Astudy and Analysis of Geomagnetic Field By using Model of International Geomagnetic Reference Field (IGRF – 2000)

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Abstract

The IGRF model is the empirical representation of the Earth magnetic field recommended for scientific use by the International Association of Geomagnetism and Aeronomy(IAGA).

Since the Geomagnetic field has the ability to change the orientation of satellite, the strength of Geomagnetic field and its horizontal component have been studied.

This paper discusses the phenomenon of the Geomagnetic field intensity and its horizontal component at diferent altitudes and at certain latitudes, the geomagnetic field data is obtained by using IGRF2000 model at Baghdad (44.7 degree East longitude) .

Introduction

Examining Earth magnetic field is extremely important in spacecraft application. Oftenly the magnetic field can negatively affect the performance of the satellite. Through its ability to change the orientation of the spacecraft, when used correctly the magnetic field may be used for satellite control (1) .

The International Geomagnetic Reference Field (IGRF) model is the empirical representation of the Earth's main magnetic field without external sources (2). By using the usual spherical harmonic expansion of the scaler potential in geocentric coordinates .

The IGRF model coefficients are based on all available data sources including geomagnetic measurements, from observatories, ships, aircrafts and satellites.

This model is meant to give a reasonable approximation near and above the Earth's surface.

It is introduced by the International Association of Geomagnetism and Aeronomy (IAGA) to provide an easily-usable model acceptable to variety of users.
The IGRF allows spot values of the geomagnetic field vector to be calculated anywhere from the Earth's core out into space. It is generally revised every five years (3).
In this work, the effect of the latitude and altitude on the field strength intensity and its horizontal component at local of Baghdad have been studied.

Earth's magnetic field

The Earth acts like a great spherical magnet, in that it is surrounded by magnetic field.That of central dipole is approximately symmetrical about an axis as shown in fig.(1), called the geomagnetic axis that is tilted 11.5° with respect to geographic axis(4).

The Earth's magnetic field, as measured by a magnetic sensor above the Earth's surface, is a composite of several magnetic fields generated by variety of sources. These fields are superimposed on each other and through inductive processes interact with each other. The most important of these sources are:
- The Earth's conductive, fluid core.
- The Earth's crust and upper mantle
-The ionosphere
-The magnetosphere.

The Earth's outer core generates more than 95 percent of the geomagnetic field. On the Earth's surface the field varies from being horizontal of magnetude about 30000 nT near the equator to vertical about 60000 nT near the poles(5).

Secular variations

The geomagnetic field does not vary linearly with time, except for a few years round 1980 (6).

Secular variations (SV) in the magnetic field occure gradually over a long period of time as a result of the dipole strength of the magnetic field is decreasing by 0.05% per year. In addition, the portion of the dipole in the Northern Hemisphere is drifting westward to 0.014 degrees per year. The (SV) are very small, but after a few years their accumulation is enough to make the magnetic field models out dated. So, IGRF is generally revised every five years

Geomagnetic Elements

Since magnetic field is a vector field, at least three elements are necessary to represent the field. The elements describing the direction of the field are Declination (D) and Inclination (I). D and I are measured in units of degrees. As shown in fig.(2), D is the angle between magnetic north and true north,(it is positive to the east and negative to the west). I is the angle between the horizontal plane and the total field vector. Elements describing the field intensity is the total field (F), horizontal component (H), vertical component (Z) and the north (X) and east (Y) components of the horizontal intensity. These elements are generally expressed in units nano tesla (10^{-9} tesla). Often the parameters which are measured are the magnetic declination D, the horizontal H, and the vertical intensity Z. From these elements, all other parameters of the magnetic field can be calculated. These components are related by the following equations (1)

$H=F\cos(I)$ -------------[1]

$Z=F\sin(I)$ ---- --------[2]

$\tan(I)=Z/H$ -------------[3]

$X=H\cos(D)$ --------------[4]

$Y=H\sin(D)$ --------------[5]

$\tan(D)=Y/X$ -------------[6]

$F^2=H^2+Z^2=X^2+Y^2+Z^2$ ------------------[7]

Where

$H^2=X^2+Y^2$

International Geomagnetic Reference Field (IGRF) model

It is a series of Spherical Harmonic models describing the Earth Magnetic field and it's (SV).

The Earth`s field B can be expressed as the negative gradient of scalor potential function V,

$B=-\nabla V$ ....[8]

V is described by a series of spherical harmonic(7)

$$V(r,\theta,\varphi)=a\sum_{n=1}^{N}\sum_{m=0}^{n}(a/r)^{n+1}(g_n^m\cos m\varphi+h_n^m\sin m\varphi)P_n^m(\cos\theta) \quad \text{---[9]}$$

where (a) is the equatorial radius of the Earth, g_n^m and $h^m{}_n$are coussian cofficients, r, θ and φ are the geocentric distance, co-elevation and East longitude from Greenwhich, and $P_n^m(\cos\theta)$ are schmidt quasi - normalized associeted Legendre function of degree n and order m ($n \geq 1$ and $m \leq n$). The maximum spherical harmonic degree of expansion is N= 10 .

