International Geomagnetic Reference Field (IGRF) and its Application to Predicting Geomagnetic Elements and Annual Changes for Nigeria.

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ABSTRACT

The 10th generation International Geomagnetic Reference Field (IGRF-10) model has been exploited to predict the geomagnetic elements and annual changes for Nigeria. The predicted values represent the mean for the year 2009.0 at altitude 0.00km.The predicted total intensity (F), horizontal intensity (H), declination (D), and the inclination (I) are compatible with values at magnetic equator where Nigeria is located. This approach of isolating the regional background field is consistent, globally accepted and serves as an important source of information about magnetic fields in Nigeria. The geomagnetic elements will be useful for geomagnetisians who are interested in isolating regional magnetic field from observed data and for exploration geophysicist whose interest is locating magnetic anomalies.

(Keywords: international, geomagnetic, intensity, generation, reference, spherical)

INTRODUCTION

The International Geomagnetic Reference Field (IGRF) is a series of mathematical models of the Earth's main field and its annual rate of change (Maus et al., 2005a). The IGRF is an Internationally agreed-to series of global spherical harmonic models of the Earth's magnetic field whose sources are mainly in the earth's core (Macmillan and Maus, 2005). The IGRF allows numerical values of the geomagnetic field vector to be calculated anywhere from the earth's core out into space. It is the product of a collaborative effort between magnetic field modelers and the institutes involved in collecting and distributing magnetic field data from satellites, observatories and surveys around the world. The idea of IGRF originated from the discussion in respect of the presentation of the results of the World Magnetic Survey (WMS).

The WMS was a mandate of the International Geophysical year which during 1957-1969, encouraged magnetic surveys on land, at sea, in the air, and from satellite (Zmuda, 1971). The body also has additional responsibility of collecting and analyzing the results. A proposal was made in 1960 by the Committee of WMS and IAGA (International Association of Geomagnetism and Aeronomy) that the various results of the WMS should be applied to spherical harmonic analysis. This proposal was accepted and the first IGRF was ratified by IAGA in 1969. Therefore, the IGRF models uses the well known spherical harmonic expansion of the scalar potential in geocentric/geodetic coordinates and the model coefficients are based on all available data sources from geomagnetic measurements from observatories, ships, aircrafts and satellites.

The IGRF is modified every five years under the auspices of the IAGA. The model coefficients could be definitive (Table1) in which no further revisions are expected. It is wrong to use the term IGRF without specifying the generation. This is important so that the actual coefficients used can be accurately established.

Measurements of the magnetic fields of the Earth are used extensively to explore its structure, particularly in the search for solid minerals, hydrocarbons, and other resources of economic value. Due to the large mineral potential of Nigeria, geoscientists from academia, government agencies, and some private investors have frequently collected magnetic data either on the ground or in the air. Airborne magnetic surveys cover substantial amounts of area in a short time, providing a large amount of data that needs to be analyzed and interpreted.

Table 1: Summary of Nomenclature and IGRF History (IAGA, 2005).

Full Name	Short Name	Valid for:	Definitive for:
IGRF 10th generation (revised 2004)	IGRF-10	1900.0-2010.0	1945.0-2000.0
IGRF ninth generation (revised 2003)	IGRF-9	1900.0-2005.0	1945.0-2000.0
IGRF eighth generation(revised1999)	IGRF-8	1900.0-2005.0	1945.0-1990.0
IGRF seventh generation(revised 1995)	IGRF-7	1900.0-2000.0	1945.0-1990.0
IGRF sixth generation (revised 1991)	IGRF-6	1945.0-1995.0	1945.0-1985.0
IGRF fifth generation (revised 1987)	IGRF-5	1945.0-1990.0	1945.0-1980.0
IGRF fourth generation (revised1985)	IGRF-4	1945.0-1990.0	1965.0-1980.0
IGRF third generation (revised 1981)	IGRF-3	1965.0-1985.0	1965.0-1975.0
IGRF second generation (revised 1975)	IGRF-2	1955.0-1980.0	-
IGRF first generation (revised 1969)	IGRF-1	1955.0-1975.0	-

One of the important stages in the analyses of potential field (magnetic and gravity) data is the removal of a background (regional) field from the observations that approximates the field whose sources are in the earth's core. Different background field techniques are usually exploited which are common in geophysical literature. Some of the techniques available in the geophysical literature for isolating regional fields include: filtering approach (e.g., Chakraborty and Agarwal, 2006; Syberg, 1972; Zurflueh, 1967); relaxation technique (e.g., Agarwal and Sivaji, 2006); upward continuation (e.g., Jacobsen, 1987); wavelets technique (e.g., Fedi and Quarta, 1998), and other methods (e.g., Wessel, 1998; Nettleton, 1954).

The use of different background fields for different surveys coupled with the fact that surveys are recorded at different times sometimes with different parameters, techniques and specifications introduces difficulties especially when adjacent surveys have to be combined. There is also an additional problem of very poor spatial distribution of magnetic observatories in Nigeria which would have been an important source of information about magnetic fields. Only one magnetic observatory exits in Nigeria and it is located at Kaduna (latitude 10^0 $18^{'}$ and longitude 7^0 $30^{'}$). It, therefore, becomes imperative to use an internationally agreed global model representing the field from the core to solve the above problems. The 10th generation international geomagnetic reference field (IGRF-10) model became very useful for this purpose.

