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MAPING OF GRAVITY FIELD OF LIBYA BY USING UPWARD CONTINUATION METHOD

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الملخص

أوجدت تقنيات عصر الفضاء الحديثة (رحلات الفضاء للقياسات الجاذبية) خلال العقدين الاخرين فرص مثالية لإيجاد خريطة لمجال الجاذبية لمعالم الأرض على المستويين العالمي والإقليمي وبدقة متناهية لتطوير مفهومنا حول مجال الجاذبية. حيث تستخدم بيانات نمذجة الجاذبية بشكل كبير لعرض المتغيرات وكذلك الحد الفاصل بين الترسيب والصخور القاعدة. وهناك طرق عدة لعرض طبوغرافية الصخور، وإحدى تلك الطرق هي ما سيتم شرحه في موضع الورقة التي بين أيدينا. يكمن أساس تقنية الارتفاع المستمر في إزالة شذوذ الجاذبية المتبقية، والذي يبين التأثير الموضعي للصخور على الجاذبية. لابد من الإشارة هنا بإن بعض البرامج استخدمت في الورقة البحثية، للمثال وليس للحصر برنامج سيرفر الاصدار 19، اما البرنامج الرئيسي المستخدم في النتائج هو برنامج كتب بلغة الفورتران 90. وذلك باستخدام بيانات حقيقة من خلال الشبكة العنكبوتية (النت) كمدخلات للبرنامج. وذلك لحسابات وعرض الخرائط الجيوفيزيائية كلما كان ذلك ممكناً.

Abstract:

The new Technology of the space age (satellite gravimetry missions) in last two decades has shown the efficacy measurements at the space to produce a global and regional map of earth's gravity field in more accuracy and details to improve our knowledge of gravity field. Modeling of gravity data is used extensively in both geology and exploration geophysics to illustrate the geometry and interference between the sediment and bed rock. Various methods are to illustrate the bed rock topography, and one of those methods, which will

describe and be used in the present paper, is called upward continuation. This method is used in exploration geophysics to estimate the value of potential (gravity) field. The principal of this method is based on removing the residual gravity anomaly which in reality shows the local effect of bedrock gravity on the observed gravity. It should be noted that some software like Surfer 19 are used in this paper, but the main program is written in Fortran 90. In order to show the capability of the program, real data from Satellite Gravity is used, to present calculation results wherever possible to geophysical map display.

Key Word*: *upward continuation method –principal and application

Introduction.

The upward continuation method effectively attenuates high wave number (k) anomalies due to near surface features, providing a powerful technique for examining deeper structure. Its process is to determine the data on surface above a surface on which the data is recorded or known. The continuation involves the application of Green's theorem and is unique if the field completely known over lower surface (usually all sources are zero). It is used to smooth out near surface effects in order to acquire information on deeper anomalies *(Robert, 1999*)and (*Akingboy et al., 2019*). Fortran 90 computer program has been written for performing the 2D upward continuation of potential (gravity) field data. A graphical result illustrate the performing of the program demonstrate the program ability. The program has a flexibility to return the counter map of observation data as well as the upward continued data level being decided by the user input. The input is adapted for the use of sets of global grids of free air gravity anomalies and elevation/bathymetry.

Precise of Geological Setting

Libyan territory is located in north part of Africa continental on the Mediterranean cost; its adjacent area and the concrete is between $\left(10^{0}-26^{0}\right)$ of east longitude and $\left(20^0 - 33^0\right)$ of north latitude. It covers an area of some $\left(1.8\times10^6\,km^2\right)$ almost has $\left(1.8\times10^3\,km\right)$ a shoreline along the Southern margin of Mediterranean Sea. Except for the northernmost parts, the country lies entirely within the Sahara. Difficulties of travel and survival have long caused the country to remain unmapped, thus geological information has been acquired slowly (*Nuri, 2001*).