The function $P_n^m(\cos\theta)$ may be written as (8)

$$p_n^m(\mu) = \frac{1}{2^n n!}\left(\frac{E_m\,(n-m)!(1-\mu^2)^m}{(n+m)!}\right)^{1/2} \frac{d^{m+n}\,(\mu^2-1)^n}{d\mu^{\,m+n}} \qquad \text{--------[10]}$$

the gaussian coefficients are determined empirically by a least-squares fit to dtermine measure of the field. A set of these coefficients constitutes a model of the field. The field B is calculated from Eq [8] and Eq [9] specifically

$$\left.\begin{aligned} B_r &= -\,\partial v/\partial r \\ B_\theta &= -(1/r)\,\partial v/\partial\theta \\ B_\varphi &= -(1/r\sin\theta)\,\partial v/\partial\varphi \end{aligned}\right\} \qquad \text{------------------------------------[11]}$$

Where B_r is the radial component measured outward positive, and B_θ is the coelevation measured south positive, and B_φ is the azimuthally component measured east positive.

In literature, the magnetic field is often presented in X,Y,Z form. The transformation from local tangential coordinates to X,Y,Z is

$$\left.\begin{aligned} X &= -\,B_\theta \cos \epsilon - B_r \sin \epsilon \\ Y &= B_\varphi \\ Z &= B_\theta \sin \epsilon - B_r \cos \epsilon \end{aligned}\right\} \qquad \text{------------------------- [12]}$$

Where the correction term for the oblateness of the Earth ϵ is (1)

$$\epsilon \equiv \lambda - \delta < 0.2^{\circ} \qquad \text{------------------------[13]}$$

Where the geodetic latitude is defined by λ, and δ is declination, which is defined by

$$\delta = 90 - \theta \qquad \text{-------------------------[14]}$$

And θ is the co-elevation.

In satellite applications, the geocentric inertial components are often used; the transformation from local tangential to geocentric inertial is

$$\left.\begin{aligned} B_x &= (B_r \cos\delta + B_\theta \sin\delta)\cos\alpha - B_\varphi \sin\alpha \\ B_y &= (B_r \cos\delta + B_\theta \sin\delta)\sin\alpha + B_\varphi \cos\alpha \\ B_z &= (B_r \sin\delta - B_\theta \cos\delta) \end{aligned}\right\} \quad \text{---------} [15]$$

Note that B is still a function of longitude φ, which is related to the right ascension α, by

$$\varphi = \alpha - \alpha_G \quad \text{----------------}[16]$$

Where α_G is the right ascension of the Greenwhich meridian .

Results and Discussion

All the results obtained in this work were calculated using IGRF model which was produced in 2000 and still valid until 2005.

Since the magnetic field is a function of longitude then all the results are given at the geographic longitude of Baghdad 44.7° E which equals to geomagnetic longitude 121.9°.

Fig.(3) shows the total field intensity with altitudes, at different values of latitudes, it can be seen that at certain latitude the total field intensity decreases as the altitude increases. This can be attributed to the fact that at low altitude intensity is approximately that of a magnetic dipole, while at high altitude it is strongly distorted.

Fig.(4) shows the variation of the total field intensity as a function of latitude at certain altitude.

As it is clear from this figure, at the surface of the Earth (0Km), the field is the weakest at the magnetic equator (being about 3.4×10^3nt). Moreover, when the latitude increases the total field increases very strongly.

However, at altitude (10000Km) a small change appears.

Fig(5) shows the Horizantal component of the magnetic field as a function of the latitude at different altitudes.

It can be seen from this figure that at the magnetic equator the magnetude of the Horizontal component is approximately equal to the magnetude of the total field intensity at the Earth surface.

We can also see that the Horizantal component decreases rapidly from the horizon at the geographic latitude of Baghdad 33.2^0 (which is equal to geomagnetic latitude 28.07^0) as the latitude increases.