THEORY AND METHODOLOGY

Theory: The mathematical models of the earth's main magnetic field and its secular variation comprises a set of spherical harmonic (or Gauss) coefficients, g_n^m and h_n^m in a series expansion of the geomagnetic potential (Barton, 1997). The negative gradient of a scalar potential v can be represented by a truncated series expansion (Equation 1); where r, θ, λ are geocentric coordinates (r is the distance from the centre of the earth, θ is the colatitude and λ is the longitude), R is a reference radius (6371.2km); $P_n^m(\theta)$ are the Schmidt semi – normalized associated Legendre functions of degree, n and order, m. An interesting characteristic of the geomagnetic field is its variance as a function of spherical harmonic degree (Maus, 2008).The full vector of the magnetic field defined in Fig.1 can be obtained from a simple set of spherical harmonic coefficient of a scalar magnetic potential (Maus, 2006).

$$V(r,\theta,\lambda,t) = R\sum_{n=1}^{n_{max}} \left(\frac{R}{r}\right)^{n+1} \sum_{m=0}^{n} \left[g_n^m(t) cos m\lambda + h_n^m(t) sin m\lambda\right] P_n^m(\theta) \quad \textbf{(1)}$$

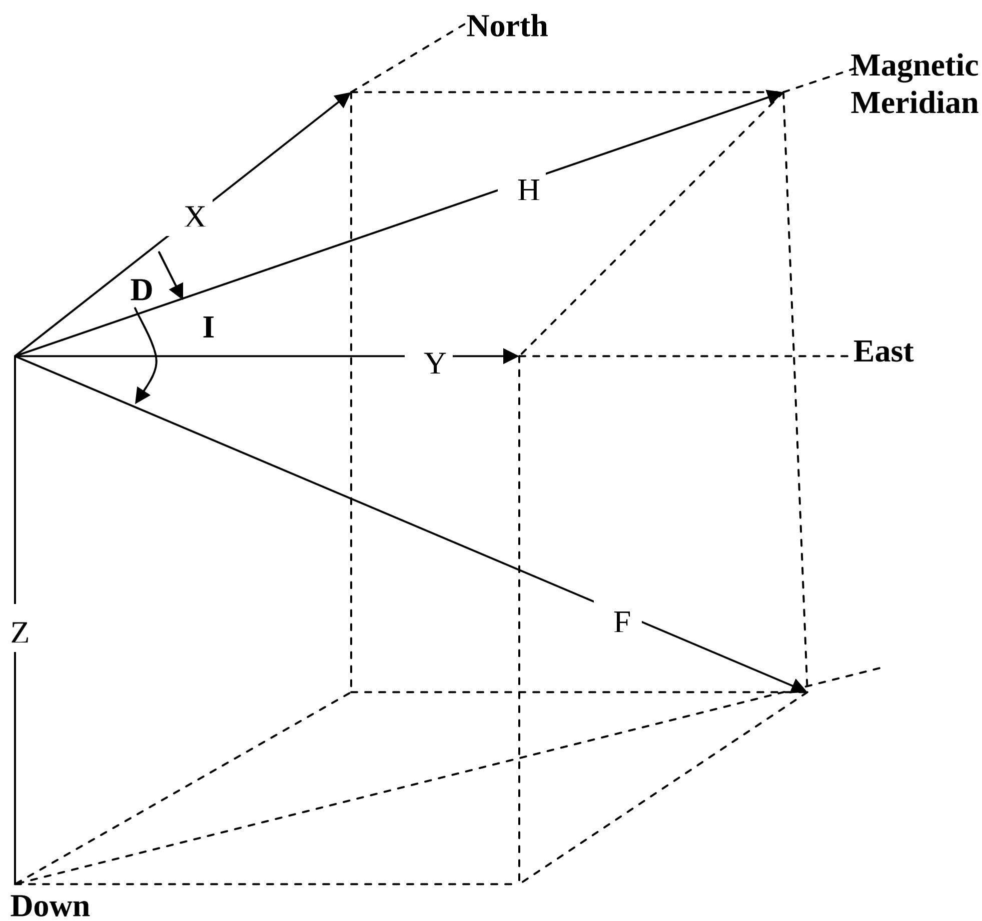

Figure 1: Definition of the Geomagnetic Field Elements: Inclination (I), Declination (D), Total Intensity (F), North Component (X), East Component (Y), and Down Component (Z) (Langel, 1987).

