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Contribution of solar quiet (Sq) daily current variations to the deep earth conductivity within the Southern African Region

Ngozi Agatha Okwesili*, Francisca Nneka Okeke and Igwe Emmanuel Awucha

Department of Physics and Astronomy, University of Nigeria, Nsukka, Enugu State, Nigeria.

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This work focuses on determining the source current systems by applying the method of spherical harmonic analysis (SHA) to geomagnetic field data obtained from ground measurements. The objectives are to establish the mantle conductivity-depth profile and to compare the results of the profiles from four stations with other research findings. The study utilizes magnetometer data obtained for the year 2011 from geomagnetic stations located in Hermanus, Maputo, Tsumeb, and Hartebeesthoek within the Southern African region. The Gauss SHA method, along with Matlab software, is employed to separate the internal and external field contributions to solar quiet (Sq) current variations. Subsequently, a transfer function is used to calculate the electrical conductivity-depth profile of the region. The results show that, across all the stations, the highest seasonal Sq current was recorded in the month of June for Hartebeesthoek, Hermanus, and Tsumeb regions. Maputo, however, exhibited an exception with nearly triple peaks in the months of March, June, and December, with the highest occurring during the December solstice. The evaluated maximum values for seasonal Sq current in Hartebeesthoek, Hermanus, Maputo, and Tsumeb are approximately 16.0, 12.5, 12.0, and 14.8 nT, respectively. An equinoxial maximum with a value of 2.1 × 103 A was observed in the seasonal external Sq current in March within the Maputo region, while a solsticial minimum with a value of 0.75 × 103 A occurred in June in the Hartebeesthoek region. The seasonal separated external Sq current system pattern appears to be the same as that of the seasonal Sq current system, indicating that the source of the Sq current system is external to the Earth. The study reveals the greatest depth of Sq current penetration and the highest electrical conductivity values within the Southern African region when compared with other research. Finally, this research contributes to establishing the electrical conductivity of Maputo and Hartebeesthoek regions, where no prior work has been conducted.

Key words: Southern African regions, conductivity-depth structure, solar quiet (Sq) daily current variations, Gauss spherical harmonic analysis (SHA).

INTRODUCTION

The Earth's geomagnetic field is not constant but continually changes, exhibiting variations with respect to time known as geomagnetic field temporal variation. These temporal changes are observed in all magnetic

*Corresponding author. E-mail: ngozi.okwesili@unn.edu.ng

elements (Jacobs and Russell, 1974). The observed temporal variations result from two distinct source regions concerning the Earth's surface: external and internal. There are two main types of variations: short-term transient variations and long-term secular variations. Short-term transient variations originate externally, while long-term secular variations have an internal origin. External field variations range from milliseconds to a few decades, with longer periods tied to solar magnetic field variations (22 and 11 years). Transient variations primarily stem from external factors and do not lead to significant or lasting fluctuations in the Earth's magnetic field. In contrast, secular variations arise from internal factors within the Earth and, over extended periods, can have a significant cumulative effect.

The variation in the solar quiet (Sq) current is primarily caused by three factors: thermal tidal forces in the atmosphere resulting from solar heating; interaction between the Earth's gaseous and plasma environment and charged particles and wave radiation intermittently emitted by the Sun; gravitational tidal forces exerted within the Earth's gaseous environment, predominantly by the Moon and to a lesser extent by the Sun (Basavaiah, 2011).

When solar-terrestrial disturbances are absent or negligible, the daily variations in the geomagnetic field are referred to as solar quiet day (Sq) variations (Campbell, 1989). These Sq variations are the result of electric currents flowing in the dynamo region of the ionosphere; approximately at an altitude of 100 km. Chapman (1919) observed that these dynamo currents are driven by winds and thermal tidal motions in the E region of the ionosphere. As the Earth rotates, its gaseous atmosphere on the dawn side comes under the influence of solar extreme ultraviolet (EUV) radiation. This EUV radiation is selectively absorbed at various altitudes above 60 to 80 km by the gases in the Earth's upper atmosphere, leading to the ionization of gases. Consequently, a conducting medium comprising free electrons and ions (mainly positive at altitudes >90 km and negative at altitudes <90 km) is formed, resulting in electric current flow. The source region for Sq is the E region of the ionosphere, and the Sq variation reflects the currents established in the conducting ionosphere. Since ionization in these layers is renewed daily by the sun, decreasing during the afternoon and night, the Sq field is more intense over the sunlit side of the Earth than over the dark side (Jacobs and Russell, 1974).

The Sq field exhibits slow variations in amplitude and phase throughout the months of the year. Additionally, the amplitude of Sq is 50 to 100% greater in years of sunspot maximum than in years of sunspot minimum (Jacobs and Russell, 1974). Sq is considered to have a zero value near local midnight, as the conductivity approaches nearly zero at this time. However, the mean Sq is not zero, which results in the daily mean differing from the midnight (baseline). The mean daily variation obtained from the five quietest days of the month is denoted as Sq. Sq primarily depends on latitude and local time and is not significantly influenced by longitude; in other words, it remains relatively consistent at all stations around any circle of latitude at corresponding local times (Jacobs and Russell, 1974). The intensity of this geomagnetic field varies over a wide range of timescales, from fractions of seconds to years, but generally follows regular trends on quiet days when magnetic field oscillations are minimal. The geomagnetic field variations, such as Sq, recorded at geomagnetic observatories, assist in determining changes in the Earth's electrical conductivity with depth and understanding the associated external source current systems (Jacobs and Russell, 1974).

The Sq method has been successfully employed in recent years to study the Earth's interior in various regions around the world. For instance, Campbell and Schiffmacher (1986) investigated the sub-continental conductivity of the upper mantle in Asia, Europe, and North America. Campbell et al. (1998) and Arora et al. (1995) established conductivity-depth profiles for the Australian and Himalayan regions, respectively. Agha and Okeke (2007) utilized Sq variations to estimate the conductivity-depth ratio in different sub-regions of the upper mantle in L'Aquila.

Similarly, Obiora et al. (2013) and Obiekezie and Okeke (2010) reported conductivity-depth profiles in West Africa. Furthermore, Ugbor et al. (2016) employed Sq daily variations to determine the mantle's conductivity-depth profile in the African geomagnetic equatorial zones, while Abidin et al. (2019) determined the mantle's conductivity-depth profile in Malaysia using Sq daily current variations.

Although the Sq method has been applied to map out the conductivity-depth structure of the upper mantle in West Africa and East Africa, not much research has been conducted in the Southern African regions, particularly Maputo and Hartebeesthoek, where no prior work has been done. Therefore, there is an opportunity to contribute to the existing knowledge in these areas. Building on the work of Obiekezie and Okeke (2010), Obiora et al. (2013), Obiora et al. (2014), Ugbor et al. (2016), and Campbell and Schiffmacher (1988), who focused on different regions of Africa, we aim to consolidate our understanding of the internal structure, composition, and physical state of the African plate as we integrate the unique features of the upper atmosphere and the Earth's interior.

The primary objective of this work is to separate the quiet-day field variations obtained in the South African region into their external and internal field contributions. Subsequently, we aim to establish the external Sq current system for the South African region and utilize the paired external and internal coefficients of the Spherical Harmonic Analysis (SHA) to determine the upper mantle's conductivity for the region. Finally, we intend to compare the results of the profiles obtained at the four stations with the findings from other research studies.

MATERIALS AND METHODS

Electric currents that flow within the atmospheric conductive region of the Earth, known as the ionosphere, induce corresponding electric currents to flow through the conductive Earth beneath them. The characteristics of these source currents and the distribution of electrically conducting materials within the Earth determine the direction, magnitude, and penetration depth of the induced currents (Campbell et al., 1998). On quiet days, geomagnetic observatories measure composite mixtures of both the source (external) currents and induced (internal) currents. By using SHA or other integral methods to separate these currents into their individual components, researchers have shown that the amplitudes and phase relationships are helpful in determining the electrical conductivity of the Earth's interior (Chapman and Bartels, 1940).