Structurally, Libya is part of the Mediterranean foreland formed by the both North African shield, and has been a site of deposition of large sheets of continental classics and several transgressions and regressions by the sea with consequent accumulation of wide variety of sedimentary rocks since the early Paleozoic (*Ben suleman, et al., 2016*). The collision of the African and European plates caused a $(N-S)$ directed Compressional stress field in the northern portion of the African continent (*Wennekers, et al. 1996*). The main tectonic events that shaped the structure of Libya are a Compressional early Paleozoic Pan-African event, the Hercynian, and extension related to Cretaceous, middle Tertiary and Holocene events. The structure of southern Libya was influenced by the Pan-African event, whereas the central part of Libya was much affected by the Hercynian tectonic events. On the other hand the structures of north Libya are attributed to the Tethyan extension and Alpine tectonic movements (*Goudarzi,1980*). The opening of the Mediterranean began in Early Jurassic with $(E-W)$ axis direction, but by the Early Cretaceous the Mediterranean Sea floor spreading had ceased entirely; consequently it has a complex subsurface geology and geological history caused by several tectonics cycles which has already mention. Figure (1.A) shows the Libyan geological map, and figure(1.B) representing conjugated topographic of Libya to figure(1.A).

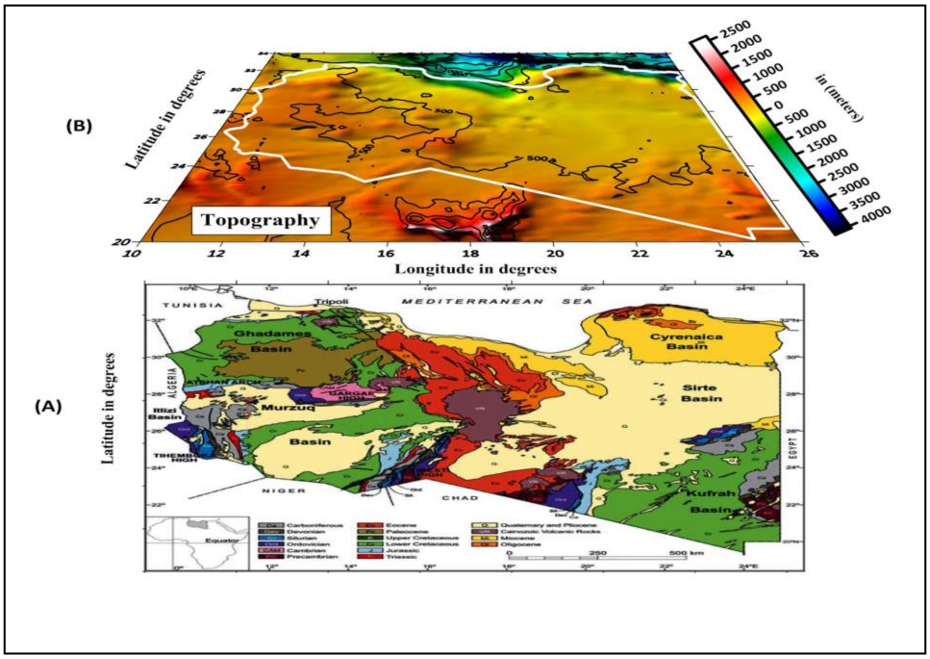

Fig (1). (1.A). Geological map of Libya, (1.B) map of the topographic surface of Libya, color scale to emphasis the (depth/elevation) in meters

MATERIAL AND METHOD

The major objectives of the present paper is, Generation of bouguer gravity anomaly image over Libyan territory and its coast. The main source of real gravity data was obtained by (extracted xyz data) the region dimensioned of about (256×5416) points in database for Libyan area through NOAA (National Oceanic and Atmospheric Administration) are public domain free air gravity via Internet. The satellite gravity data are needed to be prepared to use them in inversion process (*Kusznir, 2012*) for use with this method to generate the gravity data over studying area directly without any need to apply any change on them. Figure (2) represents free-air gravity over Libya to obtain a new free air gravity anomaly from satellite. The free anomaly map as seen by the satellite over Libya has values between (-80 to +160 mGal). The gravity data suggest the presence of high density rocks by relatively thick rocks at great depth. In the Libyan anomaly map, figure (2), free air gravity tends to be negative. It may be caused by relatively low density material in the upper mantel. While the Positive gravity anomalies tend to be located over a mass concentration associated with elevation.

