International Journal of Novel Researches in Science, Technology & Engineering
Vol. 1. No. 1 December, 2018
ISSN 2141 825X
www.oasisinternationaljournal.org

SOLAR QUIET DAILY IONOSPHERIC VARIATIONS IN THE AFRICAN REGION: A CASE STUDY OF HERMANUS STATION

by

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Abstract

Solar quiet daily (Sq) ionospheric variations in African region have been studied using Hermanus station located in South African region. The geomagnetic data in the geomagnetic components:-horizontal, H, declination D and vertical Z was used for this study. The hourly variations of the solar quiet (Sq) variations in these geomagnetic elements were studied. The study shows that the variations of solar quiet in the geomagnetic elements i.e Sq (H), Sq (D) and Sq (Z) were a dusk to dawn phenomenon and non-zero variation was observed in the night. More variability were seen for the element D. the variation in the D element Sq (D) is seen to display the directional changes in the magnetic field as the earth rotates about the sun. The variations in the three elements i.e. Sq (H), Sq (D) and Sq (Z) were generally observed to be more in the day time. The day time (0700-2000hrs) magnitudes are greater than the night time (2000-0700 hrs through 2400hrs) magnitude in all the months. These changes are attributed to changes in the ionospheric dynamic currents and ionospheric wind.

Keywords: Solar Quiet, Ionospheric Variation, African Region, Hermanus Station

Introduction

Geomagnetic deals with the magnetic properties of the earth as a whole rather than those possessed by a single object or place on earth. The earth's magnetism has been proved by William (1600), Jacobs (1987), Campbell (1997), Moldwin (2008), Onwuemechili (1960), Matsushita (1969) and Lowrie (2004), to have both internal and external origins. The field of internal origin called the main field is thought to be produced by electric currents in the liquid/fluid iron core. The composition of the fluid core has been estimated from seismic and geochemical data which showed that the major constituents is liquid iron with smaller amounts of other less-dense elements. For the generation of the magnetic field, the important parameters of the core are its temperature, viscosity and electrical conductivity. Temperature is known to be very poor inside the earth but probably exceeds 300^{c}C in the liquid core (Lowrie, 2004). The electrical conductivity of iron at 20^{c} C is 10^{7}ohm^{-1} metre $^{-1}$ and decreases with increasing temperature, Matsushita (1969). At high temperatures and pressures in the core, the electrical conductivity is estimated to be around 3.0-5.0 x 10^{5} Ohm $^{-1}$ metre $^{-1}$ which corresponds to a good electrical conductor (Williams, 2004).

The field of external origin is thought to be due to the existence of currents in the upper atmosphere due to the movement of conductive air across the lines of force of the earth's magnetic field caused by solar heating. The geomagnetic field is a dipole field having both North and South poles which are defined by earth's spin axis. The magnetic dipole axis is tilted by about 11 degrees with respect to the spin axis. At any point on the earth's surface, the measured magnetic field may differ appreciably in both magnitude and direction. In addition, the field observed at any location on the surface of the earth varies with time by measurable amounts over a period of few years and by substantial amount over say 100 years (Moldwin, 2008).

The Geomagnetic Field Elements

The magnetic field of the earth is a vector that has magnitude and direction. The magnetic field vector can be expressed as Cartesian components parallel to any three orthogonal axes. The geomantic elements (X,Y,Z) are taken to be components parallel to the geographic north and east directions and the vertically downward direction. Alternatively the geomagnetic elements can be expressed in spherical polar coordinates. The magnitude of the magnetic vector is given by the field strength F, its direction D and the inclination I.

The Cartesian (X,Y,Z) and spherical polar (F,D,I) sets of geomagnetic elements are related to each other (Lowrie, 2004).

The magnetic field vector can also be represented by the horizontal magnitude, the eastward angular directional of the horizontal component from geographic northward and the downward (vertical) component. This is called the H (horizontal), D (declination) and Z (vertical into the earth) thus HDZ representation. The magnetic field like every other vector requires any three of its orthogonal components to completely represent it.