Thus,

$$X(r,\theta,\lambda) = \sum_{n=1}^{\infty} \sum_{m=-n}^{n} \left[g_n^m \left(\frac{R}{r} \right)^{n+2} + h_n^m \left(\frac{r}{R} \right)^{n-1} \right] \partial \theta Y_n^m(\theta,\lambda) \qquad \textbf{(2)}$$

$Y_n^m(\theta,\lambda)$ is the surface spherical harmonics.

$$Y(r,\theta,\lambda) = \sum_{n=1}^{\infty} \sum_{m=-n}^{n} \left[- g_n^m \left(\tfrac{R}{r}\right)^{n+2} - h_n^m \left(\tfrac{r}{R}\right)^{n-1} \right] \frac{1}{\sin\theta} \lambda \gamma_n^m(\theta,\lambda) \qquad \textbf{(3)}$$

$$Z(r,\theta,\lambda) = \sum_{n=1}^{\infty} \sum_{m=-n}^{n} \left[-(n+1) g_n^m \left(\frac{R}{r} \right)^{n+2} + n\, K_n^m \left(\frac{r}{R} \right)^{n-1} \right] Y_n^m(\theta,\lambda) \quad \textbf{(4)}$$

$$H^2 = X^2 + Y^2 \quad \textbf{(5)}$$

$$F^2 = H^2 + Z^2 \quad \textbf{(6)}$$

$$\lim_{I \to 0} F \cos I = F = H \quad \textbf{(7)}$$

$$\lim_{I \to 0} F \sin I = 0 = z \quad \textbf{(8)}$$

$$\lim_{I \to \frac{\pi}{2}} F \sin I = F = Z \quad \textbf{(9)}$$

$$\lim_{I \to \frac{\pi}{2}} F \cos I = 0 = H \quad \textbf{(10)}$$

Methodology: The IGRF-10 (the 10th Generation standard main field model) which is the latest model adopted by the (IAGA) was used to compute the various geomagnetic element (F, Z, H, X, Y, I, D) and secular variation (dF, dZ, dH, dX, dY, dI, dD) 1^o by 1^o for Nigeria. This is a degree and order 13 models for 2005 – 2010 with models for 1900 forward enabling computation of the main field for dates between January 1, 1900 and January 1, 2010. Some of the candidate models for the 10th generation IGRF are available in literature (Lesur *et al.,* 2005; Maus *et al.,* 2005b; Maus *et al.,* 2005c).

Geomag 6.1 was used to predict the various magnetic elements and their secular variations 1^o by 1^o for Nigeria for the year, 2009. The software requires date in decimal year or in month and day. The program could be used in two ways depending on whether the predicted geomagnetic elements are referenced to the world Geodetic system, 1984 (WGS 84) or geocentric latitude and longitude. If geodetic coordinates is specified, then the height in kilometers above sea level is required. If the geocentric coordinates is specified, then the geocentric distance in kilometers is required. The program then calculates the geomagnetic field values and their rates of change (secular variation) depending on the option selected at the position and the time specified and displays the results on the screen.

We preferred the WGS 84. It is now recommended to use the World Geodetic system, 1984 (WGS 84) when specifying the IGRF in geodetic coordinates (Maus *et al.,* 2005a). This option enabled the computation of geomagnetic elements at altitude 0.00km (sea level). Most potential field data (e.g. gravity) are reduced to sea level; although any potential field data can be vertically continued.

RESULTS AND DISCUSSION

The results of the various geomagnetic elements and their secular variations are presented in Tables 2 – 8. While the north component (X) increases towards the north, its secular variation increases towards the south. The declination (D) and its secular variation follow the same pattern. The inclination/angle of dip (I) and its rate of change increases towards the north with higher values in the northeast. The total field intensity (F) increases generally to the north with higher values in the northeast and lowest values in the southwest. The annual change for the total intensity displays a general increase from south to north; however, the values in the northwest are higher than the northeasterly values.

The horizontal magnetic intensity (H) and its secular variation follow the same pattern as total intensity and its annual change. The total field intensity (Table 2) is almost comparable with the horizontal field intensity (Table 3). This could be understood from Equation (7). Nigeria is located in magnetic equator where the earth's magnetic field is horizontal. That is, where the line of zero inclination (Z = 0) is never more than 15^{o} from the equator (Telford *et al.,* 1976). The very low values of the vertical intensity (Z) as compared to the total intensity (F) and horizontal intensity (H) can be accounted for in equation (8). This implies that (Z) can only attain its higher values at the poles where I, tends to 90^{o}. This property, inclination (I) of the earth's magnetic field is, therefore, important. This property has application in exploration geophysics where magnetic anomalies are the main target. In this case, the earth's field inclination is first considered because this is the only direction of the components of any local magnetic anomalies which is measured by a total field magnetometer (Breiner, 1973).

The predicted values should not be compared to the real life data. The difference on the predicted and observed may be due to local crustal and induced fields as well as unmodeled external fields. There may also be some contributions from buildings, rail tracks, vehicles and induced current in the conducting earth. If you measure the magnetic field at a point in the earth's surface, do not expect to get the value predicted by the IGRF (IAGA, 2005).

Table 2: (a) Mean Values of Total Magnetic Intensity (F) in nanoTesla.