Two methods are commonly employed to study the electrical conductivity within the Earth's mantle over periods ranging from hours to months. The first method is the potential method, in which a SHA of the geomagnetic field is conducted to obtain the Q-response for a specific frequency. This response represents the transfer function between the external (inducing) and the internal (induced) expansion coefficients. The second approach, known as the geomagnetic depth sounding method, determines the C-response, which represents the transfer function between the magnetic vertical components and the horizontal derivative of the horizontal components. Models of the electrical conductivity within the Earth's interior can be constructed for various frequencies if one of these transfer functions is known (Olsen, 1999).

Utilizing satellites for geomagnetic measurements provides excellent spatial coverage, and upcoming missions may extend observation periods for several years, thereby reducing statistical errors in the estimated response functions.

The data used in this study consists of 1 h and 1 min data sets of geomagnetic H, D, and Z fields from four Southern African stations for the year 2011. The Hartebeesthoek, Hermanus, and Tsumeb field data were obtained from World Data Center, WDC for Geomagnetism, Kyoto Japan while Maputo field data was obtained from Kyushu University (KU). The international geomagnetic quiet days (IQD) for the years understudy were also obtained from Geoscience Australia.

Analytical and theoretical methods were adopted. Matlab software was employed in the analysis. The five magnetically quietest days were first selected from the international quiet days in each month for the years under study. The hourly values for the five quietest days of each month were added and their average value calculated. The mean of the hourly values for each day of the magnetic components denoted as BL_0 was then calculated and it was taken as the base line shown in Equation 1 as:

$$BL_0 = \frac{BL_1 + BL_2 + BL_3 + \ldots BL_{24}}{24} \tag{1}$$

where BL_1, BL_2, BL_3 … and BL_{24} are the horizontal (H), declination (D) and vertical intensity (Z) hourly values at 01:00 to 24:00 local time (LT) hours. The data analysis was done using the concept of LT. Also the Sq amplitude denoted as dBL for each hour t was calculated and was taken as the difference between the hourly values BL_t and the mean for the day BL_0 expressed as in Equation 2:

$$dBL = BL_t - BL_0 \tag{2}$$

where t = 1, 2……24 h.

Subsequently, Fourier analysis was carried out for the reconstruction of the Sq for the regions in each month, followed by the application of SHA in the separation of the external and internal contributions to the Sq variation. The use of SHA in solving the magnetic potential of the Sq field V measured from the daily mean values at universal time T for both the external and internal source current is expressed by Gauss (1838) in Equation 3 as:

$$V_n^m = C + a\sum_{n=1}^{\infty}\sum_{m=0}^{n}\left[\left\{a_n^{me}\left(\frac{r}{a}\right)^n + a_n^{mi}\left(\frac{a}{r}\right)^{n+1}\right\}\cos(m\phi) + \left\{b_n^{me}\left(\frac{r}{a}\right)^n + b_n^{mi}\left(\frac{a}{r}\right)^{n+1}\right\}\sin(m\phi)\right]p_n^m(\theta) \tag{3}$$

where $c, \theta, r, a, and\ \emptyset$ denote a constant of integration, the geomagnetic colatitudes, the geocentric distance, the Earth's radius and the local time of the observatory, respectively. The $a_n^{me}\ and\ a_n^{mi}, b_n^{me}\ and\ b_n^{mi}$ are Legendre polynomial coefficients where $e\ and\ i$ represent the external and internal values, respectively. The p_n^m are functions of colatitudes θ only and the integers $n\ and\ m$ are called degree and order, respectively; n has a value of 1 or greater and m is always less than or equal to n (Campbell, 2003).

The equivalent current function J(ϕ), in amperes, for an hour of the day is obtained from Equation 4:

$$J(\phi) = \sum_{m=1}^{4}\sum_{n=1}^{12}\left\{U_n^m\cos(m\phi) + V_n^m\sin(m\phi)\right\}P_n^m(\theta) \tag{4}$$

Having 4 as the maximum value for m and 12 as the maximum value of n. Depth (d) and conductivity (σ) values were determined. Plots of conductivity versus depth profile were done followed by error analyses based on the standard deviation of the conductivity-depth values. The depth in kilometers to a layer of conductivity (σ in S/m) which can produce the observed field measurement is given by Campbell (1997) as shown in Equation 5:

$$d_n^m = Z - P \tag{5}$$

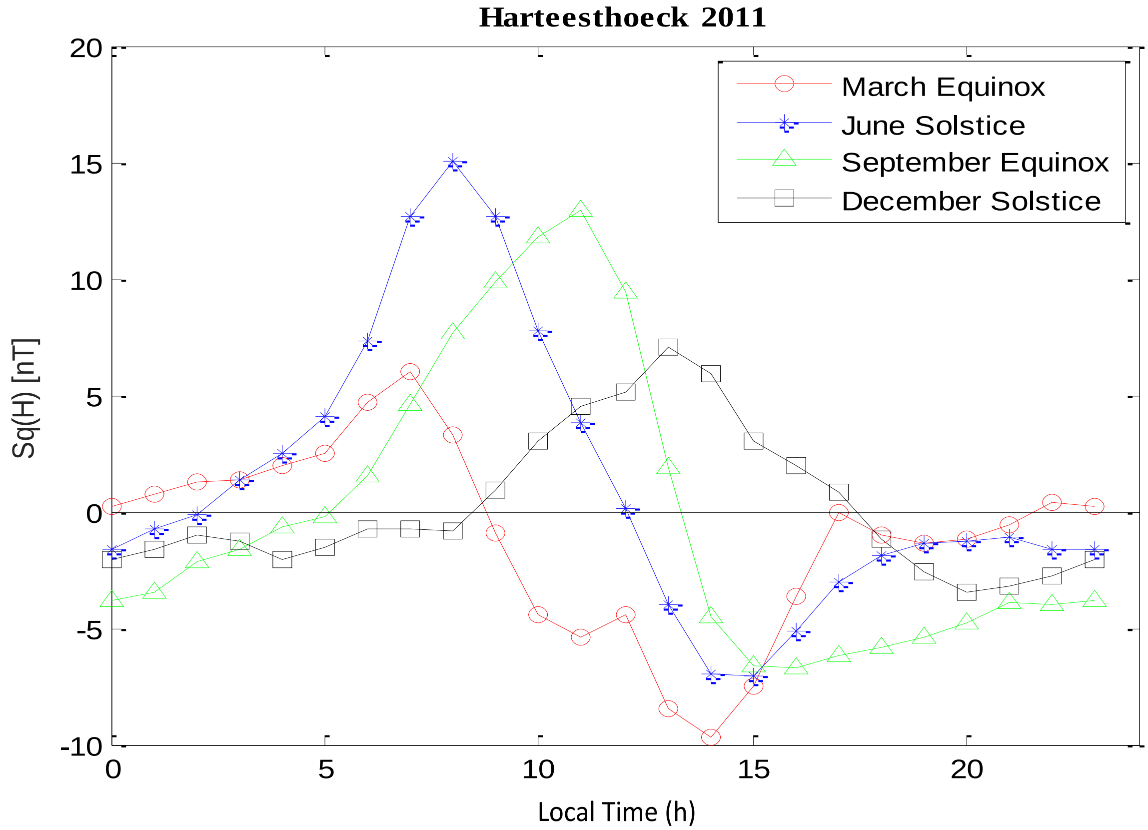
And the associated conductivity σ_n^m is given as in Equation 6:

