° along the African meridian during the year 2009 for which the solar activity was empirically low. Details of the MAGDAS are documented in Refs. [11-15]. The MAGDAS magnetometers recorded its parameters in near real time at every minute which are sent to the database. The MAGDAS database provides the H (horizontal), the Z (vertical), the D (declination) and F (total field) components of the Earth’s magnetic field. Only the horizontal component was used in this study. The year 2009 was a year of minimum solar activity with average sunspot number $R_2 = 3.1$ for which the geomagnetically quiet days—defined as the days of peak planetary geomagnetic disturbance index, $K_p \leq 2+$ were carefully selected and the typical patterns of quiet time magnetic field variations at African longitudes using the mean values of the magnetic field variations on the quiet days were further obtained. Further data pre-processing procedures were involved in the analysis which synoptically entails baseline removal, midnight departure adjustment and non-cyclic correction [16, 17] all based on the concept of local time. Thus, the solar quiet variation in H (the horizontal component), called $S_qH$ was derived. Spatial hourly contours of $S_qH$ were generated using twelve sets of monthly mean values of $S_qH$ which was determined for the year investigated. Map digitization technique was used to slice the $S_qH$ spatial contour maps at daytime hours (06 h LT (local time) to 17 h LT) in the pre-noon through the post-noon epochs. By examining cross-sections along different latitudes, the results obtained to produce plots of daytime hourly variations of $S_qH$ with latitudes in 2-D were used. On examining the variation of $S_qH$ in both hemispheres a distinct pre-noon, noontime and postnoon asymmetrical characteristics was observed and studied. The distribution of the twelve MAGDAS stations used in this study is given in Fig. 1 while Table 1 presents the geomagnetic and geographic coordinates of the network of the geomagnetic observatories investigated in this research. From a blend of spatial contour maps and 2-D graphs, careful deductions were made.

3. Results and Discussions

3.1 Prenoon-Postnoon Behaviour of $S_qH$

Mass plots of $S_qH$ with geomagnetic latitude in the northern and southern hemispheres are presented in Fig. 2 as gamut of spatial contour maps to depict these variations for a period of 12 months from January to December 2009. It could be here deduced that the daytime latitudinal dependence of $S_qH$ quite remarkably differ from one another and this may be due to the effect of solar activity. It is clear from the contour representation figures that daily minimum in $S_qH$ is obtained around 06:00 LT while day maximum occurs around 11:00 LT to 12:00 LT. Almost similar
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| Serial number | Station name     | Station code | Geomagnetic latitude ($^\circ$) | Geomagnetic longitude ($^\circ$) | Geographic latitude ($^\circ$) | Geographic longitude ($^\circ$) |
|---------------|------------------|--------------|-------------------------------|---------------------------------|-------------------------------|--------------------------------|
| 1             | Addis-Ababa      | AAB          | 0.18                          | 110.50                          | 9.04                          | 38.77                          |
| 2             | Aswan            | ASW          | 15.20                         | 104.20                          | 23.59                         | 32.51                          |
| 3             | Dal Es salaam    | DES          | -16.26                        | 110.60                          | -6.47                         | 39.12                          |
| 4             | Durban           | DRB          | -39.21                        | 96.10                           | -29.49                        | 30.56                          |
| 5             | Fayum            | FYM          | 21.13                         | 102.40                          | 29.30                         | 30.88                          |
| 6             | Hermanus         | HER          | -33.89                        | 84.55                           | -34.43                        | 19.23                          |
| 7             | Ilorin           | ILR          | -1.82                         | 76.80                           | 8.50                          | 4.68                           |
| 8             | Khartoum         | KRT          | 5.69                          | 103.80                          | 15.33                         | 32.32                          |
| 9             | Lagos            | LAG          | -3.04                         | 75.33                           | 6.48                          | 3.27                           |
| 10            | Lusaka           | LSK          | -26.06                        | 98.32                           | -15.23                        | 28.20                          |
| 11            | Maputo           | MPT          | -35.98                        | 99.57                           | -25.57                        | 32.36                          |
| 12            | Nairobi          | NAB          | -10.65                        | 108.20                          | -1.16                         | 36.48                          |