Originally, the HDZ system was used at most world observatories because the measuring instruments were suspended magnets and there was a direct application to navigation and land survey. Usually, only an angular reading between a compass northward direction and geographic north was needed. in the early days of sailing ship navigation, the important measurement for ship direction was simple D, the angle between true north and the direction to which the compass needle points.

Ancient magnetic observations therefore used the HDZ system of vector representation. Also, in the HDZ system, the data from different observatories have different components orientations with respect to the earth's axis and the equatorial plane. The XYZ coordinates system is necessary for field recordings of many high latitude observatories because of the great disparity in the geographic angle toward magnetic north at polar region sites.

The XYZ system is becoming the preferred coordinate system for most modern digital observatories and computers has made it simple to interchange the digital field representation into the three coordinate systems (Campbell, 1997).

The Geomagnetic Field Measurement

The geomagnetic B measures at any point on the earth's surface is a vector sum of several magnetic fields generated by various sources, thus

$B=B_m + B_c + B_e$...........................(1.1)

Where B_m is the main (core) field, B_c is the crustal field and B_e is the external field. The main (core) field B_m is the dominant component of the geomagnetic field. More than 90% of the field measured is the generated internally in the earths outer core hence the main field. The crustal field B_c is the portion of the magnetic field associated with the magnetism of crustal rocks while the external field is a relatively small portion of the observed magnetic field that is generated from magnetic sources external to the earth. These fields are super imposed on and interact with each other (Jacobs, 1987).

The earth's magnetic field can be grossly described as that of a bar magnet inclined at 11^0 to the earth's rotation axis with north and south poles deep inside the earth and magnetic field lines that extend well out into space. The magnetic intensity decreases with decreasing latitude. The field is stronger at the poles than at the equator. The strength of the dipole magnetic field is two times greater about 60,000DT at the magnetic poles than at the magnetic equator about 25,000Dt and falls off very quickly with distance (Campbell, 1997).

The Geomagnetic Field Variation

At any world location, the geomagnetic field is not constant in time, (Lowrie, 2004). The geomagnetic field has variations that cover period ranges from fractions of a second to millions of years. the daily record of geomagnetic field variations at any world location typically shows a multitude of irregular changes in the geomagnetic field that represents the super position in many spectral components whose amplitudes generally increases with increasing periods. Unique current sources in the upper atmosphere and magnetosphere have been identified as the origins of many of these spectral field variations, (Campbell, 1997). The variation is broadly classified under secular and transient variation.

Transient Variation

Transient variation are the smaller but more rapid oscillations in the earth's field which have a periodicity of about a day and an amplitude averaging about 25nT. They are those geomagnetic variations far more rapid than the slow secular variation and are regularly recorded at magnetic observatories. Plots of the geomagnetic field observations recorded from observations reveal that on some days, there are regular records following nearly some pattern while on some other days there are irregular variations with no specific pattern. Days of the first kind are said to be quiet while days of the second kind are said to be disturbed.

Quiet Day Variation

Quiet day variation refers to the magnetic variation on some days that are free from magnetic disturbances. On these quiet days, the magnetogram generally suggests that there may be a cyclic change in the magnet elements of period about 24hours upon which more irregular disturbances are super imposed. It was observed that if one averaged the records for a number of days free from irregular disturbances, a smooth daily variation curve was indeed obtained. The amplitude of the variation was found to depend upon the magnetic latitude of the observatory. For observatories of the latitude, the variations were similar provided they were plotted against local time. This later observation therefore suggested the sun as a controlling factor. Further analysis of the variations revealed in addition to 24 hour period, one of 25 hours recognised as being related to the moon. It was found that the 25 hours variation changed in amplitude and phase through a month. Further evidence of its lunar control. thus, the two components of the regularly daily variation as observed on quiet days are denoted Sq (Solar quiet) and Lq (Lunar quiet) for the solar and lunar influence respectively, (Lowrie, 2004).

Solar Quiet Daily Variation (SQ)

Solar quiet daily variation is a small regular variation of the geomagnetic field with a fundamental period of 24 hours. The variation is easiest to observe during periods of low solar activity when large irregular disturbances are less frequent. For this reason, it is referred to as the solar quiet variation. In reality, this type of variation in the geomagnetic field would affect the direction of a compass needle by no more than a few tenth of a degree. Inclination varies by less than a tenth of a degree and the total intensity of the magnetic field is perturbed by only a few tenths of nT. Although these effects are very small, that can be of interest to those who use measurements of the earth's fields as a tool for very precise navigation, (http://www.ngdc.noaa.gov/seg/potfld/utilish c.html.