$$\sigma_n^m = \left(\frac{5.4\times10^4}{m(\pi P)^2}\right) \tag{6}$$

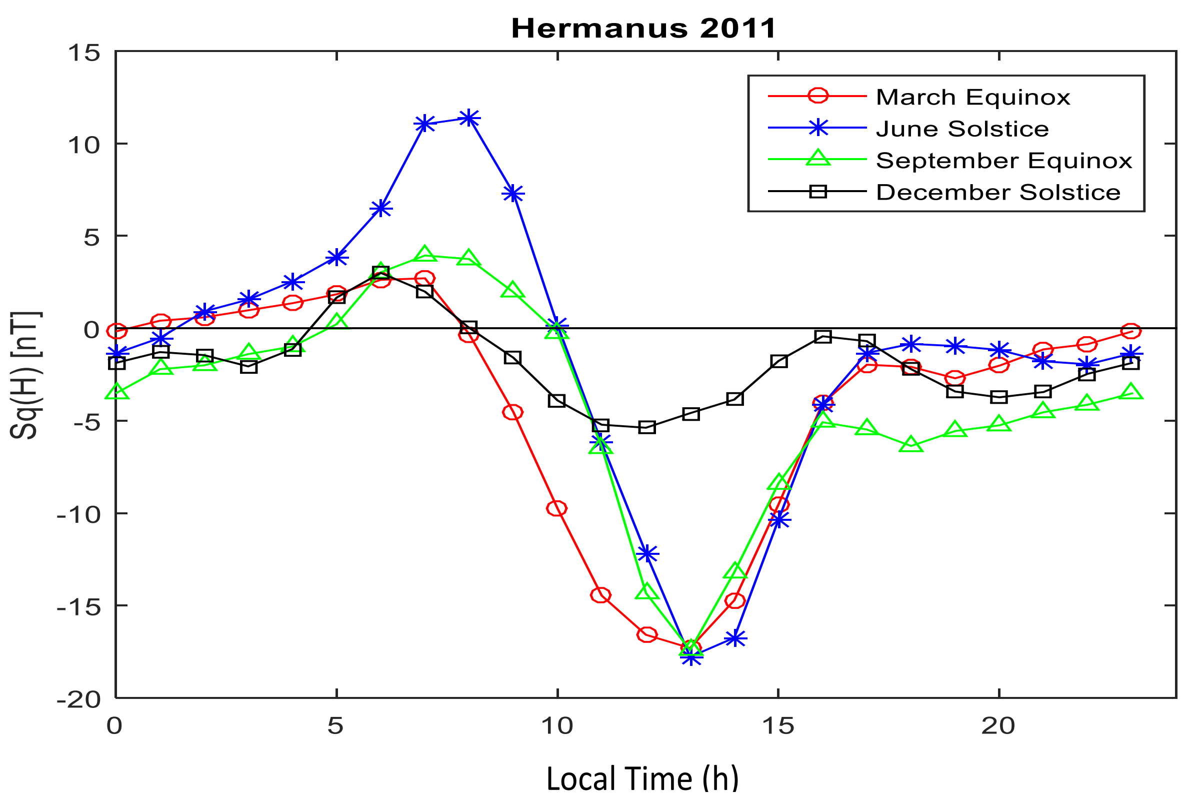
Taking R as the radius of the Earth in km, z and p are given in km.

RESULTS

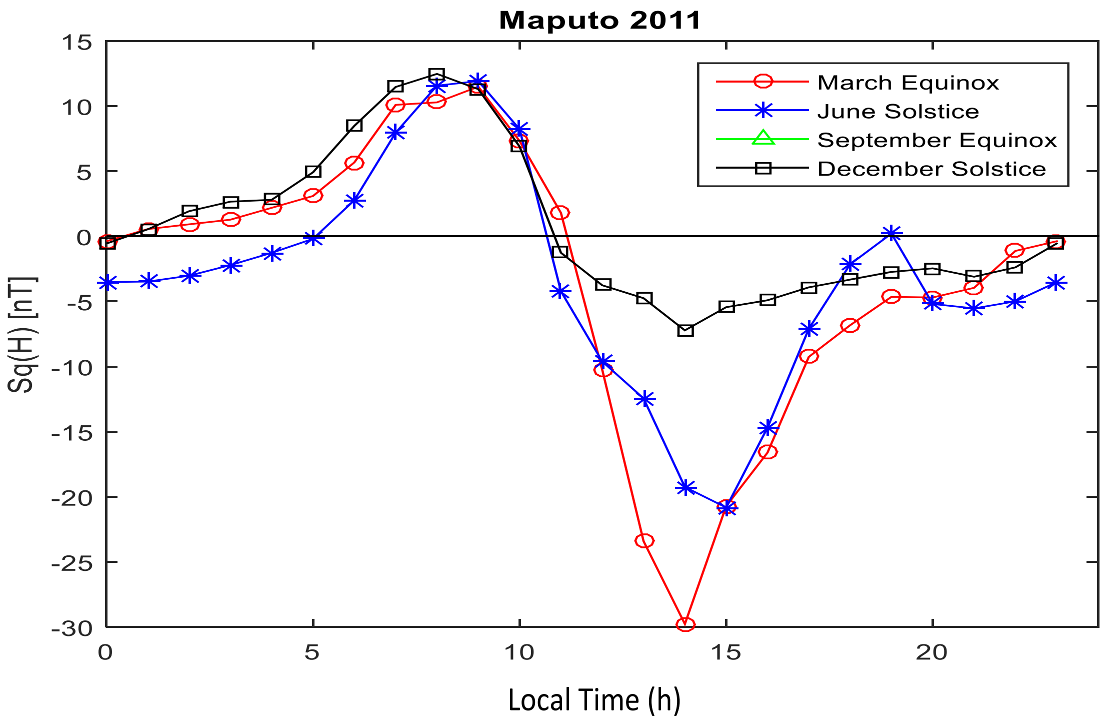
Figure 1 shows seasonal Sq current system, while Figure 2 illustrates the separated seasonal Sq currents field components variation within the Southern African region for the year 2011. The equinoctial (March and


Harteesthoeck 2011
March Equinox
June Solstice
September Equinox
December Solstice
Sq(H) [nT]
Local Time (h)
20
15
10
5
0
-5
-10
0
5
10
15
20

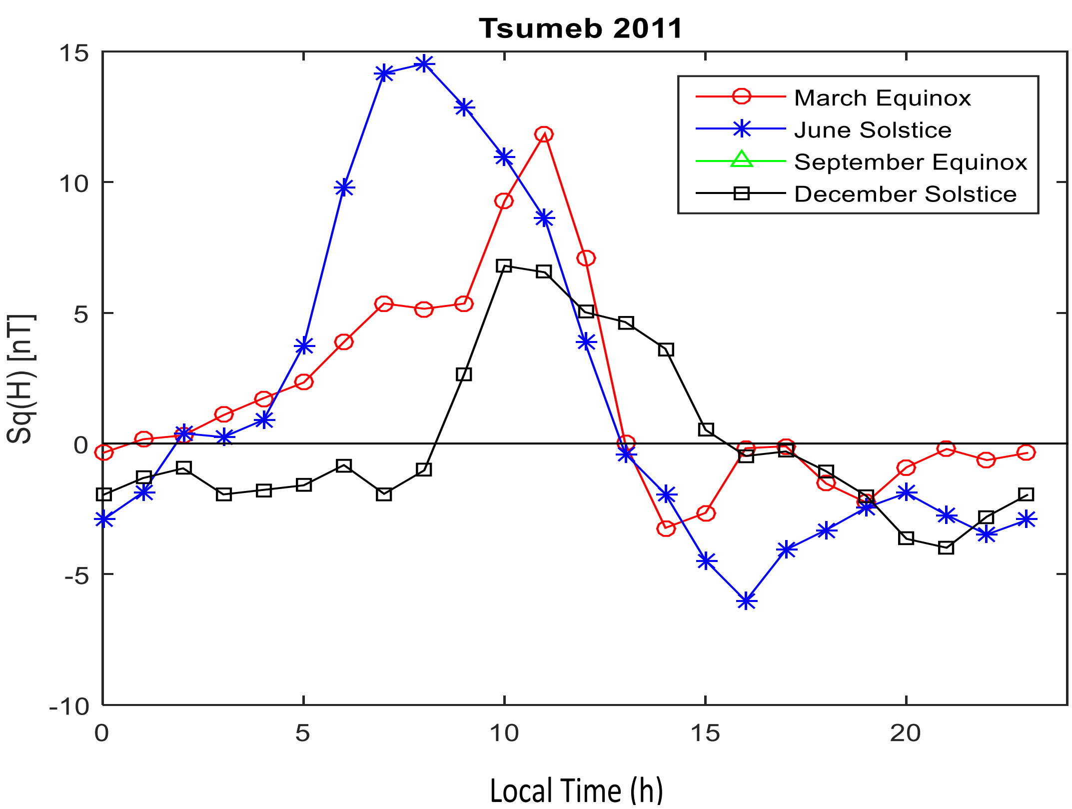
(a)


