Geomagnetic Diurnal Variation during the Total Solar Eclipse of 29 March 2006

Elvis V Onovughe

Department of Earth Sciences, Federal University of Petroleum Resources, Effurun, PMB 1221, Nigeria

Abstract   Minutes records of all three components of the geomagnetic field (X, Y, Z) from three observatories in Africa (Bangui, BNG; Mbour, MBO and Tamanrasset, TAM) have been analysed to study the effect of the geomagnetic diurnal variation during the total solar eclipse of 29 March, 2006. The main eclipse induced changes in the geomagnetic diurnal variation was observed in Tamanrasset located very close to the total eclipse axis. The study revealed a decrease of about 20nT in the X (horizontal) component and an increase of about 10nT in the Y (east) component. These observed changes may be attributed to ionospheric effects due to decrease in electron concentration and ionospheric current density.

Keywords   Geomagnetic Variation, Total Solar Eclipse, Geomagnetic Field Components, Ionosphere

1. Introduction

A total solar eclipse occurred on March 29, 2006 between 07.30 UT and 12.45 UT. The path of totality of the Moon's shadow began at sunrise in Brazil and extended across the Atlantic to Africa, travelling across West Africa to North Africa, from there across the Mediterranean Sea to Europe, where it ended at sunset. A partial eclipse was seen in the northern two-thirds of Africa, the whole of Europe, and Central Asia. The eclipse reaches the African mainland at 09:10 UT. The zone of totality is about 185km, and on the centreline it lasted for 3 minutes 30 seconds. The point of greatest eclipse is very near the Libyan border; the path width was about 183km, and the total eclipse lasted for 4 minutes 6 seconds. The path crosses Libya, and then just clips Egypt, before crossing into the Mediterranean at 10:40 UT.

It is generally known that the quiet daily geomagnetic field variations are primarily due to the dynamo currents flowing in the ionosphere E-layer. Many researchers have studied the ionospheric dynamo and the regular quiet daily variation of the geomagnetic field[1,2,3,4,5]. During solar eclipse, part of the ionosphere is shielded from the sun's heating and ionization radiation. This modifies the current pattern in this region and this is seen as a modification of the geomagnetic field observed at ground level[6]. Solar eclipses alter the ionospheric E-region process and as a result affect the regular geomagnetic daily variation known as Solar quiet (Sq), which originates primarily within the ionosphere. Therefore, the most significant changes appear in the ionosphere since the nature of the ionosphere is so closely tied to the radiation of the sun. As a result a loss of sunlight during the eclipse was expected to disturb the ionosphere. A change in the shape of the diurnal variation as recorded by geomagnetic ground stations in the vicinity must be expected, depending on the position of the shadow with respect to the Sq current system. These expected changes are small, about a few to a few tens of nanoteslas. The ionospheric effects during solar eclipse depends on several factors such as the level of solar activity, level of geomagnetic disturbance, geophysical conditions,geographical latitude and longitude and the local time[7]. Different researchers have studied geomagnetic field variations during solar eclipses with most of the results showing positive anomalies in the Y (east) component and a decrease in the X (horizontal) components[8,9,10,11,12].

Presented in this paper is the study investigating changes in the geomagnetic diurnal variation during the total solar eclipse of 29 March, 2006 as it affects some geomagnetic stations in Africa.

Table 1. The observatory stations, geographic coordinates, magnitude and timing of the solar eclipse of March 29th, 2006 at Bangui (BNG), Mbour (MBO), Tamarraset (TAM)

Station	Latitude	Longitude	Max Obscuration	Eclipse Starts	Eclipse Ends
BNG	04.367°	18.577°	50.46%	08:23:32	10:52:00
MBO	14.416°	343.020°	50.06%	08:10:17	10:12:50
TAM	22.785°	05.522°	75.22%	08:38:50	11:11:44