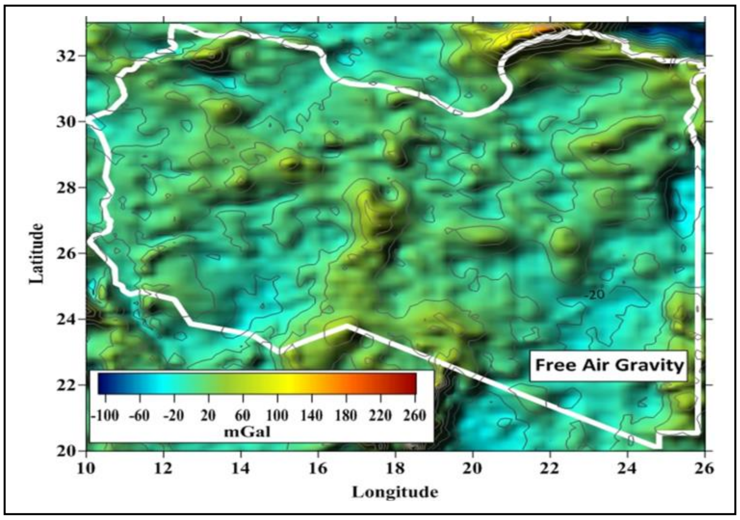

Figure (2). Shows map of the gravity field on topographic surface counter for Libya

Background

Various modern possibilities exist to model the external gravity field of the earth for the realistic case of Free-air anomalies being given on the surface of the earth's visible topography. These possibilities fall under two general types of modeling approaches (*Jaim et al., 1985*), the continuous approach and the discrete approach. In the first approach the Free-air anomalies are assumed to be known at every single point of the earth's surface. In the discrete approach, the anomalies are known only at discrete points. This article uses the simplest conceptualization of a solution of the continuous by means of analytical continued to a level surface which may be entirely above, partly above and partly below, or entirely below the earth's surface. Once the level surface anomalies are known, then under a spherical approximation the, external gravity field can be generated from these anomalies using classical procedures for data on a sphere (*Corbato*, *1965*). A general procedure for analytical continuation is using Taylor Series.

Method and Theory

Upward continuation method

The upward continuation method transfers measured data of potential field (usually gravity or magnetic) measured on one surface or level to the field that would be measured on another surface farther from all sources. This data transfer to higher level (levels) is performed by mathematical technique tools and numerical calculations (*Salimi et, al. 2012*). Figure (5) shows principal idea behind this technique. This transformation attenuates anomalies with respect to wavelength (λ)(to separate between long and short wavelengths), which is related to wave number$\left(k = \frac{1}{\lambda}\right)$, the shorter the wavelength, the greater the attenuation. These anomalies are

related to surface effects and/or the noise existed in gravity anomaly maps. So with transfer, the anomalies related to shallow surface will be weakened or vanished, and the anomalies related to wider and deeper sources appear clearly . Regional and residual anomalies integration is in fact a mixture of effects of two resources in which one is located under the other. And if these anomalies are not completely separated from each other, the regional anomaly that is the purpose of exploration can't show itself as a closed counter and the desired anomaly is poorly understood (*Grant et, al., 1965*). If more upward continuation is required, the desired anomalies can't be accurately detected. After necessary corrections are applied such as (terian correction, free air correction), first to obtain Bouger anomaly (www.*Noaa.org*) Then using the upward continuation the residual anomaly which indicates the local field is extracted from bouger anomaly. Processing of the data to obtain the Bouguer values was done using the main Fortran programs. The Bouguer gravity map is shown in Figure (3).