This regular fluctuation in the geomagnetic field is caused by electrical currents high in the ionosphere, a region that begins at an altitude of about 100km. However, in the ionosphere high energy ultra-violet rays and X-rays from the sun displace electrons from (ionize) the neutral (uncharged) molecules in the air to produce positively and negatively charged particles which allow air the air to conduct. The ionized molecules in the ionosphere release swarms of electrons that form powerful horizontal, ring like electrical currents. These act as sources of external magnetic fields that are detected at the surface of the earth. The ionization is most intense on the day side of the earth (Lowrie, 2004).

Equatorial Electrojet (EEJ)

The EEJ (dynamo) region of the equatorial ionosphere consist of two layers of currents responsible for the solar quiet daily variations in the earth's magnetic field. The worldwide solar quiet daily variation, WSq (altitude 118±7km) is responsible for the global quiet daily variation and the equatorial electrojet (altitude 106±2km) (Rabiu et al 2007). Equatorial electrojet (EEJ) is the concentration of current ribbon due to high cooling conductivity along the dip equator (Chapman 1951). It is an intense ionospheric current flowing eastward within the narrow strip flanking. The dip equator responsible for the observed enhanced horizontal neighbourhood (Chapman, 1951).

The equatorial electrojet was explained by Baker and Martyn (1953) as due to the considerable enhancement of the east-west ionospheric conductivity within a narrow latitude belt where the electric and magnetic fields are orthogonal to each other. At the earth's surface, measurements show that EEJ effect is about 450 to 500 km wide (3^0N or 3^0S dip equator in latitude.

Purpose of Study

The solar quiet day variation is believed to be caused by electric current system flowing in the lower ionosphere. These currents are believed to arise from fluctuating ionospheric winds which blow the ionized air across the lines of force of the geomagnetic field thereby generating the electric field to drive the electric currents. The purpose of this study therefore is to examine the solar quiet day ionospheric variation in the African region which is very useful in the determination of the deep-earth conductivities and in the understanding of societal and technological impacts of the solar terrestrial relationship.

Research Design

The research design used for this research is a survey research design which according to Nworgu (1999), is one which a group of people or items are studied by collecting and analysing data from only a few people or items considered to be representative of the entire group.

Method of Data Analysis

A set of observatories located in the South Africa supplied the data set used in this research.

Validity

The data set used was validated by experts from Physics and Industrial Physics Department of Nnamdi Azikiwe University, Awka.

Analysis of Data

The data set used in this study consists of the hourly values of the geomagnetic elements, horizontal intensity H, declination D, and vertical intensity Z obtained at geomagnetic observatory of Hermanus. Hermanus is a mid-latitude station location in the South African region. The geographical and geomagnetic coordinates of Hermanus observatory is as presented in Table 1.1.

Table 1.1: The Geographical and Geomagnetical Coordinates of Hermanus Station/ Observatory

Station	Geographic	Geomagnetic		
	Latitude	Longitude	Latitude	longitude
Hermanus	9.03	38.77	5.16	111.38

For this study, ten international quiet days were employed for analysis. These are the set of ten accepted geomagnetically questions days of each month based on the magnetic activity index. These days were selected from the hourly profiles of the three geomagnetic components, H, D, Z published by space physics interactive data resource.

Also, the local time (LT) for the station was employed. The base line was chosen as the average of the values of the four hours flanking the midnight plus the midnight value (00, 01, 22, and 23). Mathematically, the base line values for the geomagnetic elements H, D and Z were obtained as shown in equation 1.1 where (H_{00},D_{00},Z_{00}), (H_{01}, D_{01}, Z_{01}), (H_{22}, D_{22}, Z_{22}) and (H_{23}, D_{23}, Z_{23}) are the hourly values of H,D and Z at 00,01,22 and 23 hours local time (LT) respectively. We obtained the hourly departures dH, dD and dZ from the baseline values H_0, D_0, Z_0 can be obtained by subtracting the baseline for that particular day from the hourly values for that particular day H_T, D_T, Z_T as shown mathematically in equation 1.2.