2. Materials & Methods

Table 1 gives a summary of the observatories whose

records were analysed, their coordinates, time of the eclipse and the percentage obscuration in each area. The eclipse totality path is as shown in figure 1. Total eclipse started in eastern Brazil at 08:34:29 and ended in northern Mongolia at 11:48:01; while the partial eclipse, which was visible over most of Africa, Europe, Middle East and most of Asia, started at about 07:36:53 and ended at 12:45:45. The greatest phase was at 10:12:23 and lasted for 4mins 07secs until 10:16:30 at a coordinates of 23.2N 16.7E.
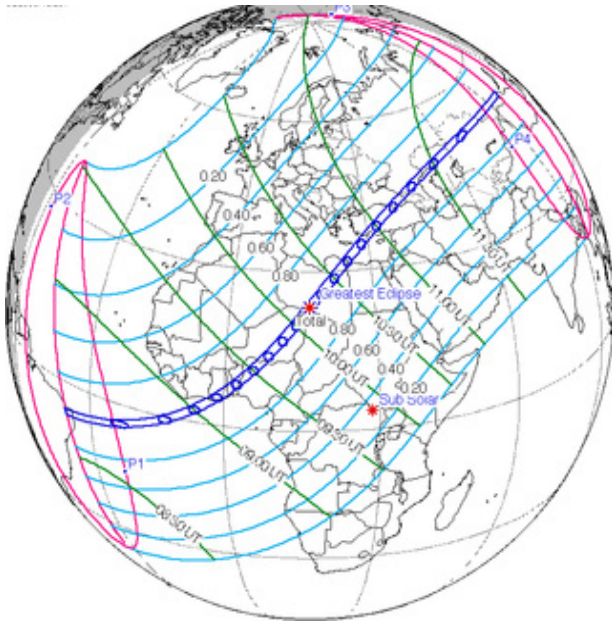
Figure 1. Path of the eclipse of 29 March 2006 (Courtesy NASA)

The study analysed data from three geomagnetic observatories gotten from the INTERMAGNET standard observatories (a set of magnetic observatories that meet exacting standards and make their data available through international centres websites within a few days of observation). Two of the observatories (Mbour, MBO and Bangui, BNG) located either side of the path of the eclipse only observe half-shadow or partial eclipse. The third, Tamanrasset, TAM, caught a glimpse of the totality of the eclipse.

The geomagnetic field at ground level is commonly expressed as XYZ components or HDZ components; where X is north-south, Y is east-west and Z is vertical components. H is horizontal, D is declination and Z is downwards or vertical component.

Minute values of all three components of the geomagnetic field (X, Y, and Z) were collected from 28 to 30 March, 2006 (the data were taken from a day before the eclipse, 28th March, on the day of the eclipse, 29th March, and a day after the eclipse, 30th March) from the three mentioned geomagnetic observatories using the INTERMAGNET site. The record for 28th and 30th were taken and studied for comparison, to see how the signature of the geomagnetic diurnal variation defers from that of the day the eclipse occurred. The overall geomagnetic activity was low, as a result the eclipse benefited from geomagnetic

quiet conditions with AP = 5. This is very important because higher geomagnetic activity or geomagnetic storm could cover changes associated with the eclipse, and therefore makes its difficult detecting the response of the ionosphere to the eclipse event.

3. Results

From the data of the three-component records at Bangui (BNG 4.3672°N, 18.5775°E), fig 2, one can identify no obvious changes in the regular Sq variation before, on or after the eclipse that can be attributed to the effect of the eclipse. The amplitude of the X-component for 28th and 29th were roughly the same, 40nT. The abrupt decrease in the X-component close to noon time may not be attributed to the effect of the eclipse as it was past the time of the greatest phase of the eclipse which was about 10:12am. A close look at the Y- and Z- components revealed no discernible change in amplitude or diurnal variation that is as a result of the eclipse. The increase in the amplitude on the 30th to about 55nT from the value of 40nT on the 28th and 29th, may just be a case of the regular Sq diurnal variation.
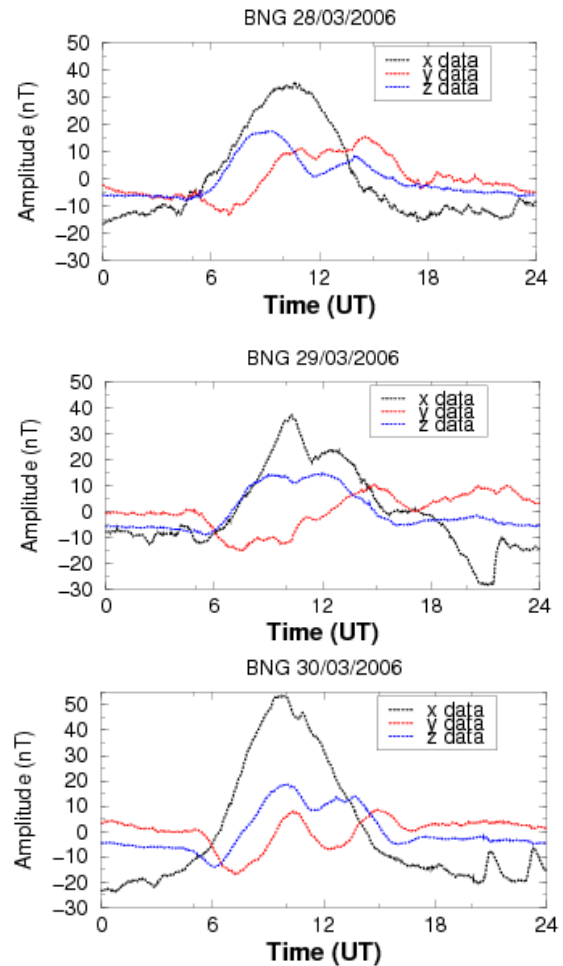
Figure 2. Diurnal variation from records of X, Y, Z at Bangui on March 28 to 30, 2006