Hermanus 2011
March Equinox
June Solstice
September Equinox
December Solstice
Sq(H) [nT]
Local Time (h)
15
10
5
0
-5
-10
-15
-20
0
5
10
15
20

(b)

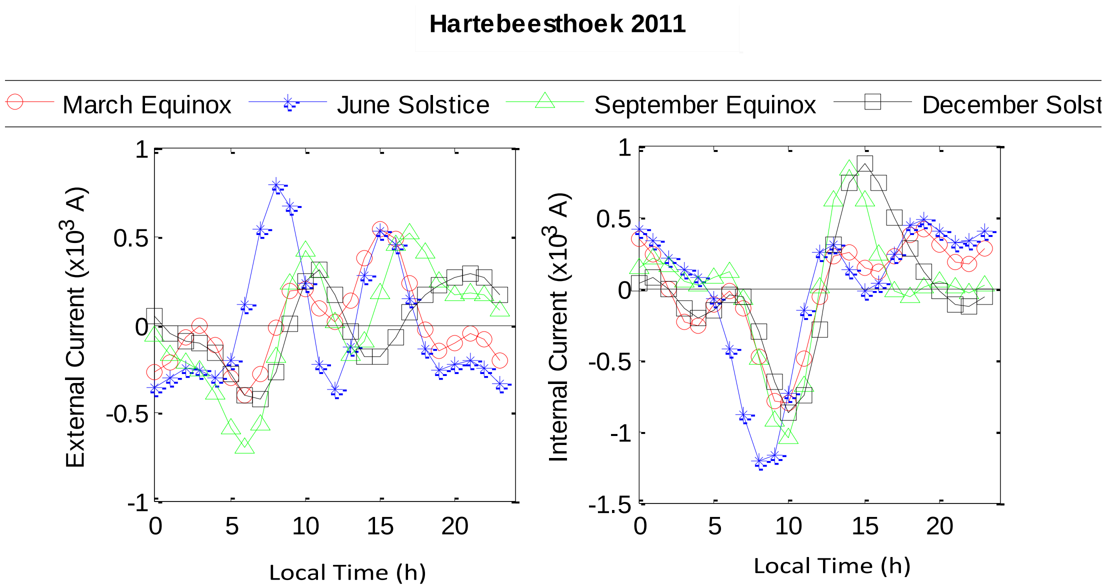


(c)

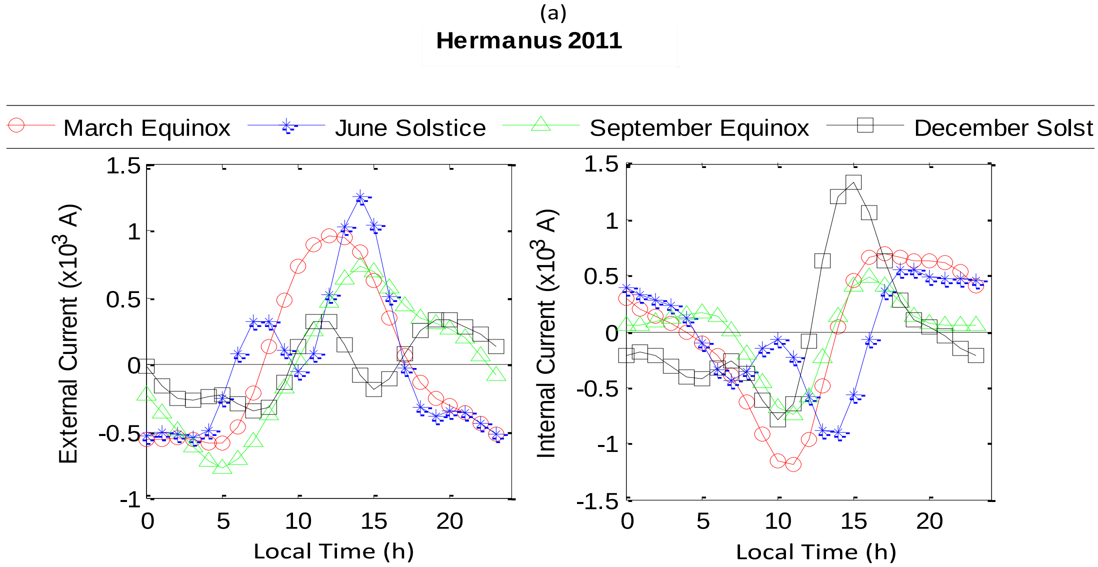


(d)

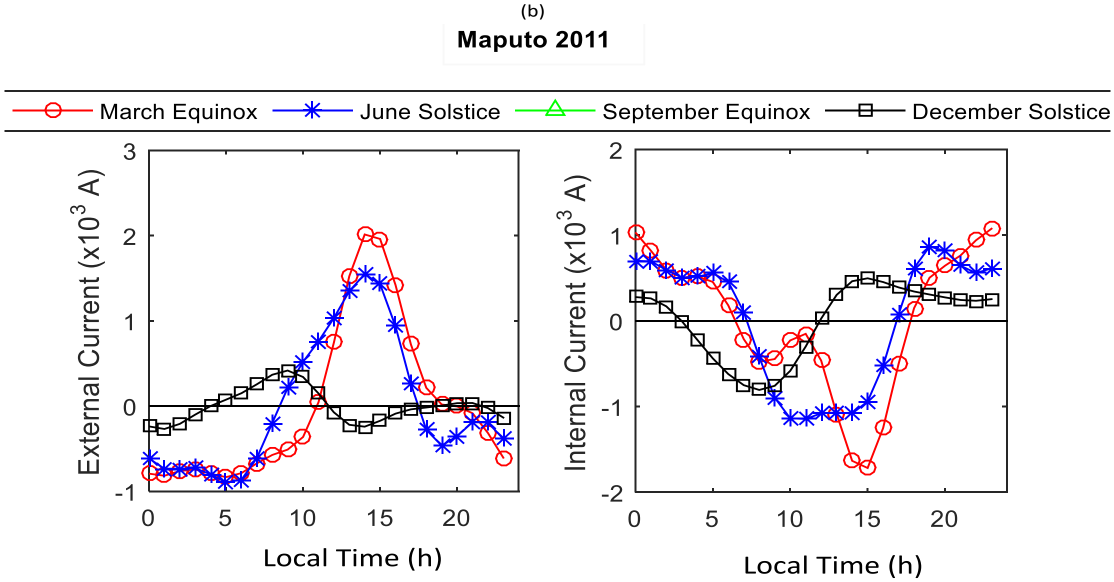
Figure 1. Showing seasonal solar quiet current variations for (a) Hartebeesthoek (b) Hermanus (c) Maputo (d) Tsumeb regions.