$Dh_T = H_T - H_0$

$Dd_T = D_T - D_0$....................................1.2

$dZ_t = Z_t - Z_0$

Where T = 0 - 23 hours Lt

The hourly departure is further corrected for non-cyclic carination, a phenomenon in which the value at 00LT is different from the value at 23Lt, Vestine (1947) and Rabiu (2000). This was done by making linear adjustment in the daily hourly departure values and by considering the hourly departures dH, dD and dZ at 00Lt 01LT............23LT as V_0, V_1-----------V_{22}.

Thus we define the non-cyclic variation (d_c) in H, D and Z as in equation 1.3

$$d_c = \frac{V_0 - V_{22}}{23} \text{-------------------------------1.3}$$

The linearly adjusted values at three hours are:

$V_0 + 0d_c$, $V_1 + 1d_c$, $V_2 + 2d_c$,------------- $V_{22} + 22d_c$, $V_{23} + 23d_c$.

In other words

$S_T (V) = V_T + Td_c$..................................(1.4)

Where S_T (V) is the solar quiet (Sq) daily variation in H,D,Z. t is the local time ranging from 00 to 23.

Thus, the hourly departures corrected for non-cyclic variation gives the solar quiet daily variation in H, D and Z; Sq (H), Sq (D) and Sq (Z). The hourly mean values of Sq (H), Sq (D), Sq (Z) are Hermanus station were obtained for all the months. These are plotted against local time to show the geomagnetic Sq monthly variation as shown in Fig 1.1, Figure 1.2 and Figure 1.3 respectively. (See Appendix A, B &C).

Results and Discussions

Solar Quiet Daily Variation in Horizontal Intensity Sq (H)

Figure1.1 display the solar quiet daily variation in H component Sq (H) at Hermanus. The signatures of the daily variation of Sq (H) variation at Hermanus as reflected in figure 1.1 shows some kind of inconsistency in the behaviour of the variation pattern for the months of May, June, July, August, September and October. it is seen to be positive in the morning up to about local noon with a peak around 10.00hours (morning peak) but the variation was almost negative in the afternoon and night time except in the months of June and July where the Sq (H) variations show slight positive enhancement during the night hours for the months of January, February, March, April, November and December. It is seen that there was slight Sq (H) enhancement in the early morning hours with a peak mostly around sunrise. For the other hours, the variation is negative in the afternoon hours and negative in the night hours. This is in consistence with the results of Okeke *et al* (1998).

The pattern of variations observed in the station which more or less deviated from the expected normal variation of having morning trough and afternoon crest could be due to local irregularities in Sq current system. The unusual variations could be as a result of some ionospheric irregularities. In addition to these contributors, atmospheric tidal winds may influence the Sq. field causing fluctuations in the Sq amplitude and distractions in the Sq shape.

Fig 1.1 also indicates that there is night time variations of Sq daily variation in the H elements, Sq (H). This night time Sq(H) variations is not observed to be zero in most cases suggesting no zero currents at night when one does not expect any ionospheric current due to very low ionospheric conductivities. This permits the inference that a variety of factors not only in the ionosphere but also in the magnetosphere and other interplanetary space may affect the shape and amplitude of the Sq variation.

This suggest that the precipitation of energetic electrons from distant magnetosphere into the ionosphere which enhances the ionospheric conductivity so that intense currents can flow even in no significant ionospheric conductivity during the night hours. The source of these night time variation could be as a result of some distant magnetospheric processes. For example, the aurora electric field of magnetospheric origin, magnetospheric currents such as tail current could significantly contribute towards the Sq (H) variation.

Also, other sources in the magnetospheric or interplanetary space which could affect Sq variability have not been ruled out thereby suggesting that some additional sources of electric field generation in the magnetospheric and certain high latitude phenomena do modulate the atmospheric dynamo current. Thus, the variability of the night time field may be as a result of the variability of the night time distant currents.