		East longitude (degrees													
		2	3	4	5	6	7	8	9	10	11	12	13	14	15
North latitude (degrees)	14	34122	34219	34316	34412	34507	34601	34694	34785	34874	34962	35048	35132	35215	35296
	13	33841	33939	34036	34132	34227	34320	34412	34502	34591	34677	34762	34845	34927	35006
	12	33582	33680	33777	33872	33967	34060	34157	34241	34329	34414	34498	34580	34659	34737
	11	33343	33441	33538	33634	33728	33821	33912	34001	34088	34173	34255	34336	34414	34490
	10	33125	33223	33321	33417	33511	33604	33604	33782	33869	33952	34034	34113	34264	34190
	9	32926	33026	33124	33220	33314	33407	33497	33585	33670	33753	33834	33912	33987	34059
	8	32748	32848	32946	33043	33138	33230	33320	33408	33493	33575	33654	33731	33804	33875
	7	32587	32688	32788	32885	32980	33073	33163	32250	33335	33416	33494	33569	33641	33710
	6	32444	32546	32647	32745	32840	33073	33023	33110	33194	33275	33352	33426	33497	33564
	5	32316	32420	32521	32620	32103	32810	32900	32987	33071	33151	32276	33300	33369	33435
	4	32201	32307	32410	32510	32607	32701	32791	32878	32962	33041	33117	33188	33256	33320

(b) Annual Changes in nanoTesla per Year in Nigeria for 2009.0 at Altitude 0.00km.

		East longitude (degrees)													
		2	3	4	5	6	7	8	9	10	11	12	13	14	15
North latitude (degrees)	14	27.1	27.0	26.9	26.7	26.5	26.2	25.9	25.6	25.2	24.9	24.6	24.2	23.9	23.6
	13	27.1	26.9	26.7	26.4	26.2	25.8	25.5	25.1	24.7	24.3	23.9	23.5	23.1	22.7
	12	27.0	26.8	26.5	26.2	25.9	25.2	25.1	24.6	24.1	23.7	23.2	22.7	22.3	21.8
	11	27.0	26.7	26.4	26.0	25.6	25.1	24.6	24.1	23.6	23.0	22.5	22.0	21.4	20.9
	10	27.0	26.6	26.2	25.8	25.3	24.8	24.2	23.6	23.0	22.4	21.8	21.2	20.0	20.6
	9	26.9	26.5	26.1	25.6	25.0	24.4	23.8	23.1	22.4	21.7	21.1	20.4	19.7	19.0
	8	26.9	26.5	25.9	25.4	24.7	24.0	23.3	22.6	21.8	21.1	20.3	19.5	18.8	18.0
	7	26.9	26.4	25.8	25.1	24.4	23.7	22.9	22.1	21.2	20.4	19.5	18.7	17.8	17.0
	6	26.8	26.2	25.6	24.8	24.1	23.7	22.4	21.5	20.6	19.6	18.7	17.8	16.9	16.0
	5	26.7	26.1	25.3	24.5	27.8	22.8	21.8	20.9	19.9	18.8	17.8	16.8	15.8	14.9
	4	26.6	25.9	25.1	24.2	23.3	22.3	21.3	20.2	19.1	18.0	16.9	15.8	14.8	13.7

Table3: (a) Mean Values of Horizontal Magnetic Intensity (H) in nano Tesla.

		East longitude (degrees)													
North latitude (deegrees)		2	3	4	5	6	7	8	9	10	11	12	13	14	15
	14	33918	34009	34098	34187	34274	34359	34443	34525	34605	34683	34758	34839	34902	34971
	13	33770	33864	33957	34048	34138	34227	34313	34398	34481	34561	34639	34715	34789	34860
	12	33575	33672	33767	33862	33954	34046	34135	34222	34300	34391	34472	34530	34626	34700
	11	33333	33432	33530	33627	33723	33817	33908	33998	34086	34171	34254	34335	34414	34490
	10	33044	33146	33246	33346	33443	33535	33539	33725	33815	33903	33988	34071	34230	34152
	9	32710	32813	32916	33017	33117	33215	33311	33405	33496	33586	33673	33758	33841	33921
	8	32330	32435	32539	32642	32744	32843	32941	33037	33130	33221	33310	33397	33481	33563
	7	31906	32013	32118	32222	32325	32426	32525	32622	32717	32809	32900	32988	33074	33157
	6	31440	31548	31654	31759	31863	32426	32064	32162	32258	32352	32443	32533	32620	32705
	5	30934	31041	31148	31253	30718	31460	31560	31659	31756	31850	31942	32033	32121	32207
	4	30389	30496	30602	30708	30812	30914	30914	31114	31211	31306	31399	31490	31579	31666

(b) Annual Changes in nanoTesla per Year in Nigeria for 2009.0 at Altitude 0.00km.

		East longitude (degrees)													
North latitude (degrees)		2	3	4	5	6	7	8	9	10	11	12	13	14	15
	14	30	29.3	29	28.7	28.3	28	27.4	26.8	26.3	25.7	25.1	24.5	23.9	23.3
	13	29	28.4	28	27.8	27.4	27	26.5	26	25.5	24.9	24.3	23.8	23.2	22.6
	12	28	27.3	27	26.8	26.4	27	25.5	25.1	24.5	24	23.5	22.9	22.4	21.8
	11	26	26.1	26	25.5	25.2	25	24.4	23.9	23.5	22.9	22.5	21.9	21.4	20.9
	10	25	24.7	24	24.1	23.8	24	23.1	23.8	22.2	21.7	21.3	20.8	19.9	20.3
	9	23	23.1	23	22.6	22.3	22	21.6	21.2	20.8	20.4	20	19.6	19.2	18.8
	8	21	21.3	21	20.9	20.6	20	20	19.7	19.3	19	18.6	18.2	17.9	17.9
	7	19	19.3	19	19	18.8	19	18.3	18	17.7	17.4	17	16.8	16.5	16.2
	6	17	17.2	17	17	16.8	19	16.4	16.1	15.9	15.6	15.4	15.2	15	14.8
	5	15	14.9	15	14.8	14.8	15	14.3	14.1	14	13.8	13.6	13.5	13.9	13.3
	4	13	12.5	13	12.4	12.3	12	12.1	12	11.9	11.8	11.7	11.7	11.7	11.7

Table 4: (a) Mean Values North Component (X) in nano Tesla.