Hartebeesthoek 2011
March Equinox
June Solstice
September Equinox
December Solst
External Current (x10^3 A)
Internal Current (x10^3 A)
Local Time (h)
Local Time (h)

(a)


Hermanus 2011
March Equinox
June Solstice
September Equinox
December Solst
External Current (x10^3 A)
Internal Current (x10^3 A)
Local Time (h)
Local Time (h)

(b)


Maputo 2011
March Equinox
June Solstice
September Equinox
December Solstice
External Current (x10^3 A)
Internal Current (x10^3 A)
Local Time (h)
Local Time (h)

(c)

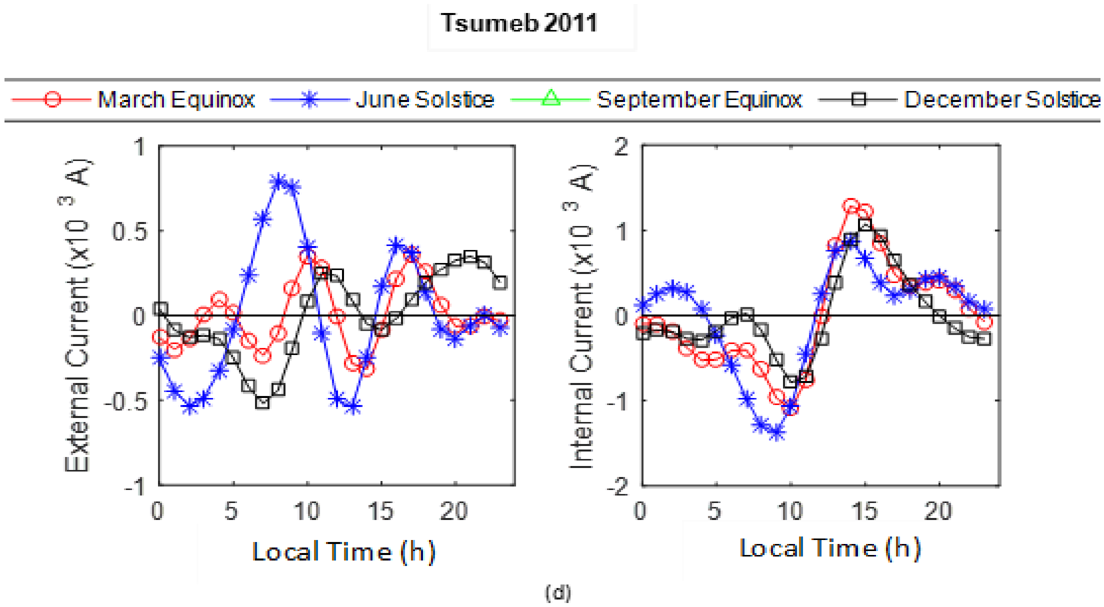


Figure 2. (a-d): Showing separated seasonal external and internal current variations for Hartebeesthoek, Hermanus, Maputo, Tsumeb regions.

September), summer and winter solstice were used to represent the yearly means of the months of March, June, September and December. The Sq current range was evaluated that helped in the viewing of the major seasonal changes which occurred in the Sq currents systems. The Sq current systems have daily and seasonal variability both in amplitudes and phases. Figure 3 shows the mantle electrical conductivity-depth profile of the four geomagnetic South African regions (showing only the trend lines). For us to understand the electrical conductivity patterns (Figure 3) of the Southern African region, the Sq current variations were examined. Data analysis methods discussed earlier were followed for each of the stations studied. Highest Sq current was recorded between the months of June and December in all the stations with the calculated maximum value occurring in the month of June and minimum in March. The stations Hartebeesthoek (HBTK) and Hermanus (HER) within the South African region are used to represent the stations located at the southernmost part of the Southern African region, while Tsumeb (TSU) in Namibia represents the stations located at the western part of the Southern African region. The Maputo (MPT) station in Mozambique represents the stations located at the Eastern part of the Southern African region. Figure 4 shows the error bar of mantle electrical conductivity-depth profiles. The dots represent the conductivity-depth computation results, while the solid lines are the regression fitted values. Figure 5 shows present profiles (HTSK, HERM, MAPT, and TSMB) compared with UOY (Ugbor et al., 2016) which was carried out within the equatorial region of West Africa.

DISCUSSION

It was observed that the variations occurred in all hours of the day from dawn to dusk in all the stations in the seasonal Sq current system (Figure 1). This variation was found to be mild at night but not necessarily zero due to currents flowing within the magnetosphere such as ring currents. Often, these currents tend to filter into the ionosphere at night even during magnetic quiet periods. The observed variations in seasonal Sq current are seen to be both in phase and in amplitude. These variations observed in the phase and amplitude is a function of the Earth's conductivity in the area (Campbell and Schiffmacher, 1988). Also, measurements made by Gilpin, Beaufoy, Cassini, Celcius and Hiorter (Von Humboldt, 1863) and by Canton (1759) who established the fact that the seasonal variation of the diurnal variation amplitudes was more than a local phenomenon. The seasonal Sq current pattern in the stations is seen to be nearly the same in all the stations. Also, midday increases were observed in most of the stations and are same around 10 h. These similarities in the seasonal Sq current pattern maybe attributed to similarities in the local ionospheric tensor conductivity.

The observed current patterns are the same throughout the stations and quite opposite to the patterns observed by Obiekezie and Okeke (2010). This could have arisen from the fact that Obiekezie and Okeke (2010) worked on the western African region around the dip equator whereas the present study was carried out within the Southern African region which has different geological properties. Across all the stations, highest seasonal Sq