Solar Quiet Daily Variation in the Geomagnetic Field Declination, Sq (D)

It is clear from figure 1.2 that Sq (D) daily variations occurred at Hermanus in all the months. It is generally observed from the plots that there was significant Sq (D) variation, the day time (0700-2000 hours) magnitudes are greater than the night time (20000-0700 hours through 2400 hours) magnitudes in all the months. Thus, the plots/signatures of the daily variation Sq (D) at Hermanus as reflected in figure 1.2 indicates that the Sq (D) daily variation has the same pattern of variation throughout the months. The signatures in these months indicate a gradual rise in intensity from morning hours to about sunrise. A decline to negative levels from about sunrise up to local noon hours, then a positive afternoon variation and a gradual fall towards sunset.

The Sq (D) variation is observed to be a dawn to dusk phenomenon which is in consonance with the result obtained by Okeke *et al* (1998), but in variance with the result of Maeda *et al* (1982) who observed the Sq (D) variation to be a dusk affair only.

Solar Quiet Daily Variation in the Vertical Intensity, Sq (Z)

Figure 1.3 shows the daily variations of Sq (Z) variations at Hermanus in all the months. The plots of the variation in the months between October to March are similar. They display consistent regular variations. They indicate a classical rise in intensity at about the sunrise, a peak at about local noon and a gentle fall towards sunset period. For the month of April to September, the Sq (Z) variation increases positively during the morning hours, dropped/reclines to low levels at about sunrise and the peak again having positive afternoon variations. The night time variations for theses months are negative.

In general, it could be observed from the plots that the day time variation of Sq (Z) amplitudes are much greater than the night time amplitudes for all the months. This is in consonance with the results of Onuwmechili (1997), Rabiu *et al* (2007) and Obiekezie and Okeke (2010). The Sq (Z) daily variations at geomagnetic quiet conditions are suggested to be associated with dynamo currents which are driven by winds and thermal tidal motions in the e-region of the ionosphere. The daily variation of the Sq (Z) variations so observed is also in agreement with the daily variation pattern of q in the earlier works in Onwumechili (1960) and Matshdhite (1969) which showed that the maximum intensity of solar quiet variation occurs around the local noon.

It has been known that a variety of factors not only in the ionosphere but also in the magnetosphere may affect the shape and amplitude of the Sq variation. The ionospheric conductivity and winds are important factors which control directly the Sq dynamo process. Thus, the variation pattern is attributed to the daily variation of the ionospheric conductivity responsible for the Sq variations since the rate of building up ionospheric Sq current is faster in the daytime than its rate after noon time.

Conclusion

Results obtained from the solar quiet daily ionospheric variations in South African region yielded some interesting results which are in consonance with results of other researchers. Based on these results obtained, the following conclusions were drawn.

The study shows that the variations of these geomagnetic elements were a dusk to dawn phenomenon, none zero variation was observed in the night. The non-zero night variation are seen to be of sources other than the ionospheric currents (Magnestospheric and Ausoral currents).

From the variations in the D elements, it is seen that the D variation display directional changes in the magnetic field within the earth's rotation about the sun.

Recommendation and Application

Based on the results obtained, the following recommendations are made.

1. **Deep-earth conductivity computations:** Quiet day ionospheric current variability has been used by some researches to determine the upper mantle conductivity. Some of these researchers include Campbell et al (1996) who determined the upper mantle conductivity in Asia region and Obikezie and Okeke (2010) who determined the upper mantle conductivity in the West African region.

2. **Radio communication impacts**: Radio wave propagation depends on the medium the waves move. A time variable and spatially inhomogeneous ionosphere can severely perturb and degrade ground-t0-satellite and satellite-to-ground communication. This can have serious impacts on different systems, but is particularly important for (a) High frequency (HF) radio communication (b) Global positioning system (GPS) and (c) navigation system.

3. **Ground system impacts:** A number of technologies systems on the ground are susceptible to space weather. During a large geomagnetic storm, large time-varying currents flow into and through the ionosphere. These currents can induce currents in long conductors on the ground such as electric power lines, telephone lines and pipelines. Induced currents in these systems can overload electric components causing failure or can decrease the lifetime of the infrastructure by enhancing corrosion. Metal will corrode when exposed to a variety of environmental conditions like moisture and air. Corrosions is enhanced if there is an electrical current flowing through the metal. Time-changing ionospheric currents can induce large current in the pipelines. Some

pipelines are especially electrically grounded to minimize this impact but many are not, therefore their lifetime and potential for leaks is increased because of space weather.