Mbour observed the least maximum obscuration of the eclipse (50%) among the three observatories whose records were analysed. The results for Mbour (MBO 14.4167°N, 16.9667°W) in figure 3, also showed no observed changes in the horizontal (X) component, but we can see the increase in amplitude from 50nT on 28th and 29th to 60nT, just as in BNG, but this has no obvious link to the eclipse. The same can be seen in Y- and Z- components.
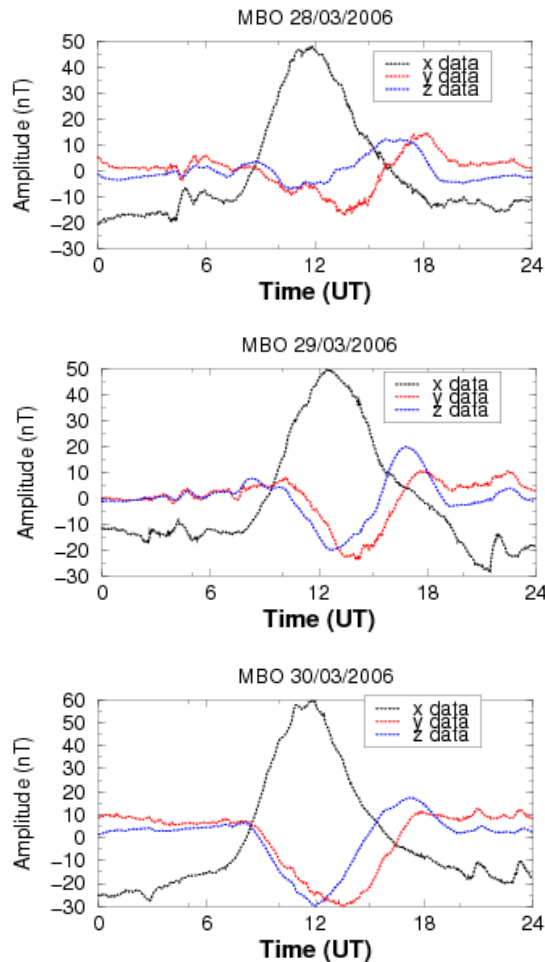
Figure 3. Diurnal variation from records of X, Y, Z at Mbour on March 28 to 30, 2006

Among the three observatories whose records were analysed Tamanrasset (TAM 22.7850°N,5.5228°E) is the closest to the path of totality of the eclipse with the greatest phase at a coordinates of 23.2°N 16.7°E (location closest to the point of the greatest phase of the eclipse). Tamanrasset, also experienced the largest maximum obscuration of the eclipse (75.22%). So, it is reasonable to assume that any eclipse induced changes in the geomagnetic signature of X, Y and Z components of the geomagnetic field will be shown more in Tamanrasset than the other observatories. From the results of the records observed at TAM (Figure 4), one can see distinct changes in the X- and Y- components during the eclipse. One can see regular changes of the geomagnetic field at TAM during the day of the eclipse, with a decrease in X (north) components of about 20nT.