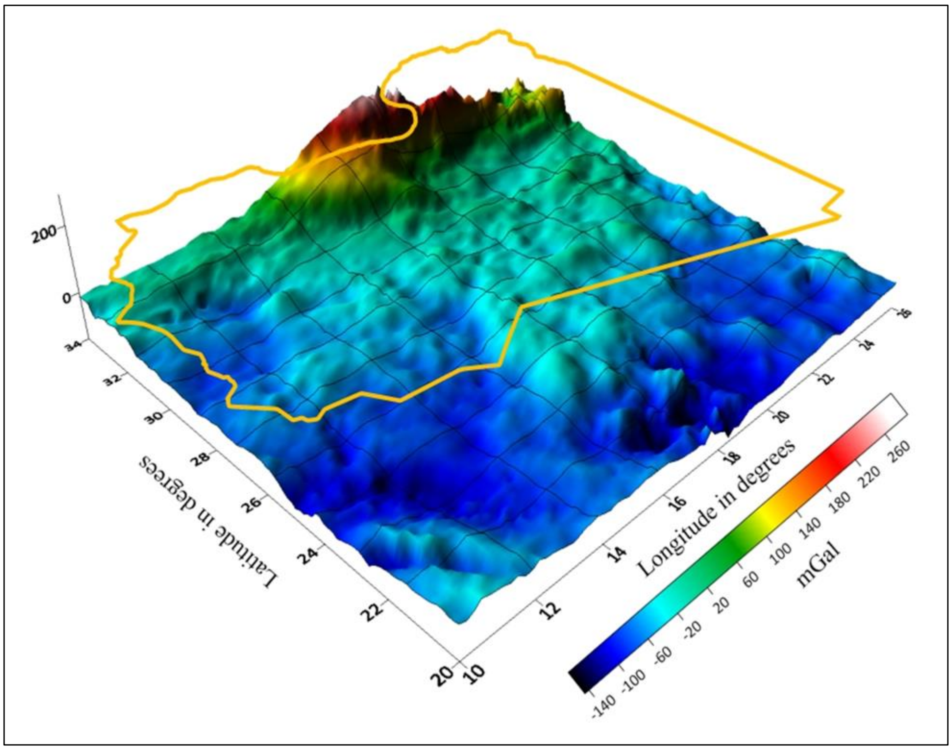

Fig. (3). Result of Bouguer gravity map for Libya

Theory

Normal gravity, corresponding to a given value of gravity anomaly at a fixed location in space, is defined to be the vertical component of attraction generated by equipotential ellipsoid of revolution The normal gravity in space is fully determined by geometric (size and shape) and the physical properties of the level. Combined with gravity anomaly the normal gravity can be used to compute the vertical attraction due to the actual earth at any location. Upward continuation, its transformation of gravity anomaly is computed at point $Q(x_0, y_0, z_0 = 0)$on the mean sea level to a point on some higher flat elevation (to avoid large topographic effect) $Q(x_0, y_0, z_0 = -h)$surface upward continuation to, $(z = -h < 0)$ figure (4). And the attraction is computed by used the equation

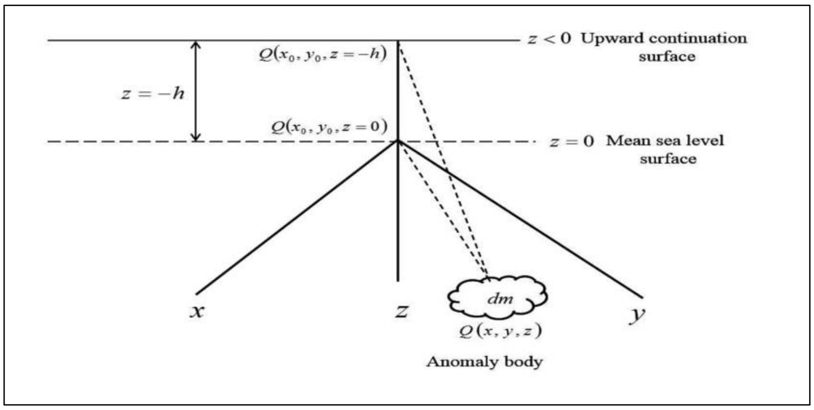

Fig 4. Representation of upward continuation technique by theoretical body in (x,y,z) coordinate system