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Http://www.ngdc.noaa.gov/sep/potfld/wtilwhc.html

Appendix A

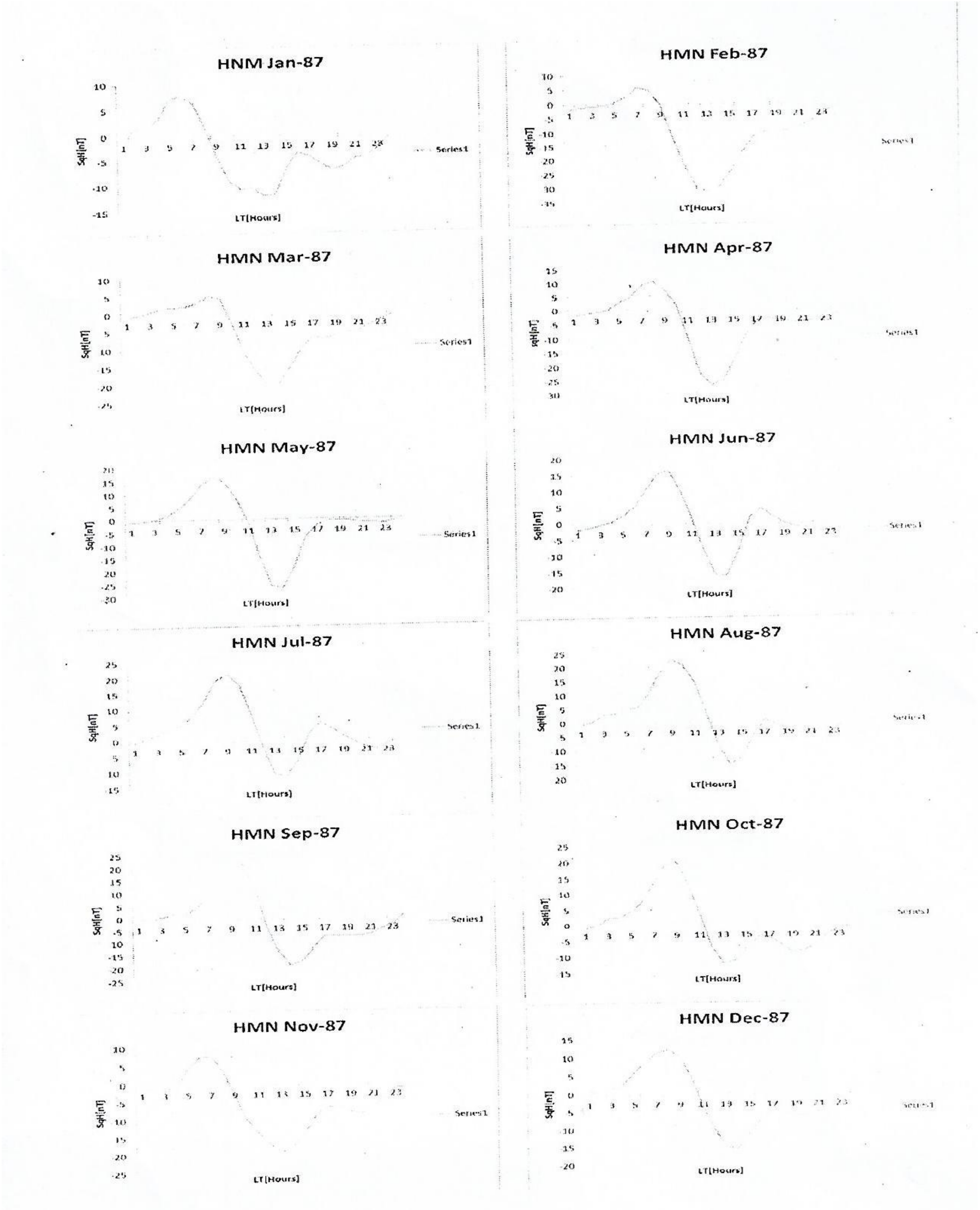

Fig. 1.1: The diurnal variation of Sq (H) at Hermanus for the months of January to December, 2005.