There is also an increase in the Y (east) component of about 10nT during the eclipse. These changes were reversed on the 30th after the eclipse. These observed changes in the X- and Y- components agree well with those described by[8, 9, 11] in their papers on eclipse.
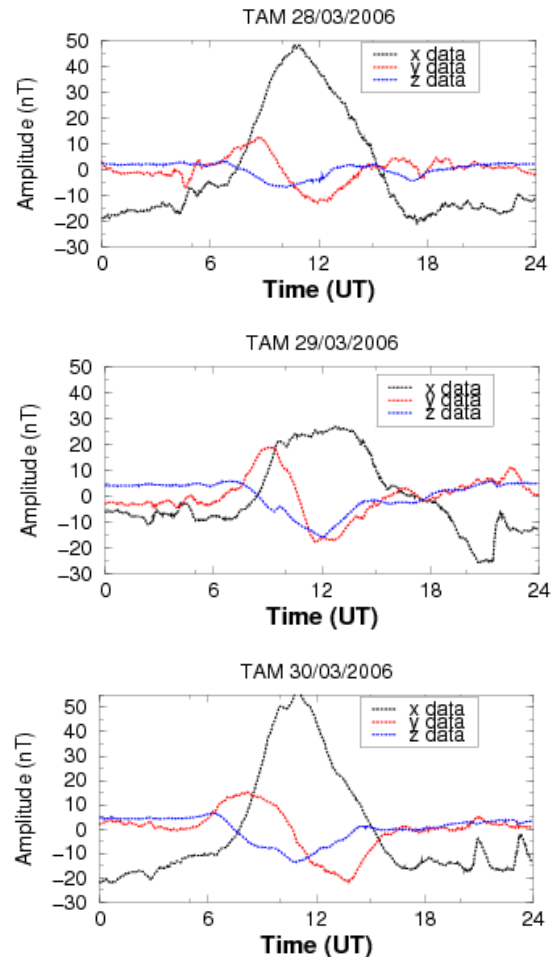
Figure 4. Diurnal Variation from records of X, Y, Z at Tamanrasset on March 28 to 30, 2006

These effects or changes seen in TAM may be attributed to the ionisation in the ionosphere.[13] noted that the ionisation in the E-layer decreases to 65% of its normal value and returns to its normal value after the eclipse. While[14] showed that the effects of the changes observed can be attributed to a 70% decrease in solar ionizing radiation flux and the electron concentration in the ionosphere during the eclipse.

4. Discussion and Conclusions

Discussion: Due to the ionization by electromagnetic radiation from the sun, the ionosphere conducts. At night time the ions recombine rapidly and conductivity drops effectively to zero. Disregarding small tidal movements ascribed to the Sun's and Moon's gravitational attraction movement of the ionosphere is induced by thermal radiation from the Sun. This is switched off in the absence of direct

solar radiation which occasionally occurs during solar eclipse – as a part of the ionosphere is shielded from the Sun's heating and ionizing radiation. As a result the current pattern in the ionosphere is modified during solar eclipse, since the electron density in the ionosphere is closely tied to the radiation from the Sun. The effect of this might be detectable as a modification to the geomagnetic field observed at the ground level.

In the current study, the changes connected with the total eclipse appeared only in Tamanrasset. Geomagnetic effects during total solar eclipse comparable to other observations are seen in Europe[8, 9, 11], where the eclipse occurred on 11 August 1999 and 1 August 2008 respectively.[8] noted an increase of 10nT in the Y component during the eclipse of 11 August 1999 and a decrease of 15nT in the X component.[9] found positive anomalies in the Y component with an amplitude increase of up to 15nT during the maximum phase of the eclipse. However, the effects of the horizontal and vertical components were not observed.[11] observed the main geomagnetic effects of the eclipse as a decrease of 8-10nT in the X component and an increase in the Y component with different ratios of quantities at different magnetic observatories. These observed changes are in accordance with those at Tamanrasset and presented here.

Tamanrasset experienced the largest obscuration of the eclipse (Table 1), and the eclipse induced changes in the geomagnetic signature X, Y, Z components of the geomagnetic field are observed here because of its closeness to the path of totality of the eclipse. As a result, the solar radiation shielding by the lunar shadow modification of the ionosphere will be more pronounced over Tamanrasset than Mbour and Bangui, whose location are further away and experienced lower obscuration compared to Tamanrasset.