		East longitude (degrees)													
North latitude (degrees)		2	3	4	5	6	7	8	9	10	11	12	13	14	15
	14	33898	33993	34086	34178	34267	34355	34440	34523	34604	34683	34759	34832	34903	34971
	13	33746	33845	33941	34036	34129	34220	34309	34395	34479	34561	34640	34716	34789	34860
	12	33547	33649	33749	33847	33943	34037	34129	34219	34305	34390	34471	34550	34627	34700
	11	33300	33405	33508	33610	33709	33806	33901	33993	34082	34169	34254	34335	34414	34490
	10	33007	33114	33220	33325	33426	33526	33526	33718	33810	33900	33986	34070	34230	34152
	9	32666	32777	32504	32992	33096	33198	33298	33395	33489	33581	33670	33757	33840	33921
	8	32280	32392	32509	32612	32719	32823	32925	33024	33121	33215	33306	33394	33480	33563
	7	31850	31964	32077	32187	32296	32402	32506	32607	32705	32801	32894	32984	33071	33156
	6	31376	31492	31606	31718	31828	32402	32041	32143	32243	32341	32435	32527	32616	32703
	5	30860	30977	31093	31206	30623	31426	31532	31136	31737	31836	31932	32025	32116	32204
	4	30305	30423	30539	30653	30765	30875	30875	31087	31189	31288	31385	31480	31572	31662

(b) Annual Changes in nanoTesla per Year in Nigeria for 2009.0 at Altitude 0.00km.

		East longitude (degrees)													
North latitude (degrees)		2	3	4	5	6	7	8	9	10	11	12	13	14	15
	14	31.3	30.9	30.4	29.9	29.3	28.7	28	27.3	26.6	25.9	25.2	24.4	23.6	22.9
	13	30.6	30.1	29.6	29.1	28.6	28	27.3	26.6	26	25.3	24.5	23.8	23	22.3
	12	29.6	29.2	28.8	28.3	27.7	27.1	26.5	25.8	25.2	24.5	23.8	23.1	22.4	21.6
	11	28.6	28.2	27.7	27.2	26.7	26.1	25.5	24.9	24.2	23.6	22.9	22.2	21.5	20.9
	10	27.3	26.9	26.5	26	25.5	25	24.4	23.8	23.2	22.5	21.9	21.2	20.6	20
	9	25.9	25.5	25.1	24.7	24.2	23.6	23.1	22.5	21.9	21.3	20.7	20.1	19.5	19
	8	24.3	24	23.6	23.1	22.7	22.2	21.7	21.1	20.6	20	19.5	18.9	18.4	17.9
	7	22.6	22.2	21.9	21.5	21	20.6	20.1	19.6	19.1	18.6	18.1	17.6	17.1	16.7
	6	20.7	20.4	20	19.7	19.3	20.6	18.4	18	17.5	17.1	16.6	16.2	15.8	15.4
	5	18.6	18.4	18.1	17.7	19	17	16.6	16.2	15.8	15.4	15	14.7	14.3	14
	4	16.4	16.2	15.9	15.6	15.3	15	14.7	14.3	14	13.7	13.3	13.1	12.8	12.6

Table 5: (a) Mean Values of East Component (Y) in nano Tesla.

North latitude (degrees)	East longitude (degrees)													
	2	3	4	5	6	7	8	9	10	11	12	13	14	15
14	-1191	-1063	-940	-821	-707	-596	-487	-381	-277	-174	-72	29	130	230
13	-1285	-1156	-1032	-912	-796	-683	-573	-465	-359	-253	-149	-46	57	160
12	-1383	-1253	-1127	-1006	-888	-773	-661	-551	-443	-336	-229	-123	-18	88
11	-1484	-1352	-1225	-1102	-983	-866	-752	-640	-529	-420	-311	-203	-95	13
10	-1587	-1454	-1326	-1201	-1080	-961	-961	-731	-618	-506	-395	-284	-174	-64
9	-1693	-1559	-1429	-1303	-1179	-1059	-941	-824	-709	-594	-481	-368	-255	-143
8	-1802	-1666	-1534	-1406	-1281	-1158	-1038	-919	-801	-685	-569	-453	-338	-223
7	-1912	-1775	-1642	-1512	-1385	-1260	-1137	-1016	-896	-776	-658	-540	-423	-306
6	-2024	-1886	-1751	-1619	-1490	-1260	-1238	-1114	-992	-870	-749	-629	-809	-390
5	-2138	-1998	-1861	-1728	-2428	-1467	-1340	-1214	-1089	-965	-841	-719	-597	-476
4	-2253	-2111	-1973	-1838	-1704	-1573	-1573	-1315	-1187	-1061	-935	-810	-686	-563

(b) Annual Changes in nanoTesla per Year in Nigeria for 2009.0 at Altitude 0.00km.