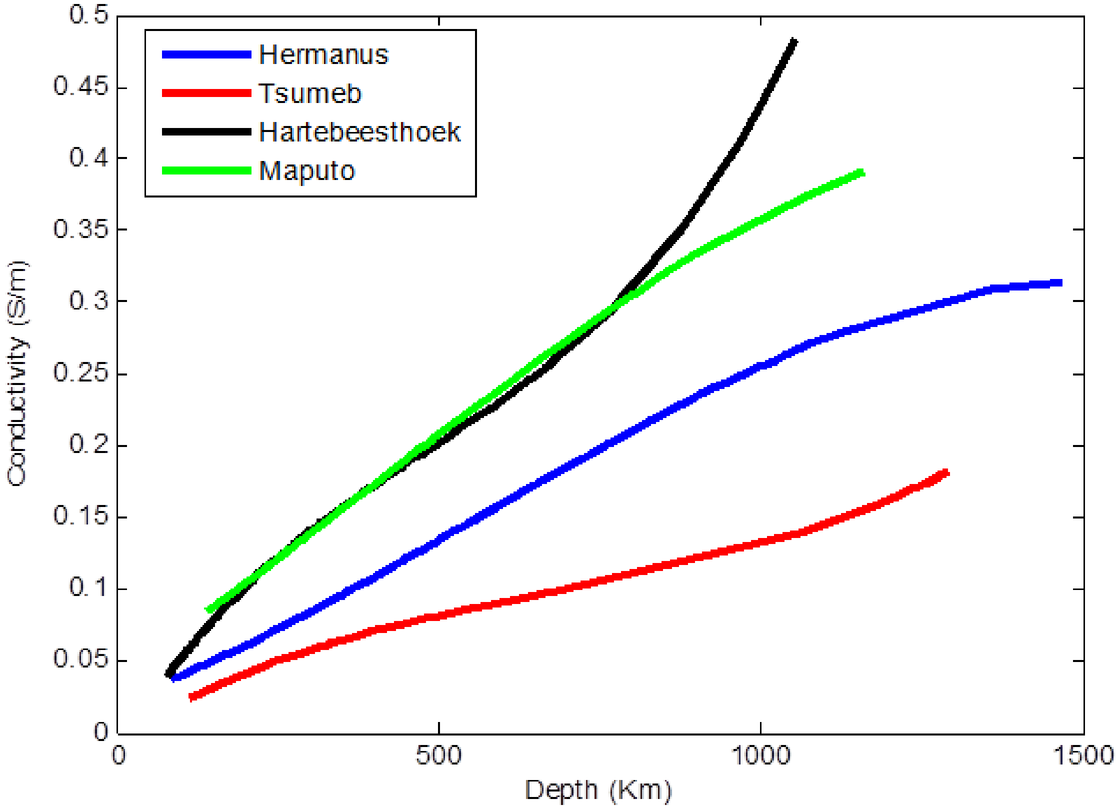
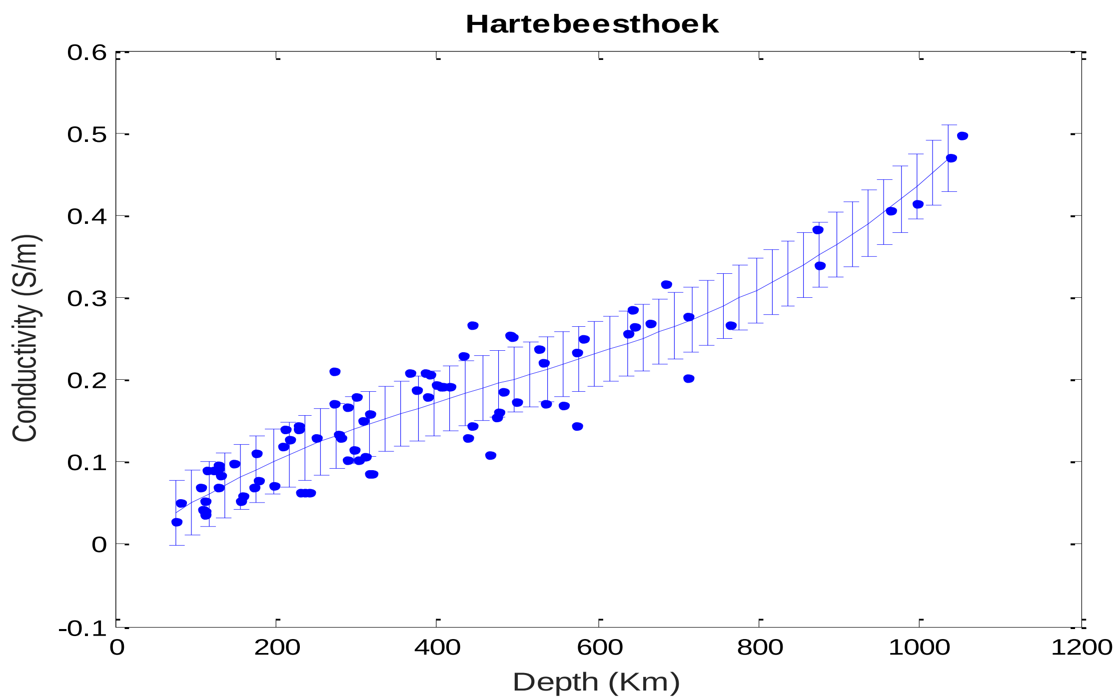
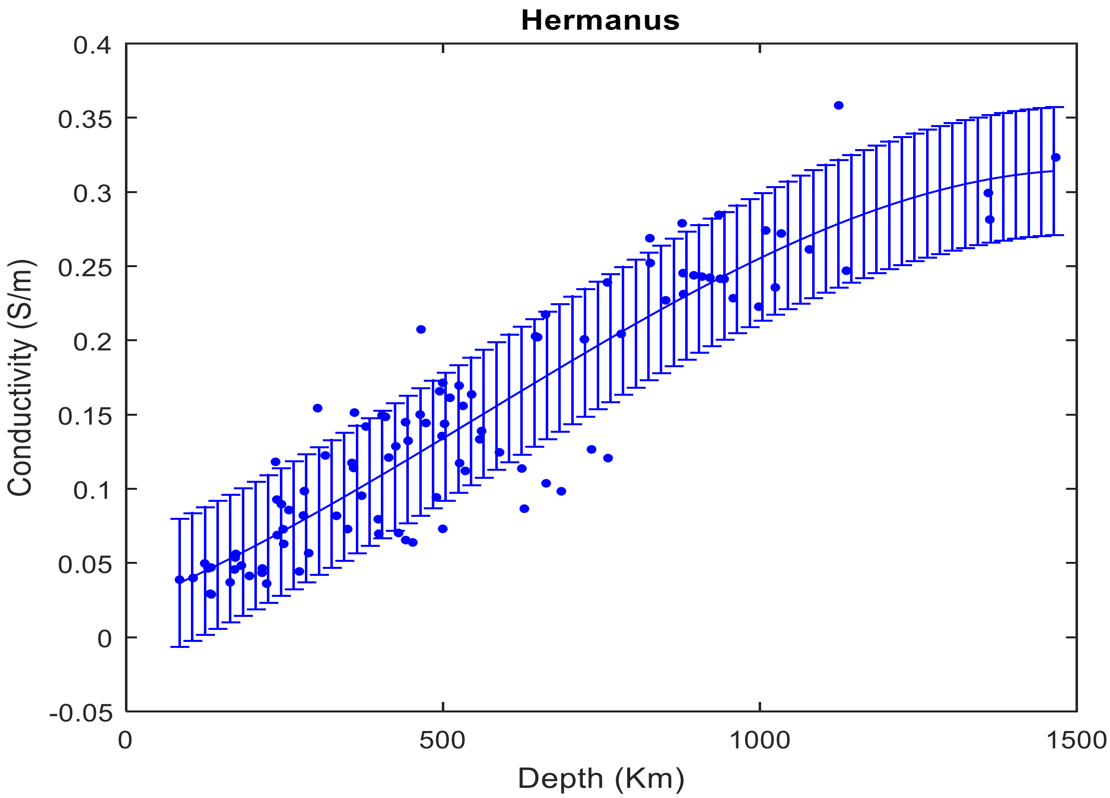


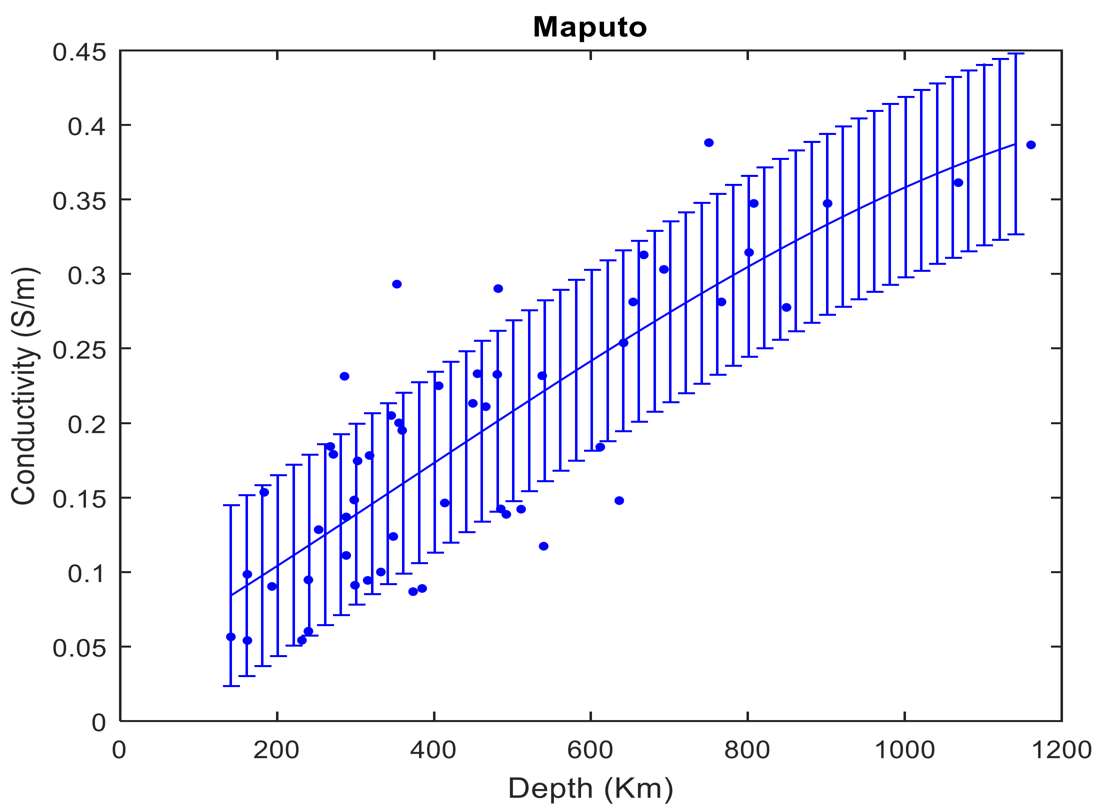
Figure 3. Mantle electrical conductivity-depth profile of the four geomagnetic South African stations (showing only the trend lines).