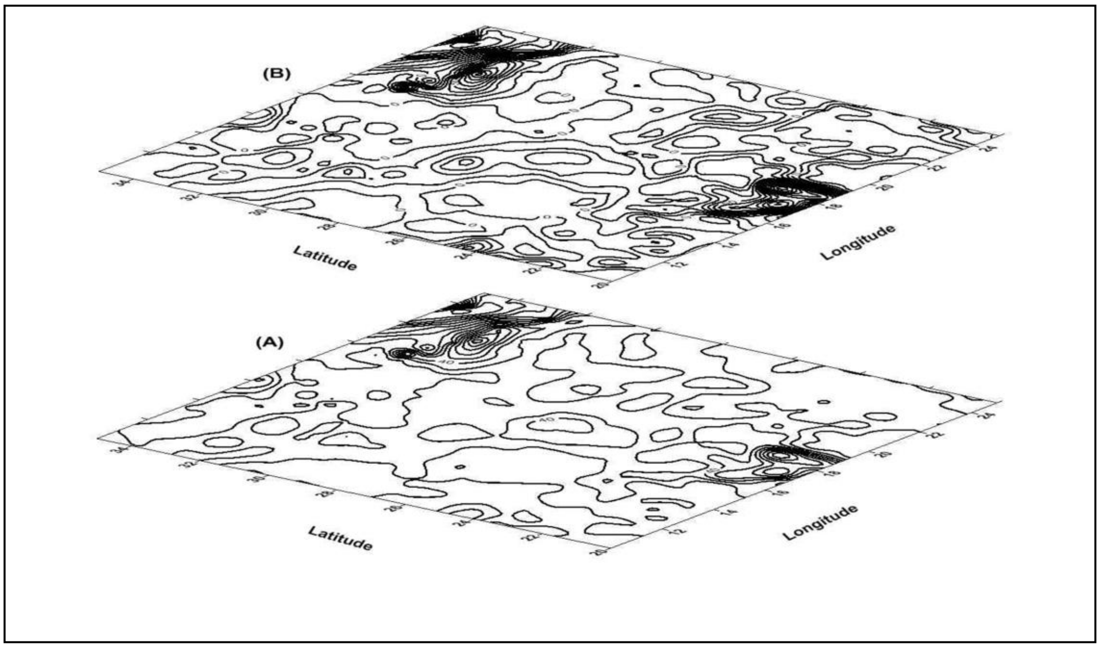

Fig. (5) Free air gravity map for Libya at two difference altitudes (A) at surface (z=0), (B) at height above (z=-h)

$$\nabla^2 U = 0$$

And a vertical component of gravitational field is given by

$$\vec{F} = \nabla U$$

Vertical derivative is one of the filtering techniques used for enhancement of the shallow source feature in the data (*Hailemichael, 2020*). Gravity anomaly (vertical component) $(\Delta g)$of gravity field which shows the change of field with depth is express as:

$$\Delta g = F_Z = \frac{dU}{dZ} \text{.....................} \quad (1)$$

$$\therefore \quad \nabla^2 g = \nabla^2 F_Z = \frac{d(\overset{=0}{\nabla U})}{dZ}$$

And for 2D flatten earth:

$$\frac{\partial^2 F_X}{\partial X^2} + \frac{\partial^2 F_Z}{\partial Z^2} = 0 \quad \text{………………..} (2)$$

Equation (2) is obviously defined as partial differential equation, and to get solution we must separate the variables. However, after a series of mathematical relationships we will have:

$$F_Z(x,z) = X(x) \times Z(z) \text{…………………. } (3).$$

And the general solution for equation (3) is

$$X(x) = a_1 e^{ikx} + a_2 e^{-ikx}$$

And the same treatment for vertical axis is:

$$Z(z) = b_1 e^{kz} + b_2 e^{-kz}$$

$$= \left(a_1 e^{ikx} + a_2 e^{-ikx}\right)\left(b_1 e^{kz} + b_2 e^{-kz}\right) \quad \text{……………… } (4)$$

Where the left side of equation (4) represents a vertical component of geological body. As we note from the same equation, as we go up ward (height), (z) becomes (negative) Negative sign is for upward continuation values, and it is clear if it very big, then (e^{-kz}) becomes very big as well, and to stop that consider $(b_2 = 0)$ in the equation (4). Because the gravity field attenuated as we go upward.

Therefore

$$F_Z(x,z) = \left(a_1 e^{ikx} + a_2 e^{-ikx}\right)\left(b_1 e^{kz}\right) \text{…………… } (5)$$

(k) Represents what is so called wave number and it is related to wavelength $\left(k=\frac{2\pi}{\lambda}\right)$ Moreover, (z) is the upward distance in upward continuation. (Where (z) is negative upward), (*Buttkus, 2000*).