The most obvious difference between the three days analysed at Tamanrasset is a decrease in the X component during the day of the eclipse by amplitude of about 20nT starting at about 10.00UT. Similarly, we observe an increase in Y component by amplitude of about 10nT as seen in Fig. 4. These effects seen at Tamanrasset may be attributed to a large percentage decrease in the solar ionizing radiation flux and the electron concentration in the ionosphere during the solar eclipse. This modification in the ionosphere can lead to decrease in the current density in the lower ionosphere and a local decrease in the north component of the magnetic induction of this current.

Conclusions: From the data of the three-components of the geomagnetic field (X, Y, Z) analysed during the total solar eclipse of 29th March, 2006, the feature seen in TAM can be liken to an eclipse signature. In summary, the following changes were observed at Tamanrasset:

➢ A decrease in the X (horizontal) component of the geomagnetic field from 50nT to 30nT, a decrease of 20nT;

➢ An increase in the Y (east) component of the geomagnetic field from 10nT to 20nT, an increase of 10nT;

➢ There is no observed change in amplitude or variation

in the Z (vertical) component caused by the eclipse.

➢ These observed changes may be attributed to ionospheric effects.

Analysis of data from the other observatories, Mbour and Bangui, during the eclipse of 29 March 2006, failed to identify any distinct or discernible daily variation or eclipse effect in the geomagnetic field, which can be adduced to the eclipse. The results presented in this work are substantially in accordance with those of other works on total solar eclipse as seen in the 11 August 1999 and 1 August 2008 eclipses in Europe.

ACKNOWLEDGEMENTS

REFERENCES

[1] S. Alex., B.D. Kadam, D.R.K. Rao, 1998. Ionopheric current systems on days of low equatorial ΔH. Journal of Atmospheric and Solar Terrestrial Physics 60, 371-379.

[2] W.H. Campbell, 1989. An introduction to quiet daily geomagnetic fields. PAGEOPH 131 (3), 315-331.

[3] K.D. Cole, 1995. A new role for the plasma sphere in "quiet ionospheric electrodynamics. Journal of Atmospheric and Terrestrial Physics 57 (7), 805-812.

[4] J. Du, R.J. Stening, 1999a. Stimulating the ionospheric dynamo – I. Simulation model and flux tube integrated conductivities. Journal of Atmospheric and Terrestrial Physics 61, 913-923.

[5] J. Du, R.J. Stening, 1999b. Simulating the ionospheric dynamo – II. Equatorial electric field. Journal of Atmospheric and Terrestrial Physics 61, 925-940.

[6] S. Chapman, and J. Bartels: Geomagnetism, Claredon Press, Oxford, UK (1940)

[7] L.W. Baran, I. Ephishov, I.I. Shagimuratov, V.P. Ivanov, and A.F. Lagovsky: 2003. The response of the ionospheric total electron content to the solar eclipse on August 11, 1999, Adv. Space Res., 31(4), 989-994.

[8] J. Strestik, 2001. The effect of the August 11, 1999 total solar eclipse on the geomagnetic field. Contrib. Geophys. Geod. 31 (1), 331-334.

[9] S.R.C. Malin, O. Ozcan, S.B. Tank, M.K. Tuncer, and O. Yazici-Cakin, 2000. Geomagnetic signature of the 1999 August 11 total eclipse. Geophys. J. Int. 140, F13-F16.

[10] O. Ozcan, M. Aydogdu, 2004. Possible effects of the total solar eclipse of August 11, 1999 on the geomagnetic field variations over Elazig-Turkey. J. Atmos. Solar-Terrestr.

Phys. 66, 997-1000.

[11] A.V. Ladynin, N.N. Semakov, S.Yu. Khomutov, 2011. Changes in the daily geomagnetic variation during the total solar eclipse of 1 August 2008 52, 343-352.

[12] J.J. Curto, B. Heilig, M. Pinui, 2006. Modeling the geomagnetic effects caused by the solar eclipse of 11 August 1999. J. Geophys. Res. 111, A07312.

[13] T.E. Van Zandt, R.B. Norton, G.H. Stonehacker, 1960. Photochemical rates in the equatorial F2-region from 1958 eclipse. J. Geophys. Res. 65, 2003-2009

[14] C.J. Davis, M. Lockwood, S.A. Bell, J.A. Smith, E.M. Clark, 2000. Ionospheric measurements of relative coronal brightness during the total solar eclipses of 11 August, 1999 and 9 July, 1945. Ann. Geophys. 18, 182-190.