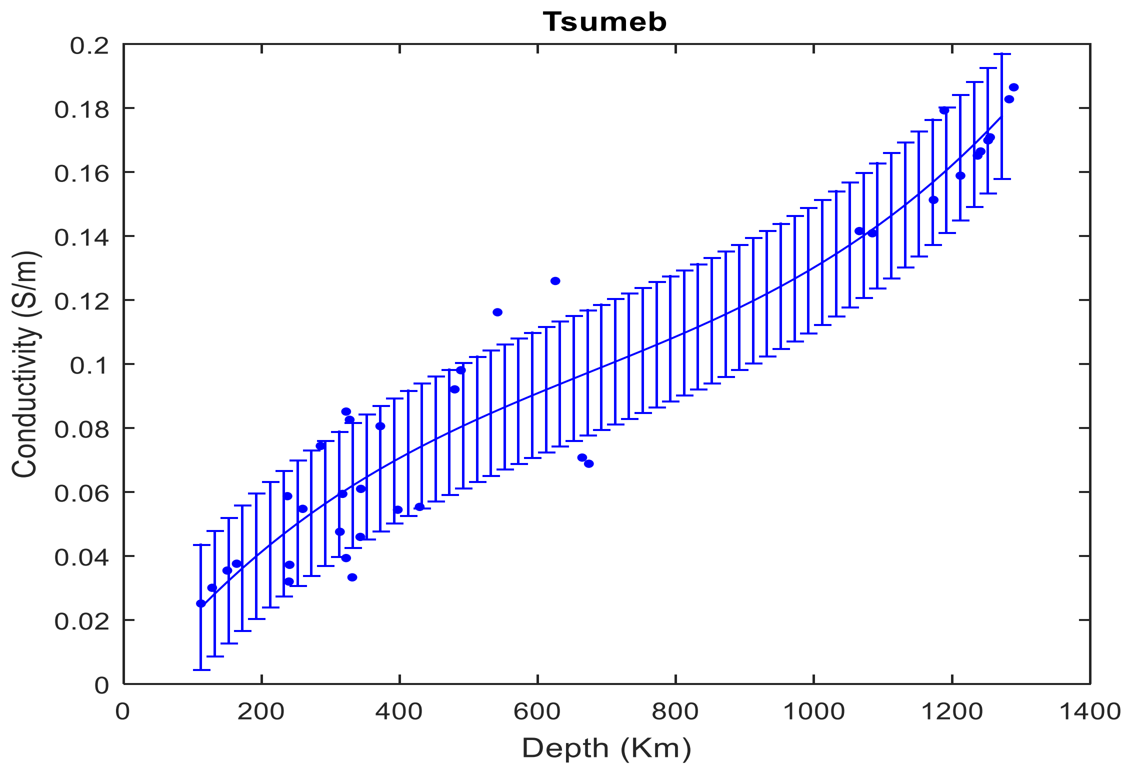
(a)


Hermanus
Conductivity (S/m)
Depth (Km)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
500
1000
1500

(b)


Maputo
Conductivity (S/m)
Depth (Km)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
200
400
600
800
1000
1200

(c)



(d)

Figure 4. Error bar of mantle electrical conductivity-depth profile of (a) Hartebeesthoeck (b) Hermanus (c) Maputo (d) Tsumeb regions.

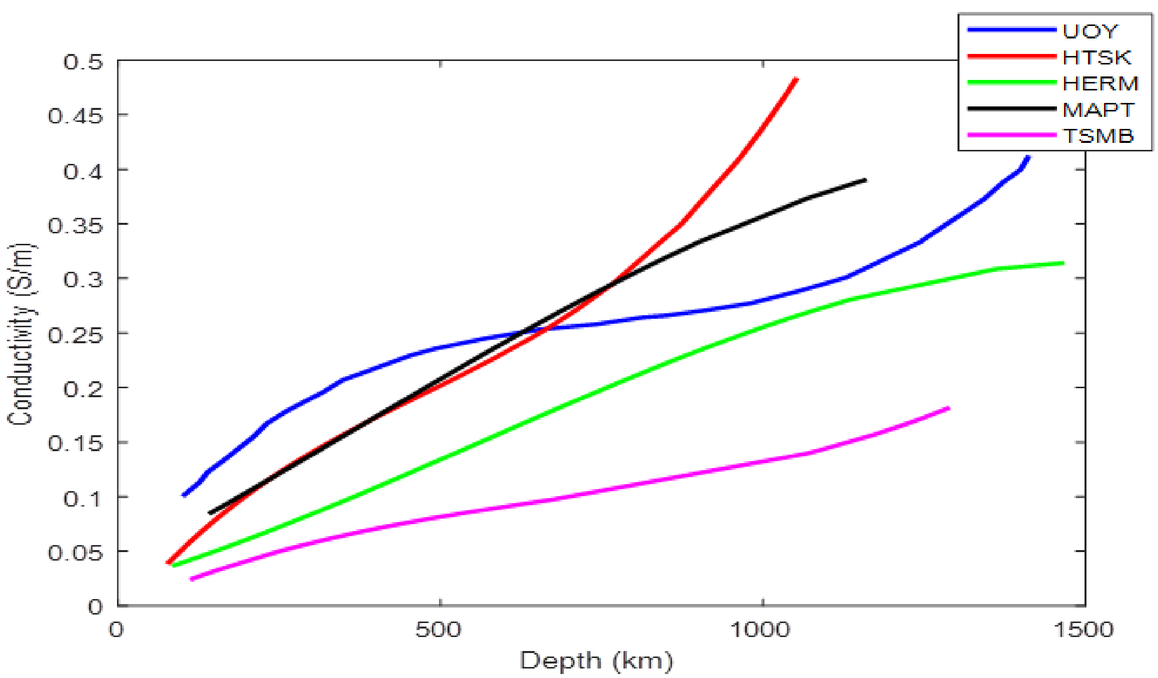


Figure 5. Present profiles (HTSK, HERM, MAPT, and TSMB) compared with UOY.
Source: Ugbor et al. (2016).