North latitude (degrees)	East longitude (degrees)													
	2	3	4	5	6	7	8	9	10	11	12	13	14	15
14	51.2	51.0	50.9	50.8	50.8	50.8	50.8	50.8	50.8	50.0	50.8	50.7	50.6	50.4
13	51.4	51.3	51.2	51.2	51.2	51.2	51.3	51.3	51.3	51.3	51.3	51.3	51.1	51.0
12	51.6	51.5	51.5	51.5	51.6	51.6	51.7	51.8	51.8	51.9	51.9	51.8	51.7	51.5
11	51.8	51.8	51.8	51.9	52.0	52.1	52.2	52.3	52.3	52.4	52.4	52.3	52.2	52.0
10	52.0	52.0	52.1	52.2	52.3	52.5	52.6	52.7	52.8	52.9	52.9	52.8	52.7	52.5
9	52.2	52.3	52.4	52.5	52.7	52.9	53.0	53.2	53.3	53.3	53.4	53.3	53.1	52.9
8	52.4	52.5	52.7	52.9	53.1	53.3	53.5	53.6	53.7	53.8	53.8	53.7	53.6	53.3
7	52.6	52.7	53.0	53.2	53.4	53.6	53.8	54.0	54.1	54.2	54.2	54.1	53.9	53.6
6	52.8	53.0	53.2	53.5	53.7	53.6	54.2	54.4	54.5	54.6	54.6	54.5	54.2	53.9
5	52.9	53.2	53.5	53.7	52.5	54.3	54.5	54.7	54.9	54.9	54.9	54.7	54.5	54.2
4	53.1	53.4	53.7	54.0	54.3	54.6	54.8	55.0	55.1	55.2	55.1	55.0	54.7	54.3

Table 6: (a) Mean Values of Vertical Intensity (Z) in nanoTesla.

North latitude (degrees)	East longitude (degrees)													
	2	3	4	5	6	7	8	9	10	11	12	13	14	15
14	3723	3790	3860	3932	4007	4083	4162	4243	4326	4411	4499	4590	4684	4782
13	2199	2259	2323	2389	2458	2529	2603	2678	2756	2837	2921	3008	3099	3194
12	683	737	794	854	917	982	1050	1120	1193	1269	1348	1431	1519	1611
11	-820	-774	-723	-670	-613	-534	-492	-428	-360	-289	-214	-135	-52	37
10	-2307	-2268	-2225	-2178	-2129	-2076	-2020	-1961	-1899	-1833	-1763	-1688	-1524	-1609
9	-3773	-3741	-3706	-3667	-3624	-3578	-3529	-3476	-3419	-3358	-3293	-3223	-3148	-3067
8	-5214	-5191	-5163	-5132	-5096	-5057	-5014	-4968	-4917	-4862	-4802	-4736	-4665	-4587
7	-6626	-6612	-6592	-6569	-6541	-6509	-6473	-6433	-6388	-6338	-6283	-6223	-6156	-6082
6	-8006	-8000	-7989	-7974	-7954	-6509	-7901	-7867	-7828	-7784	-7734	-7678	-7616	-7546
5	-9349	-9352	-9350	-9343	-9326	-9315	-9293	-9266	-9233	-9195	-9151	-9100	-9041	-8975
4	-10652	-10664	-10671	-10673	-10669	-10660	-10660	-10626	-10600	-10567	-10528	-10482	-686	-10366

(b) Annual Changes in nanoTesla per Year in Nigeria for 2009.0 at Altitude 0.00km.

North latitude (degrees)	East longitude (degrees)													
	2	3	4	5	6	7	8	9	10	11	12	13	14	15
14	-20.6	-19.0	-17.4	-15.7	-14.0	-12.3	-10.4	-8.6	-6.6	-4.6	-2.5	-0.4	1.8	4.0
13	-23.3	-21.7	-20.0	-18.3	-16.5	-14.7	-12.3	-10.8	-8.8	-6.7	-4.5	-2.3	0.0	2.4
12	-26.0	-24.3	-22.6	-20.8	-19.0	-17.1	-15.1	-13.0	-10.9	-8.7	-6.4	-4.1	-1.7	0.8
11	-28.7	-27.0	-25.2	-23.3	-21.4	-19.4	-17.3	-15.2	-12.9	-10.6	-8.2	-5.8	-3.3	-0.7
10	-31.3	-29.5	-27.7	-25.7	-23.7	-21.7	-19.5	-17.2	-14.9	-12.5	-10.0	-7.4	-2.1	-4.8
9	-33.9	-32.0	-30.1	-28.1	-26.0	-23.8	-21.6	-19.2	-16.8	-14.3	-11.7	-9.0	-6.3	-3.5
8	-36.3	-34.4	-32.4	-30.3	-28.2	-25.9	-23.6	-21.1	-18.6	-15.9	-13.2	-10.5	-7.6	-4.7
7	-38.6	-36.6	-34.6	-32.4	-30.2	-27.9	-25.4	-22.9	-20.2	-17.5	-14.7	-11.8	-8.9	-5.9
6	-40.8	-38.8	-36.2	-34.4	-32.1	-27.9	-27.1	-24.5	-21.8	-18.9	-16.0	-13.0	-10.0	-6.9
5	-42.8	-40.7	-13.6	-36.3	-46.8	-31.3	-28.7	-26.0	-23.1	-20.2	-17.2	-14.1	-10.9	-7.7
4	-44.7	-42.6	-40.3	-37.9	-35.4	-30.1	-32.8	-27.3	-24.3	-21.3	-18.2	-15.0	-11.8	-8.5

Table7: (a) Mean Values of East Declination (D) in Degrees and Minutes.