Fig. 1  Map showing the locations of the observatories in this study.
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$S_q$H patterns are observed for all the months at different latitudes. Larger variations of $S_q$H are observed during the prenoon hours in all the plots. The upper panel of the latitudinal profile of monthly mean variation of $S_q$H depicted in spatial contour mapping of Fig. 2 bears very close resemblance across the months of January, February, March, October, November and December while the lower panel presents a comparable manifestation but now in the months of July, August, September, April, May and June. The enhancement of $S_q$H seen in all the plots particularly at the low latitude region with about 40 nT in magnitude can be associated with the solar activity dependent on ionospheric intensification which is consistent with atmospheric dynamo theory [18, 19].

The prenoon value of the low latitude region exhibits higher value of $S_q$H in all the months of the year, whereas the postnoon value exhibits lower value of $S_q$H in all the months of the year and witnesses random change across the whole latitudinal zones. The slight postnoon depression characteristic is observed in $S_q$H in the months of March, April, June and August during the time interval 15:00 LT to 17:00 LT. This implies that the variation of $S_q$H during the postnoon hours is weaker during these months which represent March equinox and June solstice’s months. In almost all the months, $S_q$H enhancement is larger at the low latitude region than that at mid latitude region during the same time period. This is because there is higher photoionization effect and more pre-reversal enhancement effect that could make the $S_q$H to be well established during this period.

To garner detailed information about the asymmetrical behaviour of $S_q$H of the twelve observatories...
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Jan

Feb

Mar

Apr

May

Jun
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Fig. 3  Asymmetrical behaviour of monthly mean of $S_aH$ along African Meridian.
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investigated along the African meridian, Fig. 3 depicts postnoon variation in black line and prenoon variation in red line respectively. The plots present geomagnetic latitude on the abscissa and various $S_q H$ on the ordinate. The plots reveal that $S_q H$ exhibits marked variations mostly daily with peak build up just around noontime across the year. The pre noon values of $S_q H$ present higher magnitudes across the latitudes in comparison to the post noon values just as is the case at noontime. But pre noon variability far exceeds post noon variability as shown on the contour map panels and plots of Fig. 3.

3.2 Noon-time Variation of $S_q H$

The noon-time $S_q H$ variation data was obtained by slicing through the contour plot of the spatial
distribution at noon and plotted against the geomagnetic latitude of the stations. This result is presented in Fig. 4 as the latitudinal profiles of $S_q$H at local noon along Africa meridian depicting daily variations investigated in groups of three months: (January, February and March), (April, May and June), (July, August and September) and (October, November and December). The month of May presents a peak value of about 58 nT and hence the highest variability. This is closely followed by a value close to 54 nT in the month of July. Both peaks are exhibited around 0° geomagnetic latitude. However the month of October presents a numerical deep in $S_q$H magnitude of about 62 nT but around minus 20° geomagnetic latitude. A large noon-time diurnal variation however, seen in all the months of the year compared to the morning values in Fig. 3. Fig. is nearly the same over the whole time interval.

4. Conclusions

The results presented in this study pronounce the daily variation of $S_q$H and the asymmetrical behaviour of the daily variation of the earth’s magnetic field with respect to the latitudes over Africa during low solar activity period of the year 2009, and the following conclusions can be made based on the above results and discussions:

The diurnal variation of solar quiet daily variation followed a regular and consistent pattern with daytime magnitudes greater than the night-time magnitudes for all the months. These variations can be attributed to the variability of the ionospheric processes and physical structures such as conductivity and winds structures.

The prenoon variability was found to be greater than the postnoon variability which may be attributed to difference in photoionization. This may be due to the ionospheric disturbances originating from external drivers, such as, space weather effects, ring currents and storms.

The results indicate that the $S_q$ H variation undergoes prenoon/postnoon asymmetry. This may be due to large-scale air circulation variability in the ionosphere. It effects on ionization equilibria lead by dynamo action to the ionospheric electric currents which produce the variation of the field.

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