References

1. Kristin, L. (2001). Makovee A Nonlinear Magnetic Controller for Three-Axis Stability of Nanosatellites.
2. Division, V. working Group 8, (2000). International Association of Geomagnetism and Aeronomy (IAGA). Physics of the Earth and Planet,12039-42.
3. Barton, C. E. (1997). International Geomagnetic Reference Field (IGRF). the seventh Generation J.Geomag.49:123-148.
4. WERTZ, J.R.(1984). Spacecraft Attitude determination and control.
5. John, Quinn and Ken, Rukstales (2001).Magnetic Field of the earth U.S. geological survey (USGS)Colorado , ESRI Map Book Vol 16.
6. Lowes, F.J. (2000). The International Geomagnetic Reference Field ;A"Health"Warning 26 –5.
7. Macmillan, S. (2003) Geophs.J.Int. 155 :1051-1056.
8. IAGA Commission 2 Working Group No.4 (1969). Journal of Geomagnetism and Geoelectricity 21: (2) 569-571.

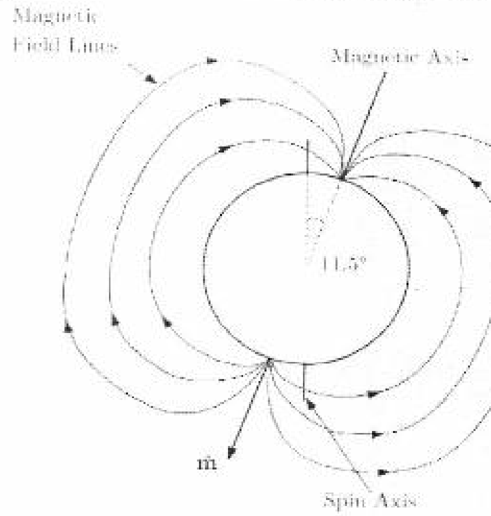

Fig. (1) Magnetic Field Model

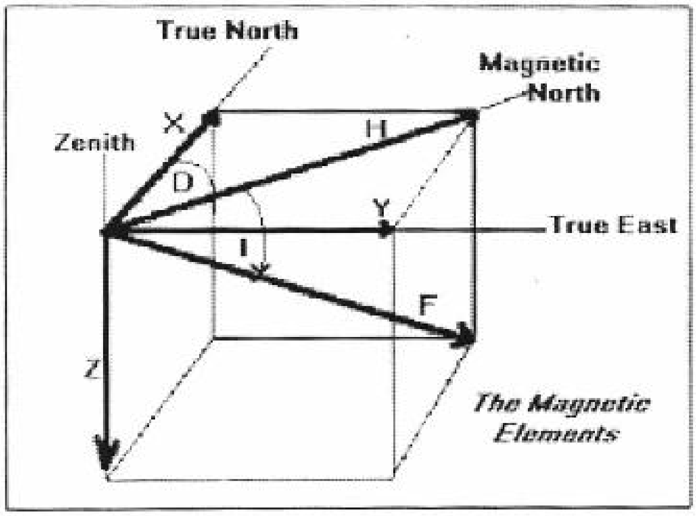

Fig. (2) Geomagnetic elements

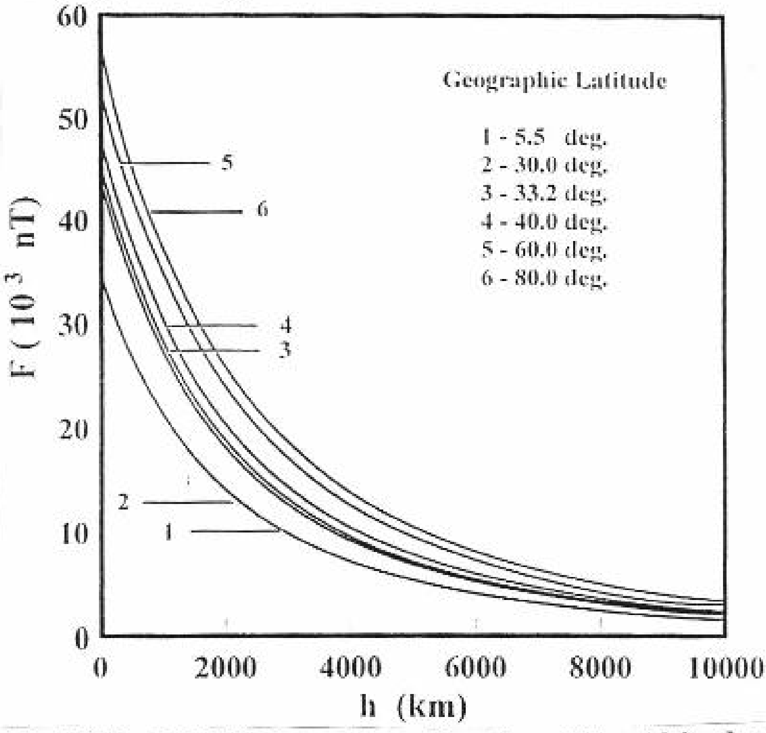

Fig (3) Total Field Intensity as function of the Altitudes at certain Latitudes