North latitude (degrees)	East longitude (degrees)													
	2	3	4	5	6	7	8	9	10	11	12	13	14	15
14	- 2°1'	- 1° 47'	- 1° 35'	- 1° 23'	- 1°11'	0° - 60'	0° - 49'	0° - 38'	0° - 28'	0° - 17'	0° - 7'	0° 3'	0° 13'	0° 23'
13	-2° 11'	- 1°57'	- 1° 44'	- 1° 32'	- 1° 20'	- 1° 9'	0° - 57'	0° - 46'	0° - 36'	0° - 25'	0° - 15'	0° - 5'	0° 6'	0° 16'
12	- 2°22'	- 2° 8'	- 1°55'	- 1° 42'	- 1° 30'	- 1° 18'	- 1° 7'	0° - 55'	0° - 44'	0° - 34'	0° - 23'	0° - 12'	0° - 2'	0° 9'
11	- 2°33'	- 2°19'	- 2°6'	- 1°53'	- 1°40'	- 1°28'	- 1°26'	- 1°5'	0° - 53'	0° - 42'	0° - 31'	0° - 20'	0° - 9'	0° 1'
10	-2°45'	- 2°31'	-2°17'	-2°4'	-1°51'	-1°39'	-1°39'	-1°14'	-1°3'	0°-51'	0°- 40'	0° - 29'	0° - 18'	0° - 6'
9	-2°58'	-2°43'	-2°29'	-2°16'	-2°2'	-1°50'	-1°37'	-1°25'	-1°13'	-1°1'	0°-49'	0°-37'	0°-26'	0°-14'
8	-3°12'	-2°57'	-2°42'	-2°28'	-2°15'	-2°1'	-1°48'	-1°36'	-1°23'	-1°11'	0°-59'	0°-47'	0°-35'	0°-23'
7	-3°26'	-3°11'	-2°56'	-2°41'	-2°27'	-2°14'	-2°0'	-1°47'	-1°34'	-1°21'	-1°9'	0°-56'	0°-44'	0°-32'
6	-3°41'	-3°26'	-3°10'	-2°55'	-2°41'	-2°27'	-2°13'	-1°59'	-1°46'	-1°32'	-1°19'	-1°6'	0°-54'	0°-41'
5	-3°58'	-3°41'	-3°26'	-3°10'	-4°32'	-2°40'	-2°26'	-2°12'	-1°58'	-1°44'	-1°31'	-1°17'	-1°4'	0°-51'
4	- 4° 15'	- 3° 58'	- 3° 42'	- 3° 26'	- 3° 10'	- 2° 55'	- 2° 55'	- 2° 25'	- 2° 11'	- 1° 56'	- 1° 42'	- 1° 28'	- 1° 15'	- 1° 1'

(b) Annual Changes in Minutes per Year in Nigeria for 2009.0 at Altitude 0.00km.

North latitude (degrees)	East longitude (degrees)													
	2	3	4	5	6	7	8	9	10	11	12	13	14	15
14	5.3	5.2	5.2	5.2	5.1	5.1	5.1	5.1	5.1	5.0	5.0	5.0	5.0	4.9
13	5.3	5.3	5.3	5.2	5.2	5.2	5.2	5.2	5.1	5.1	5.1	5.1	5.0	5.0
12	5.4	5.4	5.3	5.3	5.3	5.3	5.3	5.2	5.2	5.2	5.2	5.2	5.1	5.1
11	5.5	5.4	5.4	5.4	5.4	5.4	5.3	5.3	5.3	5.3	5.3	5.2	5.2	5.2
10	5.5	5.5	5.5	5.5	5.5	5.4	5.4	5.4	5.4	5.4	5.4	5.3	5.3	5.3
9	5.6	5.6	5.6	5.6	5.6	5.5	5.5	5.5	5.5	5.5	5.4	5.4	5.4	5.4
8	5.7	5.7	5.7	5.7	5.7	5.7	5.6	5.6	5.6	5.6	5.6	5.6	5.5	5.5
7	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.7	5.7	5.7	5.7	5.6	5.6
6	5.9	5.9	5.9	5.9	5.9	5.8	5.9	5.9	5.9	5.8	5.8	5.8	5.7	5.7
5	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	5.9	5.9	5.9	5.8
4	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.0	6.0	5.9

Table 8: (a) Mean Values of North Inclination (I) in Degrees and Minutes.