The most common method of upward continuation involves evaluation of the integral

$$g\ (x, z=-h)=\frac{1}{2\pi}\int\ G(k, z=-h)e^{-kx}dk$$

Where

$g\ (x\ , y\ , -h)=$ Total field at the point above the surface on which $g\ (x, y, 0)$ is known (mean sea level), $(h)=$ elevation above the surface, and (k) is 1-D wave number corresponding to wavelength (λ), where (G) represent Fourier Transform of gravity at (h) level. and has form

$$G\ (k, z=-h)=G(k, z=0)e^{-kh}$$

When we construct the gravity field, (k) enters calculations as exponential Kernel of Fourier transform. Areal value of (k) produces a sinusoidal variation, but (-k) is an imaginary produce an exponential decay. So long wavelength decay slowly, and short wavelength decay rapidly.

Result and discussion

A description of a procedure that can be used for the upward continuation of anomalies given on the surface of the earth will be discussed in this section.

Upward continuation method has been used to process original gravity anomaly as a common method, and its destination is to weaken local anomaly, and at last strengthens deep anomaly. It is important for deep structure study. Upward continuation values are obtained from test calculations at elevation (0.5 km, 10, and 20 km) and have been used to process data and the results have been compared. However, the research area is very large and it has a complex subsurface geological structure, it is not suitable to use a single height to upward continuation processing gravity anomaly. Then multiple upward heights continuation is proposed to process gravity data respectively at different heights.

At last obtained multiple upward height resulted and the calculated result confirms that it is suitable to use this method. Gravity anomalies contours become smoother than before and the deep structures become clearer with the increased height of continuation. It is more meaningful for studying the crust and geologic structure of the overall the target specific location.

The upward continuation process was applied on gravity data of Libya at (0.5 km, , 10, and 20 km respectively) to expose the result at those various levels as shown in Figures (6, 7, and 8 respectively). The upward continued data revel increases attenuation and broadens the high wave number anomalies, off course with increasing height above the lower level. It mean with increasing observation to gravity source distance.

The difference is immediately obvious, the total field data was upward continued to 0.5 km m (Figure 6), 10.0km (Figure 7) and 20.0 km (Figure 8). Upward continuation to 0.5 km did not have that significant effect on the original total field data. Upward continuation to 10.0km did however have a significant filtering effect to the north, the gravity highs at the central and the north-south lineament towards the eastern boundary. Upward continuation to 20.0 km reveals a marked distinction between any of the other upward continued data and the original data.