Appendix B

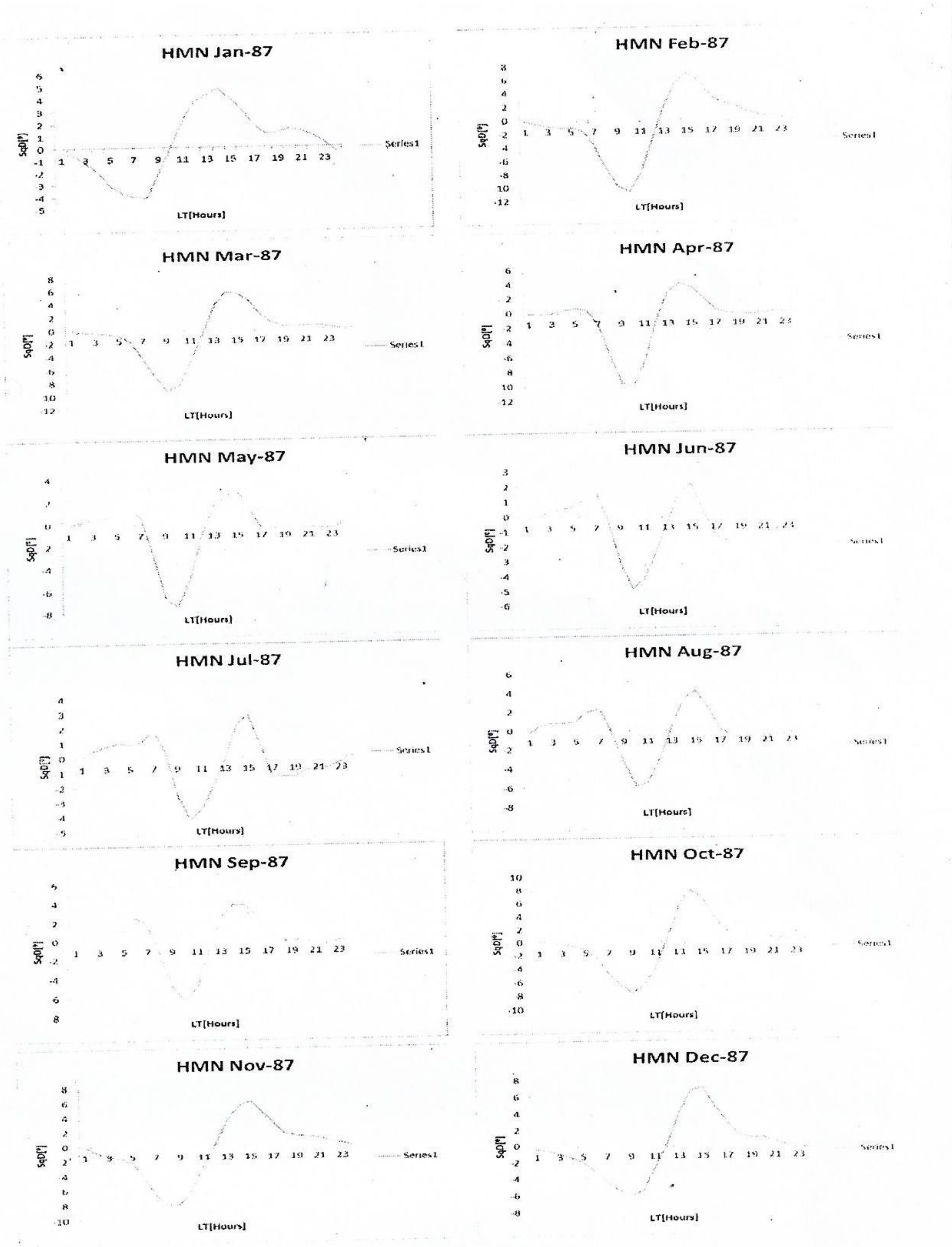

Fig. 1.2: The diurnal variation of Sq (D) at Hermanus for the months of January to December ,2005