North latitude (degrees)	East longitude (degrees)													
	2	3	4	5	6	7	8	9	10	11	12	13	14	15
14	6°16'	6°22'	6°27'	6°34'	6°40'	6°47'	6°53'	7°0'	7°7'	7°15'	7°22'	7°30'	7°39'	7°47'
13	3°44'	2°47'	3°55'	4°1'	4°7'	4°14'	4°20'	4°27'	4°34'	4°42'	4°49'	4°57'	5°5'	5°14'
12	1°10'	1°15'	1°21'	1° 27'	1°33'	1°39'	1°46'	1°52'	1°60'	2°7'	0° - 14'	2°22'	2°31'	2°39'
11	- 1° 25'	- 1° 20'	- 1° 14'	- 1°8'	- 1° 3'	0° - 56'	0° - 50'	0° - 43'	0° - 36'	0° - 29'	0° - 21'	0° - 14'	0° - 5'	0° 4'
10	- 3° 60'	- 3° 55'	- 3° 50'	- 3°44'	- 3°38'	- 3° 26'	- 3° 32'	- 3° 20'	- 3° 13'	- 3° 6'	- 2° 58'	- 2° 50'	- 2° 42'	- 2° 33'
9	- 6° 35'	- 6° 30'	- 6° 25'	- 6° 20'	- 6° 15'	- 6° 9'	- 6° 3'	- 5° 56'	- 5° 50'	- 5° 43'	- 5° 35'	- 5° 27'	- 5° 19'	- 5° 10'
8	- 9° 10'	- 9° 6'	- 9° 1'	- 8° 56'	- 8° 51'	- 8° 45'	- 8°39'	- 8° 33'	- 8° 27'	- 8° 20'	- 8° 12'	- 8° 4'	- 7° 56'	- 7° 47'
7	- 11° 44'	- 11° 40'	- 11° 36'	- 11° 31'	- 11° 26'	- 11° 21'	- 11° 15'	- 11° 9'	- 11°3	- 10° 56'	- 10° 49'	- 10° 41'	- 10° 33'	- 10° 24'
6	- 14° 17'	- 14° 14'	- 14° 10'	- 14° 6'	- 14° 1'	- 11° 21'	- 13° 50'	- 13° 45'	- 13° 38'	- 13° 32'	- 13° 25'	- 13° 17'	- 13° 8'	- 12° 60'
5	- 16° 49'	- 16° 46'	- 16° 43'	- 16° 39'	- 16° 53'	- 16° 30'	- 16° 24'	- 16° 19'	- 16° 13'	- 16° 6'	- 15° 59'	- 15° 51'	- 15° 43'	- 15° 34'
4	- 19°19	- 19°16'	- 19°13'	- 19°10'	- 19°6'	- 19°2'	- 18°57'	- 18°51'	- 18° 45'	- 18° 39'	- 18° 32'	- 18° 25'	- 18° 16'	- 18° 8'

(b) Annual Changes in Minutes per Year in Nigeria for 2009.0 at Altitude 0.00km.

North latitude (degrees)	East longitude (degrees)													
	2	3	4	5	6	7	8	9	10	11	12	13	14	15
14	-2.4	-2.2	-2.1	-1.9	-1.7	-1.5	-1.4	-1.2	-1	-0.8	-0.6	-0.4	-0.1	0.1
13	-2.5	-2.4	-2.2	-2	-1.9	-1.7	-1.5	-1.3	-1.1	-0.9	-0.6	-0.4	-0.2	0
12	-2.7	-2.5	-2.4	-2.2	-2	-1.8	-1.6	-1.4	-1.2	-1	-0.7	-0.5	-0.3	0
11	-2.9	-2.7	-2.5	-2.3	-2.1	-1.9	-1.7	-1.5	-1.3	-1	-0.8	-0.6	-0.3	-0.1
10	-3.1	-2.9	-2.7	-2.5	-2.3	-2.1	-1.8	-1.6	-1.4	-1.1	-0.9	-0.6	-0.1	-0.4
9	-3.2	-3	-2.8	-2.6	-2.4	-2.2	-2	-1.7	-1.5	-1.2	-1	-0.7	-0.5	-0.2
8	-3.4	-3.2	-3	-2.8	-2.6	-2.3	-2.1	-1.8	-1.6	-1.3	-1.1	-0.8	-0.5	-0.2
7	-3.6	-3.4	-3.1	-2.9	-2.7	-2.5	-2.2	-2	-1.7	-1.4	-1.2	-0.9	-0.6	-0.3
6	-3.7	-3.5	-3.3	-3.1	-2.8	-2.5	-2.3	-2.1	-1.8	-1.5	-1.2	-0.9	-0.6	-0.3
5	-3.9	-3.7	-3.4	-3.2	-4.3	-2.7	-2.5	-2.2	-1.9	-1.6	-1.3	-1	-0.7	-0.4
4	-4.1	-3.8	-3.6	-3.4	-3.1	-2.8	-2.6	-2.3	-2	-1.7	-1.4	-1.1	-0.8	-0.5

CONCLUSION

The geomagnetic field model for the year, 2009.0 and the associated secular variation model at altitude 0.00km have been produced for Nigeria. The model is based on predicted annual mean and secular variation determined from the 10th generation International Geomagnetic reference field (IGRF- 10). This model provides a reliable description of the main field. The predicted values will be useful to geomagnetisans who are involved in geomagnetic modeling and to exploration geophysicist whose interest is locating magnetic anomalies.

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