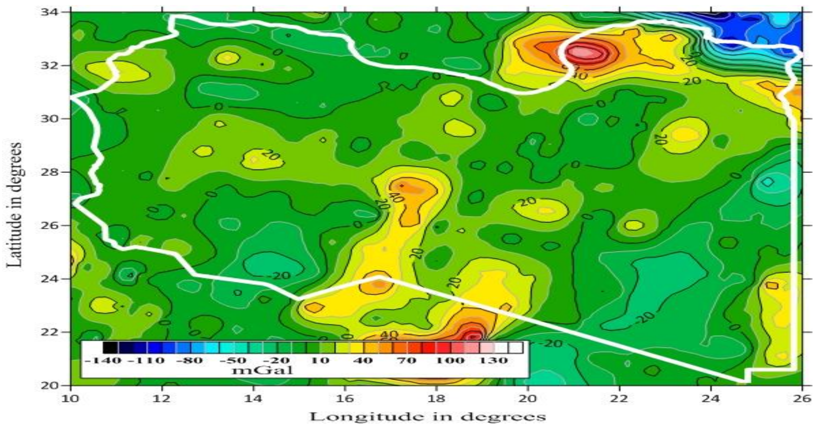

Figure. 6. **(**0.5km**)** height

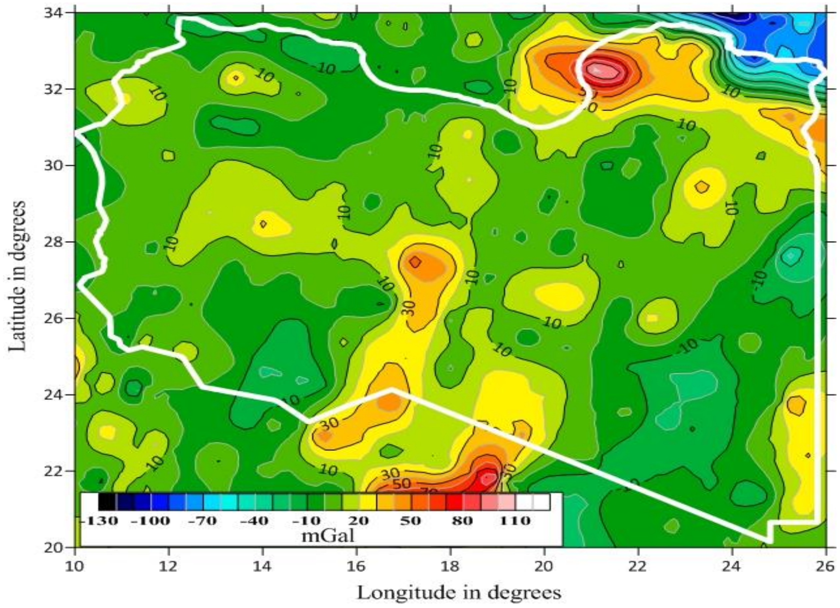

Figure. 7. (10km) height

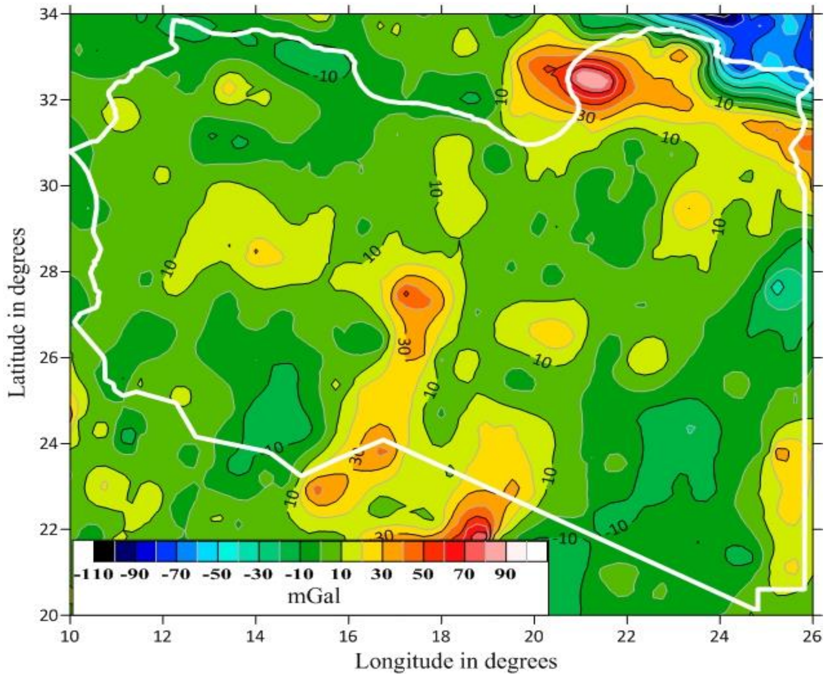

Figure. 8. (20km) height

CONCLUSION

- The upward continuation method to extract residual gravity from regional gravity, technique is used as to smooth out near surface effects and tie at different highest. This method is usually used in geophysics exploration, when we want to image deep structure.
- The upward continuation is used in gravity survey to determine the nature of the regional gravity pattern over a large area, made by different flying altitudes.
- A study of the gravity field is of direct application to geological structures because it integrates the entire mass distribution.
- Gravity is a tool effectively used to solve some of geological setting ambiguous that lies either beneath or on earth surface.
- The results obtained in this paper are easily data modified; consequently the flexibility of the program which had been used, and designed to calculated gravity in the region where only the latitudinal and longitudinal changes with respect to elevation.
- Gravity measurements from satellites provided high quality for mapping, from point of view of accessing more structure details to improve our knowledge about gravity field.
- Generally, all the upward continuation maps in the present study reflect varying gravity anomalies with respect to height of upward continuation.

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