NRIAG Journal of Astronomy and Geophysics xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

NRIAG Journal of Astronomy and Geophysics

journal homepage: www.elsevier.com/locate/nrjag

Full length article

The Egyptian geomagnetic reference field to the Epoch, 2010.0

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A R T I C L E I N F O

Article history:
Received 8 November 2016
Revised 15 March 2017
Accepted 17 March 2017
Available online xxxx

A B S T R A C T

The present work is a compilation of two tasks within the frame of the project "Geomagnetic Survey & Detailed Geomagnetic Measurements within the Egyptian Territory" funded by the "Science and Technology Development Fund agency (STDF)". The National Research Institute of Astronomy and Geophysics (NRIAG), has conducted a new extensive land geomagnetic survey that covers the whole Egyptian territory. The field measurements have been done at 3212 points along all the asphalted roads, defined tracks, and ill-defined tracks in Egypt; with total length of 11,586 km. In the present work, the measurements cover for the first time new areas as: the southern eastern borders of Egypt including Halayeb and Shlatin, the Quattara depresion in the western desert, and the new roads between Farafra and Baharia oasis. Also marine geomagnetic survey have been applied for the first time in Naser lake.

Misallat and Abu-Simble geomagnetic observatories have been used to reduce the field data to the Epoch 2010. During the field measurements, whenever possible, the old stations occupied by the previous observers have been re-occupied to determine the secular variations at these points.

The geomagnetic anomaly maps, the normal geomagnetic field maps with their corresponding secular variation maps, the normal geomagnetic field equations of the geomagnetic elements (EGRF) and their corresponding secular variations equations, are outlined. The anomalous sites, as discovered from the anomaly maps are, only, mentioned. In addition, a correlation between the International Geomagnetic Reference Field (IGRF) 2010.0 and the Egyptian Geomagnetic Reference Field (EGRF) 2010 is indicated.

1. Introduction

The geomagnetic field is the sum of magnetic fields from several sources: the main field created by electric currents flowing in the Earth's core and is subjected to secular variation, the crustal field due to magnetization of rocks, external fields caused by electric currents flowing in the ionosphere and the magnetosphere, and induction fields due to electric currents induced in the Earth's crust and mantle by the time variations of the external fields. The geomagnetic field is usually presented (Chapman and Bartels, 1940; Parkinson, 1983; Campbell, 1997) by a potential equation:

$$V(r,\theta,\phi,t) = a\sum_{n=1}^{N}\left(\frac{a}{r}\right)^{n+1} \times \sum_{m=0}^{n} P_n^m(\theta)(g_n^m(t)\cos m\phi + h_n^m(t)\sin m\phi) \quad (1)$$

where (θ) and (ϕ) are geocentric colatitudes and longitudes, (r) is the radial coordinate, (a) is the spherical Earth's radius, $P_n^m(\theta)$ is an associated Legendre polynomial with Schmidt's normalization, and the entire sum is called Spherical Harmonic Expansion (SHE), g_n^m and h_n^m are suitable coefficient, named Gauss elements of terrestrial magnetism, the two summation indices (n and m) are called degree and order respectively, and the maximum degree (N) being considered depends on the quality and amount of the observational database.

The geocentric components of the main geomagnetic field components are derived (Barraclough, 1987) by partial differentiation of Eq. (1)

$$X = \frac{1}{r}\frac{\partial V}{\partial \theta},\ Y = \frac{-1}{r\sin\theta}\frac{\partial V}{\partial \phi},\ Z = \frac{\partial V}{\partial r} \quad (2)$$

where (X, Y and Z) denote the northward, eastward and radially inward components respectively, of the field. In the case of the

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Peer review under responsibility of National Research Institute of Astronomy and Geophysics.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.nrjag.2017.03.004
2090-9977/

Please cite this article in press as: Deebes, H.A., et al. The Egyptian geomagnetic reference field to the Epoch, 2010.0. NRIAG Journal of Astronomy and Geophysics (2017), http://dx.doi.org/10.1016/j.nrjag.2017.03.004

secular variation (X', Y' and Z') are to be regarded as representing the time rates of change of the quantities referred to above.

For some applications, the declination D, the inclination I, the horizontal intensity H, and the total intensity F are required. These components are calculated from X, Y, and Z using the relations,

$$H = \sqrt{X^2 + Y^2},\ F = \sqrt{X^2 + Y^2 + Z^2},\ D = arctan(Y/X), \quad I = arctan(Z/H) \tag{3}$$

The accurate estimation of magnetic anomalies requires effective removal of the core and the external field components from the magnetic observations. Since continuous geomagnetic records in Egypt are sparse and not well-distributed, there is a clear need to improve the accuracy of the core field (Normal Field) and its secular variation. The geomorphologic conditions in Egypt limit the presence of man and the capability of installing, running, and preserving conventional geomagnetic observatories for continuous recording of the geomagnetic field. Now NRIAG have the new Abu-Simble observatory equipped by automatic instruments that are checked twice a year for maintenance. Its data is transferred to the head quarter at NRIAG by satellites.

In spite of the small number of the permanent stations (2 observatories) and their spatial distribution, and the field measurements that are limited mostly along the asphalted roads, defined tracks, and ill-defined tracks, yet the collected observations represent a precious ensemble that is important to monitoring the secular variation. In fact, the repeat stations are not many; however, in combination with other land surveys that reflect single occupations of sites, they can help to fill in some gaps both in sites and time for enhanced reconstruction of the secular variation.