Appendix C

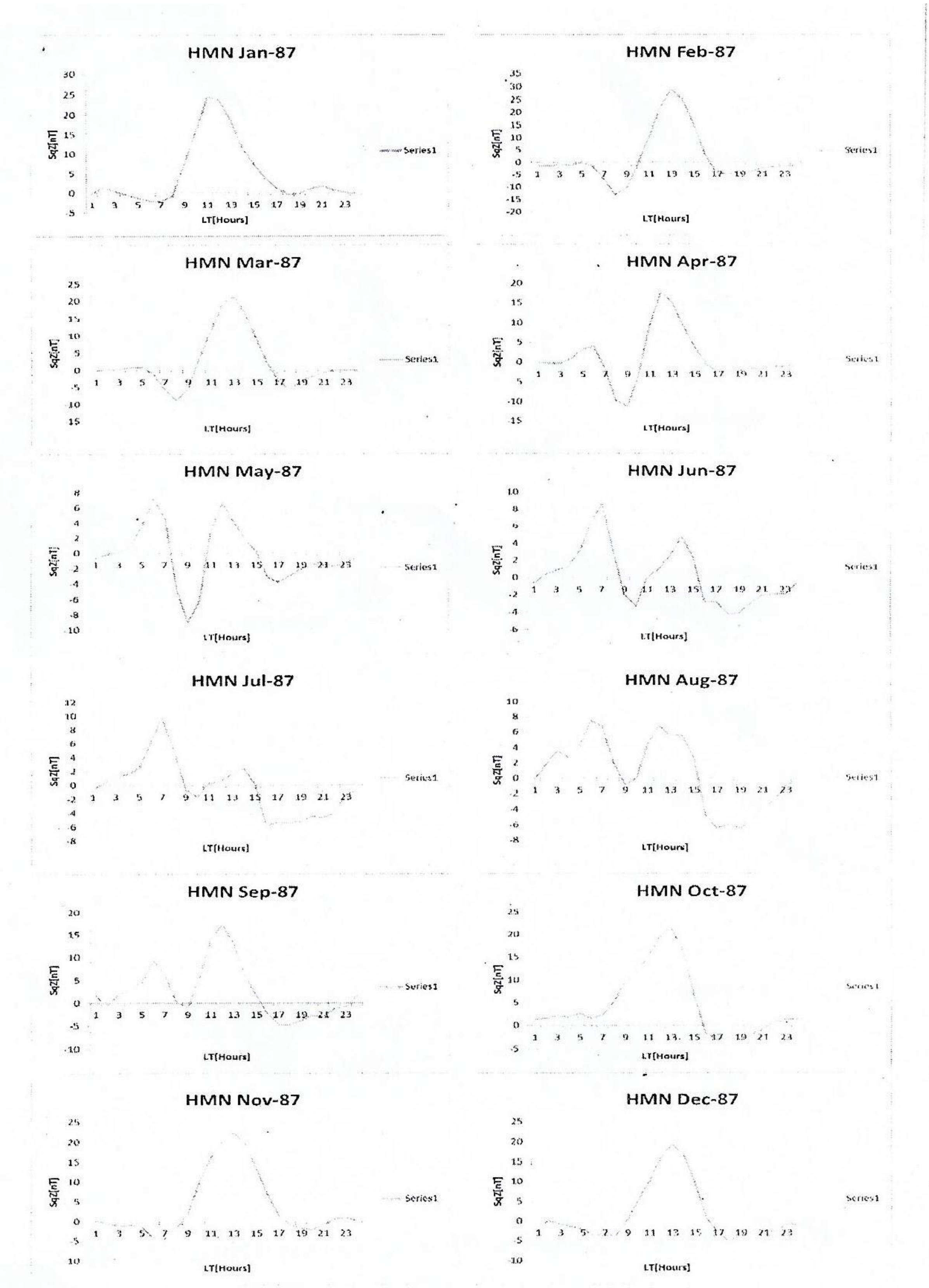

Fig. 1.3: The diurnal variation of Sq (Z) at Hermanus for the months of January to December, 2005