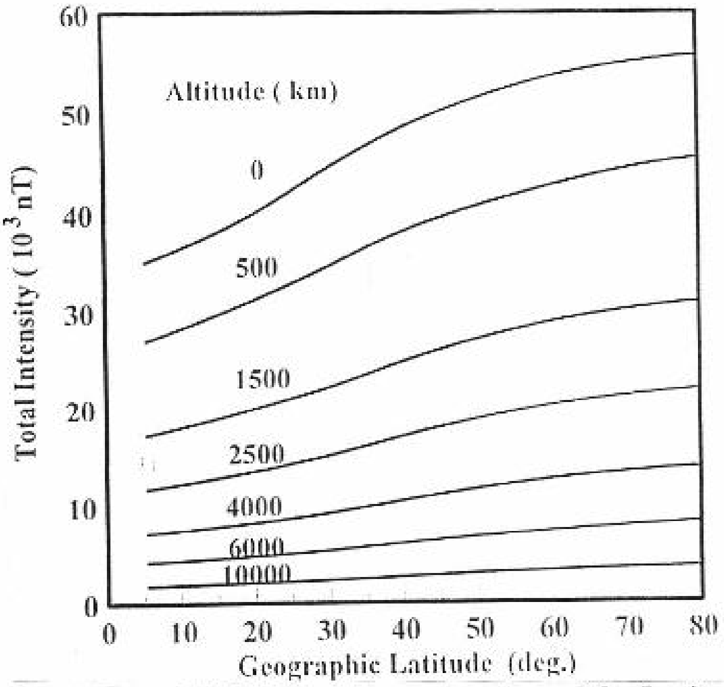

Fig (4) Total Field Intensity as function of the Latitudes at deferent Altitudes

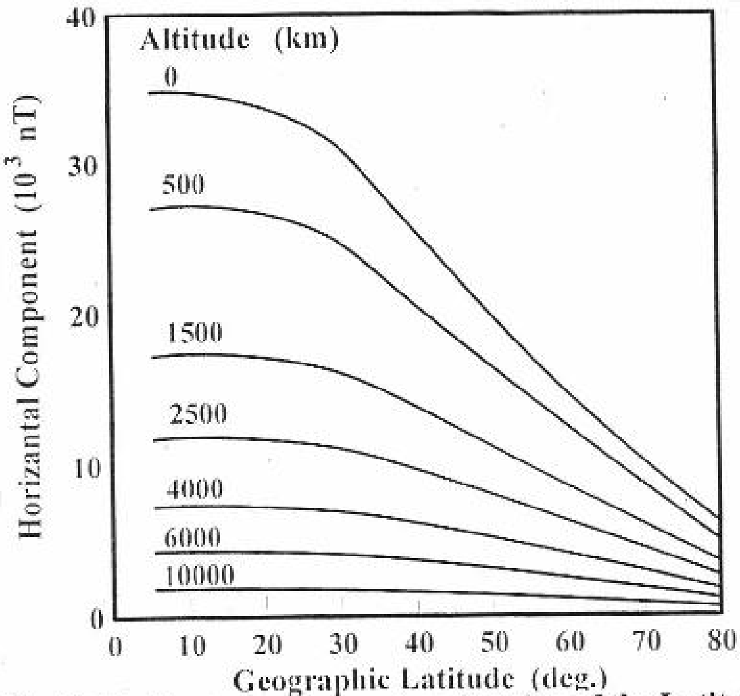

Fig (5) Horizontal component as function of the Latitudes at deferent Altitudes

دراسة وتحليل المجال المغناطيسي الأرضي بأستخدام النموذج الدولي المرجعي للمجال المغناطيسي الأرضي (IGRF - 2000)

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الخلاصة

يعتبر النموذج الدولي المرجعي للمجال المغناطيسي الأرضي هو التمثيل العددي للمجال المغناطيسي الأرضي المعترف به للأستعمال العلمي من قبل المنظمة الدولية لعلم المغناطيسية الأرضية والأنواء الجوية .

بما أن المجال المغناطيسي الأرضي يمتلك القدرة على تغيير مسار الأقمار الصناعية، لذا فان شدة المجال المغناطيسي الأرضي ومركبته الأفقية قد تمت دراستها .

هذا البحث يناقش ظاهرة شدة المجال المغناطيسي الأرضي ومركبته الأفقية عند ارتفاعات مختلفة وعلاقتها مع تغير خطوط العرض الجغرافية عند خط الطول الجغرافي لموقع بغداد(خط طول 44.7 درجة شرقا). إن بيانات المجال المغناطيسي الأرضي أستحصلت من النموذج الدولي للمجال المغناطيسي الأرضي (IGRF-2000) .