In case of relatively small area, many authors (e.g. Bucha, 1957; Fahim, 1968) found that it is satisfactory to drive the core field (the normal field) T(x,y) and its secular variation by adopting one central point to which all the reductions can be done by applying Taylor's Expansion

$$T(x,y) = a_0 + b_1(x - x_0) + b_2(y - y_0) + c_1(x - x_0)^2 + c_2(x - x_0)(y - y_0) + c_3(y - y_0)^2 \tag{4}$$

where (a_0) represents the value of the element at the central point, (b_1, b_2, c_1, c_2, and c_3) are the coefficients of the expansion, and (x_0, y_0) represent the coordinates of the central point. In the present work, each value of geomagnetic element measured in the field is used in a quadratic function of Taylor's Expansion depending on the site's latitude and longitude, considering El-Minia (Latitude 28°06.3′ N & Longitude 30°45.5′ E) as a central point.

2. Geomorphology and geology of Egypt

Egypt occupies the north eastern corner of Africa, situated between latitudes 22° and 32° N and between longitudes 25° and 32° E, embraces a total area of almost one million km^2 (Fig. 1). The greatest part of Egypt consists of barren and desolate desert. The River Nile divides the country into two distinct morphological and geological regions: Western Desert & Eastern Desert. The Western Desert is essentially a plateau desert with vast expanses of rocky ground and numerous extensive and closed-in depressions. Its most important topographical features are Kharga, Farafra, Bahariya Oases, El-Gulf Elkabir plateau and the Arbaeen desert. The land to the east of the Nile forms one geomorphological region, it is divided into the Eastern Desert and Sinai Peninsula which separated from main land of Egypt by the Gulf of Suez and the Suez Canal. The Eastern Desert consists essentially of a backbone of high rugged mountains running parallel to and at a relatively short distance from the coast. Sinai Peninsula continuous with the Asiatic continent. Its core consists of an intricate complex of high and very rugged igneous and metamorphic mountains.

The geology of Egypt includes rocks from the Archaean early Proterozoic times and on ward. These oldest rocks are found as inliers in Western Desert. In contrast, the rocks of the Eastern desert are largely late Proterzoic age. Through the country this older basements is overlain by Palaeozoic sedimentary rocks. Cretaceous rocks occur commonly whilst sediments indicative of repeated marine transgression and regression are characteristic of the Cenozoic (Said, 1990; Issawi et al., 1999).

In Sinai, the Paleozoic rocks were suggested for beds overlying the Precambrian basement in the southwestern Sinai. The Mesozoic strata crops out in northern Sinai where an almost complete sequence from Triassic to Cretaceous is known. The end of Oligocene witnessed the rifting movements that brought the gulf of Suez to its modern shape (Neev, 1975; Said, 1990; Abdelkhalek et al., 1993; Rabeh, 2003, and Deebes, 2012).

3. Historical review of the magnetic survey in Egypt

The first reliable magnetic survey in Egypt started by Captain Lyons (Lyons, 1910) between the years 1893 and 1901 at different places of the country. Also, the Pola Expedition headed by Rossler made other observations along the Red Sea Coast, during 1895–1898, on her way from the Mediterranean to the Indian Ocean. Results of these surveys were published by Keeling (1907). Later Hurst made a magnetic survey along the Nile Valley in Egypt and the Sudan in 80 points during 1908–1914. Using the results of the Pola Expedition together with his data, Hurst (1915) constructed magnetic maps showing the isogonic lines for Egypt and the Sudan to the Epoch 1910. During 1918, the Carnegie Institution of Washington during a world survey carried out some observations at some points in Egypt (Carnegie Institution, 1920). These results were used by Knox Shaw, together with the old data of 1910 to construct a Declination map to the Epoch 1920 then to the Epoch 1930 (Fig. 2). After that, Madwar made some repeat observations at the old Hurst stations along the Nile Valley and constructed a declination map to the Epoch 1940. He, also, made some field survey in the Sudan during 1952 (Madwar, 1954). During the period 1957–1966, and in view of the "World Magnetic Survey" plan sponsored by the I.A.G.A., Fahim performed absolute observations of the elements H, Z, D at 148 stations together with 861 points for the Z and H components distributed over the country (Fahim and Wienert, 1958). Fahim published the geomagnetic maps reduced to the Epoch 1965 (Fahim, 1968). Ibrahim (1971) used Fahim's data with the old observations and produced the normal geomagnetic field of U.A.R. for the Epoch 1965 and its secular variations. Then, since 1970 until now, the members of the geomagnetic department in NRIAG have performed detailed surveys at separated parts of Egypt e.g. (Deebes et al., 1978; Deebes and Ahmed, 1979, and Deebes et al., 1980).

4. The present magnetic survey to Epoch 2010.0

During the period 2010–2011, the land Geomagnetic survey for the Whole Territory of Egypt is conducted by three missions conducted to measure the geomagnetic elements F, I, and D in the Egyptian territory (Western Desert, Eastern Desert, Nile Valley, Sinai, and Naser lake). The following considerations are followed In each trip: (a) Misallat geomagnetic observatory (29.51444°N, 30.889525°E) is considered as a tying point for the field measurements at the northern part of Egypt. (b) Abu-Simble geomagnetic observatory (22.489672°N, 31.544821°E) is considered as a tying point for the measurements at the southern part of Egypt. (c) Five subsequent measurements are done at each point of observation to

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