current was recorded during the months of June for Hartebeesthoek, Hermanus and Tsumeb regions, with an exception of Maputo region which has nearly triple peaks in the months of March, June and December having its highest during the December solstice. The evaluated seasonal Sq current maximum values for Hartebeesthoek, Hermanus, Maputo and Tsumeb are approximately 16.0, 12.5, 12.0, and 14.8 nT with the corresponding minimum values of about -9.5, -18.5, -29.5 and -6.0 nT, respectively (Figure 1). These minimum values were obtained in March equinox for all the stations with an exception of Hermanus region that has triple minimum value of -18.5nT obtained in March, June and September and Tsumeb region with minimum obtained in June respectively. The calculated maximum value occurred during the June solstice in Hartebeesthoek region and minimum in March equinox in Maputo region. Therefore, the solstical Sq currents reflected in values exceeded the equinoctial Sq currents values. This is found to be in agreement with Campbell et al. (1993) who found the solsticial currents to be higher than the equinoctial currents. It also is contrary to the works of Obiekezie and Okeke (2013) that earlier observed their maximum peak in the month of March within the West Africa region. The Sq generation is affected generally by the transport of the ionization and the solar ionization at E region altitudes in mid and low latitude regions. These two in turn are affected by the geographic latitudes and time about the earth. The solstice maximum found here is not surprising since the stations are within the Southern African regions that normally have high intensity of Sun especially during the soltices. Therefore, it is expected that the solar ionization should be high. Towards the latter part of 18th Century, Canton (1759) discovered the seasonal variability of the Sq field by observing that the solar quiet day variations (Sq) are greater in summer than in winter.

From Figure 2, it was also seen that the variations in both the external and internal currents is a dawn to dusk phenomenon following the same phase and amplitude in all the regions. The external and internal currents variations exhibit the same pattern in all the stations with the external and internal currents variations having opposite patterns to each other. The external current range provided a simple way to view a full year's change in the seasonal external Sq current system. The yearly averages of March, June, and December were used to represent the equinoxial, summer, and winter solsticial variations of these external and internal currents. We observed in the seasonal external Sq current an equinoxial maximum with a value of 2.1×10^3 A in March within the Maputo region and a solsticial minimum in June (winter solstice) with a value of 0.75×10^3 A in the Hartebeesthoek region. Also, the September equinox did not reflect in Maputo and Tsumeb region which may be attributed to the climatic conditions of the area at that particular year. The separated seasonal external Sq current (Figure 2) pattern is seen to be same to that of the seasonal Sq current (Figure 1); this thereby proves that the source of Sq current system is external to the earth. This is agreement to the works of Schuster (1889, 1908) who proved that the source of Sq current system is external to the earth when he made an innovation to Gauss' SHA method by adapting it to the measurements of geomagnetic field daily variations.

Generally, an increase in the electrical conductivity starting from the crust down to the earth's mantle within the Southern African regions were observed from all the profiles apart from areas within the earth layers where discontinuities were observed (Figure 3). Hence, this agrees with the global model for electrical conductivity profile (Campbell and Schiffmacher, 1986; Campbell et al., 1998). The highest electrical conductivity value of 0.498 Sm^{-1} at the corresponding depth of 1052.8 km was recorded in Hartebeesthoek with the Tsumeb station having the lowest electrical conductivity value of 0.187 Sm^{-1} at the corresponding depth of 1269.5 km. Hermanus station has the highest penetration depth of about 1467.0 km with conductivity value of 0.387 Sm^{-1} while the lowest penetration depth was found in Hartebeesthoek. These findings could be attributed to the mantle compositions of that area, the closer to the equator of the area and the oceanic effect. The ground is soft in Hermanus station due to the surrounding ocean which gave rise for easy penetration of the Sun while the Hartebeesthoek station with the highest conductivity is found at upland where there is more Sun unlike Hermanus. Hartebeesthoek and Maputo profile showed an intersection between 200.0 to 480.0 and 750.0 to 800.0 km depth range. Therefore, we suggest that these depth ranges are likely to be areas where the chemical compositions of the Earth are homogeneous in the two regions and that the Earth materials are subjected to nearly the same conditions of temperature and pressure. This is not surprising since Hartebeesthoek and Maputo are close to each other on the eastern part of Southern African region. Furthermore, Tsumeb and Hermanus profiles exhibited no intersection with any of the other profiles depicting lateral differences between the regions under study. Interestingly; Tsumeb region is located in the western part while Hermanus is found in the southern part of the study region, all within Southern African region.

The standard deviation values for Hartebeesthoek, Hermanus, Maputo and Tsumeb based on the error bars plotted (Figure 4) were 0.081, 0.100, 0.092 and 0.053, respectively. The scattered points in the plots showed more concentrations from the crust down to about 800 km depth. Moreover, at greater depths beyond 800 km, there was reduction in density of the scattered plots. The scattered points observed in the plots may be due to the magnetic field contribution from sources other than solar quiet time field conditions, variability in source current locations, error from field measurements and error from SHA fittings. A polynomial trend line of order 3 was fitted to the data points in order to get an average values from the many scattered points based on a locally weighted profile regression fittings described by Cleveland (1979). The mean conductivity values evaluated were seen to be increasing downwards in all the stations. This increase in conductivity within the first few kilometers of the crust and some parts of the upper mantle agrees closely with the works of Campbell and Schiffmacher (1988), who stated that the Earth's temperature increases with depth, therefore, the electrical conductivity increases with depth due to its dependence on temperature.

The results of the conductivity-depth profiles of our study show similar trends and compares well with previous researches carried out in other regions of the globe (Ugbor et al., 2016). For instance, in Figure 5, the conductivity depth profiles of these study are compared with the conductivity depth profile of the Addis Ababa (denoted with blue trend line) located on the equatorial region of East Africa. The results of our study in the Southern African region at shallow depth, is relatively smaller than the East African conductivity-depth profile upto a depth of about 600 and 650 km, where it intersected with that of Maputo and Hartebeesthoek profiles respectively indicating likely similar material constituents within this depth range.

Some striking features were observed from Figure 5. For instance we obtained the greatest depth of penetration of Sq current into the interior of the Earth of about 1467 km than that obtained by the previous researcher as has been earlier discussed. We attributed this to the effects from the deeper 3-D structures such as gold, cupper, etc., the hydrated transition zone and effect from the ocean, since the Hermanus region with highest depth of Sq penetration is observed near the Atlantic oceans. Also, the calculated average electrical conductivity values in the Southern African regions at some depths are higher than that obtained in East African region. This feature may be attributed to the higher solar zenith angle within the local summer hemisphere which initiated the greater conductivity (Yamazaki et al., 2012). The enhanced conductivity within the ionosphere could have been inducted into the Earth leading to an increase in the Earth's conductivity.

Conclusions

This work deals with the determination of the source current systems through the application of SHA method on the geomagnetic field data obtained from ground measurements; to determine the mantle conductivity-depth profile and to compare results of the profiles of the four stations with other research work. This geomagnetic data obtained from MAGDAS, Japan installed in the Southern African region has enabled the evaluation of the Sq current within the Southern African regions. From these results, we concluded that all the stations have similar Sq current pattern with daily and seasonal variations. That a dawn to dusk phenomenon were observed in the currents variations; being maximum during the June Solstice and minimum in March equinox. Also, we observed in the seasonal external Sq current an equinoxial maximum in March within the Maputo region and a solsticial minimum in June (winter solstice) in the Hartebeesthoek region. The seasonal separated external Sq current system pattern is same as that of the seasonal Sq current system, proving that the source of Sq current system is external to the Earth. Invariably, the conductivity increases downwards into the interior of the Earth, attaining its highest values within the lower mantle which agrees with the global model. The calculated average conductivity values at some points in the Southern African regions are higher than that obtained in other regions. Also, we obtained the greatest depth of penetration of Sq current into the interior of the Earth. Finally, we were able to establish the electrical conductivity of Maputo and Hartebeesthoek regions where no work has been done at all.

It was suggested that more observatories should be installed in South African region and the world in general for further works to be carried out as this will help to throw more light on the upper mantle conductivity.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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